DEPARTMENT OF THE INTERIOR
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THE SEVEN-STOREY RIVER: GEOMORPHOLOGY OF THE POTOMAC RIVER CHANNEL BETWEEN BLOCKHOUSE POINT, MARYLAND, AND GEORGETOWN, DISTRICT OF COLUMBIA, WITH EMPHASIS ON THE GORGE COMPLEX BELOW GREAT FALLS

by

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with apologies to Thomas Merton

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ABSTRACT

Between the top of Great Falls and Roosevelt Island just above Memorial Bridge, District of Columbia, the modern Potomac River channel is governed by 5 baselevels (including sealevel) separated by drops of 10-20 ft each; Great Falls, with a total drop of about 50 feet, is itself a succession of pools separated by cascades each 10-15 ft high. For the channel of the paleo-Potomac River, thus, multiple baselevel control is a distinct possibility. Indeed, 7 strath (abandoned channel) levels can be identified within the Potomac River valley between White's Ferry near Leesburg, Virginia and Memorial Bridge, a distance of some 50 km. The two higher and older straths are at least partly alluvial. The next oldest strath is the last pre-gorge level; it and the other four are all bedrock channels. Geomorphic evidence (channel-bottom features, rock benches, channels and scour ponds, plungepools, hanging lateral potholes) along the river are used to decipher the four straths within the gorge; these are mustually separated by 10-20 feet elevation difference. The tops of Olmsted Island and Bear Island, and extensive rock exposures near the river at Great Falls National Park are representative remnants of the youngest pre-gorge channel. Gorge formation was due to simultaneous retrogression of cascades that served as local baselevels. An analogue is that of a series of power shovels working in tandem upstream, rather than a single shovel biting into the height of the entire working face. The inferred history of formation of the gorge is corroborated by the morphological features of Difficult Run, a tributary joining Potomac River just below Mather Gorge. A bed of large (ca. 2 m) boulders composed of the basal Paleozoic Weverton Quartzite at Glade Hill within the Great Falls National Park is a flood deposit from the oldest and highest of the 7 straths. Hydraulic computations indicate that no geologically and hydrologically unreasonable conditions were required to form the boulder bed, but the results do indicate a paleo Potomac River valley that differed from the modern valley in having a steeper and monotonical slope (ca. 0.07% rather than 0.05%) all the way from the Blue Ridge Province through the Mesozoic Basin into the Piedmont. The results also suggest a valley floor as much as 130 ft higher at Harpers Ferry than it is today. Unfortunately, there is no information on the age of the gorge complex or its alluvial predecessors. A fluviatile

Miocene-Pliocene deposit is present at Gantt Hill and Freedom Hill, two monadnack-like hillocks rising above the modern upland surface at Tyson's Corner. This deposit is 250 ft higher than the Glade Hill boulder deposit and 100-150 ft higher than the upland surface. Applying a rate of land denudation of 0.1-0.2 km/m.y. for the area, based on rate of saprolite formation, these elevations require the entire gorge complex to be a Pleistocene or even Holocene product, possibly initiated by stepwise sealevel lowering during onset of glaciation. Preservation of feldspar grains in arkose beds within the Glade Hill boulders corroborates the youthfulness of even the oldest of the seven straths.

INTRODUCTION

Between the top of Great Falls, Maryland and Virginia and tidewater near Key Bridge (Figures 1 and 2), a distance of about 22 km, the Potomac River has an overall sinuosity of just over 1.2. In that distance, the river level drops from about 144 ft to sealevel, with an average gradient of 0.2%. Even between the base of Great Falls at about 90 ft and tidewater, the rate of drop is still a steep 0.13% [1,2]. This gradient is very close to that of the Susquehanna River in a comparable stretch across the Piedmont, between 0.05% and 0.1% (Pazzaglia and Gardner, 1993). In contrast, from Tenfoot Island downstream to the Great Falls Water Supply Dam (diverting water to the Dalecarlia Reservoir) at Conn Island just above Great Falls, a distance of about 15 km, the water level drops 29 ft, for a gradient of 0.06%. Rejuvenation of the river below Great Falls is clearly indicated. Indeed the valley within this reach is confined to a gorge whose rim is as high as 60 ft above

[1] Hack (1982, p. 16) stated that the average slope in Mather Gorge, with unspecified reach, is 0.009 (0.9%). This is much too large. Between the northwest corner of Rocky Island (entrance to Mather Gorge) and Difficult Run the distance is 2.2 km and the water surface drops 10 ft, for a slope of 0.001; within the straight section of Mather Gorge, the distance is 1.3 km, the elevation drop is 6 ft, and the slope is the same.

[2] In this report I will use the metric system to the extent feasible. However, because contour intervals and control points on the topographic maps are given in feet, mixing of units is inevitable. The conversion of 3281 ft to the kilometer is no more vexing than the non-decimal conversion of 5280 ft to the mile.

water level at normal discharge. Even in the lower portions of this reach, this valley side is known as the Potomac Palisades. If the relief to the river bottom is included, the gorge is as much as 170 ft deep (J.C. Reed, Jr., 1993, written commun.).

In Part I of this study, I describe the morphological database, and use these data to reconstruct the mode of retreat of the falls, including the contemporary cataracts, and the concomitant carving of the gorge by the cumulative effect of independent retreat of several levels of cataracts, each 10-20 feet high. The upstream migration of these cataracts produced the intermediate straths. The modern Great Falls is itself a transient clustering of cataracts.

In Part II of this study, I describe evidence for at least two additional strath levels higher and older than those of the gorge system. Altogether, 7 straths, not including the modern channel, are recognized for the Potomac River valley.

The Potomac Gorge is carved into schist, metagreywacke, diamictite, and minor granite and amphibolite of the Piedmont (Reed and others, 1980, and references therein). The metamorphic rocks have been recrystalllized into andalusite-, sillimanite-, and kyanite bearing schists; locally, migmatite has developed. These rocks have been deformed by folds and faults and are disrupted by several sets of fractures and joints which strongly influenced the history of the channel and shapes of outcrops.

PART I. THE POTOMAC GORGE COMPLEX; MORPHOLOGICAL DATA

Baselevels of the Potomac River

The water surface elevations of the modern Potomac River (Table 1) varies with discharge, but the average elevations shown on the topographic maps of the U.S. Geological Survey and of the National Park Service provide synoptic views. I use the slopes of these water surface levels to construct the average gradients given in Table 2. The modern gorge floor as reported by Reed (1981, also written communin., 1993) are generalized on Figure 3.

Between the Great Falls Water Supply Dam and tidewater, the modern Potomac River is controlled by five natural baselevels that form nickpoints. In an upstream direction, they are at: sealevel, the top of Little Falls, the top of Stubblefield Falls, the top of Yellow Falls, and the top of Great Falls (see profile of the modern river in Figures 2 and 3 and Table 2 for locations and elevations); the stretches between nickpoints have gradients comparable to those above Great Falls.

Morphological Features Indicating Past Stages of Downcutting

Morphological features I used to establish stages of gorge downcutting (i.e. strath levels) fall into five categories: concordant summits, plungepools, paleochannels and ponds, rock benches, and potholes. In terms of origin, benches and broad concordant summits convey similar information. However, concordant summits are widespread features whose former continuity from one point to the next is fairly certain. By contrast, benches are local features whose correlation requires adopting a working hypothesis, to be described later.

Figure 3 and Table 3 give the locations of these morphological features relative to a reference line, shown on Figure 2, which consists of straight segments located within the modern thalweg (Table 4). Because the morphological features do not all fall on this reference line, their locations, given in Table 3 as distance (km) from the arbitrary zero point at the south end of Gladys Island, are projected orthogonally to the nearest segment of this line. Where possible, locations are determined using the National Park Service topographic map for the river region, original scale 1:1,200 (1 inch = 100 ft; the maps available to me have been reduced to a horizontal scale of 1:2,400) and contour interval of either 2 or 5 ft. Where these detailed maps are unavailable, the U.S. Geological Survey 1:24,000 topographic quadrangle maps, using a contour interval of 10 ft, were used. Comparison of the U.S.G.S. map and the simplified, condensed map based on the NPS map, at the same contour interval of 10 ft, for the Great Falls Park area (Zen and Prestegaard, 1994, figure 1) highlights the different qualities of the two map series.

Concordant Summits

The broad, concordant summits of large, generally flat-topped, smooth, water-worn rock islands within the channel system are interpreted to be remnants of former straths. The most obvious of these is the youngest pre-gorge strath; it has an elevation of about 140 ft above sealevel near the upper end of Mather Gorge, and provides a starting point for discussion. This strath is important because it provides a nearly uninterrupted set of elevation data spanning some 10 km of river distance from Great Falls to below Cabin John Bridge (Figures 1, 2 and 3).

In the upstream direction, this strath merges with the bedrock floor of the modern river on which the Great Falls Water Supply Dam is erected. The dam, with its top at 150.5 ft (National Park Service topographic map) is 6 to 10 feet high (Hahn, 1992, p. 46, and my own measurements), so that the bedrock floor is between 145 and 141 ft above sealevel. At the dam, the floor is not yet affected by the declivity of Great Falls 0.5 km downstream. This strath must have served as a continuous bedrock channel floor at some time past, and so defines an isochron or instantaneous river profile. This strath has a longtitudinal gradient of 0.06% (2 ft per km) between Olmsted Island and Sherwin Island, and 0.04% farther downstream as far as it can be traced (Figure 3). The gradient is comparable to those of the gentle segments of the modern river (Table 2), and guided me in reconstructing the transient straths nested within the gorge.

In detail, the strath surface is hummocky with a few (1-3) meters of local relief, both positive and negative, that represents former rock islands and scoured closed depressions (Zen and Prestegaard, 1994). The strath is similar across its width; there is no visible favoured thalweg. Preserved lateral potholes, eroded into the paleo islands at or near the former water surface (Zen and Prestegaard, 1994) constrain the probable average water surface level closely. Widespread occurrence on rounded, water-worn rock outcrops of vein quartz that protrude mm or at most 1-2 cm suggests that the amount of post-strath land surface reduction is negligible.

Downstream from Plummers Island, evidence for this strath is scanty and problematic. The levels (Table 3) at High Island and the terraces of Potomac Heights and Harrison School must be used warily.

A second set of concordant plateau-like summits on Cedar, Chatauqua, Ruppert, Cabin John, Sycamore and other islands defines a younger strath. This is the dominant set below Plummers Island; the topographic bench at the downstream end of Plummers Island is part of this strath carved into the older strath level. Isolated island summits within the gorge system upstream from Cabin John Bridge (small island off the east end of Offutt Island; Herzog Island; islets off Difficult Run and in Stubblefield Falls), as well as numerous water-cut benches (Table 3), show that this set extends well into Mather Gorge.

The summits of some isolated islands are conical rather than broad and plateau-like. These might be the remnants of once-broader summits and thus provide minimum elevations, but their value for geomorphic reconstruction is necessarily less compelling. Examples, in addition to High Island, include the rugged summit of Roosevelt Island, where the river is at modern tidewater level. In Figure 3, these points are accompanied by up-pointing arrows.

Plungepools

One definite (*P0426*) and two possible (*P0605*, *P0633*) plungepools have been recognized within the gorge system. The outlets provide strath levels because at these locations the strath lasted long enough for the plungepools to form. Ponds derived from plungepools are oval to circular rather than narrowly elongate (which is the shape typically resulting from local scouring of the river floor), show water-worn, amphitheatre-like walls, an outlet sill, and an inlet that is a cascade. The two possible plungepools possess these qualities except that their inlets do not seem steep enough to have caused the pools. Nevertheless, they do denote local stasis.

Paleo-channels and Ponds

These features are described together because the ponds included here are narrow and elongate, and are interpreted as segments of paleo-channels. For the ponds, elevations of the outlet sills, rather than their bottom evidence for local baselevel stability. The channels are locally well preserved, for instance several on Bear Island (*C0528*, *C0530*), including Widewater (*C0511*), and Black Pond behind Madeira School (*C0751*). The ravine-like channels on Olmsted Island, across several of which the Boardwalk is built (*C0377*, *C0420-1*, *C0420-2*), are readily visible. The hidden gorge on Rocky Island (or Rocky Islands, as designated on the U.S.G.S. topographic map because at water level above 95 ft the island becomes two) is a magnificent paleo channel; it was as much as 60 ft deep (*C0449*).

Some channels are long, very narrow "shoestrings". An outstanding example is the channel that bounds Plummers Island on the north: it is nearly 600 meters long, is cut into bedrock for the entire distance, has a low sinuosity (1.2), and has a steady width of about 15 meters for an aspect ratio of 40. It is an active subsidiary channel of the modern river but must be an older feature because its outlet sill (*C1263*), at 53 ft, is nearly 100 ft above a channel deep just off the sill (at -45 ft; J.C. Reed, Jr., 1993, written commun.; see Figure 3 near the 12-km mark).

Other shoestring channels include one that during modern floods separates the main part of Bear Island from a small hillock opposite Sherwin Island (*C0636*; sinuosity = 1.8); a bedrock-bounded oxbow (*C1238*; sinuosity 2.4) immediately north of the shoestring channel at Plummers Island, just described; and one bounding Cabin John Island on the north side (*C1495*). The high-sinuosity channels require that some of the intermediate straths lasted long enough to allow meanders to cut into the bedrock floor.

A pair of channels between Rocky Island and Olmsted Island are transverse and arcuate. The lower one (*C0420-3*) at 77 ft separates the two islands and is an active channel except during very low flow. The upper strath, parallel to it, is offset to the north (up-river) by about 50 m, and is at 111 ft (*C0420-5*). Why these narrow arcuate channels are favoured at this site is not clear.

Rock Benches

Rock benches are surfaces of river erosion and mostly belong to intermediate and diachronous straths keyed to some migrating baselevel. To be included in my dataset, a bench must show evidence of erosion by running water such as presence of potholes, flutes, or other plastic forms. Large benches may contain small prominences that were likely islets. An example is the sizable area at ~95 ft level immediately below the observation platform at the end of the boardwalk, Great Falls Tavern Visitor Center, C and O Canal Park (*B0382*). This bench has a ca. 5 ft nubbin (top at 105 ft). Potholes, both vertical and lateral, on both sides of this paleo-islet occur to a maximum elevation of 96 ft; above that level, the rock surface displays flutes only.

Potholes

Inclusion of potholes in Table 3 requires explanation. Pothole formation requires a period of local stasis but the length of time needed may not be very long, certainly briefer than that for the formation of concordant summits. Although the pothole data are less persuasive than some other data, they are consistent. One site in Virginia shows several potholes on a 10-meter high, vertical, joint-bounded cliff near the upper end of Mather Gorge (*H0431*, *H0432*). Here, vertical and lateral potholes are found at two distinct levels. One lateral, formed near a small step in the cliff, has a cylindrical basin resembling a vertical pothole. I interpret these potholes as the local record of straths whose record is not otherwise preserved on the vertical cliff (and incidentally demonstrate the antiquity of the cliffs as morphological features). Pothole *H0425* is graded to a plungepool, *P0426*, at the 115 ft strath level.

Potholes *H0533* and *H0595* were exposed when the C and O Canal at Widewater was drained following flood damage of January 1996, and record events not otherwise observable in this stretch of the paleo channel. Together with the water-worn bedrock channel exposed by the draining at the head of Widewater (*C0511*), the record shows that this segment of the Canal was an active channel at least through the formation of the

95-ft level of the gorge. At this stage of channel development, Bear Island was already a topographic high separated from the mainland, no longer involved in the shifting channel system except at the southwestern tip adjacent to the end of Mather Gorge.

Mode of Cataract Retreat Within the Gorge Complex

While reconstructing the morphological history of the Potomac River gorge, I distinguish the "strath", which is the remains of a paleo channels, and the "isochron" which is the instantaneous river profile. For a segment of a riverbed everywhere at grade with a single baselevel, the strath is an isochron (see also Pazzaglia and Gardner, 1993, for analogous features on the Susquehanna River). For a riverbed graded to several baselevels, as the modern Potomac River is, the whole is an isochron; however, the segments bounded by slope breaks (local baselevels) at Great Falls, Yellow Falls, Stubblefield Falls, and Little Falls would become straths if preserved.

In a following section I summarize possible modes of excavation of the gorge and evaluate their effectiveness, and conclude that "quarrying", that is, bodily removal of blocks of rocks through hydraulic lift and "drilling", formation of potholes aided by enlargement of fractures by abrasion, are likely the most important. At any given location along the channel, downward erosion by quarrying must have been episodic because an interval of downcutting would be triggered by the upstream passage of a cataract by this point, to be succeeded by a period of quiesence when the new strath is temporarily established (see Schumm, 1975). The presence of the nickpoints means that events in the distal downstream sections cannot significantly affect the evolution of the upstream sections of the gorge complex. Eustatic sealevel lowering or epeirogenic uplift, for instance, would create new, lower baselevels and could initiate downcutting at the distal end, but unless such changes are accompanied by climatic changes or non-uniform uplift and deformation, the upstream sections would not immediately sense it.

How may the individual features indicating local baselevel be allocated within the framework of isochrons? Obviously, a feature cannot be isochronous with one of higher elevation farther downstream. However, a lower-elevation feature might be related to any higher-elevation feature upstream. The guideline of 0.06% gradient suggests but cannot prove connections, but features that cross-cut at a given site could help to determine whether they belong to the same isochron. For example, behind Madeira School two clusters of nubbins define two reference elevations (*S0703*; *B0668*); a pothole-bearing bench (*B0669*) cuts them. The bench has the same elevation as Yellow Pond (*C0701*), which, like Black Pond (*C0751*) was a channel segment. I recognize here four elevation levels belonging to four isochrons.

The concept of "strath" is more useful than "isochron" to reconstruct the morphological history because I have no independent means to ascertain the instantaneous connectivity of the morphological features. The data of Table 3 and Figure 3 are examined to see if a pattern can be discerned. These data do seem to define several down-stream inclining arrays, here interpreted as straths. For convenience of reference, these will be referred to hereafter as the 140-ft strath, the 115-ft strath, the 95-ft strath, and the 77-ft strath, using their elevations near the entrance to Mather Gorge. A yet lower, 53-ft level is locally mappable below Cabin John Bridge (e.g. *C1263*) and may define another strath (Figure 3). The modern channel is lower than all of these.

My working hypothesis is that the straths lower than the 140-ft level are diachronous, so that each level did not complete its upstream erosion before the next level commenced. Thus, each strath was bounded above and below by baselevel-defining cataracts, and migrates upstream by the retreat of these cataracts. Because the rates of headward migration of the cataracts may vary, the fetches of individual straths varied with time.

The vertical separations of successive straths at any point are 5-10 meters (10-30 ft), and maintain the characteristic values along the river so steadily that the elevations of strath-defining features can be predicted with fair confidence. This can come about only if cataracts preserve their identity and height as they migrate upstream. The vertical separations between straths are also consistent with the heights of modern cataracts in the gorge, for example, the Yellow, Stubblefield, and Little Falls (Table 2). Even at Great Falls, the overall drop of 45-50 ft is distributed, depending on the channel, over 3 or 4 major cataracts each having 10-15 ft of drop and separated by relatively flat fetches (Figure 4). The pattern of data points in Figure 3 hints at the possibility that the transient straths are not dead records but merge with the individual level reaches within Great Falls, where upstream erosion may be presumed to be still active. Because straths are diachronous, the age of formation of a given strath should become younger in an upstream direction. Cosmogenic nuclide dating of erosion surfaces could thus provide a direct way to measure the rate of cataract recession.

How closely bunched were the successive cataracts during gorge formation? Are minor separations such as those now found at Great Falls, 50-100 meters long (Figure 4), the rule? The answer is no, based both on the existence of the three lower "falls" showing that dispersal of cataracts is important even today, and on the following observations bearing on horizontal separations between paleo-cataracts.

The nearly level paleo-channel on Bear Island (*C0528*) is at an elevation of 116 ft, though its downstream end is modified in response to a later and lower baselevel. This channel is part of the 115-ft strath and is about 480 meters long. The upstream end of the channel is utilized by the C and O Canal between Lock 16 and Lock 19. The elevation increase between the locks, about 30 ft, must have started near Lock 16, so the paleochannel can be extended as far as this lock for a total distance of about 750 m.

Widewater (*C0533*) on the canal, beginning just downstream from Lock 15, delineates another paleochannel (see Milton, 1989); an abandoned channel across the lower end of Bear Island (Table 3, *C0607*) could be its outlet. The channel at Widewater contains well-preserved lateral potholes corresponding to at least the 115 ft and 95 ft levels; these are visible when the canal was dry, for instance during the summer of 1996 after the January 1996 flood had destroyed part of the towpath. The distance between the downstream end of the abandoned channel and Lock 15 is about 1.1 km; the maximum bottom elevation of this channel is 111 ft and so was graded to the same baselevel as channel *C0528*, especially if we remember that this channel is about 1 km downstream from the first, and its elevation should be about 2 ft lower.

The hidden gorge on Rocky Island (Figure 5) is graded to the 77 ft baselevel; it terminates upstream in a rock ledge (*B0425*) which was a cataract. Between that point and the mouth of the gorge (*C0449*) the distance is 260 m. Elsewhere on Rocky Island, channels and ponds define short segments of the 115 and 95 ft straths. Two channels at the south end of Olmsted Island are cut off by the arcuate transverse channel graded to the 77 ft level that circumscribes the north end of Rocky Island; just 70 m away, on Rocky Island, two aligned truncated channels are found (compare *C0420-1*, *C0420-2*, *C0433*). If these were once continuous, the minimum fetches would be each about 300 m.

The strath at Black Pond behind Madeira School (*C0751*), at 85 ft (part of the 95-ft strath), is 340 meters long. This segment of the strath begins and ends at the modern river channel across a zigzag. The successful channel is nearly twice as long as the Black Pond strath and the relations show that downcutting of the gorge must have proceeded in vertically restricted packets delimited by the height of the local cataract, rather than by a single cataract that spanned the entire range of relief. The relations at the hidden gorge and its terminating rock ledge on Rocky Island tells the same story.

The shoestring channel separating Bear Island and a small island next to it (*C0636*) at 72 ft elevation has a length of about 850 m and was a stretch of a younger strath. However, the channel has a sinuosity of 1.8 so the effective fetch was less. The shoestring channel (*C1263*) at the north side of Plummers Island, controlled by a rock sill at 53 ft, is 600 m long and has a low sinuosity of 1.2.

These data, recording several distinct stages of strath formation, show that many individual fetches were hundreds of meters long, much longer than the fetches between modern cataracts of Great Falls. These reconstructed channels entail longitudinal gradients consistent with the guiding 0.06% gradient.

In contrast, data also exist to show that bunching or coalescence of cataracts also happened, locally producing composite falls nearly as high as Great Falls. For example, at the northwest corner of Rocky Island (Figure 5), a pond, segment of a former channel having an outlet sill at 110.5 ft (*C0433*) is connected via a steep, straight, joint-controlled bedrock ravine ("the connector" on Figure 5) to a bench at 77 ft (*B0444*). The ravine is very brushy, but waterworn features are extant along its walls; towards the bottom of the ravine potholes are abundant. I interpret the ravine as having accommodated in a single leap the 32-ft local drop in a horizontal distance of about 140 meters, a gradient (7%) nearly twice that of the modern Great Falls. A later, lower outlet on the west (modern river) side of this pond, having a sill at 104 ft, apparently resulted from a rockfall as the upper part is jagged and is not waterworn, even though toward its base there are potholes. The bunching might be controlled by local abundance of metagreywacke strata (J.C. Reed, Jr., 1996, written commun.); this interesting idea should be tested.

To summarize: during the formation of the Potomac River gorge, straths at different levels were constantly evolving as their bounding cataracts migrated upstream. At any given time, several channel levels were in active use, separated from one another by cataracts 10-20 ft high. Individual straths lengthened and contracted, but bunching of cataracts seem to have occurred only rarely. Unfortunately, nothing more specific can be said of the instantaneous configurations of the gorge during its formation, pending determinations of the *ages* of erosion features.

Some Corroborative Data and Inferences

In this section, I discuss some topical issues related to the process of gorge excavation and to other evidence testing my hypothesis.

1. Modes of Excavation of the Potomac River Gorge

Possible processes of gorge excavation include the following: caprock failure, chemical solution, abrasion, bodily removal of rock blocks by hydraulic lifting ("quarrying"), and removal of rocks through formation and linking of hydraulically formed cavities, principally potholes ("drilling").

Caprock failure requires contrasting rocks with a strong caprock overlying with low dip over a weak rock, so that undermining can cause the strong caprock to fall and the nickpoint to retreat. This is what happens at

Niagara Falls, but do not apply here because the Piedmont metamorphic rocks of the gorge do not have the necessary geometry or material contrast.

Chemical solution of bedrock cannot be an important process because the dominant rocks are schists and greywackes, which do not dissolve readily.

Abrasion must have occurred, possibly aided by minor chemical solution, to form the smooth, rounded surfaces typical of the bedrock straths. The process evidently also led to the sculpting of the p-forms. However, the process likely burnished the surfaces, but did not define the main features, as its rate is probably much slower than the next two processes.

Hydraulic quarrying involves bodily removal of rock blocks by hydraulic pounding and lifting, and by the incremental displacement of blocks during freeze-thaw cycles. The blocks are defined by surfaces of weakness such as contrasting bedding and fractures; once moved from the original position, the blocks could be reduced by percussion, abrasion, and further fracturing. This process is likely most efficacious at sites where a nickpoint is passing by, and then mostly during floods. At a given time and place, the vertical drop across a nickpoint, defined largely by the height of a cascade, controls the vertical range of operation of this process.

Drilling is caused mainly by the formation of potholes, both lateral and vertical (Zen and Prestegaard, 1994), and can be surprisingly effective. I have found three documented rates for pothole enlargement. One is in the Navajo Sandstone in a seasonal tributary within Zion National Park, monitored over 5 years (Gregory, 1950). One is in granite near Heidelberg, Germany, monitored over 70 years (Putzer, 1971). The third is in a freshly-cut tailrace of a hydroelectric project, in ophiolite near Zermatt, Switzerland, where the slope was 6% and where the current was presumably continuous, turbulent, and sediment-laden (Vivian, 1970). The average annual rates of enlargement are respectively 3 cm, 3 cm, and over 1 m. Even the lower rates suggest that a pothole 1 m across could form in a few decades, so that pothole formation may be validly considered a geologically instantaneous event. When potholes grow, they may impinge on one another (as may be seen along the Billy Goat Trail on Bear Island, or near the entrance to Mather Gorge on the Virginia side), the rock is cut up like Swiss cheese, and wholesale removal to a depth of the potholes (as much as 2-3 m) is readily accomplished.

Formation of lateral potholes is by abrasion by sand-sized sediment load, by percussion, and possibly by cavitation; as discussed elsewhere, large boulders acting as percussion stones cannot be the principal agent (Zen and Prestegaard, 1994).

Combination of the processes of quarrying and drilling probably accounts for most of the excavation of the Potomac gorge.

2. Channels Around Rocky Island

I have already described geomorphic features on Rocky Island and adjacent parts of Olmsted Island, including the hidden gorge, the arcuate circum-island channel and the probable former continuation of higher-level straths across it, and the evidence for bunching of cataracts when the main declivity was at this position. The 110.5 ft pond (*C0433*) was an active part of the 115 ft strath. At that time, apparently a network of distributary, bedrock-floored channels developed, one of which (*C0420-5*), with uncertain connectivity to the pond, formed another arcuate channel that parallels the younger one of the 77-ft strath. At that time, further, the higher, 140-ft cataract was located at least as far upstream as the dog-leg section of the present gorge, upstream of the circum-island channel (easily excavated because of the orientation of a zone of joints; Reed and others, 1980). The rock barrier at the head of the hidden gorge that bisects Rocky Island (*B0425*) is a part of the 95 ft strath; remnant benches corresponding to this level, decorated with potholes, adorn the sides of the hidden gorge (*B0437*, *B0443*). As discussed, the 110.5 ft pond directly discharged to the 77-ft strath, which is the same level as a rock sill marking the west end of the transverse channel (*C0420-3*), exposed during very low flows. The excavation of the 95-ft strath and even the hidden gorge itself overlapped in time the use of the 110.5 ft pond as an active channel, and this higher-level channel was a barrier between the strand that used the hidden gorge and the strand that became the modern channel. Thus, the modern configuration of Rocky Island resulted from different patterns of retreat of three major and one minor strands, all keyed to the 77-ft baselevel (Figure 5; this configuration may have a close parallel with the modern Great Falls, with its three parallel strands keyed to the same baselevels above and below, and encompassing a total horizontal distance comparable to the length of Rocky Island). The two flanking major strands were more active than the hidden gorge strand which was "hung-up" by the rock barrier at its head. A plausible sequence of events is that the eastern strand retreated most rapidly, eventually to behead the hidden-gorge and the minor strands, until, with the western strand now near sill *C0420-3*, the two strands joined there. If this reconstruction is correct, fetches of the eastern strand, including the L-bend, would be 500 meters long. If this arcuate strath represents an incised meander, as its shape suggests, its incision at this point would have to be no older than the 77-ft level.

Referring to Figure 5 again, note that the Potomac River is about 70 m wide just upstream from Rocky Island, and has a similar width below Rocky Island in the straight part of Mather Gorge. Yet the main channel along the west side of Rocky Island is only about half that width - the narrowest part of the entire river within the scope of this study. As there is no tributary entering the river between these points, and as the bedrock is the same, what hydraulic factors could cause a river, cutting a gorge, change its width so suddenly, and then reverse itself? The answer, it seems, lies in the existence of the eastern and hidden-gorge channels, each about 20 m wide. Added to the main channel on the western flank, the total width equals the width of Mather Gorge. The eastern channel is utilized when the river level rises above 77 ft (sill *C0420-3*), and the hidden-gorge channel, above about 90 ft (sill *B0425*). The river has its own flow-diversion mechanism today.

To have a bedrock channel split into several subchannels is not unusual; to have the total width conserved requires delicate hydraulic adjustment. How could this be? The simplest explanation seems to be that the splitting of the channel began on an open, flat, smooth bedrock valley floor and was caused by local obstacles such as rock prominences whose existence then is shown by the lateral potholes. The geometric and dynamic parameters within the subchannels were initially sensibly identical and the channel was dynamically and energetically indifferent to the split. However, after being entrapped into the subchannels, further downcutting led to different hydraulic conditions. The rates of erosion responded to these differences and the growth of the subchannels diverged even though the subchannels maintained their width. I propose this is how the subchannels at Rocky Island came into being.

3. Is the Alignment of Mather Gorge Controlled by a Fault?

Reed and others (1980, p. 28) noted that if the measured strikes of the Devonian-age mafic dikes on the two shores of Mather Gorge were projected toward each other, they would miss by about 25 meters. Reed and others (1970) cited magnetic and other field data to support the idea that a fault beneath the river caused the offset, stating that "the straight and steep-sided gorge here has been cut by the river in the crushed and broken rock along the fault". This inference is much cited (e.g. Southworth and others, 1996; Milton, 1989; Davies, 1989). A straight fault causing Mather Gorge should emerge on Rocky Island; it may in fact be the locus of the "connector" ravine described previously.

Still, the use of the misalignment as evidence for a fault is permissive as it is not obvious that the strikes of the dikes should remain undeviating for the width of the gorge, about 70 m here, which is more than an order of magnitude greater than the horizontal dimensions of exposure of these thin (20-30 cm) dikes. If the fault does exist, it must extend upward at least to an elevation of 115 ft, the minimum rim elevation of the gorge on Bear Island, because shoestring channels (e.g., *C0528, C0595*), a plungepool (*P0426*), and clusters of potholes (*H0431, H0547*) are all part of that strath and vector toward the modern gorge. Yet the morphology of the 140-ft strath gave no indication of a fault-controlled thalweg premonitory of the gorge, and Mather Gorge angles across the 140-ft strath.

Tormey (1980, p. 154) pointed out that Mather Gorge lies within the compass quadrant in which joints are concentrated. Certainly, there is an abundance of steep joints along Mather Gorge that parallel the channel.

The argument is inconclusive here. If for whatever reason a gorge having nearly vertical walls is excavated, the rocks along the unsupported walls can be expected to fail by fracture normal to the principal extensional stress, just as in quarry operations the removal of overburden rocks results in "unloading joints" parallel to the upper surface (Jahns, 1943). In contrast, the evidence for the antiquity of joint-controlled cliffs that contain potholes might be taken as supporting Tormey's idea.

The stretch of the modern Potomac River between Little Falls dam and the outflow channel cut for the unused Dalecarlia hydroelectric plant (Hahn, 1992, p. 25) is as straight as Mather Gorge, is exactly as long (1.3 km), and is even slightly narrower at normal discharge level (60 m vs. 70 m at Mather Gorge). It is more subdued scenically because the difference in elevation between normal waterlevel and the rock bench flanking it is about 20 ft, rather than 60-70 ft as at Mather Gorge. Does a fault control this straight stretch also?

Shepherd and Schumm (1974) report straight channel development in their flume experiments, for which the substrate was free of faults or joints. Their straight channel superficially resemble Mather Gorge. Even though the experiments are merely analogues, without scaling factor to extend to natural relations, we need to consider the possibility that straight segments could result from downcutting of broad, flat bedrock channels. Once entrenched in a straight channel, the river cannot readily escape (see, also, Seidl and Dietrich, 1992).

4. The "Hanging Valley" Near Patowmack Canal

A steep natural ravine connects the former collecting basin of the Patowmack Canal and Mather Gorge. Small cascades with base at about 122 ft level occur just upstream from the trestle bridge of the River Trail in the Great Falls National Park. This ravine could be a hanging valley developed after the cataracts of the Potomac River retreated past the confluence. However, even granting the uncertainties introduced by post-colonial human activities (see Milton, 1989), the original catchment area of the ravine stream could hardly have been 1 km^2, probably insufficient to cut the valley. Alternatively, the ravine could record a former cataract of the main river whose life was cut short by more rapid retreat of other parallel cataracts; like the plungepools, it was bypassed.

5. Potholes on the 140-ft Strath

The 140-ft strath is dotted with potholes, both vertical and lateral (Zen and Prestegaard, 1994), between the head of Olmsted Island and the downstream end of Mather Gorge. Yet this same strath below Sherwin Island has few potholes. Lack of lateral potholes can be explained by an absence of significant rock obstacles on the former strath. Lack of vertical potholes may be explained either by a lack of turbulence or by water depth too great for the vortices to touch bottom (Zen and Prestegaard, 1994). Total absence of turbulence seems improbable, but a smooth longitudinal gradient and lack of nickpoints might explain the decrease in turbulence and the difference in erosion pattern.

6. An Episode of Aggradation?

North of Plummers Island, a small, shallow oxbow channel (*C1238*) having a sinuosity of 2.4, is cut into bedrock. Oxbows in bedrock can best be explained as being superposed from a sediment-covered floor, so they suggest that during an interval of formation of the 77-ft strath, deposition, rather than downcutting, temporarily prevailed. What triggered this fluviatile regime? Deposition was not due to marine incursion because the elevations systematically inclined toward the river mouth. I suggest that the river carried so much sediment load, possibly during the waxing phase of an episode of glaciation, that part of it was dropped out of transportation as a consequence of gorge formation (cf. Schumm, 1975, pp. 74, 80).

7. Abandoned Valley Near Glade Hill, Great Falls National Park

A large abandoned valley, now a wetland containing a small, underfit stream (Milton, 1989), occurs on the west side of Glade Hill in the Great Falls National Park. The valley has a constant width of about 120 m; its floor is mostly between 146 and 150 ft, but locally reaches 156 ft due to the encroachment of a colluvial apron from the southwest hillside. At its head the valley is coterminous with Glade Hill and is parallel to the foliation in the bedrock. The valley serves as a channel only when flood crests are higher than about 150 ft at this point.

Using shallow seismic refraction methods, Lee (1993) determined two depth-to-bedrock profiles of this valley near its two ends and reported bedrock between 140-145 ft elevation beneath river sand and gravel, in close agreement with the data of Milton (1989). This channel may have either preceded or was synchronous with the 140 ft strath, as the bedrock elevations of the two cannot be distingushed; Reed and others (1980, p. 10) considered them to be coeval. This interpretation is supported by the fact that the channel is coextensive with Glade Hill and, if the width of the hill is subtracted, the total width of the 140-ft strath remains nearly constant, just like the relations at Rocky Islands.

When did this channel begin its existence? A boulder deposit on top of Glade Hill at the older 200-ft level, described below, shows that the initiation of the channel could not be older than that level. As baselevel dropped and the 200-ft strath was dissected, initially to the 155-ft level, however, separate channels on both sides of what became Glade Hill formed. Indeed, remnants of the 155-ft level, as discussed below, exist on both right and left sides of the prow of Glade Hill itself, showing that this channel indeed existed at that time.

8. The Channel Deeps

Reed (1981; also unpublished data) showed that the the modern Potomac River channel, downstream of Mather Gorge, locally contains enclosed basins reaching as much as 25 m below the modern sealevel. The shape of these closed pools, described by Reed as spoon-shaped and free of sediment fill, is not consistent with plungepools. Such closed basins have been described in other large rivers, for example the Susquehanna River (to below sealevel; Thompson, 1990; Mathews, 1917; Pazzaglia and Gardner, 1993) and The Dalles on the Columbia River (Bretz, 1924). Shepherd and Schumm (1974) observed scoured deeps that reach below the indisputable baselevel in their flume study.

Scoured deeps have been preserved as ponds along the thalwegs of channels (e.g. Table 3), and small closed depressions on the broad, 140-ft strath probably are analogous features. Even those deeps below the modern sealevel were well above sealevel during the peak of the last Wisconsinian glaciation, when sealevel was about 100 m below the present surface (Dillon and Oldale, 1978; Fairbanks, 1989). The deeps might have formed as scours and are kept flushed and clean by modern floods; they seem most common immediately downstream from steep bottom grades (Figure 3).

One could also argue that even though the deeps do not now have the shape of plungepools, their erosion was almost certainly triggered by the retreat of cataracts; thus, the locus of excavation also must have migrated with time. If they started out as plungepools, the depth of their effective erosion would be time-dependent, and complicated shapes could be expected.

One could argue that, because of headward retreat, a cataract encountering a pond left from a higher-level could be expected to suddenly diminish in height, so that these older ponds controlled the levels of transient straths. Some of the data scatter (Figure 3) may reflect this effect; but the elevation data (Table 3 and Figure 3) for summits, potholes and plungepools are independent of the deeps. Benches tend to be preserved along margins of channels and should not be seriously affected. Channels and ponds are obviously more vulnerable, but those having elongate morphology, represented by most of my data, would not be expected to be former deeps and the use of outlet sills to estimate strath levels of channel-related ponds should remove much of this concern.

9. Records From Difficult Run

Difficult Run joins the Potomac River from the southwest (Figure 3). Within the Great Falls National Park, the following reaches of the river are recognized in a downstream direction (Figures 6 and 7):

I. A relatively gentle reach having a gradient of 0.17% over a distance of 6 km from just below the bridge for Old Georgetown Pike (Virginia State Route 193) to Wolftrap Run (see Figure 8). At the Route 193 bridge, flanking alluvial terraces are at 162 ft and the water surface during normal discharge is about 5 ft lower. Rocky Run enters Difficult Run here with concordant confluence, supporting the inference that this strath was of considerable duration.

II. A bedrock cascades-and-pool section, 370 m long, between 152-ft and 135-ft level, consisting of four cascades and three pools and an overall gradient of 1.8%. The pools have fetch-to-width ratios of about 7. At 145 ft the bedrock has vertical potholes and may record a brief stillstand. At the downstream end of this reach, a large, mid-channel alluvial bar having about 2 m relief, now tree-covered and marginally eroding, occurs at 135 ft. This inactive bar is taken as a record of the coarse sediment load dropped out of Difficult Run as it met the Potomac River. A waterworn rock bench at 135 ft a short distance downstream from the bar and flanking a miniature gorge on the north side shows that the bar probably did not merely record a pause in the stream profile on its way to a distant confluence. The 135-ft contour, thus, is a significant record, a point confirmed by comparable elevations of the summit of Sherwin Island across the river. It is in fact the 140-ft strath adjusted to its downstream location. Difficult Run was even then already in a deeply incised valley and the confluence was deeply embayed within the tributary valley. The channel below this level was excavated since the upper cataracts of the Potomac, dissecting the 140-ft strath (i.e. the direct ancester of the modern Great Falls), retreated past the confluence.

III. A steep channel below 135 ft that breaks into a miniature gorge between 120 ft and 95 ft and that levels off at about 90 ft. The distance of this reach is 320 m and the gradient is 3.8%, the same as at Great Falls

(Table 2). A series of cataracts, one of which is about 10 ft high, occurs here. The rock bench at about 130 ft shows many potholes, both lateral and vertical, recording the duration of the 140-ft level (here at 135 ft).

IV. A final section between the 90 ft point and the confluence with the Potomac River at 73 ft during normal discharge (*C0661*). This section is 416 m long, with an overall gradient of 1.2%. It includes a second alluvial bar astride the channel topping out at 92 ft. The bar records the 95-ft strath in the Potomac River, again followed downstream by a rock bench at 90 ft. The bar suggests a lengthy stillstand, in agreement with the extensive record of this pothole-rich level within the Potomac Gorge (Figure 3). This reach is a morphological twin of the reach of the Potomac River between the confluence and the base of Great Falls, 2980 m long, as erosion of both started simultaneously. The length ratio of the two reaches is 2980/416 = 7.2; the estimated volumes of rocks excavated within them, based on the National Park Service topographic map, are respectively 5.2×10^6 m^3 and 0.5×10^6 m^3 for a ratio of 10:1 (see Appendix 4 for details).

Small rock-floored benches on the south side of the valley and downstream from the mini-gorge, at about 115 ft level, could be part of the 115-ft strath, but I have not examined them on the ground. I have not been able to distinguish this strath level within the rock gorge of Difficult Run; it should be near the level of the second small cascade below the alluvial bar.

To relate the features in the valley of Difficult Run to those of the Potomac River, I must first demonstrate that the tributary relation existed during the time of interest, which for our purpose begins with the deposition of the Glade Hill boulder bed just upstream from Difficult Run valley (see below). This demonstration is made by observing that (1) along the entire watershed divide for Difficult Run and its tributaries, the saddles are never lower than 260 ft (290 ft if two sags near its mouth are excluded) and none of them has the configuration for a former channel, and (2) the longitudinal profiles of Difficult Run and its principal tributaries (Figure 8) show a step between two gentler reaches; the step could be correlated to that between the 155-ft and 200-ft straths in the Potomac River, described below.

I have so far tacitly assumed that the confluence point between Difficult Run and Potomac River has always been at its present position. Might this be false? For instance, could the channel of Black Pond behind Madeira School (*C0751*) be part of Difficult Run rather than the Potomac River? This asignment would make the zigzag course of Potomac River easier to understand. However, Black Pond is part of the 95 ft strath level, which is recorded in Difficult Run by an alluvial bar suggesting its terminus. Further, the area surrounding Black Pond is entirely within the trough of the 140-ft strath, and none of the surrounding hills exceeds 130 ft. I conclude that it was truly part of the Potomac valley and any shift in the position of the confluence was minor.

10. Turkey Run

An abbreviated record of intermediate straths is found in Turkey Run, opposite Minnie Island and downstream from the Cabin John Bridge (Figure 2). Here, a short cascade-and-pool sequence in bedrock is at 57 ft level (8 ft lower than a 65-ft BM), which agrees with the summit levels of Minnie Island and other concordant summit levels nearby as part of the 77-ft strath. Upstream, Turkey Run becomes more gentle to 100 ft, just above the Parkway overpass, when another series of riffles begins. The 100-ft level is consistent with th 115-ft strath level at Great Falls.

PART II. TWO PRE-GORGE CHANNEL LEVELS ABOVE THE 140-FT STRATH

The Potomac River had two strath levels higher than the 140-ft strath. The lower of the two is at 155 ft near Mather Gorge whereas the higher one is at about 200 ft (Figure 9).

First, however, I must show that even this early the main channel of the ancient Potomac River followed the present course, at least above the Fall Line (approximately the modern tidewater limit near Georgetown). This is done simply by highlighting the 250-ft contour lines flanking the modern channel below Leesburg, VA (the 200-ft strath would be nearly at 250 ft near Leesburg). This contour line, even though locally convoluted by tributaries, faithfully follows the modern channel, so the lower contours must do the same. Above the Fall Line, the river had no alternative course; distances and appropriate morphological features noted along the modern channel indeed may be used to interpret the ancient river.

The 155-ft Strath (Figure 9)

Evidence for this strath comes from Difficult Run and from the main Potomac River (Figure 1). Within Difficult Run, this strath is Reach I and is clearly older than the 140-ft strath. Over a distance of 6 km Reach I has a slope of 0.17%. This gradient means that the confluence with the Potomac River should be at 147 ft. Upstream, this reach ends at a steeper section near Lawyers Road at between 220 and 250 ft (Figure 8); the same slope break also appears in the profiles of the four large tributaries of Difficult Run (Little Difficult Run, The Glade, Piney Branch, and Wolftrap Run) not seriously modified by construction.

On the Virginia side of the Potomac River, upstream from Great Falls, a raised alluvial terrace is defined sharply against small ridges and their intervening ravines along a nearly straight line, with the ridges and ravines trending at a high angle into the line. I shall refer to this configuration as the "trimmed spurs" (Figure 9). This stretch extends uninterrupted from opposite Blockhouse Point, just downstream from the contact between the Piedmont and the Mesozoic Culpeper Basin, downstream to a point opposite the west end of Clagett Island, a distance of 5.2 km. The elevation at the base of the spurs is interpolated at 195 ft at the upper end and 180 ft at the lower end, for a gradient of 0.09% (3 ft per km). The schist in a vertical, water-smoothed remnant of river bluff at the base of one spur is weathered only to the extent that quartz veins stand a few mm in relief against the mica-rich laminae.

The trimmed spurs and hillslopes can be followed downstream, with some interruptions, to a point west of Minnehaha Island at 166 ft (National Park Service 2-ft contour topographic maps are used here; the relations on the Maryland side are not useful because of the C and O Canal), 8.0 km below the 195-ft mark mentioned above. This extended reach has the same gradient of 0.09%. Projection of this gradient to the modern confluence with Difficult Run (see Table 4) yields an elevation of 146 ft, in excellent agreement with the 147-ft value from Difficult Run, given above. I conclude that the elevations at the trimmed spurs and at Reach 1 of Difficult Run record the same strath, and, further, that the ancient confluence of the two streams was not far from the modern position. The 155-ft level also explains the deep embayment of the 140-ft level into the Difficult Run valley as resulting from nickpoint retreat after the baselevel dropped to the 140-ft level.

On the Maryland shore, upstream from Blockhouse Point and within the Mesozoic Basin, the same trimmed spurs can be followed for 6.7 km between a point 1.5 km above Lock 24 (Seneca Creek) and BM 219 below Cabin Branch. The elevation change of about 20 ft yields a nominal gradient of 0.08% which is indistinguishable from the 0.09% value. The 155-ft strath has an overall width of 0.9 km at Blockhouse Point and near Bealls Island, both within the Piedmont, of 1.4 km at Katie Island and at Seneca Creek, and of 2 km at Tenfoot Island, all within the Mesozoic Basin (however, the width of the active channel within this strath was likely considerably less). For comparison, the 140-ft strath generally has a width of ca. 1 km.

The 200-ft Strath (Figure 9)

The 200-ft strath is the highest strath so far recognized; it is recorded by a boulder bed at Glade Hill and by erosional features including nickpoints and channel scarps that might have been meander bends. As far as I know this strath is not bedrock-floored.

The Giant Boulder Bed on Glade Hill

Glade Hill rises above the 140-ft strath west of Mather Gorge (Figure 3). It is narrow (300 meters wide at the base, 100 meters across the top), elongate, NNW-SSE oriented, and, unusual for the Piedmont, has a flat top. At the downstream end, a large abandoned stone quarry has destroyed the original ridgeline, but over most of its length the hillcrest is natural. The northeast flank of the hill declines to the 140 ft strath through the 155-ft strath. On the southwest side of the hill, a carriage road and a buried sewer-conduit have destroyed the natural base of the slope.

Unweathered Piedmont crystalline rocks can be followed from the 140-ft strath to 190 ft on the southwest side of Glade Hill. However, the broad, level hilltop is paved by a boulder bed. The contact is located to within 5 m of map distance at about 195 ft elevation. The boulders consist of quartzite and fine-pebble feldspathic (arkosic) conglomerate. Whereas some boulders of quartzite might match the Sugarloaf Quartzite near the west edge of the Piedmont (Scotford, 1951), the assemblage as a whole can only be matched with rocks of the Cambrian Weverton Quartzite and possibly some quartzite from the superjacent Harpers Formation (Appendix 1), found west of the Mesozoic Culpeper Basin (Burton and others, 1992; Johnson, 1993), 40-70 km upstream (Table 7). An enigmatic 2-meter boulder of Mesozoic diabase now resting on the 140 ft strath directly below the quarry-truncated crestline of the hill (Reed and others, 1980) could have rolled down from the hill and would be the only non-Cambrian boulder. The only clast on the hill that could be derived from a Piedmont source, and that by no means certain, is a 2-meter, rounded boulder of laminated milky vein quartz; Piedmont rocks are not otherwise found even as chips in the matrix soil. Because the immediately underlying bedrock is completely unaltered, lack of boulders of Piedmont rocks cannot be explained by deep weathering.

Based on 280 boulders, the median value is 43 cm for the maximum diameter and 30 cm for the intermediate diameter (Figure 10 and Table 5); the largest maximum diameter is 2.2 meters and the largest intermediate diameter is 1.5 meters (several boulders of this size occur toward the southeast end of the hill). Where the third dimension of a boulder is not observed, it is assumed to be the minimum diameter. The boulders are well-rounded though many are far from spherical, as can be gleaned from the dimensions given in Table 5. The rounding may simply reflect abrasion during transport of what was initially a collection of irregularly shaped blocks. The boulders show no more weathering than the etching-out of detrital feldspar grains in some arkosic layers.

How were these boulders transported to Glade Hill, and how old might they be? Some "soft" constraints may be imposed. The base of the fluviatile Miocene-Pliocene sediments, resting unconformably on Piedmont rocks, was observed at 470 ft elevation at Gantt Hill and Freedom Hill, two monadnack-like hillocks at Tysons Corner that rise above the modern upland surface, now rapidly being leveled off by constructions, about 10 km to the south (Hack, 1975; Darton, 1951; Mixon and others, 1989). In the summer of 1994 I observed a transient exposure of the unconformity at 430 ft on Park Run Drive just east of Westpark Drive, Tysons Corner. Even this lower elevation is about 120 ft (40 meters) higher than exposures of the Piedmont rocks on the upland surface flanking the Mather Gorge section of the river - at about 300 ft near the intersection of Old Georgetown Pike (Virginia Route 193) and Old Dominion Drive, 1.5 km from the Visitor Center of Great Falls National Park, and at a similar elevation along the road to Great Falls Tavern Visitor Center of the C and O Canal National Park on the Maryland side, directly opposite (Figure 11). The top of Glade Hill is yet another 100 ft lower, in a trough that is the forerunner of the Potomac River channel within the upland bedrock surface. The boulder bed must be a channel deposit in an already incised Potomac River valley. We can rule out the idea that the boulder bed was a flood deposit formed during the active stage of the 140-ft strath, because if that were the case, they should be found abutting the upstream end of the hill and on the surrounding strath rather than on the flat hilltop.

Reed (1981) described occurrences of ca. 2 m diameter boulders in terrace deposits at or above the level of the 140 ft strath (his terrace I and terrace II, the latter may coincide with the level of the top of Glade Hill). He commented that some of the boulders "are ice-polished and bear distinct striations reminiscent of glacial striae", and pointed out that those on terrace I may have been reworked from nearby higher terraces. I have already referred the boulder of Mesozoic basaltic rock on bedrock on the 140-ft strath (Reed's Terrace I) in

Great Falls Park to such an origin. Indeed, exotic boulders of this size consisting of basalt and Weverton-like quartzite today line the Park's service roads, and smaller (up to 30 cm) but similar boulders are frequently encountered elsewhere on the 140-ft and lower straths within the gorge complex. These boulders must have been quite numerous before both natural and human intervention obscured their provenance.

To move blocks 2 meters across by river flow sustained over a distance of as much as 70 km requires unusual hydraulic conditions. Sevon (1994) invoked outbursts of glacial Lake Lesley near Williamsport, Pennsylvania, to explain overturned Mesozoic basaltic blocks several meters across in the Susquehanna River at Conawego Falls (see Pazzaglia and Gardner, 1993, for a detailed discussion of succession of terraces, soil profiles, and boulder deposits and their petrographic affinity within the lower reaches of the Susquehanna River gorge system). However, the Potomac River basin was beyond the reach of Quaternary glacial meltwater, and indeed monstrous floods are probably unnecessary for the transportation of the Glade Hill boulders (Appendix 1).

The only possible correlative to the Glade Hill boulder bed, called to my attention by Scott Southworth of the U.S. Geological Survey, is a single rounded boulder of Weverton(?) Quartzite, 2.5 x 1.4 x 0.8 m, partly damaged by construction but still retaining crustose lichen cover, resting on a late Tertiary(?) cobble-rich terrace deposit (Lee, 1979; Burton and others, 1992) nested in a degraded former river channel bend at the corner of McPherson Circle and Bentwood Road in Sterling, Virginia (longitude, 77°25'08"; latitude, 39°03'02", both ±2"), at an elevation of 245 ft, 15.8 km above the zero reference km point in Table 4. If it is in-place (I doubt that construction workers had brought such a large boulder to the place!) and is on the same strath as the Glade Hill boulder bed, it would imply an average channel gradient of 0.07% (drop of about 45 ft in 22 km).

Correlation of the McPherson Circle boulder with the Glade Hill boulder bed is strengthend by the fact that both points lie within 1 ft of a least-squares regression line (n=24, r^2=0.93; Zen, in prep) that extends between Glade Hill and Harpers Ferry and that relates the amount of entrenchment of tributaries to the river distance. This line also includes the nickpoints of ravines in the "trimmed spurs" section opposite Blockhouse Point, discussed below. Therefore, in the discussion below and in Appendix 1, I accept the McPherson Circle boulder as a valid piece of evidence. This gradient, extrapolated, predicts that the channel should meet modern tidewater about 90 km from Glade Hill, rather than the modern 20 km, placing it somewhere near Maryland Point (Figure 1), still well short of Chesapeake Bay.

Erosional Features: Nickpoints and Channel Scarps

Over a distance of 1.2 km within the section of trimmed spurs opposite Blockhouse Point, small ravines bracketing the spurs contain steepened gradients (indicated by riffles and erosion to bedrock ledges) between placid stretches. The upper elevations of these steep sections range in elevation between 225 and 240 ft (estimated $\pm$5 ft), about 30 ft above the 155-ft strath. These nickpoints provide the upper limit to the original nickpoints and are consistent with the 200-ft strath (predicted at about 230 ft here). The 155-ft and 200-ft levels differ by about 35 ft here but by 45 ft at Glade Hill; the discrepancy reflects the steeper gradient of the lower level.

Another possible support for the existence of this level is the longitudinal step in Difficult Run and its tributaries, mentioned above, that delimits the upstream end of Reach I in Difficult Run (Figure 8). The step, between 220 and 250 ft elevation, is not bedrock controlled (Drake and others, 1989). It is interpreted as the remnant of nickpoint retreat when the Potomac River dropped from the 200-ft strath to the 155-ft strath.

Recognition of the 200-ft and the 155-ft straths explains another puzzle. All around the north end of Glade Hill and within the southwest portion of the open picnic area, water-rounded bedrock outcrops are exposed between the 140-ft strath and 170 ft. These outcrops have been slightly weathered so that quartz veins stand out in relief by a few mm, comparable to the degree of weathering of the cliff opposite Blockhouse Point (p. 25). There is no saprolite even though the higher reaches were likely above even very large floods (the highest recorded flood of 1936 should have reached no higher than about 150 ft). These water-rounded rocks record the combined effects of the transition from the 155-ft strath to the 140-ft strath and from the 200-ft strath to the 155-ft strath, which latter, on the northeast side of Glade Hill, is preserved as a large rock bench at 155 ft containing ~1 m high water-worn nubbins with lateral potholes. This location, at the base of a former rock island, provides the lone evidence that the 155-ft channel was not everywhere alluvium-floored.

The overall modern water surface gradient of the Potomac River between Harpers Ferry and the south end of Gladys Island, about 3 km upstream from the Great Falls Water Supply Dam (far enough upstream to remove any effect of ponding by the dam), is 0.04% (90 ft drop in 70 km of river distance). Hydraulic calculations (Appendix 1 and Table 6) indicate that the river slope was at least 0.05% between Glade Hill and Harpers Ferry. The least-squares regression line that includes the boulder at McPherson Circle and the nickpoints near Blockhouse Point implies a paleoslope of 0.07% (Appendix 1 and Zen, in prep). Now, at Glade Hill the elevation difference between the boulder bed and the 140-ft strath, which is the modern channel above the dam, is 60 feet, so the difference in elevation between the modern channel and the upstream projection of the 200-ft strath would be as high if there were no slope differential. Higher paleoslope would require more downcutting at Harpers Ferry. In fact, the baselevel drop that terminated the 200-ft strath as an active channel also caused the entrenchments of the tributaries of the Potomac River as far as Cumberland, MD (Zen, in prep).

SUMMARY AND CHRONOLOGY

In summary, evidence from the Potomac River suggests the following sequence of events (Figure 11):

* Miocene-Pliocene succession at Tyson's Corner at ca. 450 ft.
* Formation of a broad proto-Potomac valley at some level between 300 ft and 210 ft.
* Incision of a strath, 200 ft near Mather Gorge; formation of meander bends at least as far upstream as White's Ferry. Deposition of boulder bed at Glade Hill.
* Incision of a younger strath, 155-ft near Mather Gorge, at least between Cabin Branch and Difficult Run.

Initiation of entrenchment of the tributaries of the Potomac River between Great Falls and Cumberland, Maryland.

* Isochronous 140 ft strath, including the abandoned valley west of Glade Hill at $\pm$ 145 ft.

* Inception of gorge erosion.

* Baselevel drop leading to strath, about 115 ft level along Mather Gorge.

* Baselevel drop leading to strath, about 95 ft level near Mather Gorge.

* Baselevel drop leading to strath about 77 ft level near Mather Gorge; intermediate aggradation followed by incision.

* Baselevel drop leading to strath, about 53 ft level at Plummers Island.

* Modern river strath.

The Miocene-Pliocene fluviatile sediments, attributed to a paleo-Potomac River (Hack, 1975; Drake and others, 1979; Zen, in prep), limit the above sequence of events to the last 5 million years. Following the Miocene-Pliocene deposition, approximately 120 ft (40 m) of denudation of the Piedmont rocks lowered the upland surface to the 300-350 ft level. Pavich and others (1985) pointed out that this is a minimum estimate because the fluviatile sediments were probably laid down in a valley below the upland surface. Even ignoring this point, the time required would be about 3 m.y. if we use a denudation rate of 0.02 km/m.y. (2 cm/k.y.), which is the average for post-Triassic denudation of the New England Appalachians (Zen, 1991). A longer time interval is implied if the rate of saprolite formation in the area, within a factor of 2 of 0.01 km/m.y. (Pavich and others, 1985; see Reed, 1981), is used for the estimation (see, also, Pazzaglia and Gardner, 1993). Downcutting of the wide valley preceding the deposition of the boulder bed, likely a time-consuming process, however, could have been concomitant to the general lowering.

All told, cutting of the gorge complex would have to be no older than Pleistocene, perhaps during the glacial events, as some of the preceding discussions have tacitly assumed. Were the baselevel drops, causing the cataracts to form either by a series of baselevel drops or by dispersion of cascades after a single drop, related to a chronology of sealevel *lowering* during the onset of the last major glaciation? The data in a recent study of Quaternary deepwater temperature changes in the North Atlantic, reflecting the increase of volume of ice, suggest that during onset of the last glaciation sealevel lowering might have been stepwise (Dwyer and others, 1995, figure 3), but the basis for the inference is shaky. Moreover, eustatic sealevel lowering does not necessitate downcutting; much depends on the slope of the newly exposed land. The apparently constant 2-ft per km gradient for the successively lower straths is another problem for this explanation. An alternative idea is that the baselevel changes reflect crustal uplift (Hack, 1982; Pazzaglia and Gardner, 1994), again presumably episodic. Could tens of meters of uplift happen within the short timespan implied by the unaltered rocks (see also Newell, 1984)? Elsewhere (Zen, in prep) I argue that a mechanism of crustal warping is inconsistent with the similarity of the modern and paleo slopes of the Potomac River as far as Keyser, MD. Any crustal uplift would have to be epeirogenic.

Two ^{14}C dating of peaty material from terraces determined by Meyer Rubin and reported by Reed (1981) are 9.5 Ka and 16 Ka; the former sample was at the 145-ft abandoned valley west of Glade Hill (Milton, 1989). These numbers do not date the formation of the strath as the vegetation grew sometime after the strath formed (or was abandoned); however, they are consistent with the hypothesis that this strath was Pleistocene in age.

Potholes on the 140-ft strath have been related to the hydraulic conditions of the paleo-Potomac River prior to the incision of Mather Gorge (Zen and Prestegaard, 1994). Potholes are also associated with the intermediate straths. It would be nice to date these potholes, not only for their ages but to test the diachronous development of potholes on the intermediate straths predicted by my idea of strath migration. Cosmogenic radionuclide decay could yield the age of exposure in air of the pothole surfaces, especially if the process of pothole formation may be considered as geologically instantaneous.

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Appendix 1. Hydraulic Parameters for the Glade Hill Boulder Bed

To estimate the hydraulic conditions for the transportation and deposition of the boulders at Glade Hill, I began with three related questions: (1) What combination of hydraulic parameters could have moved boulders this size; could floods similar in size to those in the modern record move such boulders? (2) What must have been the hydraulic conditions for the *delivery* of the boulders into the main channel of the paleo-Potomac River? Finally, (3) what is the implication of the fact that the boulders are exclusively from rock units west of the Piedmont, and dominantly from the Weverton Quartzite beyond the Mesozoic Basin?

I used the following relations:

(1) *omega* = *tau*.$\underline{u}$ = XDS$\underline{u}$

(2) *tau* = XDS

(3) $\underline{u} = R^{2/3}S^{1/2}/n$ (Manning's formula)

(4) RP = A = DW

(5) Q = DW$\underline{u}$ (mass conservation)

(6) P = W+2D (rectangular channel; see below)

(7) $Fr = \underline{u}/(gD)^{1/2}$

(8) Re = $\underline{u}$D/mu

Where:

omega is the "unit stream power" in watts/m^2 or, equivalent to that, in newtons/m/s (Bagnold, 1980; Williams, 1983).

tau is the bedshear, = XDS in newtons/m^2 (Bagnold, 1966).

$\underline{u}$ is the average downstream speed of uniform flow, in m/s.

n is the Manning coefficient of roughness, formally in s/$m^{1/3}$ (see Chow, 1959).

S is the dimensionless friction slope (approximated by the channel and/or the water-surface slope).

Q is the flux or discharge in m^3/s.

A is the channel cross-sectional area in m^2.

D is the average water depth in the cross-sectional area A, in m.

W is the channel width in m.

R is the hydraulic radius of the channel in m.

P is the wetted perimeter in m.

Fr is the Froude number.

Re is the Reynolds number.

The numerical values of four physical constants used are: g, the gravitational acceleration, 9.8 m/s^2; rho, the density of the fluid (assumed to be pure water), 1000 Kg/m^3; X, the specific weight of the fluid (rho.g), 9800 N/m^3; mu, the kinematic viscosity for water, 1×10^{-6} m/s.

If we eliminate S from (1) by the Manning Formula (3), we obtain:

omega = $XD\underline{u}S = XDn^2\underline{u}^3/R^{4/3}$ (9)

which is identical to the equation of O'Connor, Webb and Baker (1986; see also Kieffer, 1990) except for the factor D/R. Because for rectangular and relatively deep channels D/R may significantly depart from unity, it is hereby explicitly preserved.

Four of the variables must be specified to obtain solutions to the hydraulic relations; I chose $\underline{u}$, n, W, and D. These four variables are nested so that for every $\underline{u}$ several values are tested for n; for every n, several values are tested for W, and for every W, several D values are tested. Solutions are thereby obtained for R, S, Q, *tau*, and *omega*, allowing estimation of conditions for transportation to, and deposition at, Glade Hill of the boulders of observed maximum sizes (Table 6). Lack of adequate channel and flow data precludes more sophisticated and detailed approach such as step-backwater calculations. Nevertheless, the tabulated values should allow the reader to define permissible hydraulic values corresponding to variable channel geometry in order for the boulders to be transported.

Because the Glade Hill boulders are monolithic, must have come from the Blue Ridge terrane at least 30-40 km away but include no boulder of Piedmont rocks, the transportation most likely was by a single or a very few flood events rather than by incremental movement across the width of the Piedmont. The hydraulic conditions upstream from Glade Hill must have been uniformly favourable for transportation from the source area to Glade Hill.

A preliminary estimate of the appropriate range of $\underline{u}$ can be made, at least for the average current speed rather than the near-bed speed that governs tractive transport. Costa (1983) pointed out that turbulence in the channel should reduce the vertical gradient in $\underline{u}$; he recommended a correction factor of 20% between near-bed and average speeds. Based on Hjulstrom (1933) as extended by Kieffer (1990) to cobbles larger than 500 mm diameter, an average speed of 6-7 m/s is expected for maximum medium diameter of 1.5 m (see below), consistent with the relations suggested by Costa (1983, equation 10; 6.3 m/s), by O'Connor (1993; 6 m/s for maximum medium diameter of 1.5 m), or by the mean of the logarithm of $\underline{u}$ for the upper and lower bounds of Williams (1983; 6.7 m/s). The very large Reynolds numbers (on the order of 10^8; Table 6) shows that extreme turbulence indeed can be expected.

Chow (1959), Chaudhry (1993), Limerinos (1970) and Jarrett (1984) discussed how n might be affected by channel characteristics. Kieffer (1990) used n=0.035 for the Colorado River. Because for bedrock channel the value of n would not be governed by feedback effects of sediment deposition, I calculated results for n = 0.020, 0.025, 0.035, and 0.045 (Table 6).

The channel cross-section is assumed to be rectangular. For its width W, I used for the Potomac River 100, 200, 300 and 400 m, comparable to the widths during normal flow of the modern river just below Mather Gorge, at Cabin John Bridge, at Key Bridge, and just above Little Falls Dam, respectively. For the average water depth D, I chose increments of 5 m from 5 m to 40 m, and a few feeder channel computations for D=3. Table 6 shows that for large D, D and R could differ significantly.

Solutions for Boulder Deposition

At Glade Hill, the minimum channel width is the preserved width of the boulder bed, 100 m. For the slope S from McPherson Circle to Glade Hill, I accept the implication of the boulder of Weverton(?) Quartzite near McPherson Circle as an upstream equivalent of the Glade Hill bed (see main text), indicating a gradient of 0.07% up to that point. The gradient must track the overall slope fairly closely, for if the conditions of the river from Glade Hill all the way to the source area was simultaneously favourable for the transport of the boulders, the slope above McPherson Circle could hardly be less. If the McPherson Circle boulder is irrelevant, then (Table 6) boulder transport could occur on a slope as low as 0.05%.

For the upper limit of S, I chose, for my preferred dataset, a value of 0.1%; those results falling between these limits are shown by the asterisk mark (*) in Table 6. This upper limit would place the elevation near Leesburg, VA at about 120 ft above the modern channel level. A second grouping of the results shown by the mark "$" in Table 6 are defined by gradient limits of 0.1% and 0.3%; these are barely acceptable as topograhic projection from Glade Hill to Leesburg at the upper gradient limit would place the strath up in the air. However, this upper limit was the *local* slope of water surface above Great Falls during the flood of March 1936, the largest documented flood in a stretch of the river having a nearly identical channel slope (Grover, 1937, Table 15).

O'Connor (1993) discussed errors introduced by substituting the water-surface slope or channel slope for energy slope. He further pointed out that the critical value of unit stream power for boulder deposition is not necessarily same as that for boulder mobilization, an approximation commonly adopted. Lack of data compels me to use the channel slope for energy slope. To cover the uncertainty in values for boulder mobilization vs. deposition, I consider, for deposition at Glade Hill, all values of the unit stream power between 0.5 and 1.5 Kw/m^2 [1].

The results (Table 6) confirm that a current speed of 6-7 m/s prevailed. A value of 5 m/s would generate unit stream power too low but a value of 8 m/s too high for deposition of boulders having maximum median diameter of 1.5 m. The calculated range agrees with the speed-diameter relations mentioned previously.

Although we do not know the value of Q, the largest modern flood recorded at Little Falls gauging station was the 1936 flood, having a flux of about 14,000 cms (Stanton, 1993). If we accept Q values no more than twice this, say 30,000 cms, as reasonable, then acceptable results are further constrained. Those values that simultaneously satisfy the criteria for S, *omega*, and Q are shown by ** or $$ in Table 6. The reader can easily use his own screen for other reasonable choices. Once a choice is selected for deposition of the boulders at Glade Hill, other combinations of channel and hydraulic values can be tracked that will ensure that the unit stream power upstream from Glade Hill will be at least as great.

Solutions for the Feeder System

Here, a valid solution is even more tenuous because we know neither the location nor the nature of the feeder system. The candidate source areas are the outcrop areas of the Weverton Quartzite and the Sugarloaf Quartzite that are accessible to and flank the Potomac River valley. Four such areas are known. From the farthest to the nearest to Glade Hill, these are (1) the compound ridges called South Mountain and Elk Ridge in Maryland and Blue Ridge and Short Hill Mountain in Virginia; (2) Catoctin Mountain on both sides of Potomac River near Point of Rocks; (3) the Sugarloaf Mountain area in Maryland; and (4) Hogback Ridge (a continuation of Catoctin Mountain) immediately west of Leesburg, Virginia (see Burton and others, 1992; Johnson, 1993; Cleaves and others, 1968).

The quartzite occurrences at area (1) have been described by Stose and Stose (1946) and Nickelsen (1956); at area (2) by Whittaker (1955) and Burton and others (1995), and at area (3) by Scotford (1951). This last quartzite is of uncertain stratigraphic affinity, though likely a correlative of part of the Weverton, and bears strong resemblance to many of the Glade Hill boulders. Area (4) at Hogback Ridge is the nearest to Glade

Hill, has least overall channel sinuosity and greatest average slope, but also minimal occurrence of massive quartzite strata and lack several rock types found at Glade Hill. Table 7 summarizes the information and assumes a shared distance of 22 km from Glade Hill to the quartzite boulder at McPherson Circle. The distances, channel slopes and sinuosities for the four sites above this common point are, respectively and in the same order, 51 km, 0.04%, 1.3; 36 km, 0.05%, 1.3; 30 km, 0.16%, 1.4; and 16 km, 0.31%, 1.0.

The Sugarloaf source requires the boulders to be transported for a distance between 1.5 and 3 km on a gentle slope; in this interval, there is no obvious mechanism to concentrate floodwater into channels to enhance its power.

At Hogback Ridge near Leesburg, the lower beds of the Weverton Formation form the resistant "gate" to several narrow, steep streams emerging from the Blue Ridge upland to the Mesozoic Basin, so that relatively small flux values might conceivably move boulders efficiently. One particularly instructive stream north of the Leesburg city limits emerges into the Mesozoic Basin at, as of 1995, Locust Hill Farm. This channel has a slope of 1.7% over a distance of 1.8 km (all slope measurements made on the U.S. Geological Survey topographic map, scale 1:24,000, and in an upstream direction starting at the mountain front). As of 1995, this stream still preserves its natural configuration, and consists of a flat-bottomed double channel with an outer channel width of 100 m and a inner channel width of about 50 m. The bedrock floor was littered with large, angular to subrounded and transported boulders as much as 3 m across. The blocks most likely were moved during the June, 1995 flood. Topographically, the site provides an attractive model for the injection of the boulders of Glade Hill.

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[1] Williams (1983) proposed three pairs of discriminant functions, regressed from empirical data, for movement of large boulders, each pair separating the three regimes of "no movement", "possible movement", and "definite movement". These functions permit direct estimation of *omega*, *tau* and $\underline{u}$. I avoided these relations for two reasons. First, the three *independently* regressed relations violate the constraint that *omega* = *tau* . $\underline{u}$. Second, if one accepts the Manning formula, which Williams did, then *omega* must vary as $\underline{u}^3$ and *tau* must vary as $\underline{u}^2$, but his formula for *omega* violates that condition. These defects can be partially fixed by accepting only two of his regressed relations and deriving the third from them (the best results are obtained if one derives *omega* as a product of *tau* and $\underline{u}$).

Nevertheless, the paucity of massive quartzite at Hogback Mountain, and the distance to be traversed along gentle slopes both here and downhill from Sugarloaf Mountain, make both sources unlikely. Despite its great distance, area (1) is the best candidate source areas. Here the compound ridges of Blue Ridge and South Mountain on the west flank of the Blue Ridge anticlinorium are underlain by massive beds of the right kinds of rock. The rocks occur down to the river level, and bound the 190-m defile between Maryland Heights and Loudoun Heights below Harpers Ferry. Projection of the 0.07% slope would place the paleo channel at about 350 ft above sealevel. I speculate that large rock slides were triggered during the cold, wet Quaternary glacial period, and the debris pile furnished the source for the boulders.

In Table 6, solutions that have *omega* of 2.0 or greater, width of 100 m or less, Q of more than 5.6 kcms (a value of 5.6 corresponds to a channel where W=100, D=5.6, and u=10), and slope between 0.15 and 1% are denoted by the mark "#". For slope greater than 1% but less than 4%, appropriate to the mountain streams near Leesburg, the solutions are denoted by the mark "@". If in addition Q is 5.6 or less, double marks are shown.

In a study of the interrelation between hydraulic and geomorphic features of a gorge section of Burdekin River in Queensland, Australia, Wohl (1992) described a bedrock channel that, in physical dimensions, gradient, peak flow, and erosional features bear considerable similarity to the modern Potomac River in Mather Gorge. Large boulder bars dot the channel where the unit stream power diminishes due to changes in channel geometry. Wohl's numerical computations, some using Williams' (1983) regression relations, give hydraulic parameters that permitted transportation of boulders as much as 1.2 m across, with u a few m/s and *omega* a few hundred w/m^2. Unfortunately, the Glade Hill boulder bed has so little associated vital data that a firm comparison of the two systems cannot be made.

Hobbs (1967) described historical and Native American fishing weirs on the Potomac River consisting of blocks of rocks that have not been removed by the flood of 1936; though no dimension was given, these blocks were not as large as 1 meter (Scott Southworth, 1995, oral communication), indicating that the modern river channel geometry and hydraulic parameters differ from those associated with the Glade Hill boulder beds. These weirs are in the section of the river within the Mesozoic Basin, which has a water-surface slope of only about 0.03% (Zen, in preparation).

Appendix 2. Least-Squares Data Fitting to the 140-ft Strath

Inspection of the data points for the 140-ft strath (Figure 3A) shows that those points at distances less than 7 km from the zero point have slightly higher slope than those points farther downstream. Thus I made least-squares fit for these upper set of points (equation a, n=9) and for those downstream (equation b, n=15) both separately and as a single population (equation c, n=24). The distance and elevation data are from Table 3. Probable error was calculated from the formula $[\text{sigma} (<y>-y_i)/n]^{1/2}$ where <y> is the expected value of y corresponding to the distance for y_i, and n is the number of points. Numbers between <> are elevations predicted by the regression equations, to be compared with the input data. Where two numbers appear between a single set of <> brackets, the first one refers to that predicted by the subset regressions (points 1-9 and 10-24, respectively); the second one refers to that predicted by the regression for the full set of data (1-24).

140-ft Strath (X in 10 m; Y in ft)

Point	Y	Point	Y
1. C0283	143 <144.5; 140.6>	13. S0845	125 <129.2; 133.0>
2. B0348	144 <143.4; 139.7>	14. S0847	129 <129.2; 133.0>
3. B0388	143 <142.7; 139.2>	15. S0869	134 <129.0; 132.7>
4. S0427	142 <142.0; 138.7>	16. S0919	127 <128.6; 132.0>
5. S0482	142 <141.0; 137.9>	17. S0929	130 <128.6; 131.9>
6. B0535	141 <140.1; 137.2>	18. S1030	127 <127.8; 130.5>
7. B0552	140 <139.8; 137.0>	19. S1180	130 <126.7; 128.5>
8. S0626	139 <138.5; 136.0>	20. S1238	126 <126.2; 127.7>
9. S0693	136 <137.4; 135.1>	21. S1253	125 <126.1; 127.5>
10. S0703	≥132 <130.3; 134.9>	22. S1797	125 <122.0; 120.2>
11. S0823	≥129 <129.4; 133.3>	23. B1983	122 <120.6; 117.7>
12. S0833	126 <129.3; 133.2>	24. B2376	115 <117.6; 112.4>

Regression equations:

(a) $h = 45.54 - 5.3 \times 10^{-4}d$ (meters; data set 1-9. $r^2 = 0.866$)

(b) $h = 41.32 - 2.3 \times 10^{-4}d$ (meters; data set 10-24. $r^2 = 0.675$)

(c) $h = 44.01 - 4.1 \times 10^{-4}d$ (meters; data set 1-24. $r^2 = 0.756$)

Appendix 3. Description of Map Sheets Showing Details of Database for Table 3.

The set of topographic maps included in Appendix 3 are parts of the National Park Service topogrphic map, original scale 1:1,200 (my set is at the photocopy-reduced scale of 1:2,400), contour interval variously at 2 ft or 5 ft. The features recorded in Table 3 are here entered to complete the record of data. In all these figures, the orientation is such that downstream direction of the river is to the left.

Appendix 4. Comparison of the Bedrock Channels of Mather Gorge and Difficult Run

The initiation of downcutting of lower reaches of Difficult Run (DR) depended on retreat of cataracts of Potomac River past the confluence. The main cataracts of the Potomac are now at Great Falls, and of the corresponding cataracts of Difficult Run, at the waterfalls just below the pothole-scoured bedrock channel. Because the 140-ft strath is at 135 ft level at the confluence, I used this contour of the NPS topographic map to sketch in the channel configuration prior to the start of this excavation.

The thalweg length from the confluence to Great Falls along Potomac Gorge, largely within Mather Gorge (MG), is 2980 m; that to the waterfalls in Difficult Run is 416 m, the distance ratio is 7.2. The base of both cataracts is at 90 ft. Thus, the ratio of the average slope of the two segments as far upstream as the base of the cataracts should be in the inverse ratio of their thalweg length, approximately, or 1/7, DR being steeper.

I next estimated the *present* channel cross section. For MG I used the depth sounding of Reed (see main text), and for the shallow DR I simply used the topographic maps. The segment of DR below the falls at 90-120 ft shows two sharply contrasting valley shapes, an upper one wide and shallow and a lower one steep and deep. I distinguished them in the computations below.

Despite the different shapes, the two segments of DR below the 135 ft level do have similar cross section areas when approximated by trapezoidal sections:

Geometric factors of Difficult Run (DR) and Mather Gorge (MG)

All measurements in meters

	DR		MG
	Upper portion	Lower portion	
Width at 135-ft contour	140	120	
Width at base	84	24	
Average width	112	72	72
Length	252	120	2980
Depth of valley	12.2	18.3	24.4
Cross section in m^2	1365	1317	1755
Volume, in 10^3 m	344	158	5231

(DR volume sum = 502)

Volume ratio, Mather Gorge/Difficult Run 10.4

Despite the much larger discharge and drainage area of the Potomac River (the ratios of both its drainage area above Great Falls to that of Difficult Run, and of the mean discharge, are at least 100; the areal ratio from planimetry and the discharge ratio from Grover, 1937, pp. 101, 127), the efficacy of excavation in the Mather Gorge section of Potomac River was scarcely better than in Difficult Run. The answer may lie partly in the fact that Difficult Run has a bottom gradient 7-times steeper than that of Mather Gorge, and partly in the fact that Mather Gorge is very straight, whereas Difficult Run has several large, though gentle, curves. The curves probably enabled greater degree of lateral erosion and compensated for the smaller stream power.

FIGURE CAPTIONS

Figure 1. Index map of the study area in the lower part of the Potomac River basin. Source of map: Grover, 1937, and Stanton, 1993. Heavy dash-dot, boundary of the basin. Heavy dash, geological provinces simplified from Cleaves and others, 1968, and Johnson, 1993 (CP, Coastal Plain; PM, Piedmont; MZ, Mesozoic Basin; BR, Blue Ridge; VR, Valley and Ridge). Light lines, shoreline and rivers. Solid circles: 1, Williamsport. 2, Harpers Ferry. 3, Weverton. 4, Point of Rocks. 5, Sugarloaf Mountain. 6, Whites Ferry. 7, Leesburg. 8, BM 219 below Cabin Branch. 9, Lock 24 on the Chesapeake and Ohio Canal. 10, McPherson Circle. 11, Blockhouse Point. 12, Great Falls. 13, Difficult Run. 14, Key Bridge. 15, Washington, D.C. 16, Maryland Point. 17, Baltimore. 18, Annapolis. Other features: A, Conococheaque Creek. B, Antietam Creek. C, Shenandoah River. D, Goose Creek. E, Seneca Creek. F, Monocacy River. G, Rock Creek. H, Anacostia River. I, Patuxent River. J, Patapsco River. K, Chesapeake Bay.

Figure 2. (A)-(F), U.S. Geological Survey topographic maps (scale 1:24,000, contour interval 10 ft) encompassing part of the Potomac River of this report, showing the reference mid-thalweg line and bend points given in Table 4. Data points listed in Table 3 are given in the set of maps of Appendix 3. Quadrangle names: (A), Washington West. (B) Washington West (right) and Falls Church (left). (C), Falls Church. (D), the four-corners area of Falls Church (lower right), Vienna (lower left), Rockville (upper right) and Senena (upper left). (E), Seneca. (F), Seneca (right) and Sterling (left).

Figure 3. Location and elevation of paleo-strath data, Potomac River. (A), Data; locations of datapoints are projected to the mid-thalweg reference line of Figure 2 as explained in the text. Symbols: circles, summits; crosses, channels and ponds; up-pointing triangles, benches; down-pointing triangles, plungepools; squares, potholes (see Table 3). Up-pointing arrow associated with a data symbol indicates that the elevation recorded for the point is a minimum value (see text). Filled carats along sealevel line are reference points (Table 4), starting with the zero-distance point at the south end of Gladys Island at the

left end. Arrows along sealevel line give prominent baselevels along the modern river. Data for modern water surface elevations are from Table 1; ticks at Great Falls are from Figure 4. Irregular line below the modern water surface line gives sounding data for the modern riverbed; short ticks along base, Reed's reference mileage markers, zero at Chain Bridge and negative in downstream direction; both from J.C. Reed, Jr., written communication, 1993. (B), Interpretation of the strath levels based on the dataset. From top to bottom these are the 140-ft, 115-ft, 95-ft, 77-ft, and 53-ft straths of the text. The 140-ft strath shown is the least-squares fit for the entire data set (Appendix 2).

Figure 4. Water surface profile of modern Great Falls according to the National Park Service topographic map, showing the western (The Spout; triangles), the middle (The Streamers; crosses) and eastern (Maryland Falls; circles) strands. Upper profile, vertical exaggeration = 10. Lower profile, the main falls on expanded scale and no vertical exaggeration.

Figure 5. Details of Potomac River in the vicinity of Rocky Island, showing locations of data points discussed in the text. Dotted lines, reconstructed thalwegs of abandoned bedrock channels.

Figure 6. Profile of water surface for the last 1.2 km of Difficult Run from the National Park Service topographic map having contour interval 5 ft. Reaches of the stream, I-IV, are discussed in the text. Mesa-like icons at 155 ft, 130 ft, and 88 ft represent alluvial bars; relief on the icon represents relief between top of bars (approximating former water level) and elevation of flanking and degradational modern channels. Carats represent rock benches preserved on valleyside.

Figure 7. Topographic map of Difficult Run, based on National Park Service topographic maps, contour interval 5 ft. The accentuated 135-ft contour marks the projected shoreline for the time when the 140-ft strath was the active riverbed of the Potomac River; the deep embayment is interpreted to result from nickpoint retreat when the Potomac River strath dropped from 155-ft to 140-ft. Heavy bars delimit Reaches I-IV of Figure 6.

Figure 8. Profile of Difficult Run and four of its tributaries from headwaters to confluence with Potomac River. Crosses, Difficult Run; circles, Little Difficult Run; up-pointing triangles, The Glade; down-pointing triangles, Piney Branch; squares, Wolftrap Run. For details of the lowermost 1.2 km, see Figure 6 (marked by box).

Figure 9. Data on the 155-ft and 200-ft straths, upstream from Great Falls. Elevations at Difficult Run confluence are projected as discussed in the text; the projected continuation of the 140-ft strath (dash-dot line) refers to the elevation of the river bottom; it projects about 6 ft lower than the level of the modern river surface (short dashes). Error bars for the 155-ft strath apply only at the limits of boxes; the boxes are intended to show that data are continuous between the limits. The slight change in the slope of this strath across the boundary of the Mesozoic Basin and Piedmont is within the limits of uncertainty.

Figure 10. Cumulative plot of boulder diameters for the Glade Hill boulder bed. Only unbroken boulders are measured; where the third diameter cannot be obtained, it is conservatively assumed to be the minimum diameter. Crosses, maximum diameters (n=280); triangles, median diameters (n=278). The curves show that the boulders are likely from a single population.

Figure 11. Synoptic and schematic cross-section of the Potomac River valley, showing the relations among strath levels (indicated by arrows to the right; 140-ft strath accented). Cross-section of the river strath and of the upland surface are depicted approximately at the upper end of Mather Gorge. Off-section data are projected approximately without fully adjusting for elevation changes in the projection. The profile of Difficult Run is schematic except for the elevations of nickpoints; these elevations have been adjusted for the effect of longitudinal declinations of the straths and indicate correlations of morphological features in the main river and in the tributary. Horizontal distances not to scale. The only Tertiary rocks shown are the Miocene/Pliocene beds at Tyson's Corner; all other bedrocks are Piedmont rocks.

TABLE CAPTIONS

Table 1. Selected modern water level data (see Figure 3) from National Park Service and U.S.G.S. topographic maps. Last digit in decameters (10 m).

Table 2. Modern water-surface profile of Potomac River.

Table 3. Elevation and location data for strath levels shown in Figure 3. Hyphenated designations apply if more than one point of the same category fall on the same projected distance. Last digit in decameters (10 m).

Table 4. Data for the reference thalweg line of Figure 3. Last digit in decameters (10 m). Digits for data points upstream from arbitrary zero point are preceded by a minus (-) sign.

Table 5. Boulder diameters of Glade Hill bed.

Table 6. Hydraulic calculations for Glade Hill boulder beds. See Appendix 1.

Table 7. Outcrop locations and river parameters of Weverton Quartzite as possible sources of the Glade Hill boulder bed.

APPENDIX CAPTIONS

Appendix 1. Boulder bed at Glade Hill

Appendix 2. Least squares fit to 140-ft strath

Appendix 3. Detailed location data of points shown in Table 3.

Appendix 4. Comparison of the bedrock channels of Difficult Run and Mather Gorge

TABLE 1. DATA USED TO CONSTRUCT CONTEMPORARY WATER LEVELS OF FIGURE 3

Note: these are levels at water surfaces at discharge levels used in mapmaking; they should NOT be compared with the data sets of Table 3 which are on rocks presumed located at former river bottoms. The numerical values following letter "W" represents distances, in km, from reference point at south end of Gladys Island (see Table 3); last digit is 10 m. All data taken from the National Park Service map except for those four values beginning with W2388 and on downstream, which are outside of coverage area for this map series and are taken from the USGS topographic map for the Washington West quadrangle.

W0000. South end Gladys Island, MD (156)
W0036. North end Bealls Island, MD (155)
W0088. South end Bealls Is. (155)
W0216. North end Conn Island, MD (154)
W0290-1. South end Conn Is. at aqueduct dam, top, MD (152)
W0290-2. Base of dam, same site, MD (142)
W0316. Top of white water above Great Falls (138)
W0350. Top of Great Falls series, MD-VA (130)
W0360. Step 1 in cataracts, MD (127)
W0365. Step 2 in cataracts, MD (113)
W0370. Step 3 in cataracts, MD (100)
W0372. Base of Great Falls cataracts, MD-VA (88)
W0389. Bend in river course, MD-VA (86)
W0454. South tip of Rocky Island, MD (77)
W0559. South end of straight section of Mather Gorge, MD-VA (74) W0661. Bend in river course, Difficult Run MD-VA (69)
W0691. River bend opposite Cupid's Bower, Sherwin Is., MD (68) W0717. Bend in river course northeast of Black Pond, MD-VA (68) W0811. West end of Offutt Island, MD (68)
W0929. Bend in course, between Vaso and Turkey Is., MD (62)
W0977. Bend in course, east of Turkey Is., MD (60)
W1149. Bend in course above Cabin John Bridge, MD-VA (52)
W1207. I-495 (Cabin John) bridge, outerloop, VA-MD (51)
W1349. Bend in course, below Cabin John Bridge (50)
W1493. Bend in course off Cabin John Island, MD (44)
W1747-1. South tip of Snake Island, top of lower dam, MD (41)
W1747-2. South tip of Snake Island, base of lower dam, MD (31)
W1827. Bend in course off High Island (24)
W1876. Falls Church/Washington West quad boundary (22)
W1964. Bend in course, Little Falls (10)
W2015. Bend in course below Chain Bridge (5)
W2171. Bend in course (3)
W2222. Bend in course off Georgetown Reservoir (2)
W2388. Bend in course above Three Sisters Island (1)
W2538. Key Bridge (0)
W2646. Bend in course at Harbor Place development (0)
W2778. Memorial Bridge, DC (0)

TABLE 2. PROFILES AND GRADIENTS OF THE MODERN POTOMAC RIVER

Segment	Fetch, km	Elevation change, ft	Gradient
	I. Individual fetches		
A. Tenfoot Island to intake dam above Great Falls	16.9	35	0.06%
B. Base of intake dam to 138 ft contour (head of whitewater, Great Falls)	0.5	4	0.24%
C. Great Falls	0.4	50	3.81%
D. Base of Great Falls to entrance of Mather Gorge	0.4	6	0.46%
E. Entrance of Mather Gorge to top of Yellow Falls	4.0	14	0.11%
F. Yellow Falls	1.2	10	0.25%
G. Base of Yellow Falls to top of Stubblefield Falls	0.5	1	0.06%
H. Stubblefield Falls	1.7	9	0.16%
I. Base of Stubblefield Fls to top of Little Falls	6.0	15	0.08%
J. Little Falls	2.2	23	0.32%
K. Base of Little Falls to tidewater at Key Bridge	5.6	10	0.05%
	II. Combined fetches		
B-D, the "Great Falls sequence"	1.3	60	1.41%
Steep segments B,C,D,F,H, and J only	6.4	102	0.49%
Gentle segments E,G,I, and K only	16.1	40	0.08%
Overall, B to K	22.5	142	0.19%
Grand overall, A to K	39.4	177	0.14%

TABLE 3. MORPHOLOGICAL FEATURES INDICATING STRATH LEVELS

Reference points used to construct the running profile are shown in Table 4. Projection is to nearest reference line; where two lines are equidistant, projection is to the longer line.

Concordant Summits (S; 48 points)

S0379. Summit of island in middle of Great Falls, MD (116)
S0427. Summits, Rocky Is., MD (≥142)
S0482. Summits, west end Bear Is., MD (142)
S0535. Summits, middle of Bear Is. southeast of cross channel, MD (141)
S0626. Summits, east end Bear Island, MD (139)
S0647. Summit of small island off SE corner of Bear Island (117)
S0693. Summit, Sherwin Is., MD (136)
S0703. Summits, northeast of Black Pond behind Madeira School, VA (≥132)
S0823. Summit, Offutt Is. MD (≥129)
S0833. Broad area at west end of Marsden tract (126)
S0835. Summit of island east of Offut Is., MD (≥76)
S0845. Summit, Perry Island (125)
S0847. Summit, Hermit Island (129)
S0869. Broad summit, Marsden tract (134)
S0905. Summit, Herzog Is., MD (81)
S0919. Summit, Turkey Is, MD (127)
S0929. Summit, Vaso Is., MD (130)
S1018. Summit, island at west end of Stubblefield Falls, MD (81)
S1030. Summit, Carderock, MD (127)
S1180. Broad summit, first downstream from large outflow near Lock 14 (130)
S1197. Summit upcanal from Lock 14, toward river (99)
S1225. Summit, west end of Plummers Island (106)
S1226. Summits directly opposite summit of Plummers Island (99)
S1238. Summit, Plummers Is., MD (126)
S1253. Summit, tract northeast of Plummers Is. MD (125)
S1308. Summit, Swainson Island, MD (USGS topo name) (67)
S1313. Summit, Swainson Island, MD (NPS topo name) (67)
S1347. Summit, Wade Island, MD (57)
S1378. Summit, Langley Is, VA (55)
S1399. Sharp summit knob at west end of Minnie Island, MD (≥75)
S1414. Summit, Minnie Island, MD (67)
S1452. Summit, unnamed island between Minnie and Cedar islands, MD (58)
S1491. Summit, Cedar Island, MD (63)
S1493-1. Summit, Cabin John Island, MD (61)
S1493-2. Summit, small islands off Cabin John Island, MD (49)
S1553. Summit, Chatauqua Is., MD (61)
S1572. Summit, large island below Cabin John Is. (57)
S1603. Summit, Ruppert Island (56)
S1644. Summit, Sycamore Is., MD (58)
S1692. Summit, knoll above (east) of C&O Canal above Little Falls Dam, MD (132)
S1740. Summit, Snake Island (≥44)
S1797. High Island, MD (125)
S1821. Summit, island off High Island, MD (32)
S1865. Summit, small island opposite Lock 6 (29)

S1894. Summit, head of narrow gorge below Little Falls (33)
S1916. Knob upstream from Little Falls Branch (30)
S2428. Three Sisters Island, DC (≥5)
S2608. Summit, Roosevelt Is., DC (≥44)

Plungepools (P; 3 points)

P0426. Plungepool, Great Falls Park, VA (115)
P0605. Pond (plungepool?) outlet, southwest of cross-channel C0607, east end Bear Island, MD (88)
P0633. Plungepool pond just west of oxbow channel C0636, east end of Bear Island, MD (87)

Channels and Ponds (C; 46 points)

C0088. River bottom, south end Bealls Island, MD (144)
C0283. Base of aqueduct dam at bend nearest Virginia, MD (143)
C0377. Olmsted Island, blind channel below boardwalk (117)
C0382. Pond on Olmsted Is. near observation platform (129)
C0420-1. Olmsted Is., channel above footbridge of boardwalk above main fishladder (120)
C0420-2. Olmsted Is., channel (97)
C0420-3. Sill at west end of transverse channel, Rocky Is. (77)
C0420-4. Channel, Olmsted Is. above boardwalk, MD (130)
C0420-5. Moat (arcuate) channel, south end of Olmsted Island behind rampart facing 77-ft moat channel (111)
C0432-1. Pond outlet, NE corner of Rocky Is., MD (116.5)
C0432-2. Small pond next to River Trail, VA (131)
C0433. Pond outlet, NW corner Rocky Is, MD (110.5)
C0439. Pond, northeast side of east rib of Rocky Is., MD (90)
C0446. Pond, east side of east rib of Rocky Is., MD (85)
C0449. Mouth of hidden gorge, Rocky Is., MD (80)
C0451. Mouth of east channel, Rocky Is., MD (80)
C0511. Channel floor at Widewater, MD (93)
C0528. Cross channel middle of Bear Island (S of pond), MD (116)
C0530. Lower cross-channel, middle of Bear Island with pond, MD (100)
C0595. Diagonal cross channel, Bear Island (115)
C0607. Cross channel, east end of Bear Is., MD (111)
C0636. Oxbow channel between main and 117.5-ft sometime is., Bear Is., MD (72)
C0650. Sill of channel between Bear and Sherwin islands (70)
C0661. Confluence of Difficult Run (73)
C0689-1. E-W valley = abandoned channel, s end Sherwin Island (115)
C0689-2. Channel draining into shoestring channel, C0636 (85)
C0691. E-W valley = abandoned channel, n-most, Sherwin Is. (103)
C0701. Yellow Pond behind Madeira School, VA (75)
C0751. Black Pond behind Madeira School, VA (85)
C0753. Sill, large ponds north side of river downstream of Sherwin Is. (70)
C0774. Cross channels, Marsden Tract, MD (105)
C1122. Pond near river east of Carderock recreation area, MD (53)
C1238. Shoestring channel, oxbow, opposite summit of Plummers Is. (74)
C1263. Sill at outlet of shoestring channel, north side of Plummers Island (53)
C1305. Shoestring channel north of Swainson Island, MD (56)
C1407. Top of level stretch, Turkey Run, south of GWPway (100)
C1411. Rocky gorge by 65 ft benchmark, Turkey Run (57)

C1495. Shoestring channel north of Cabin John Island, MD (47)
C1589. Shoestring channel on nameless is. below Cabin John Is. (49)
C1925. Channel, Little Falls Branch (16)
C2002. Pond below Chain Bridge (10)
C2061. Pond outlet opposite Galena Place, Georgetown (12)
C2078. Pond opposite Galena Place, Georgetown (17)
C2159. Channel near Fletcher boathouse (13)

Bench and Strath (B; 60 points)

B0348. Strath, Olmsted Island, MD (144)
B0379. Water-worn bench rich in potholes, side of falls, Great Falls, VA (126)
B0382. Broad bench below observation platform, MD (96)
B0388. Strath, Great Falls Park, VA (143)
B0407. Bench in dogleg section of river, VA (96)
B0424. Bench, NW corner Rocky Is, MD (112)
B0425. Choke rock at head of fossil gorge, Rocky Is., MD (96)
B0427. Cove just below entrance to Mather Gorge, VA (88)
B0437. Small bench with potholes, hidden gorge just below outflow of pond on east rib of Rocky Is., MD (96)
B0443. Bench with potholes, entrance to hidden gorge, Rocky Is. (90)
B0444. Bench, outlet of connector channel, at water level, Rocky Is., MD (79)
B0525. Strath, VA side, narrow stretch (140)
B0537. Fluted bench, end of carriage road, VA (116)
B0559-1. Cowhoof rock, VA (75)
B0559-2. Bench with lateral potholes above Cowhoof rock, VA (115)
B0565. Rock jutting out into river, downstream from Cowhoof rock, VA (72)
B0570. Bench at base of big cliffs above Cowhoof rock, VA (90)
B0602. Bench with large lateral potholes, upstream from P0605 (85)
B0609. Bench in cove, VA side, opposite P0605 (92)
B0631. Bench at extreme SE corner of Bear Island, MD (95)
B0638-1. Flat hilltop of island surrounded by channel, C0636, Bear Is. (103)
B0638-2. Flat hilltop at E end of Bear Is. opposite Sherwin Island (115.5)
B0641. Flat hilltop, waterworn, small island nestled in oxbow shoestring channel, east end of Bear Island (117.5)
B0652. Bench, small island off Difficult Run (90)
B0668. Bench west of Black Pond overlooking river, VA (114)
B0669. Bench with potholes, west side of Black Pond, river level, VA (73)
B0679. Bench, SE corner Sherwin Is. (83)
B0691. Bench, NW corner Sherwin Is. (77)
B0693. Small islet south side of channel at culvert crossing to Sherwin Is. (71)
B0698. Bench, northeast corner of Sherwin Is. (105)
B0826. Bench on east side of Offutt Is. (86)
B0857-1. Bench below day use area, Marsden tract (89)
B0857-2. Bench, east end of Perry Island [Qal] (90)
B0858. Bench, east end Hermit Island (92)
B1011. Bench near river, W of ravine west of Carderock MD (116)
B1202. Bench surrounding 99 ft summit, S1197 (76)
B1219. Bench, northwest corner of Plummers Island (73)
B1235. Bench southwest of cabin, Plummers Island (106)
B1241. Benches east of summit, Plummers Island (77)

B1253. Bench near east end of Plummers Island (68)
B1349. Bench above Langley Is., VA, opposite Wade Is. (60)
B1404. Knob north of Minnie Is. (54)
B1409. Bench on north side of Minnie Is. (59)
B1680. Bench between C&O Canal and road, above Little Falls Dam (107)
B1697. Narrow bench above Little Falls Dam, VA (55)
B1790. Bench on river side of C&O Canal below upper end of High Island (51)
B1812. Bench, southeast end of High Island, MD (52)
B1881. Strath above Little Falls and Chain Bridge, near lock #6 (27)
B1964. Bench at District of Columbia line, MD (24)
B1983. Bench, Potomac Heights, DC (122)
B2015. Strath, Chain Bridge, MD (24)
B2060. Strath, downstream from Chain Bridge, MD (20)
B2099. Knob on river, Georetown (9)
B2128. Knob near B2123 (16)
B2154. Knob near Fletcher boathouse, Georgetown (13)
B2155. Knob near Fletcher boathouse, Georgetown (5)
B2188. Bench opposite Reservoir Road (15)
B2222. Knob on river, Georgetown (5)
B2376. Bench, Harrison School, DC (115)
B2538. Bench, Rosslyn Circle, VA (60)

Potholes (H; 8 points)

H0425. Lateral pothole related to P0426 (132)
H0431. Two lateral pothole on cliff, one having vertical at base, entrance to Mather Gorge, VA (114)
H0432. Vertical pothole on cliff, just below H0431 (104)
H0533. Lateral pothole by towpath, Widewater, MD (120)
H0547. Base of lateral potholes, Bear Is., MD (115)
H0565. Potholes on bench, Bear Is. opposite Cowhoof Rock (100)
H0595. Lateral pothole next to towpath, Widewater (94)
H0617. Lateral potholes at slope break along Billy Goat Trail (118)

Grand total, 165 points

Other data points

I. In Difficult Run, not plotted:

*Bench along trail, DR1, (90).
*Benches (3) on opposite side of valley from trail, DR 2, (115).
*Alluvial bar, DR3, (92).
*Alluvial bar, DR4, (131).
*Top of pothole zone, DR5, (128).
*Bench, top of gorge section, DR6, (135).

II. Data on elevations related to the 155-ft and 200-ft straths; distances are from the zero-km reference point (negative, upstream; positive, downstream). Distance in units of 10 m.

A. 200-ft strath

*Boulder of Weverton Quartzite(?), McPherson Circle and Bentwood Road @245 ft, -1575.
*Nickpoint at upper end of steep stream gradient, near Fairfax County-Loudoun County line and opposite Blockhouse Point:
*Shallow ravine below BM "Lowes", @240 -0813.
*Deep valley with access road next downstream, @230±5 ft, -0806.
*Valley next downstream with road ending at sewerline vent, @235±5 ft, -0772.
*Valley next down with dam and pond, @230±5 ft, -0732.
*Valley next down, @225±5 ft, -0705.
*Base of boulder bed, south end of Glade Hill, @200±3 ft, +0485

B. 155-ft strath

*West end of continuous trimmed spurs, Maryland side near BM 219 downstream from Cabin Branch, @220±10 ft, -1865; continuing to

*Just upstream from Lock 24 on Chesapeake and Ohio Canal, @195±8 ft, -0910

*West end of continuous trimmed spurs, Virginia side just below boundary of Fairfax-Loudoun County line and opposite Blockhouse Point, @190±5 ft, 190±5 ft, -0765; continuing to

*Opposite west terminus of Clagett Island, Virginia side, @175±7 ft, -0295.

*Pipeline crossing near east end of Watkins Island, Virginia side, 170±8 ft, -0105; continuing to

*Opposite Minnehaha Island, Virginia side, 165±5 ft, +0060.

*North end of Glade Hill, water-worn rockbench with lateral potholes @154 ft, +0445.

TABLE 4. DISTANCES ALONG REFERENCE LINE

Point data refer mainly to the "bend points" of Figure 1, sequence is positive in downstream direction. Distance in kilometers from point R0000; last digit shown is 10 meters (for instance, R0038 is 380 meters downstream from zero point). "R-" means point is above point R0000. For every point, the latitude north and longitude west are given in that order (e.g. 390356 = 39°03'56"N) between square brackets [], as is the name of the 7-1/2 minute topographic quadrangles published by the U.S. Geological Survey (WW, Washington West; FC, Falls Church; Vn, Vienna; Sn, Seneca; Rk, Rockville; and St, Sterling). Precision of location of points is 1 mm, which translates to 1 second of longitude and 2/3 second of latitude. Though the measurements were made on paper copies, no systematic error is introduced, provided paper shrinkage is uniform, because the dimensions of each copy was individually calibrated within a few hours of measuring. The estimated precision led to an estimated uncertainty of the latitude and longitude of ±2 seconds for the control points. The location of data points has the same uncertainty, but errors in projection must be added to both. The overall error is estimated to be ±4 seconds (100 m) for the projected location of the data points of Table 3. The relative ground locations of data points, however, are much more precise because individual features are locatable on the National Park Service 1:2,400 maps to ±2 mm (5 m ground distance). Note that even the largest uncertainty is not enough to affect the main conclusions. Last entry within square brackets [] refer to the point designations of Figure 2.

R-1400. West end Tenfoot Island [390356; 772335; St; 35]
R-1247. West end Sharpshin Island [390353; 772232; St; 34]
R-0940. Bend point off Lock 24 [390354; 772025; Sn; 33]
R-0758. East end Pond Island [390334; 771915; Sn; 32]
R-0578. East end Katie Island [390317; 771804; Sn; 31]
R-0276. East end southern Sycamore Island off Watkins Island [390228; 771617; Sn; 30]
R0000. South end Gladys Island [390140; 771442; Rk; 29]
R0036. North end Bealls Island [390131; 771432; Rk; 28]
R0088. South end Bealls Island [390113; 771429; Rk; 27]
R0216. North end Conn Island [390037; 771453; Rk; 26]
R0290. South end Conn Island at dam [390015; 771505; Sn; 25]
R0341. Bend point along Seneca-Vienna quadrangle boundary [390000; 771511; Sn/Vn; 24]
R0389. Bend point off SW corner Olmsted Island [385944; 771511; Vn; 23]
R0420. Bend point off NW corner Rocky Island [385941; 771459; FC; 22]
R0559. Bend point off S end Mather Gorge [385858; 771441; FC; 21]
R0661. Bend point off Difficult Run [385840; 771404; FC; 20]
R0691. Bend point off Sherwin Island [385847; 771357; FC; 19]
R0717. Bend point below Sherwin Is., NE of point off Black Pond [385848; 771346; FC; 18]
R0804. Bend point off Offutt Island [385823; 771327; FC; 17]
R0929. Bend point between Turkey Island and Vaso Island [385824; 771237; FC; 16]
R0977. Bend point downstream of Turkey Island [385812; 771222; FC; 15]
R1149. Bend point above I-495 bridge [385808; 771110; FC; 14]
R1207. Upstream side of Cabin John (I-495) bridge (outer loop) [385809; 771049; FC; 13]
R1349. Bend point off Wade Island [385807; 770950; FC; 12]
R1493. Bend point off Cabin John Island [385759; 770852; FC; 11]
R1747. Bend point off south end of Snake Island [385654; 770747; FC; 10]
R1827. Bend point off head of narrow channel near High Island [385629; 770737; FC; 9]
R1964. Bend point at Little Falls [385557; 770703; WW; 8]
R2015. Bend point just below Chain Bridge [385542; 770657; WW; 7]
R2171. Bend point just upstream from Canal Rd/Reservoir Rd corner [385502; 770616; WW; 6]
R2222. Bend point opposite Georgetown Reservoir [385447; 770609; WW; 5]
R2388. Bend point above Three Sisters Is [385415; 770515; WW; 4]
R2538. Bend point at Key Bridge (tidewater) [385407; 770413; WW; 3]
R2646. Bend point off Harbor Place and Kennedy Center [385356; 770331; WW; 2]
R2778. Memorial Bridge [385314; 770322; WW; 1]

Table 5. Boulder sizes on Glade Hill, Great Falls National Park. All boulders on or near summit area. The few duplicate entries are identical measurements on different boulders.

I. Ranked by maximum, then median diameter, in cm. Est. $\pm$ 3 cm. A question mark (?) means no reliable measurement. A greater sign (>) means the actual dimension is at least as large as given.

226-150->30

200-150->80, 200-150->50

170-80->55

130-90->20

110-66->25

100-72->20

98-50->25, 96-70-50, 96-65->10, 95-48->20, 90-44->15, 90-39->35

86->50-24, 84-52->10, 84-50->20, 83-50-25, 80-48->25, 80-46->20

79-50-50, 79-40->15, 78-39->10, 77-60->15, 76-26-?, 75-42->10, 75-41-?, 74-50-38, 73-36->26, 72-44-36, 70-50->16

69-47->17, 68-60-30, 68-55->26, 68-40->30, 66-55->30, 66-38->10, 65-56->38, 65->40-?, 64-48->38, 64-41-22, 63-56->19, 63-50->25, 63-47->20, 63-40->25, 63-30-20, 63-20->12, 62-37-30, 60-45->30, 60->39->15, 60->39->10, 60->39-?, 60-37-18, 60-25-?

59-48->15, >58->50->18, 58-48->25, 58-39->15, 58-38->22, 58-38->15, 58-37->18, 58-30->10, 57-48->15, 57->30-20, 56-56->10, 56-43->15, 56-42->10, 56-38->15, 56-36->10, 56-26-16, 55-45->10, 55-40->20, 55-35->15, 55-20->12, 54-40->18, 54-39->20, 54-36->13, 53-52->14, 53-48-?, 53-38->10, 52-48->10, 52->46->10, 52-42->20, 52-42->10, 52-40->12, 52-38-22, 52-36->20, 52-30->20, 52-29->10, 52->28-?, 51-42->10, >51-38-?, 51-26->18, 51->21->13, 50-45-15, 50-44-25, 50-38-?, 50-36-10, 50-33-30, 50-33->15, 50-30->20, 50-30->15, 50-29->17, 50-29->10, 50-28-20, 50-25->18, 50->21->12

49-39-36, 48->37-?, 48-34->20, 48-33->15, 48->28-18, 48-26-?, 47-43-?, 47-42->20, 46-38-?, 46-33->15, 46-28->10, 45-42->10, 44-40->10, 44-37->10, 44-32->10, 44-30-?, 44-28-?, 44-27->10,
43-37-22, 43-32->15, 43-30-?, 43-27-?, 43-19-?, 42-38->20, 42-38->10, 42-35->14, 42-29->10, 42-23->12, 42-22->13, 41-24->14, >40-34->10, 40-40->14, 40->38-23, 40-35-?, 40-32->15, 40-30->12, 40-30->10, 40-29-?, 40-28->10, 40-26->10, 40-24->20, 40-24->15, 40-24-?, 40->23->10, 40-15->8

39-29->10, 39-29->10, 39-27->10, 39-24-21, 38-34->10, 38-33->10, 38-32-23, 38-32->16, 38-32-?, 38-30->15, 38-29-14, 38-29->10, 38-28-?, 38-25->15, 38-25-?, 37-24->18, 36-29->15, 36-28->23, 36-26->10, 36-24-21, 36-24-20, 36-22->12, 36-21-?, 36-19-18, 36-?-17, 35-34-20, 35-28-?, 35->27->14, 35-27-26, 35-27-?, 35-25->15, 35-25->14, 35-24->22, 35-21->10, 35-21-8, 35-20->15, 34-30->10, 34-30-10, 34-27->10, 34-26->10, 34-24-23, 34-24->10, >33-28-?, 33-32-?, 33-30->11, 33-29->10, 33-28-18, 33->26->15, 33-24->10, 32-31->10, 32-28->17, 32-28->17, 32-26->15, 32-26->10, 32-22->10, 32-21->12, 32-20->11, 32-20->10, 31-30->10, 31-27->10, 31-22-15, 30-27->10, 30-27-?, 30-26-20, 30-25->14, 30-23->20, 30->20-14, 30-20-15, 30-20->10, 30-18-12, 30-?->13

29-28->10, 29-27-24, 29-25->12, 29-24->10, 29-21-15, 29-20->10, 29-20->10, 29-18-9, 29-17-10, 28-26-20, 28-24-14, 28-23->12, 28-23->10, 28-22-20, 28-21-20, 28-18-16, 27-24-?, 27-23->10,
27-22->15, 27-21->10, 27-20->15, 27-18->10, 27-17->10, 27-15->10, 26-24-?, 26-23->10, 26-23-?, 26-22-16, 26-22->11, 26->20-?, 26-20-20, 26-19->19, 26-17-11, 26-17->8, 26-16-12, 26-16->10,
25-18-6, 24-23->10, 24-22-?, 24-17-14, 24-16->14, 23-20-12, 23-20->10, 23-18->10, 23-14-10, 22-21-?, 21-18-14, 21-15-?, 21-14-11, 20-16-13, 20-16-7, 20-14->10

18-15>10, 18-15-8, 17-14-9, 17-12-10, 16-13-9, 15-11-6

II. Ranked by median, then maximum diameter, in cm. Est. ± 3 cm. A question mark (?) means no reliable measurement. A greater sign (>) means the actual dimension is at least as large as given.

226-150->30, 200-150->80, 200-150->50

130-90->20

170-80->55

100-72->20, 96-70-50

110-66->25, 96-65->10, 77-60->15, 68-60-30

65-56->38, 63-56->19, 56-56->10, 68-55->26, 66-55->30, 84-52->10, 53-52->14, 86->50-24, >58->50->18, 98-50->25, 84-50->20, 83-50-25, 79-50-50, 74-50-38, 70-50->16, 63-50->25

95-48->20, 80-48->25, 64-48->38, 59-48->15, 58-48->25, 57-48->15, 53-48-?, 52-48->10, 69-47->17, 63-47->20, 52->46->10, 80-46->20, 60-45->30, 55-45->10, 50-45-15, 90-44->15, 72-44-36, 50-44-25, 56-43->15, 47-43-?, 75-42->10, 56-42->10, 52-42->20, 52-42->10, 51-42->10, 47-42->20, 45-42->10, 75-41-?, 64-41-22, 65->40-?, 79-40->15, 68-40->30, 63-40->25, 55-40->20, 54-40->18, 52-40->12, 44-40->10, 40-40->14

60->39->15, 60->39->10, 60->39-?, 90-39->35, 78-39->10, 58-39->15, 54-39->20, 49-39-36, 40->38-23, 66-38->10, 58-38->22, 58-38->15, 56-38->15, 53-38->10, 52-38-22, >51-38-?, 50-38-?, 46-38-?, 42-38->20, 42-38->10, 48->37-?, 62-37-30, 60-37-18, 58-37->18, 44-37->10, 43-37-22, 73-36->26, 56-36->10, 54-36->13, 52-36->20, 50-36-10, 55-35->15, 42-35->14, 40-35-?, 48-34->20, >40-34->10, 38-34->10, 35-34-20, 50-33-30, 50-33->15, 48-33->15, 46-33->15, 38-33->10, 44-32->10, 43-32->15, 40-32->15, 38-32-23, 38-32->16, 38-32-?, 33-32-?, 32-31->10, 57->30-20, 63-30-20, 58-30->10, 52-30->20, 50-30->20, 50-30->15, 44-30-?, 43-30-?, 40-30->12, 40-30->10, 38-30->15, 34-30->10, 34-30-10, 33-30->11, 31-30->10

52-29->10, 50-29->17, 50-29->10, 42-29->10, 40-29-?, 39-29->10, 39-29->10, 38-29-14, 38-29->10, 36-29->15, 33-29->10, 52->28-?, 48->28-18, 50-28-20, 46-28->10, 44-28-?, 40-28->10, 38-28-?, 36-28->23, 35-28-?, >33-28-?, 33-28-18, 32-28->17, 32-28->17, 29-28->10, 35->27->14, 44-27->10, 43-27-?, 39-27->10, 35-27-26, 35-27-?, 34-27->10, 31-27->10, 30-27->10, 30-27-?, 29-27-24, 33->26->15, 76-26-?, 56-26-16, 51-26->18, 48-26-?, 40-26->10, 36-26->10, 34-26->10, 32-26->15, 32-26->10, 30-26-20, 28-26-20, 60-25-?, 50-25->18, 38-25->15, 38-25-?, 35-25->15, 35-25->14, 30-25->14, 29-25->12, 41-24->14, 40-24->20, 40-24->15, 40-24-?, 39-24-21, 37-24->18, 36-24-21, 36-24-20, 35-24->22, 34-24-23, 34-24->10, 33-24->10, 29-24->10, 28-24-14, 27-24-?, 26-24-?, 40->23->10, 42-23->12, 30-23->20, 28-23->12, 28-23->10, 27-23->10, 26-23->10, 26-23-?, 24-23->10, 42-22->13, 36-22->12, 32-22->10, 31-22-15, 28-22-20, 27-22->15, 26-22-16, 26-22->11, 24-22-?, 51->21->13, 50->21->12, 36-21-?, 35-21->10, 35-21-8, 32-21->12, 29-21-15, 28-21-20, 27-21->10, 22-21-?, 30->20-14, 26->20-?, 63-20->12, 55-20->12, 35-20->15, 32-20->11, 32-20->10, 30-20-15, 30-20->10, 29-20->10, 29-20->10, 27-20->15, 26-20-20, 23-20-12, 23-20->10

43-19-?, 36-19-18, 26-19->19, 30-18-12, 29-18-9, 28-18-16, 27-18->10, 25-18-6, 23-18->10, 21-18-14, 29-17-10, 27-17->10, 26-17-11, 26-17->8, 24-17-14, 26-16-12, 26-16->10, 24-16->14, 20-16-13, 20-16-7, 40-15->8, 27-15->10, 21-15-?, 18-15->10, 18-15-8, 23-14-10, 21-14-11, 20-14->10, 17-14-9, 16-13-9, 17-12-10, 15-11-6

36-?-17, 30-?->13

Table 6. Hydraulic Calculations for Glade Hill Boulder Bed

6A

n = 0.020

u =			5				6				7				8			
W	D	R	Q	S	t	om	Q	S	t	om	Q	S	t	om	Q	S	t	om
100	5	4.55	2.5	0.133	65	0.33	3	0.191	94	0.56$$	3.5	0.260	128	0.89$$	4	0.340	167	1.33
	10	8.33	5	0.059	58	0.29	6	0.085	84	0.50**	7	0.116	114	0.80$$	8	0.152	149	1.19$$
	15	11.54	7.5	0.038	56	0.28	9	0.055	81	0.49	10.5	0.075	111	0.77**	12	0.098	144	1.16**
	20	14.29	10	0.029	57	0.28	12	0.042	81	0.49	14	0.057	111	0.78	16	0.074	145	1.16**
	25	16.67	12.5	0.023	58	0.29	15	0.034	83	0.50	17.5	0.046	113	0.79	20	0.060	147	1.18**
	30	18.75					18	0.029	85	0.51	21	0.039	116	0.81	24	0.051	151	1.21
200	5	4.76	5	0.125	61	0.31	6	0.180	88	0.53$$	7	0.245	120	0.84$$	8	0.320	157	1.25
	10	9.09	10	0.053	52	0.26	12	0.076	74	0.45	14	0.103	101	0.71$$	16	0.135	132	1.06$$
	15	13.04	15	0.033	48	0.24	18	0.047	69	0.41	21	0.064	94	0.66**	24	0.083	123	0.98**
	20	16.67	20	0.023	46	0.23	24	0.034	66	0.40	28	0.046	90	0.63	32	0.060	118	0.94 *
	25	20.00	25	0.018	45	0.23	30	0.027	65	0.39	35	0.036	89	0.62	40	0.047	116	0.92
300	5	4.84	7.5	0.122	60	0.30	9	0.176	86	0.52$$	10.5	0.239	117	0.82$$	12	0.313	153	1.23
	10	9.38	15	0.051	50	0.25	18	0.073	71	0.43	21	0.099	97	0.68**	24	0.130	127	1.02$$
	15	13.64	22.5	0.031	45	0.23	27	0.044	65	0.39	31.5	0.060	88	0.62 *	36	0.079	116	0.92 *
	20	17.65	30	0.022	43	0.21	36	0.031	61	0.37	42	0.043	84	0.59	48	0.056	109	0.87
	25	21.43	37.5	0.017	41	0.21	45	0.024	59	0.36	52.5	0.033	81	0.57	60	0.043	105	0.84
400	5	4.88	10	0.121	59	0.30	12	0.174	85	0.51$$	14	0.237	116	0.81$$	16	0.309	152	1.21
	10	9.52	20	0.050	49	0.24	24	0.071	70	0.42	28	0.097	95	0.67**	32	0.127	124	0.99 $
	15	13.95	30	0.030	44	0.22	36	0.043	63	0.38	42	0.058	86	0.60	48	0.076	112	0.90 *
	20	18.18	40	0.021	41	0.21	48	0.030	59	0.35	56	0.041	80	0.56	64	0.054	105	0.84
	25	22.22	50	0.016	39	0.20	60	0.023	57	0.34	70	0.031	77	0.54	80	0.041	100	0.80

Table 6. Hydraulic Calculations for Glade Hill Boulder Bed (continued)

6B

n = 0.025

u =			5				6				7				8			
W	D	R	Q	S	t	om	Q	S	t	om	Q	S	t	om	Q	S	t	om
100	5	4.55	2.5	0.208	102	0.51$$	3	0.299	146	0.88$$	3.5	0.407	199	1.40	4	0.531	260	2.08##
	10	8.33	5	0.092	91	0.45	6	0.133	131	0.78$$	7	0.181	178	1.24$$	8	0.237	232	1.86
	15	11.54	7.5	0.060	88	0.44	9	0.086	127	0.76**	10.5	0.117	173	1.21$$	12	0.153	226	1.80
	20	14.29	10	0.045	88	0.44	12	0.065	127	0.76**	14	0.088	173	1.21**	16	0.115	226	1.81
	25	16.67	12.5	0.037	90	0.45	15	0.053	130	0.78	17.5	0.072	176	1.23**	20	0.094	230	1.84
	30	18.75	15	0.031	92	0.46	18	0.045	133	0.80	21	0.061	181	1.27**	24	0.080	236	1.89
	35	20.59					21	0.040	137	0.82	24.5	0.054	186	1.30	28	0.071	243	1.95
	40	22.22									28	0.049	192	1.35	32	0.064	251	2.01
	45	23.68													36	0.059	259	2.08
200	5	4.76	5	0.195	96	0.48	6	0.281	138	0.83$$	7	0.382	187	1.31	8	0.499	245	1.96
	10	9.09	10	0.082	81	0.40	12	0.119	116	0.70$$	14	0.161	158	1.11$$	16	0.211	207	1.65
	15	13.04	15	0.051	75	0.37	18	0.073	108	0.65**	21	0.100	147	1.03**	24	0.130	192	1.53$$
	20	16.67	20	0.037	72	0.36	24	0.053	104	0.62	28	0.072	141	0.99**	32	0.094	184	1.47 *
	25	20.00	25	0.029	71	0.35	30	0.041	102	0.61	35	0.056	138	0.97	40	0.074	181	1.44 *
	30	23.08	30	0.024	70	0.35	36	0.034	101	0.60	42	0.047	137	0.96	48	0.061	179	1.43 *
	35	25.93									49	0.040	137	0.96	56	0.052	179	1.43
300	5	4.84	7.5	0.191	94	0.47	9	0.275	135	0.81$$	10.5	0.374	183	1.28	12	0.489	240	1.92
	10	9.38	15	0.079	78	0.39	18	0.114	112	0.67$$	21	0.155	152	1.06$$	24	0.202	198	1.59
	15	13.64	22.5	0.048	71	0.35	27	0.069	102	0.61**	31.5	0.094	138	0.97 *	36	0.123	181	1.44 $
	20	17.65	30	0.034	67	0.33	36	0.049	96	0.58	42	0.067	131	0.92 *	48	0.087	171	1.37 *
	25	21.43	37.5	0.026	64	0.32	45	0.038	93	0.56	52.5	0.051	126	0.88	60	0.067	165	1.32 *
	30	25.00	45	0.021	63	0.31	54	0.031	91	0.54	63	0.042	123	0.86	72	0.055	161	1.29
	35	28.38									73.5	0.035	121	0.85	84	0.046	159	1.27
400	5	4.88	10	0.189	93	0.46	12	0.272	133	0.80$$	14	0.370	181	1.27	16	0.484	237	1.90
	10	9.52	20	0.077	76	0.38	24	0.111	109	0.66$$	28	0.152	149	1.04$$	32	0.198	194	1.55
	15	13.95	30	0.047	68	0.34	36	0.067	99	0.59 *	42	0.091	134	0.94 *	48	0.119	175	1.40 $
	20	18.18	40	0.033	64	0.32	48	0.047	92	0.53	56	0.064	126	0.88 *	64	0.084	164	1.31 *
	25	22.22	50	0.025	61	0.31	60	0.036	88	0.53	70	0.049	120	0.84	80	0.064	157	1.26 *
	30	26.09	60	0.020	59	0.30	72	0.029	86	0.51	84	0.040	116	0.82	96	0.052	152	1.22
	35	29.79									98	0.033	114	0.80	112	0.043	149	1.19

Table 6. Hydraulic Calculations for Glade Hill Boulder Bed (continued)

6C

n = 0.035

u =			5				6				7				8			
W	D	R	Q	S	t	om	Q	S	t	om	Q	S	t	om	Q	S	t	om
100	5	4.55	2.5	0.407	199	1.00	3	0.586	297	1.72	3.5	0.797	391	2.73##	4	1.041	510	4.08@@
	10	8.33	5	0.181	178	0.89$$	6	0.261	256	1.54	7	0.355	348	2.44 #	8	0.464	455	3.64 #
	15	11.54	7.5	0.117	173	0.86$$	9	0.169	249	1.49$$	10.5	0.230	338	2.37 #	12	0.301	442	3.54 #
	20	14.29	10	0.088	173	0.87**	12	0.127	249	1.50$$	14	0.173	339	2.38 #	16	0.226	443	3.55 #
	25	16.67	12.5	0.072	176	0.88**	15	0.104	254	1.52	17.5	0.141	345	2.42	20	0.184	451	3.61 #
	30	18.75	15	0.061	181	0.90**	18	0.089	260	1.56	21	0.121	354	2.48	24	0.157	463	3.70 #
	35	20.59	17.5	0.054	186	0.93	21	0.078	268	1.61	24.5	0.106	365	2.55	28	0.139	477	3.81
	40	22.22					24	0.071	277	1.66	28	0.096	377	2.64	32	0.125	492	3.94
	45	23.68					27	0.065	286	1.72	31.5	0.088	389	2.72	36	0.115	508	4.07
	50	25.00					30	0.060	296	1.77	35	0.082	402	2.82	40	0.107	526	4.20
200	5	4.76	5	0.382	187	0.94	6	0.550	270	1.62	7	0.749	367	2.57	8	0.979	480	3.84
	10	9.09	10	0.161	158	0.79$$	12	0.232	228	1.37$$	14	0.316	310	2.17	16	0.413	405	3.24
	15	13.04	15	0.100	147	0.73**	18	0.144	211	1.27$$	21	0.195	287	2.01	24	0.255	375	3.00
	20	16.67	20	0.072	141	0.71**	24	0.104	203	1.22$$	28	0.141	276	1.93	32	0.184	361	2.89
	25	20.00	25	0.056	138	0.69	30	0.081	199	1.19**	35	0.111	271	1.90	40	0.144	354	2.83
	30	23.08	30	0.047	137	0.69	36	0.067	197	1.18 *	42	0.091	269	1.88	48	0.119	351	2.81
	35	25.93					42	0.057	197	1.18	49	0.078	268	1.88	56	0.102	351	2.80
	40	28.57					48	0.050	198	1.19	56	0.069	269	1.89	64	0.090	352	2.82
300	5	4.84	7.5	0.374	183	0.92	9	0.539	264	1.58	10.5	0.733	359	2.52	12	0.958	469	3.76
	10	9.38	15	0.155	152	0.76$$	18	0.223	219	1.31$$	21	0.304	298	2.08	24	0.397	389	3.11
	15	13.64	22.5	0.094	138	0.69**	27	0.135	199	1.19$$	31.5	0.184	271	1.90	36	0.241	354	2.83
	20	17.65	30	0.067	131	0.65**	36	0.096	188	1.13 *	42	0.131	256	1.79	48	0.171	335	2.68
	25	21.43	37.5	0.051	126	0.63	45	0.074	182	1.09 *	52.5	0.101	247	1.73	60	0.132	323	2.58
	30	25.00	45	0.042	123	0.62	54	0.060	177	1.06 *	63	0.082	241	1.69	72	0.107	315	2.52
	35	28.38					63	0.051	175	1.05	73.5	0.069	238	1.67	84	0.091	311	2.49
	40	31.58									84	0.060	236	1.65	96	0.079	308	2.46
400	5	4.88	10	0.370	181	0.91	12	0.533	261	1.57	14	0.726	356	2.49	16	0.948	464	3.72
	10	9.52	20	0.152	149	0.74$$	24	0.218	214	1.29$$	28	0.297	291	2.04	32	0.388	381	3.05
	15	13.95	30	0.091	134	0.67**	36	0.131	193	1.16 $	42	0.179	263	1.84	48	0.233	343	2.75
	20	18.18	40	0.064	126	0.63 *	48	0.092	181	1.09 *	56	0.126	246	1.72	64	0.164	321	2.57
	25	22.22	50	0.049	120	0.60	60	0.071	173	1.04 *	70	0.096	235	1.65	80	0.125	307	2.46
	30	26.09	60	0.040	116	0.58	72	0.057	168	1.01	84	0.078	228	1.60	96	0.101	298	2.38
	35	29.79					84	0.048	164	0.98	98	0.065	223	1.56	112	0.085	291	2.33

Table 6. Hydraulic Calculations for Glade Hill Boulder Bed (continued)

6D

n = 0.045

u =			5				6				7				8			
W	D	R	Q	S	t	om	Q	S	t	om	Q	S	t	om	Q	S	t	om
100	5	4.55	2.5	0.672	330	1.65	3	0.968	474	2.85##	3.5	1.318	646	4.52@@	4	1.721	843	6.75@@
	10	8.33	5	0.300	294	1.47$$	6	0.431	423	2.54 #	7	0.587	576	4.03 #	8	0.767	752	6.01 #
	15	11.54	7.5	0.194	285	1.43$$	9	0.280	411	2.47 #	10.5	0.381	559	3.92 #	12	0.497	731	5.85 #
	20	14.29	10	0.146	286	1.43$$	12	0.210	412	2.47 #	14	0.286	561	3.93 #	16	0.374	733	5.86 #
	25	16.67	12.5	0.119	291	1.46$$	15	0.171	420	2.52 #	17.5	0.233	571	4.00 #	20	0.304	746	5.97 #
	30	18.75	15	0.102	299	1.49$$	18	0.146	430	2.58	21	0.199	586	4.10 #	24	0.260	765	6.12 #
	35	20.59	17.5	0.090	308	1.54	21	0.129	443	2.66	24.5	0.176	603	4.22 #	28	0.230	788	6.30 #
	40	22.22	20	0.081	318	1.59	24	0.117	457	2.74	28	0.159	623	4.36 #	32	0.207	813	6.51 #
	45	23.68	22.5	0.074	328	1.64	27	0.107	473	2.84	31.5	0.146	643	4.50	36	0.191	840	6.72 #
	50	25.00	25	0.069	339	1.70	30	0.100	489	2.93	35	0.136	665	4.66	40	0.177	869	6.95 #
200	5	4.76	5	0.632	310	1.55	6	0.910	446	2.68	7	1.239	607	4.25	8	1.618	793	6.34
	10	9.09	10	0.267	262	1.31$$	12	0.384	377	2.26	14	0.523	513	3.59	16	0.683	669	5.36
	15	13.04	15	0.165	242	1.21$$	18	0.237	349	2.09	21	0.323	475	3.33	24	0.422	621	4.96
	20	16.67	20	0.119	233	1.17$$	24	0.171	336	2.01	28	0.233	457	3.20	32	0.304	597	4.77
	25	20.00	25	0.093	229	1.14**	30	0.134	329	1.97	35	0.183	448	3.14	40	0.239	585	4.68
	30	23.08	30	0.077	227	1.13**	36	0.111	326	1.96	42	0.151	444	3.11	48	0.197	580	4.64
	35	25.93	35	0.066	226	1.13 *	42	0.095	326	1.96	49	0.129	444	3.11	56	0.169	579	4.64
	40	28.57	40	0.058	227	1.14	48	0.083	327	1.96	56	0.114	445	3.12	64	0.148	582	4.65
300	5	4.84	7.5	0.619	303	1.52	9	0.891	437	2.62	10.5	1.212	594	4.16	12	1.584	776	6.21
	10	9.38	15	0.256	251	1.26$$	18	0.369	361	2.17	21	0.502	492	3.44	24	0.656	643	5.14
	15	13.64	22.5	0.155	228	1.14$$	27	0.224	329	1.97	31.5	0.305	448	3.13	36	0.398	585	4.68
	20	17.65	30	0.110	216	1.08$$	36	0.159	311	1.87	42	0.216	423	2.96	48	0.282	553	4.42
	25	21.43	37.5	0.085	208	1.04 *	45	0.122	300	1.80	52.5	0.167	408	2.86	60	0.218	534	4.27
	30	25.00	45	0.069	204	1.02 *	54	0.100	293	1.76	63	0.136	399	2.79	72	0.177	521	4.17
	35	28.38	52.5	0.058	201	1.00	63	0.084	289	1.73	73.5	0.115	393	2.75	84	0.150	514	4.11
	40	31.58	60	0.051	199	0.99	72	0.073	286	1.72	84	0.099	390	2.73	96	0.130	509	4.07
400	5	4.88	10	0.612	300	1.50	12	0.881	432	2.59	14	1.199	588	4.11	16	1.567	768	6.14
	10	9.52	20	0.251	246	1.23$$	24	0.361	354	2.12	28	0.492	482	3.37	32	0.642	629	5.03
	15	13.95	30	0.151	222	1.11$$	36	0.217	319	1.91	42	0.295	434	3.04	48	0.386	567	4.54
	20	18.18	40	0.106	208	1.04 $	48	0.152	299	1.79	56	0.208	407	2.85	64	0.271	531	4.25
	25	22.22	50	0.081	199	0.99 *	60	0.117	286	1.72	70	0.159	389	2.72	80	0.207	508	4.07
	30	26.09	60	0.065	192	0.96 *	72	0.094	277	1.66	84	0.128	377	2.64	96	0.168	493	3.94
	35	29.79	70	0.055	188	0.94	84	0.079	271	1.63	98	0.107	369	2.58	112	0.140	481	3.85
	40	33.33									112	0.092	363	2.54	128	0.121	474	3.79

TABLE 6. HYDRAULIC CALCULATIONS FOR GLADE HILL BOULDER BED (Continued)

6E Possible Hydraulic Parameters for Feeder Channels of Glade Hill Boulder Bed

n = 0.035

W	D	R	u	Q	S	t	om	Fr	Re
50	3	2.67	5	0.75	0.823	242	1.21	0.92	15
			6	0.90	1.185	349	2.09@@	1.11	18
			7	1.05	1.614	474	3.32@@	1.29	21
			8	1.20	2.108	620	4.96@@	1.48	24
			9	1.35	2.667	784	7.06@@	1.66	27
			10	1.50	3.293	968	9.68@@	1.84	30
	5	4.17	5	1.25	0.457	224	1.12	0.71	25
			6	1.50	0.658	322	1.93	0.86	30
			7	1.75	0.895	439	3.07##	1.00	35
			8	2.00	1.169	573	4.58@@	1.14	40
			9	2.25	1.480	725	6.53@@	1.29	45
			10	2.50	1.827	895	8.95@@	1.43	50
100	3	2.83	5	1.50	0.765	225	1.13	0.92	15
			6	1.80	1.102	324	1.94	1.11	18
			7	2.10	1.499	441	3.09@@	1.29	21
			8	2.40	1.958	576	4.61@@	1.48	24
			9	2.70	2.479	729	6.56@@	1.66	27
			10	3.00	3.060	900	9.00@@	1.84	30
	5	4.54	5	2.50	0.407	199	1.00	0.71	25
			6	3.00	0.586	287	1.72	0.86	30
			7	3.50	0.797	391	2.73##	1.00	35
			8	4.00	1.041	510	4.08@@	1.14	40
			9	4.50	1.318	646	5.81@@	1.29	45
			10	5.00	1.627	797	7.97@@	1.43	50

6F Froude Number (Fr) and Reynolds Number (Re) as Functions of Depth and Current Speed

CURRENT SPEED, u

		Fr				Re			
		5	6	7	8	5	6	7	8
W	5	0.714	0.857	1.000	1.143	25	30	35	40
A	10	0.505	0.606	0.707	0.808	50	60	70	80
T	15	0.412	0.495	0.577	0.660	75	90	105	120
E	20	0.357	0.429	0.500	0.571	100	120	140	160
R									
	25	0.319	0.383	0.447	0.511	125	150	175	200
D	30	0.292	0.350	0.408	0.467	150	180	210	240
E	35	0.270	0.324	0.378	0.432	175	210	245	280
P	40	0.253	0.303	0.354	0.404	200	240	280	320
T									
H	45	0.238	0.286	0.333	0.381	225	270	315	360
	50	0.226	0.271	0.316	0.361	250	300	350	400
	55	0.215	0.258	0.302	0.345	275	330	385	440
D	60	0.206	0.247	0.289	0.330	300	360	420	480

Notes

Units: W, channel width, R, hydraulic radius, D, average depth,
all in meters

Q, flux, in kilocubic meters per second (10^3 cms)
S, slope, in percent
tau (t), basal shear stress, in newtons/m^2
omega (om), unit stream power, in kilowatts/m^2 or kilonewtons/m/s
u, current speed, in m/s
Re, Reynolds number, in units of 10^7

To go from values for u_i to values for u_j, the appropriate scaling factor is:

For Q, Fr, Re, u_j/u_i

For S, tau, $(u_j/u_i)^2$

For omega, $(u_j/u_i)^3$

Significance of marks *, $, #, and @ (indicated to the right of the stream power values for a specific value of u) is as follows.

For the main channel:

$0.5 \leq$ *omega* ≤ 1.5; $W \geq 100$ m

* $0.06\% \leq S \leq 0.1\%$; $Q > 30$
** $0.06\% \leq S \leq 0.1\%$; $Q \leq 30$

$ $0.1\% < S \leq 0.3\%$; $Q > 30$
$$ $0.1\% < S \leq 0.3\%$; $Q \leq 30$

For the feeder channel:

omega ≥ 2.0; $W \leq 100$ m

\# $0.15\% \leq S \leq 1.0\%$; $Q > 5.6$
\## $0.15\% \leq S \leq 1.0\%$; $Q \leq 5.6$

@ $1.0\% < S \leq 4.0\%$; $Q > 5.6$
@@ $1.0\% < S \leq 4.0\%$; $Q \leq 5.6$

TABLE 7. POTENTIAL SOURCE AREAS FOR WEVERTON QUARTZITE BOULDERS OF GLADE HILL BOULDER BED

From McPherson Circle boulder at 245-ft elevation to Glade Hill:

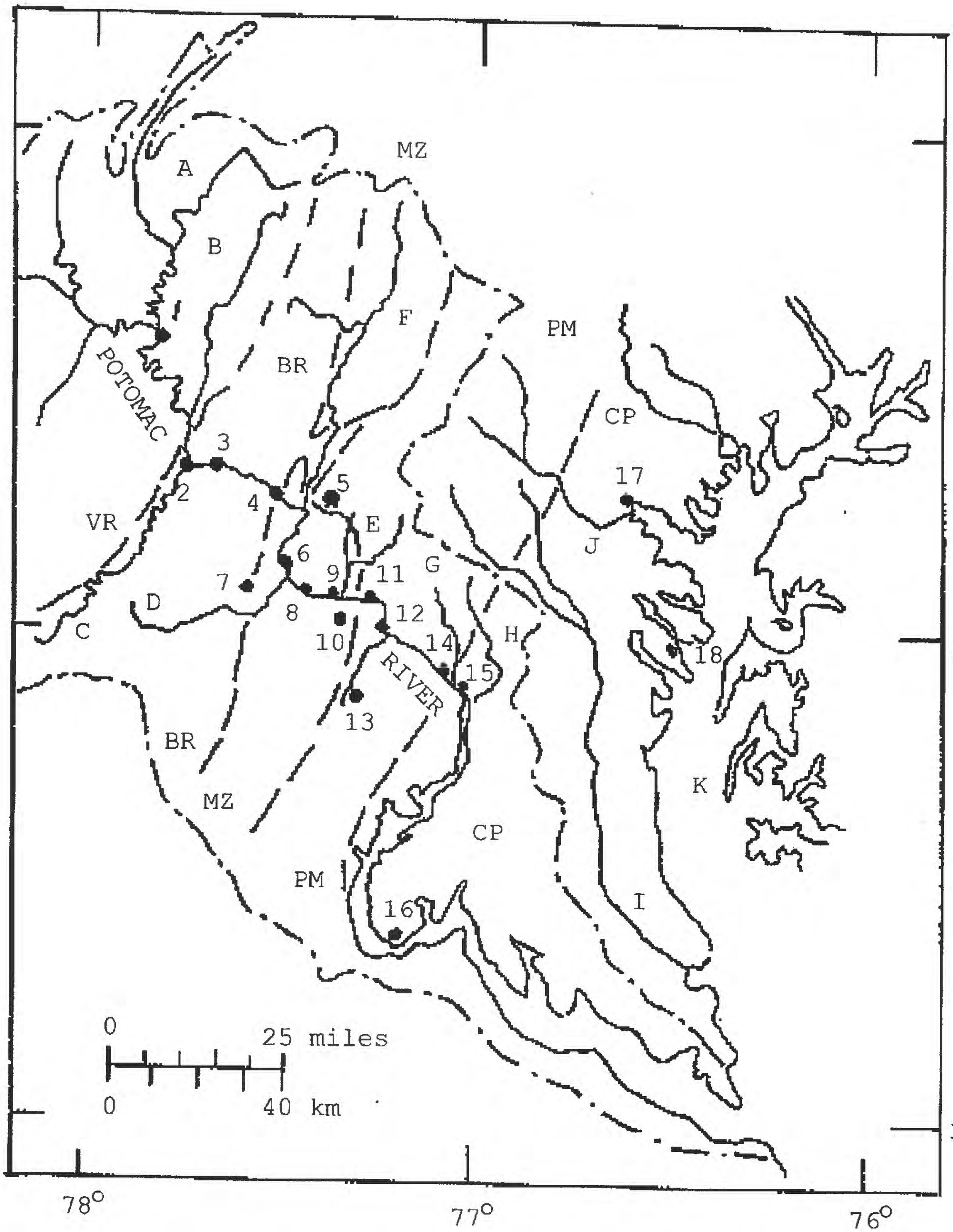
Distance along river channel, 22 km
Distance along a beeline, 16 km
Sinuosity, 1.35
Average slope, 0.07%

I. Possible sources and distances (in km) of Weverton Quartzite to McPherson Circle:

Shorthill Mountain	Catoctin Mountain	Sugarloaf Mountain	Leesburg
DISTANCE ALONG THE RIVER CHANNEL			
51	36	30	16
DISTANCE ALONG A BEELINE			
38	27	21	16
SINUOSITY			
1.3	1.3	1.4	1.0
Elevation increase (ft) from McPherson Circle would be, if S is:			
0.06%			
31	22	18	10
0.3%			
153	108	90	48

II. Total distances from source to Glade Hill, km

Shorthill Mountain	Catoctin Mountain	Sugarloaf Mountain	Leesburg
70	55	49	35



MZ
A
B
F
PM
BR
POTOMAC
CP
3
2
5
17
4
VR
E
J
6
7
9
11
G
D
8
12
C
10
14
H
18
RIVER
15
13
BR
K
MZ
CP
PM
16
I
0
25 miles
0
40 km
40°
39°
38°
78°
77°
76°

Figure 1

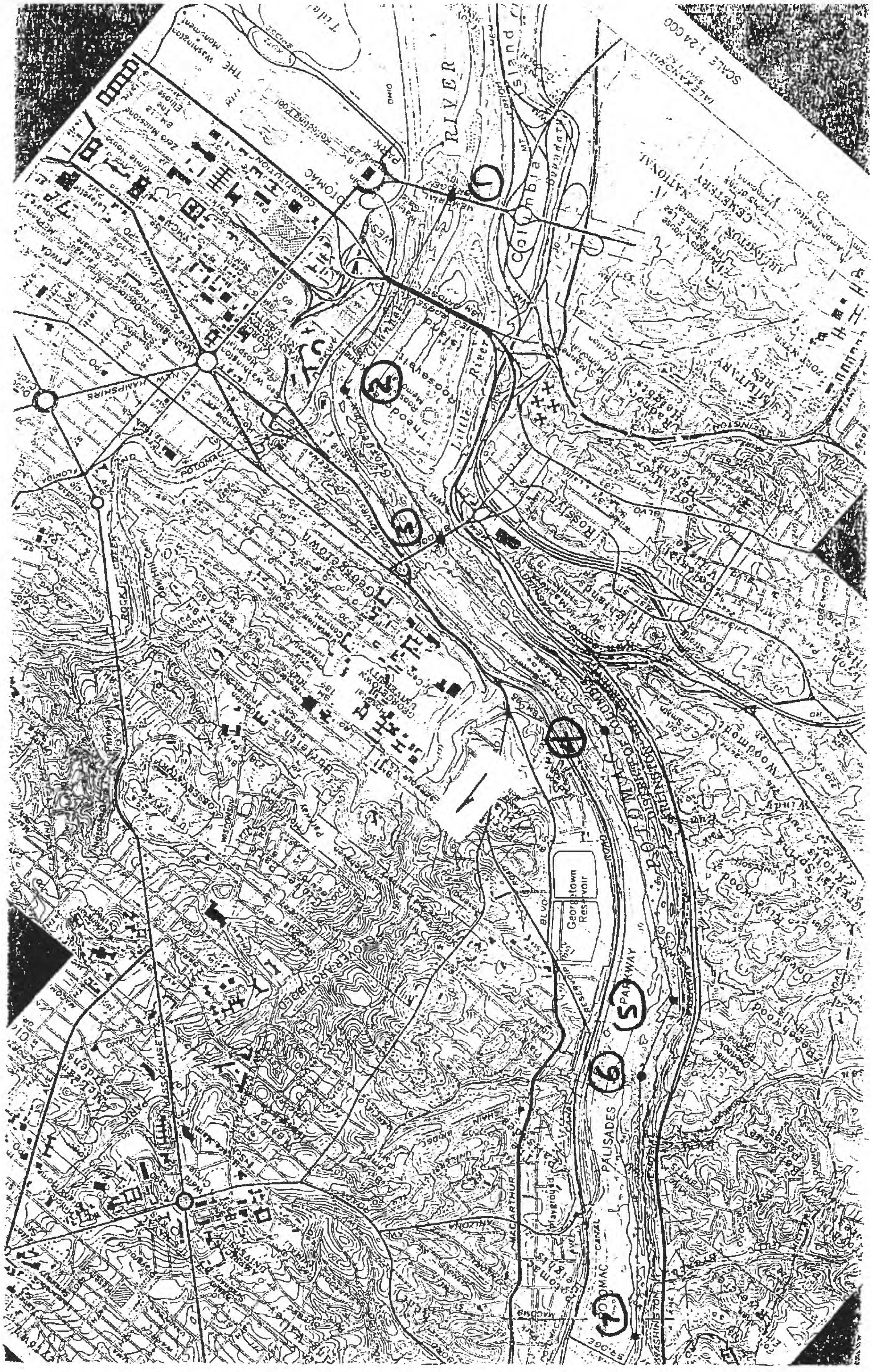
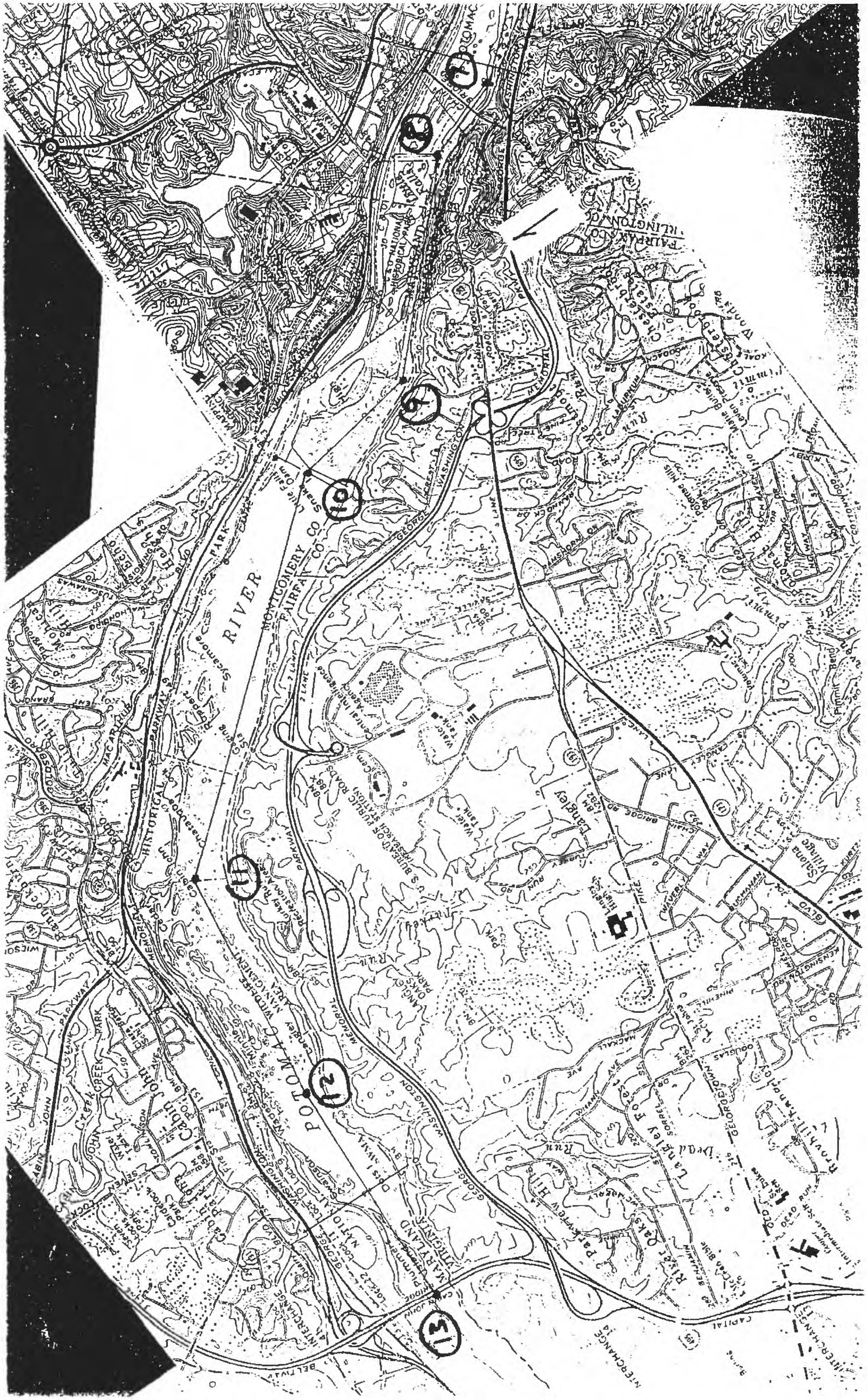
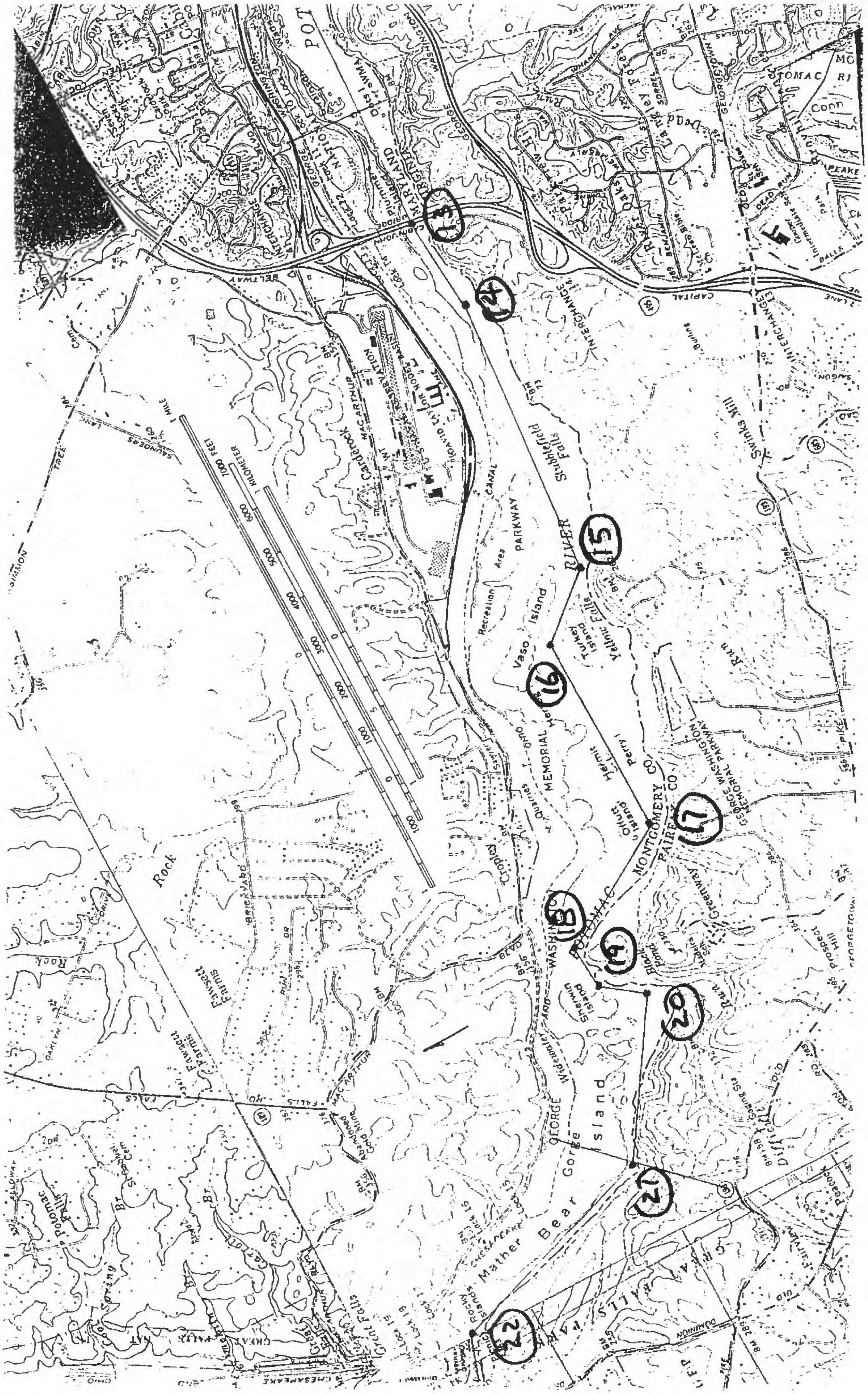


Fig. 2A



ZGW Fig 2(B)

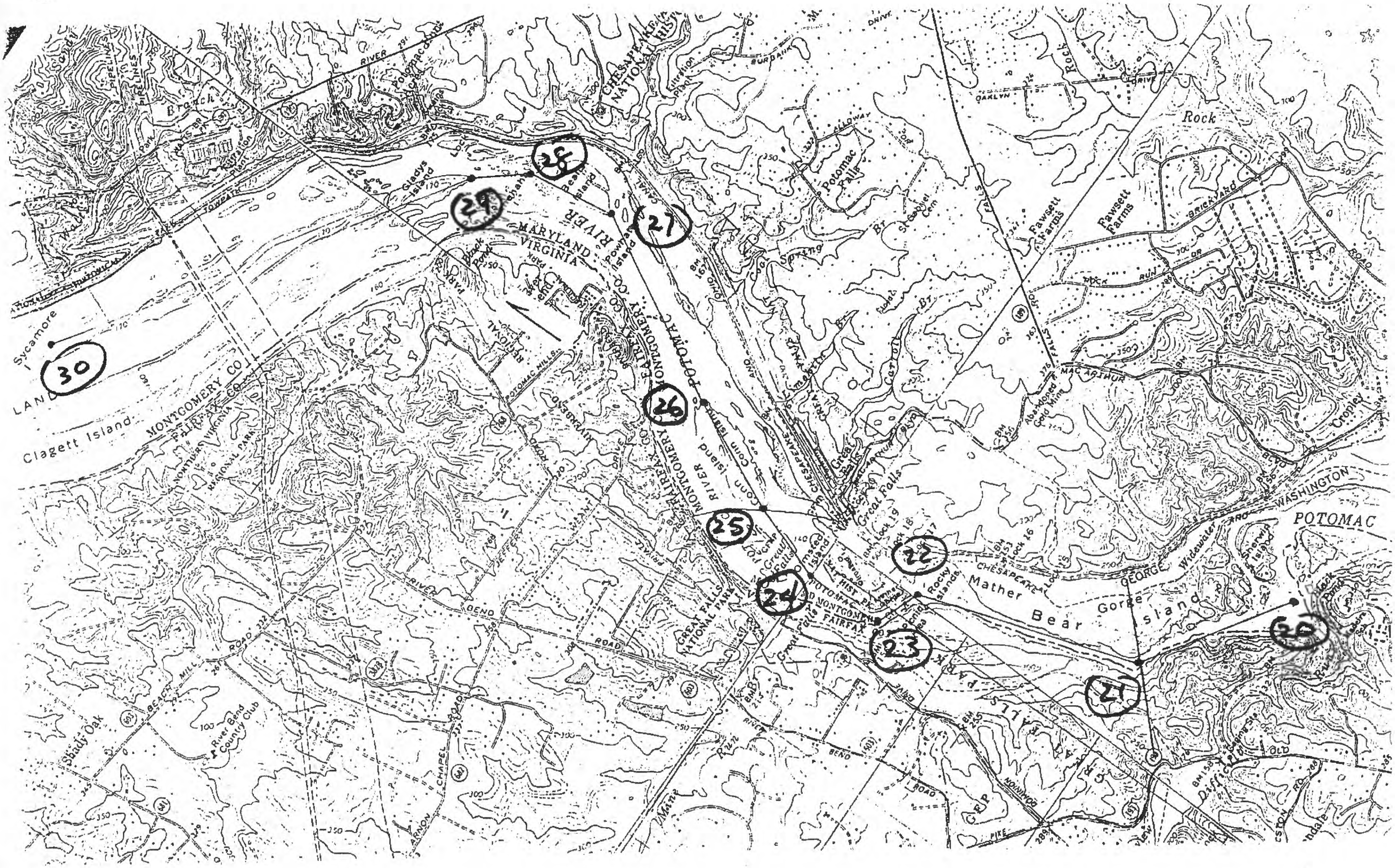
ig. 2B



ZGN Fig 2(C)

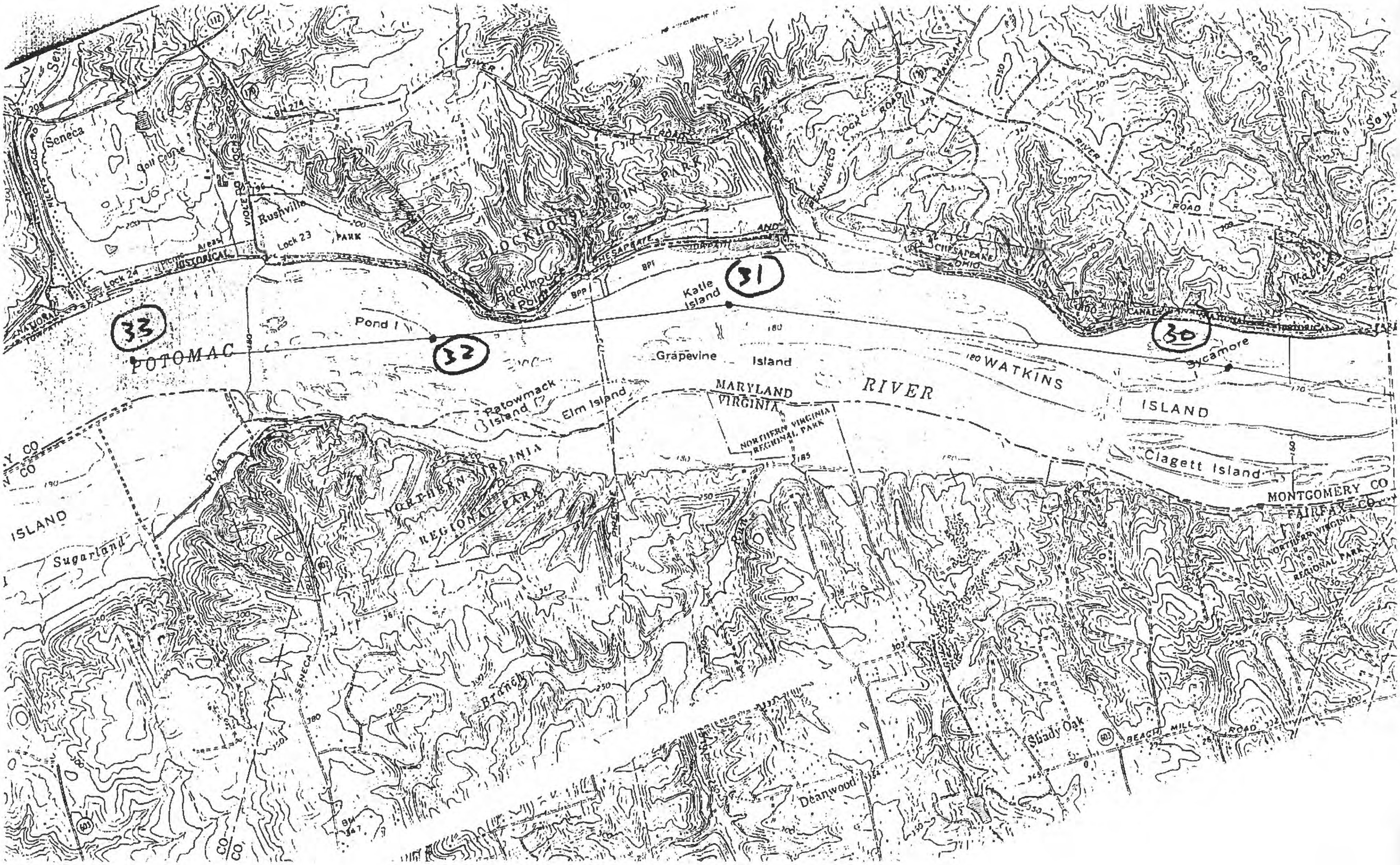
Fig. 2C

9.2D

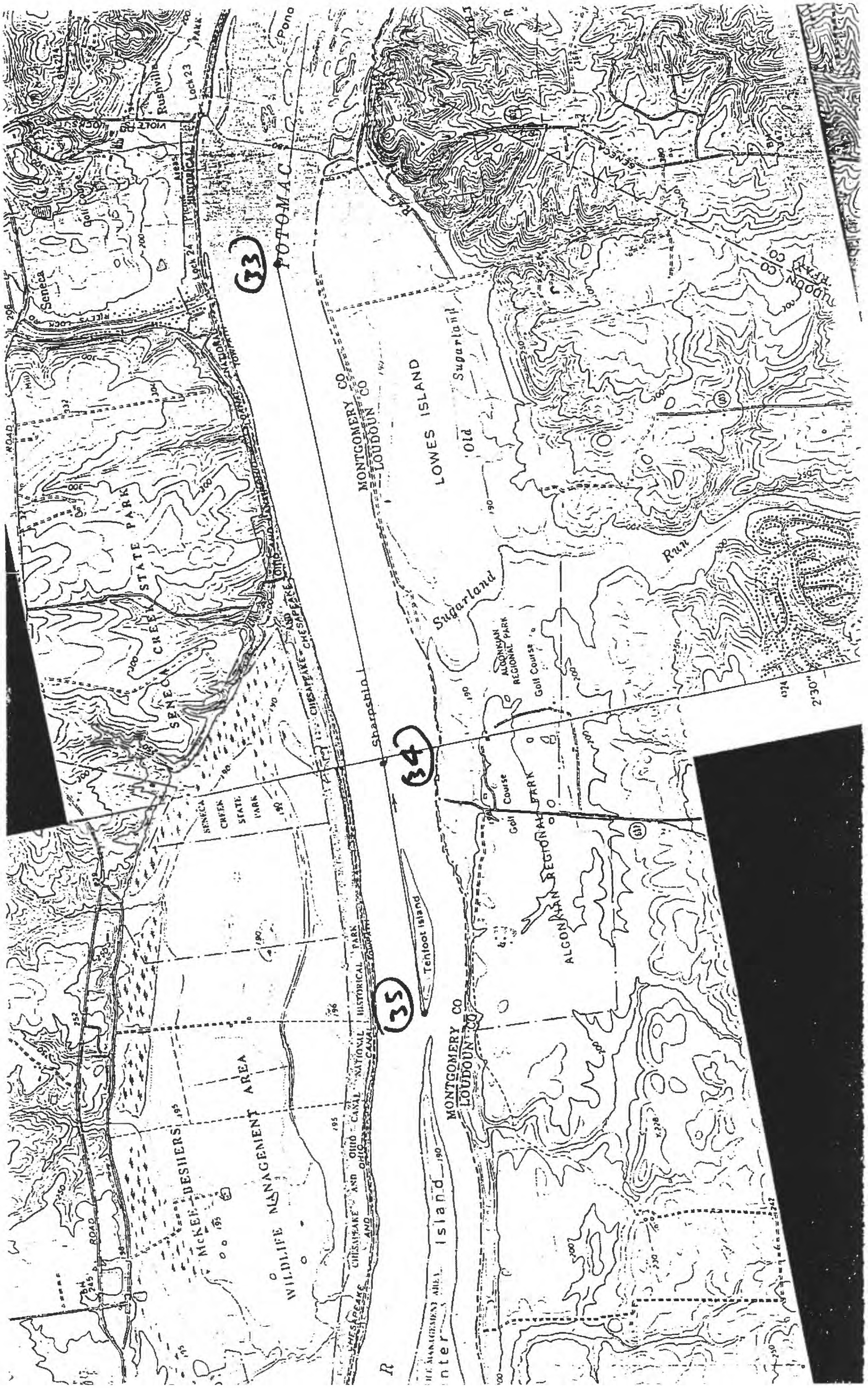


ZEN Fig 2 (D)

82


Seneca
Golf Course
Rushville
Lock 23
Lock 24
PARK
HISTORICAL
CHESAPEAKE
AND
OHIO
CANAL
NATIONAL
Pond I
Katie Island
Grapevine Island
POTOMAC
RIVER
WATKINS
ISLAND
Sycamore
Clagett Island
Patowmack Island
Elm Island
MARYLAND
VIRGINIA
NORTHERN VIRGINIA REGIONAL PARK
MONTGOMERY CO
FAIRFAX CO
ISLAND
Sugarland
Branch
SENECA
Shady Oak
BEACH MILL ROAD
Deanwood
RIVER ROAD
LOCK ROAD
33
32
31
30

ZEN Fig 2(E)


POTOMAC
MONTGOMERY CO
LOUDOUN CO
LOWES ISLAND
Old Sugarland
Sugarland Run
SENECA CREEK STATE PARK
CHESAPEAKE AND OHIO CANAL NATIONAL HISTORICAL PARK
Sharpshin
Tenfoot Island
McKEE-BESHERS WILDLIFE MANAGEMENT AREA
ALGONKIAN REGIONAL PARK
Golf Course
Seneca
Lock 24
Lock 23
Island
33
34
35

ig. 2F

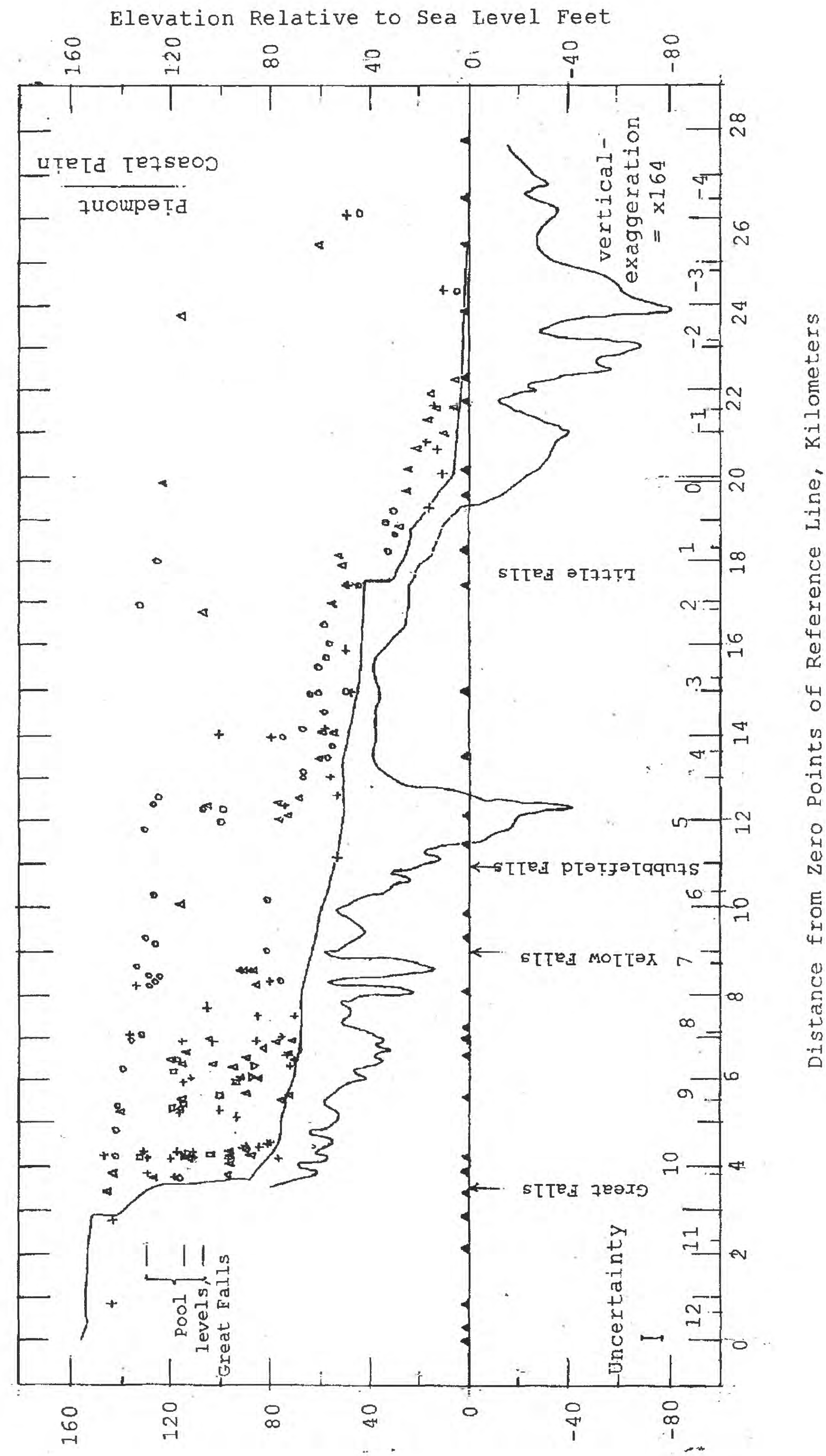

Elevation Relative to Sea Level Feet
160
120
80
40
0
-40
-80
Coastal Plain
Piedmont
vertical-
exaggeration
= x164
Little Falls
Stubblefield Falls
Yellow Falls
Great Falls
Pool
levels,
Great Falls
Uncertainty
Distance from Zero Points of Reference Line, Kilometers
0
2
4
10
12
14
16
18
20
22
24
26
28

Fig. 3A

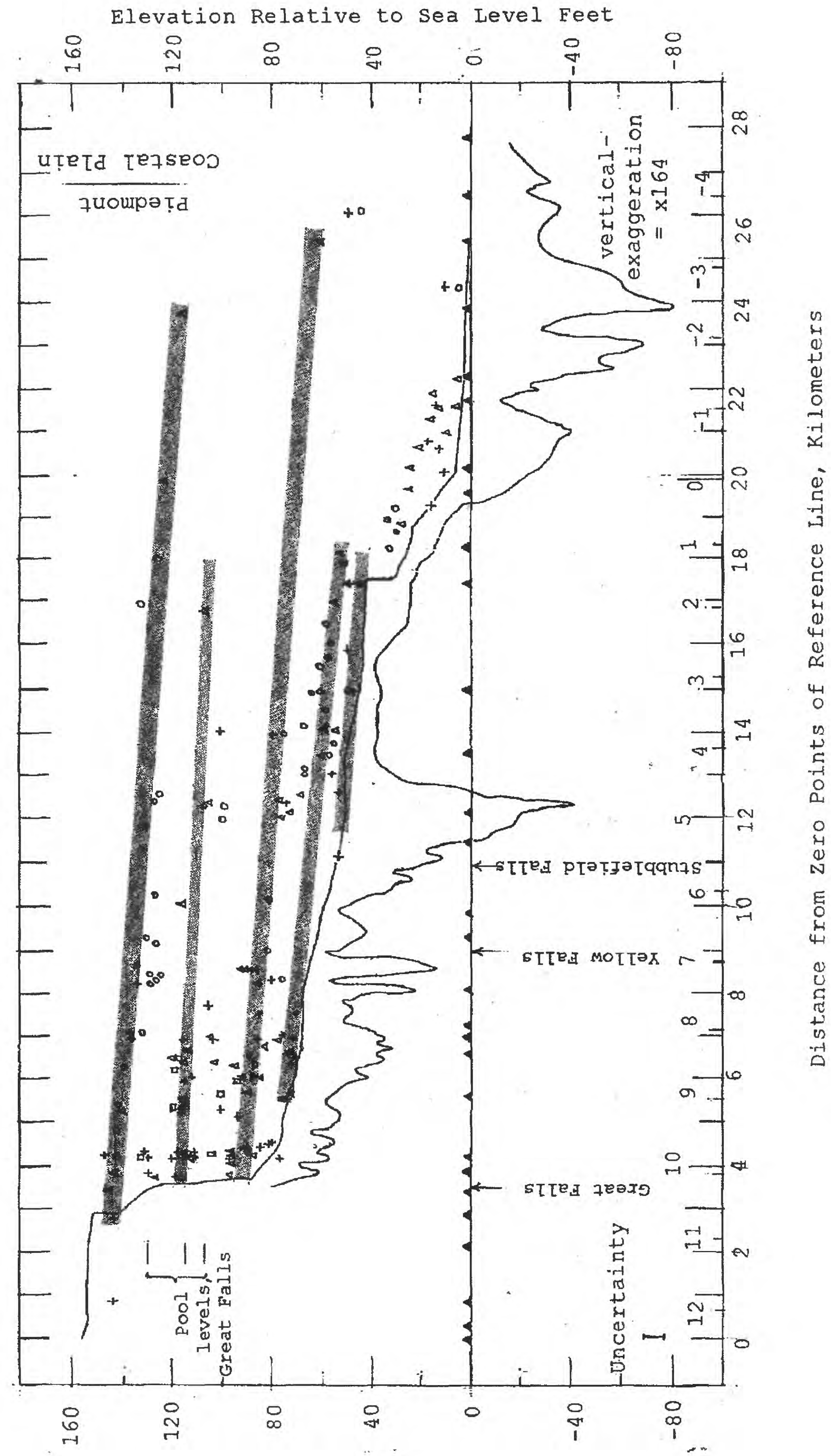
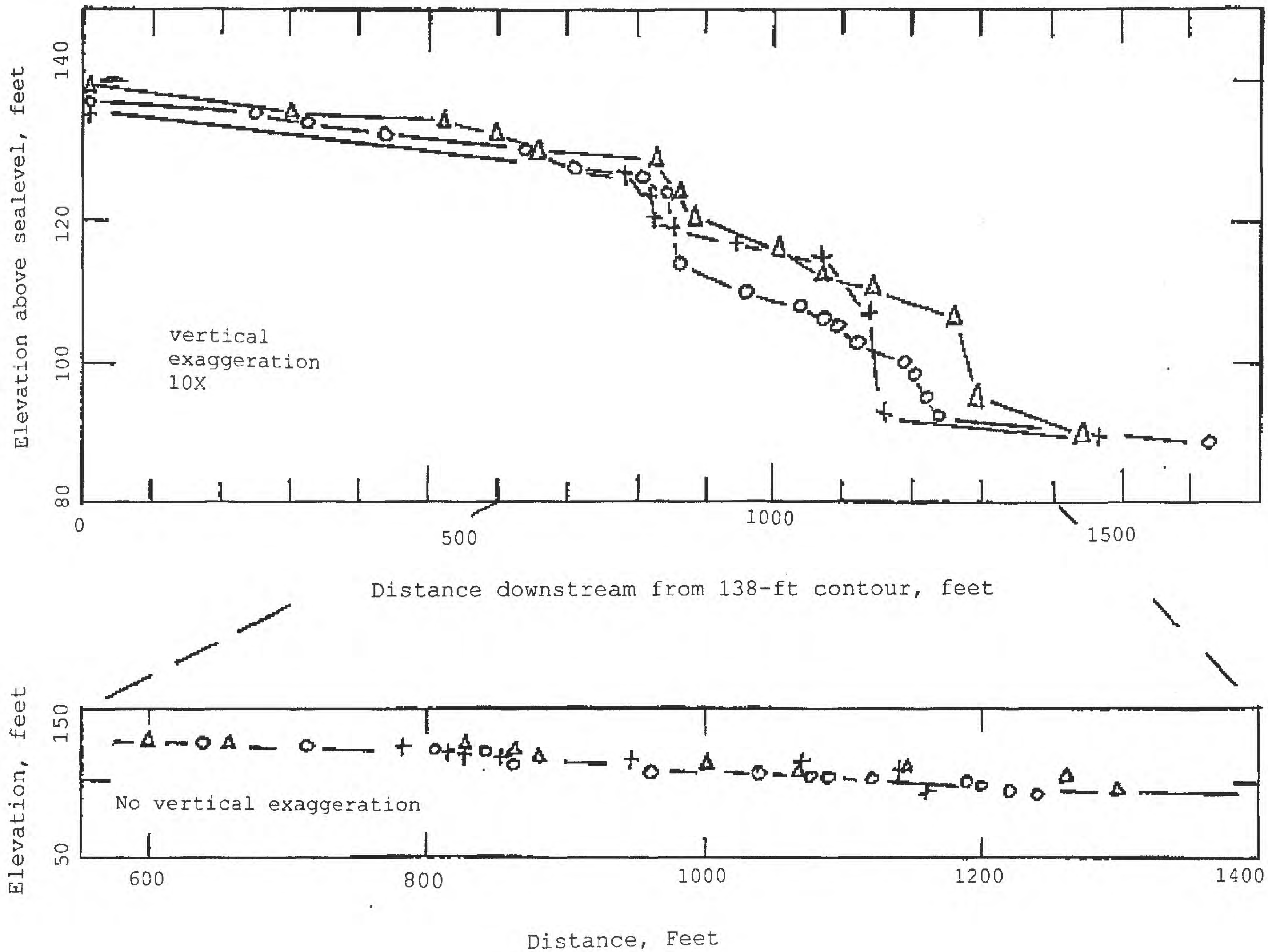

Elevation Relative to Sea Level Feet
Distance from Zero Points of Reference Line, Kilometers
Coastal Plain
Piedmont
vertical-exaggeration = x164
Stubblefield Falls
Yellow Falls
Great Falls
Pool levels, Great Falls
Uncertainty

Fig. 3B

Fig. 4



Elevation above sealevel, feet
140
120
100
80
0
500
1000
1500
vertical
exaggeration
10X
Distance downstream from 138-ft contour, feet
Elevation, feet
150
50
No vertical exaggeration
600
800
1000
1200
1400
Distance, Feet

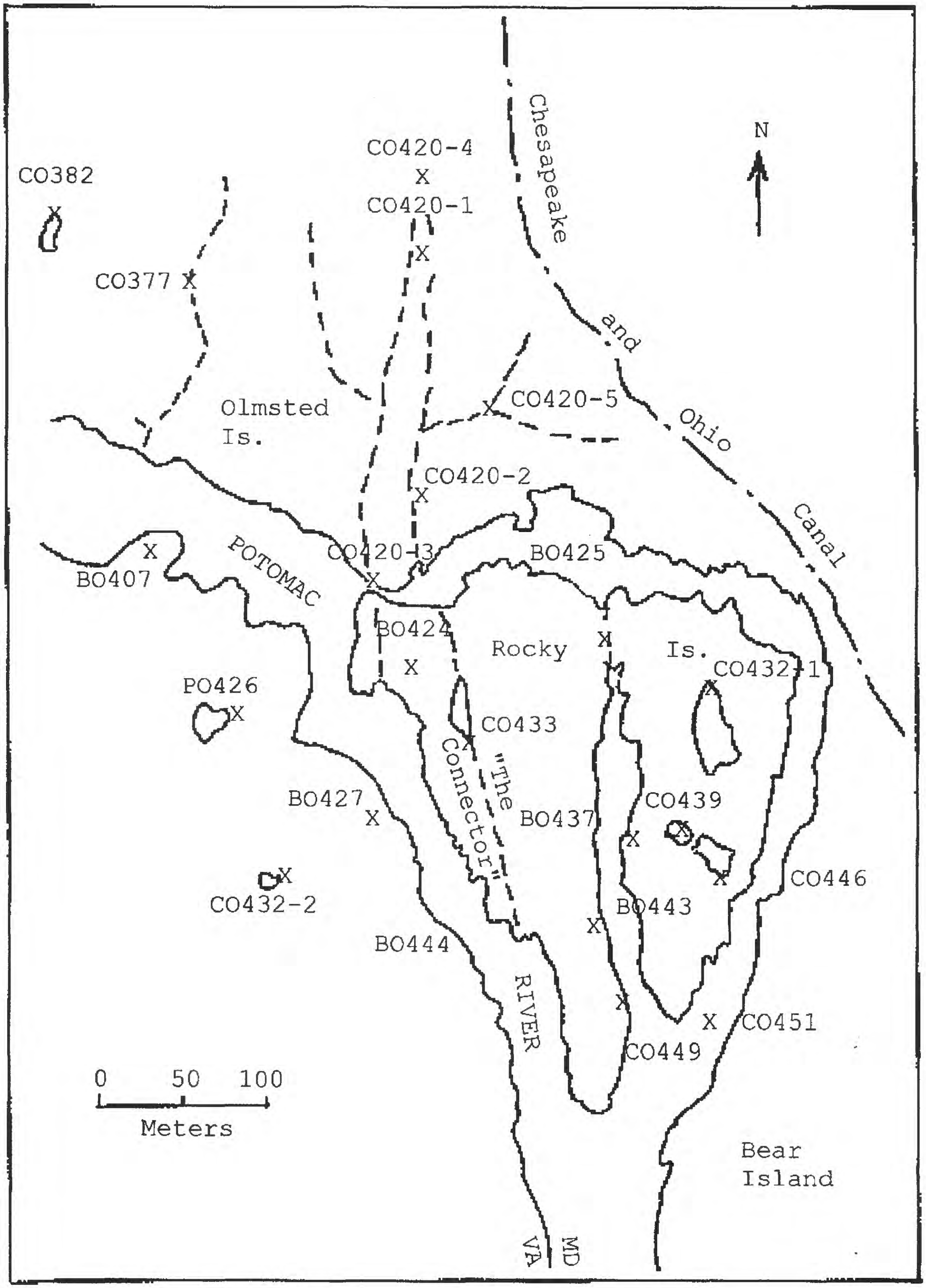
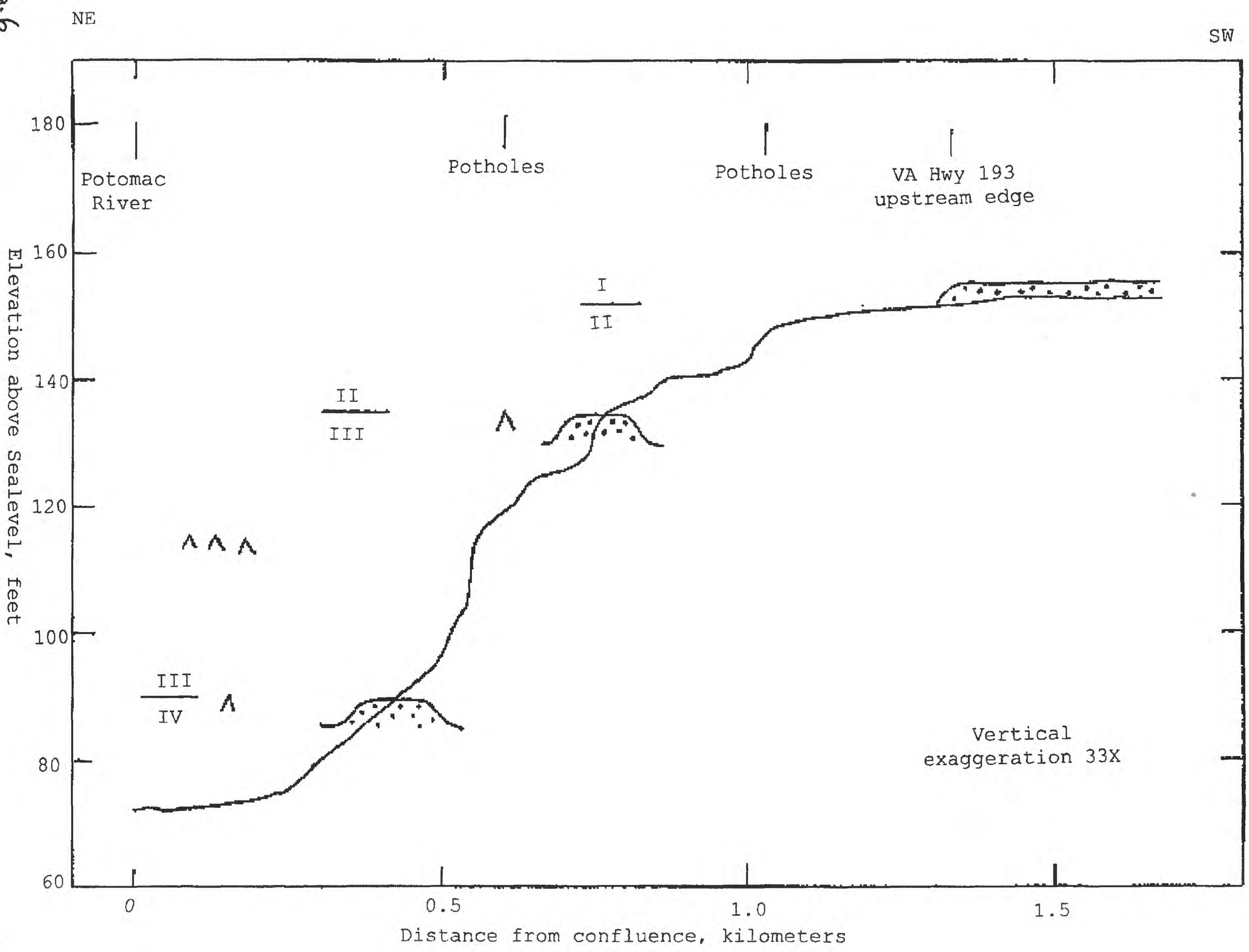
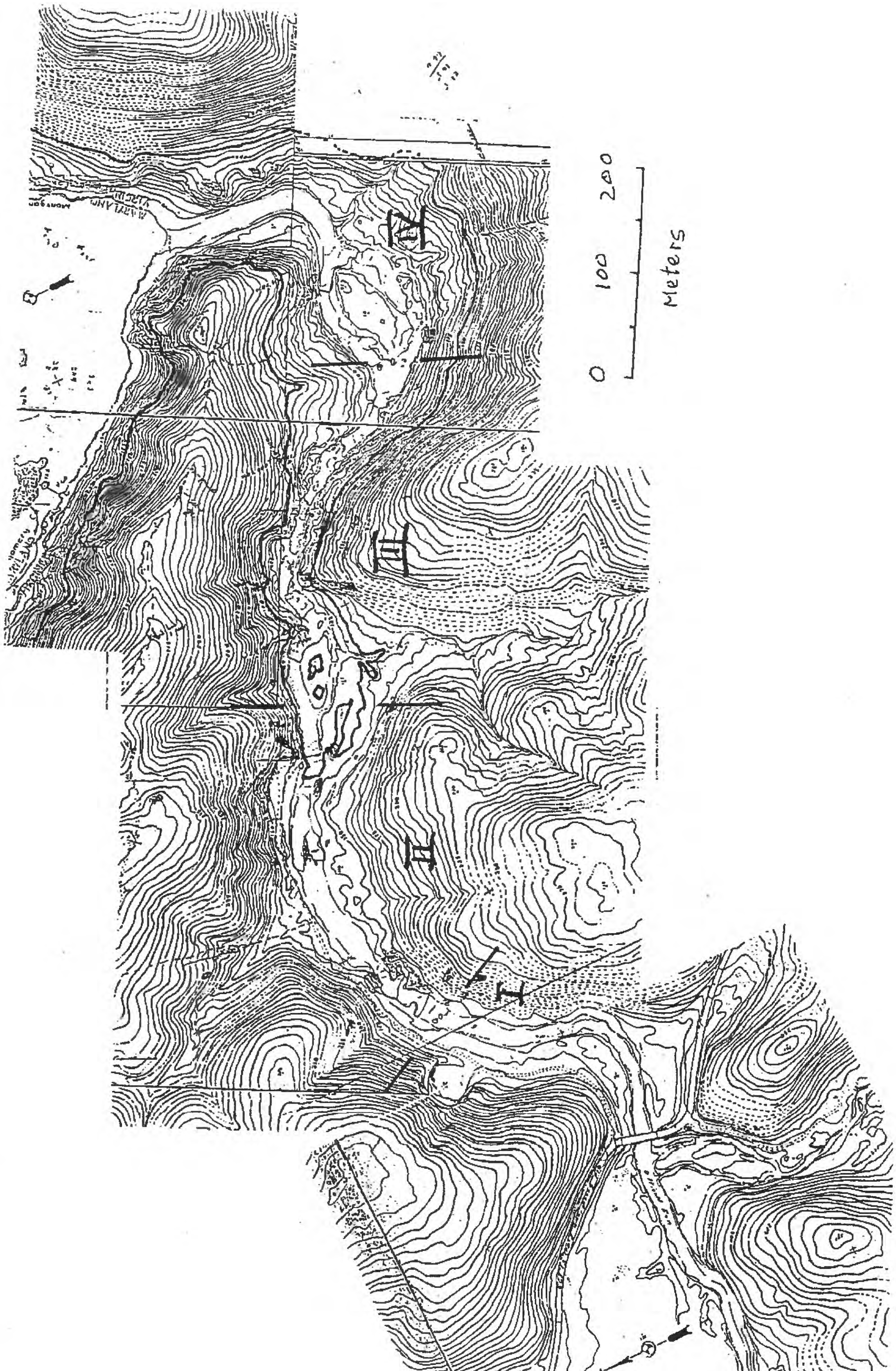

Chesapeake
and
Ohio
Canal
N
C0420-4
C0420-1
C0382
C0377
Olmsted
Is.
C0420-5
C0420-2
C0420-3
B0425
B0407
POTOMAC
B0424
Rocky
Is.
C0432-1
P0426
C0433
"The
Connector"
B0427
B0437
C0439
C0446
C0432-2
B0443
B0444
RIVER
C0451
C0449
0
50
100
Meters
Bear
Island
VA
MD

Fig. 5

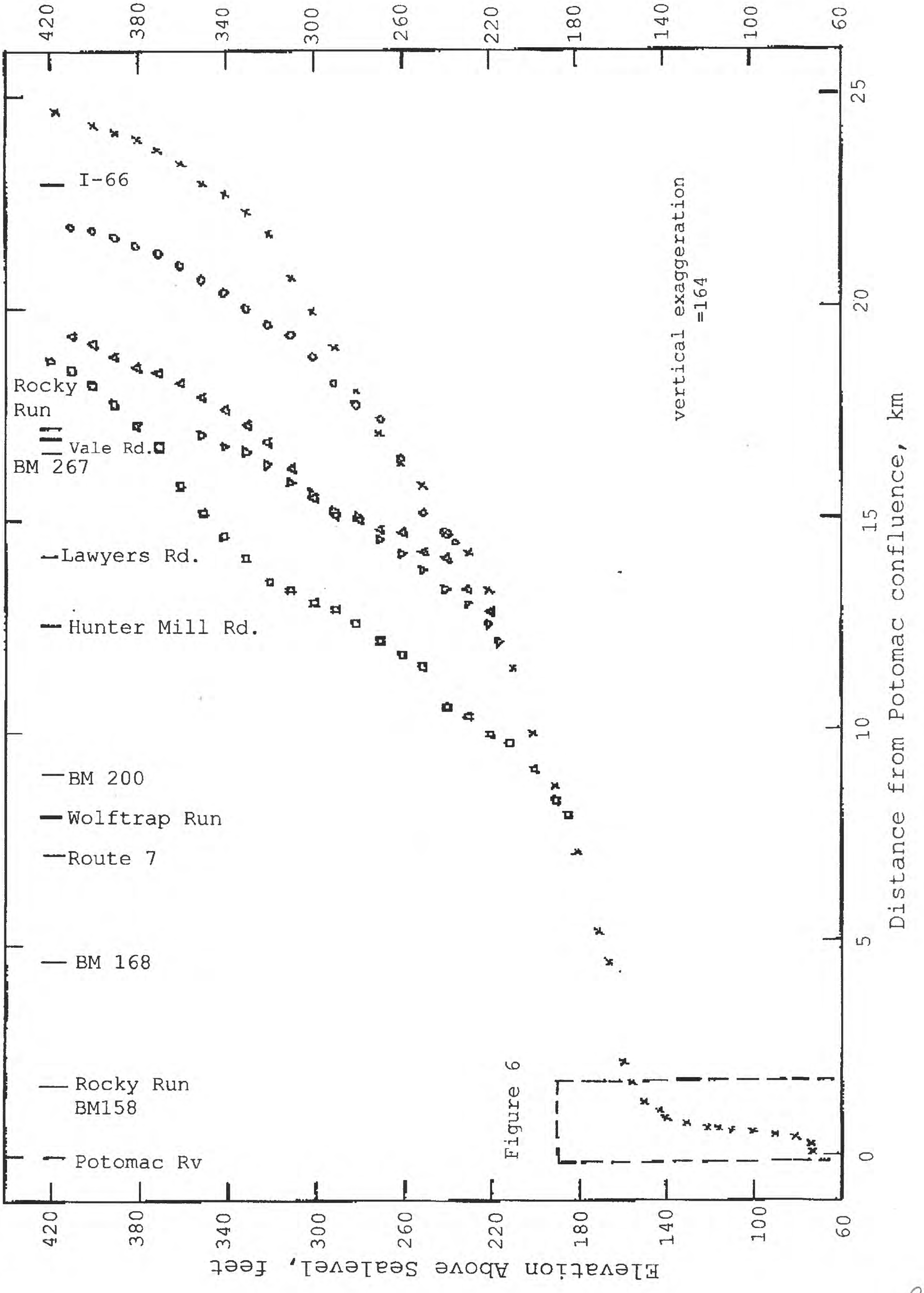
Fig. 6


NE
SW
Potomac River
Potholes
Potholes
VA Hwy 193 upstream edge
I / II
II / III
III / IV
Vertical exaggeration 33X
180
160
140
120
100
80
60
Elevation above Sealevel, feet
0
0.5
1.0
1.5
Distance from confluence, kilometers



Zen Figure 7

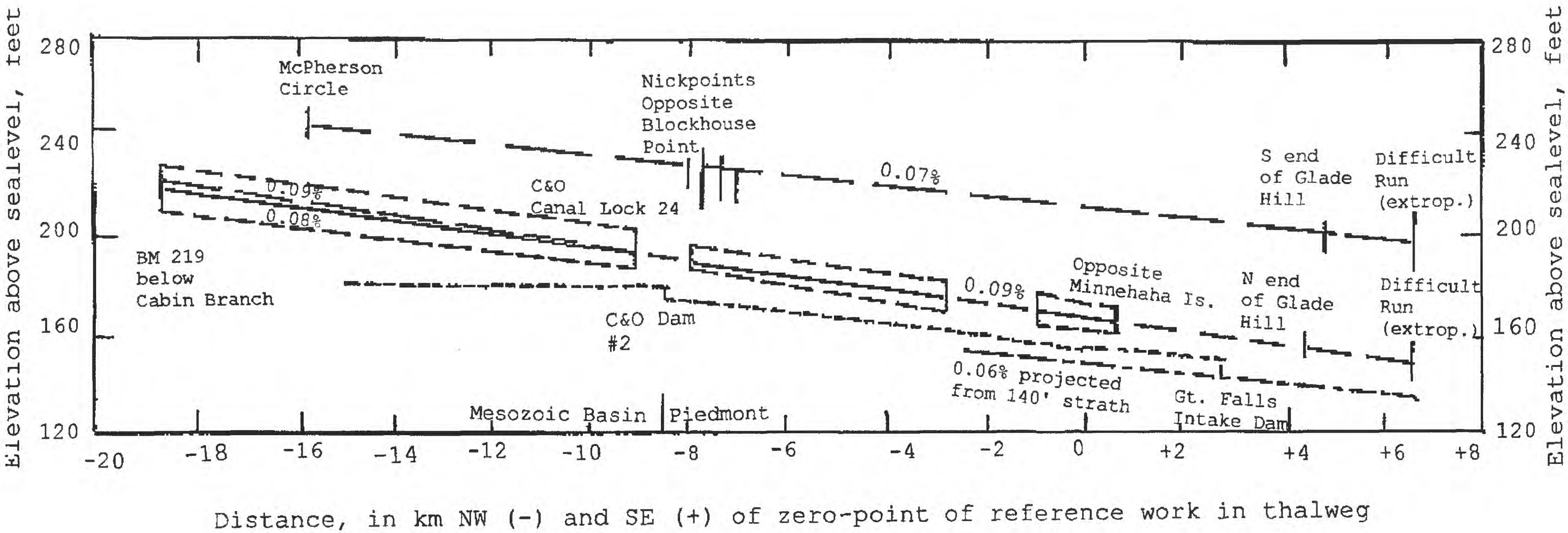
Fig. 7



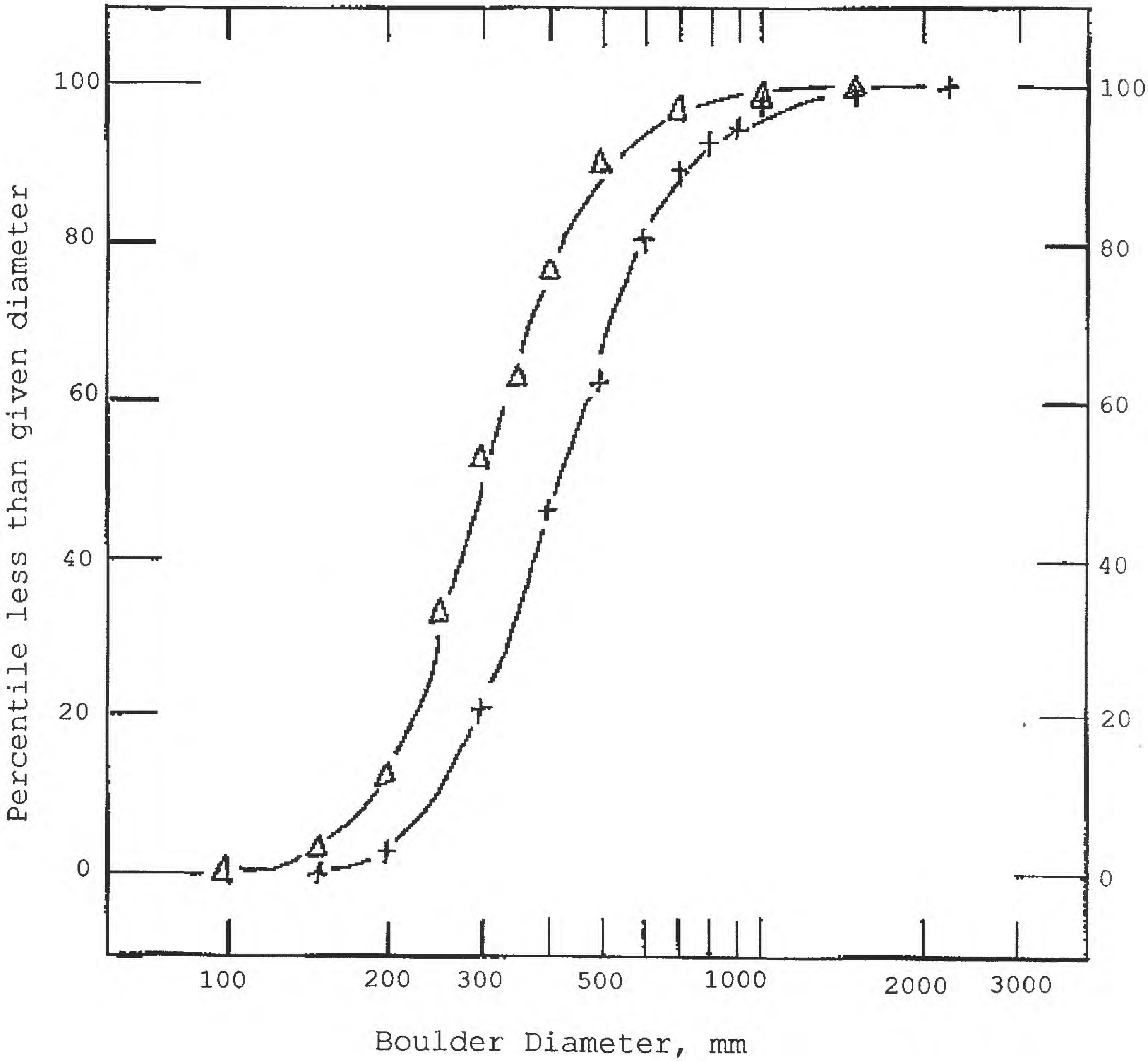
I-66
Rocky Run
Vale Rd.
BM 267
Lawyers Rd.
Hunter Mill Rd.
BM 200
Wolftrap Run
Route 7
BM 168
Rocky Run BM158
Potomac Rv
Figure 6
vertical exaggeration =164
Distance from Potomac confluence, km
Elevation Above Sealevel, feet

Fig. 8

Fig. 9



Elevation above sealevel, feet
280
240
200
160
120
McPherson Circle
Nickpoints Opposite Blockhouse Point
0.07%
S end of Glade Hill
Difficult Run (extrop.)
0.09%
0.08%
C&O Canal Lock 24
BM 219 below Cabin Branch
C&O Dam #2
0.09%
Opposite Minnehaha Is.
N end of Glade Hill
Difficult Run (extrop.)
0.06% projected from 140' strath
Gt. Falls Intake Dam
Mesozoic Basin
Piedmont
-20
-18
-16
-14
-12
-10
-8
-6
-4
-2
0
+2
+4
+6
+8
Distance, in km NW (-) and SE (+) of zero-point of reference work in thalweg



Percentile less than given diameter
100
80
60
40
20
0
100
200
300
500
1000
2000
3000
Boulder Diameter, mm

Fig. 10

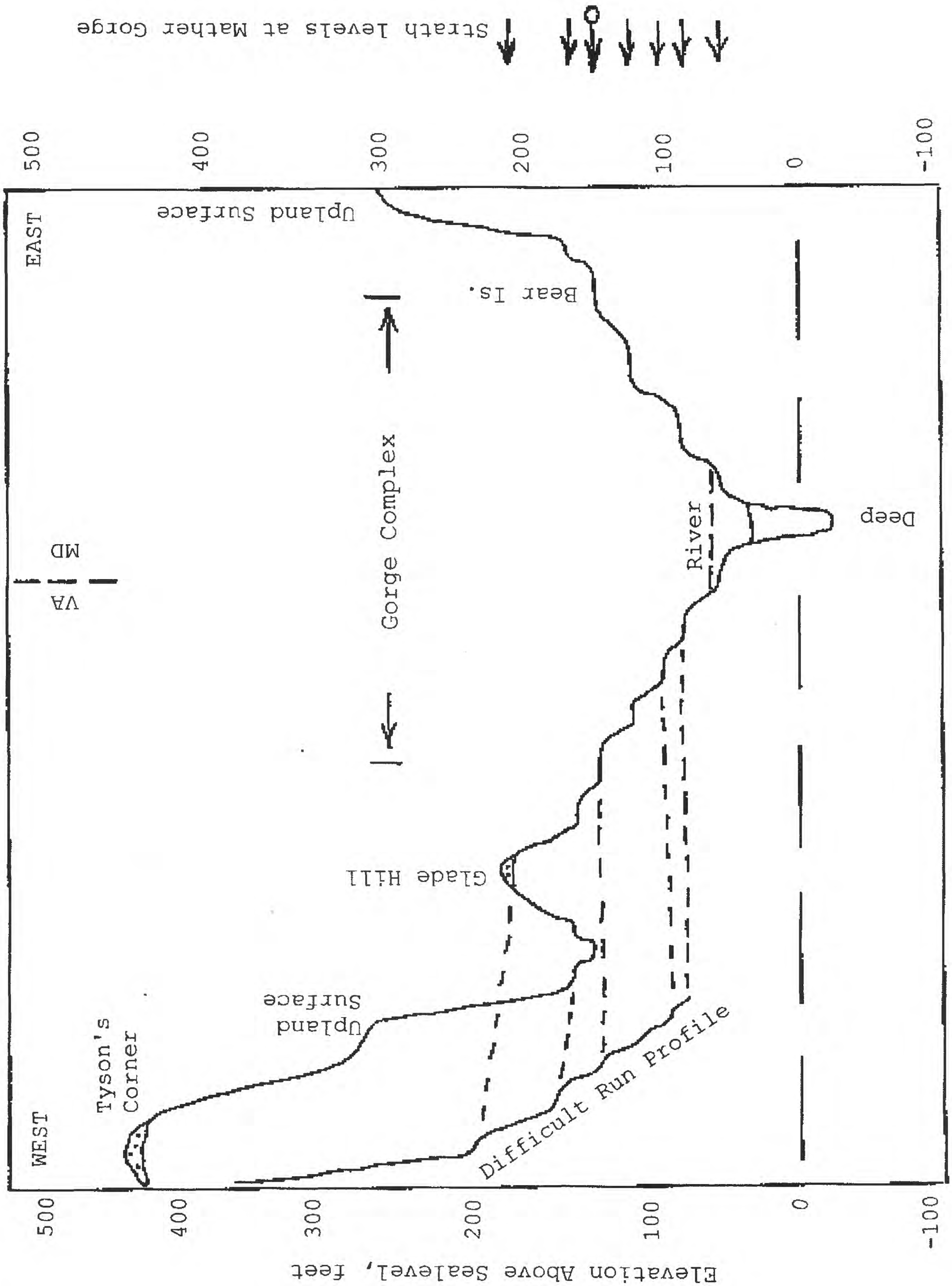
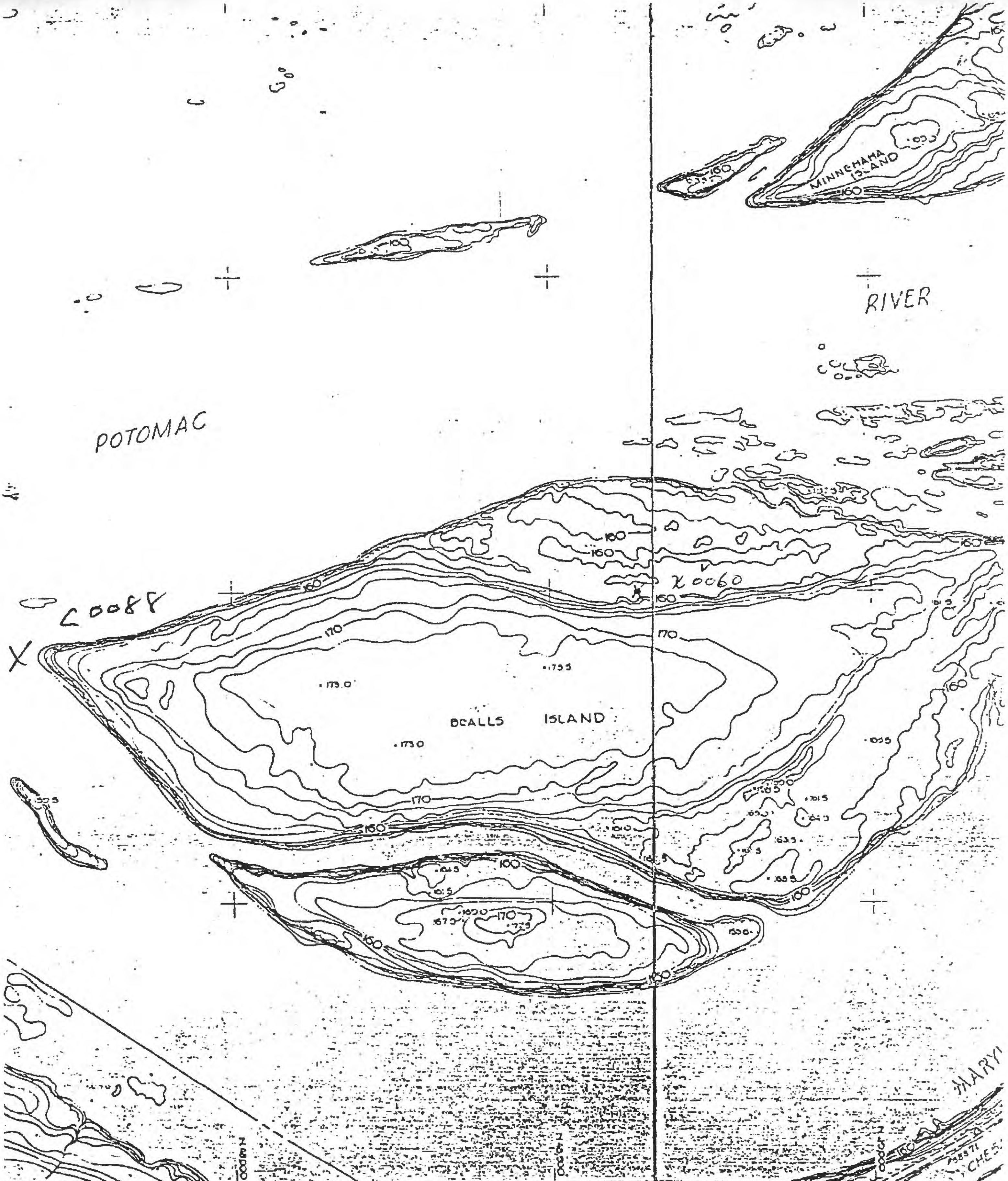

Strath Levels at Mather Gorge
Upland Surface
Bear Is.
Gorge Complex
MD
VA
River
Deep
Glade Hill
Upland Surface
Tyson's Corner
Difficult Run Profile
EAST
WEST
500
400
300
200
100
0
-100
Elevation Above Sealevel, feet

Fig. 11



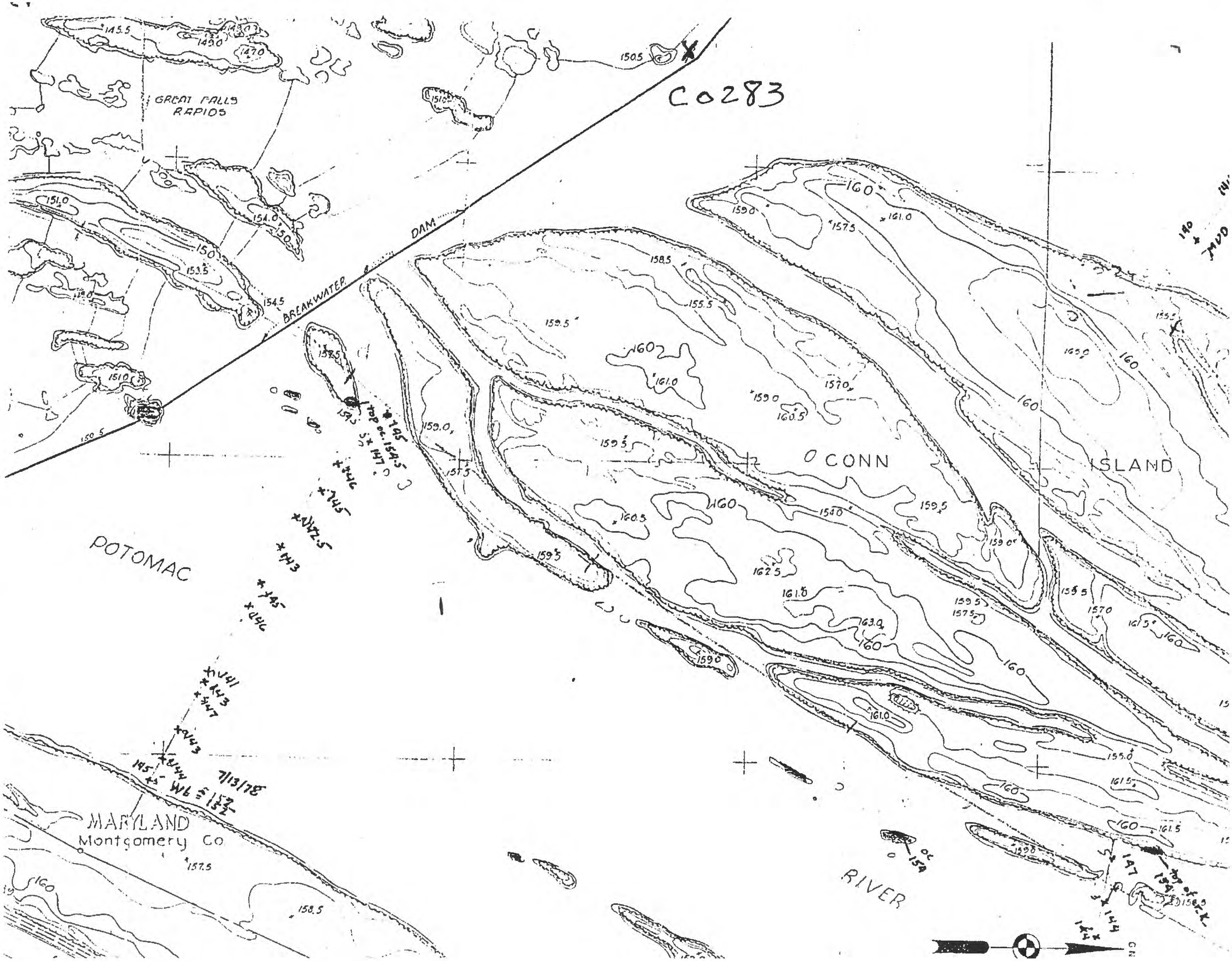
	Elevation
86.93	169.463
54.58	168.756
92.36	169.508
21.89	168.091
90.32	169.156
76.50	169.171

Station	Bearing	Distance	Coordinates Northing	Coordinates Easting	Elevation

Sheet 2A (2)
117-10-4-49(2)

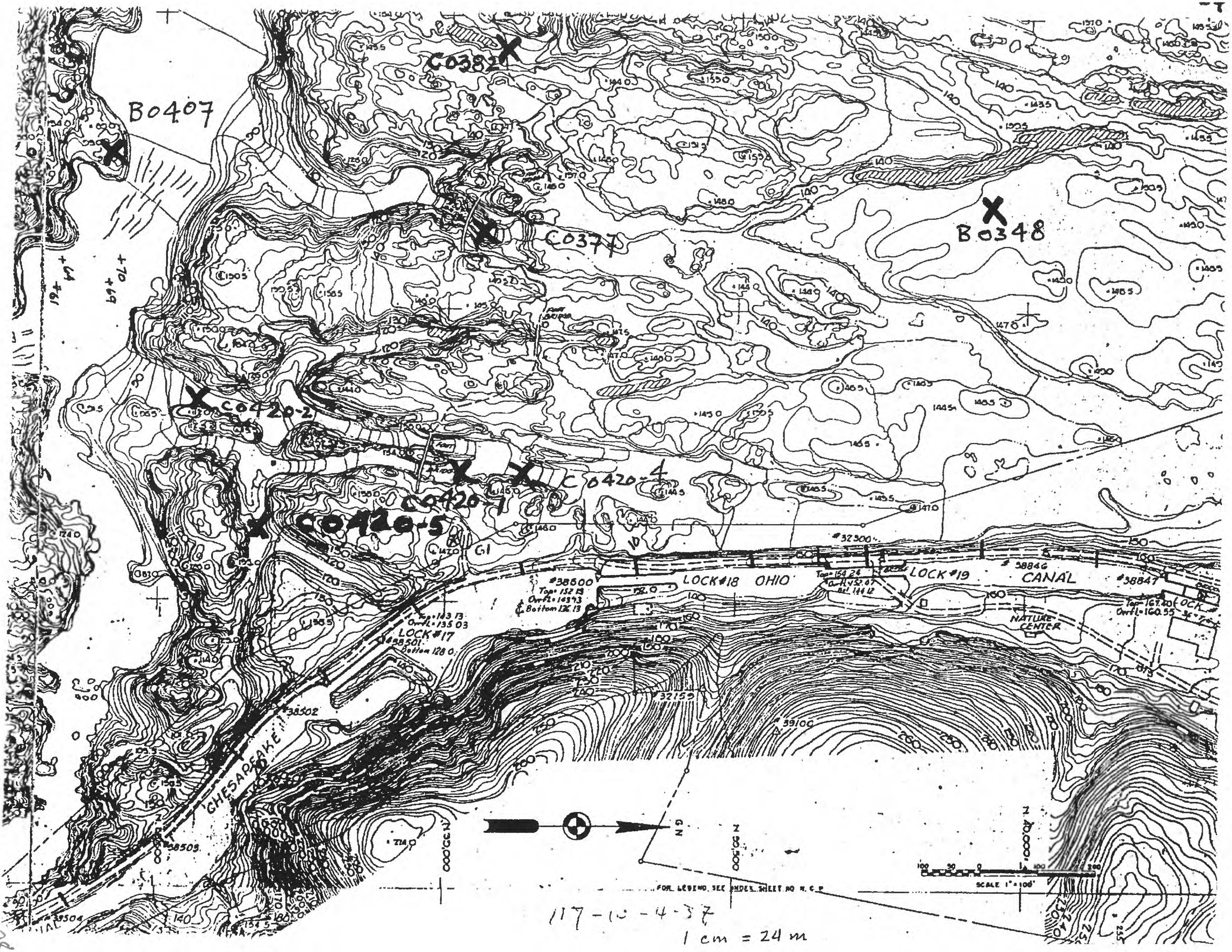
HORIZONTAL DATUM

CHECKED BY: Match Line to Sheet No. 117.10-4-48
FIELD: ______ DATE ______
OFFICE: ______ DATE ______
SUBMITTED: ______ DATE ______
APPROVED: ______ DATE ______



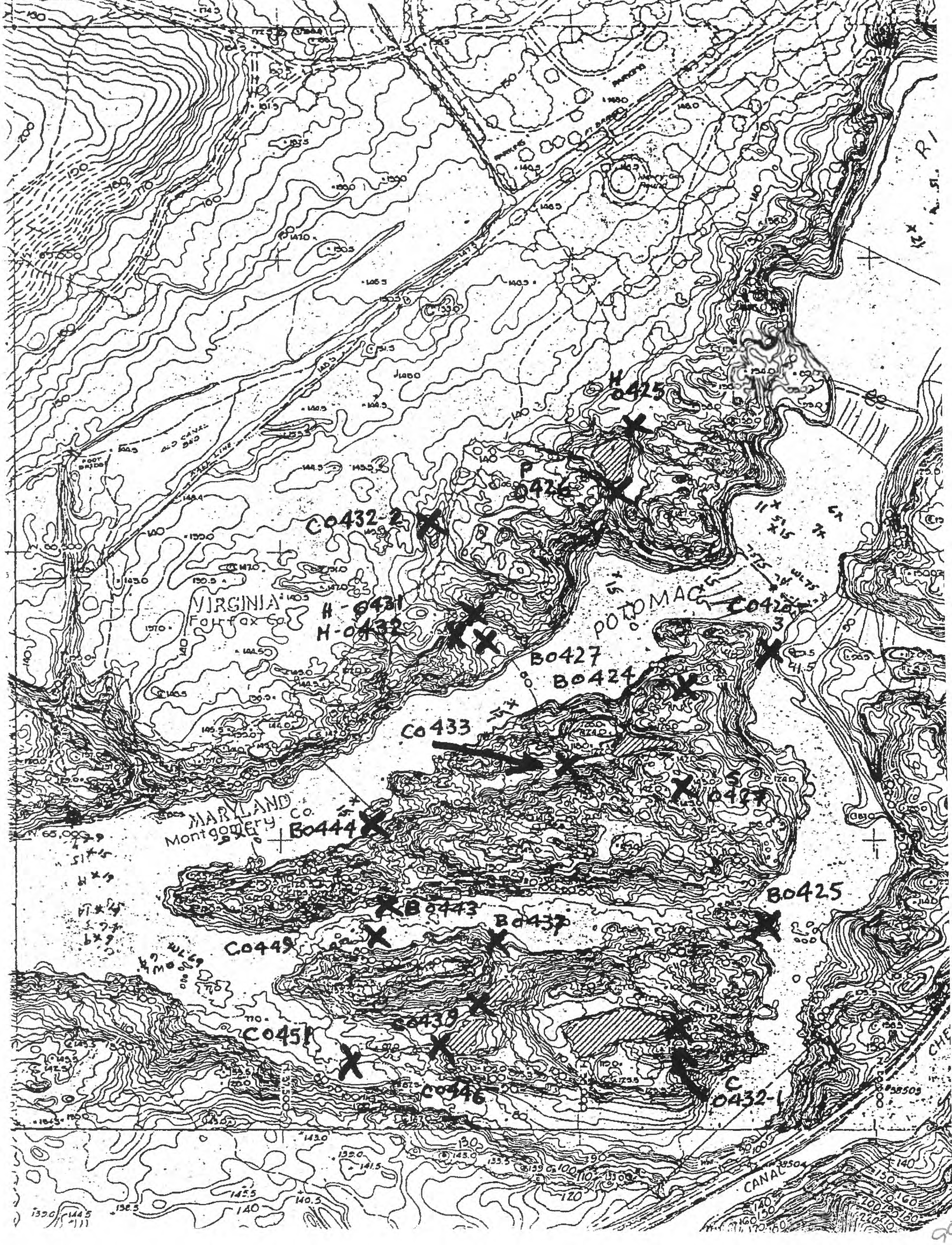
Co283
GREAT FALLS RAPIDS
DAM
BREAKWATER
O CONN
ISLAND
POTOMAC
RIVER
MARYLAND
Montgomery Co
7/13/78
WL = 152

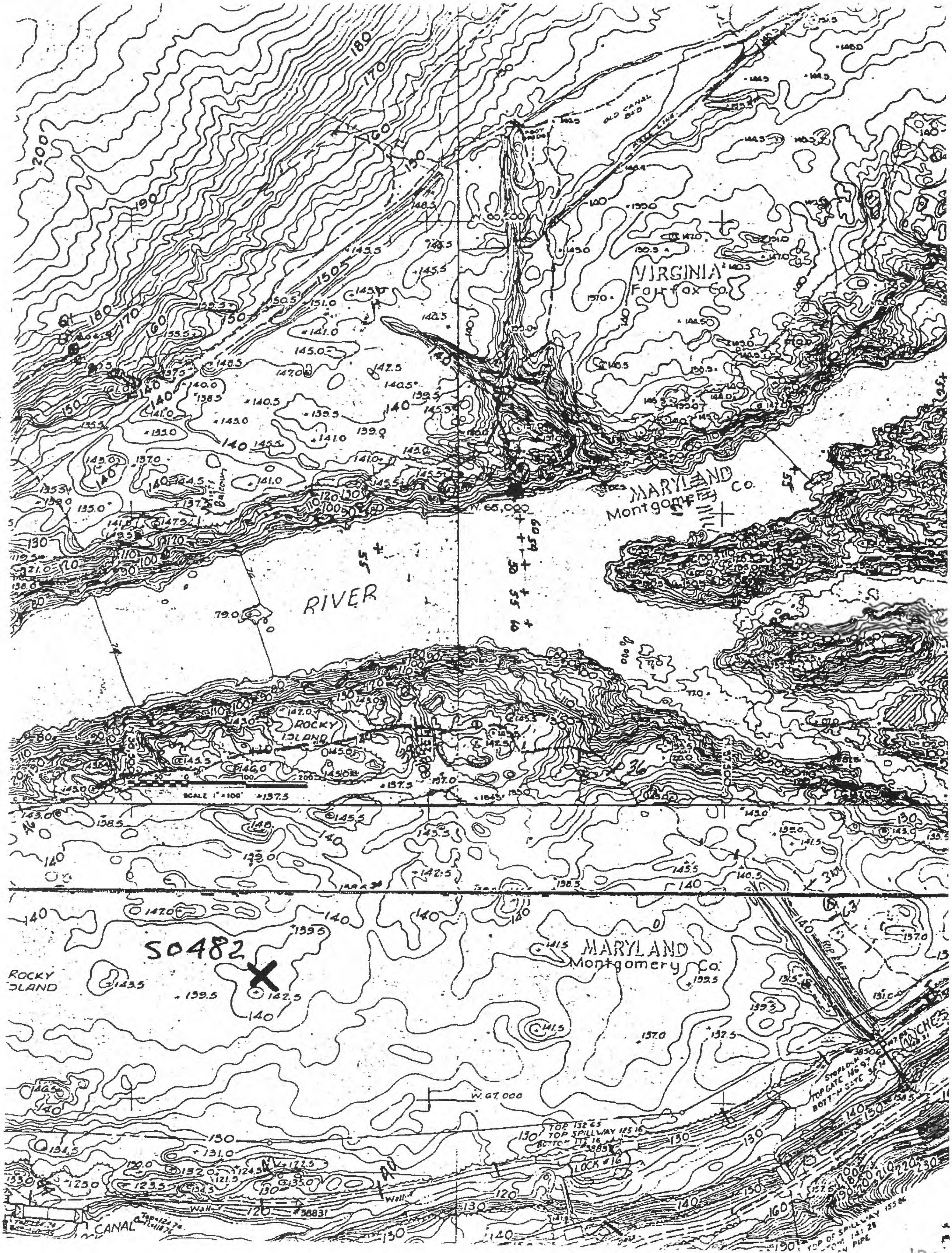

POTOMAC RIVER
MARYLAND
Montgomery Co.
VIRGINIA
Fairfax Co.
RAPIDS
FALLS
RIVER
PARK
PARKING
STEPS
ADMIN BLDG
B 0382
B 0379R
S 0379

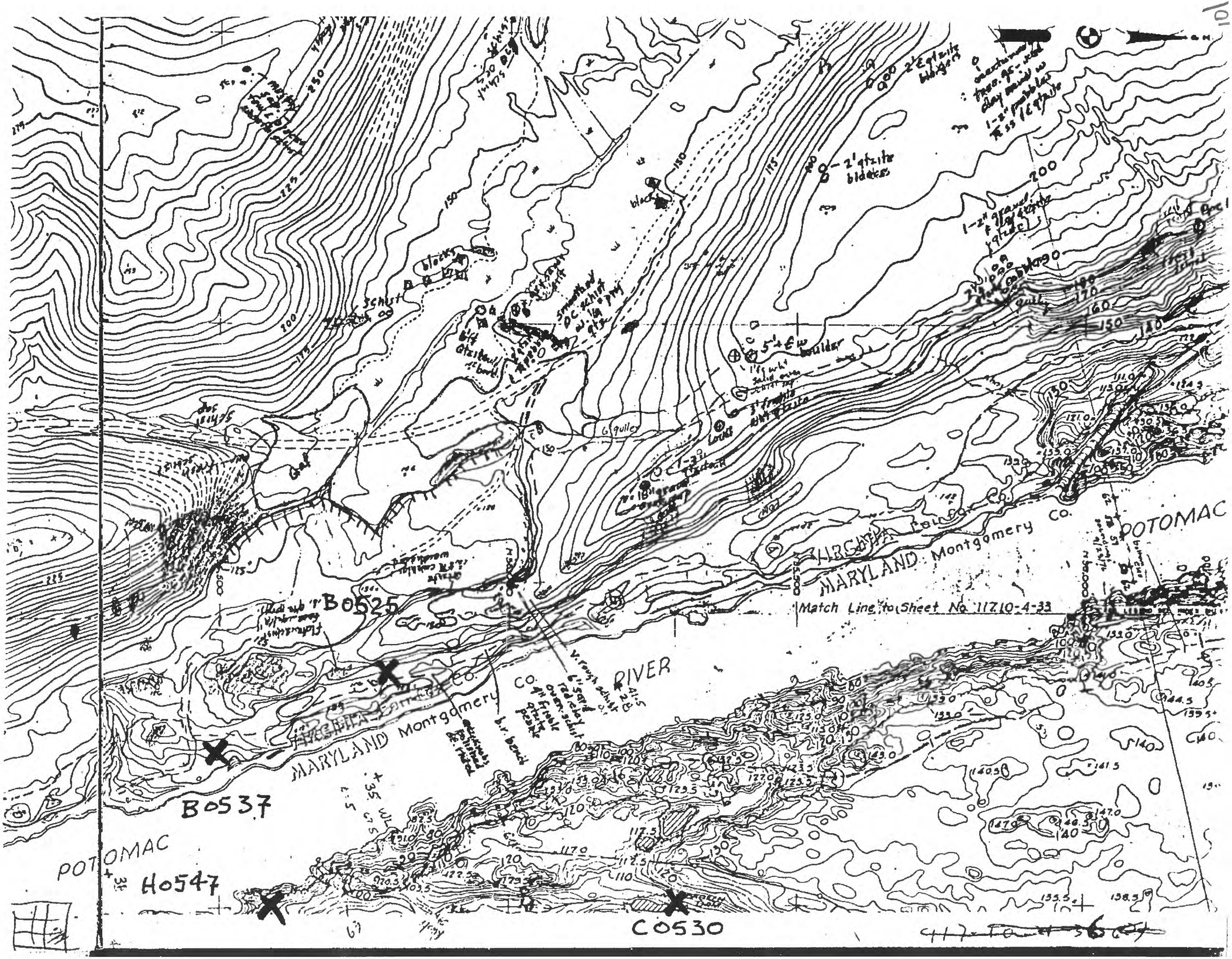


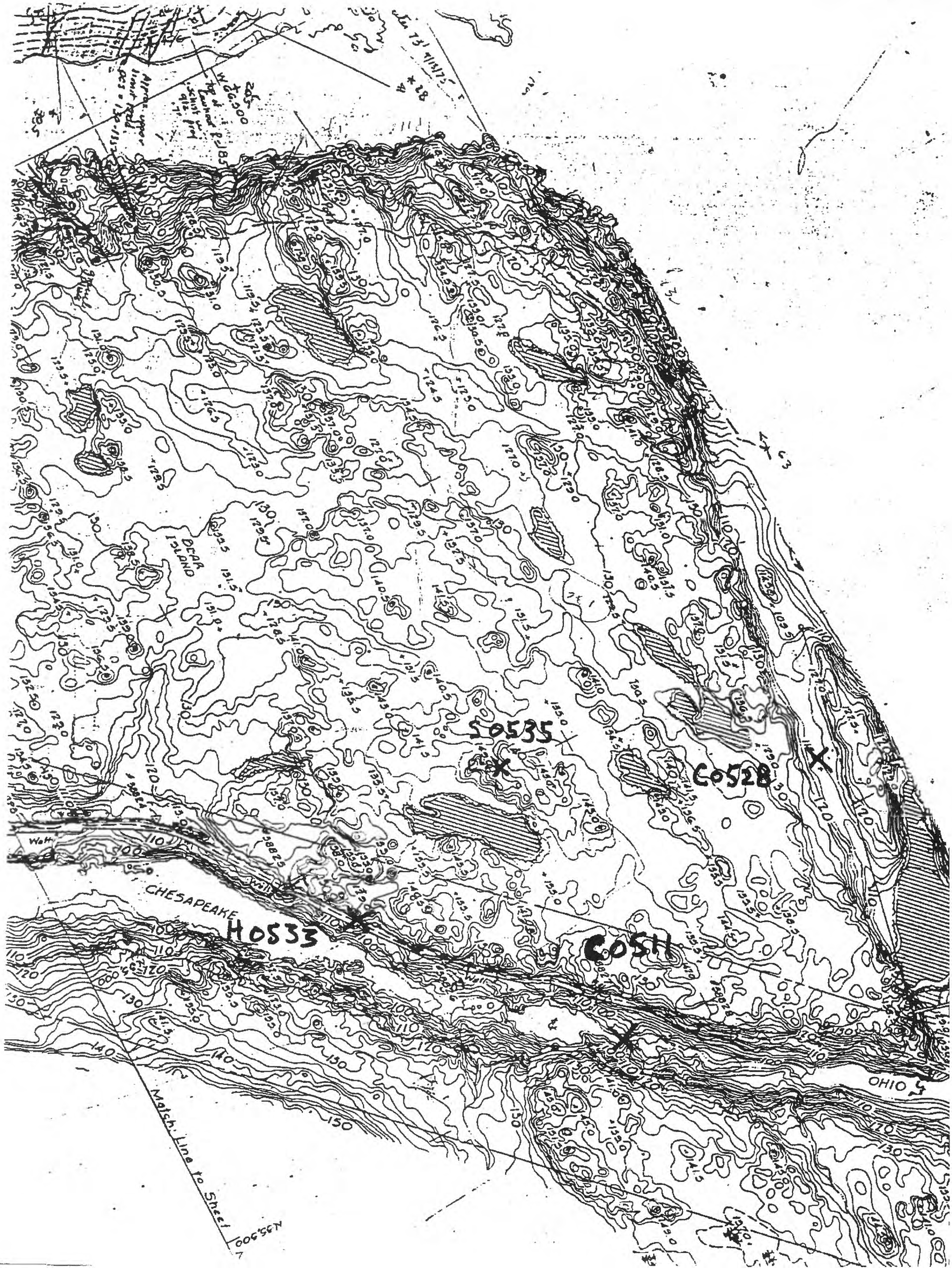
C0382
B0407
C0377
B0348
C0420-2
C0420-4
C0420-1
C0420-5
LOCK #17
LOCK #18
OHIO
LOCK #19
CANAL
NATURE CENTER
CHESAPEAKE
N 39,000
N 39,500
N 40,000
SCALE 1" = 100'
FOR LEGEND SEE INDEX SHEET NO. N.C.P.
GN
117-10-4-37
1 cm = 24 m

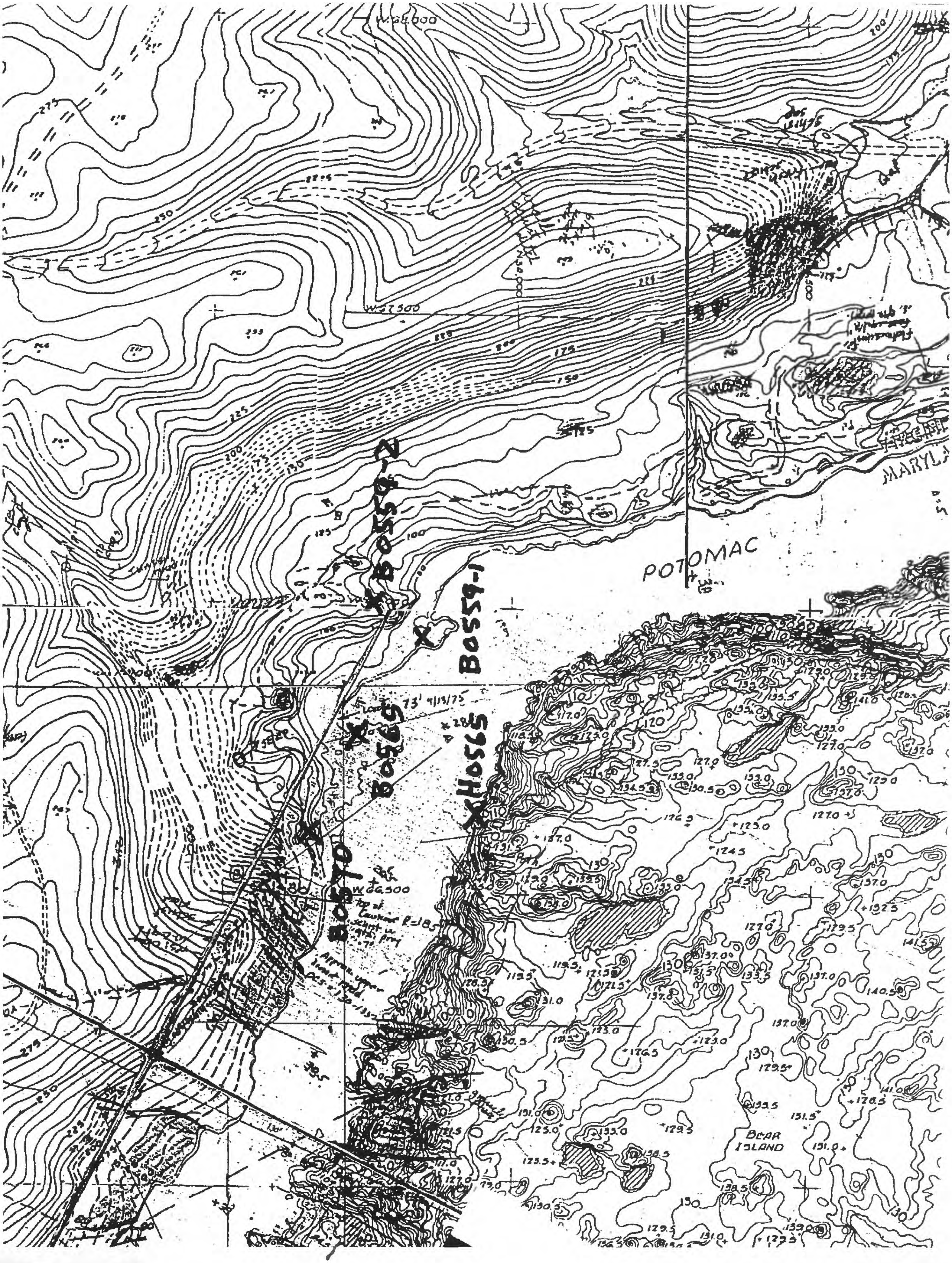
98


VIRGINIA
Fairfax Co.
MARYLAND
Montgomery Co.
POTOMAC
CANAL
FOOT BRIDGE
OLD CANAL
H 0425
P 0426
Co432-2
H-0431
H-0432
B0427
B0424
C0420-3
Co433
0427
B0444
B0443
B0437
B0425
C0449
C0451
C0439
C0446
C 0432-1

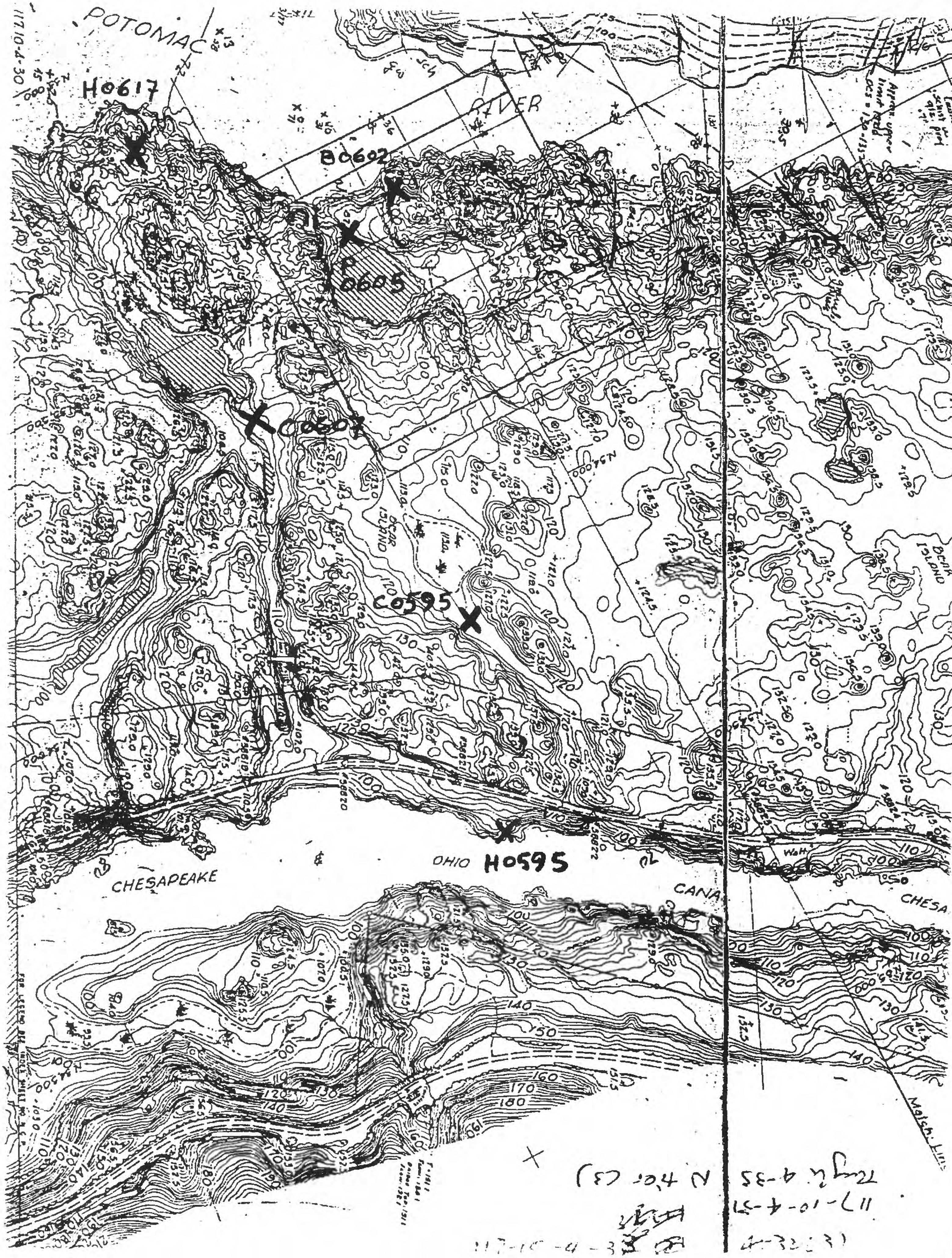

VIRGINIA
Fairfax Co.
OLD CANAL BED
MARYLAND
Montgomery Co.
RIVER
ROCKY ISLAND
SCALE 1" = 100'
S0482
ROCKY ISLAND
MARYLAND
Montgomery Co.
W. 65,000
W. 67,000
TOP SPILLWAY
LOCK #16
CANAL
STOPLOCK
TOP GATE
BOTTOM GATE
Wall


POTOMAC
MARYLAND Montgomery CO.
Match Line to Sheet No. 11710-4-33
RIVER
MARYLAND Montgomery CO.
POTOMAC
B0525
B0537
H0547
C0530
5'+Ew boulder
2' qtzite blocks
blocks
schist
Gap
gulley
1-2" gravel
200
150
175
225
250

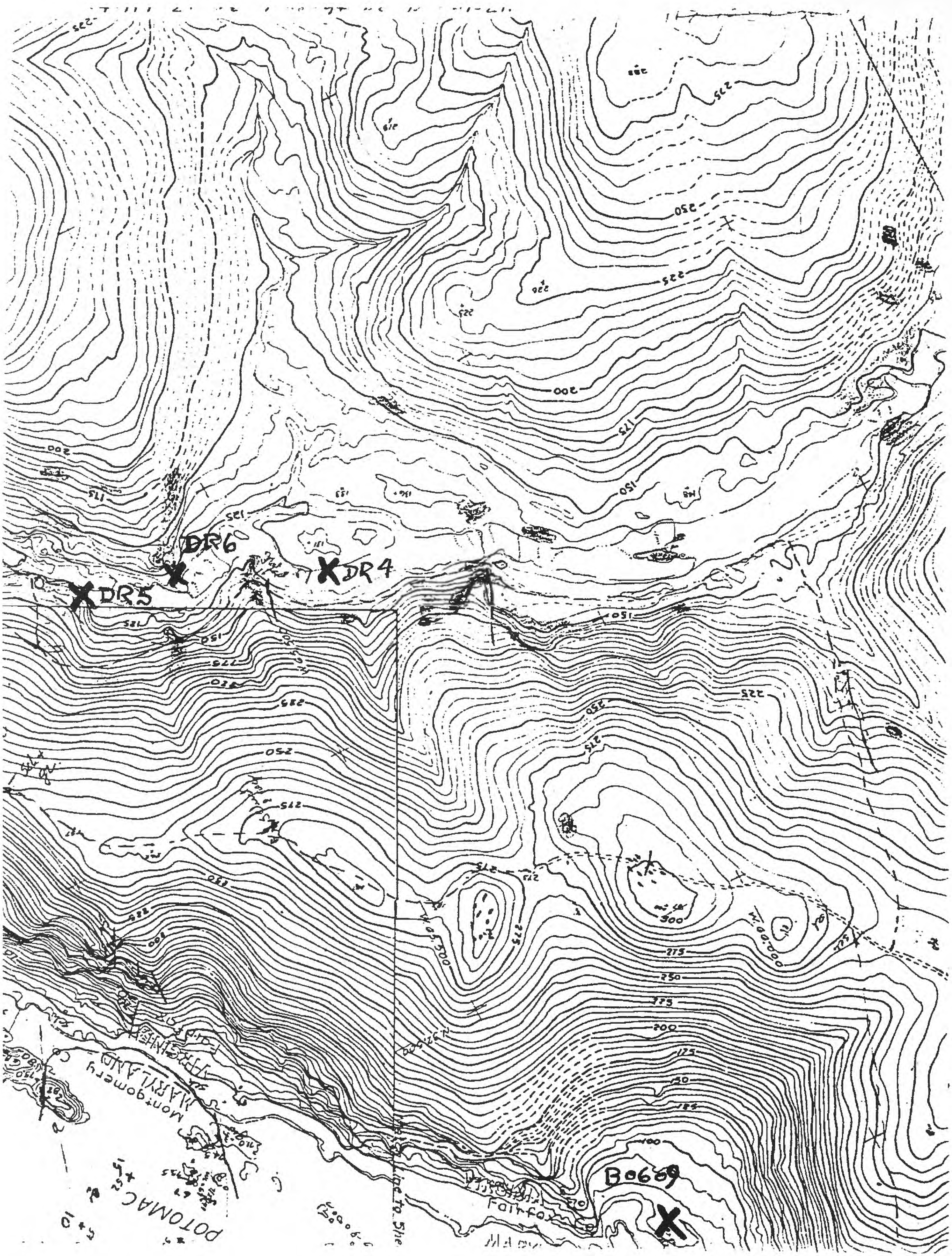

S0535
C0528
H0533
C0511
CHESAPEAKE
OHIO
BEAR ISLAND
Match Line to Sheet

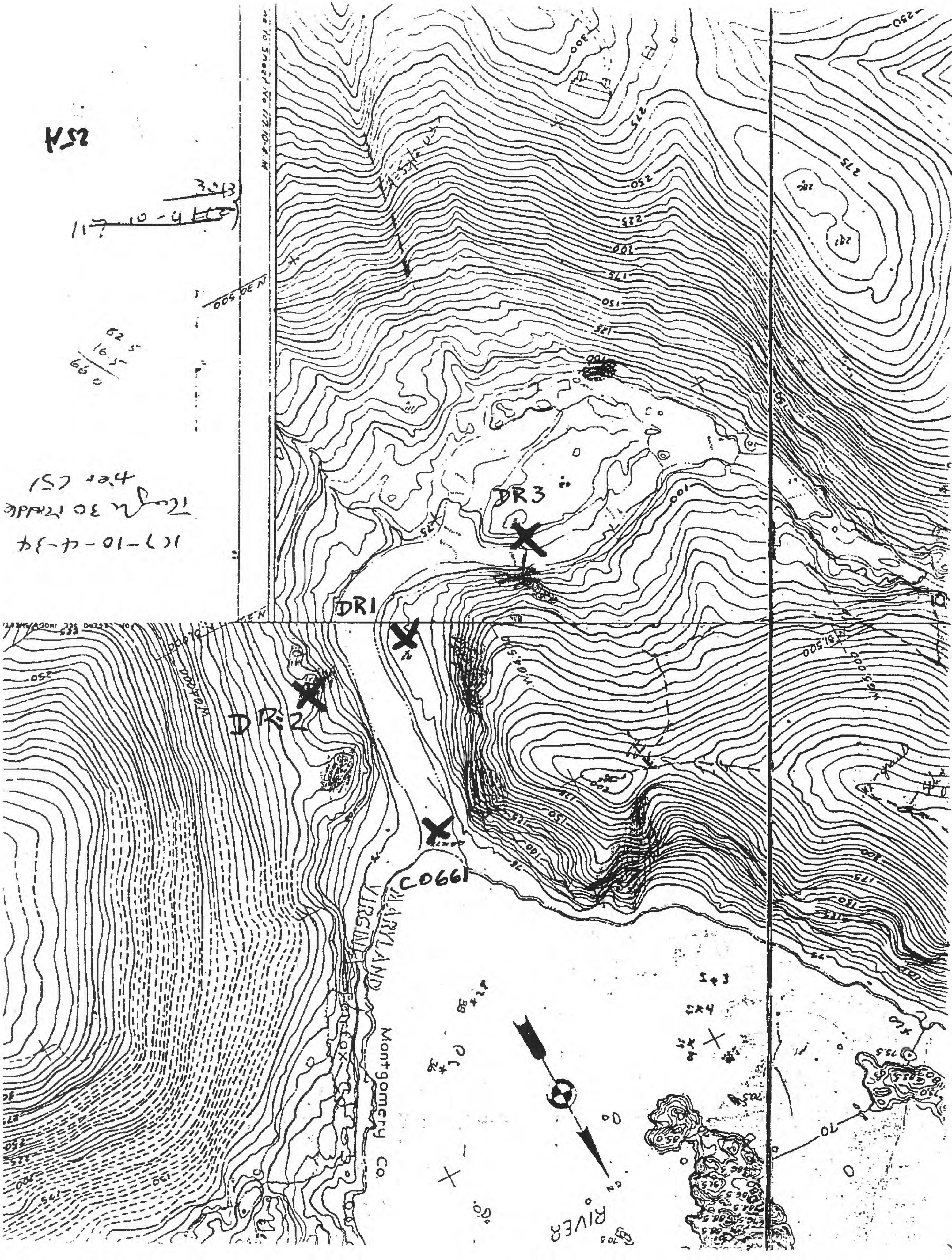


POTOMAC
MARYLA
BEAR ISLAND
B0559-2
B0559-1
B0565
B0565H
B0570
W 66,500
W 67,500
W 68,000

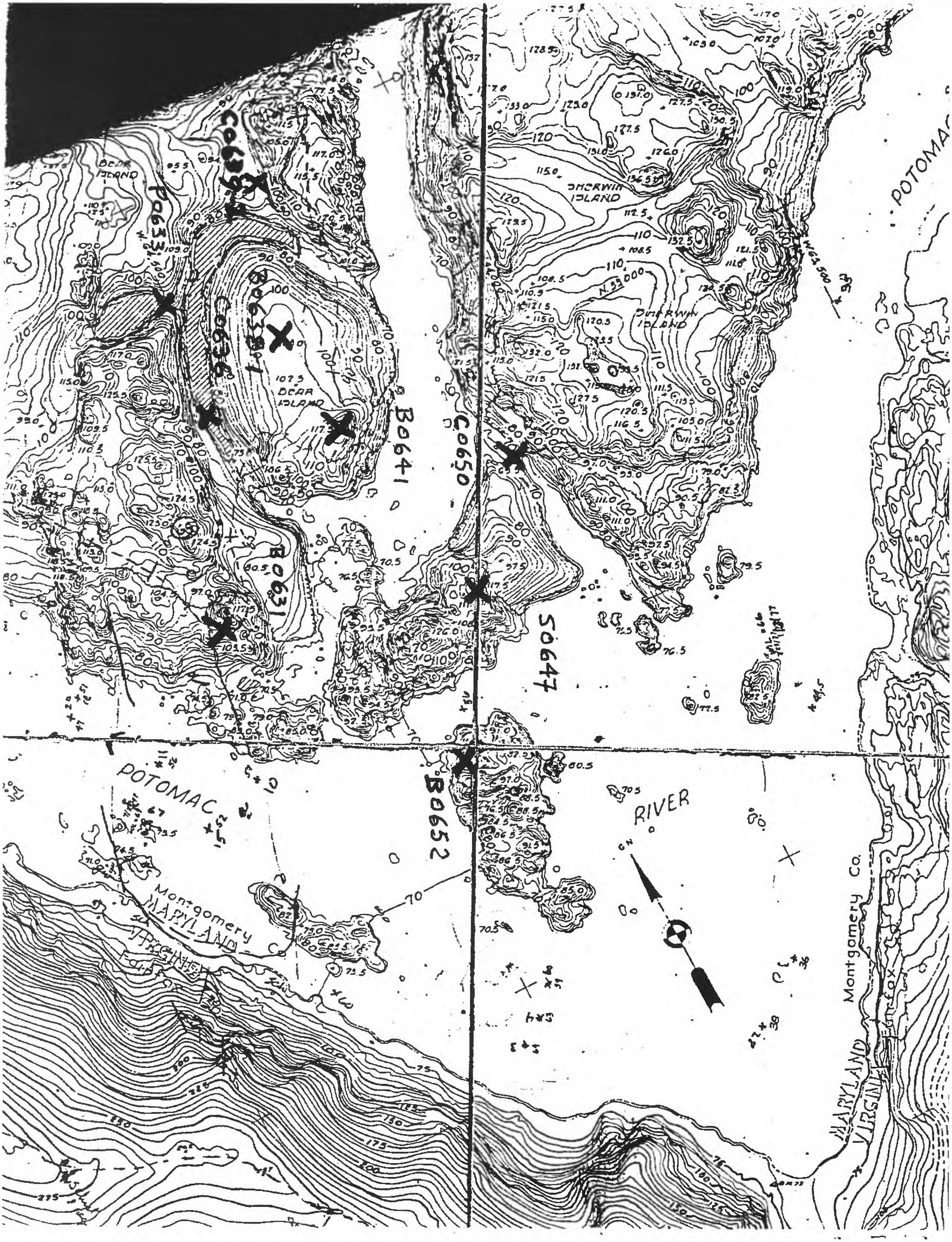

POTOMAC
RIVER
H0617
B0602
0605
C0607
C0595
H0595
CHESAPEAKE
OHIO
CANA
CHESA
ISLAND

104

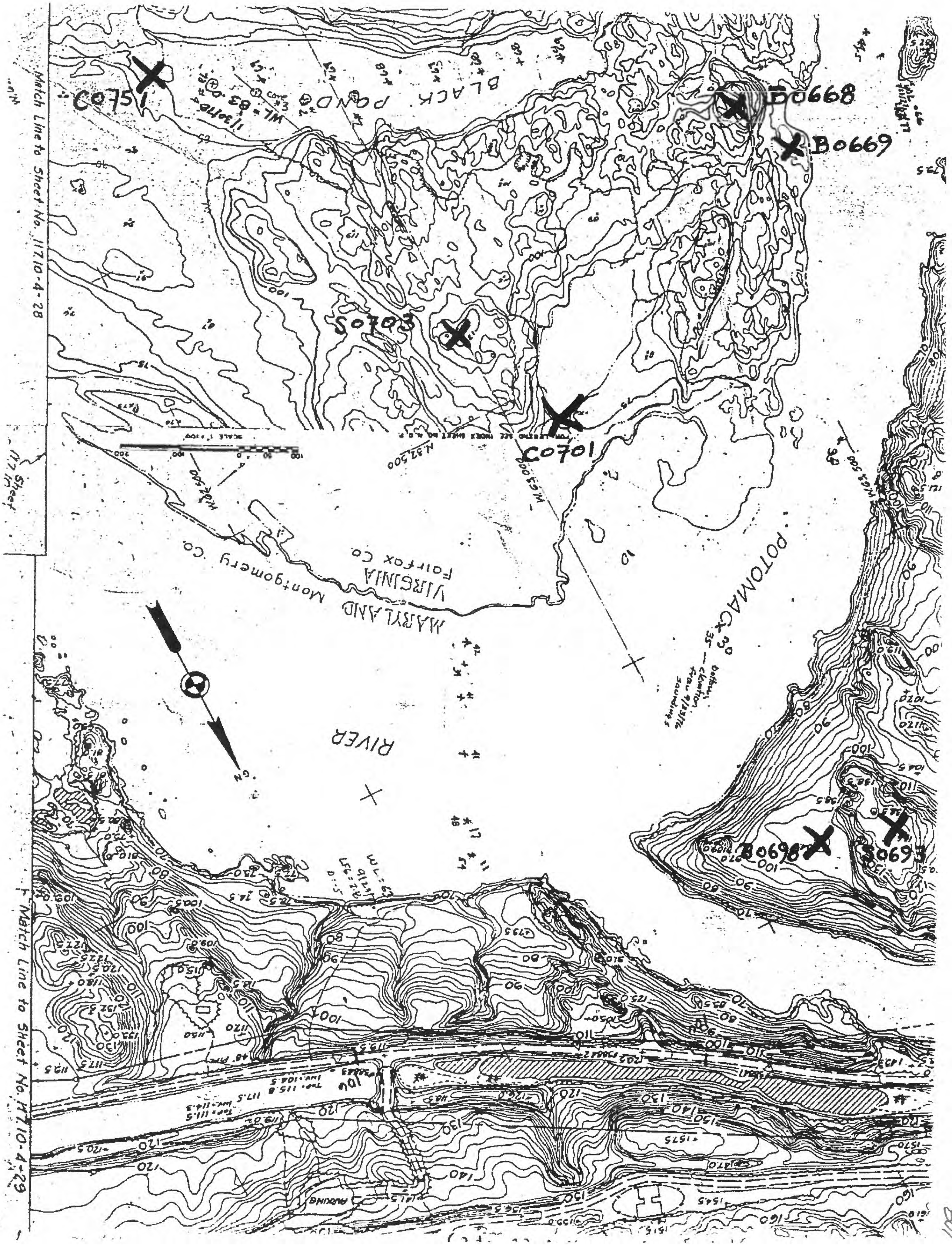

DR6
DR5
DR4
Fairfax
Montgomery
MARYLAND
POTOMAC

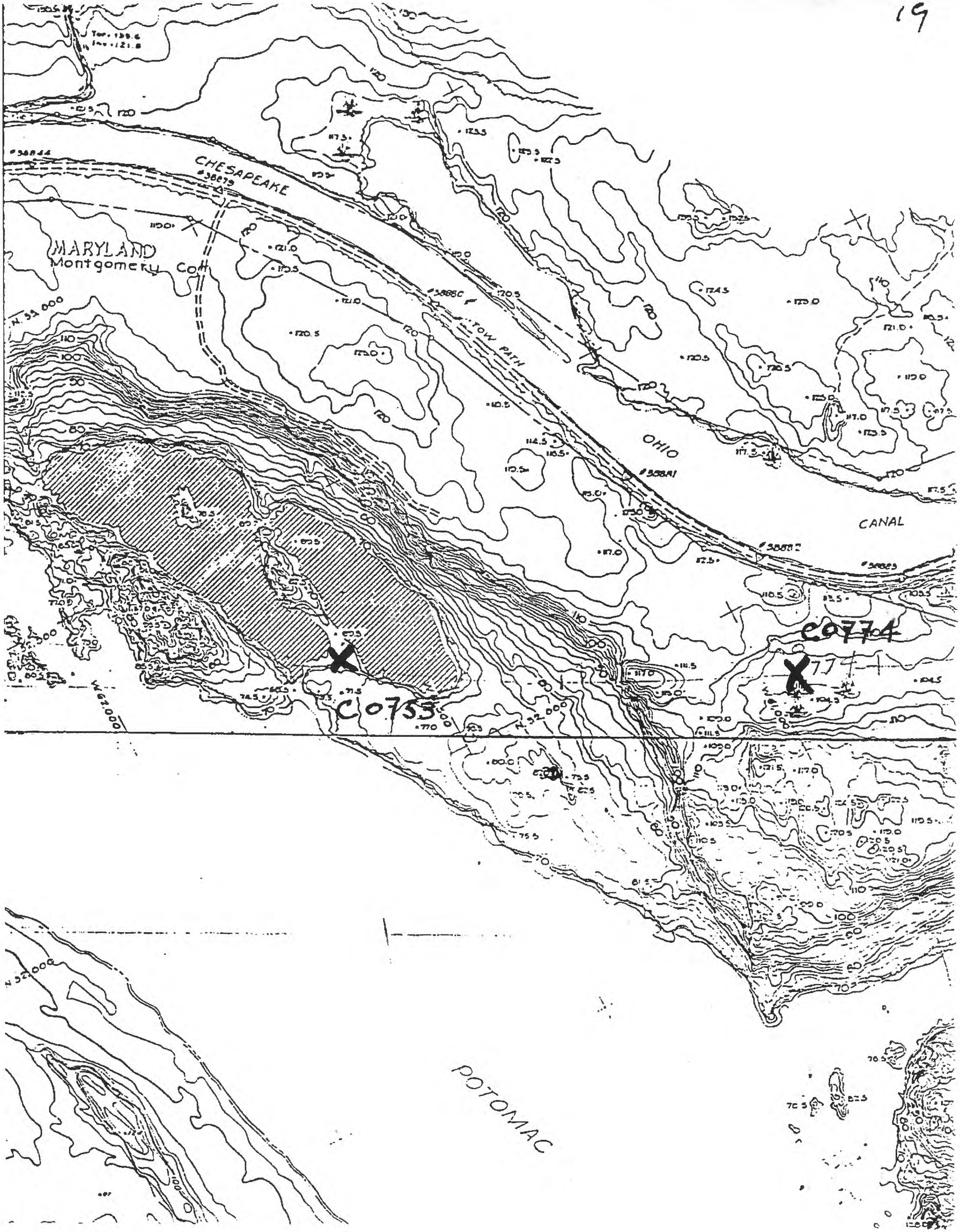

DR3
DR1
DR2
C0661
VIRGINIA
MARYLAND
Montgomery Co.
Fairfax
RIVER

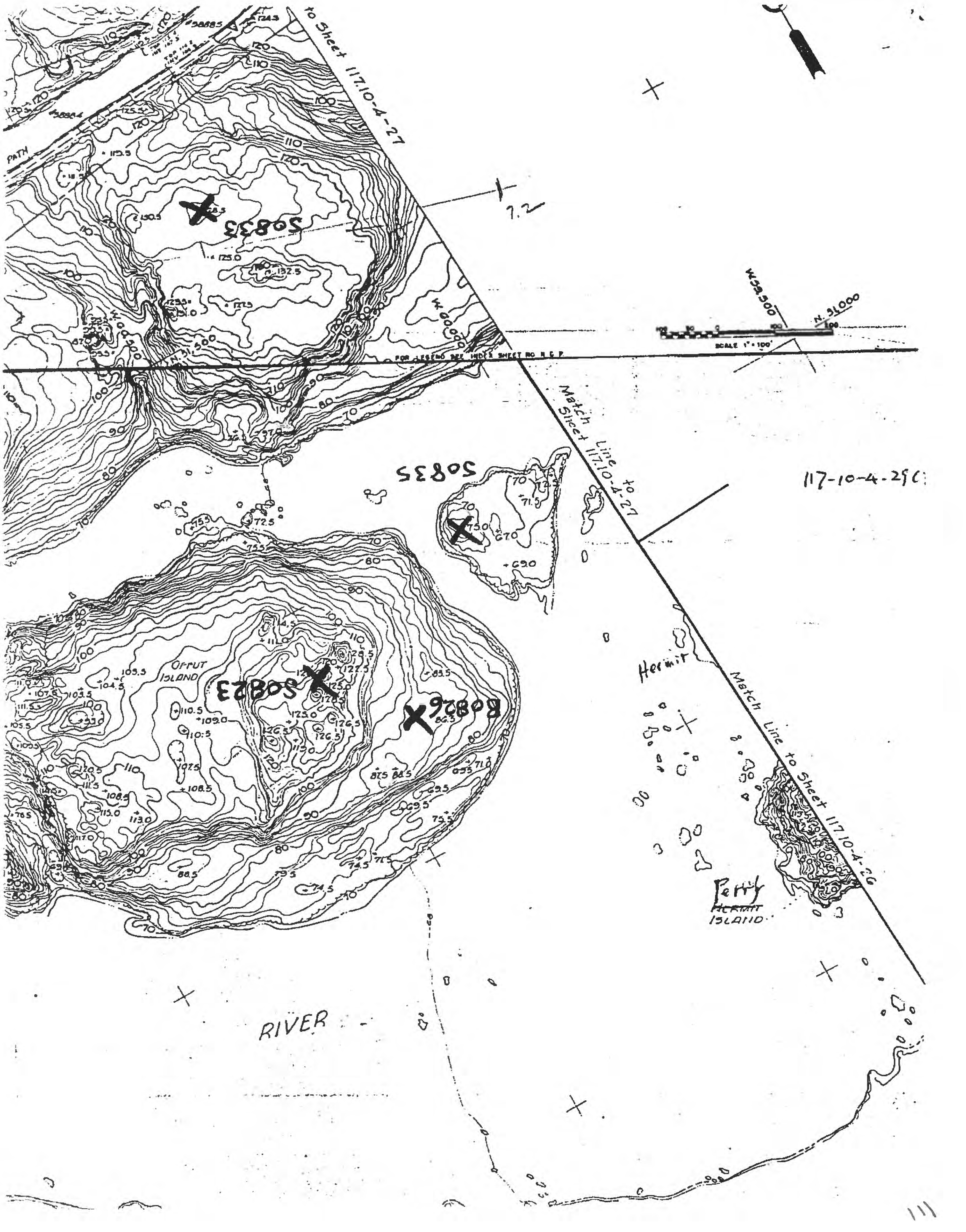
106


BEAR ISLAND
SHERWIN ISLAND
POTOMAC
POTOMAC
RIVER
Montgomery
MARYLAND
Montgomery Co.
MARYLAND
VIRGINIA
B0641
C0650
B0631
S0647
B0652

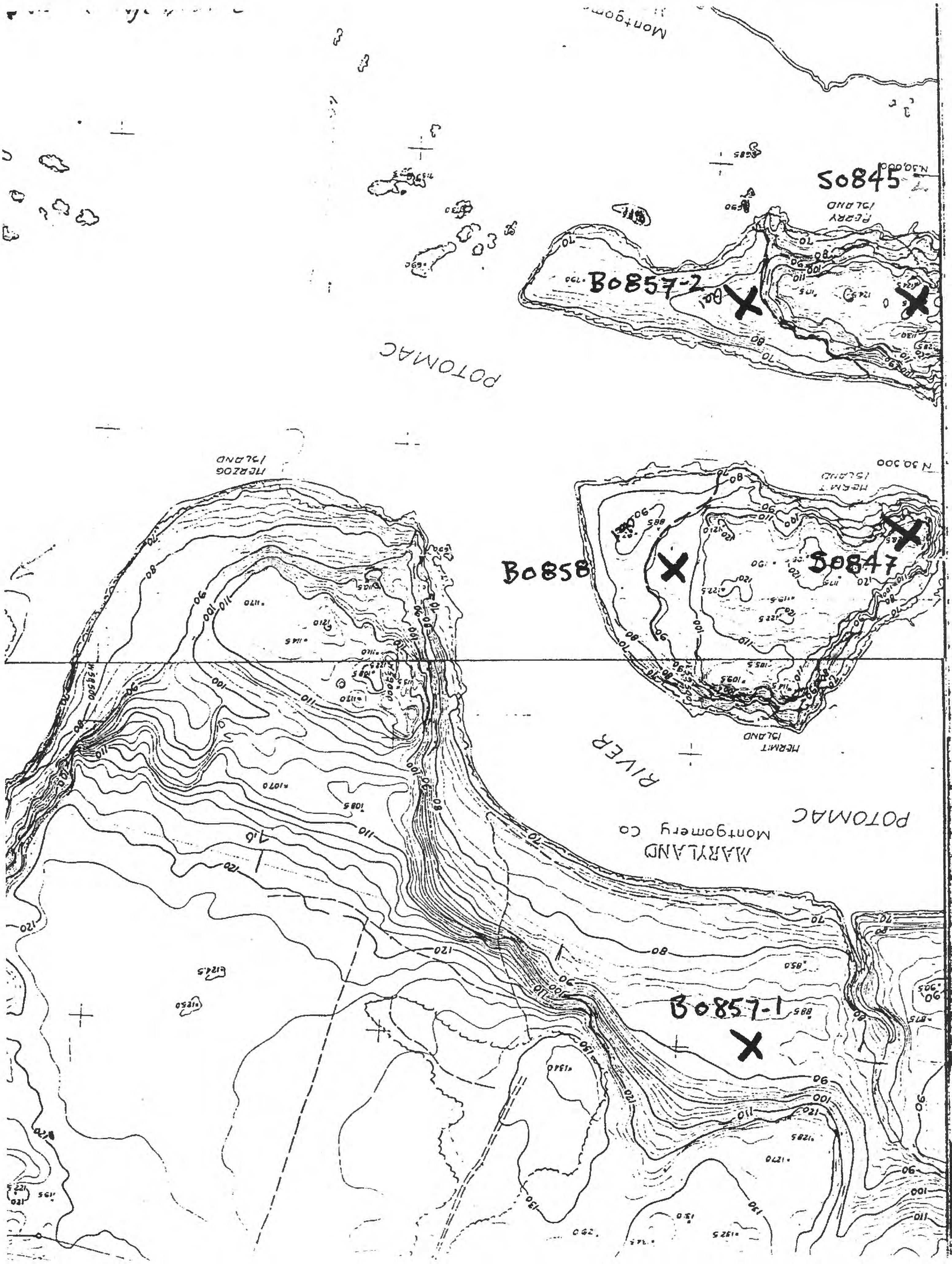

B0693
B0691
S0626
S0693
C0691
B0638-2
C0689
B0679
BEAR ISLAND
SHERWIN ISLAND

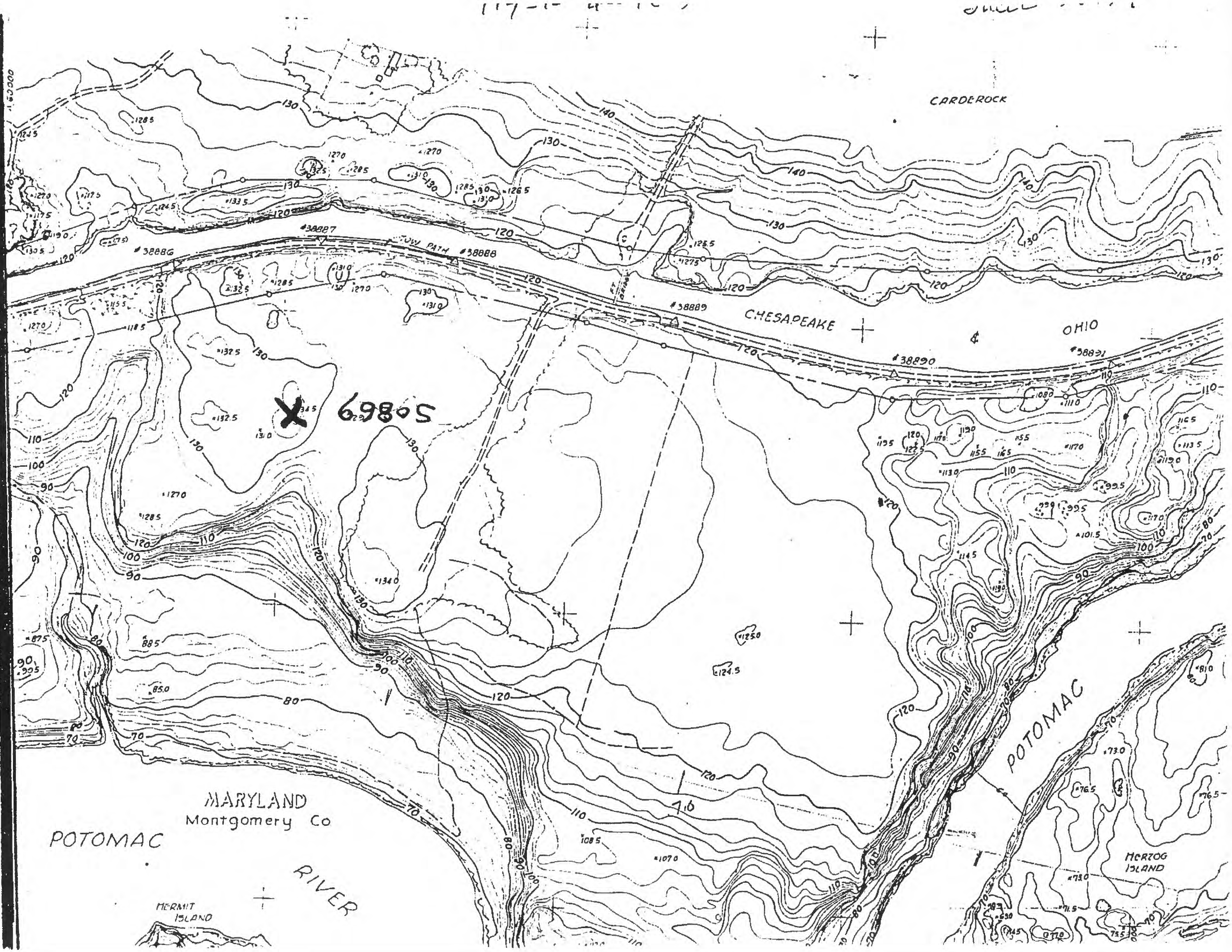

C0751
B0668
B0669
S0703
C0701
S0693
BLACK POND
POTOMAC
RIVER
VIRGINIA
Fairfax Co.
MARYLAND Montgomery Co.
Match Line to Sheet No. 117.10-4-28
Match Line to Sheet No. 117.10-4-29


CHESAPEAKE
OHIO
CANAL
TOW PATH
MARYLAND
Montgomery Co.
POTOMAC
C0753
C0774



to Sheet 117.10-4-27
PATH
FOR LEGEND SEE INDEX SHEET NO.
SCALE 1" = 100'
N. 31,000
Match Line to Sheet 117.10-4-27
117-10-4-29C
OFFUT ISLAND
Hermit
Match Line to Sheet 117.10-4-26
HERMIT ISLAND
RIVER

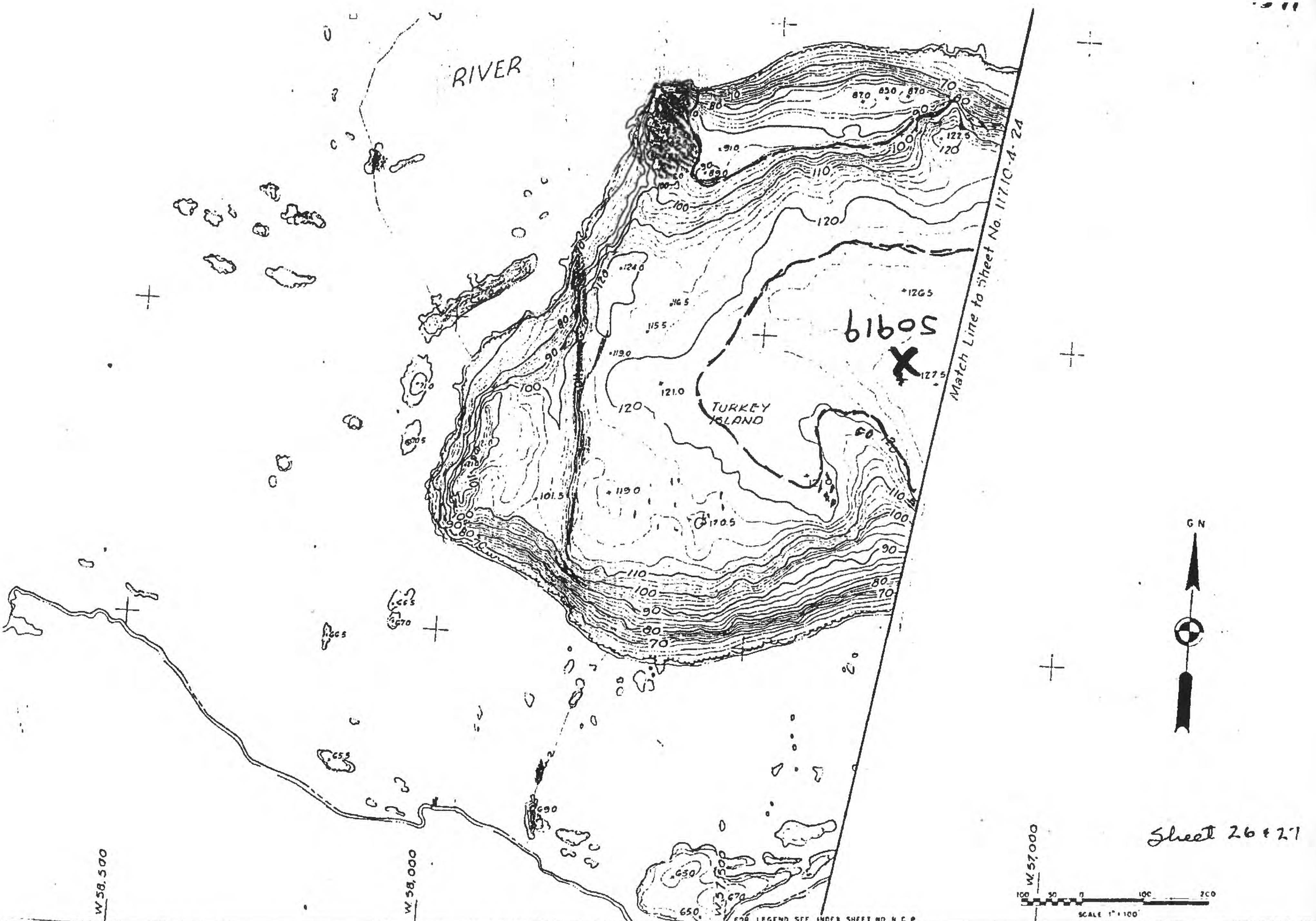

S0845
B0857-2
B0858
S0847
B0857-1
POTOMAC
RIVER
POTOMAC
MARYLAND
Montgomery Co
HERMIT ISLAND
HERZOG ISLAND
PERRY ISLAND
Montgomery


CARDEROCK
CHESAPEAKE
&
OHIO
TOW PATH
#38886
#38887
#38888
#38889
#38890
#38891
50869
MARYLAND
Montgomery Co
POTOMAC
RIVER
POTOMAC
HERZOG ISLAND
HERMIT ISLAND

113

117-10-4-27(2)

114



Coordinates		
Northing	Easting	Elevation

CHECKED BY
FIELD: ______ DATE
OFFICE: ______ DATE
SUBMITTED: ______ DATE

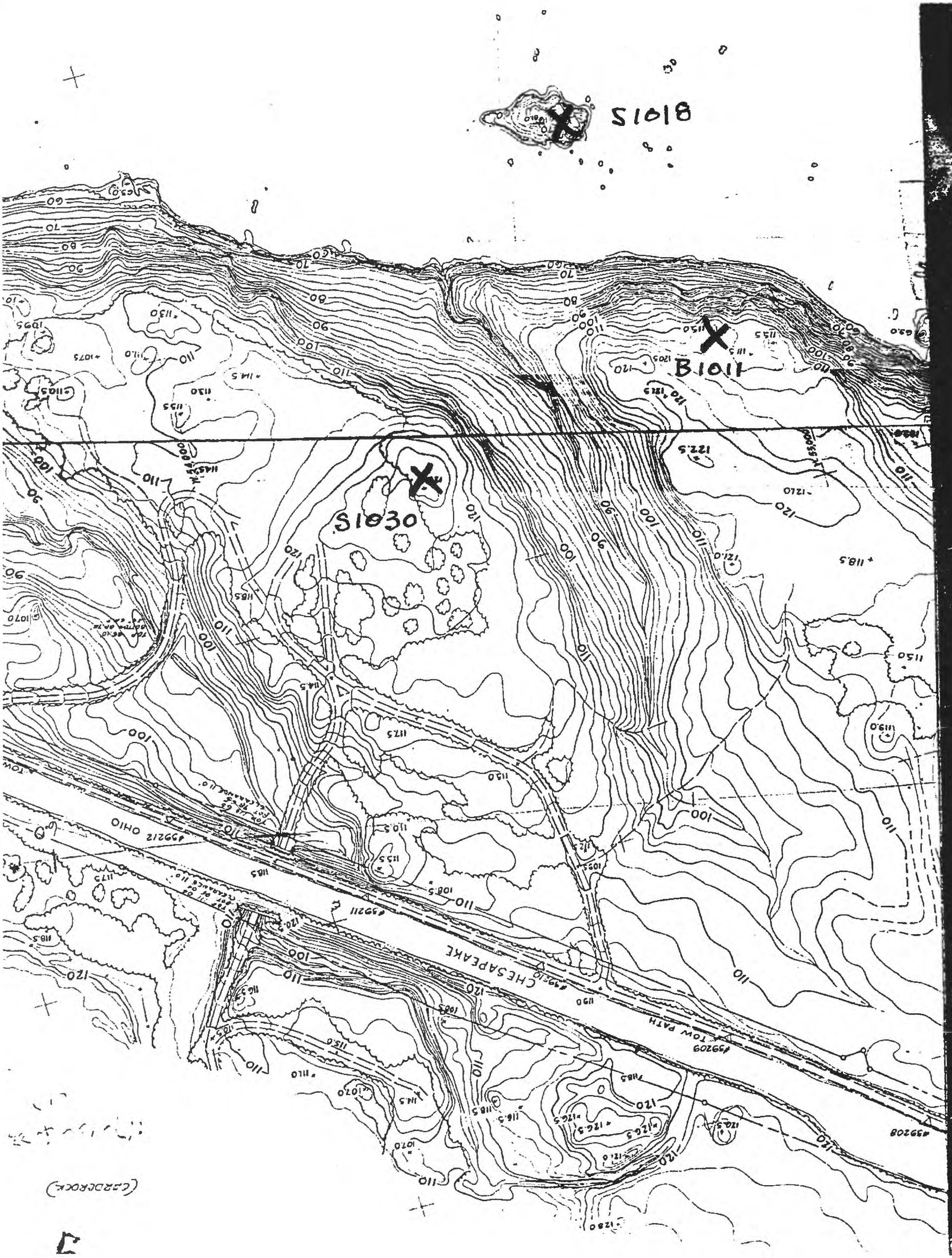
PREPARED BY
MADDOX & HOPKINS
CONTRACT NO 14-10-028-1214

SURVEYED BY	DATE	PLOTTED BY	DATE

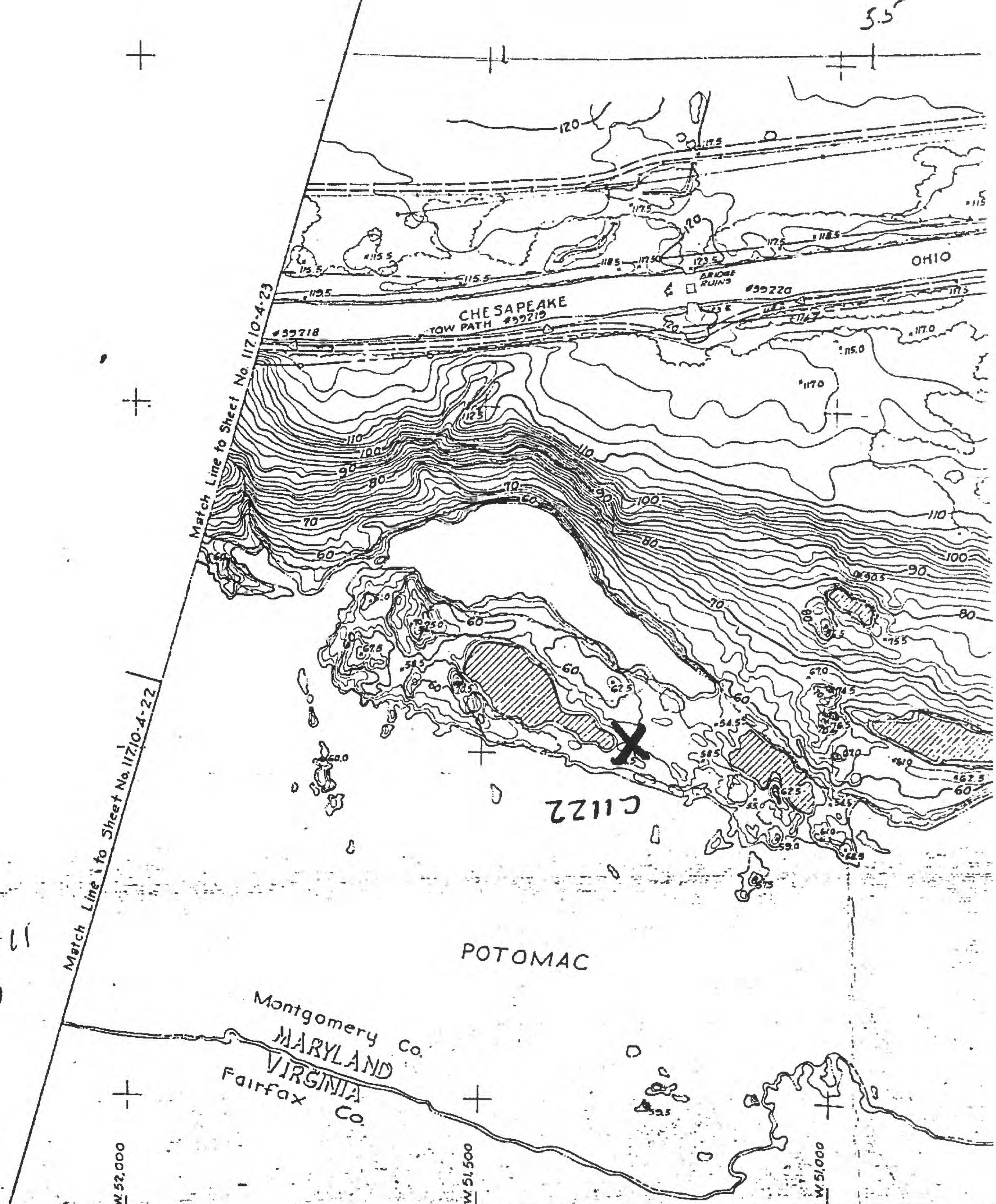
UNITED STATES
DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE
NATIONAL CAPITAL PARKS
ENGINEERING BRANCH

TOPOGRAPHY

117-10-4-26(C3)


S1018
B1011
S1030
CHESAPEAKE

117·10-4-21



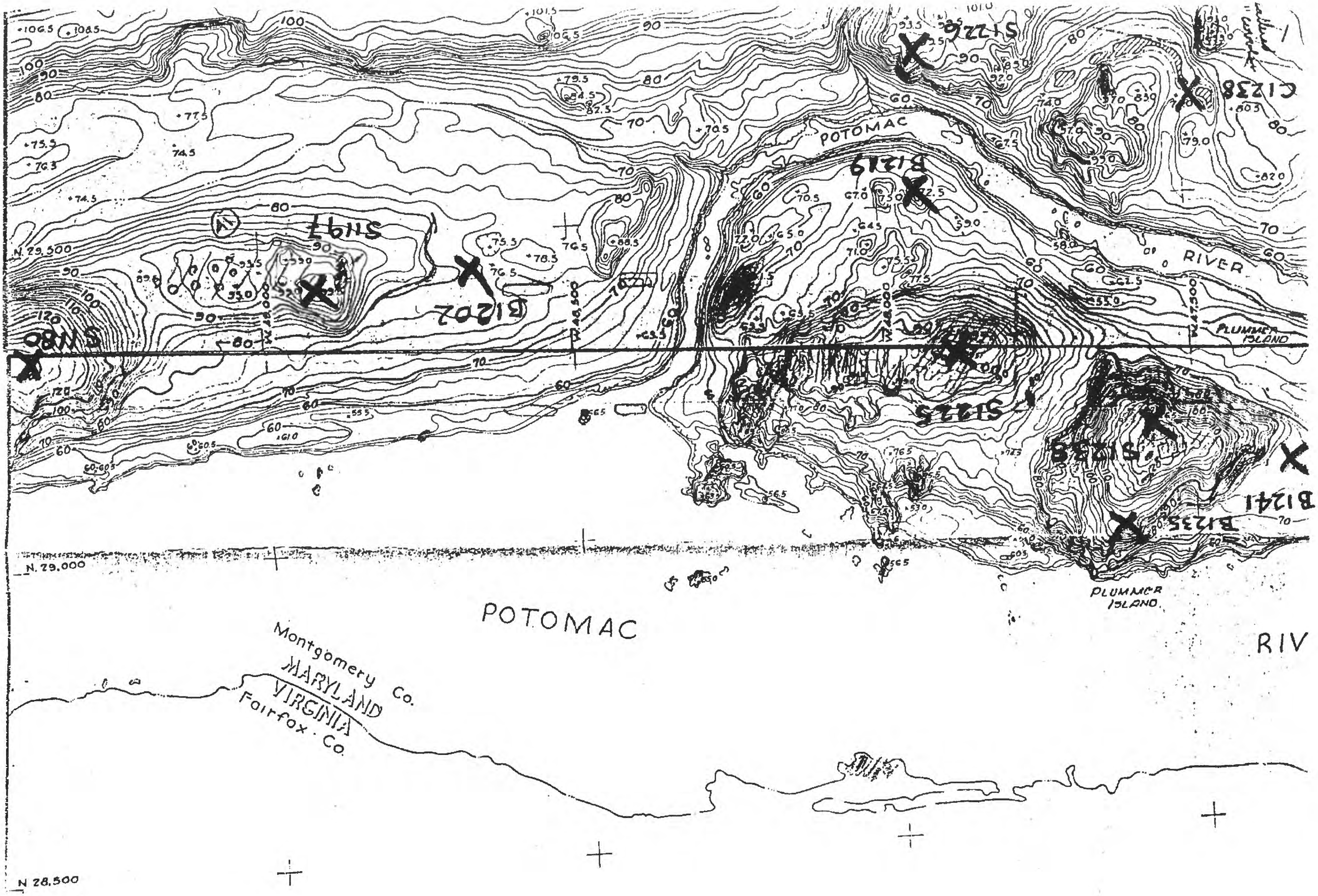
Distance	Coordinates Northing	Coordinates Westing	Elevation
	29,582.23	51,774.04	119.053
60.16	29,610.74	51,415.05	119.155
63.57	29,661.36	51,055.22	118.440
56.36	29,714.31	50,702.80	118.612
51.26	29,763.49	50,355.02	118.665
53.93	29,815.02	50,004.88	118.929
04.50	29,875.77	49,604.87	118.892

Station	Bearing	Distance	Coordinates Northing	Coordinates Easting	Elevation

117-10-4-21 (1)

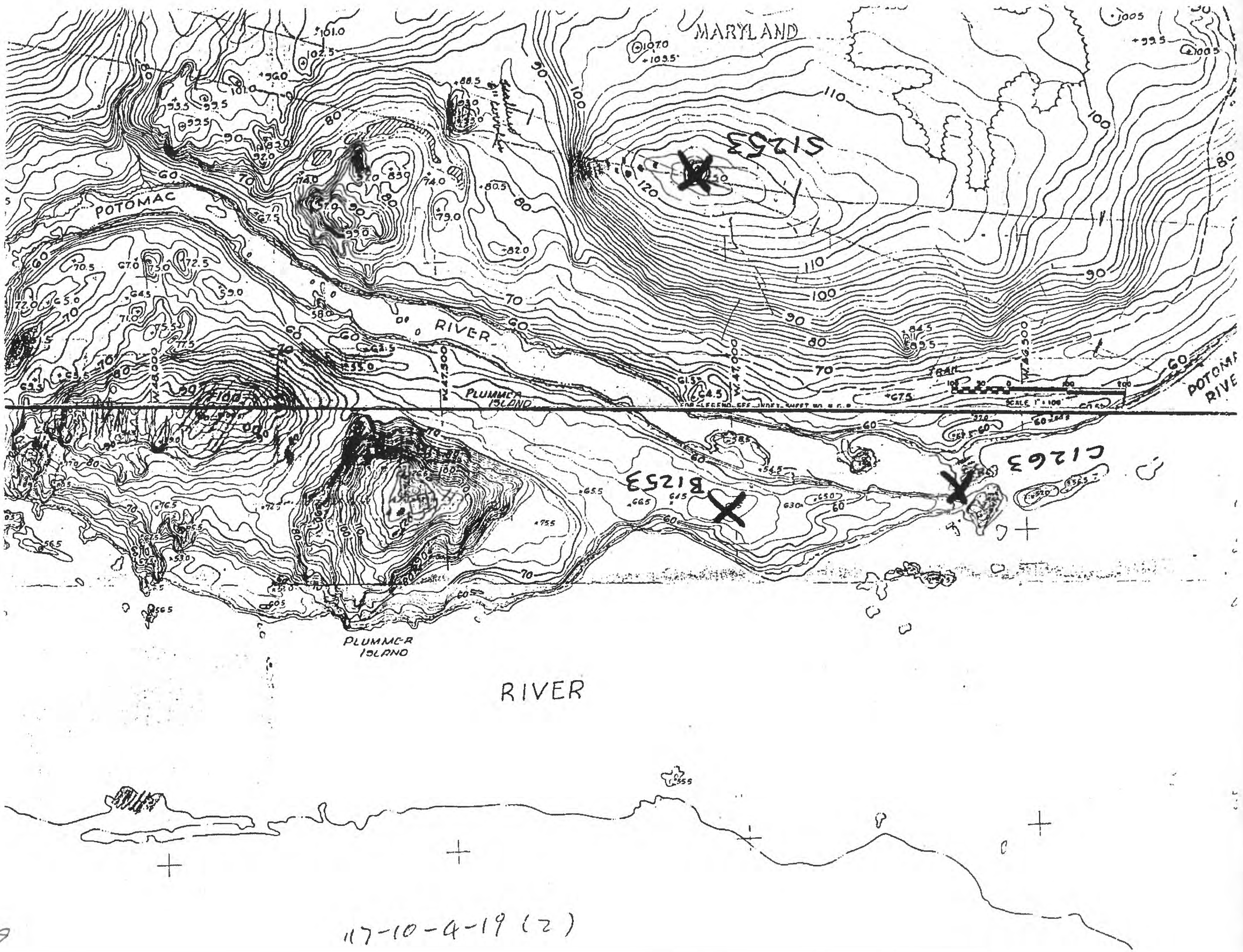
HORIZONTAL DATUM
VERTICAL DATUM LOW WATER

CHECKED BY
FIELD
OFFICE
SUBMITTED
APPROVED
CHIEF ENGINEER


POTOMAC
RIVER
PLUMMER ISLAND
POTOMAC
RIV
Montgomery Co.
MARYLAND
VIRGINIA
Fairfax Co.
N. 29,500
N. 29,000
N 28,500
S1226
C1238
B1219
S1197
B1202
S1225
S1228
B1235
B1241

17-10-4-(9(1)

118



117-10-4-19 (2)

119

120

117.10-4-18(1

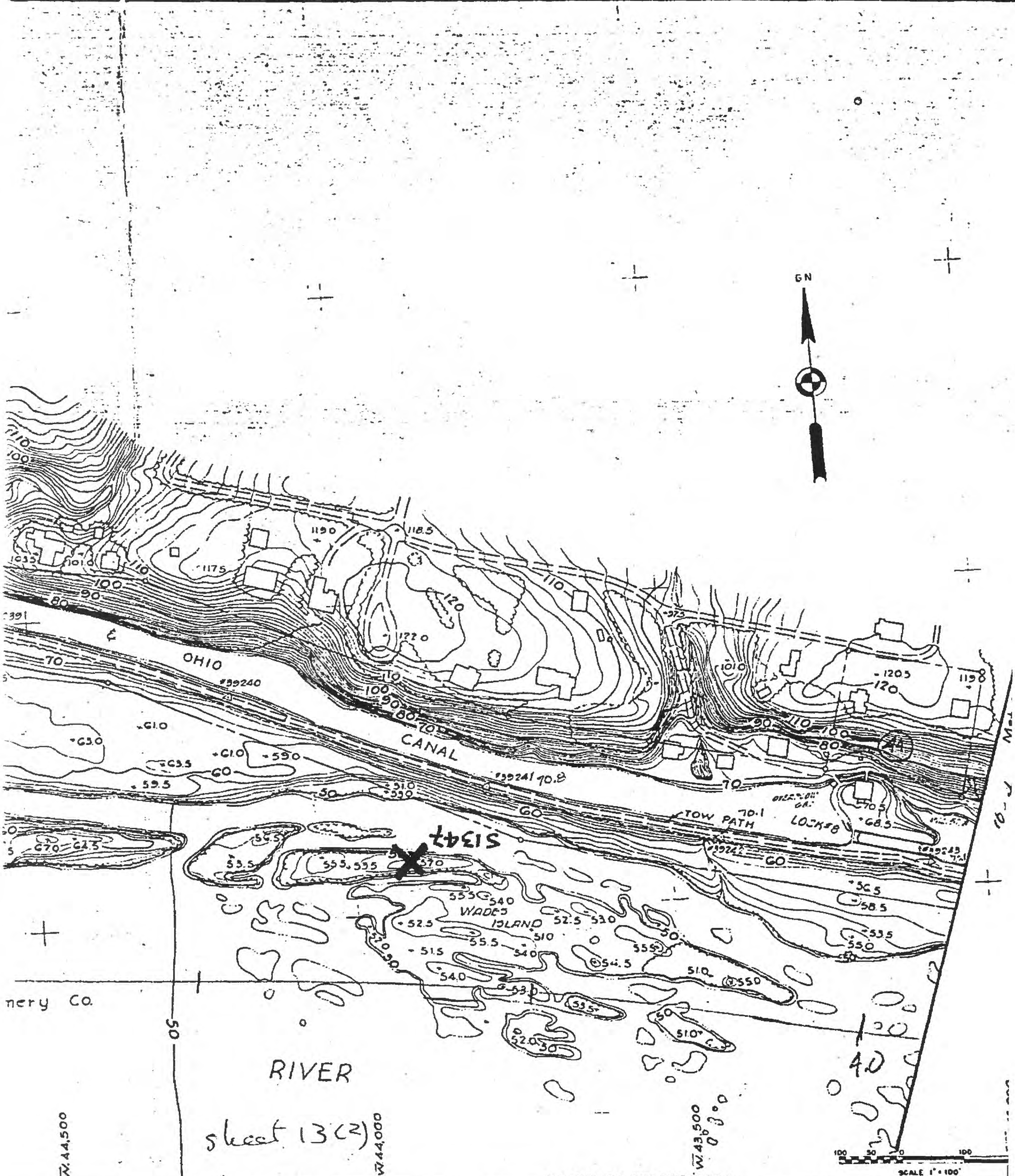
Station	Bearing	Distance	Coordinates Northing	Coordinates Westing	Elevation
39233	S. 86°21'59"E.	339.92	30,067.31	46,235.46	89.742
39234	S. 89°24'48"E.	368.14	30,045.77	45,896.20	86.784
39235	N. 84°49'07"E.	244.26	30,042.00	45,528.05	86.327
39236	S. 89°27'02"E.	199.49	30,064.06	45,284.77	86.536
39237	S. 87°57'53"E.	260.37	30,062.15	45,085.28	78.469
39238	S. 77°40'58"E.	282.34	30,052.88	44,825.06	78.646
			[illegible]	44,549.20	70.435

Station	Bearing	Distance	Coordinates Northing	Coordinates Westing	Elevation
					70.435
39239	S. 70°45'30"E.	386.94	29,865.13	44,183.85	70.435
39240	S. 67°17'18"E.	431.73	29,698.44	43,785.57	70.827
39241	S. 74°27'10"E.	377.48	29,597.26	43,421.88	70.091
39242	S. 79°39'36"E.	337.80	29,536.63	43,089.55	70.080
39243					

HORIZONTAL DATUM

VERTICAL DATUM: LOW WATER

117.10-4-18 (2)



FOR LEGEND SEE INDEX SHEET NO. N.C.P.

Elevation			
70.435	CHECKED BY: Match Line to Sheet No. 11710-4-17	PREPARED BY	UNITED STATES
70.495	FIELD: ______ DATE: ______	MADDOX & HOPKINS	DEPARTMENT OF THE INTERIO
70.827	OFFICE: ______ DATE: ______	CONTRACT NO. 14-10-028-1214	NATIONAL PARK SERVICE NATIONAL CAPITAL PARKS ENGINEERING BRANCH

SURVEYED BY | DATE | PLOTTED BY | DATE

TOPOGRAPHY

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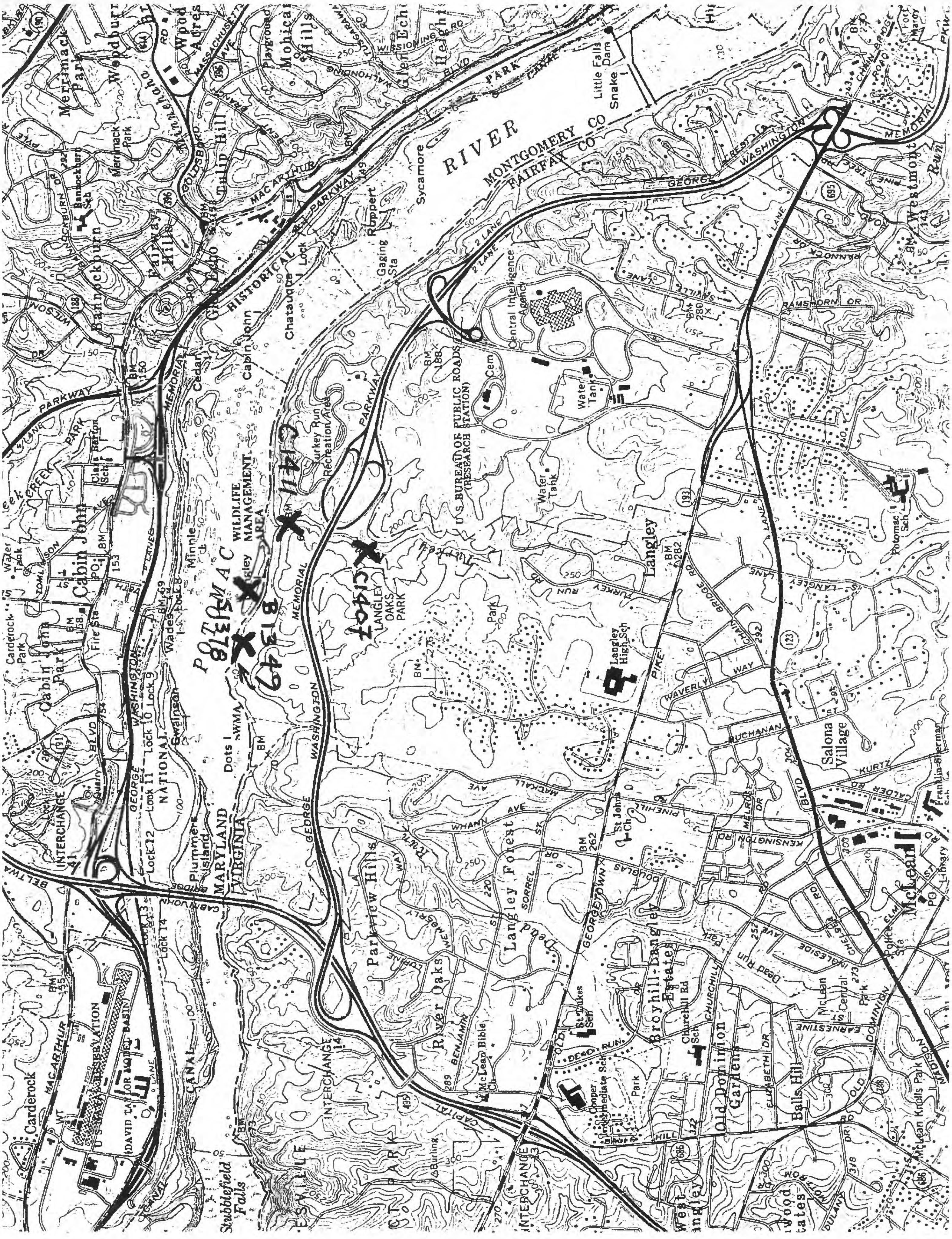
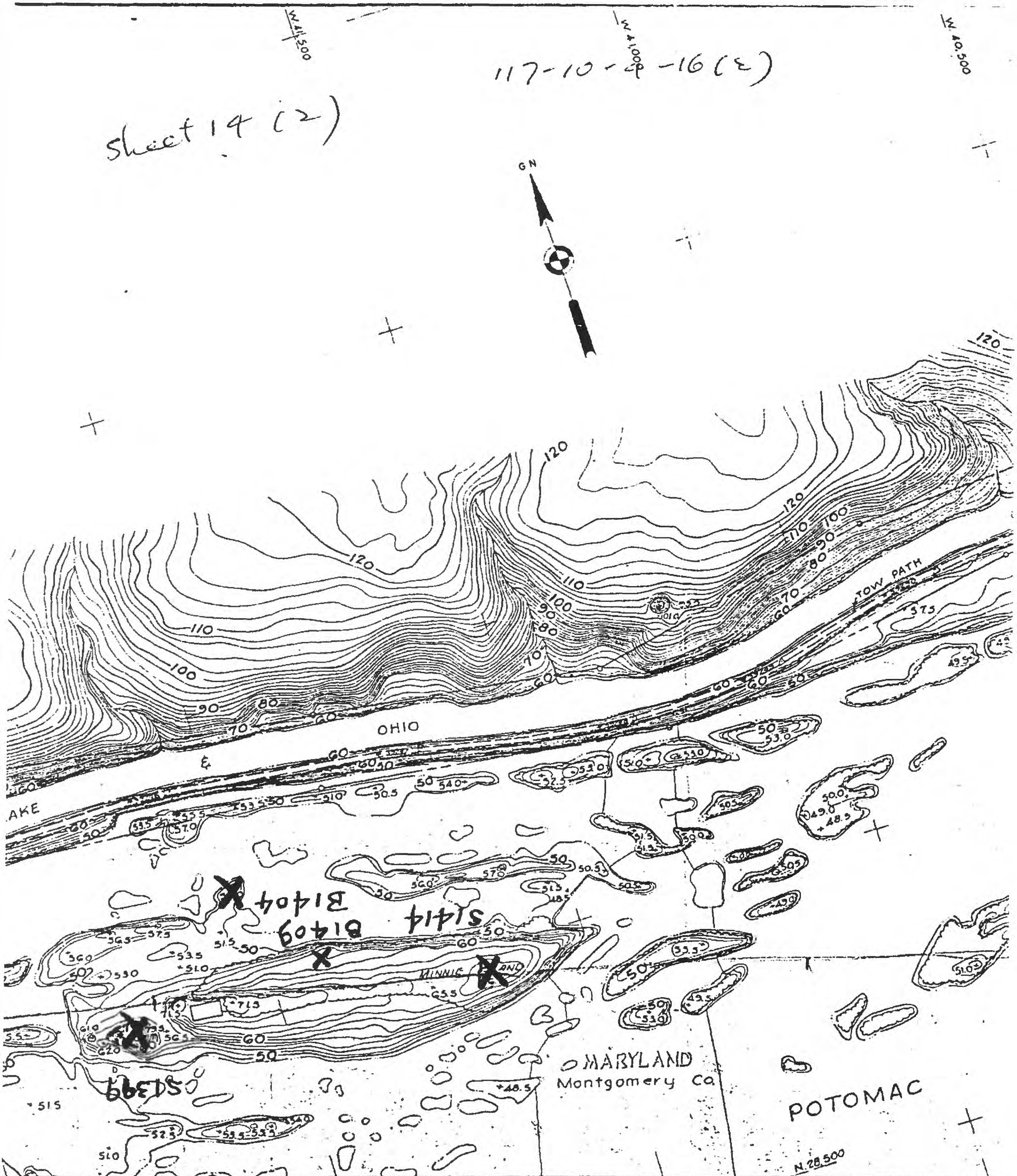


POTOMAC
RIVER
MONTGOMERY CO
FAIRFAX CO
MARYLAND
VIRGINIA
WILDLIFE MANAGEMENT AREA
GEORGE WASHINGTON MEMORIAL PARKWAY
CLARA BARTON PARKWAY
NATIONAL CANAL
Cabin John
Carderock
Bannockburn
Glen Echo
Langley
McLean
Salona Village
Langley Forest
Parkview Hills
River Oaks
Broyhill-Langley Estates
Old Dominion Gardens
Balls Hill
Central Intelligence Agency
U S BUREAU OF PUBLIC ROADS (RESEARCH STATION)
Langley High Sch
Langley Oaks Park
Turkey Run Recreation Area
Plummers Island
Little Falls Dam
Stubblefield Falls
CAPITAL BELTWAY



Elevation	Station	Bearing	Distance	Coordinates Northing	Coordinates Easting	Elevation
	39244	N 75°45' 38" W	399.99	29,430.23	42,701.85	
	39245	N 82°01' 43" W	318.92	29,394.00	42,386.01	
	39246	S 89°24' 12" W	317.91	29,397.31	42,068.12	
	39247	N 81° 55' 35" W	410.80	29,338.61	41,661.36	
	39248	N 00° 20' 15" W	349.70	29,281.54	41,380.89	
	39249	S 86° 10' 00" W	293.24	29,298.47	41,067.62	
	39250	S 76° 04' 09" W	292.87	29,366.90	40,789.36	
	39251	S 87° 18' 25" W	306.09	29,394.08	40,478.34	
	39252	S 89° 27' 09" W	297.18	29,396.86	40,181.17	
	39253	N 76° 28' 10" W	391.41	29,304.00	39,800.84	

HORIZONTAL DATUM

VERTICAL DATUM LOW WATER

CHECKED BY Match Line to Sheet No. 117.10-4-15

FIELD: ______ DATE: ______

OFFICE: ______ DATE: ______

SUBMITTED ______ SIGNATURES DATE: ______

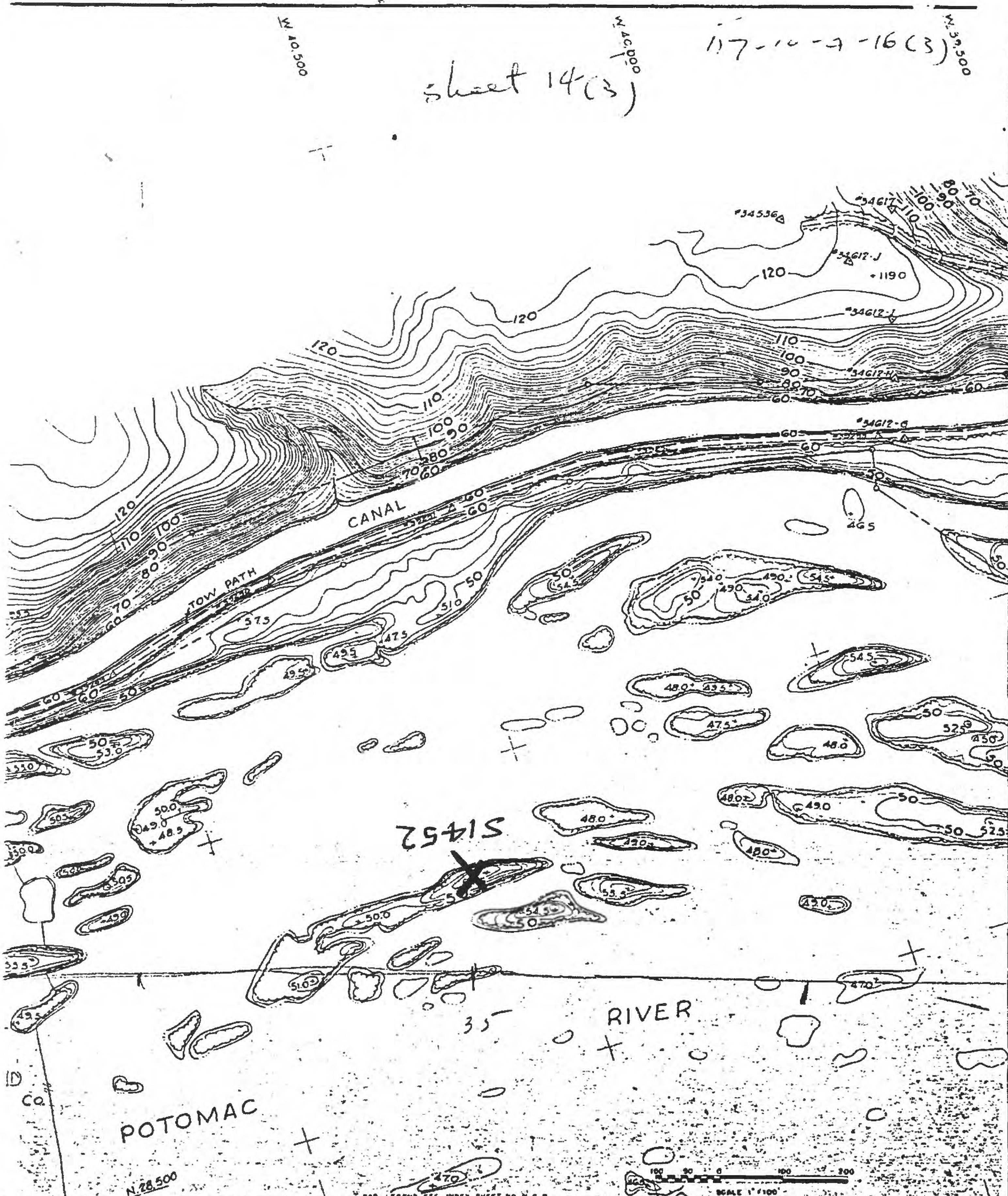
APPROVED ______ DATE: ______

CONT

SURVEYED BY

FIELD BOOK

COMPUTATIONS BY



h Line to Sheet No. 117.10-4-15 DATE DATE SIGNATURES DATE	PREPARED BY MADDOX & HOPKINS CONTRACT NO. 14-10-028-1214 SURVEYED BY / DATE / PLOTTED BY / DATE FIELD BOOK / TRACED BY	UNITED STATES DEPARTMENT OF THE INTERIOR NATIONAL PARK SERVICE NATIONAL CAPITAL PARKS ENGINEERING BRANCH **TOPOGRAPHY** Key Bridge to Seneca Creek	REGION N.C.P. WASHINGTON, D.C SHEET 16 OF 58 DRW. NO. N.C.P.

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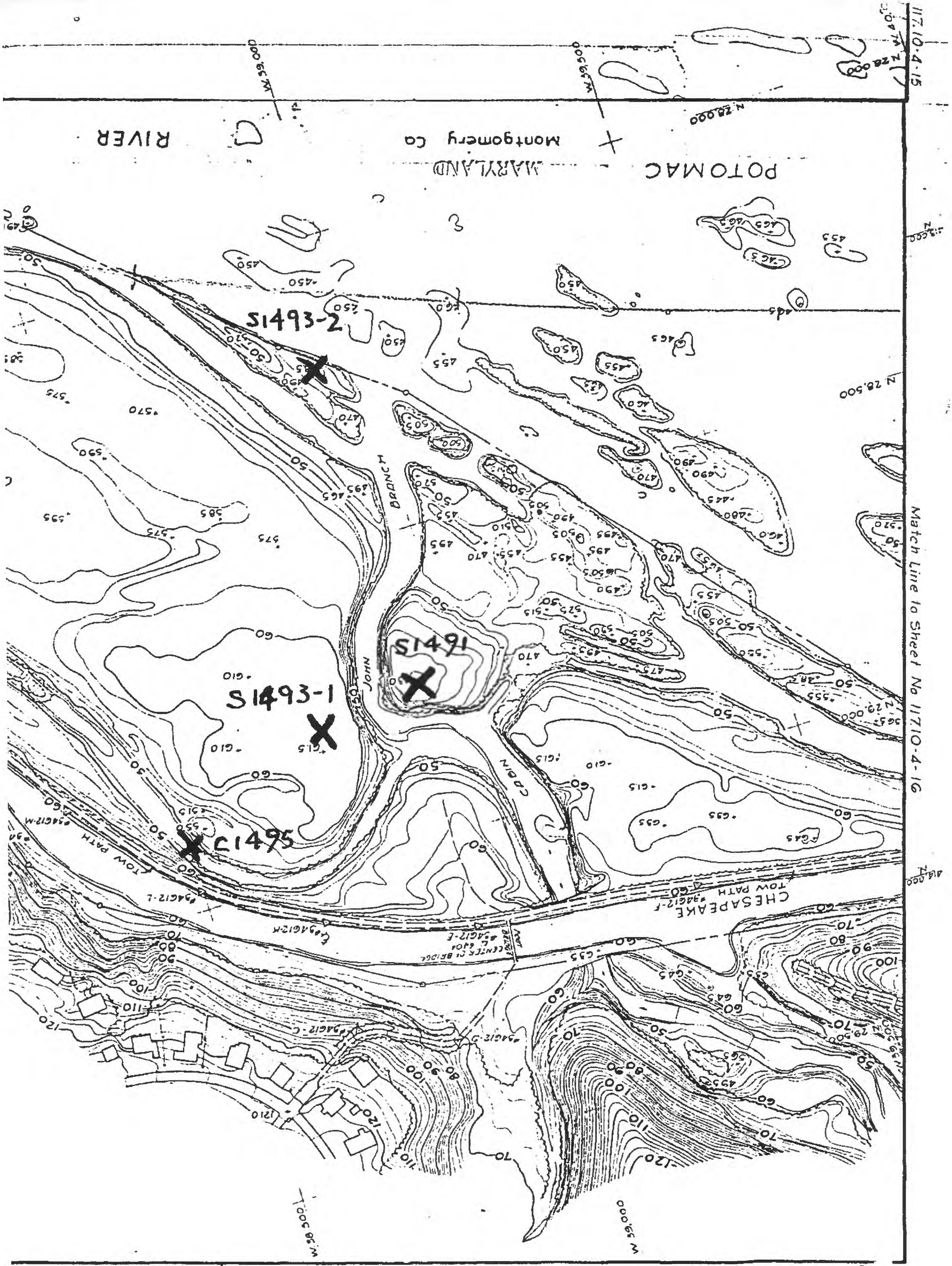
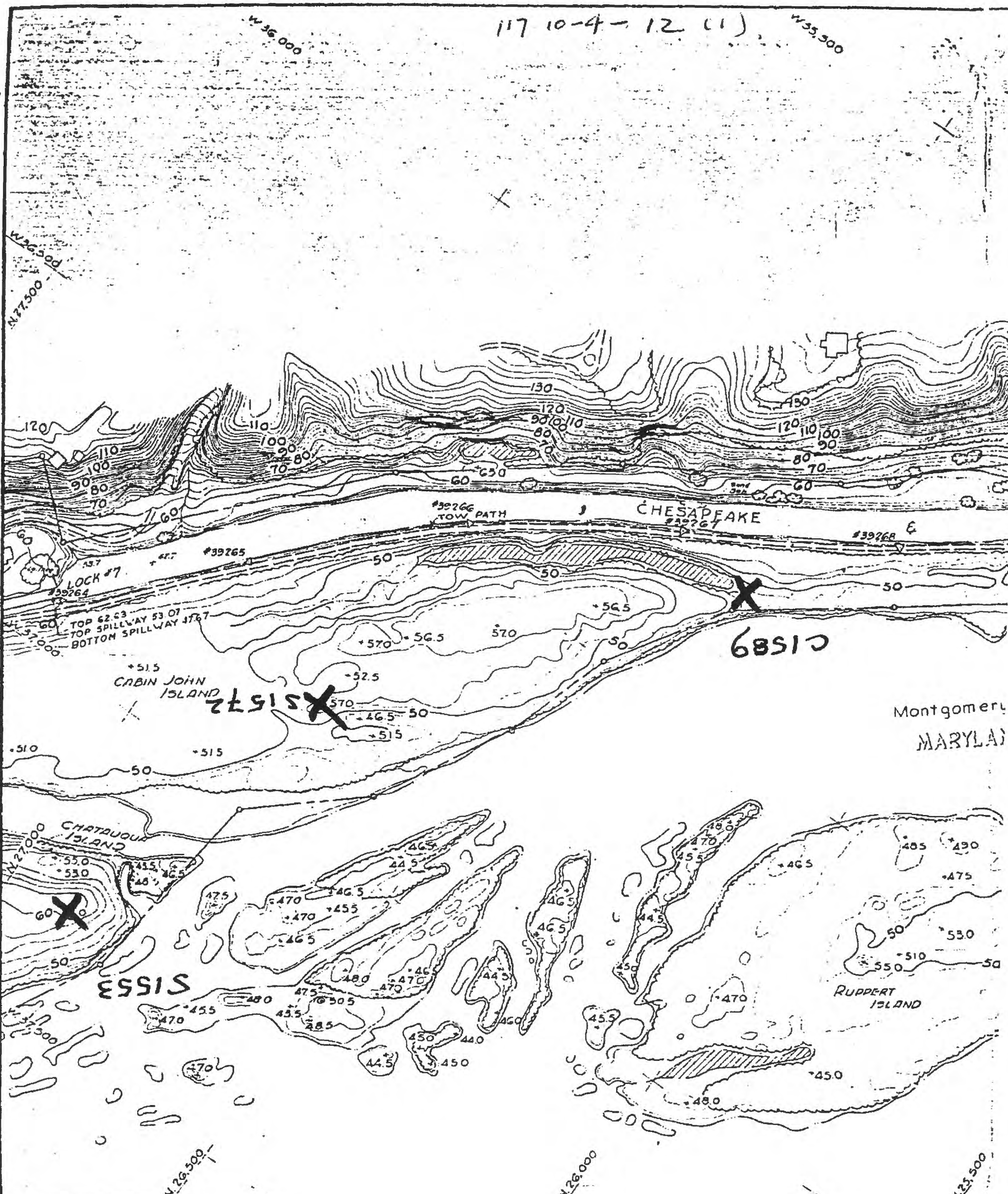

POTOMAC
RIVER
MARYLAND
Montgomery Co
S1493-2
S1491
S1493-1
C1495
JOHN BRANCH
CABIN
CHESAPEAKE
TOW PATH
Match Line to Sheet No 117.10-4-16
117.10-4-15

117-10-4-14(1)

117 10-4-12 (1)



Station	Bearing	Distance	Coordinates Northing	Coordinates Westing	Elevation
39316	N.34°40'51"	471.96	24,609.51	34,882.09	54.354
39317	N.26°46'48"W.	436.18	24,997.61	35,150.66	55.005
39318	N.44°20'29"W.	369.01	25,587.00	35,347.20	54.550
39270	N.46°32'51"W.	355.96	25,650.90	35,605.13	54.822
39269	N.39°13'43"W.	354.32	25,895.70	35,863.56	55.179
39268	N.30°45'51"W.	338.89	26,170.16	36,087.65	55.052
39267			26,461.15	36,261.34	54.890

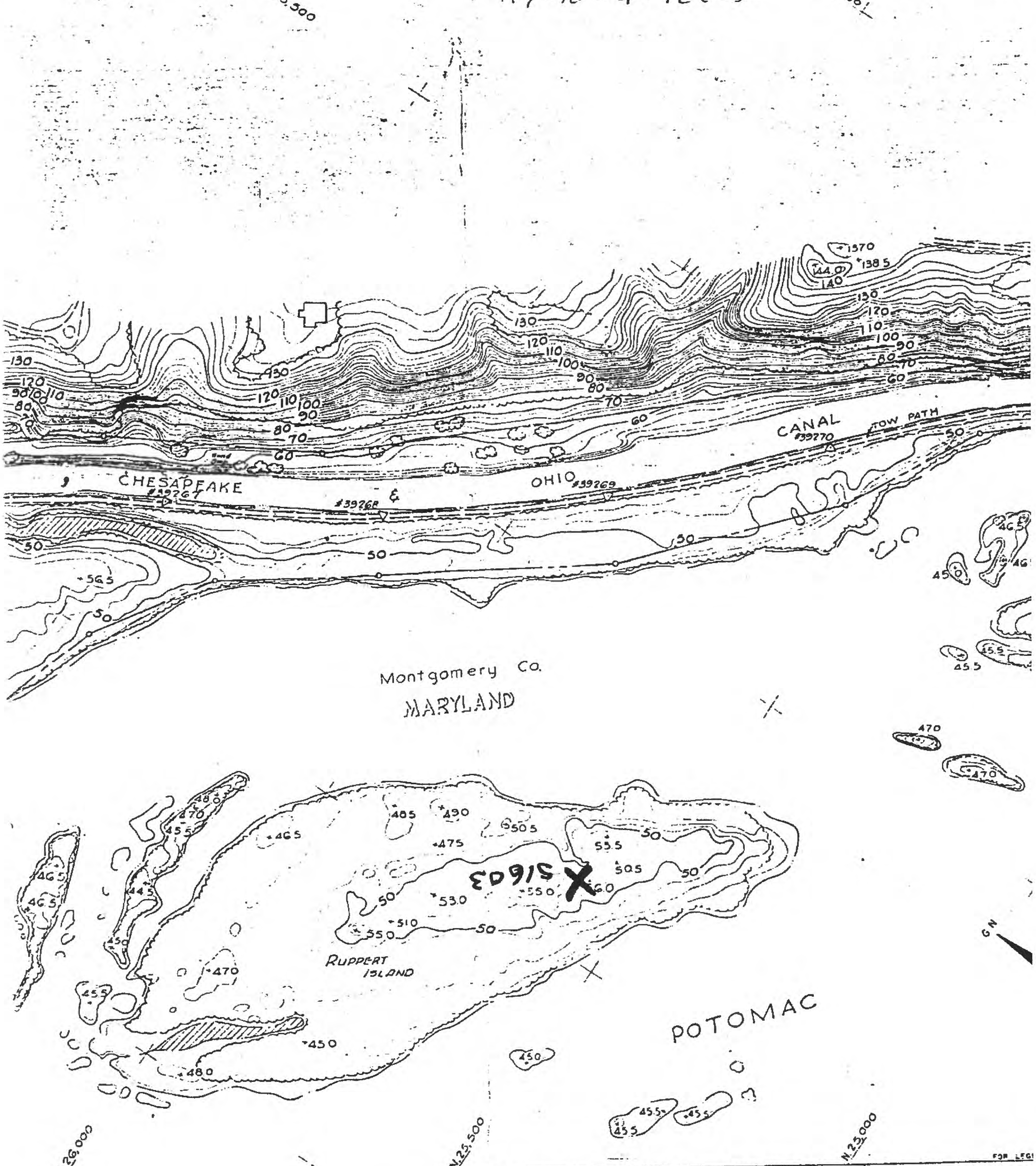
Station	Bearing	Distance	Coordinates Northing	Coordinates Westing	Elevation
39267	N.32°52'52"W.	334.47			54.890
39266	N.45°36'58"W.	347.82	26,738.82	36,447.81	54.551
39265	N.46°52'15"W.	305.30	26,987.10	36,696.41	55.007
39264			27,190.81	36,919.23	67.73

Sheet 1 (6,(1))

HORIZONTAL DATUM

VERTICAL DATUM LOW WATER

117-10-4-12(2)



Station	Bearing	Distance	Coordinates Northing	Coordinates Westing	Elevation
39267	N.32°52'52"W.	334.47	26,738.82	36,447.81	54.896
39266	N.45°36'58"W.	347.82	26,987.10	36,696.41	54.551
39265	N.46°52'15"W.	305.30	27,190.81	36,919.23	55.007
39264					62.736

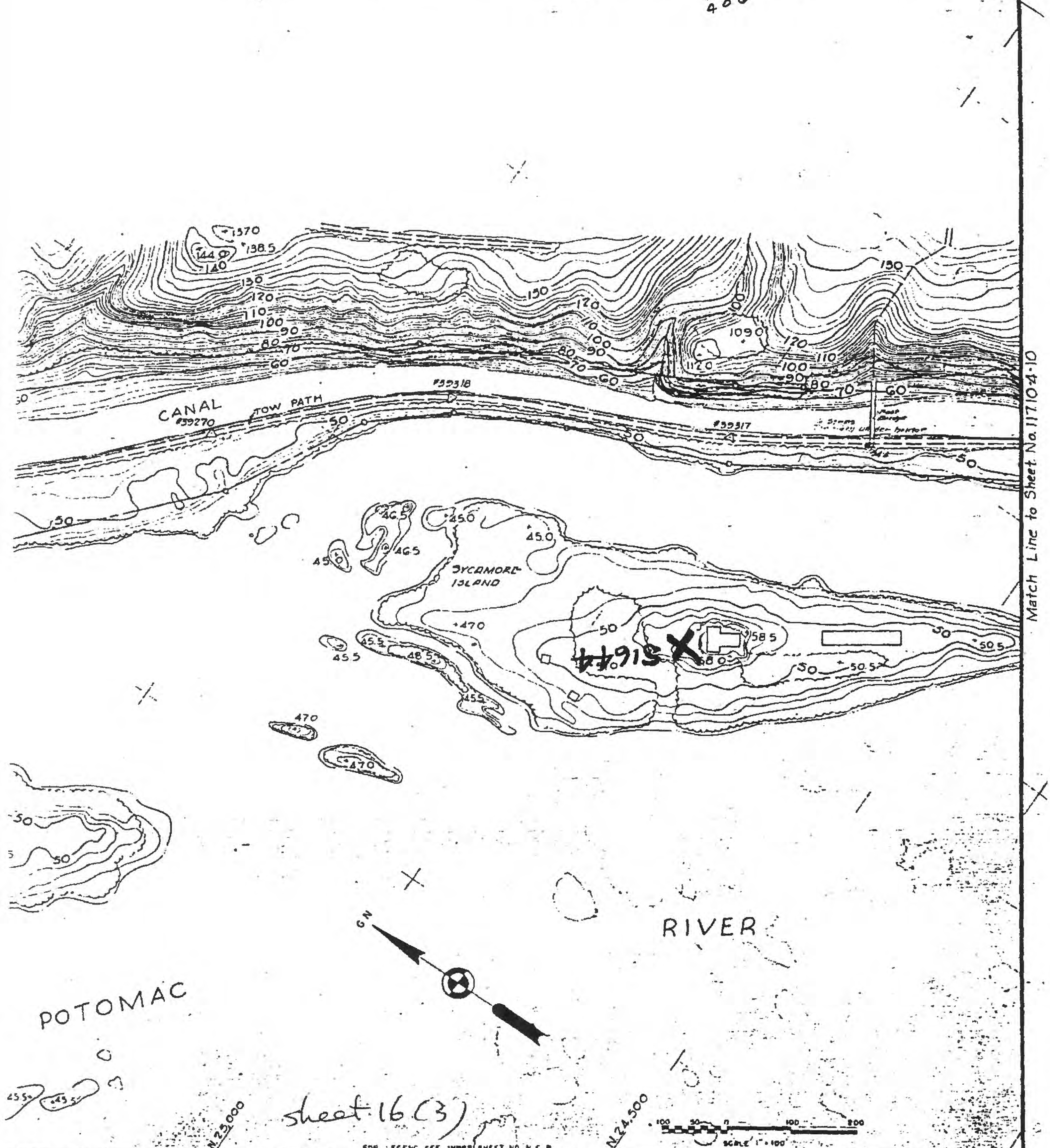
~~sheet 16(2)~~

HORIZONTAL DATUM
VERTICAL DATUM LOW WATER

CHECKED BY Match Line to Sheet No. 117.10-4-11
FIELD ________ DATE
OFFICE ________ DATE
SUBMITTED ________ DATE
APPROVED ________ CHIEF ENGINEER DATE

PREPARED
MADDOX
CONTRACT NO
SURVEYED BY | DATE
FIELD BOOK
COMPUTATIONS BY

117-10-4-12(3)   132/406



Line to Sheet No. 117.10-4-11 DATE DATE DATE DATE	PREPARED BY MADDOX & HOPKINS CONTRACT NO. 14-10-028-1214	UNITED STATES DEPARTMENT OF THE INTERIOR NATIONAL PARK SERVICE NATIONAL CAPITAL PARKS ENGINEERING BRANCH	REGION N.C.P. WASHINGTON, D.C. SHEET 12 OF 55
ENGINEER	SURVEYED BY / DATE / PLOTTED BY / DATE FIELD BOOK / TRACED BY COMPUTATIONS BY / CHECKED BY	TOPOGRAPHY Key Bridge to Seneca Creek GEO. WASH. MEM. PKWY. and CHESAPEAKE & OHIO CANAL	DRW. NO. N.C.P. 117.10-4-12

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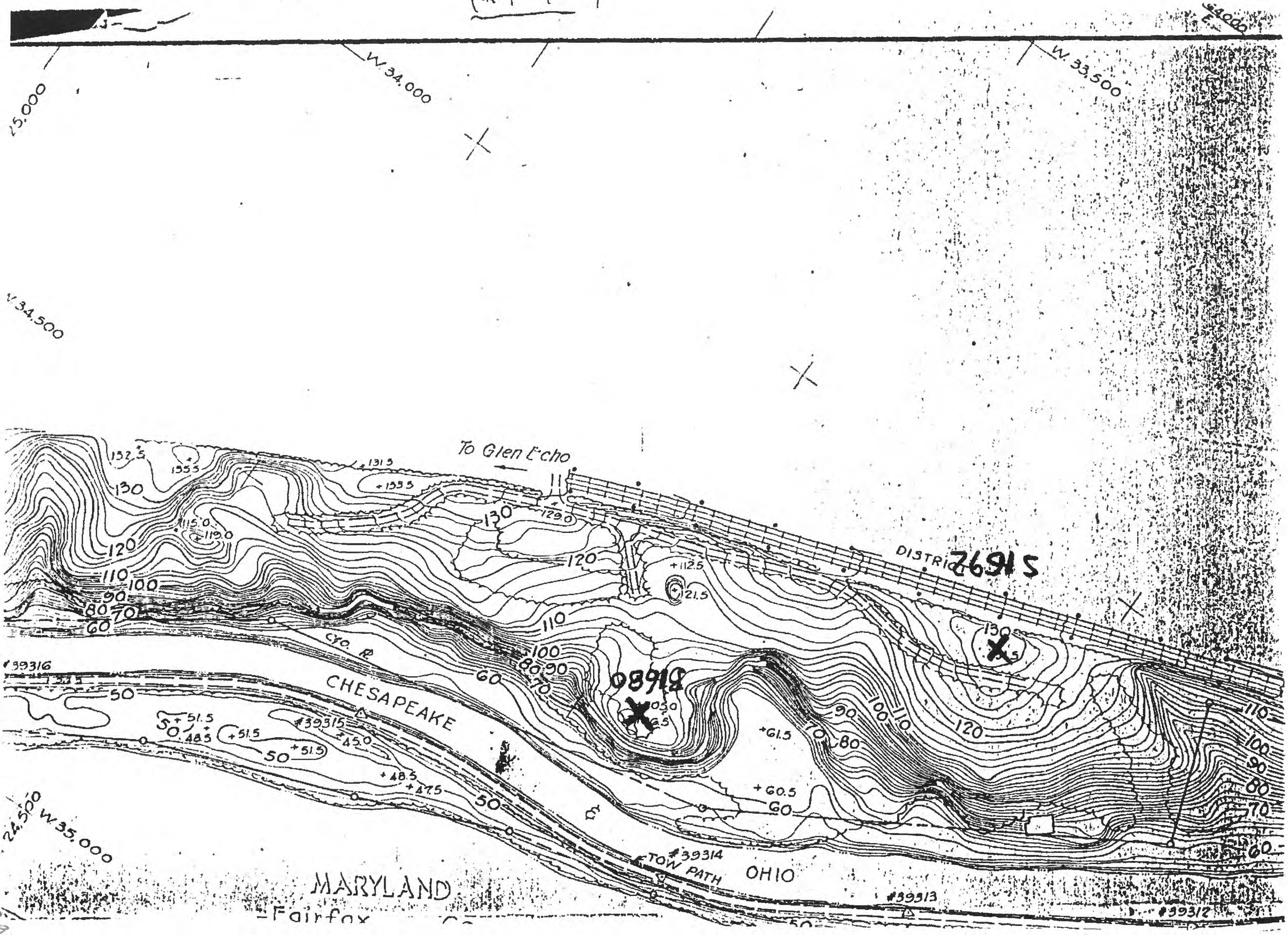
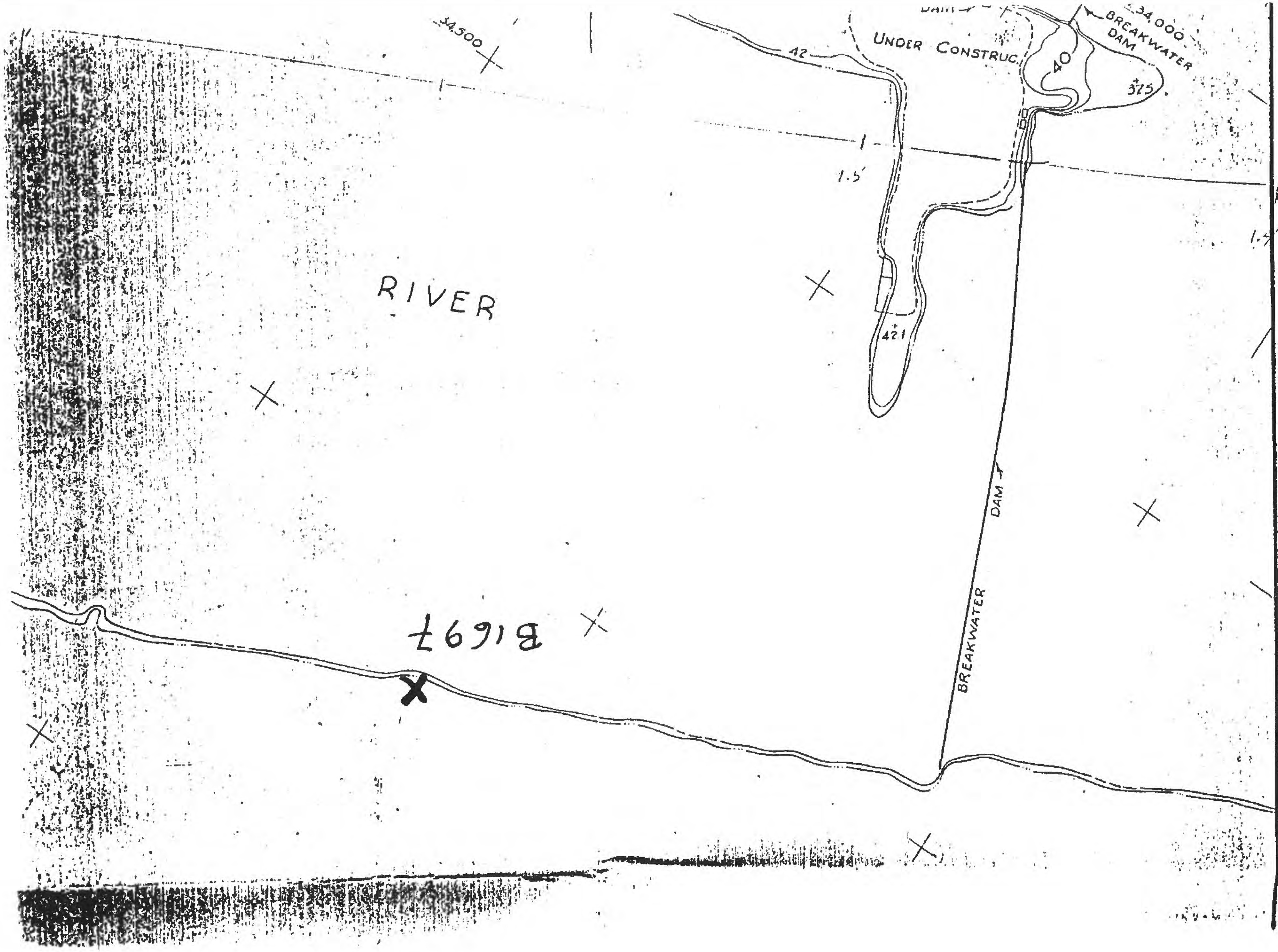
117-10-4-10

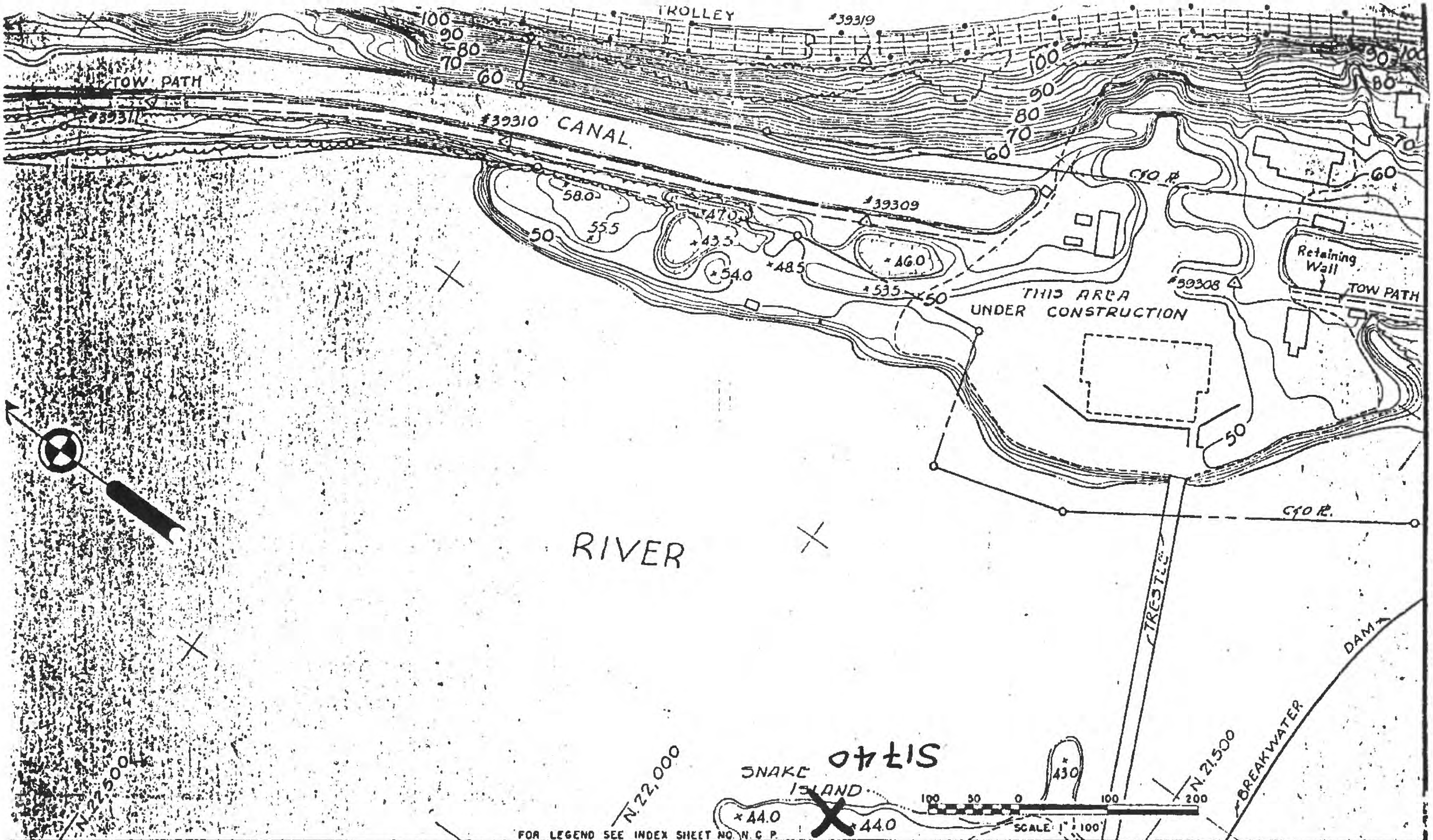
1	2	3
4	5	6

117-10-4-10 (1)




RIVER
B1697
34,500
42
1.5'
UNDER CONSTRUC.
40
421
375
34,000
BREAKWATER DAM
BREAKWATER
DAM

117-10-4-9(6)



FOR LEGEND SEE INDEX SHEET NO. N.C.P.

Match Line to Sheet No. 117.10-4-9

DATE:
DATE:
DATE:
SIGNATURES
DATE:
CHIEF ENGINEER

PREPARED BY
MADDOX & HOPKINS
CONTRACT NO. 14-10-028-1214

SURVEYED BY: SEE SHEET 1 FOR SIGNATURES	DATE	PLOTTED BY:	DATE
FIELD BOOK:		TRACED BY:	
COMPUTATIONS BY:		CHECKED BY:	

UNITED STATES
DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE
NATIONAL CAPITAL PARKS
ENGINEERING BRANCH

TOPOGRAPHY
Key Bridge to Seneca Creek
GEO. WASH. MEM. PKWY. and CHESAPEAKE & OHIO CANAL

REGION
N.C.P.
WASHINGTON, D.C.
SHEET 10 OF 58
DRW. NO.
N.C.P.
117.10-4-10

117-10-4-10(6)

131

Sheet 17 (1)
adjoins sheet 18 at bottom

117.10-4-8

MAP

117-8-D-01-L11

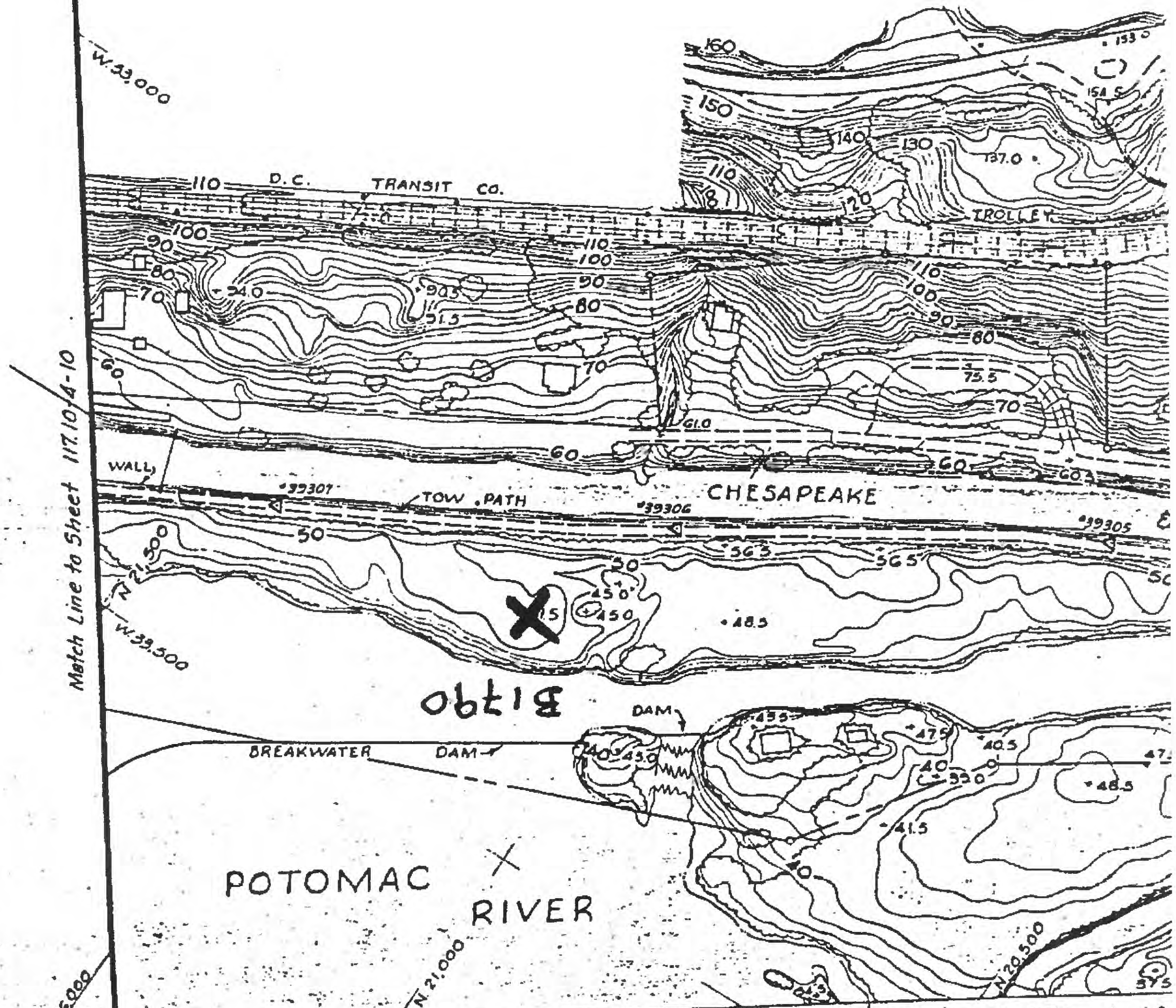
W 32,000

N 407,000

W 32,500

N 22,000

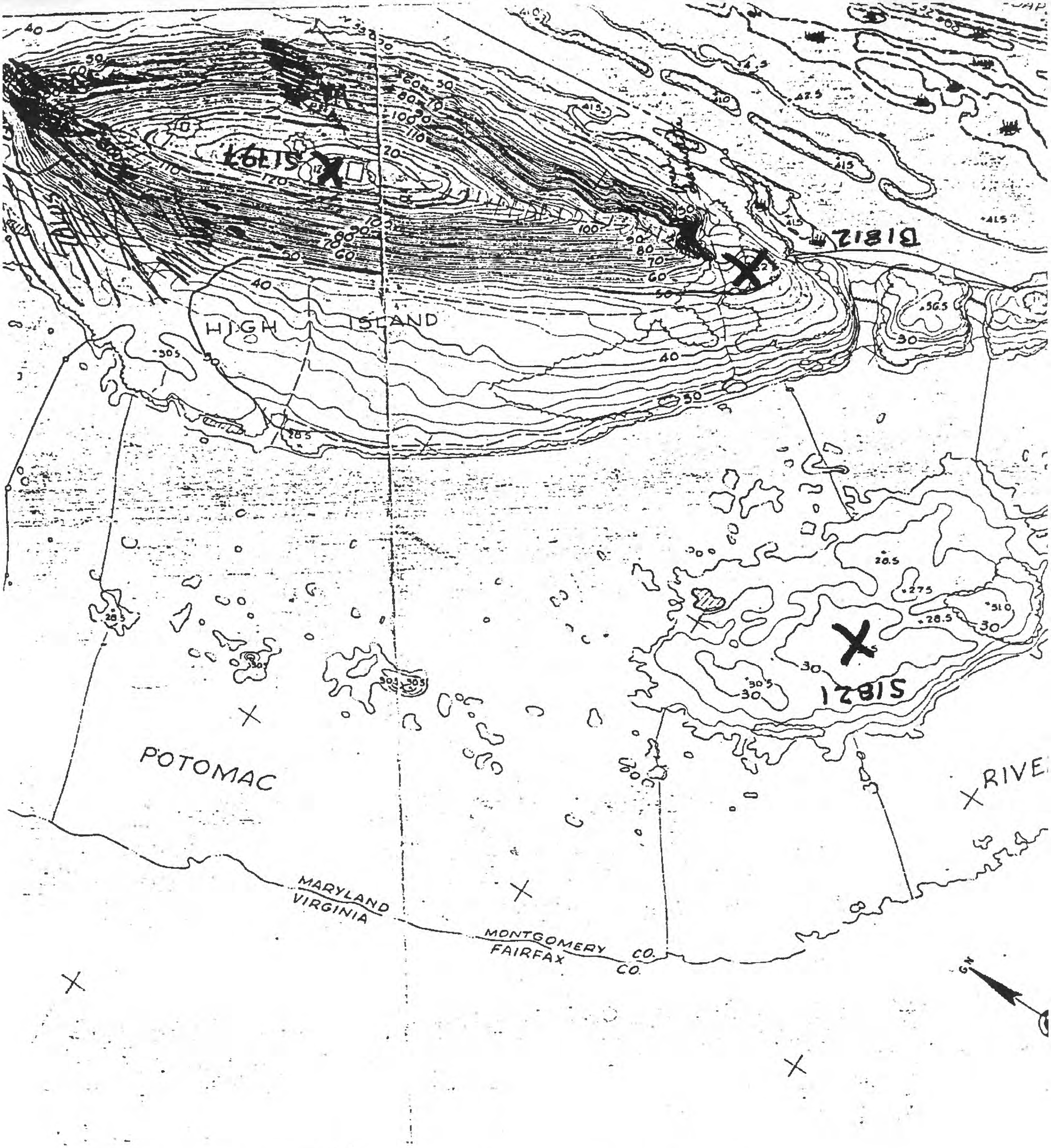
W 33,000



Station	Bearing	Distance	Coordinates Northing	Coordinates Easting	Elevation
39301			19,038.46	32,437.32	45.33
	S. 17° 00' 26" E.	407.88			
39302			19,428.50	32,556.62	48.10
	S. 11° 01' 13" E.	427.14			
39303			19,547.76	32,638.27	48.28
	S. 11° 37' 36" E.	437.95			
39304			20,276.72	32,726.53	54.72
	S. 21° 13' 26" E.	397.55			
39305			20,647.31	32,870.45	54.96
	[illegible]	456.40			

Station	Bearing	D
39306		
	N. 29° 30' 57" W	
39307		

HORIZONTAL DATUM



Sheet 18 (2)   117-10-4-7(2)

FOR LEGEND SEE INDEX SHEET NO

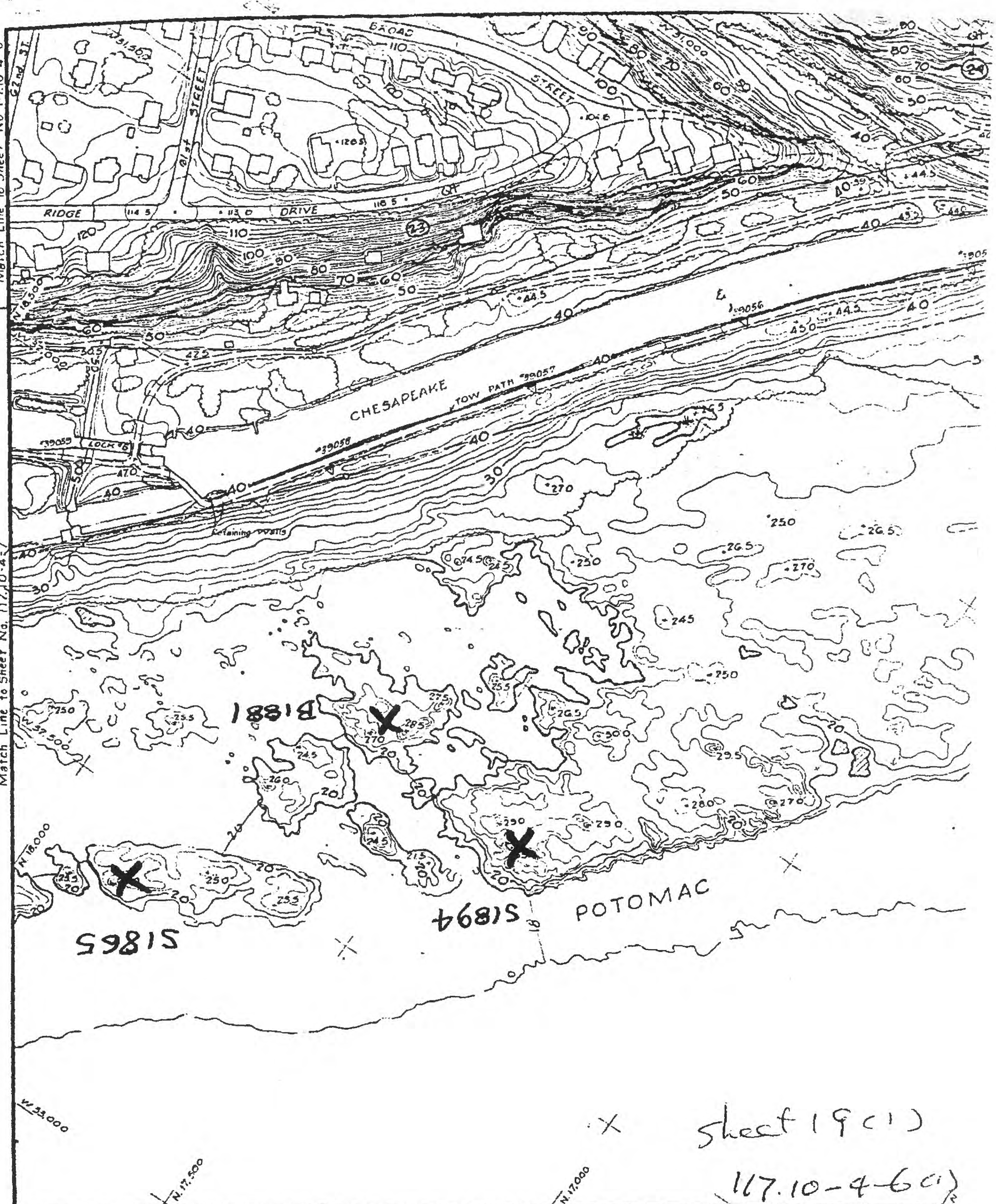
Bearing	Distance	Coordinates Northing	Coordinates Easting	Elevation

HORIZONTAL DATUM
VERTICAL DATUM: LOW WATER

CHECKED BY:
FIELD: ________ DATE: ________
OFFICE: ________ DATE: ________
SUBMITTED: ________ DATE: ________
APPROVED: ________ CHIEF ENGINEER DATE: ________

PREPARED BY
MADDOX & HOPKINS
CONTRACT NO. 14-10-028-1214

SURVEYED BY:	DATE	PLOTTED BY:
FIELD BOOK		TRACED BY:
COMPUTATIONS BY:		CHECKED BY:



sheet 19(1)

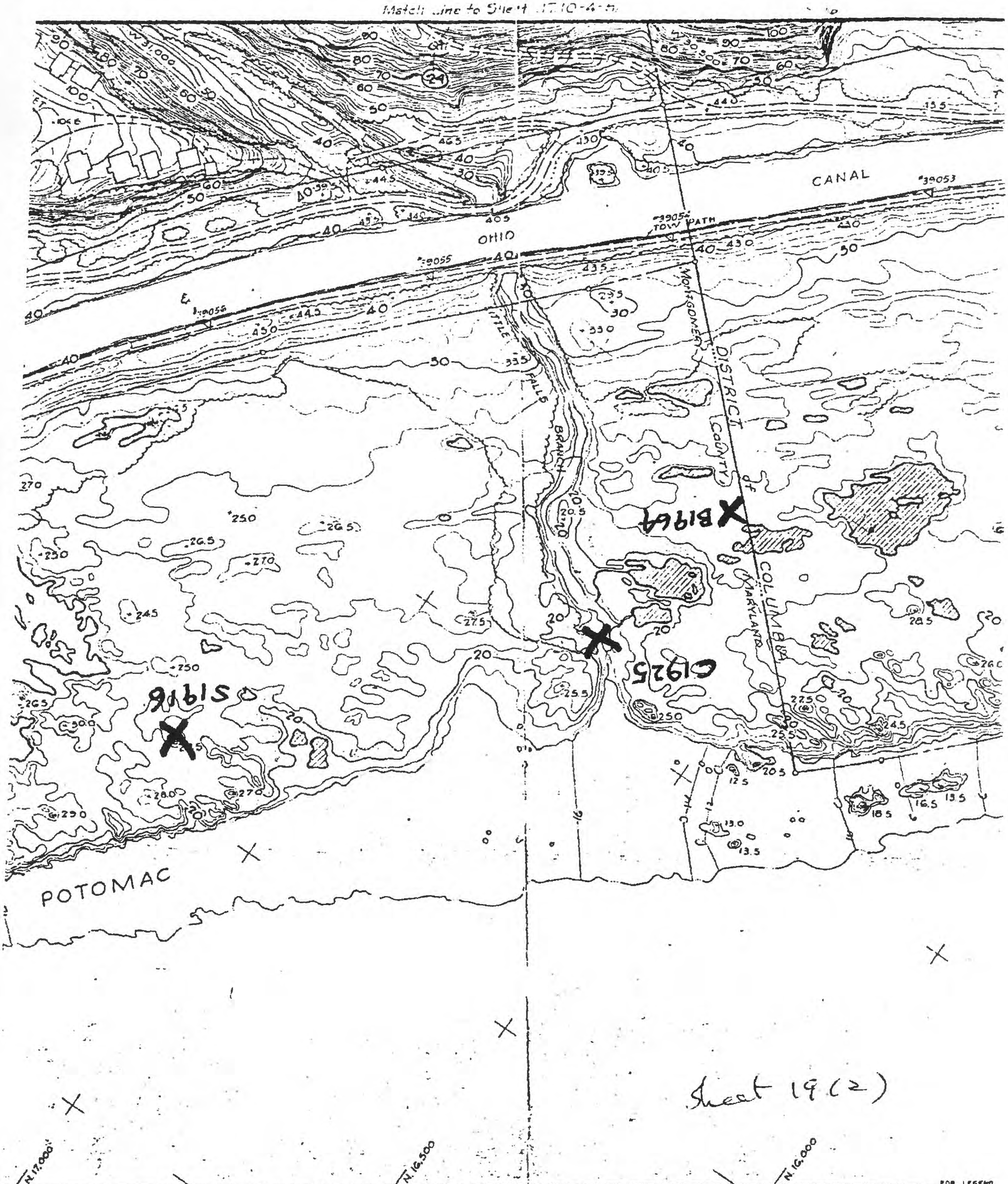
117.10-4-6(1)

Station	Bearing	Distance	Coordinates Northing	Coordinates Easting	Elevation
39059	S. 33° 24' 44" E.	394.07	18,276.13	32,106.22	51.49
39058	S. 36° 10' 26" E.	343.36	17,947.23	31,889.25	43.46
39057	S. 52° 04' 05" E.	349.42	17,756.09	31,604.01	40.05
39056	S. 47° 39' 11" E.	365.10	17,541.29	31,328.41	40.16
39055	S. 43° 51' 14" E.	392.80	17,295.35	31,038.57	41.33
39054	[illegible]	[illegible]	17,012.10	30,786.43	40.94

Station	Bearing	Distance	Coordinates Northing	Coordinates Easting
39053	S. 38° 16' 12" E.	329.23	16,717.65	30,489.40
39052	S. 32° 43' 04" E.	397.94	16,458.88	30,289.20
39051	S. 31° 04' 00" E.	401.81	16,174.07	30,074.11
39050			15,779.89	29,866.76

HORIZONTAL DATUM

VERTICAL DATUM LOW WATER



Station	Bearing	Distance	Coordinates Northing	Coordinates Easting	Elevation
39053			16,712.65	30,489.40	39.28
	S.38° 16' 12" E.	329.23			
39052			16,458.88	30,289.29	39.01
	S.32° 45' 04" E.	397.94			
39051			16,124.07	30,074.11	40.12
	S.31° 04' 00" E.	401.81			
39050			15,779.89	29,866.76	39.28

CHECKED BY: 17-10-4-6(2)
FIELD: DATE:
OFFICE: DATE:
SUBMITTED: DATE:
DATE:

FOR LEGEND
PREPARE
MADDOX B
CONTRACT NO. 14

SURVEYED BY	DATE
FIELD BOOK	
COMPUTATIONS BY	

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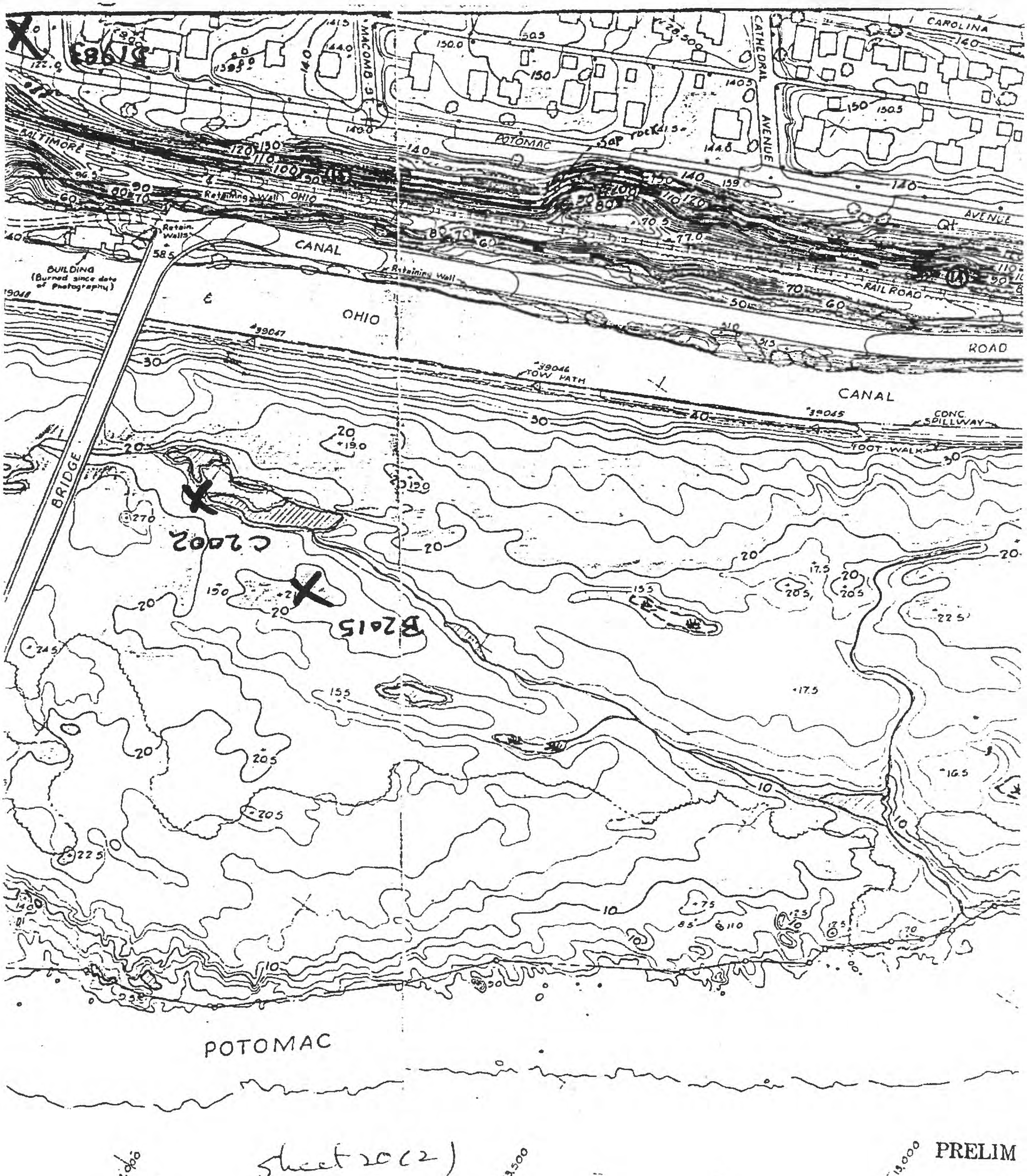


sheet 20 (2)

N 14,000 N 13,500 N 13,000

PRELIM

FOR LEGEND SEE INDEX SHEET NO. N.C.

Distance		Northing	Easting	Elevation
		13,762.44	28,916.95	40.70
'12"E.	440.68	13,390.03	28,661.54	40.28
'11"E.	432.13	13,056.52	28,406.55	40.37
'23"E.	466.04	12,729.05	28,074.96	40.05

(Coordinates)

...NTAL DATUM

VERTICAL DATUM LOW WATER

CHECKED BY 117-10-4-5 (2)

FIELD: DATE:

OFFICE: DATE:

SUBMITTED: DATE:

APPROVED: DATE:

CHIEF ENGINEER

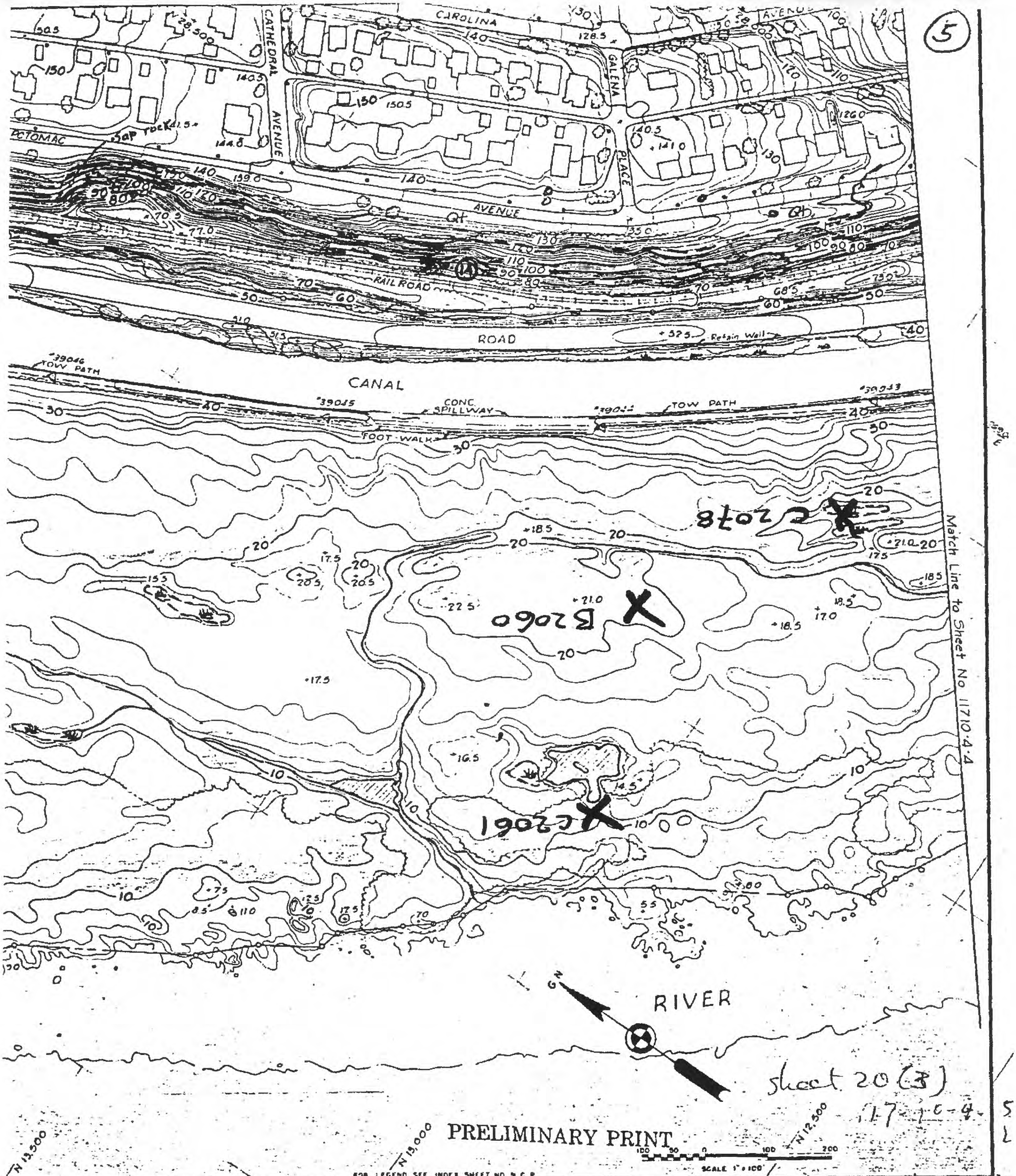
PREPARED BY

MADDOX & HOPKINS

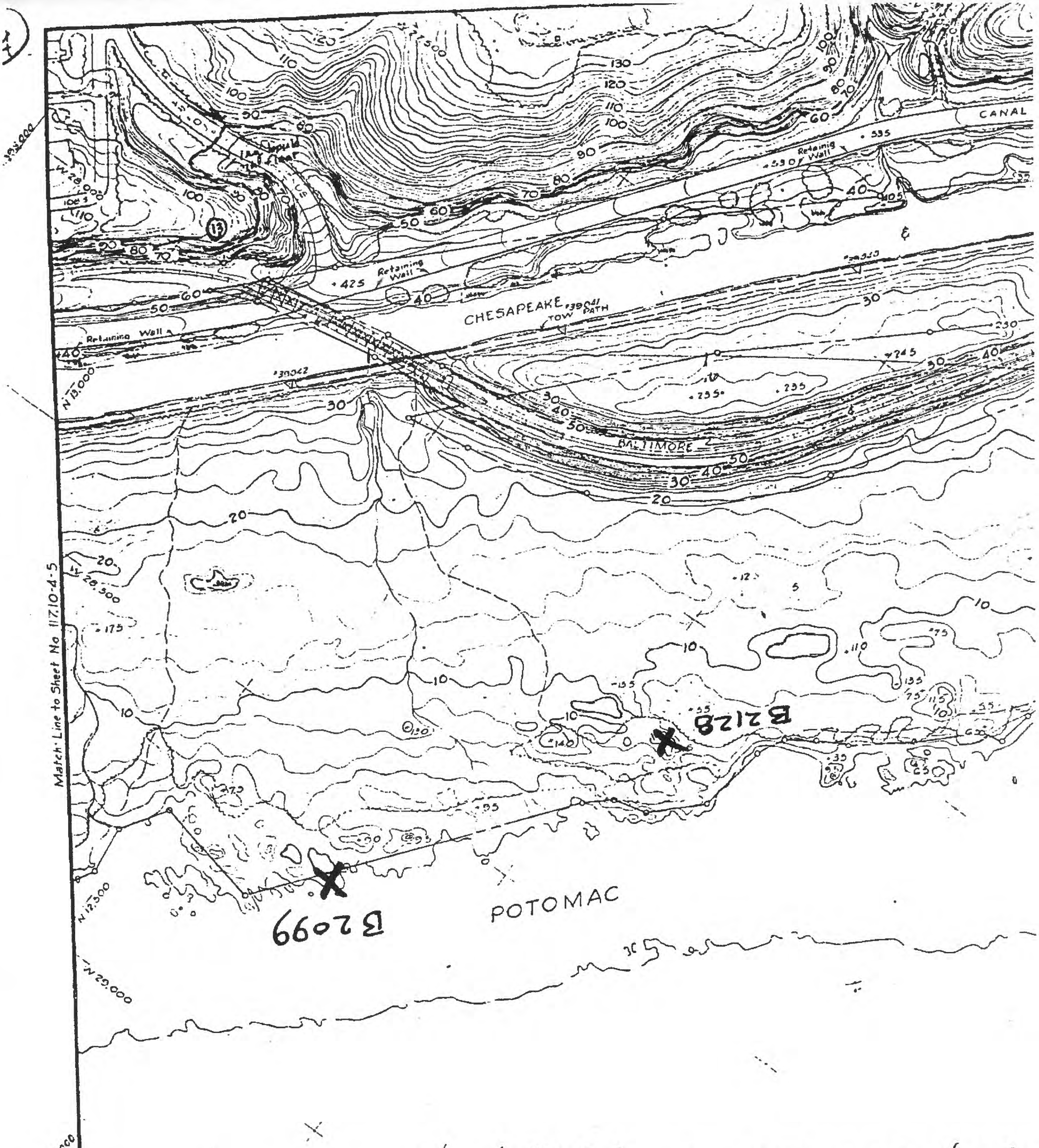
CONTRACT NO 14-10-028-1214

SURVEYED BY	DATE	PLOTTED BY
FIELD BOOK		TRACED BY
COMPUTATIONS BY		CHECKED BY

136



DATE	PREPARED BY MADDOX & HOPKINS	UNITED STATES DEPARTMENT OF THE INTERIOR NATIONAL PARK SERVICE NATIONAL CAPITAL PARKS ENGINEERING BRANCH	REGION N.C.P. WASHINGTON, D.C.
DATE	CONTRACT NO 14-10-028-1214		SHEET 5 OF 94
DATE	SURVEYED BY / DATE / PLOTTED BY / DATE	TOPOGRAPHY	DRW. NO.
	FIELD BOOK / TRACED BY	Key Bridge to Seneca Creek	N.C.P.
DATE / CHIEF ENGINEER	COMPUTATIONS BY / CHECKED BY	GEO WASH. MEM. PKWY. and CHESAPEAKE & OHIO CANAL	117 10-4-5



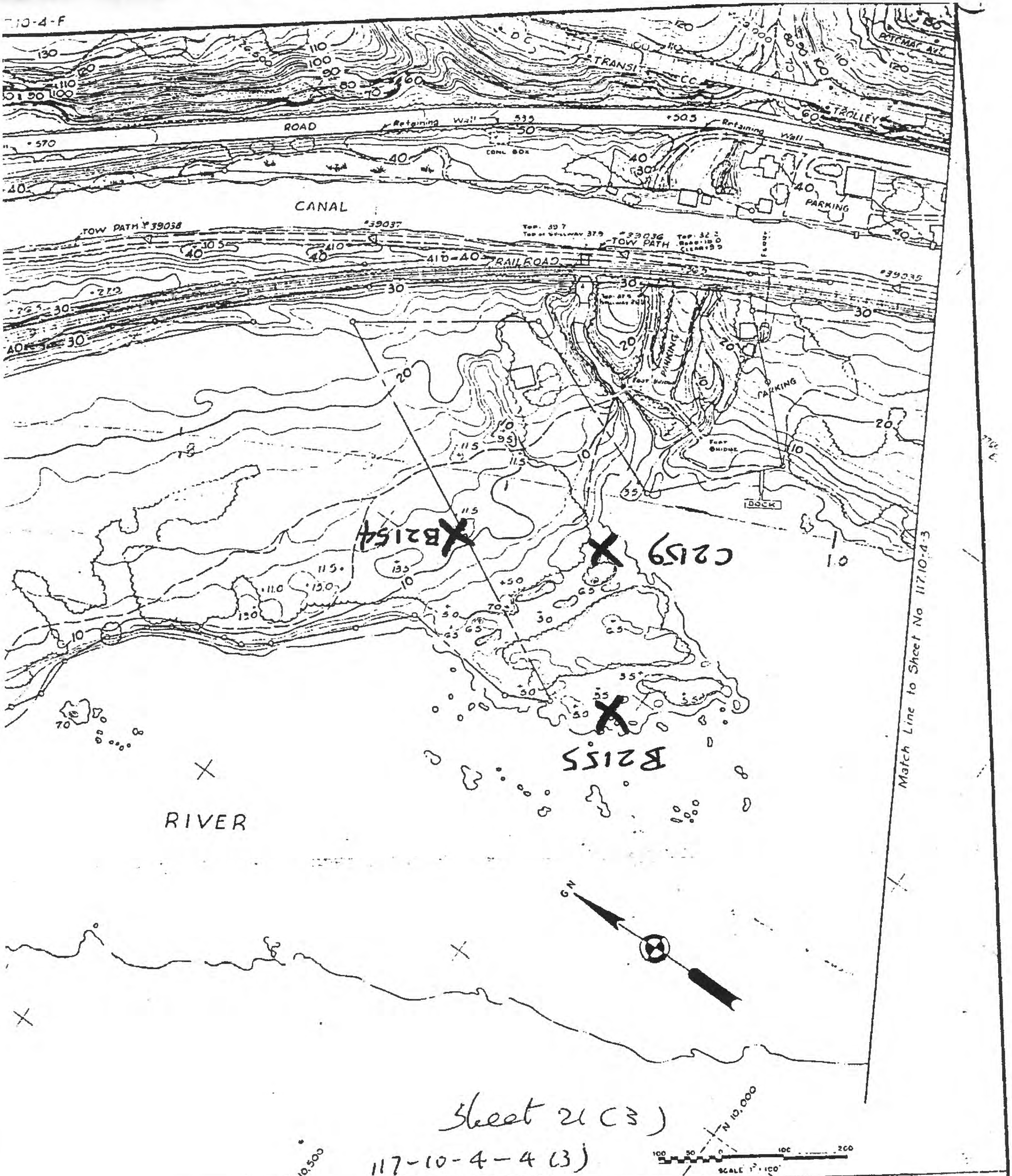
Sheet 21(1) 11F.10-4-4(f)

Station	Bearing	Distance	Coordinates Northing	Coordinates Easting	Elevation
			12,729.63	28,074.96	40.02
39042	S.47°45'22"E.	435.45	12,456.28	27,752.60	39.59
39041	S.47°58'36"E.	466.39	12,124.06	27,406.13	39.63
39040	S.47°15'43"E.	403.62	11,850.14	27,109.68	39.86
39039	S.42°57'05"E.	373.74	11,576.95	26,855.36	39.79
39038	S.36°45'53"E.	363.44	11,285.66	26,638.00	39.88
39037					

Station	Bearing	Distance	Coordinates Northing	Coordinates Easting
			10,945.61	26,424.90
39036	S.27°59'40"E.	433.14	10,563.15	26,221.59
39035	S.26°54'56"E.	464.64	10,147.62	26,013.67
39034				

HORIZONTAL DATUM

VERTICAL DATUM LOW WATER



FOR LEGEND SEE INDEX SHEET NO N C P

PREPARED BY
MADDOX & HOPKINS
CONTRACT NO. 14-10-028-1214

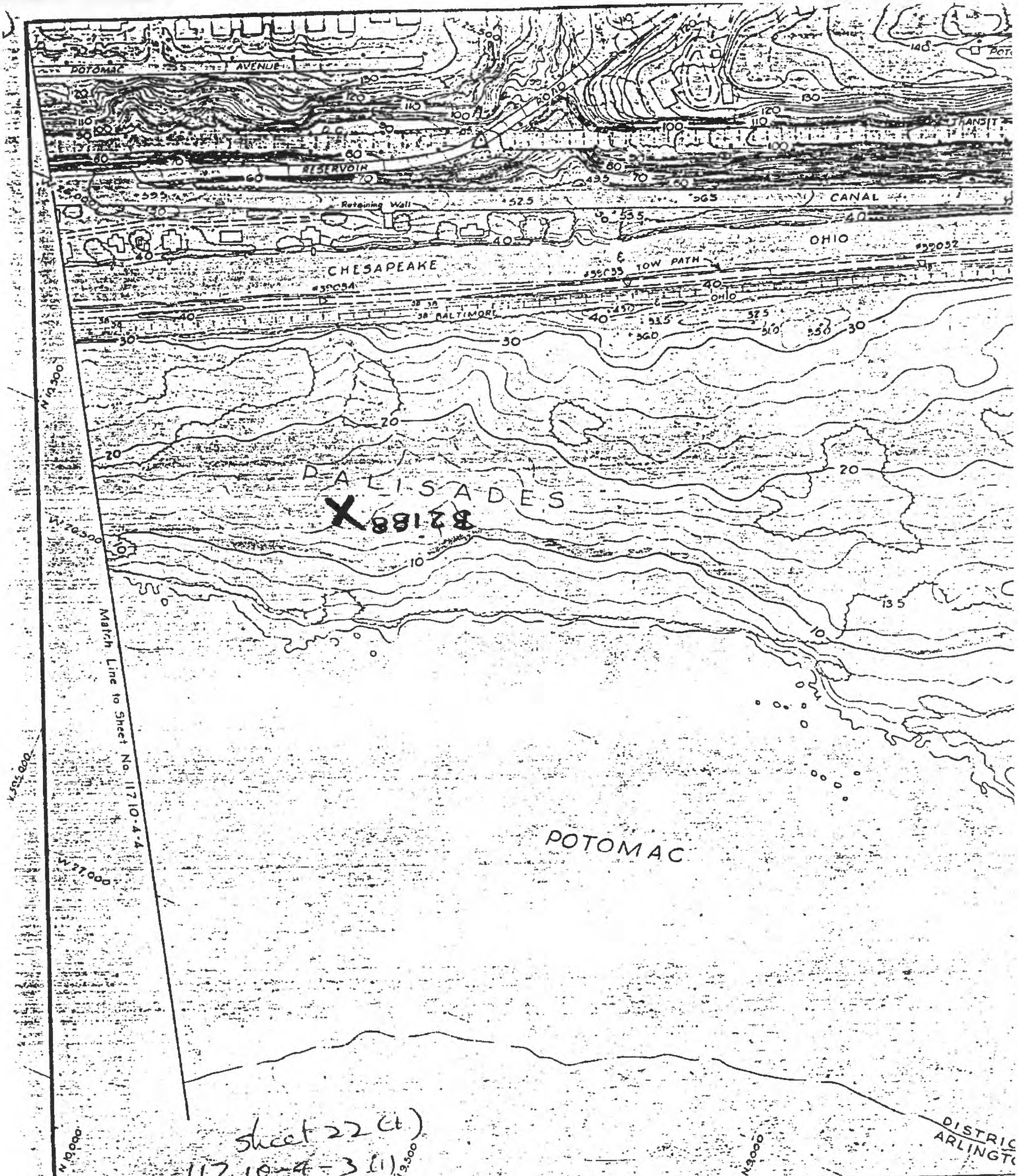
SURVEYED BY	DATE	PLOTTED BY	DATE
FIELD BOOK		TRACED BY	
COMPUTATIONS BY		CHECKED BY	

DATE
DATE
DATE
DATE

UNITED STATES
DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE
NATIONAL CAPITAL PARKS
ENGINEERING BRANCH

TOPOGRAPHY
Key Bridge to Seneca Creek
GEO WASH MEM PKWY and CHESAPEAKE & OHIO CANAL

REGION
N.C.P.
WASHINGTON, D.C.
SHEET 4 OF 53
DRW NO
N.C.P.
117.10-4-4



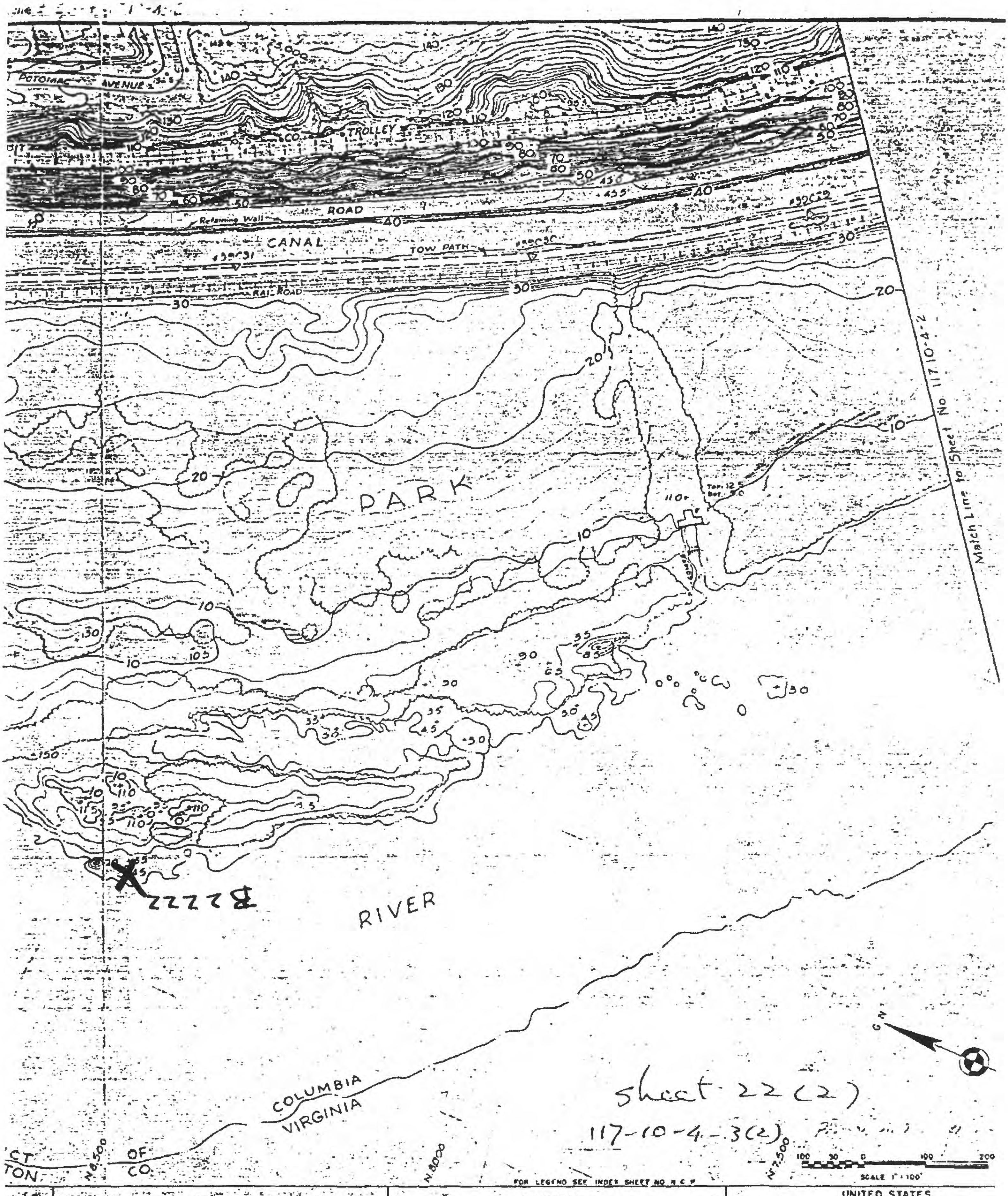
sheet 22 (Lt.)
117.10-4-3 (1)

Station	Bearing	Distance	Coordinates Northing	Coordinates Easting	Elevation
39034			10,147.62	26,013.67	39.90
	S.25°51'19"E.	491.28			
39033			9,705.51	25,799.42	41.44
	S.26°32'10"E.	466.94			
39032			9,287.76	25,590.81	39.73
	S.26°35'05"E.	467.56			
39031			8,869.62	25,381.56	39.77
	S.26°48'55"E.	492.57			
39030			8,358.94	25,163.87	39.20
	S.32°51'57"E.	452.88			
39029			8,058.54	24,918.10	39.19
	S 38°52'04"E.	517.15			
39028			7,659.78	24,596.71	39.25

Station	Bearing	Distance	Coordinates Northing	Coordinates Easting	Elev

HORIZONTAL DATUM

VERTICAL DATUM LOW WATER



CHECKED BY FIELD ____ DATE ____ OFFICE ____ DATE ____	PREPARED BY MADDOX & HOPKINS CONTRACT NO 14-10-028-1214		UNITED STATES DEPARTMENT OF THE INTERIOR NATIONAL PARK SERVICE NATIONAL CAPITAL PARKS ENGINEERING BRANCH
SUBMITTED ____ DATE ____ APPROVED ____ DATE ____	SURVEYED BY ____ DATE FIELD BOOK COMPUTATIONS BY	PLOTTED BY ____ DATE TRACED BY CHECKED BY	TOPOGRAPHY Key Bridge to Seneca Cre GEO WASH MEM PKWY and CHESAPEAKE & OI

Washington Cathedral
CATHEDRAL
Woodley Park
NATIONAL ZOOLOGICAL PARK
FULTON
WOODLEY
Radio Tower (WRC)
CALVERT
U S NAVAL OBSERVATORY
Glover Park
BENTON
Whitehaven Parkway
Holy Rood Cem
Dumbarton Oaks Park
Kalorama Park
Kalorama Circle
WYOMING
CALIF
Columbian Sch
Cooke Sch
EUCLID
Meridian Park
Morgan Sch
Adams Sch
Police Sta
Burleith
Gordon Jr High Sch
Fillmore Sch
Western High Sch
RESERVOIR
Library
Jackson Sch
Montrose Park
Oak Hill Cem
ROCK CREEK
Sheridan Circle
FLORIDA
Augustines Sch
Dupont Circle
MASS
Scott Circle
Foxhall Village
Hospital
GEORGETOWN UNIVERSITY
Playground
Visitation Convent
Police Sta
Hyde Sch
Georgetown
Francis Jr High Sch
NEW HAMPSHIRE
Thomas Circle
Fire Sta
Cem
Park
CANAL
WHITEHURST
FREEWAY
Columbia Hosp
Stevens Sch
Washington Circle
Doctors Hospital
Farragut Square
McPherson Square
YWCA
PENNSYLVANIA
EYE
Geo Washington Hospital
GEORGE WASHINGTON UNIVERSITY
Lafayette Park
YMCA
Grant Sch
The White House
Zero Milestone
The Ellipse
CONSTITUTION
GEORGE WASHINGTON MEM
KEY BRIDGE
Highlands
Rosslyn
Theodore Roosevelt Memorial
Kennedy Center
Little River
Roosevelt Island
THEO ROOSEVELT BRIDGE
Wilson Sch
Colonial Village
Fort Myer Heights
Courthouse
Radnor Heights
U S Marine Memorial
Carillon
WEST POTOMAC
Water Gate
Lincoln Memorial
Reflecting Pool
THE Washington Monument
PARK
KUTZ BRIDGE
MEMORIAL BRIDGE
Tidal Basin
U S MILITARY RES
FORT MYER
Columbia Island
Boundary Channel
RIVER
OHIO DRIVE
MT VERNON MEM HY
Jefferson Memorial
Arlington House The Robert E Lee Memorial
ARLINGTON NATIONAL CEMETERY
Tomb of the Unknowns
Amphitheater
Cem
Sewage Disposal
LADY BIRD JOHNSON MEMORIAL PARK
Navy & Marine Memorial
GEO MASON BRIDGE
EAST
ORNERS 4.1 MI.
FAIRFAX 14 MI.
5'
'20
(ALEXANDRIA)
5561 I SE
MOUNT VERNON 14 M
2'30"
ALEXANDRIA VA 5 M
FREDERICKSBURG VA 53 M