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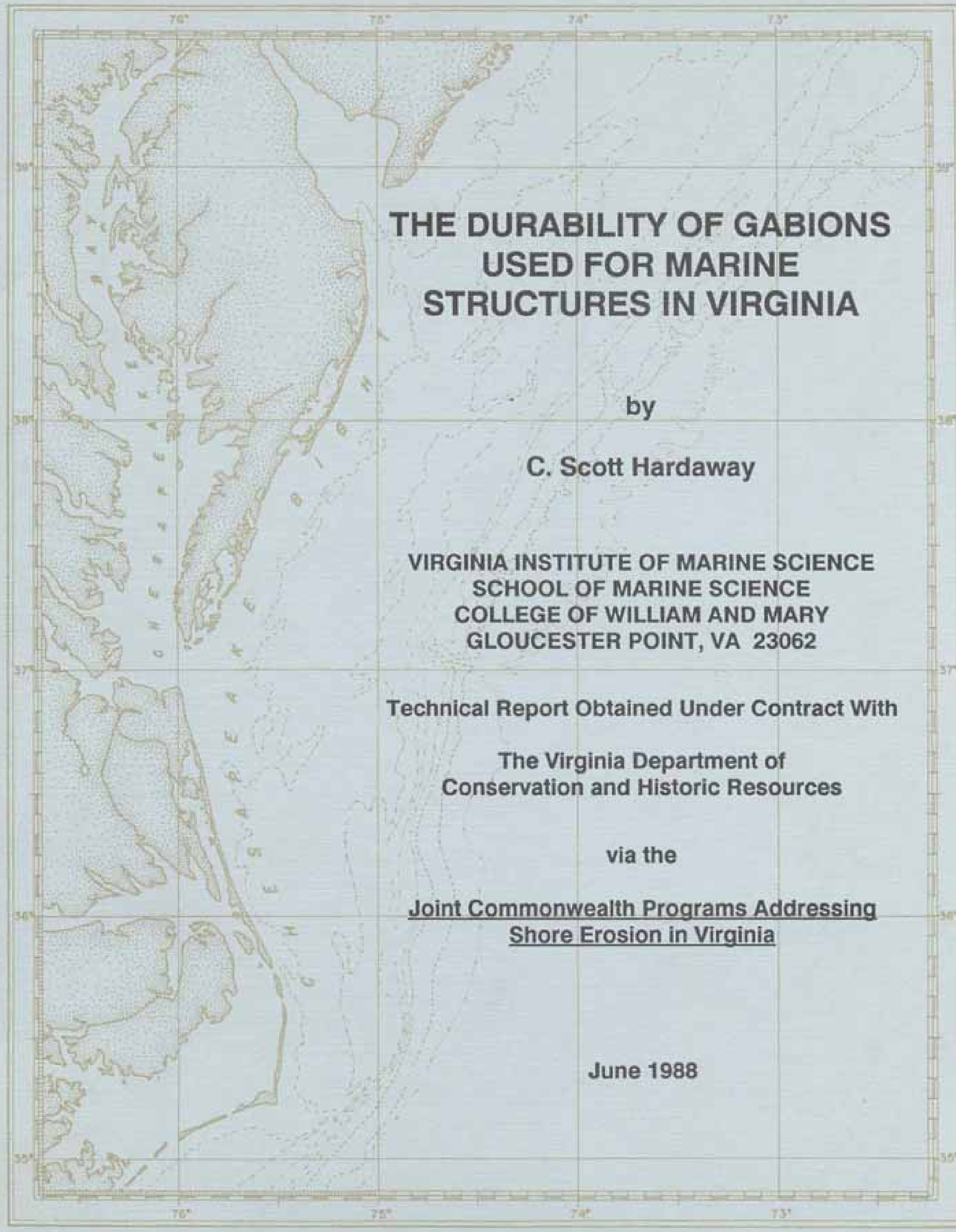
The Durability of Gabions Used for Marine Structures in Virginia

C. Scott Hardaway Jr.
Virginia Institute of Marine Science



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Technical Report Obtained Under Contract With

The Virginia Department of
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<u>Joint Commonwealth Programs Addressing Shore Erosion in Virginia</u>

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Introduction

Gabions have been used for coastal structures in Virginia since the early 1960s. Shoreline property owners have used gabions for sills, spurs, groins, revetments and breakwaters. The success of a given structure depends on the durability of the gabion itself. The durability of a gabion in turn appears to depend upon construction technique and several environmental factors. These factors include local water's salinity, exposure to wave action, subjugation to floating debris and duration of submergence (i.e. position relative to MHW). The purpose of this report is to relate the above factors to gabion durability using selected sites in Virginia's Chesapeake Bay estuarine system as examples.

Box gabions consist of rectangular units fabricated from a double twist, hexagonal mesh of soft annealed, heavily galvanized wire (Figure 1). The wire is 3 mm in diameter and can be coated with 0.5 mm of polyvinyl chloride (PVC) for marine purposes. The gabions generally are filled with granite rocks weighing between 30 and 80 pounds. However, shoreline property owners have used broken concrete, bricks and a combination of rocks, broken concrete and bricks. Gabions come in various sizes (Table 1). U.S. standard size "C", "F" and "D" are the most commonly used in Virginia.

The following section deals with gabion emplacements throughout the tidal waters of Virginia (Figure 2). The sites are grouped according to the type of structure which was built. These include revetments, groins, sills, spurs, and breakwaters. Each group of structures is exposed to similar conditions such as duration submerged and exposure to sunlight. For instance, gabion breakwaters generally are partially

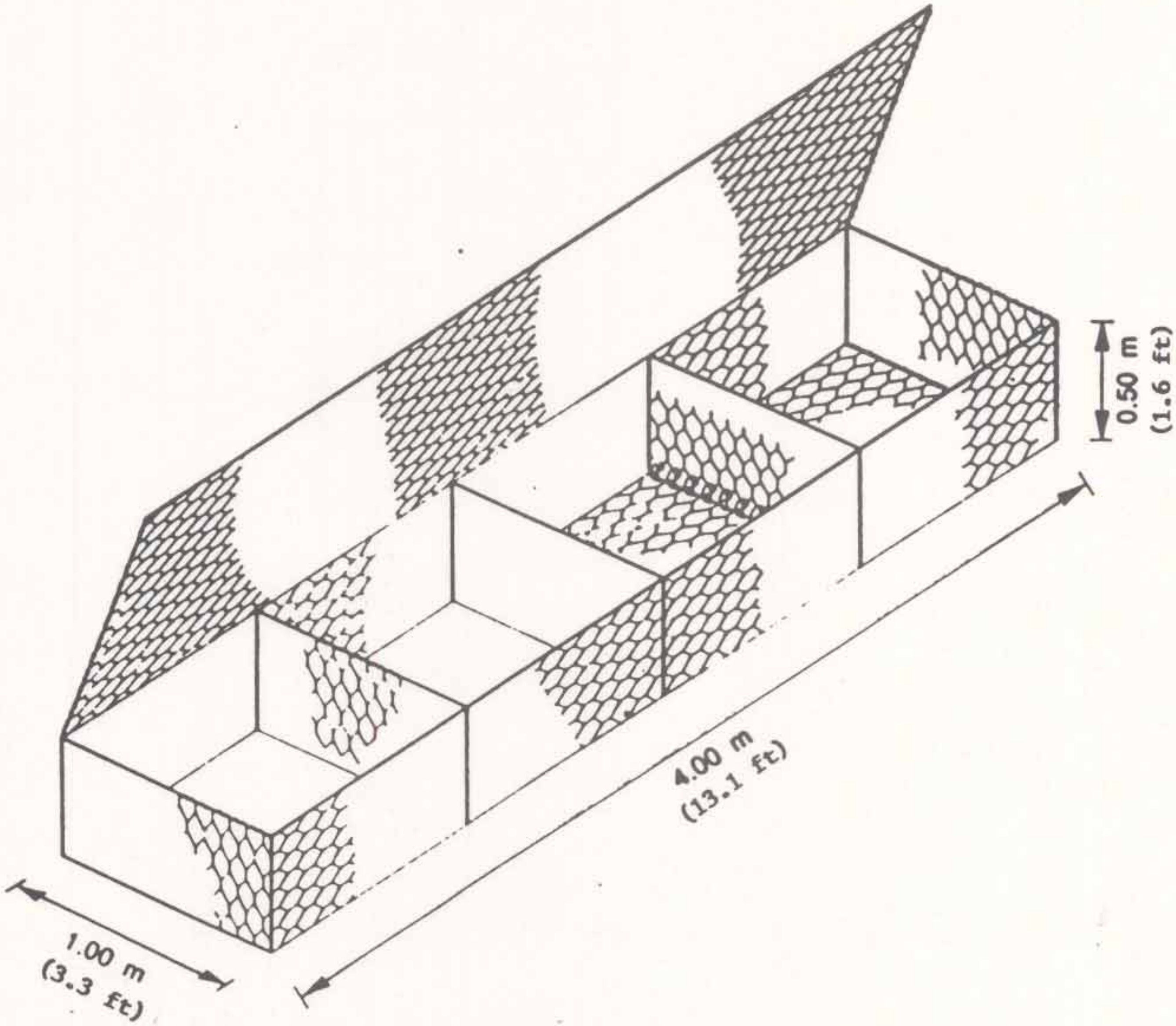


Figure 1. Gabion basket perspective - size F metric.

HEAVY DUTY GALVANIZED GABIONS

SPECIFICATIONS

	GALVANIZED GABIONS	P.V.C. COATED
Mesh Opening	Type 8 x 10 (3" x 4")	Type 8 x 10 (3" x 4")
Wire For Netting	3.00 mm. (.1181") ± 2½% approximately U.S. Gauge 11	2.7 mm. (.1063") ± 2½% approximatelly U.S. Gauge 12
Wire For Selvedges And Corners	3.90 mm. (.1535") ± 2½% approximately U.S. Gauge 9	3.40 mm. (.1338") ± 2½% approximately U.S. Gauge 10½
Wire For Binding	2.20 mm. (.0866") ± 2½% approximately U.S. Gauge 13½	2.20 mm. (.0866") ± 2½% approximately U.S. Gauge 13½
Zinc Coating	Oz. .80-Sq. Ft.	Oz. .80-Sq. Ft.
P.V.C. Coating		0.4 mm. (0.015")

RECOMMENDED *NEW* ✓ STANDARD METRIC SIZES

ALSO AVAILABLE IN P.V.C. COATED WIRE

Letter Code of Size	Length—Width Depth in Meters	Approximate equivalents in Feet	No. of Diaphragms	Cpacity		Color code used on metal label inserted in each unit to distinguish sizes
				Cubic Meters	Cubic Yards	
A	2x1x1	6'6"x3'8"x3'3"	2	2	2.616	BLUE
B	3x1x1	9'9"x3'3"x3'3"	2	3	3.924	WHITE
C	4x1x1	13'1"x3'3"x3'3"	3	4	5.232	BLACK
D	2x1x.5	6'6"x3'3"x1'8"	1	1	1.308	RED
E	3x1x.5	9'9"x3'3"x1'8"	2	1.5	1.962	GREEN
F	4x1x.5	13'1"x3'3"x1'8"	3	2	2.616	YELLOW
G	2x1x.3	6'6"x3'3"x1'	1	0.6	0.785	BLUE-RED
H	3x1x.3	9'9"x3'3"x1'	2	0.9	1.177	BLUE-YELLOW
I	4x1x.3	13'1"x3'3"x1'	3	1.2	1.570	BLUE-GREEN

U.S. SIZES

Letter Code	Length	Width	Height	Number of Cells	Capacity Cubic Yards	Color Code
A	6'	3'	3'	2	2.0	BLUE
B	9'	3'	3'	3	3.0	WHITE
C	12'	3'	3'	4	4.0	BLACK
D	6'	3'	1'6'	2	1.0	RED
E	9'	3'	1'6'	3	1.5	GREEN
F	12'	3'	1'6'	4	2.0	YELLOW
G	6'	3'	1'	2	0.66	BLUE-RED
H	9'	3'	1'	3	1.0	BLUE-YELLOW
I	12'	3'	1'	4	1.33	BLUE-GREEn

Figure 2. Gabion sizes and specifications (after Maccafferri).

Figure 3. Selected gabion installations in the Virginia portion of the Chesapeake Bay Estuarine System.

submerged over a tidal cycle whereas sills are often fully submerged over the same tidal cycle. The type of the structure will dictate the degree of exposure to environmental conditions.

Field Assessment

The gabion installations were visited and inspected. Field assesment of the installations indicates that the condition of the PVC coating is of major importance to the durability of the structure. Generally, if the PVC had worn off, the wire showed signs of rust. If the PVC was completely worn and the wire heavily rusted, breakage usually occured. The VIMS Demonstration Project report, personnel from the Shoreline Erosion Advisory Service (SEAS) who provided some of the sites for assessment, and interviews property owners provide information on the dates of installation and methods of construction. Factors other than environmental ones are the type of fill material and the construction technique. A qualitative rating of good, fair or poor was devised for construction technique, the condition of the wire and general condition of the structure (Table 2). Location maps and photos for the sites in the following sections are found in the Appendix and are accordingly referred to in the text.

Revetments

Revetments generally consist of gabions placed end to end and running parallel to shore. Revetments may be constructed of two or more baskets stacked and tied on top of each other or of a line of single baskets. Revetments are built to retain soil on the landward side and protect the base of a fastland bank from wave action. Some sites also had groins.

Table 1. Qualitative Ratings and Definitions for Gabion Installations

Rating	Definition
Construction Technique	
Poor = 1	Fill material packed loosely, not full; wire loosely laced
Fair = 2	Fill material packed loosely, full; wire adequately laced
Good = 3	Fill material packed tightly, full; wire laced tightly
Condition of PVC Wire	
Poor = 1	>5% broken wire, general abrasion or loss of PVC and rusted wire, some holes
Fair = 2	<5% broken wire, minor loss of PVC and slightly rusted wire, no holes
Good = 3	<1% broken wire, PVC rust colored, not abraded, no holes
General Condition of Structure	
Poor = 1	Numerous major (>1 ft in diameter) holes and loss of fill
Fair = 2	No major holes, some broken wire, exposed fill with no major losses
Good = 3	No broken wire, no holes or loss of fill

Hog Island Wildlife Management Area, James River, Surry County (Figure A1)

Some of the oldest known gabion structures along tidal waters in the Commonwealth occur at Hog Island Wildlife Management area on the James River. Three separate installations were built in 1962 (oral communication, Mr. Clyde Abernathy).

1) West Shore

The west shore revetment has one groin associated with it (Figure A2). The 96-foot long revetment is built of size "C" baskets. The overall structural condition is failure of the gabions. There are massive holes along the front face and on top of the structure and there is loss of rock fill. Mr. Abernathy attributes much of this damage to floating stumps and logs coming down the James River and striking the structure. The single gabion groin is in similar condition.

2) Mr. Abernathy's House

The revetment in front of Mr. Abernathy's house is composed of size "C" gabions sitting on top and back of two size "F" gabions (Figure A3). They were filled with a combination of rock and large cinderblocks. The condition of the structure is massive failure along the front face of upper size "C" baskets and across the tops of the fronting size "F" baskets. Mr. Abernathy stated that an old wooden barge had broken loose during a storm on 4 November 1985 and caused the bulk of the damage.

3) Heron Rook

The approximately 800-foot long gabion revetment at the Heron Rook has eight groins associated with it (Figure A4). Both type structure are built of size "C" baskets and are filled with rock. The revetment is generally intact. However, it has rotated seaward in many places. There are only two basket failures on the northern half of the revetment. These occur at the juncture of groins and revetment. The southern half has 11 baskets with large holes and loss of rock. Most of these failures also occur adjacent to the groins. The groins have also failed at the junction as well as at their ends. The south half of the Heron Rook revetment may be more exposed to floating debris than the north half which is partially protected by marsh headland just upriver. This may account for the higher number of basket failures in the downstream section.

L.R. Evans, Rappahannock River, Lancaster County (Figure A5)

The gabion revetment along the property of L.R. Evans is composed of three layers of size "F" baskets stacked slightly stair-stepped and filled with rock (Figure A6). Overall the structure is in good shape. The PVC coating is split intermittently and the wire rusted. This occurs mostly where the wire twists and bends. The lower half of the structure is intertidal with no beach. Numerous small oysters have attached to the basket and rocks below MSL.

Sills

In 1977 the Virginia Institute of Marine Science (VIMS) initiated a project to test the effectiveness of sills and spurs. A sill is a low structure placed at the base of the foreshore beach slope where it will act as a hinge for the formation of an elevated beach face. When successful, the backshore elevation is increased as well. The effect of the "perched" beach is to provide an elevation increase which will reduce the number of occasions when waves, in conjunction with storm surge, directly attack the fastland (Anderson et al., 1978).

Results from the project showed that gabions were superior to the large, sand filled bags which were also used for sill construction. Since then, gabion sills have been emplaced by several waterfront property owners.

Demonstration Project Sites

Saxis, Pocomoke Sound, Accomack County (Figure A7)

The sill at Saxis, built in 1978, is composed of size "C", rock filled baskets with alternating 12-foot sand bags. It is 220 feet long and was placed initially at ~ -0.5 foot MLW. The sand bags have deteriorated. The baskets were inspected in 1983 and were partially buried and very much intact. Today the entire sill is covered with sand and is assumed to still be in good shape (Figure A8).

Silver Beach, Chesapeake Bay, Northampton County (Figure A9)

The gabion sill at Silver Beach is constructed of size "C" baskets filled with rock. It is 150 feet long and was initially one half of a continuous sill (Figure A10). The other half was made of sand bags which have since deflated with only remnants of cloth remaining. Four to 5 basket cells have failed and are completely void of rock. The PVC wire on the remaining baskets is scarred and rusted. Sand on the beach side covers the bottom half of the structure. Numerous large pieces of broken concrete are strewn across the beach and nearshore. Most likely this loose debris occasionally strikes the exposed portion of the gabion sill and abrades the PVC.

D. Smith, Chesapeake Bay, Middlesex County (Figure A11)

The gabion sill at the D. Smith site was placed at about MLW, is 180 feet long and is composed of size "C" baskets. Soon after installation in 1978, sand began to fill behind the sill. Today, it is completely buried and presumed intact (Figure A12).

D. Vann, York River, Gloucester County (Figure A13)

This site was not part of the aforementioned Demonstration Project but was installed in the same year (1978). The structure was filled loosely with broken concrete (Figure A14). This may be the only site in the report that did not use Maccafferri gabions. Much of the sill has failed along the tops of the baskets. The structural failure appears attributable to poor construction. Loose packing of broken concrete which has shifted under wave action scarred and abraded the PVC inducing rust and causing subsequent breakage of the wire.

Herndon, Chesapeake Bay, ~~Middlesex~~ Mathews County (Figure A11)

There are three gabion sill installations at the Herndon site. The northern-most is at -3.0 feet MLW (1), the middle sill at -0.5 foot MLW (2) and the southern sill at -0.5 foot MLW (3) (Figure A15). Sills 1 and 2 are intact with abundant growths of oysters, sponges, and such. Sill 3 was placed adjacent to the existing bulkhead where it acted partially as a spur. The basket at the juncture of the bulkhead has failed with the loss of the stone fill.

Mizelle, James River, Isle of Wight County (Figure A16)

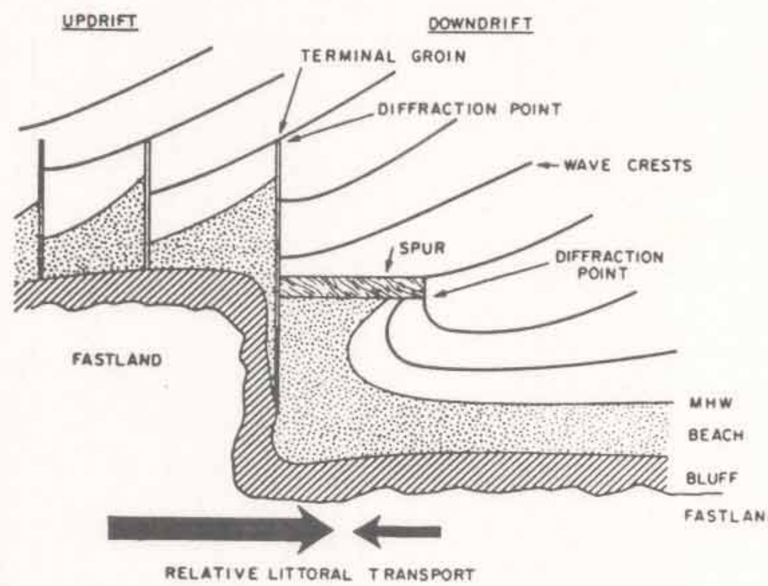
The sill at the Mizelle site apparently was constructed as a scour apron in front of a wooden bulkhead. The size "F" baskets are filled with broken concrete. After emplacement of the sill, additional broken concrete was stacked behind it and against the bulkhead (Figure A17). Subsequent wave action has moved the loose pieces of broken concrete across the top of the sill. This has caused abrasion of the PVC wire and in some places basket failure.

Funston, Mobjack Bay, Gloucester County (Figure A18)

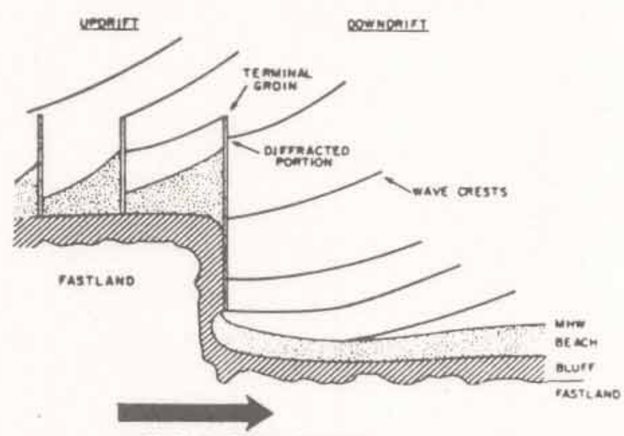
The gabion sill at the Funston site initially was installed in the spring of 1987. Apparently it still is under construction (Figure A19). The structure is 360 feet long. Some of the size "D" baskets have been set in place but not filled with rock. The packing is poor and the tieing is loose. Since it is a recent structure, the PVC wire is still in good shape. However, given the poor construction technique and long fetch exposure, the potential for premature basket failure is high.

Spurs

The principle of the use of a spur on a groin is illustrated in Figure 4. While a groin will trap sand on the updrift side there is, in almost all cases, concommitent erosion on the downdrift side of the groin. The erosion is due to two effects. First the littoral drift is interrupted by the groin itself. The second effect causing the downdrift erosion is wave diffraction at the end of the groin. The process of diffraction causes the wave crests to bend and become perpendicular to the groin. Wave action thus is concentrated at the junction of the groin with the fastland. If the erosion notch captures



Updrift wave approach with spur



"Updrift" approach of waves

Figure 4. Spur application to a groin (Anderson et al., 1983).

the junction of the groin and the fastland, the structure will become isolated from the bank and fail to collect sand. The purpose of the spur is to utilize the diffraction of waves at the tip of the spur to drive a fillet of sand into the corner behind the spur. This sand fillet acts to prevent the encroachment of the erosion notch at the junctions of the groin and fastland (Anderson et al., 1978).

VIMS, York River, Gloucester County (Figure A20)

The gabion spur at VIMS was installed on 20 March 1978. The spur consisted of two size "D" gabions tied together and placed near MLW on the downdrift side of a large wooden groin. This site not only tested the spur concept, but also the use of expended tire casings as fill material. Approximately 130 used automobile tires were compacted into two bundles of 65 tires each and bound together with 1 1/4 inch steel bands. Each bundle weighed approximately 1,600 pounds in air. Soon after installation, the bands on one of the bundles were broken. Approximately 18 weeks later, the remaining bundle's bands broke due to corrosion. On 20 April 1978 a northeast storm rotated the gabion about 40 degrees landward by strong wave action and increased water levels. This separated it from the groin by about 2 feet.

Today the PVC coating is in good shape with minor slits and rust color at the twists which is exposed above MHW (Figure A21). The wire has several breaks across the top. The tire casings which were used as fill could not produce the proper filling volume to keep the basket tight.

Herndon, Chesapeake Bay, Middlesex County (Figure A11)

There are three gabion spurs at the Herndon site (Figure A22). They were installed in 1978, the same time as the sill installations.

The spurs were constructed of size "C" baskets and placed at about -0.5 ft MLW. They have since suffered major failure of the baskets at the juncture of the spur and groin. This pattern of failure supports the theory of concentrated wave energy possibly in combination with floating debris at those points. This appears to be true especially if the spur is exposed above MLW.

Summerille, Potomac River, Northumberland County (Figure A23)

The spur installation at Summerille was successful immediately at trapping sand. Built in 1978, it remains a success today. However, in 1986 the gabion had become broken and was losing its rock fill mostly due to the adverse action of ice and floating debris in the Potomac River (personal communication, Mr. Summerille). Riprap had to be placed over the deteriorating gabions to maintain the integrity of the spur. Failure had occurred along the entire 60-foot section of the spur.

Booth, York River, Gloucester County (Figure A20)

The spur at the Booth site consists of one size "C" basket. It was emplaced in 1978. The gabion has been buried for several years and is presumed to be very much intact.

Breakwaters

VIMS, York River, Gloucester County (Figure A20)

The gabion breakwaters at VIMS were installed in October of 1983. The size "C" and "F" baskets were handfilled on land. They then were installed using a tracked backhoe and "I" beam lift. Hooks from the "I" beam grasped the sides of each basket and placed it in the approximate position at about 0.0 ft MLW. Unfortunately, the hooks tore some of the wire. Consequently a few holes developed. Otherwise, the wire and structure is generally in good shape (Figure A24). Marine growth below MSL includes small oysters, barnicles and algae.

Krumbein, Jackson Creek, Middlesex County (Figure A25)

The gapped breakwater system is composed of four segments each with 2 size "C" baskets placed at about 0.0 ft MLW. The baskets were installed in the spring of 1986. The structure was well packed with fill, but poorly tied together. The wire is not coated with PVC and already is showing signs of rust.

Schermerhorn, York River, Gloucester County (Figure A26)

Installation of the gabion breakwater system began in June of 1987 and proceeded over several months. The system is composed of three breakwater units of which two are 36 feet long and one is 48 feet long (Figure A27). Size "C" baskets were used. They were properly filled and tied. Being a recent installation, the PVC wire and baskets are very much intact.

Results

Results of the field and various environmental assessments for gabion installations in Virginia are shown in Table 3. Significant structural failure was found at several locations. Major factors for basket failure appear to be intertidal installations with poor construction and long term exposure to constant wave action (i.e. long fetch), ice and/or floating debris (i.e. stumps and logs). Poor packing of fill material leads to abrasion of the PVC, corrosion of the galvanized wire and finally breakage with loss of fill. Poor packing was seen at Vann, Funston and Mizelle. The use of sharp edged, broken

Table 2. Parameters Assessment of Gabion Installations

Structure Site	Average Fetch (nm)	Shore Orientation Normal Exposure	Average Salinity (ppt)	Mean Tide Range (ft)	Age (Yrs)	Position Relative to MLW (ft)	Average Basket Height (ft)	Fill Material	Construction Technique	General Condition of PVC Wire	General Condition of Structure	Remarks
Revetments												
Hog Island:												
West Shore (1)	3.2	282°	1	2.1	25	0.5	3.0	R	Good*	Good*	Fair*	
Abernathy (2)	2.4	039°	1	2.1	25	0.5	3.0/1.5	R, CB	Fair	Good	Poor	
Heron Rook (3)	2.4	039°	1	2.1	25	0.0/0.5	3.0	R, CB	Good	Good	Fair	
L.R. Evans	2.6	225°	14	1.3	8	-0.5	1.5	R	Fair	Fair	Fair	
Sills												
Saxis	12.9	300°	18	2.2	9	1.0	3.0	R	Good	Good	Good	Buried
Silver Beach	25.3	275°	22	1.8	9	-0.5	3.0	R	Good	Fair	Poor	
D. Smith	18.8	028°	17	1.2	9	2.0	3.0	R	Good	Good	Good	Buried
D. Vann	6.7	237°	16	2.8	9	-0.5	1.5	BrC, CB	Poor	Poor	Poor	
Funston	10.6	145°	17		2	-0.5	1.5	R	Poor	Good	Good	
Mizelle	4.9	030°	12	2.8		0.0	1.5	BrC	Fair	Fair	Poor	
Herndon (1)	20.0	054°	17	1.2	9	-3.0	3.0	R	Good	Good	Good	
Herndon (2)	20.0	054°	17	1.2	9	-0.5	3.0	R	Good	Good	Good	
Herndon (3)	20.0	054°	17	1.2	9	-0.5	3.0	R	Good	Fair	Poor	
Spurs												
VIMS	4.0	263°	17	2.4	9	0.0	3.0	Tr	Good	Good	Good	
Summerille	9.5	055°	15	1.2	9	0.0	3.0	R	Good	Fair	Poor	
Herndon (3)	20.0	054°	17	1.2	9	-0.5	3.0	R	Good	Poor	Poor	
Booth	8.5	268°	17	2.4	9	1.0	3.0	R	Good	Good	Good	Buried
Groins												
Maynard												
Breakwaters												
VIMS	4.0		17	2.4	5	-0.5	3.0	R	Fair	Good	Fair	
Krumbein	6.1	110°	17	1.2	1	0.0	3.0	R	Good	Fair	Good	
Schermerhorn	1.5	227°	16	2.5	1	0.0	3.0	R	Good	Good	Good	

* See Table 1 for definitions of Good, Fair and Poor.

R - rock CB - cinder block BrC - broken concrete Tr - tire concrete instead of rounded quarry stone probably causes increased rate of abrasion of the PVC. The use of non-PVC coated wire should be discouraged. Long term wear on all baskets occurs at the twists and bends of the wire. When pressure is applied to the basket by waves, floating debris or foot traffic, breakage occurs most often at these twists and bends.

A pattern emerged which indicates a high potential for failure where baskets are built at right angles to a bulkhead, groin or each other. This was observed at several sites including Hog Island's West Shore and Heron Rook and Herndon and Summerille (past inspections). The reason for "juncture failure" or "juncture puncture" appears to be a combination of concentrated wave action and floating debris being trapped at the junction point and battering the wire wearing off the PVC; the wire then corrodes and breaks. At the 25-year old Hog Island revetment/groin sites, time was also a major factor.

Salinity may also play an important role. Higher salinities may accelerate corrosion of the wire once the PVC wears off. This is difficult to substantiate since most installations occur between average salinities of 15 to 18 ppt. However, salinity is near zero at the Hog Island revetment/groin installation and the PVC wire is generally in good shape.

Time is an important factor overall. As soon as a gabion is placed in the marine environment, it becomes subject to the various environmental factors which will eventually destroy it. Installations which escape this eventuality are those that become completely buried by sand such as Booth, D. Smith, and Saxis. They are likely to remain structurally intact until they are once again exposed to the "elements."

Discussion

One idea behind the use of gabions as marine structures should be to allow the average waterfront property owner a "low-cost", do-it-yourself approach to shoreline erosion control. Along the lower section of the rivers and main bay stem one can expect a basket life of 5 to 10 years depending on construction technique and type of structure. Sills and spurs that quickly become buried under an abundant sediment supply are successful installations whose basket life may increase to 20 to 30 years. However, many situations around the Chesapeake Bay system are sediment limited. Consequently, shorter life spans can be expected. The use of beach fill may increase the basket life by simple burial of all or portions of the structure.

Conclusions

1. Intertidal installations using gabions will limit the life of the structure unless it is buried by sand.
2. The use of broken concrete and other sharp edged fill material for gabions tends to abrade the PVC wire and cause "premature" failure.
3. Placing gabions perpendicular against groins, bulkheads or other gabions may cause basket failure at the juncture point.

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APPENDIX A

SITE LOCATIONS FOR GABION INSTALLATIONS WITH CORRESPONDING PHOTOS

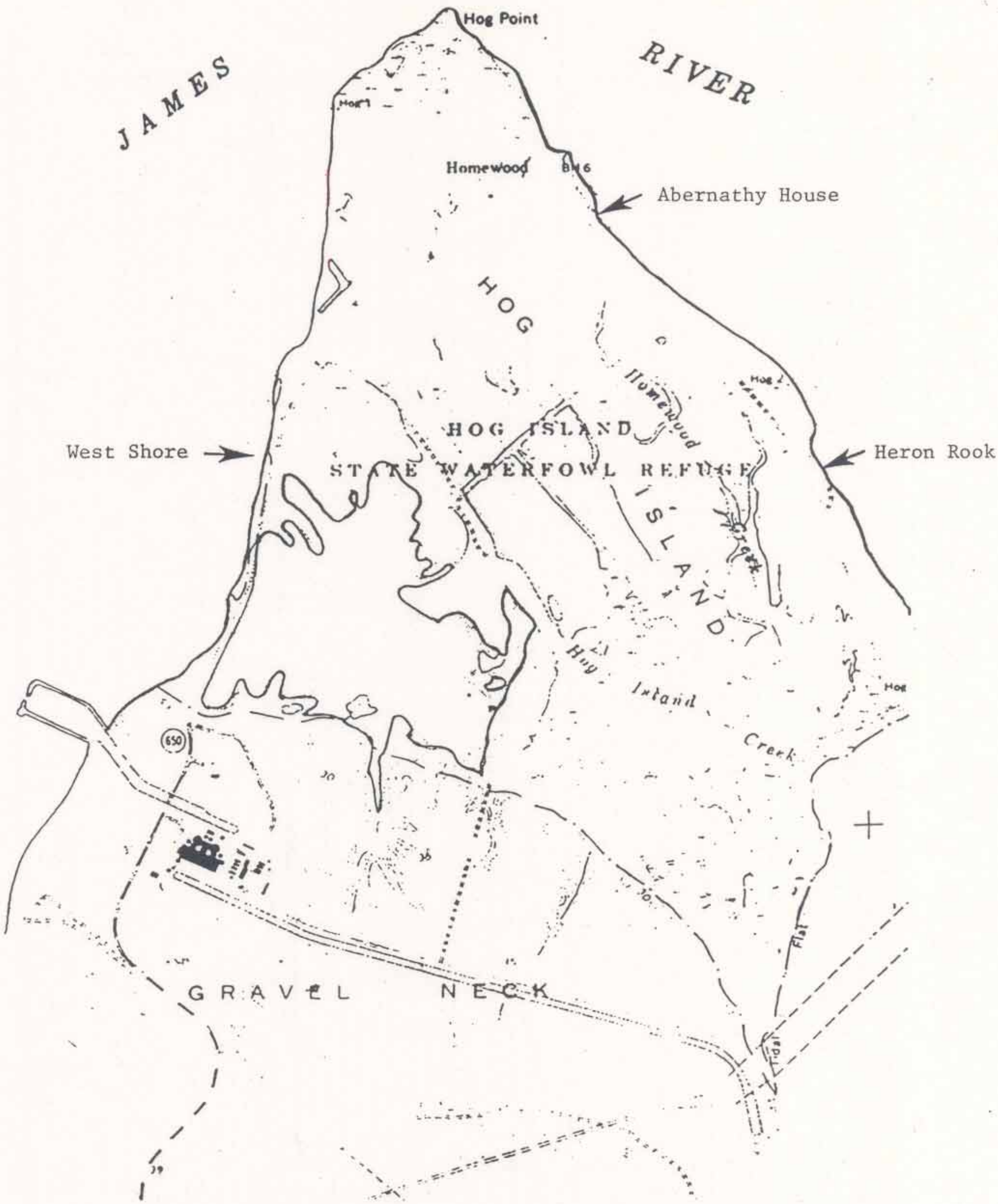

Figure A1. Gabion installations: West Shore, Mr. Abernathy's House and Heron Rook, Hog Island Wildlife Area, James River, Surry County. From Hog Island Quadrangle. Scale: 1 inch = 2000 feet.

Figure ALA. West Shore Site, looking southward along the structure.

Figure A2B. West Shore Site, close-up of the structure. Note failure of wire and loss of rock.

Figure A3A. Mr. Abernathy's House, looking northward along the structure.

Figure A3B. Mr. Abernathy's House, closeup of the structure. Note failure of wire along top of lower gabions.

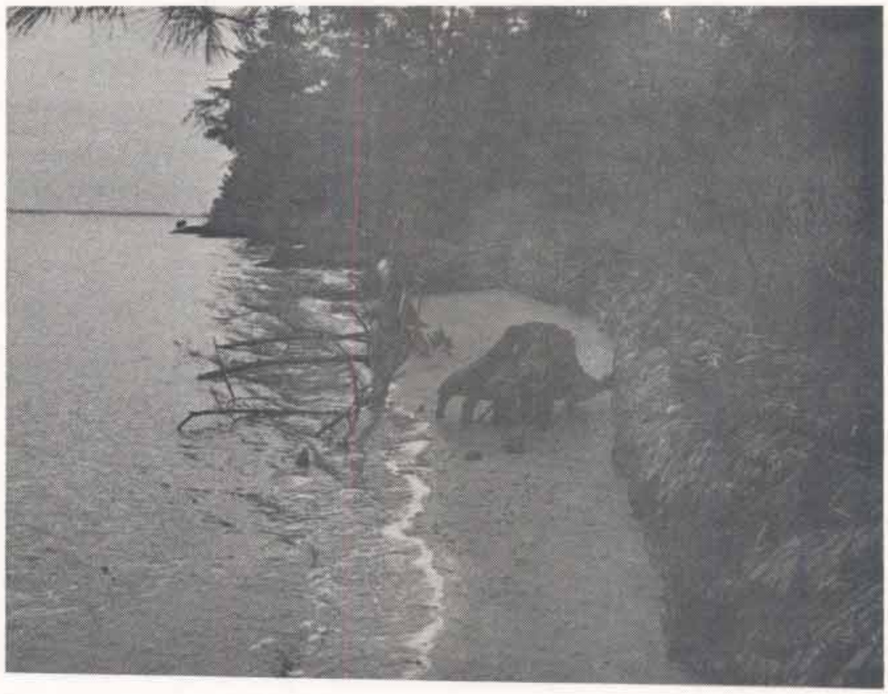

Figure A4A. Heron Rook Site, looking southward along the structure.

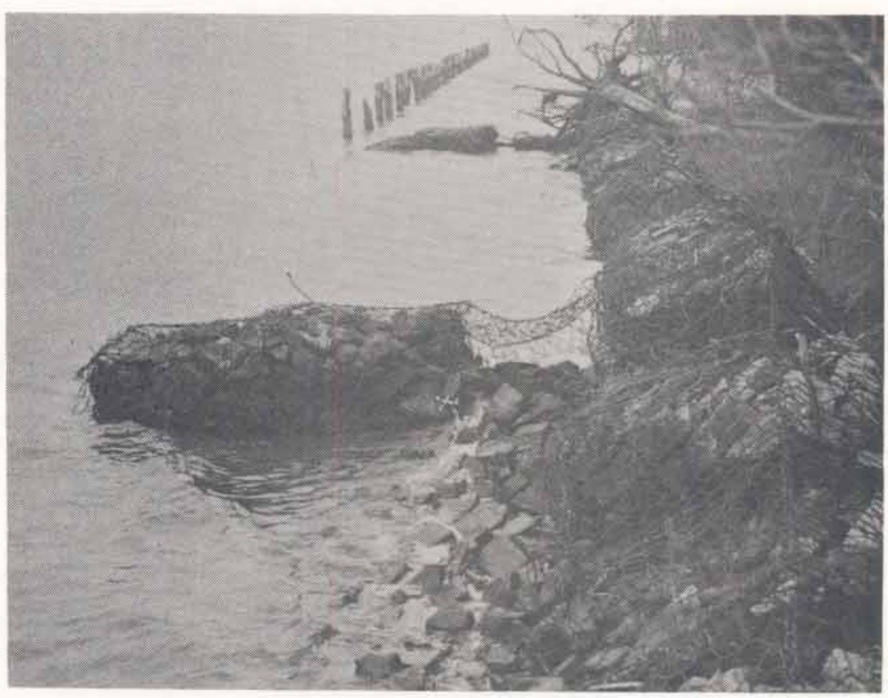

Figure A4B. Heron Rook Site, closeup of the structure. Note failure at juncture of revetment and groins.

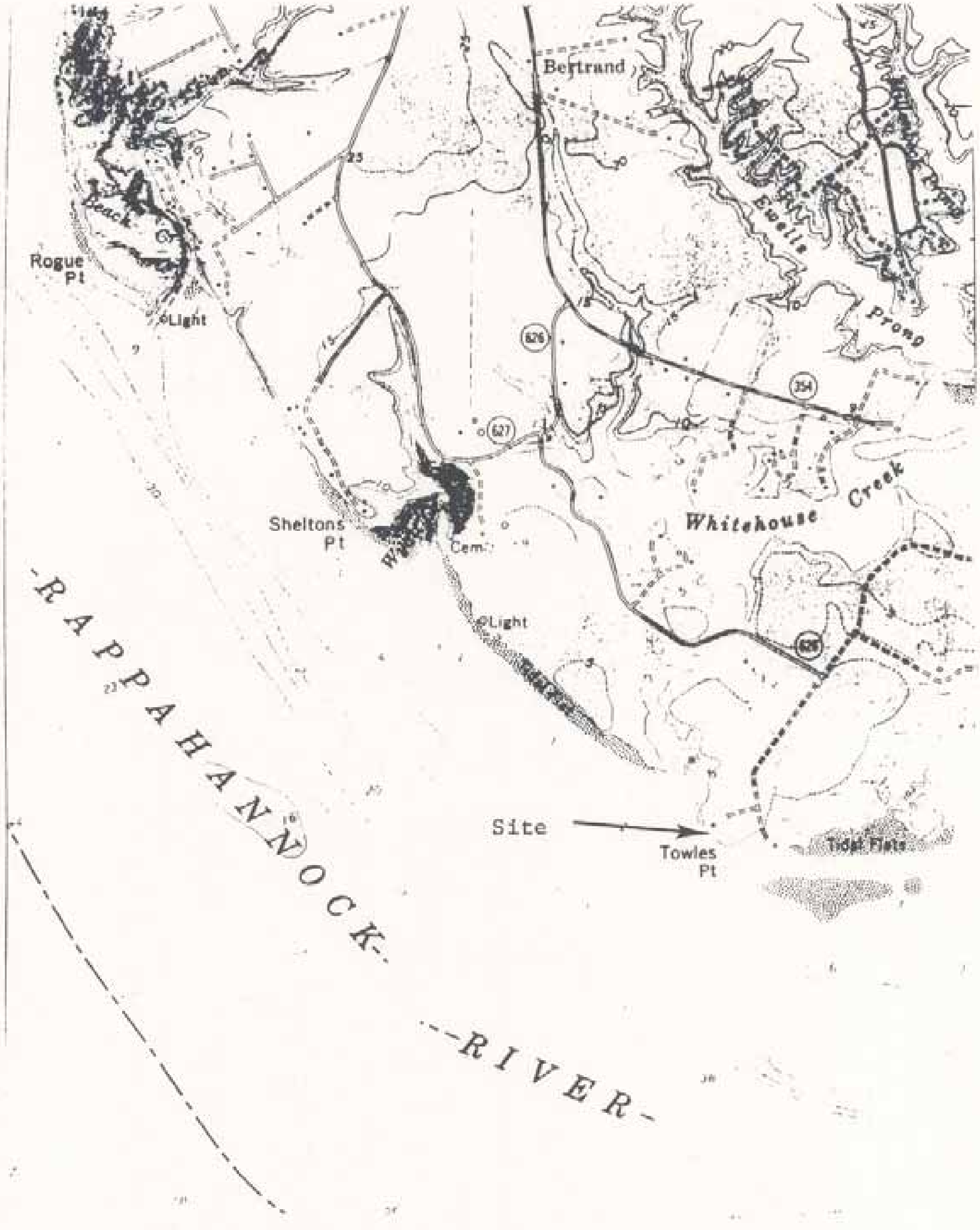

Figure A5. L.R. Evans Site, Rappahannock River, Lancaster County. From Urbanna Quadrangle. Scale: 1 inch = 2000 feet.

Figure A6A. L.R. Evans Site, looking northward along the structure.

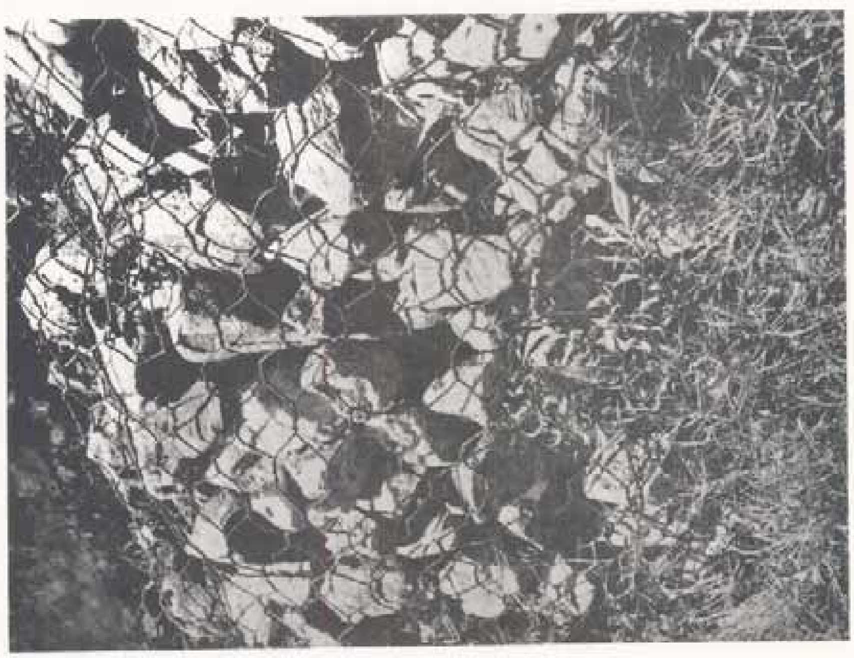

Figure A6B. L.R. Evans Site, closeup of structure, intact.

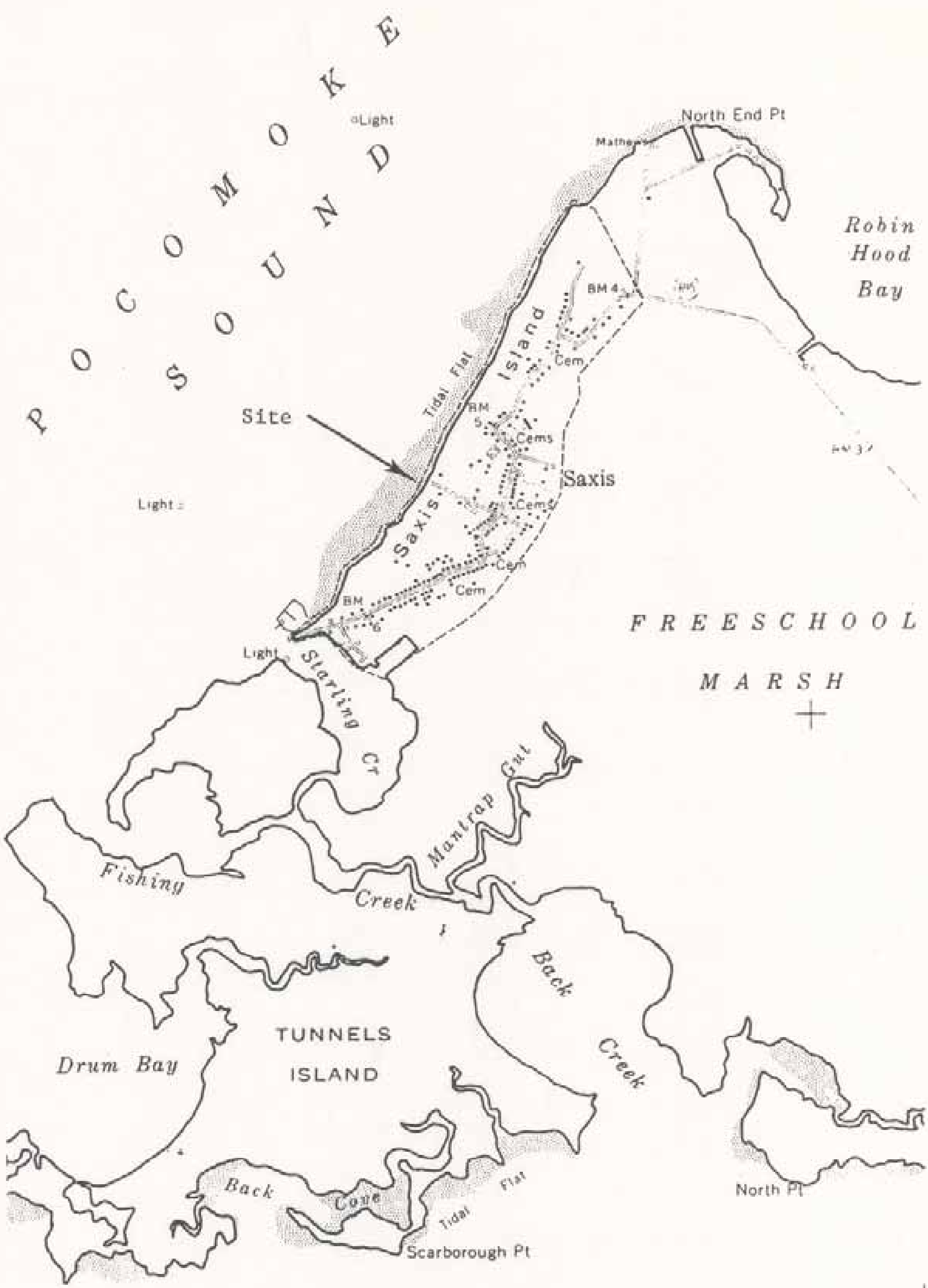

Figure A7. Saxis Site, Pocomoke Sound, Accomack County.
From Saxis Quadrangle, Virginia-Maryland.
Scale: 1 inch = 2000 feet.

Figure A8. Saxis Site, looking northward along the shore. Sill structure is buried just above water's edge.

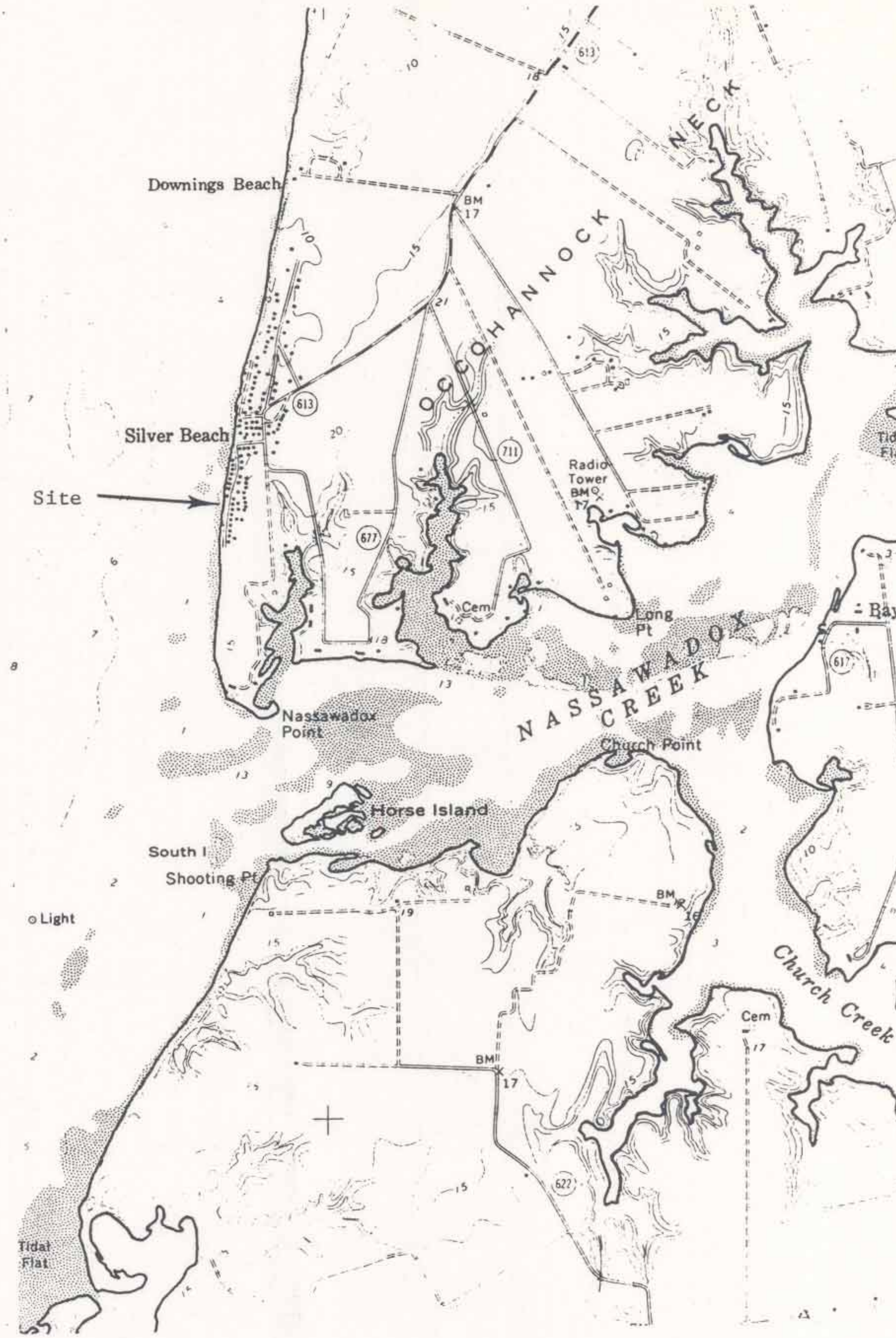

Figure A9. Silver Beach Site, Chesapeake Bay, Northampton County. From Franktown Quadrangle. Scale: 1 inch = 2000 feet.

Figure AIOA. Silver Beach Site, looking northward along the shore. Gabion sill is seen on left of photo.

Figure AIOB. Silver Beach Site, closeup of the structure. Note the failure of wire in middle of sill.

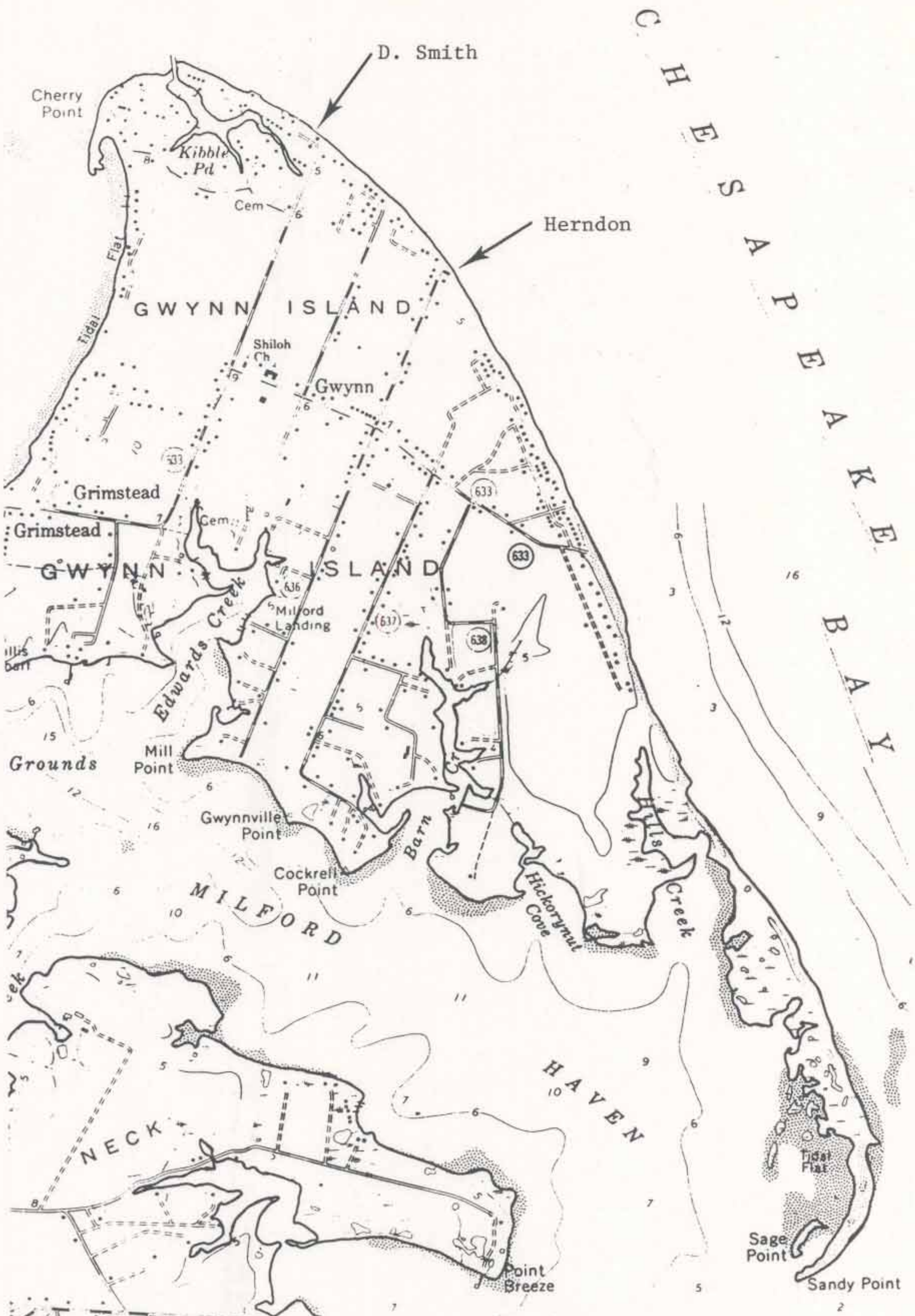

Figure All. D. Smith and Herndon Sites, Chesapeake Bay, Middlesex County. From Deltaville and Mathews Quadrangles. Scale: 1 inch = 2000 feet.

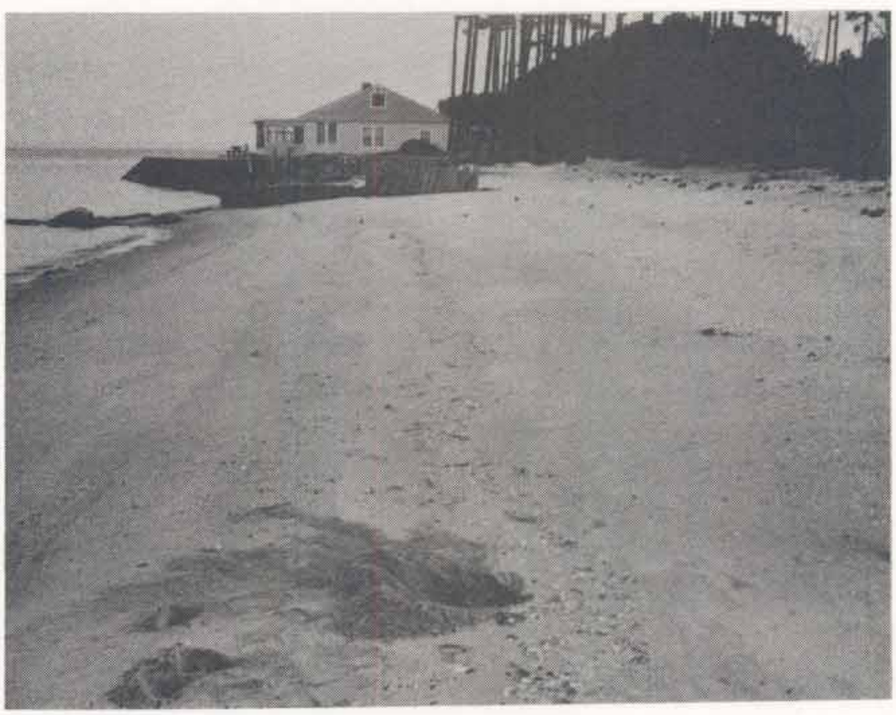

Figure A12. D. Smith Site, looking south along the shore. Sill structure is buried and runs parallel to the shore. The hole in the beach designates location of structure.

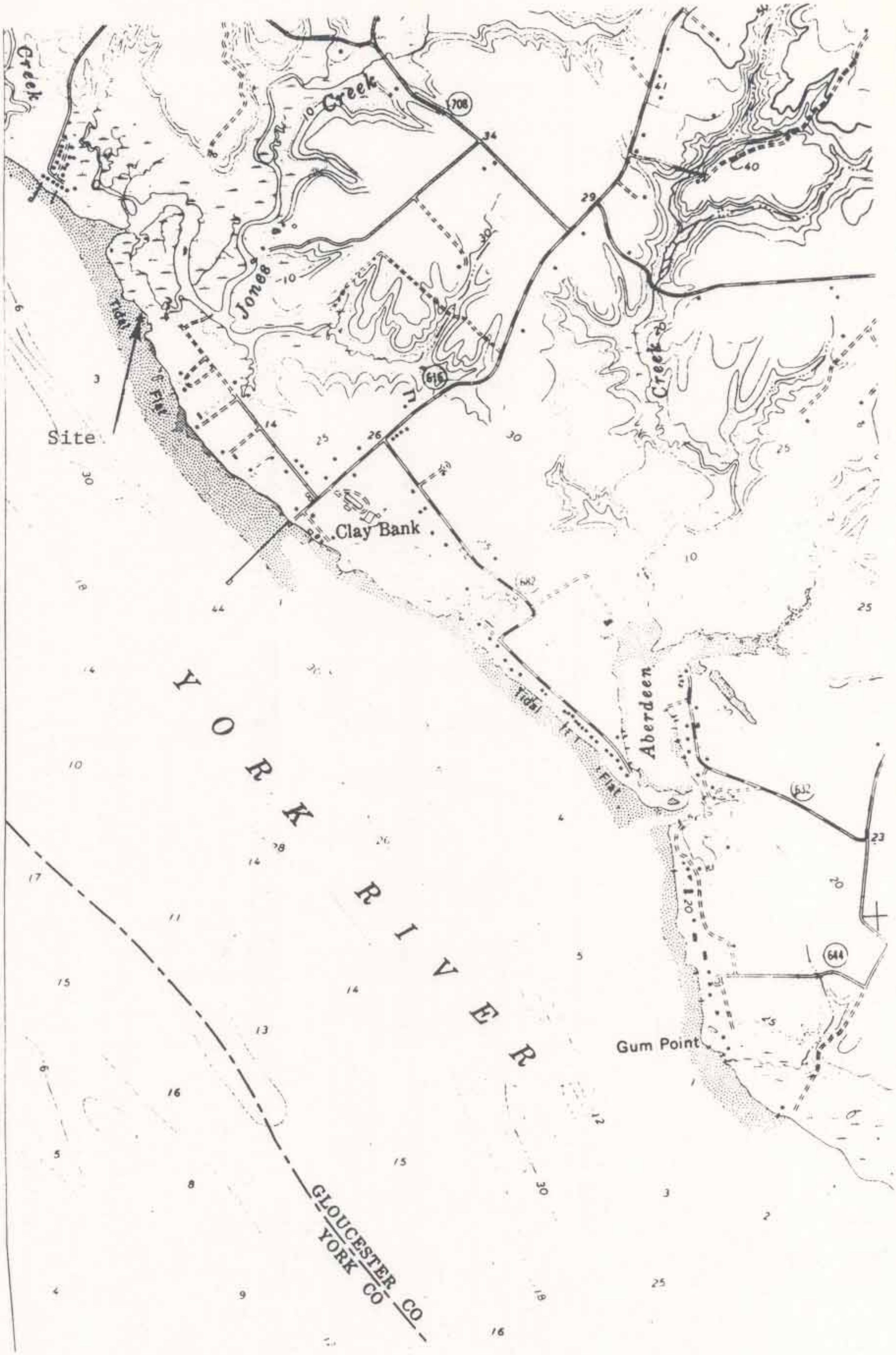

Figure A13. D. Vann Site, York River, Gloucester County.
From Clay Bank Quadrangle. Scale: 1 inch = 2000 feet.

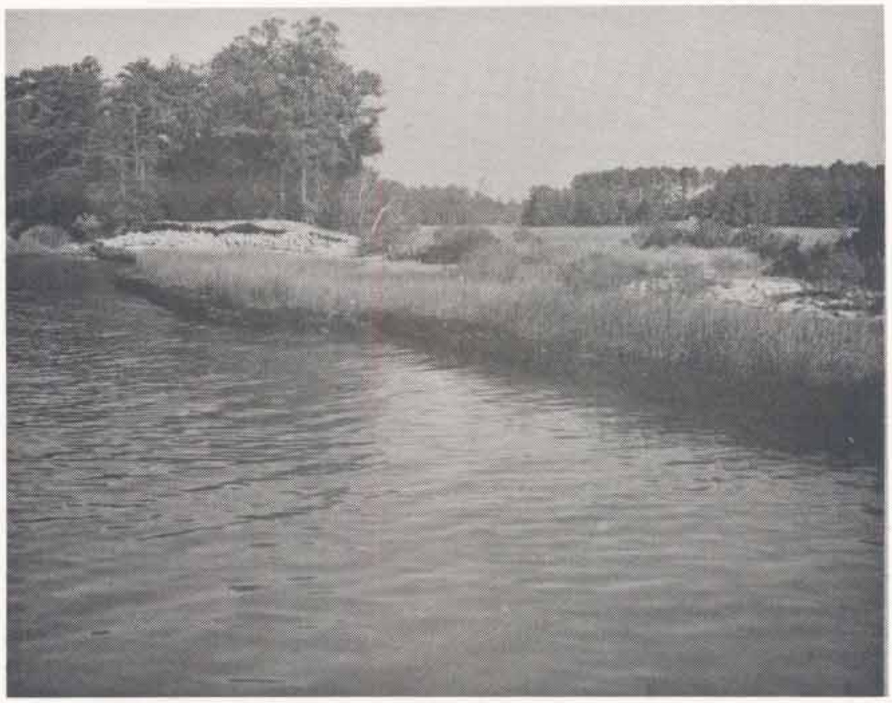

Figure A14A. D. Vann Site, looking northward along the structure.

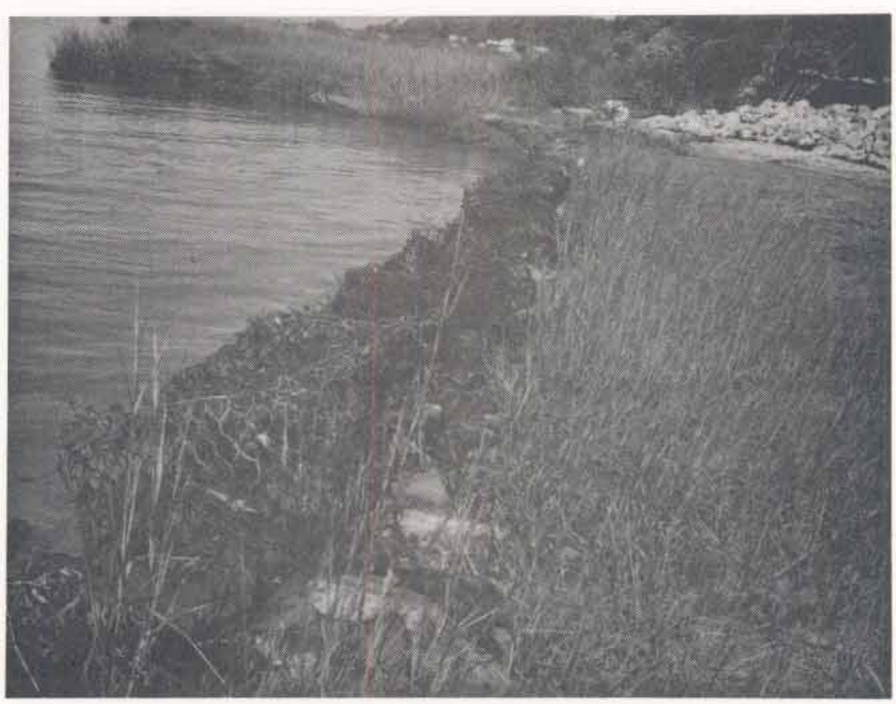

Figure A14B. D. Vann Site, closeup of north end of the structure. Basket wire deteriorated with massive failures.

Figure AlSA. Herndon Site, looking south along sill installations 1 and 2.

Figure AlSB. Herndon Site, closeup of sill installation 3 adjacent to the bulkhead. Note failure at junction point.

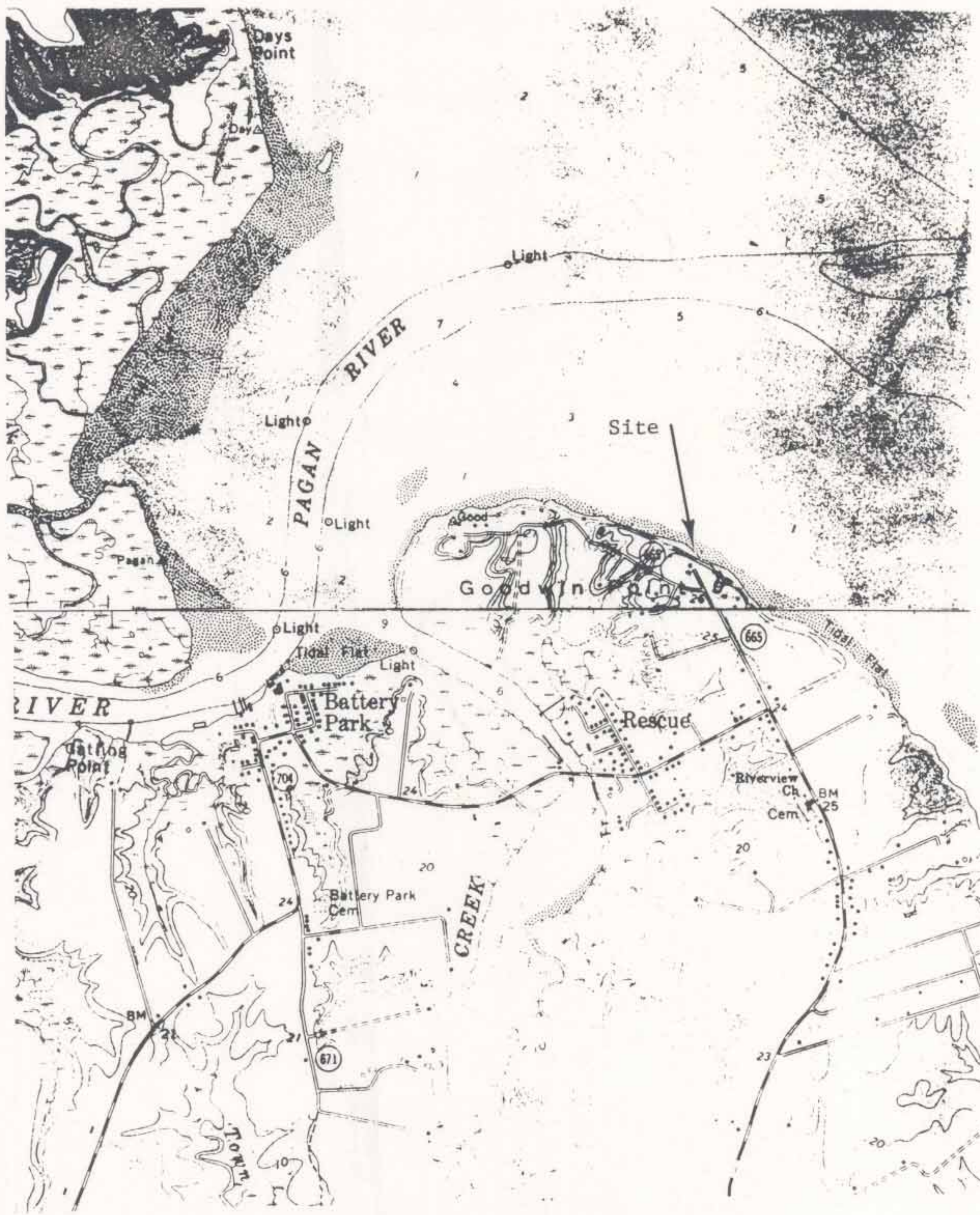

Figure A16. Mizelle Site, James River, Isle of Wight County. From Benns Church and Mulberry Island Quadrangles. Scale: 1 inch = 2000 feet.

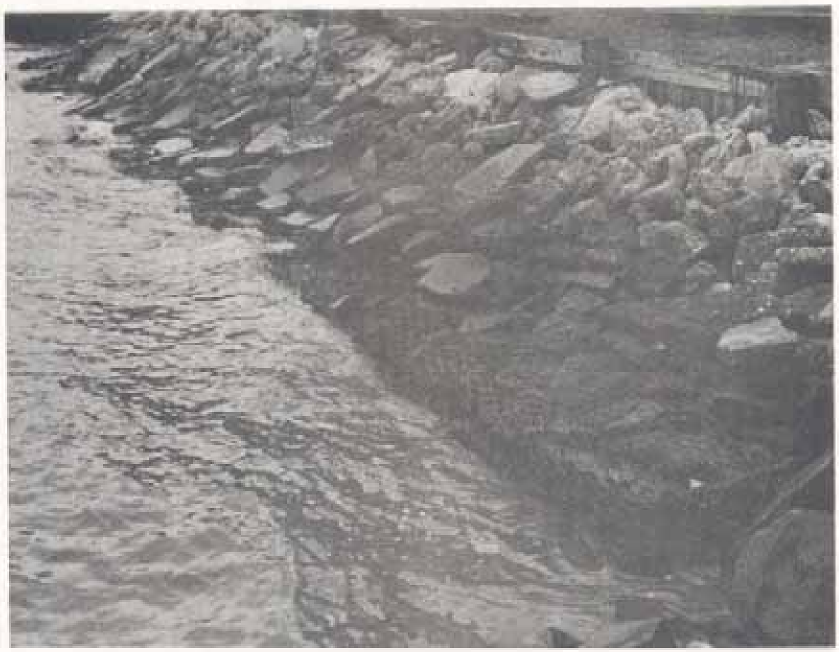

Figure AI7A. Mizelle Site, looking south along the structure.

Figure AI7B. Mizelle Site, closeup of the structure. Note failure and broken concrete along top of baskets.

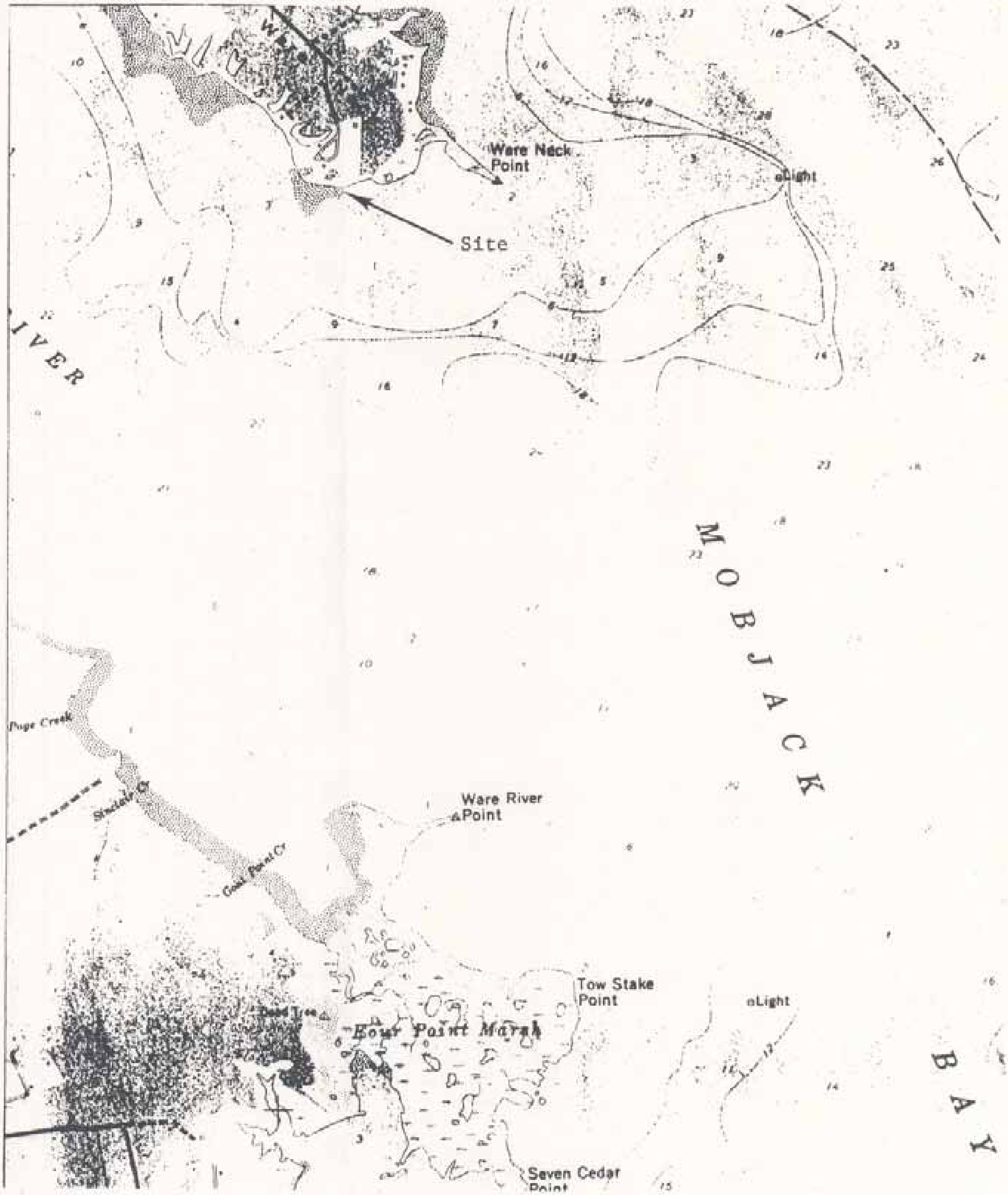

Figure A18. Funston Site, Mobjack Bay, Gloucester County.
From Achilles Quadrangle. Scale: 1 inch = 2000 feet.

Figure AI9A. Funston Sitet looking east along the structure. Note unfilled basket, job still incomplete.

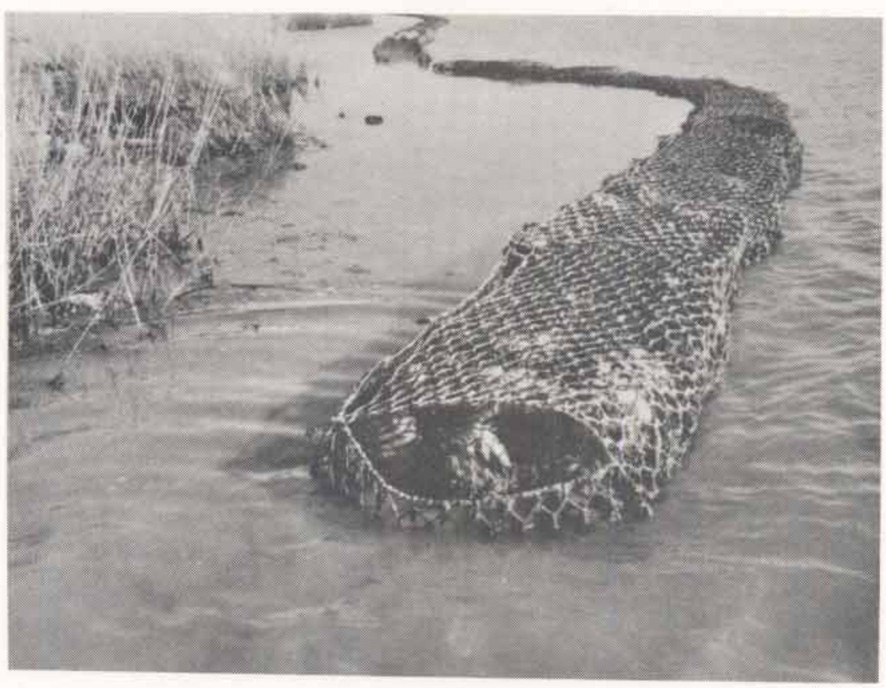

Figure AI9B. Funston Site, closeup of the structure. Note loosely tied basket top.

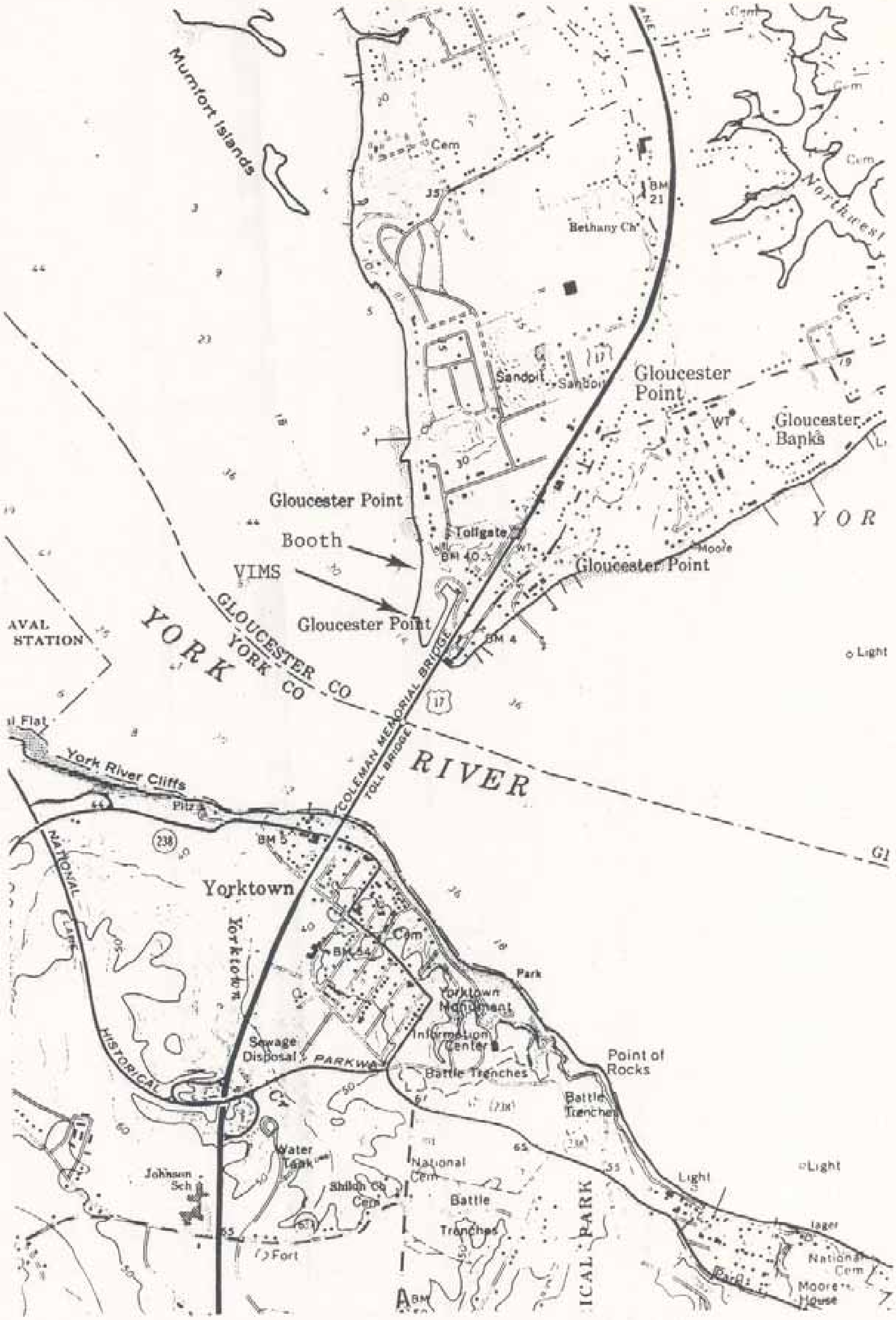

Figure A20. VIMS (2 Sites) and Booth Sites, York River, Gloucester County. From Achilles, Clay Bank, Poquoson West and Yorktown Quadrangles. Scale: 1 inch = 2000 feet.

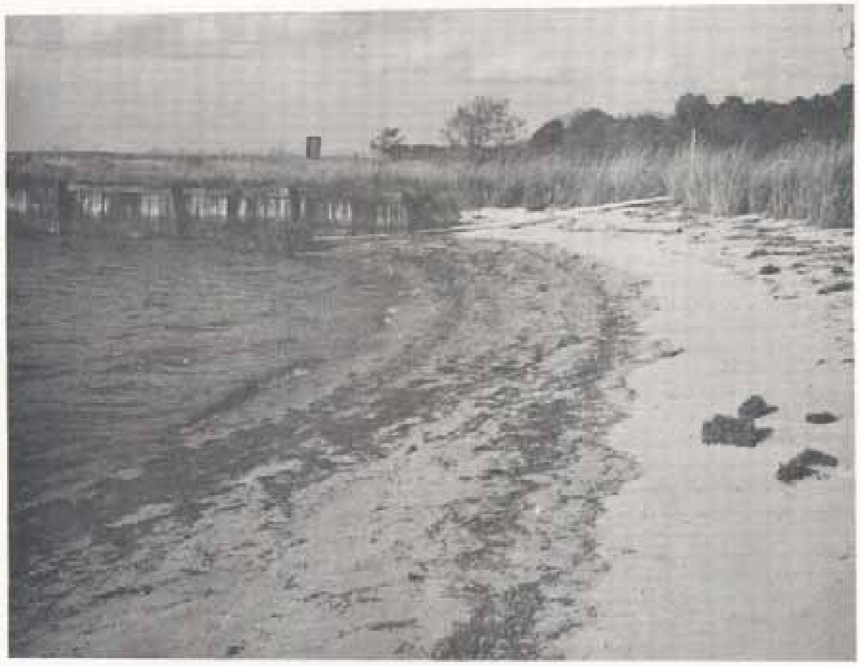

Figure A21A. VIMS Spur Site, looking north at the structure next to wooden groin.

Figure A21B. VIMS Spur Site, closeup of the structure. Note tire bundles used as fill.

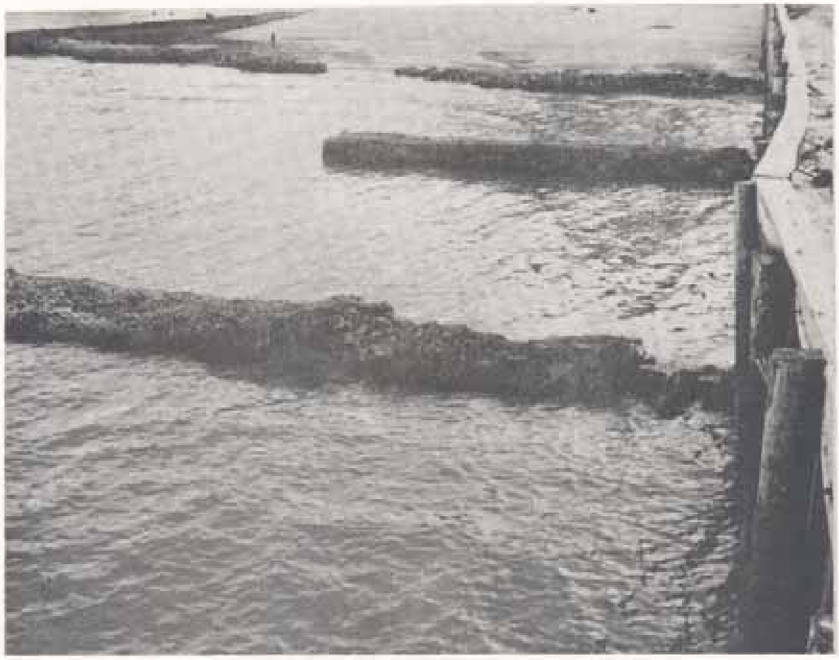

Figure A22A. Herndon Spur Site, looking west at spur and sill structures.

Figure A22B. Herndon Spur Site, closeup of spur. Note failure at junction point at groin.

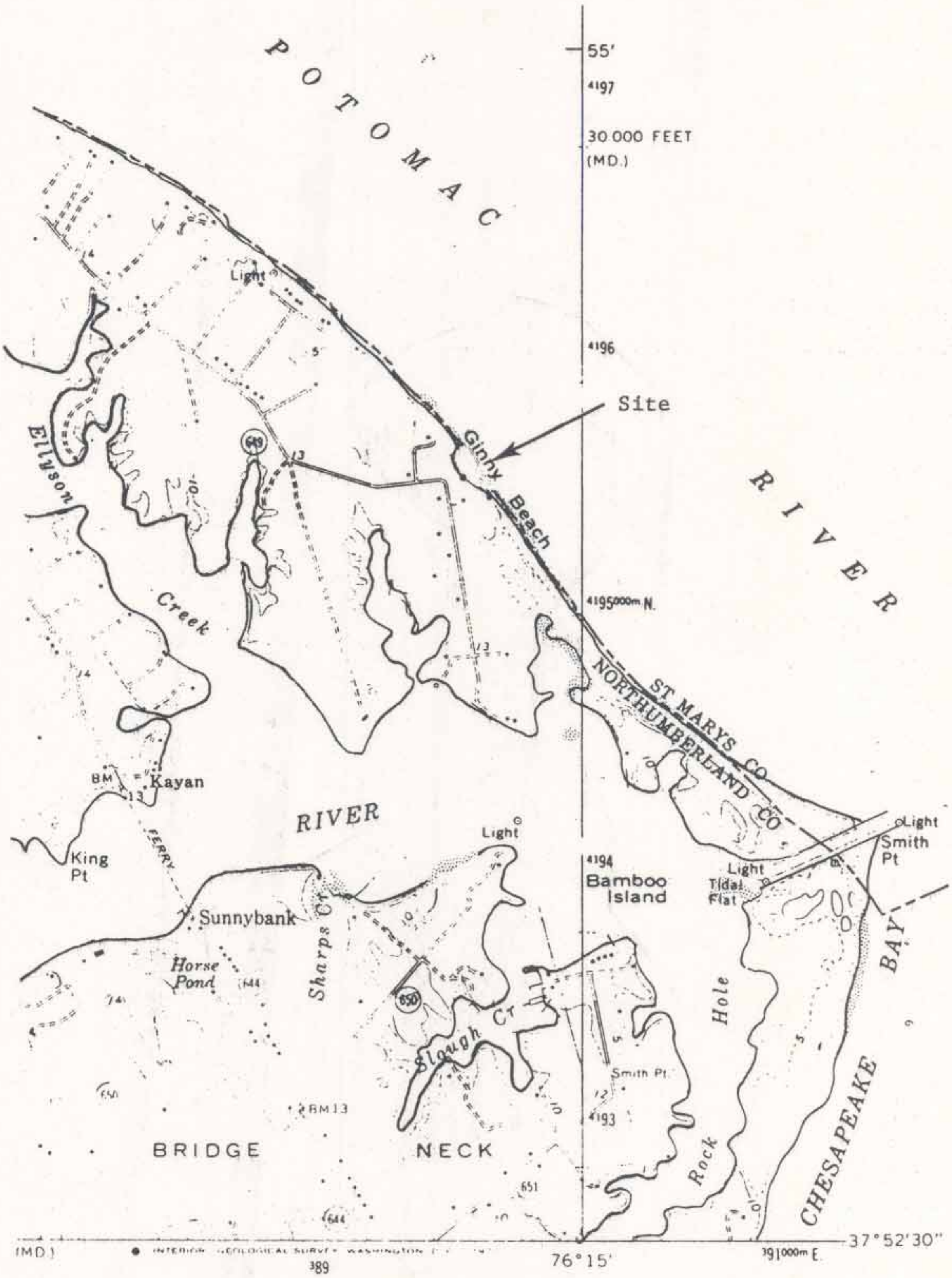

Figure A23. Summerille Site, Potomac River, Northumberland County. From Burgess Quadrangle. Scale: 1 inch = 2000 feet.