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TRAFFIC SLOPE TESTS OF MILITARY INVENTORY ITEMS AND THEIR EFFECTIVENESS IN RIVERINE EGRESS TESTS

by

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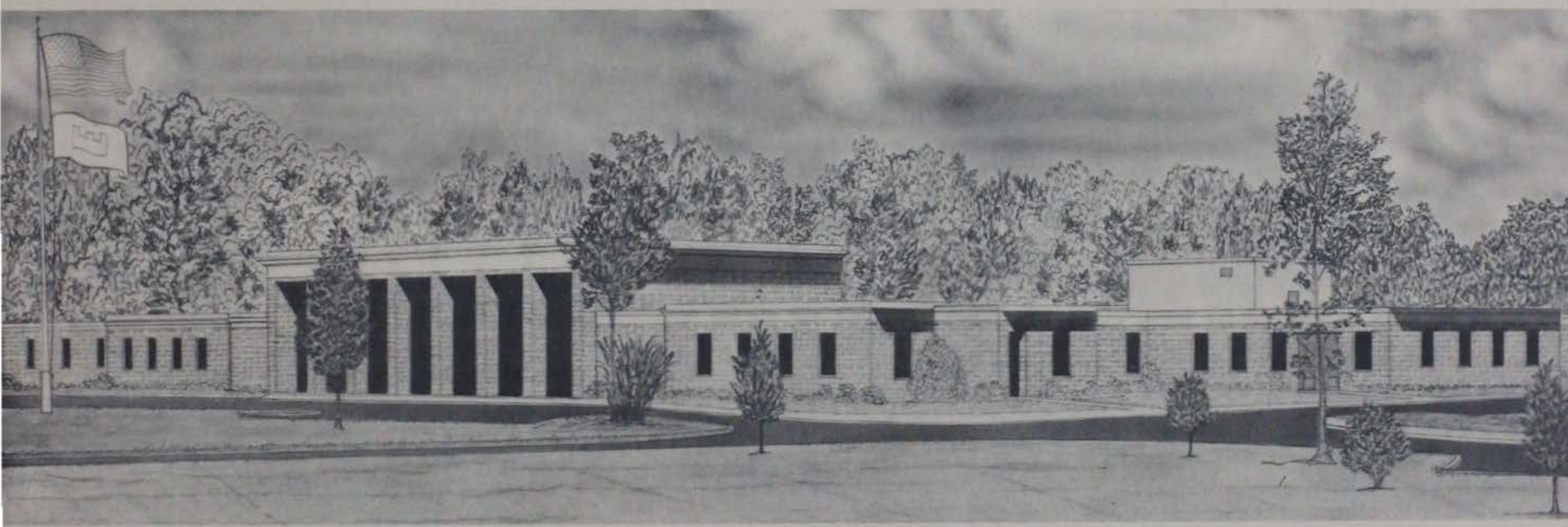

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Tests were conducted on 25 percent unsurfaced slopes and 25 percent slopes surfaced with the depot inventory items, T17 membrane and M8A1 and M19 landing mats, to determine their effectiveness in support of wheeled and tracked vehicle traffic in tactical bridge access/egress roles.

The T17 membrane would not satisfy any of the requirements alone but may be used in conjunction with the mats or other surfacings to waterproof the subgrade to achieve the surfacing requirements. (Continued)

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20. ABSTRACT (Continued)

The M19 mat will support all of the traffic required by the Letter of Agreement (LOA) but does not meet installation rates in either the assault vehicle egress role or the bridge equipment access role and will not provide sufficient traction when wet and muddy as required in the egress role.

The M8A1 mat placed either normally or inverted will support the required traffic of the LOA. Inverted, the surface will provide adequate traction for the M113 armored personnel carrier to egress a stream where the bank is sloped 25 percent. The M8A1 mat placement rate will not meet any of the installation rates required in the LOA.

PREFACE

This study was conducted during the period July-September 1978 at the U. S. Army Engineer Waterways Experiment Station (WES) by personnel of the Geotechnical Laboratory (GL). General supervision was provided by Dr. D. C. Banks and Mr. J. P. Sale, Acting Chief and former Chief, GL, and Dr. P. F. Hadala and R. G. Ahlvin, Acting Assistant Chief and former Assistant Chief, GL. Personnel actively engaged in planning and conducting the investigation were Messrs. R. L. Hutchinson (retired), W. L. McInnis (retired), H. L. Green, W. E. Willoughby, and G. L. Carr. The organization and consolidation of the report were accomplished by Messrs. Carr and Willoughby.

The U. S. Army Mobility Equipment Research and Development Command (MERADCOM) and the Office, Chief of Engineers (OCE), U. S. Army, jointly initiated the study. The MERADCOM authorized Project IL162733AH20-B8 under 6.2 funds entitled "Expedient Surfacing and Soil Investigation" and Project 1L463726DG01-12 under 6.3A funds entitled "Tactical Bridge Access/Egress Investigation." The OCE authorized Project 4A762719AT40, Task 02, entitled "Techniques for Tactical Bridge Access/Egress."

Commanders and Directors of the WES during the investigation and the preparation of this report were COL John L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. Fred R. Brown.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
inches	25.4	millimetres
miles (U. S. statute) per hour	1.609344	kilometres per hour
pounds (force) per square inch	6894.757	pascals
pounds (mass)	0.4535924	kilograms

TRAFFIC SLOPE TESTS OF MILITARY INVENTORY ITEMS AND THEIR EFFECTIVENESS IN RIVERINE EGRESS TESTS

PART I: INTRODUCTION

Background

1. Military operations in the 1980 time frame will require rapidly emplaced gap crossings to enable troops to effectively counter enemy threats. Emplaced gap crossings must be capable of allowing mission essential traffic to cross before enemy threats are effectively applied and maintaining subsequent traffic flow. Poor soil conditions or steep slopes along river and streambanks must be overcome to allow movement by tactical assault vehicles at the most tactically advantageous locations (Headquarters, Dept. of the Army, 1976).

2. In concept, the desired egress capability will be used primarily in the assault phase of tactical riverine crossing operations (Headquarters, Dept. of the Army, 1979). Ideally, the capability should be obtained through the use of inventory depot items by engineers in the main battle area to aid the riverine crossing of swimming and fording vehicles and to gain access to bridges or raft loading points for assault and follow-up forces (Headquarters, Dept. of the Army, 1978).

3. Initially, some modifications or adaptations of standard inventory surfacings or soil strengthening materials will be used in an attempt to meet the goals stated in the Letter of Agreement (LOA) (Welker, 1979) by day or night. Swimming and fording combat vehicles should be able to exit streams with slopes within the normal climbing capability of the vehicles (<25 percent). In addition, egress points must be capable of withstanding 25 passes by vehicles up to and including Military Load Class (MLC) 60. The egress "system" envisioned in the LOA will hopefully enable one squad of an engineer combat company, using current equipment, to simultaneously install two 5-m-wide egress systems (adjacent on the bank) within 15 min after arrival at the exit bank.

Purpose and Scope

4. During the period July-September 1978, personnel of the Geotechnical Laboratory, U. S. Army Engineer Waterways Experiment Station (WES), conducted egress tests within the boundaries of the WES reservation. Two areas were selected, one upland area adjacent to Porters Chapel Road and the other area adjacent to the north end of Brown Lake. Slopes of 23-25 percent were selected in silty clay (CL) soil adjacent to Porters Chapel Road and lean clay (CL) soil near Brown Lake. Each area was graded smooth. Slope-climbing tests were conducted with a combat-loaded M54 dump truck and two tracked vehicles, the M48 tank and M113 armored personnel carrier (APC). Tests were conducted on bare slopes, on T17 membrane surfaced slopes, and on M19 and M8A1 mat-surfaced slopes, both dry and wet. Also tests were conducted where the vehicles tracked through a wet clay at the toe of the slope. In addition, drawbar pull tests were conducted with the M113 APC on T17 membrane stretched and anchored on level ground. The purpose of these tests was to determine if any depot inventory items were suitable, and to what degree, to use as access/egress surfacing for a riverine crossing in a combat assault role.

PART II: TEST PROGRAM

Upland Area Tests

Unsurfaced slopes

5. Initial tests were conducted on the WES reservation on 25 percent slopes constructed in a roadbank of medium-brown silty clay (CL). Tests were conducted with the M113 APC at a gross vehicle weight of 22,865 lb;* the M54, 6 × 6, dump truck at 70 psi and 40,000 lb, and the M48 tank at 106,000 lb. Results of these tests are shown in Table 1.

6. The initial sequence of tests was conducted on a dry, unsurfaced soil with no membrane or mat surfacing. All three vehicles completed the required 25 passes on the dry slope, and the rut depth after traffic by all vehicles was 4-1/2 in. However, when wetted with spray from a water truck, the surface became very slippery, and vehicle performance was reduced considerably. The M113 APC completed two passes, the M54 truck no passes, and the M48 tank one pass (Table 1). Photo 1 shows the area and vehicles on the slope when dry and also when wet.

M19 mat-surfaced slopes

7. The next sequence of tests was conducted on another 25 percent silty clay slope near the one used for the previous tests. The slope was covered with clay gravel and then with a 4- by 4-ft M19 mat (Green and Ellison, 1969; Depts. of the Army and Air Force, 1968; Headquarters, Dept. of the Army, 1965, 1966a, 1968, and 1973) anchored (Gerard, 1969) to the slope. Initially, the vehicles attempted slope-climbing tests on the mat in the dry condition. All vehicles completed the required 25 passes (Photo 2 and Table 1) although the mat slid downhill slightly in the M113 test series and nearly 7 in. in the M54 and M48 test series. The mat surface was then wetted with spray from the water truck (continuously during the tests), and the test series was repeated. Again, all vehicles completed the required 25 passes. The mat movement was similar

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

to that in previous tests except that in the M54 tests only 1-1/2 in. of movement occurred.

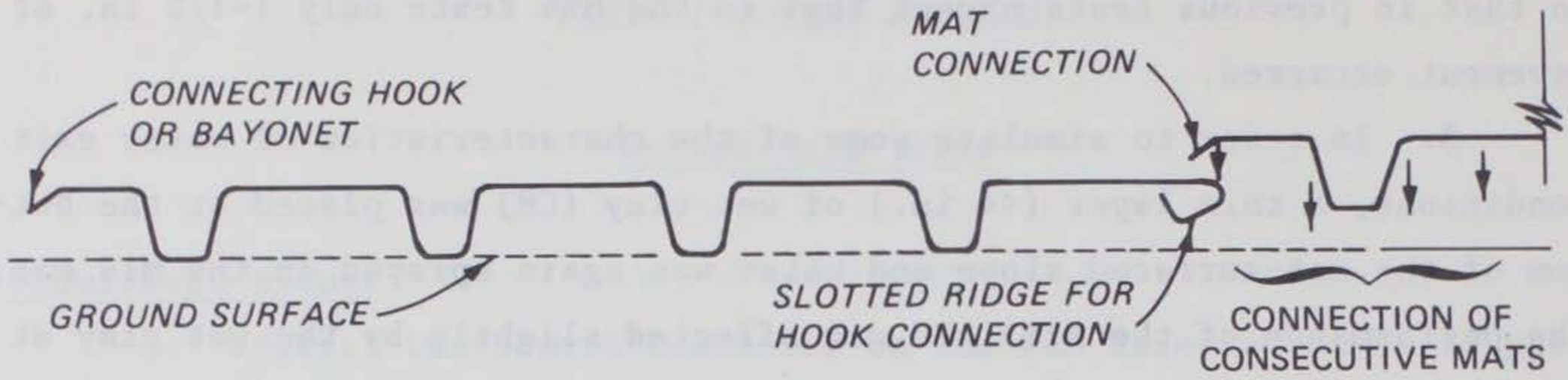
8. In order to simulate some of the characteristics of water exit conditions, a thin layer (<4 in.) of wet clay (CH) was placed at the bottom of the mat-surfaced slope and water was again sprayed on the M19 mat. The performance of the M113 APC was affected slightly by the wet clay at the bottom of the slope, and the vehicle completed with difficulty the required 25 passes. However, the M54 truck was unable to complete a single pass, and the M48 tank could complete only five passes with extreme difficulty, because of the surface slipperiness caused by the wet clay and water.

9. Similar tests with the same M19 mat, unanchored, and with the same surface conditions produced similar results (as the anchored) but with substantial mat movement as shown in Table 1. Wet clay tests were not conducted, as previously described, but similar results could most probably be expected.

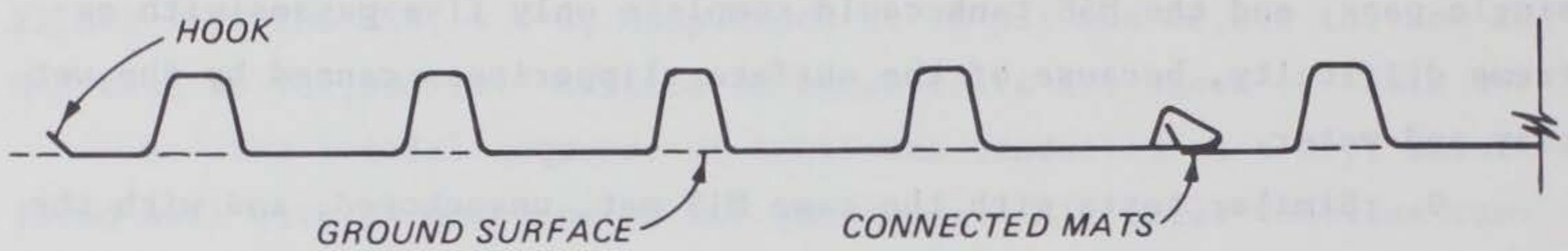
M8A1 mat-surfaced slopes

10. Tests similar to those above were performed at the same site using the M8A1 (Headquarters, Dept. of the Army, 1973; Tucker, 1968; and Garrett, 1959). Mat placement (top side up) began at the toe of the slope in the normal brick placing pattern as shown in Figure 1, except the ends were offset approximately 1 ft. The mats were anchored in the offset area. Tests were conducted with the M113 APC, M54 truck, and M48 tank on the mat initially in the dry condition. All three vehicles were able to complete 25 passes with little mat movement downslope (Table 1). The mat surface was then sprayed with water from the water truck, and all three vehicles operated up the slope. Again, all three vehicles were able to complete the required 25 passes with little difficulty, although slightly more downhill mat movement occurred in these tests than in the dry surface tests. No tests were conducted with the wet clay layer at the base of the slope with the anchored mat.

11. The anchors were removed from the M8A1 mat on the same slope, and tests were begun with the unanchored M8A1 in the dry surface condition. All three vehicles were able to complete the required 25 passes



a. Normal placement position



b. Inverted position

Figure 1. Normal and inverted placement positions of M8A1 mat

with about the same mat movement as in the anchored tests (Table 1). The surface was sprayed with water, and tests were conducted with the three vehicles. All three vehicles were able to complete 25 passes with approximately the same mat movement as in the anchored tests. A thin layer of fat clay (CH) was placed at the bottom of the mat-covered slope, and tests were conducted with the three vehicles while the mat and clay surfaces were sprayed with water. Results of these tests were similar to those of the M19 tests. The M113 APC was able to complete 25 passes with difficulty, and the M54 truck attempted three passes and completed none, while the M48 tank completed three passes with difficulty (Photo 3). Mat movement in all three test series was negligible.

12. Because of the design features of the M8A1 mat (Figure 1), the mat appears to provide better tractive surface (for vehicles) in the inverted position than in the normal placement position. Accordingly, the mat used in the previous tests was overturned and reanchored, and tests were conducted on the same 25 percent slope (with clay). The M54 truck was still unable to complete a single pass with the wet clay layer at the bottom of the slope, whereas the tracked M113 and M48 completed

the required 25 passes with some difficulty.

T17 membrane-covered slopes

13. The area was cleared of mats, checked for 25 percent slope, and prepared for the membrane test. The graveled slope was covered with a T17 membrane (Headquarters, Dept. of the Army, 1966b) section composed of sheets of membrane bonded together. The membrane was anchored at the top of the slope by excavating a small ditch, laying the membrane inside, driving tack anchors, and covering it with the excavated material. Three tack anchors were then placed along each side of the membrane at approximately equal intervals to anchor the membrane to the slope.

14. Tests were again conducted with the M113 APC, M54 truck, and M48 tank in both dry and wet surface conditions. All three vehicles were able to complete the required 25 passes with little difficulty, although the repetitive traffic caused tears in the membrane in the wet-surfaced tests, as indicated in Table 1. Membrane movement was about the same for each vehicle in both (dry and wet) of the test series. In all tests, the membrane wrinkled and stretched with each pass but returned to almost the same point after traffic (Photo 4). Tests were also conducted with the three vehicles with the wet clay layer added at the toe of the slope. All three vehicles experienced extreme difficulty in even getting up onto the membrane-covered slope. Only the M113 APC was able to get up onto the slope, then only by using a 20-ft start on dry soil. In all attempts, the membrane deformed considerably and was torn across the slope width and severely damaged in tests with both of the tracked vehicles.

15. During all of the tests mentioned previously, membrane abrasion by underlying gravel was considerable and even severe in some places. These abrasions, however, were not considered to be the causative factor in the membrane tearing during the tests.

Brown Lake Tests

16. Tests were conducted on 23-25 percent slope constructed in lean clay (CL) at the north end of Brown Lake (Figure 2) on the WES reservation. Slope-climbing tests were conducted with only the M113 APC

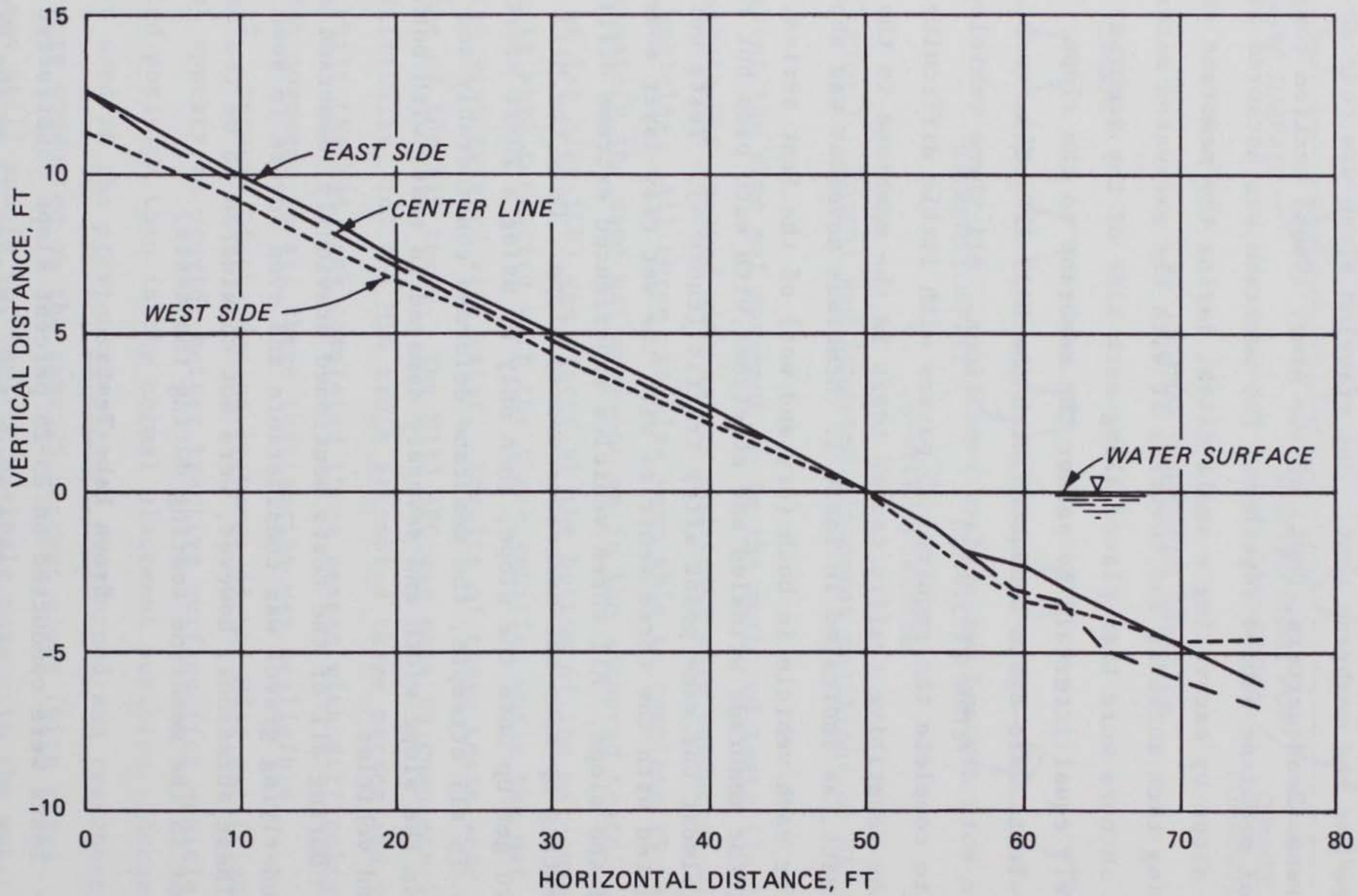


Figure 2. Before traffic profile, Brown Lake slope

loaded to 23,495 lb. In addition to the vehicle tests, the time of membrane or mat placement and the number of personnel required for placement were also annotated.

T17 membrane-covered slopes

17. An 18- by 77-ft membrane section composed of bonded sheets of T17 membrane was folded into a 4- by 5- by 1-ft bundle and placed at the toe of the slope, adjacent to the water. Five men then unfolded the section and pulled 57 ft up the slope in 32 sec. Two men in two boats placed 20 ft of membrane out in the lake in 7 min and secured the membrane to the lake bottom (2-5 ft below the water surface) with sandbags attached to the membrane pad with ropes. Three men then placed four 1-ft-long side anchors in 1-1/2 min. A 2- by 6-in. board wrapped inside several folds of membrane was placed in a shallow ditch at the top of the slope, then secured with six drive tack anchors, and covered with excavated soil. This phase of the entire procedure, depicted in Photo 5, required an additional 10.5 min. The elapsed time was 19.5 min.

18. In the initial test with the M113 APC, the driver of the vehicle experienced difficulty in aligning the vehicle with the membrane-covered slope. As the driver maneuvered the vehicle into position for the slope-climbing test, the vehicle pressed the 18-ft-wide membrane down into the soft lake bottom, pulling the membrane edges and sandbags to a point adjacent to the tracks of the vehicle. As the vehicle attempted to climb the slope, the membrane and sandbag ropes became entangled in the left track, pulling the membrane down the slope toward the water. The slope side anchors tore the membrane 12 to 15 ft, and the 2- by 6-in. anchor board was pulled 10 to 12 ft downslope. The vehicle continued upslope with the membrane severely stretched and wrinkled as shown in Photos 5i-5k.

19. Analysis of the first lake tests on the membrane-covered slopes indicated that (a) the short 1-ft-long anchors were not of sufficient length to prevent downslope sliding of the membrane, (b) the membrane, by necessity, required additional anchoring at the top of the slope, (c) a fold of membrane was required near the water's edge and the

membrane pad should be wider, both to allow for conformation to the vehicle ruts in the lake bottom, and (d) the sandbag anchors, by necessity, should be tied to a small steel cable and placed at least 20 ft from the membrane edge. Accordingly, all of these suggestions were incorporated into the second membrane test.

20. A larger membrane section, 36 by 100 ft, was refolded and delivered to the lake site. The unfolding procedure used previously was again employed, except the placement of the membrane from the top down the slope required five men a total of 35 sec to complete. A ditch approximately 3-1/2 ft wide by 2 ft deep by 25 ft long was excavated with a hydraulic backhoe. The membrane was placed along the perimeter of the ditch and secured with seven 1-ft anchors evenly spaced along the inside of the 25-ft ditch. The ditch was filled with the excavated soil and side anchors were placed along the edges of the membrane section at 10-ft intervals. A 4-ft fold was left in the membrane section at the water's edge, and the remainder of the membrane was pulled out into the lake and anchored using the M113 APC and a boat, each with two men aboard. Steel cables, 20 ft long, were attached to the membrane and to sandbags dropped into the water perpendicular to the membrane length to secure the membrane section and prevent floating or limited lateral movement. Photos 6a-6f depict this procedure.

21. The M113 APC entered the lake and swam around to a position in the lake aligned with the membrane on the slope. On the initial pass, the M113 APC was able to place both tracks up onto the membrane section after pulling the 4-ft fold of the membrane section into the lake. However, the vehicle was not able to climb completely out of the lake. The vehicle backed out into the lake and aligned for a second attempt. A small tear in the membrane was noted at the water's edge. On the second attempt, the membrane tore and shredded in numerous places under the vehicle tracks. While maneuvering into position for a third attempt to climb the slope, the driver noted that the left running gear was inoperative. The vehicle was turned around into a position that facilitated removal from the lake. The vehicle was then pulled out of the lake and up the slope by the M48 tank. As soon as the M113 APC

exited the water, the reason for immobilization was readily apparent. Some six to eight wraps of T17 membrane had been pulled around the sprocket between the sprocket and tracks. The rolled membrane thickness had forced the track away from the sprocket, thereby immobilizing the vehicle (Photos 6g-6n). In addition, one of the cables used to anchor the sandbags was entangled in the track. The exact cause of the entanglement, however, could not be determined. After the M113 APC was repaired, several unsuccessful attempts were made to exit the lake up the 25 percent slope (Photos 6o-6r). However, the M113 APC could only exit the lake at the prepared ramp (Photo 6s) where the slope was less than 15 percent.

22. Analysis of the T17 test results indicate several problem areas relative to the membrane section tests: (a) membrane edges in turbulent water are subject to entanglement in the vehicle running gear, and ropes or cables attached to the membrane as anchors may increase the risk of such entanglement; (b) vehicle tracks push the membrane into the lake bottom, thereby creating a slippery surface at the water's edge, which may also contribute to vehicle slope-climbing problems; and (c) time and equipment needed to anchor and place the membrane exceed the LOA requirements.

M8A1 mat-covered slopes

23. Slope-climbing tests were conducted on the same 25 percent slope used in the membrane test described previously, but in these tests the slope was covered above and/or below the water's edge with the M8A1 mat. The mats were connected in the normal manner, hooks downslope and perpendicular to the slope (across the slope width), to form parallel "runs" 18 in. wide composed of interconnected mat pieces. Initially, 5 runs were placed across the slope itself, and 11 runs were placed parallel to these runs but underwater beginning at the water's edge. The mat was anchored on the slope with four screw-type anchors (Photos 7a-7f).

24. In the initial vehicle test on a dry slope, the M113 APC entered the lake and maneuvered into position to climb the slope. The vehicle attempted to climb the slope five times without success (Table 2). The mat surface apparently had an insufficient traction surface for the

vehicle track system as the vehicle merely spun its tracks on the mat with no forward movement (Photos 7g-7i).

25. For test No. 2, 16 runs of mat were pulled up the slope and flipped over with a crane so that the support ridges on the bottom of the mat were facing upward, i.e., the mat was inverted relative to its normal placement condition. Ten runs of mat were pushed into the water by a bulldozer, and six runs were left on the slope. The mat was not anchored at the start of the test. The vehicle entered the lake and maneuvered into test position. The vehicle then eased up onto the mat, touching some 15 ft or so out into the water, and by very slowly moving forward was able to exit on the slope in the second attempt. The support ridges on the mat created tractive surfaces such that the cleats on the track system were able to gain sufficient support for the vehicle to complete one pass with difficulty, a very marginal single pass. However, the vehicle pushed 3 runs of mat into the water, leaving 3 runs upslope and 13 underwater. Consequently, the test was continued with 3 runs upslope, 13 in the water, and the mat anchored with the rolled edge of the mat downslope to determine any advantage of having more mat in the water (Photo 8).

26. Five attempts at passage were made by the vehicle from the water with 3 runs upslope and 13 underwater, but only two passes were completed (Table 2) with the mat surface dry. The test was temporarily halted when the cables slipped and the mats moved completely into the water, pushed there by the track system pulling downslope on the mat when gaining traction. Therefore, the mat was reanchored by cable to the ground with the first mat at the water's edge. Three anchors were placed in the slope on each side of the mat and tied together with cable. The mat was inverted with the rolled edge of the mat downslope, and the test continued.

27. The vehicle entered the lake and swam around into position for the next pass of traffic. The vehicle eased up onto the mat, and after several spinning attempts, the vehicle was able to complete one pass up the dry mat and slope. However, the mat was pulled completely into the water. Testing was continued, and the vehicle completed

26 passes without much difficulty, although the vehicle tracks spun to varying degrees upon contact with the mat. At the end of test No. 2, the mats had moved into the lake such that the first mat (toward the slope) was 18 in. out from the water's edge. The driver of the vehicle developed a swimming-climbing technique, which improved vehicle performance in the latter half of the passes. The vehicle needed a higher gear (third) for better water speed and maneuverability but a low gear for slope climbing. Accordingly, the driver would reach full speed (3-5 mph) in the water in third gear while moving toward the slope; then immediately prior to mat contact, he would downshift to low gear. At the moment of contact, the driver would then accelerate onto the mat and continue upslope. This procedure seemed to push the vehicle onto the mat by inertia and weight transfer, and the shift to low gear then increased the traction capability of the vehicle upslope on the mat and slope (Photos 9a-9l).

28. For test No. 3, 16 runs of mat were left in position (after the previous tests), and the slope was sprayed with water from a truck. The M113 APC had little difficulty completing 15 passes before being stopped because of anchor failure on the left side. After the anchor was repaired, tests were continued; the vehicle completed 3 more passes (total of 18) without much difficulty (Photos 9m-9r). However, it was discovered that the first 5 runs of mat at the water's edge had been disconnected from the other 11 runs, which had been pushed farther out into the lake. The five panels were removed from the lake by crane and were heavily damaged by vehicle traffic, especially at the panel joints (Photo 10). Evidently, the rolled edge, when placed downslope, was rather easily opened up and unrolled by the track system spinning on the rolled section. After unrolling, the panels then easily disconnected with little effort.

29. Two runs were replaced in the water (though not attached to the 11 runs already in the water) about 2 ft from the water's edge and anchored to the slope. The slope was again sprayed with water from a water truck to simulate a rainy or surface slipperiness condition on the slope and traffic continued. The vehicle had difficulty getting onto

the mat at first, but after apparently seating the mat in the lake bottom, the vehicle completed 5 passes (total of 23) without difficulty before anchor failure occurred on the left again. The mat was reanchored, and 2 more passes were made to complete the required 25 passes to conclude test No. 3.

30. The slope was checked for test No. 4, and negligible change was noted. The panels of mat were retrieved from the water, and five runs were reconnected with the top side up. The mats were then shoved into the water a distance of 4 ft from the water's edge and anchored. The rolled edge was downslope, and the slope was continuously sprayed with water during traffic. The vehicle attempted to climb onto the mat but could not gain sufficient traction to exit the water. The tracks would catch momentarily on the connector hooks of the mat but could not develop sufficient traction; thus spinning and backsliding occurred. Five attempts were made at passage with no success (Photos 11a-11e).

31. The five runs of mat were then pulled from the lake, inverted (by crane) with the hooks downslope, and anchored and replaced underwater some 2.5 ft from the water's edge for test No. 5. The slope was sprayed with water prior to and during testing. However, in five attempts at passage, the vehicle was not able to complete a single pass. In test No. 6, the mat was pushed farther into the water so that the first panel was 4 ft from the water's edge. In four attempts, the vehicle was still unable to complete a single pass although both slow- and fast-speed runs were attempted (Photo 11).

32. The five runs of mat were removed from the lake by crane and replaced with two runs of mat about 4 ft into the lake for test No. 7. The slope was again sprayed with water to simulate wet-season conditions. The vehicle made the first approach at full speed, and upon encountering the mat underwater, the vehicle appeared to "seat" the mat into the lake bottom, then override the mat and continue upslope. After two passes, the mat had been pushed out into the lake another 2 ft. The vehicle was able to complete 8 passes in 10 attempts with little difficulty. However, the left-side anchor became loose, and the test was stopped. The relative ease of the slope climbing of the vehicle in the 8 passes

indicated that the vehicle could complete the required 25 passes with little difficulty, and so this test was stopped (Photos 11g-11h).

33. For test No. 8, two runs of mat were placed in the lake in the original configuration, i.e., surface up, but with the rolled edge the farthest out in the water, approximately 4 ft from the water's edge. The surface of the slope was left dry. The vehicle was able to complete 9 passes in 11 attempts with high slippage and poor control (Photos 11m-11q). Analysis of the test results indicated that the overlap edge (hook) may have provided sufficient traction to complete the required passes. However, it appeared that the slope had been decreased by traffic at the water's edge and may have aided the vehicle passage. Reprofiling of the slope (Figure 3), however, did not show any large slope changes.

34. In summary, the M8A1 mats provided the vehicle somewhat marginal assistance in exiting the lake. However, unless placed in exactly the right position and anchored securely, the vehicle was unable to utilize the mats. Also, the mat (and membrane) required rather long periods of time for placement, more on the order of 2 to 3 hr or more, rather than the 15 min or less that was desired. Wetting the slope did not appear to hinder vehicle passage to any great degree in these tests, although clay slopes may produce slippery conditions more so than those experienced in these tests. Differences in soil strength as determined from the average of cone index measurements before and after traffic (Figure 4) were not significant.

Drawbar Pull Tests

35. A firm, dry, level grass-covered area within the boundaries of the WES reservation was selected for drawbar pull tests (Photo 12) using an M113 APC partially loaded to 19,950 lb. The area was 100 percent covered with Bermuda grass atop silty clay soil. The vehicle was instrumented for the tests, and a 20,000-lb load cell was connected by cables to a loaded M113 APC. Only maximum pull values and pull values at 100 percent slip were measured.

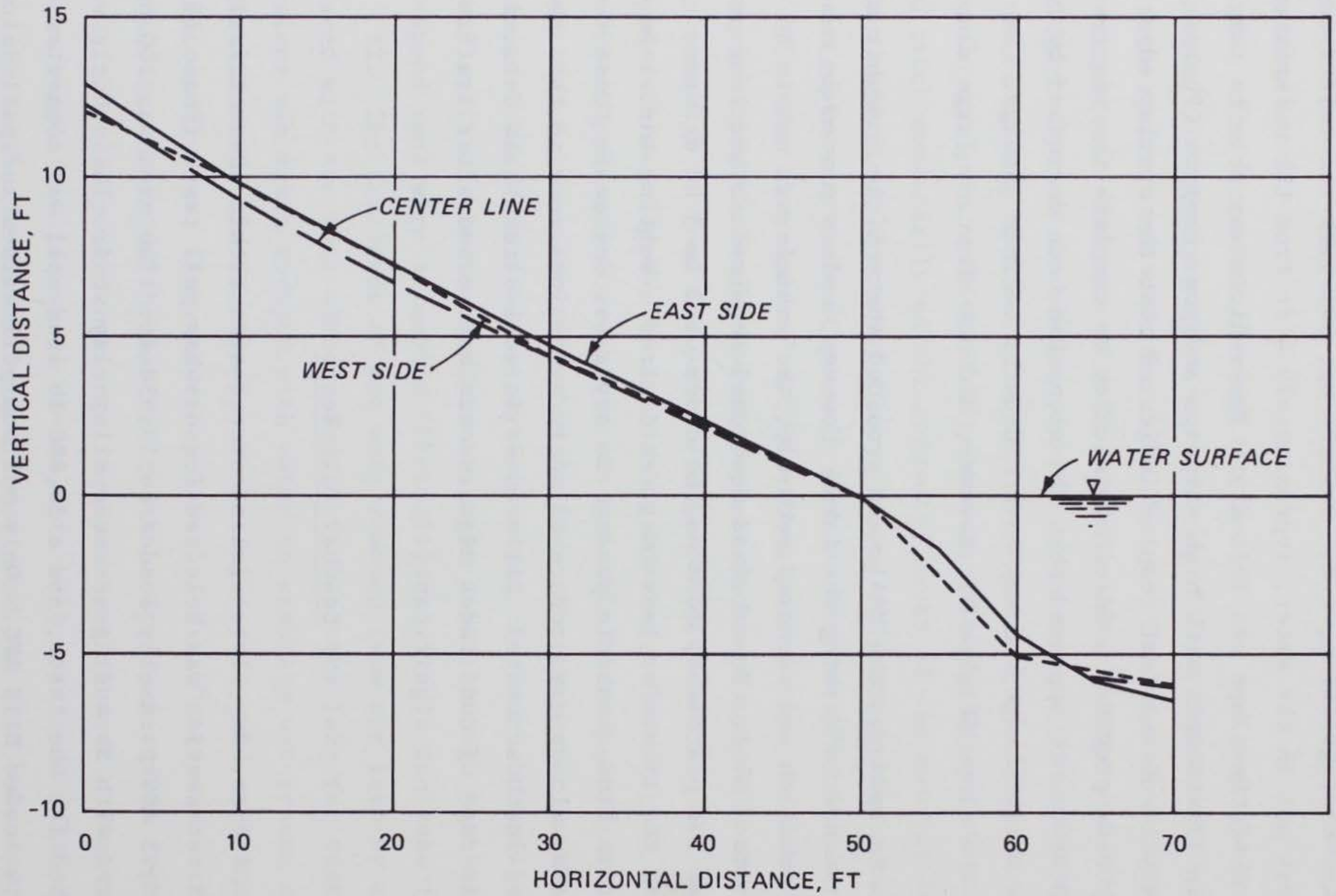


Figure 3. After traffic profile, Brown Lake slope

Meas. No.	Cone Index Depth, in. SFC	1	2	3	4	5	6	9	12	15	18
						Before Traffic					
1	70	170	250	240	300	230	230	250	650	750+	750+
2	140	200	200	200	185	180	225	310	400	350	340
3	140	260	250	270	290	330	370	420	530	600	750+
4	130	190	175	160	190	190	215	720	750+	750+	750+
5	150	170	150	180	300	230	300	330	300	220	220
6	130	170	150	140	140	125	185	300	250	220	210
7	260	350	340	260	240	300	270	250	180	170	250
8	170	270	340	420	320	240	240	230	200	210	300
9	120	250	330	410	330	290	280	250	320	280	250
10	170	180	180	160	200	230	270	260	330	330	410
Avg	148	221	236	244	250	234	258	332	391+	388+	423+

Average Cone Index by Depths, in.: 0-6 = 236; 6-12 = 326+; 12-18 = 438+

						After Traffic					
1	50	150	210	240	300	230	230	250	475	600	750+
2	110	170	200	270	300	180	220	255	440	570	550
3	125	200	250	290	330	190	220	320	500	720	750+
4	120	200	270	320	285	230	245	325	450	560	600
5	130	190	280	300	270	230	260	370	580	750+	750+
6	125	210	220	270	290	250	270	330	250	220	250
7	150	230	300	300	320	240	265	345	320	280	340
8	140	240	340	320	330	300	340	470	430	330	410
9	120	180	320	310	290	265	240	305	180	210	250
10	120	210	260	190	240	250	285	340	260	170	210
Avg	119	198	265	281	296	236	258	331	388	441+	486+

Average Cone Index by Depths, in.: 0-6 = 236; 6-12 = 326; 12-18 = 438+

Figure 4. Before and after traffic cone indexes for 25 percent slope, Brown Lake

36. Initially, a vehicle test was conducted on dry grass as an in situ condition. The vehicle was able to develop 13,922 lb of drawbar pull during the test as a maximum and 13,200 lb at a 100 percent slip. These values correspond to drawbar pull coefficients (drawbar pull, lb ÷ vehicle weight, lb) of 0.70 and 0.66, respectively.

37. A 36- by 100-ft membrane pad was next unrolled, stretched, and staked at the sides and ends with anchors. The test was conducted dry as in the dry grass tests. The vehicle was able to develop a maximum of 13,287 lb with 10,494 lb at 100 percent slip, corresponding to drawbar pull coefficients of 0.67 and 0.53, respectively. In this test, the membrane stretched and wrinkled beneath the tracks at the high-pull values but returned to almost the original position after traffic. The membrane material around the anchors also tore in the direction of pull, especially during the high-pull portion of the test.

38. The membrane was sprayed with water from a water truck continually during the next test series on wet membrane. The pull was reduced considerably to 7109-lb maximum with only 4062 lb at 100 percent slip, or drawbar pull coefficients of 0.36 and 0.20, respectively. Membrane stretching and wrinkling occurred as in the dry membrane tests. The tracks were then sprayed while the membrane was wet to simulate water existing from a lake or river with similar pulls and coefficients as the previous tests at a maximum of 7024 lb (0.35) with 3980 lb (0.20) at 100 percent slip.

39. The membrane was removed and the grass sprayed for the next test series. On the wet grass, the vehicle developed a maximum of 7363 lb (0.37) with 7363 lb (0.37) at 100 percent vehicle slip. The vehicle was towed in neutral gear for the motion resistance measurement, which averaged 1875 lb (0.094) for these tests.

40. As shown in these tests, the dry membrane reduced the maximum pull obtained by the M113 APC in dry grass less than 20 percent, but this reduction increased to about 60 percent from dry, when the membrane was wet, although the wet grass also reduced the pull from that at the dry grass condition by almost this amount. However, using the usual assumption that the drawbar pull coefficient is approximately equal to

the slope in percent for tests in firm soils, the M113 APC should be able to climb a maximum wet membrane-covered slope of 20-35 percent. This assumption coincides with the results of the lake tests in which the slope-climbing capability of the M113 APC was rather marginal on 23-25 percent slope at Brown Lake.

PART III: SUMMARY OF TEST RESULTS AND RECOMMENDATIONS

Summary of Test Results

41. Results of this study are summarized below:

a. Tests with T17 membrane-covered slopes (25 percent or less) in upland areas and adjacent to a lake indicate that the membrane must be anchored extremely well on the slope and that the membrane itself does not necessarily assure traction at the toe of the slope at the water/soil interface. When wet, the membrane becomes relatively slick but still produces a sufficient traction surface for vehicle passage, provided the vehicle can negotiate the slope.

b. Tests on mat-surfaced slopes (M8A1 or M19) indicate the same problems that were encountered in the membrane tests. When the mat was moved totally underwater, the vehicle negotiated the slopes, sometimes easily and other times marginally, depending on the mat configuration and the presence of any points on the mat for the vehicle to gain sufficient traction to climb the slope. The vehicles negotiated the mat-covered slopes rather easily, wet or dry, when sufficient traction was obtained to climb the slope.

c. Placement times of 15 min were not achieved. In fact, placement of the membrane or mat on riverbanks or slopes by any of the means used in the tests requires at least twice the time stated in the LOA. Also, engineer equipment must be available for anchor placement, mat placement upside down on the slope, and mat or membrane anchorage underwater.

d. Membrane placed in lake bottoms underwater must be placed so that allowances are made for the membrane movement to conform to vehicle ruts in the soft lake-bottom mud and the edges are anchored to the lake bottom to prevent entanglement in vehicle running gear. Cables attached to sandbags that were used to anchor the mat to the lake bottom in the tests reported herein became exposed with vehicle traffic and were easily entangled in the vehicle traction elements.

e. The M113 APC was able to exit the lake at an unimproved soil ramp where the slope was less than 15 percent. The slope that represents its limiting capability is unknown.

Recommendations

42. Of the currently available depot items, which were considered for evaluation as a surfacing of a slope used in an egress mode, the following recommendations are warranted:

a. The T17 membrane, M19 mat, and M8A1 mat, when placed in normal placement patterns, will not support significant traffic on a 25 percent slope, primarily because of inadequate traction (coefficient of friction).

b. Although the M19 and M8A1 mats will provide structural support to both wheeled and tracked vehicles on 25 percent slopes and less when dry, the membrane is torn and is not effective if used alone.

c. To achieve the necessary traction required on a 25 percent slope, especially when mud is tracked on the slope surface, it appears that the M8A1 mat must be placed with the bottom side (ribs) up for tracked swimmers, such as the M113 APC. However, this placement will not meet the LOA because its placement-time requirements far exceed those of the LOA.

d. A surfacing should be developed that would provide the necessary structural strength for the tactical vehicles as well as the necessary tractive surfacing to allow climbing the 25 percent slope in a muddy environment.

e. Where egress improvement is desired and the stringent time, manpower, and equipment limitations of the LOA are not present, expedient methods are available. One method would be to flatten the slope using a D-7 bulldozer or use the combat engineer vehicle (CEV). The other is the inverted M8A1 installation described in c. above.

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Table 1

Summary of Traffic Test on 25 Percent Slope (14 Degrees), Upland Area

Mat Type	Vehicle	Dry Passes	Dry Maximum Mat Moved, in.	Wet Passes	Wet Maximum Mat Moved, in.	Wet Clay* Passes	Wet Clay* Maximum Mat Moved, in.	Remarks
Unsurfaced soil (no mat)	M113	25	--(1)**	2	--	--	--	(1) Rut depth of 4-1/2 in. after traffic of three vehicles
	M54	25	--	0	--	--	--	
	M48A1	25	--	1	--	--	--	
M19 anchored	M113	25	1/8	25	3/8	25	1/8	
	M54	25	6-3/4	25	1-1/2	0	0	
	M48A1	25	6-3/4	25	6-1/4	5(2)	1-1/4	(2) Plus three attempts
M19 unanchored	M113	25	3-7/8	25	7-1/4	--	--	
	M54	25	19-5/8	25	4	--	--	
	M48A1	25	16-1/4	25	8-1/8	--	--	
M8A1 anchored	M113	25	3/8	25	1/2	--	--	
	M54	25	3/4	25	1-3/8	--	--	
	M8A1	25	1/2	25	1-1/8	--	--	
M8A1 unanchored	M113	25	3/8	25	1/4	25(3)	5/8	(3) Slid off of mat edge on last pass
	M54	25	1/4	25	1	0(4)	1/8	(4) Attempted three passes
	M48A1	25	1/2	25	5/8	3(5)	--(6)	(5) Plus three attempts (6) Slight
M8A1, inverted anchored	M113	--	--	--	--	25	5-1/2(7)	Failed 1st attempt. Successful after tank traffic
	M54	--	--	--	--	0	--	
	M48A1	--	--	--	--	25	12-1/4(7)	(7) Clay superwet
T17 membrane anchored	M113	25	1-1/2	25	3(8)	4(11)	--	(8) Caused 5-1/4- and 2-1/4-in. tears
	M54	25	3	25	3/8(9)	0	2-1/2	(9) Caused 1- and 1-1/2-in. tears
	M48A1	25	5	25	3-3/4(10)	0	--(12)	(10) No change (11) Ten attempts with 20-ft start made four passes, membrane severely damaged (12) Membrane torn across entire width

* Tests required vehicles to track through wet clay at toe of slope.

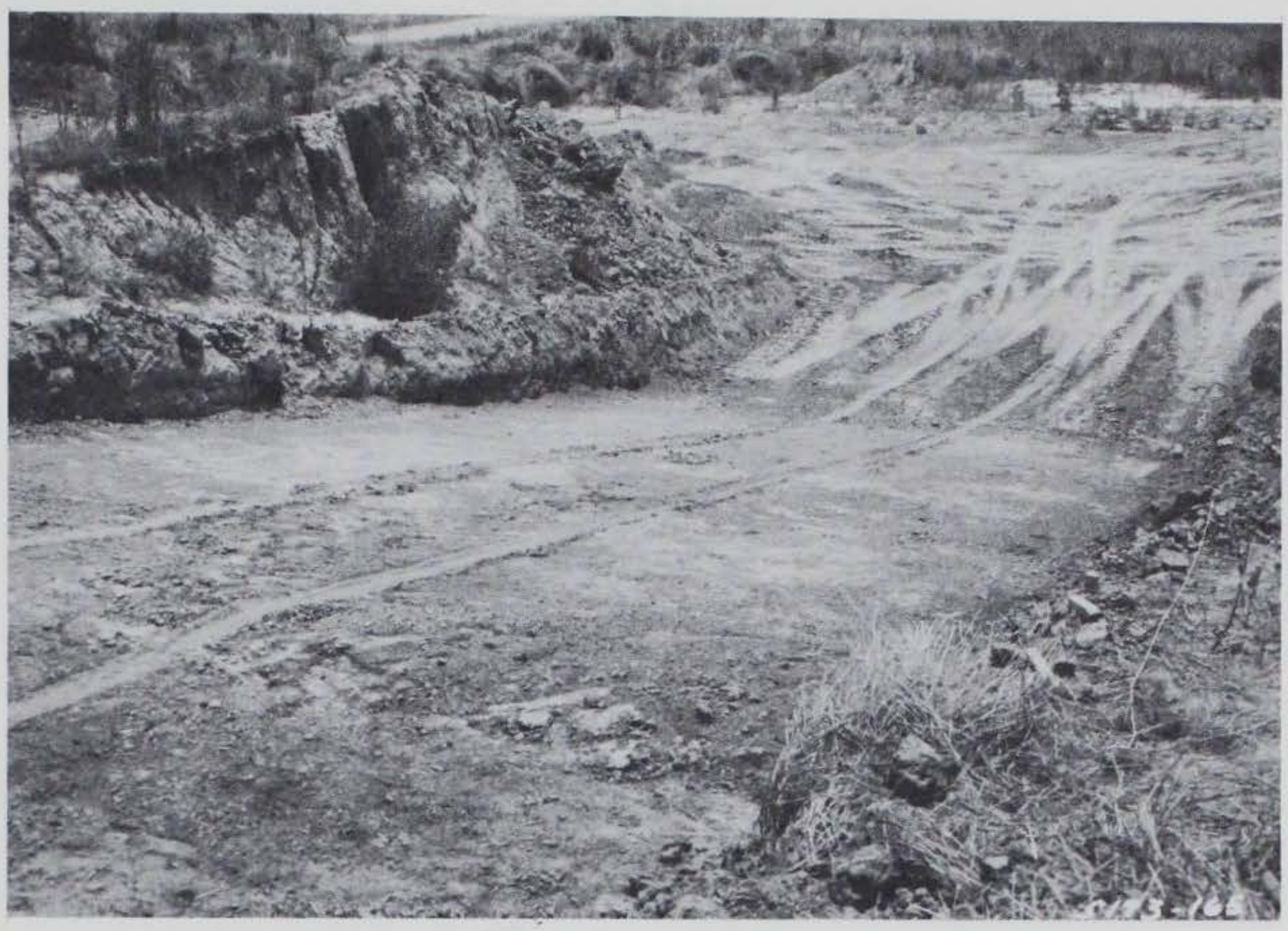
** Numbers in parentheses refer to similarly numbered comments under the Remarks heading.

Table 2

Summary of Tests of the M8A1 on 25 Percent Slope, Brown Lake

Test	Attempts	Passes	Mat Surface Up/Down	Mat End in Water, 1st	Distance from Water Edge to 1st Mat,* ft	Slope Condition	Remarks
1	5	0	Up	Hook	NA**	Dry	11 runs in water, 5 runs on slope
2	2	1	Down	Rolled	NA	Dry	10 runs in water, 6 runs on slope
	5	2	Down	Rolled	NA	Dry	13 runs in water, 3 runs on slope
	31	26	Down	Rolled	NA	Dry	After 3 passes, all mats in water, and after 8 passes, all mats 18 in. in water
3	15	15	Down	Rolled	1.5	Wet	16 runs in water
	19	18	Down	Rolled	1.5	Wet	Anchor failed. Bank 5 runs disconnected from 11 runs. Half panel loose in 5 runs. Replaced with 2 runs in water
	28	25	Down	Rolled	2.0	Wet	
4	5	0	Up	Rolled	4.0	Wet	5 runs
5	5	0	Down	Hook	2.5	Wet	5 runs only. 2 slow and 3 fast attempts
6	4	0	Down	Hook	4.0	Wet	Slow and fast speed
7	10	8	Down	Hook	4.0	Wet	2 runs only. After 2 passes, mat 6 ft in water
8	11	9	Up	Rolled	4.0	Dry	2 runs only. Poor control of vehicle

NOTE: In the last test, the slope in and near the water had probably decreased because of traffic.
* Other mats were farther out in water.
** Not available.



a. Dry slope

b. M54 truck completing 25 passes on dry slope

Photo 1. Unsurfaced 25 percent slope test area (Sheet 1 of 4)

c. M113 APC completing 25 passes on dry slope

d. M48 tank on dry slope

Photo 1. (Sheet 2 of 4)

e. M54 truck attempting to travel up the wet slope

f. M113 APC attempting to travel up the wet slope

Photo 1. (Sheet 3 of 4)

g. M48 tank attempting to travel up the wet slope

Photo 1. (Sheet 4 of 4)

a. M19 surfacing on 25 percent test slope

b. M54 truck making initial pass on dry mat slope

Photo 2. Twenty-five percent test slope area surfaced with the M19 mat (Sheet 1 of 2)

c. M113 APC making 25 passes on dry mat slope

d. M48 tank making initial pass on dry mat slope

Photo 2. (Sheet 2 of 2)

a. M54 truck attempting to make a pass up the slope

b. M48 tank attempting to make fourth pass up the slope

Photo 3. Traffic on 25 percent slope surfaced with M8A1 mat, wet, after exiting wet clay soil at toe of slope (Sheet 1 of 2)

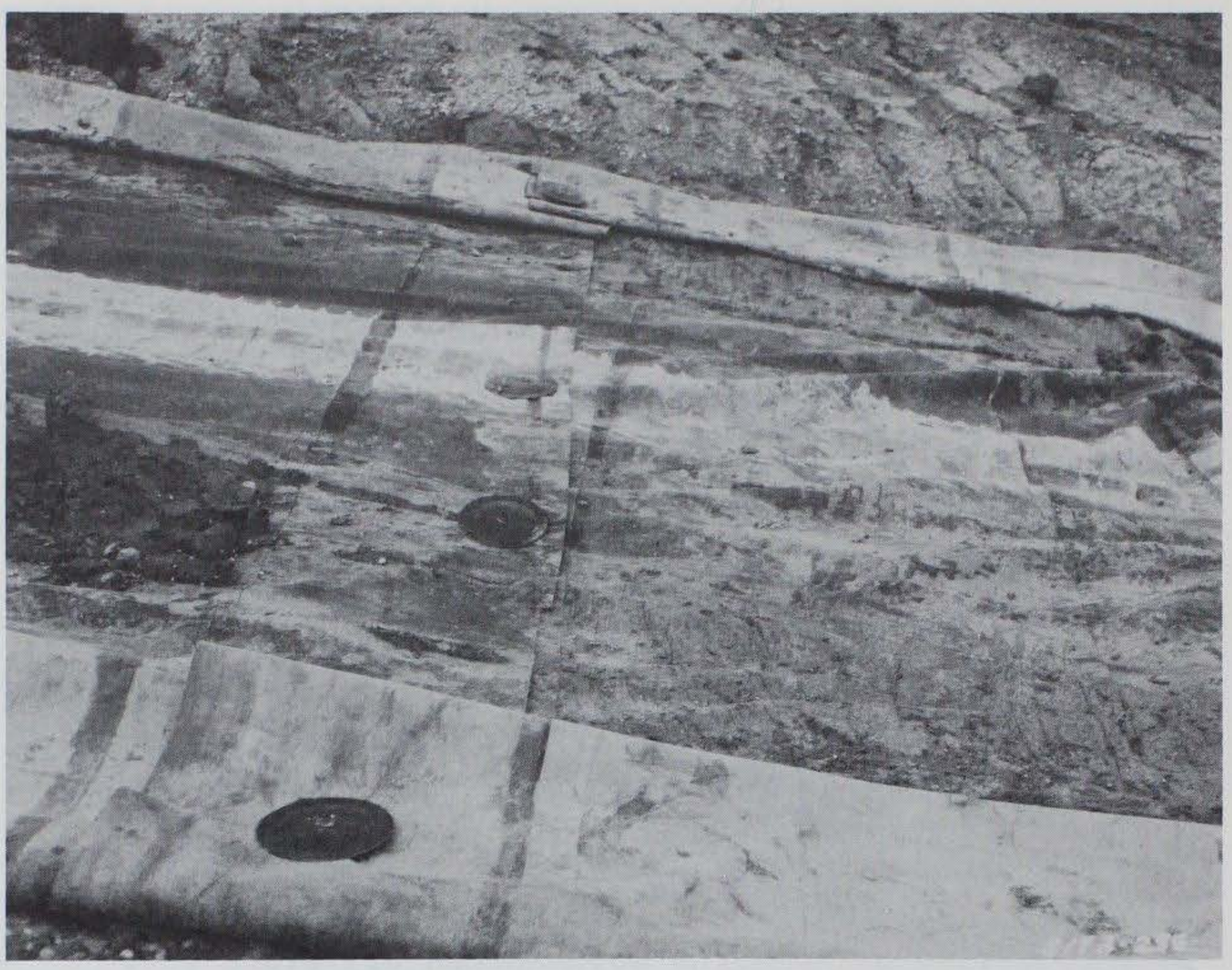
c. M113 APC making one of 25 passes up the slope

Photo 3. (Sheet 2 of 2)

a. View of membrane movement on dry slope with traffic by the M48 tank

b. View of membrane and dry slope after vehicle traffic

Photo 4. T17 membrane-covered slope tests, upland areas (Sheet 1 of 5)



c. View of replaced and tacked membrane prior to vehicle traffic on the wet slope

d. M113 APC attempting to negotiate 25 percent membrane-covered slope while slope is wet

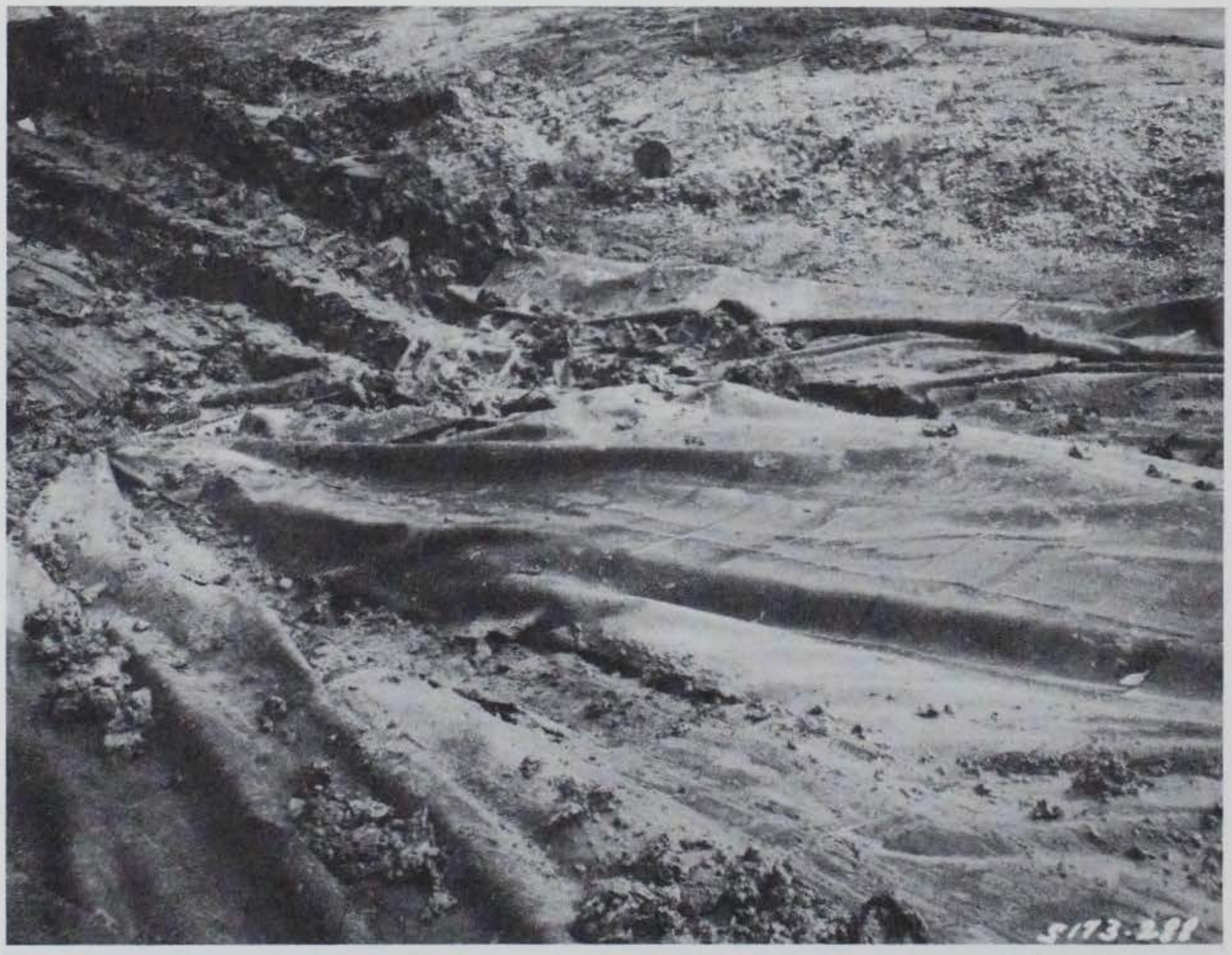
Photo 4. (Sheet 2 of 5)

e. M54 truck attempting to negotiate a wet 25 percent membrane-covered slope with a wet clay layer at toe of slope

f. M48 tank attempting to negotiate a wet 25 percent membrane-covered slope with a wet clay layer at toe of slope

Photo 4. (Sheet 3 of 5)

g. M113 APC stretching and tearing a wet membrane-covered slope

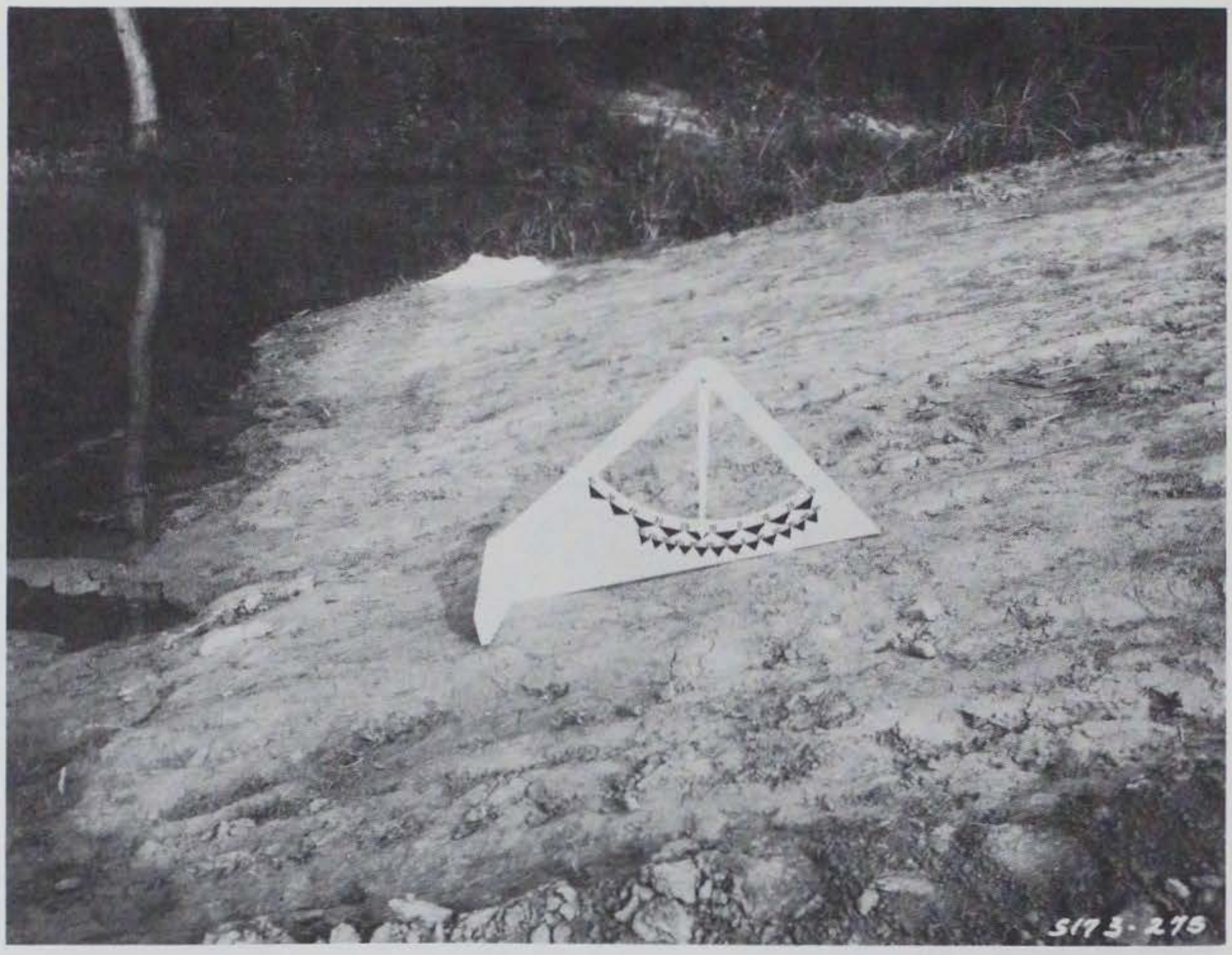


h. View of membrane stretching at the membrane-clay layer interface

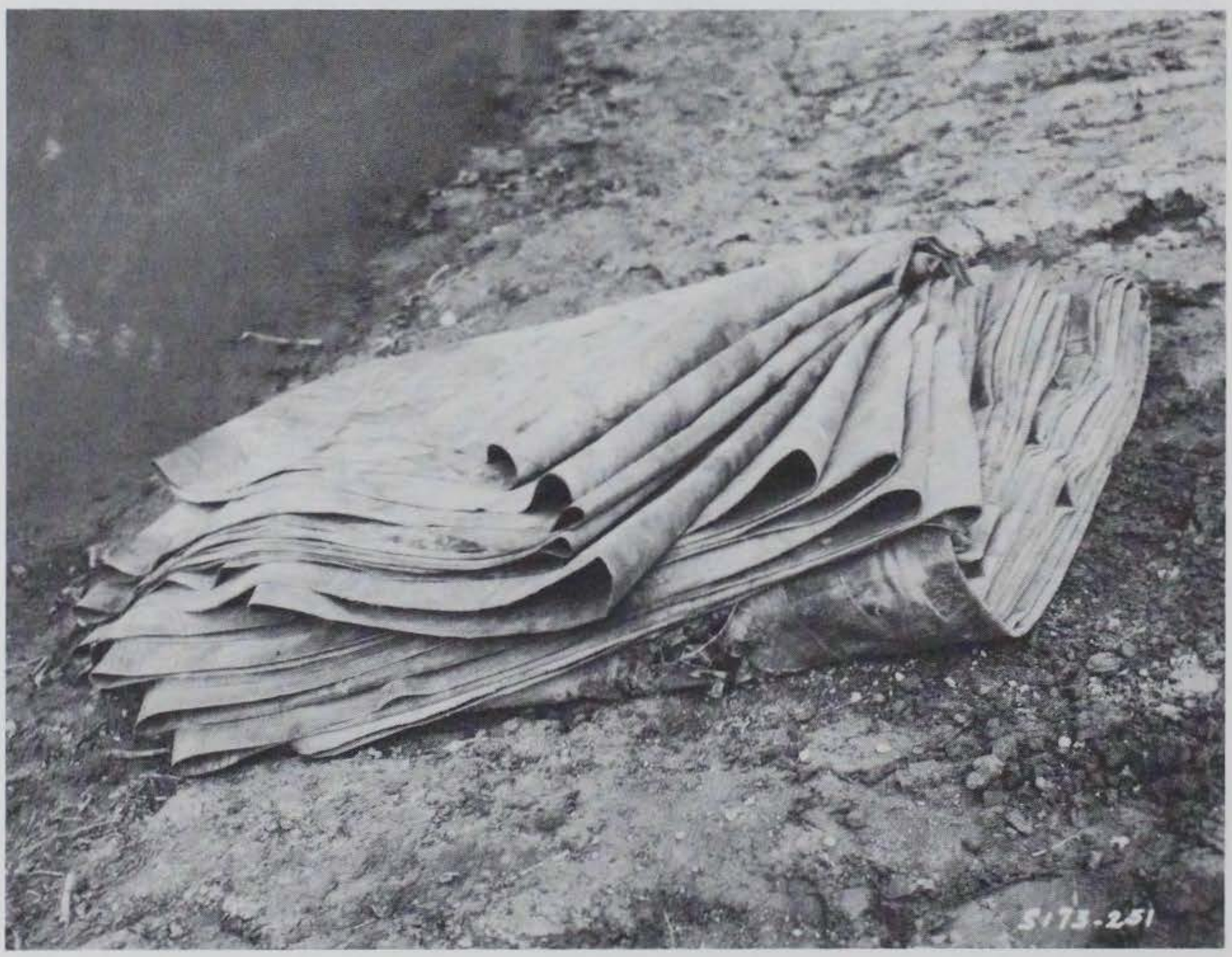
Photo 4. (Sheet 4 of 5)

i. View of membrane-covered slope after all traffic tests completed

Photo 4. (Sheet 5 of 5)



a. Slope indicator showing 25 percent slope



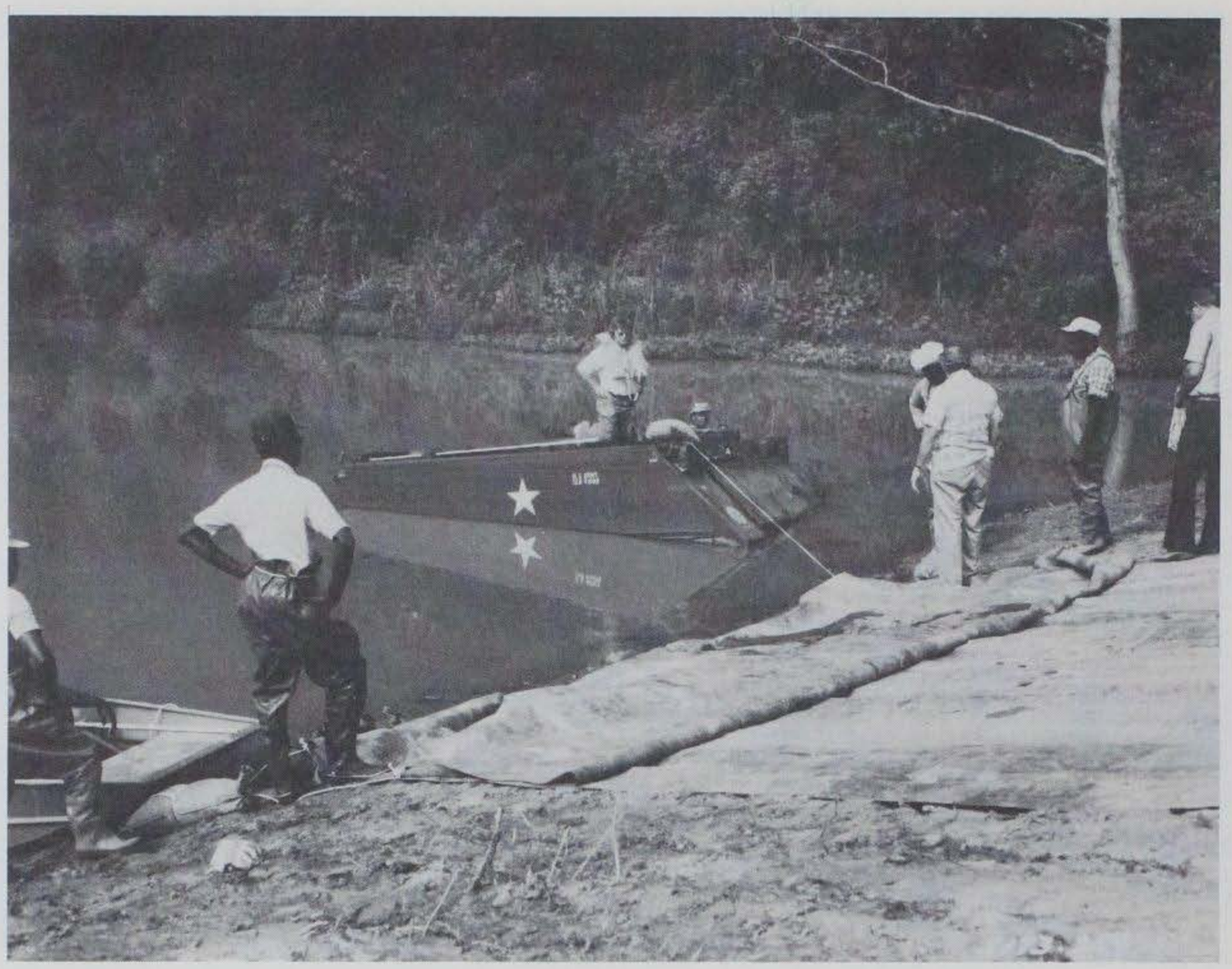
b. View of folded membrane as delivered to slope site

Photo 5. T17 membrane-covered slope tests,
Brown Lake area (Sheet 1 of 6)

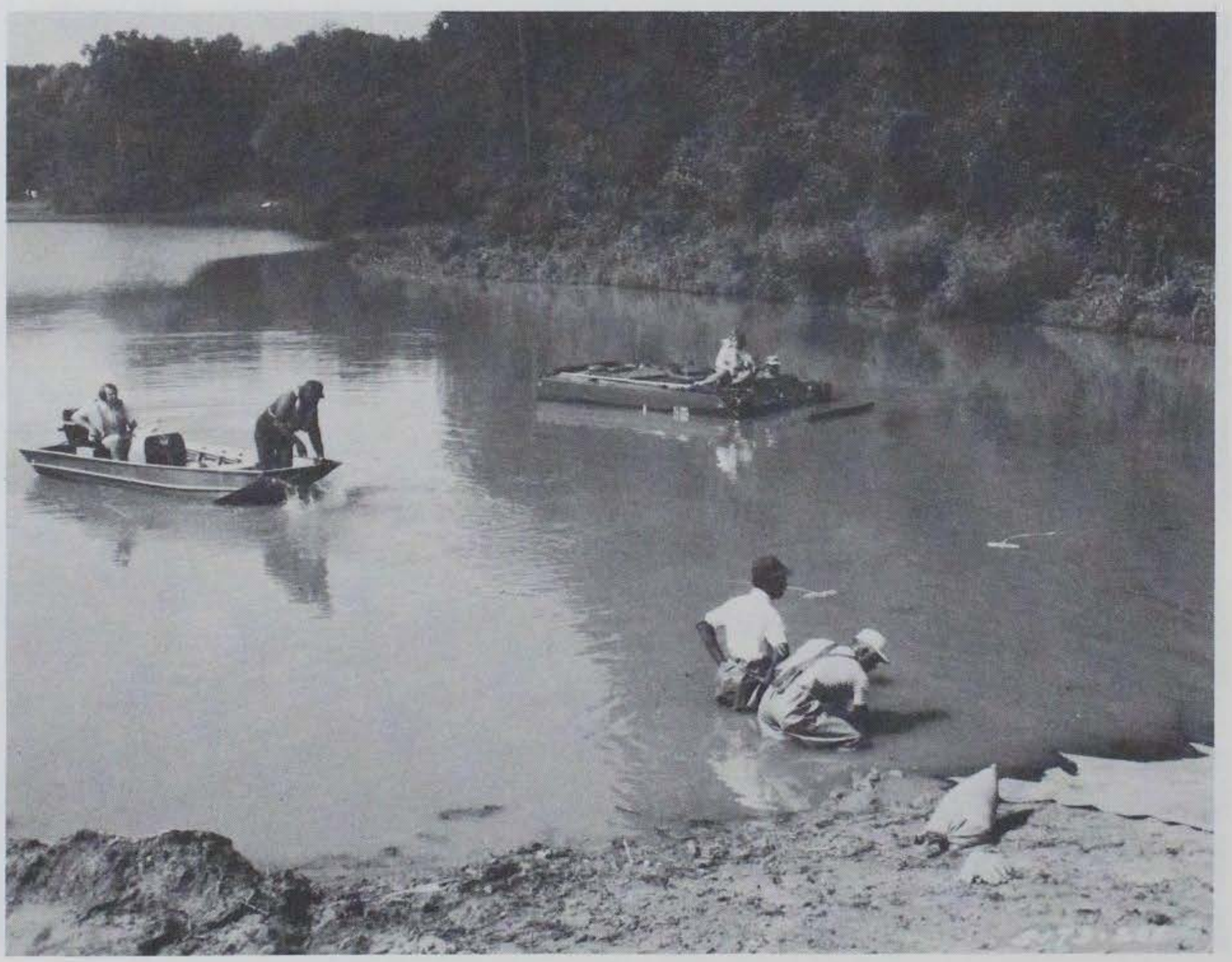
c. Lateral unfolding procedure to place membrane across slope

d. Stretching of membrane upslope prior to anchoring

Photo 5. (Sheet 2 of 6)

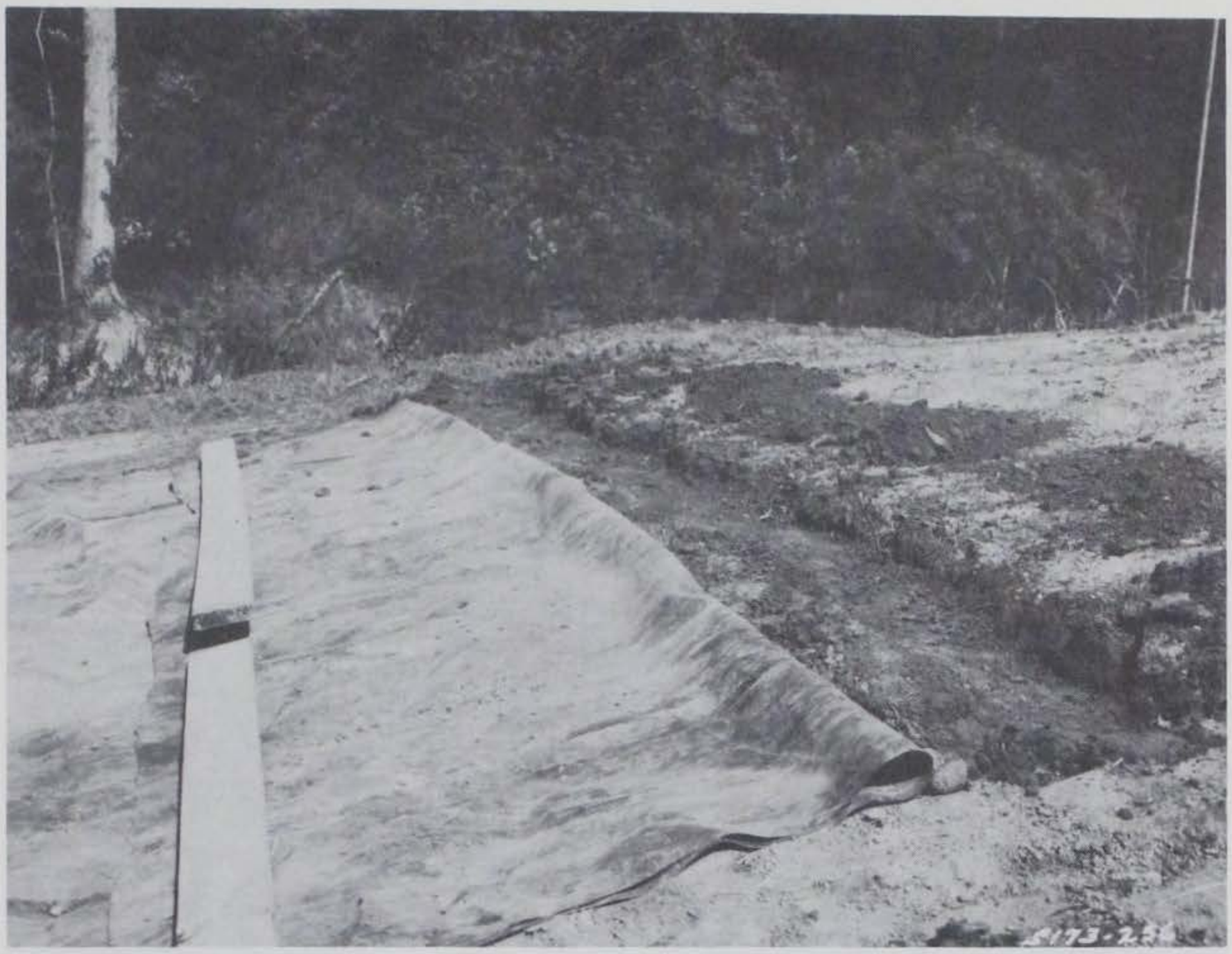


e. Membrane placement into lake underwater



f. Cable and sandbag anchoring of membrane in lake

Photo 5. (Sheet 3 of 6)

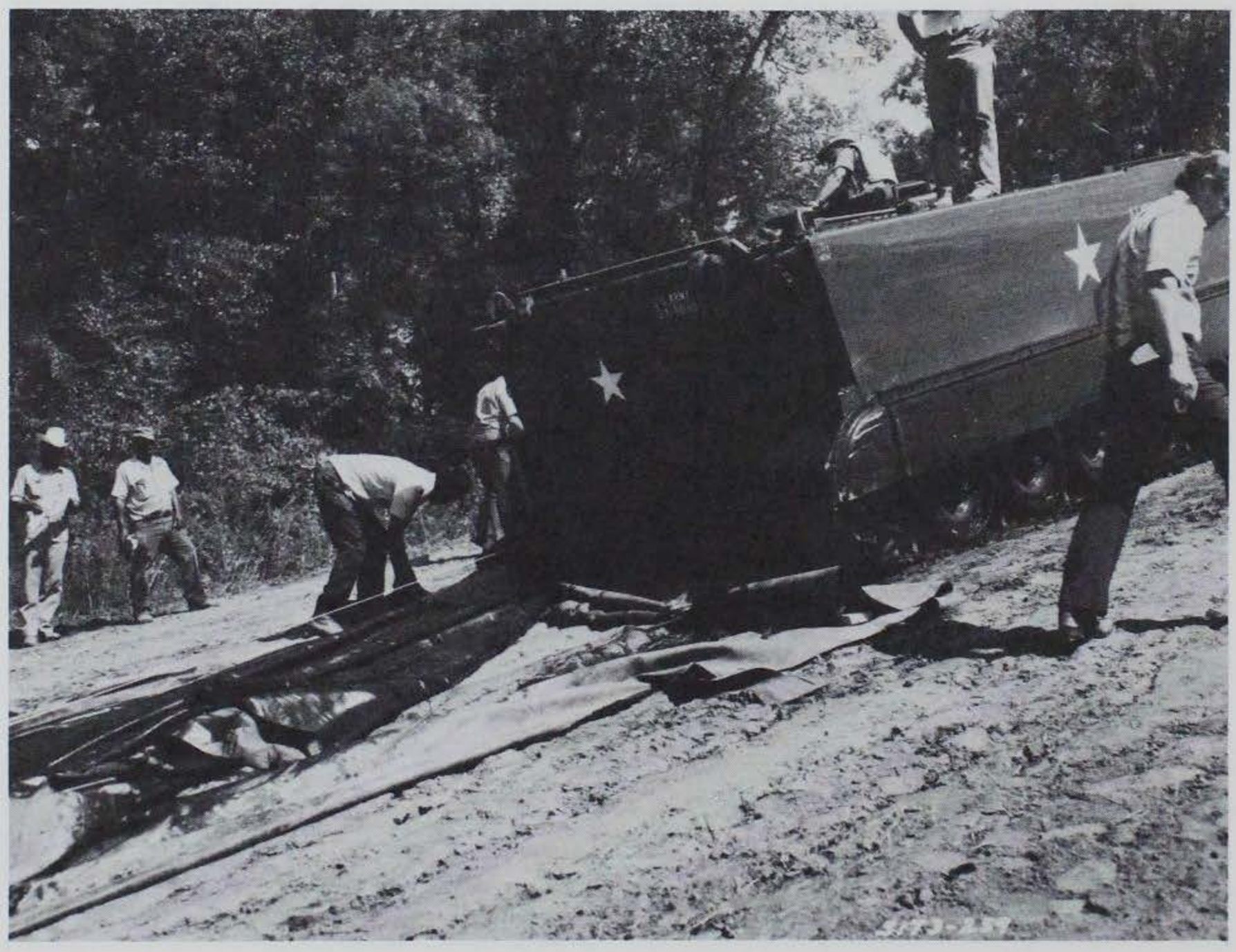


g. Small trench at top of slope used to anchor membrane folded around 2- by 6-in. board

h. Anchor placement on membrane at 2- by 6-in. fold

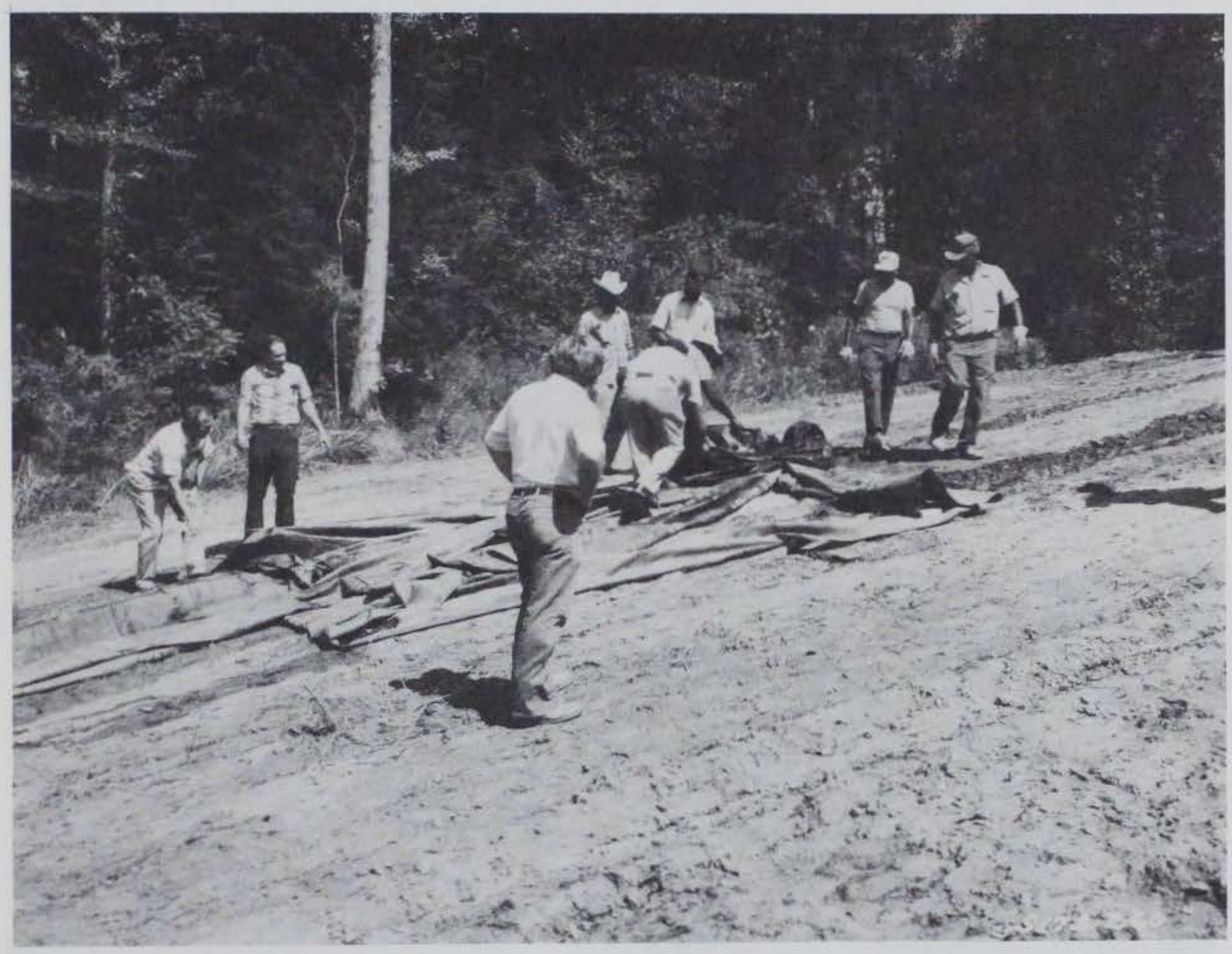
Photo 5. (Sheet 4 of 6)

i. Initial slope-climbing test with the M113 APC showing membrane pulled downslope



j. Sandbag/cable and membrane wrapped up in vehicle track system

Photo 5. (Sheet 5 of 6)



k. Membrane position and condition at end of test

Photo 5. (Sheet 6 of 6)

a. Folded 36- by 100-ft T17 membrane as delivered to top of slope

b. Lateral unfolding of membrane across width of slope

Photo 6. T17 membrane-covered slope tests (w/fold), Brown Lake area (Sheet 1 of 10)

c. Pulling of membrane downslope prior to anchoring

d. Ditch, 3-1/2 by 2 by 25 ft, excavated at top of slope for membrane anchoring

Photo 6. (Sheet 2 of 10)

e. Side anchor placement by manual labor

f. Sandbag anchor placement in water by boat (note the 4-ft fold left in membrane at water's edge)

Photo 6. (Sheet 3 of 10)

g. Initial vehicle contact with underwater membrane showing unfolding of 4-ft fold at water's edge

h. M113 APC attempting to climb onto membrane on slope

Photo 6. (Sheet 4 of 10)

i. M113 APC almost up out of water and onto slope

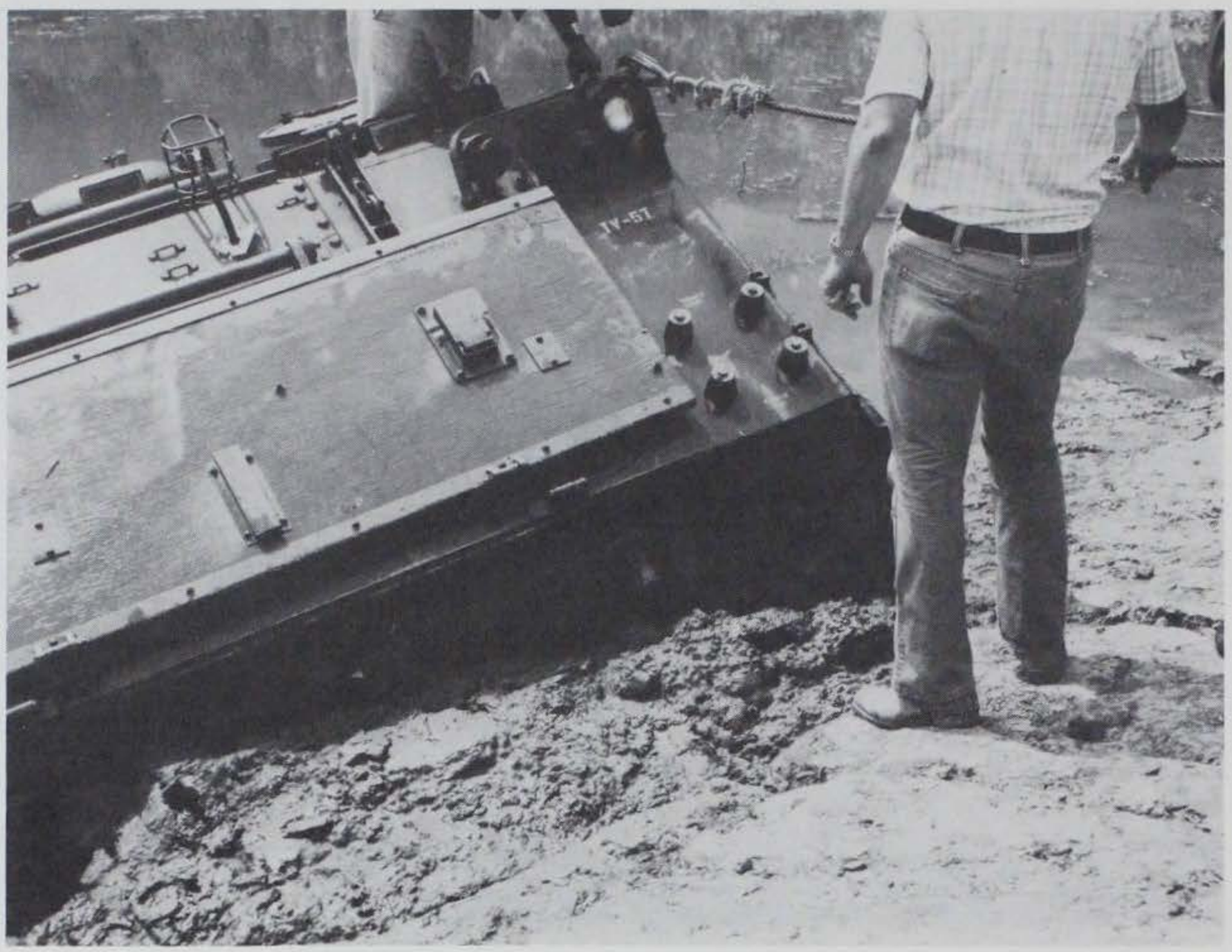
j. Vehicle sliding back into water after spinning on membrane

Photo 6. (Sheet 5 of 10)

k. Damaged membrane shredded at water's edge by spinning tracks of vehicle

l. Vehicle immobilized by membrane entangled in track system

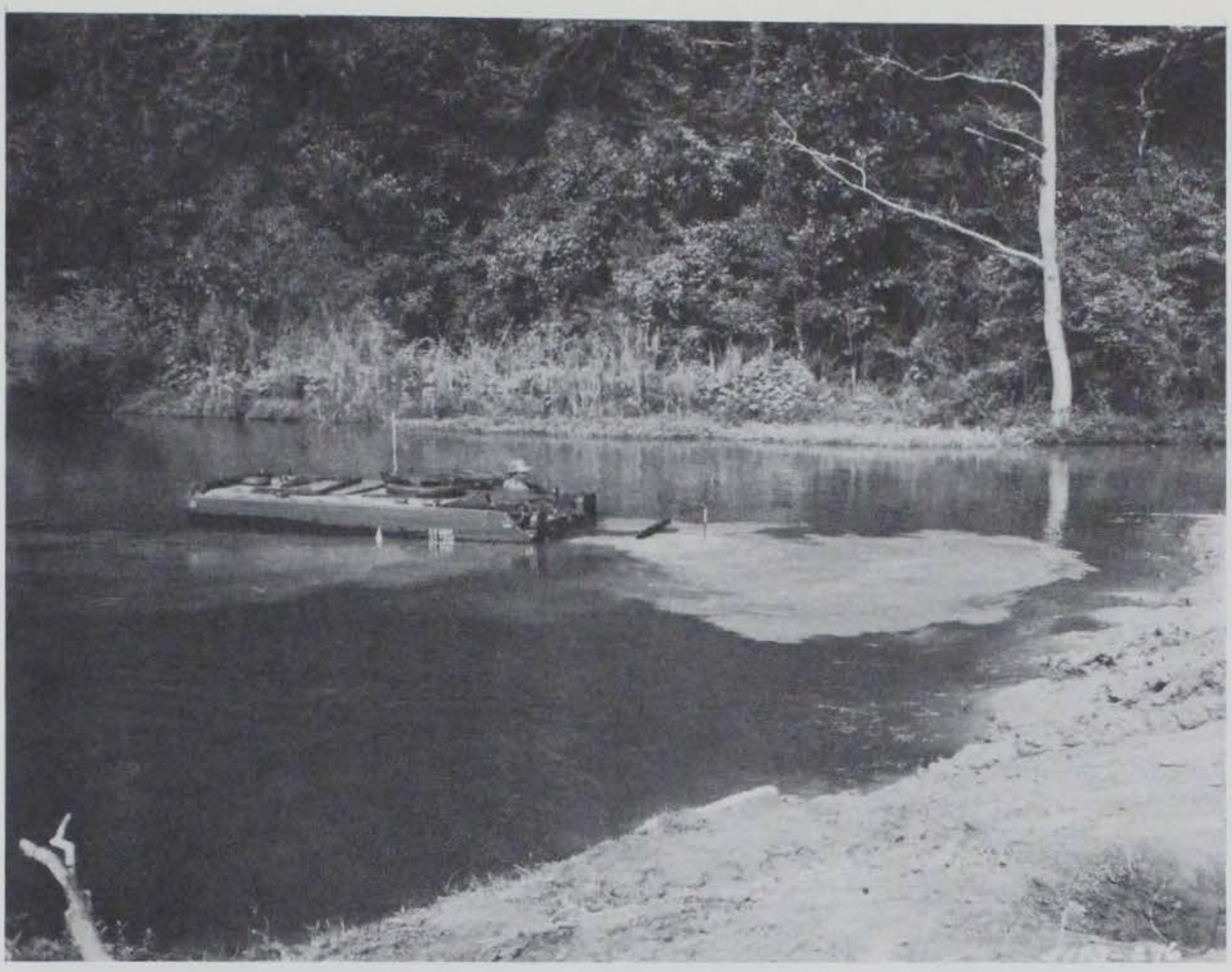
Photo 6. (Sheet 6 of 10)



m. Vehicle being pulled from lake, showing damage to left sprocket

n. Membrane entangled in left sprocket (note steel anchor cable in sprocket, which may have caused initial entanglement)

Photo 6. (Sheet 7 of 10)

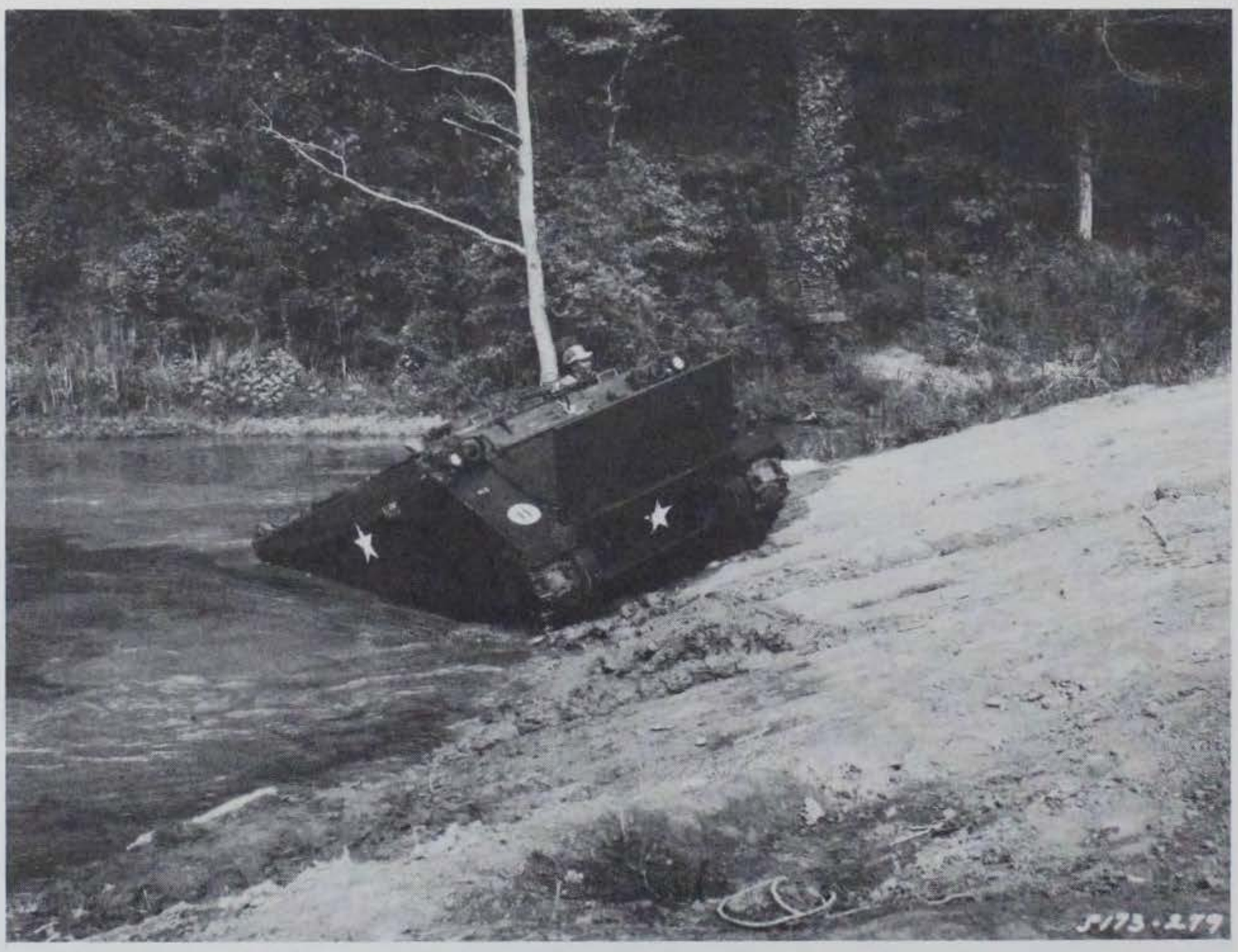


o. After repair vehicle attempted to climb unsurfaced slope

p. Vehicle just climbing onto base of slope at water's edge

Photo 6. (Sheet 8 of 10)

q. Vehicle tracks spinning on slope at water's edge

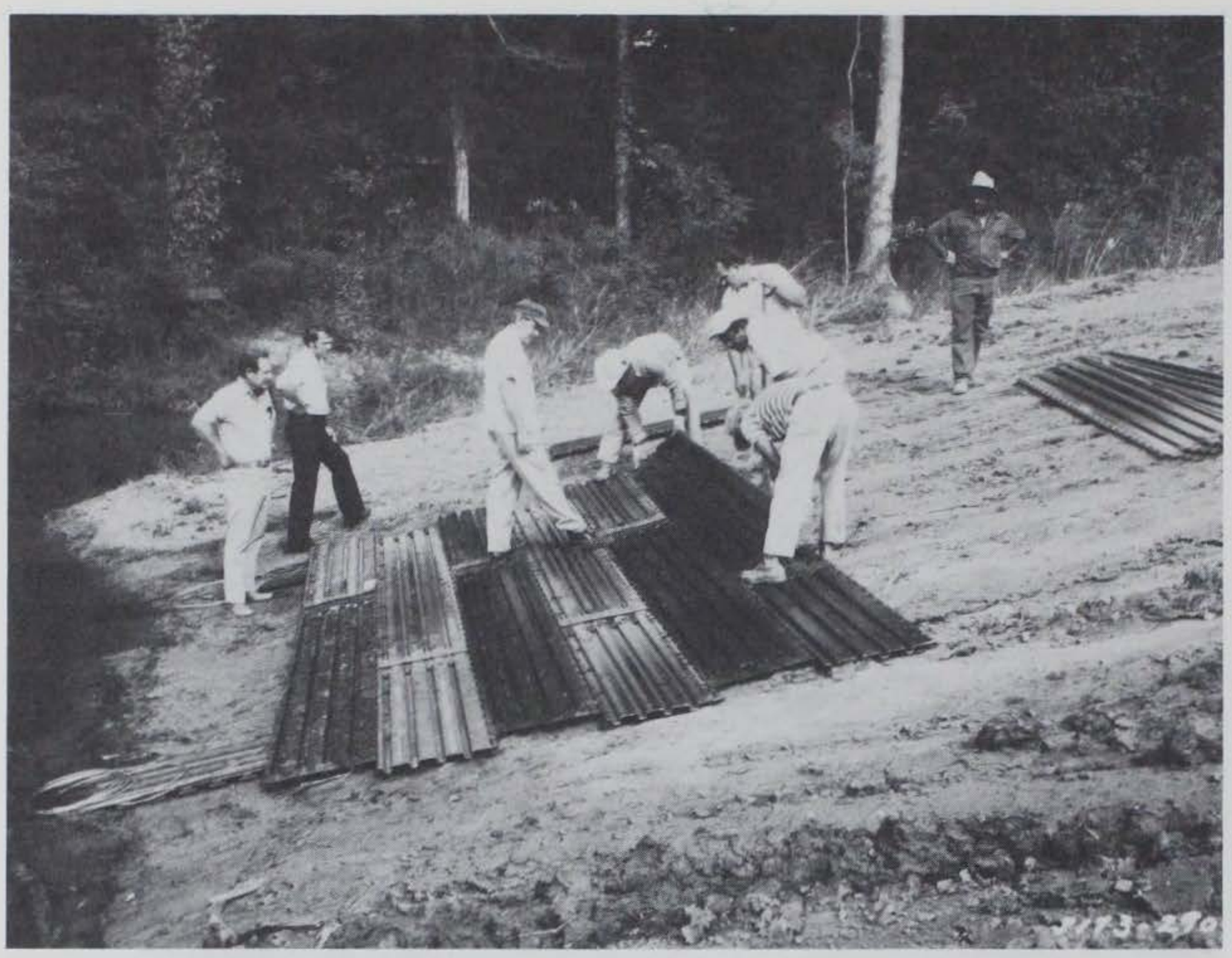


r. Vehicle attempting to climb slope at an angle to slope center line

Photo 6. (Sheet 9 of 10)

s. Vehicle exiting lake at ramp constructed earlier

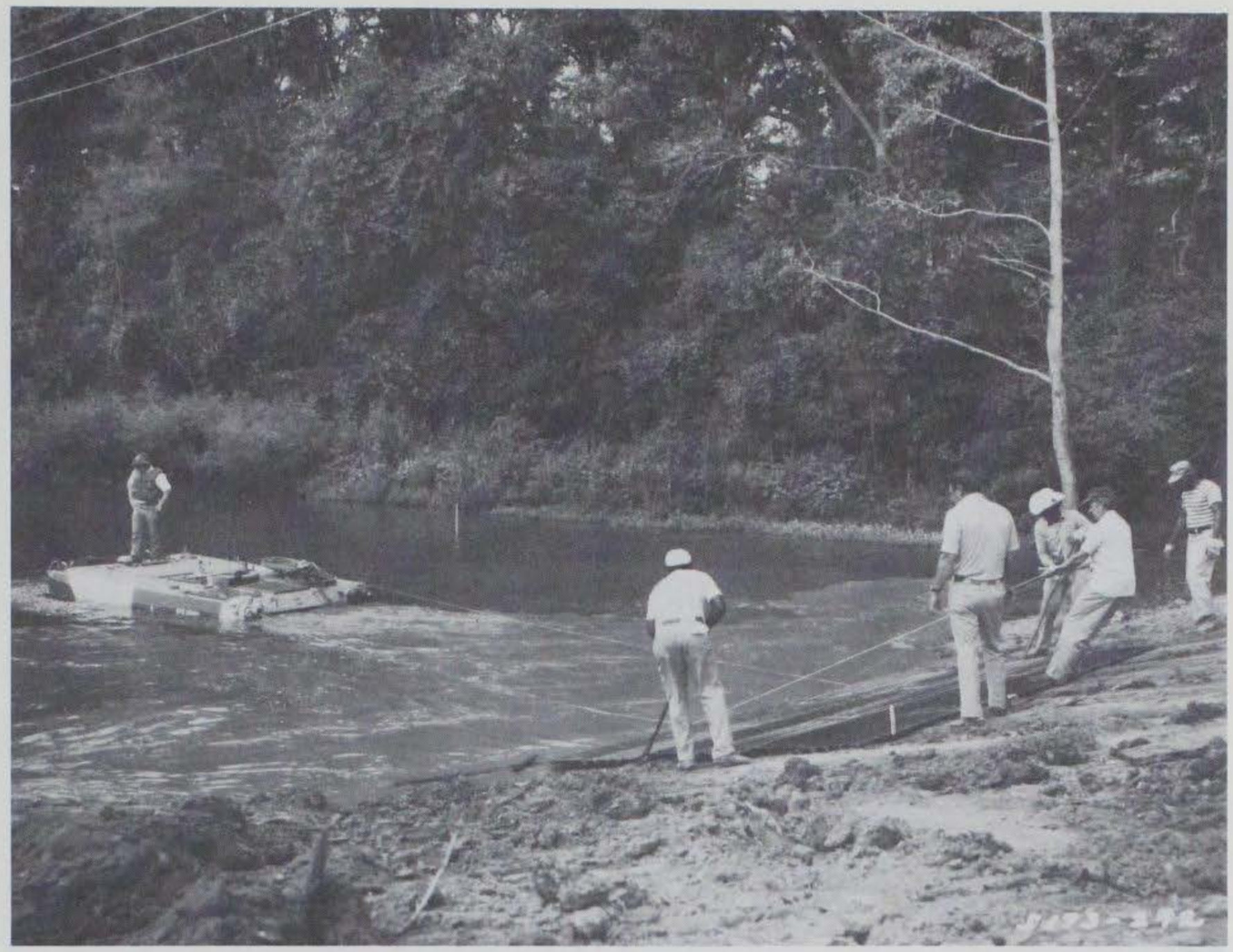
Photo 6. (Sheet 10 of 10)



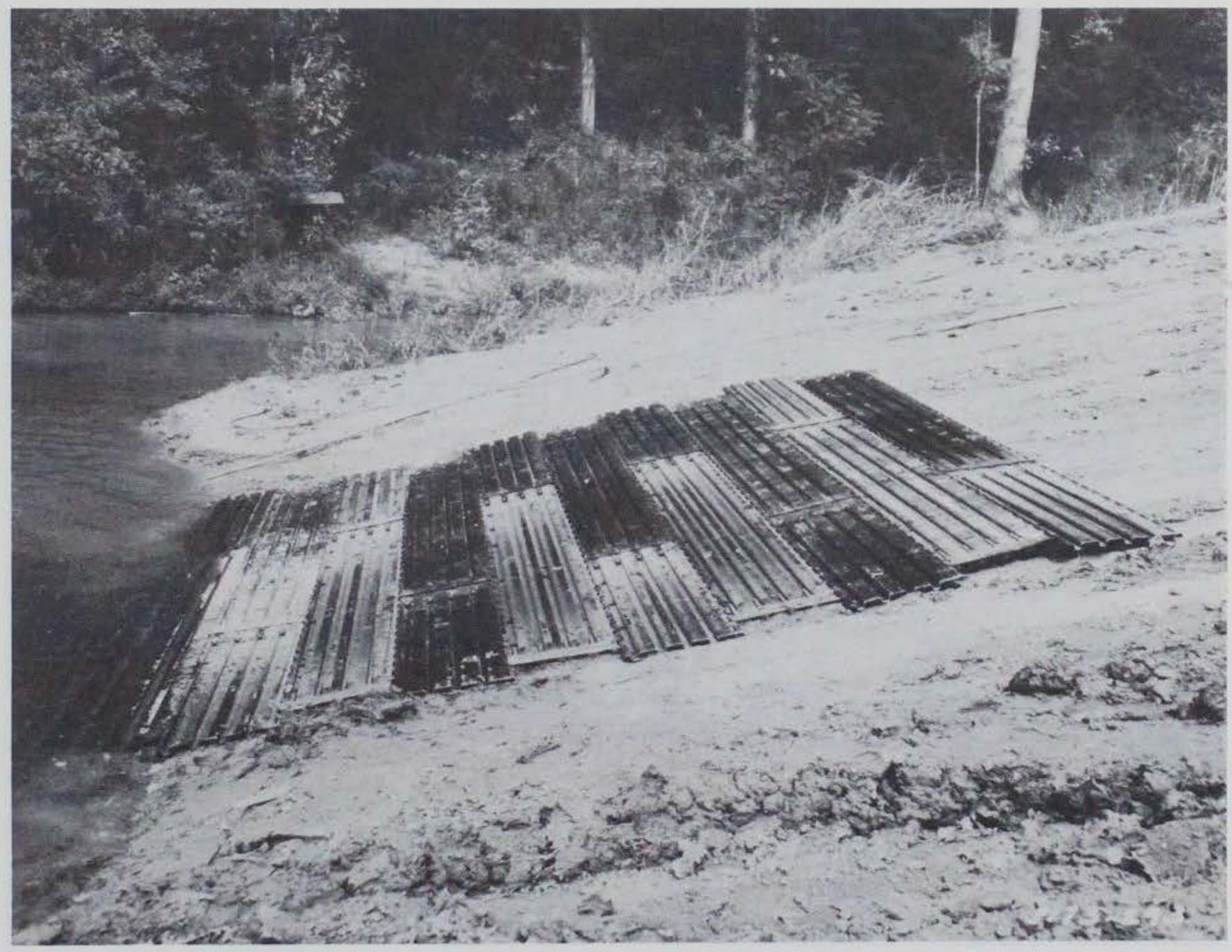
a. Placement of mat, right side up on slope

b. Mat slid into lake and additional sections added on slope

Photo 7. M8A1 mat-covered slope tests, Brown Lake area
(Sheet 1 of 5)



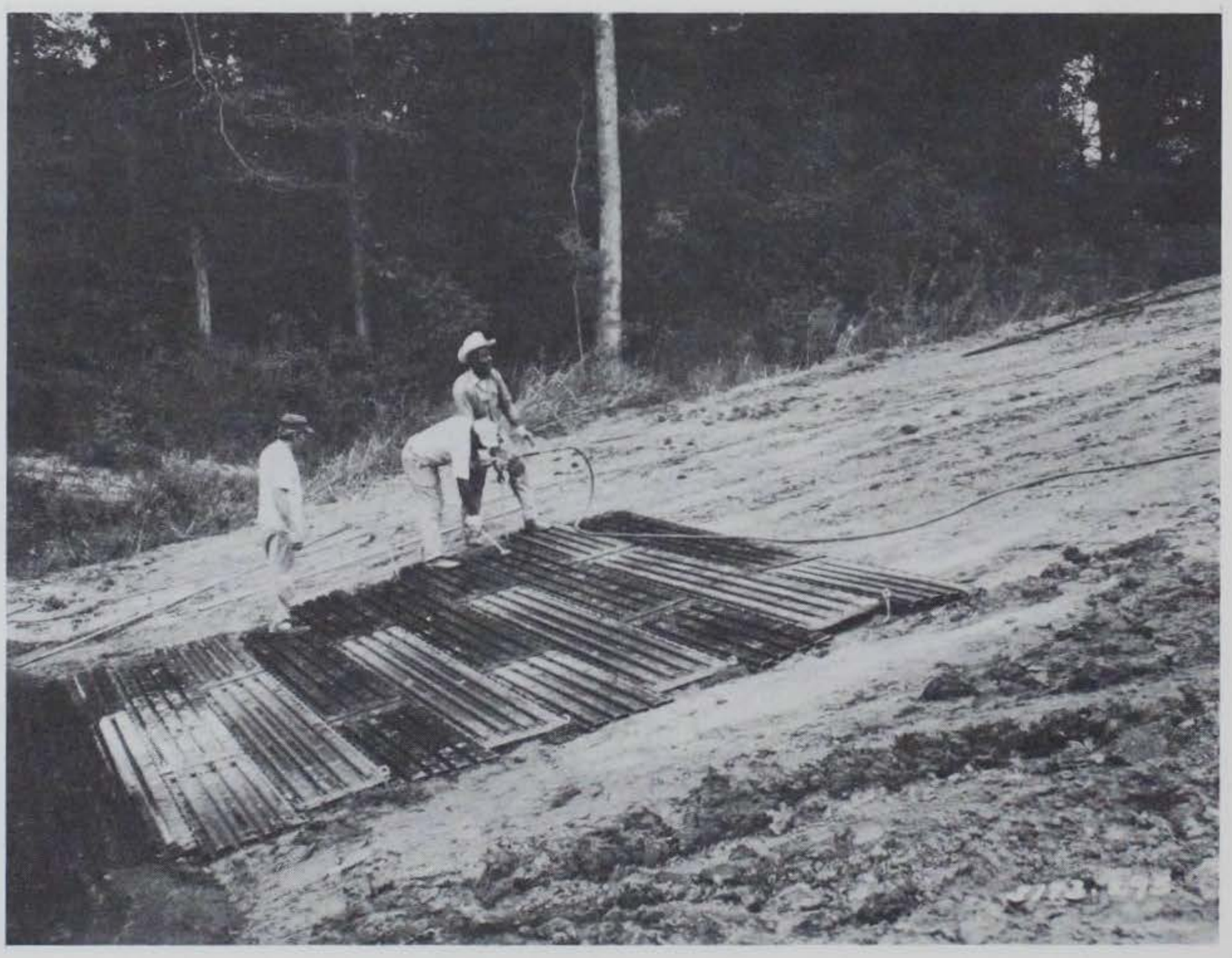
c. Mat sections being dragged by cable into lake



d. Mat sections on slope and in lake prior to anchoring

Photo 7. (Sheet 2 of 5)

e. Anchor placement to prevent downward sliding into lake



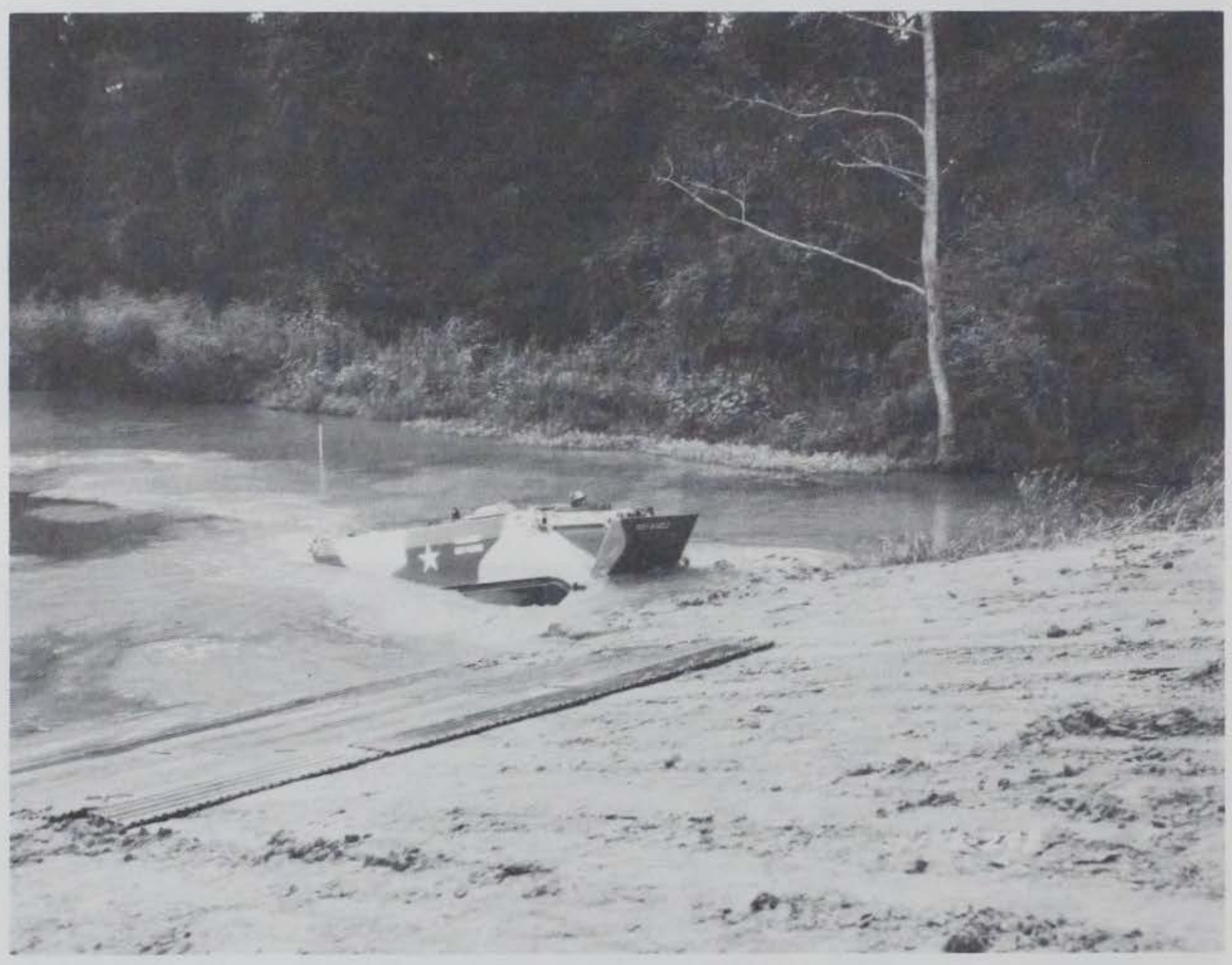
f. View of final anchor placement prior to tests

Photo 7. (Sheet 3 of 5)

g. Initial vehicle test on mat, right side up

h. Vehicle attempting to climb onto mat but tracks spinning

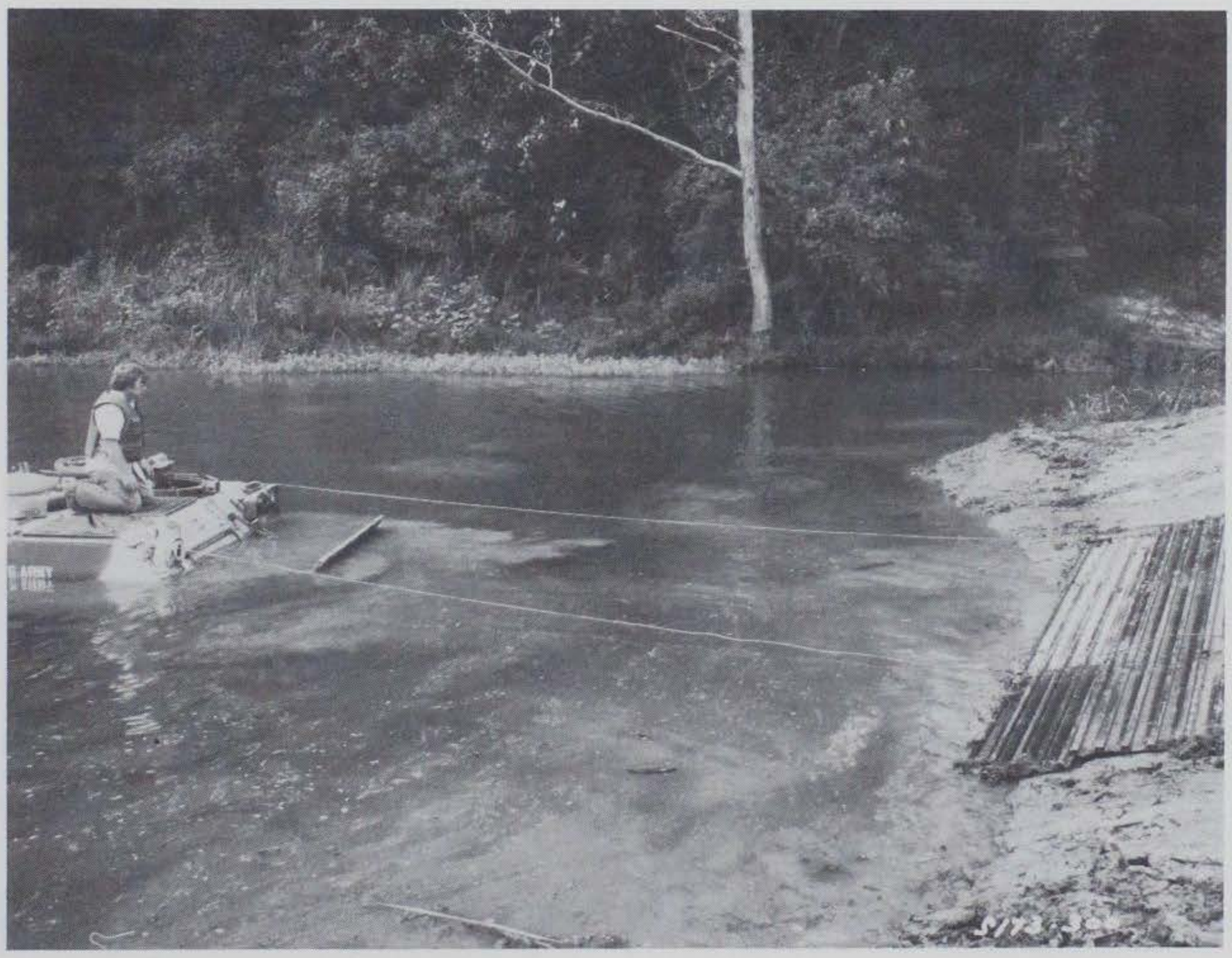
Photo 7. (Sheet 4 of 5)



i. Test conducted on unsurfaced slope without success

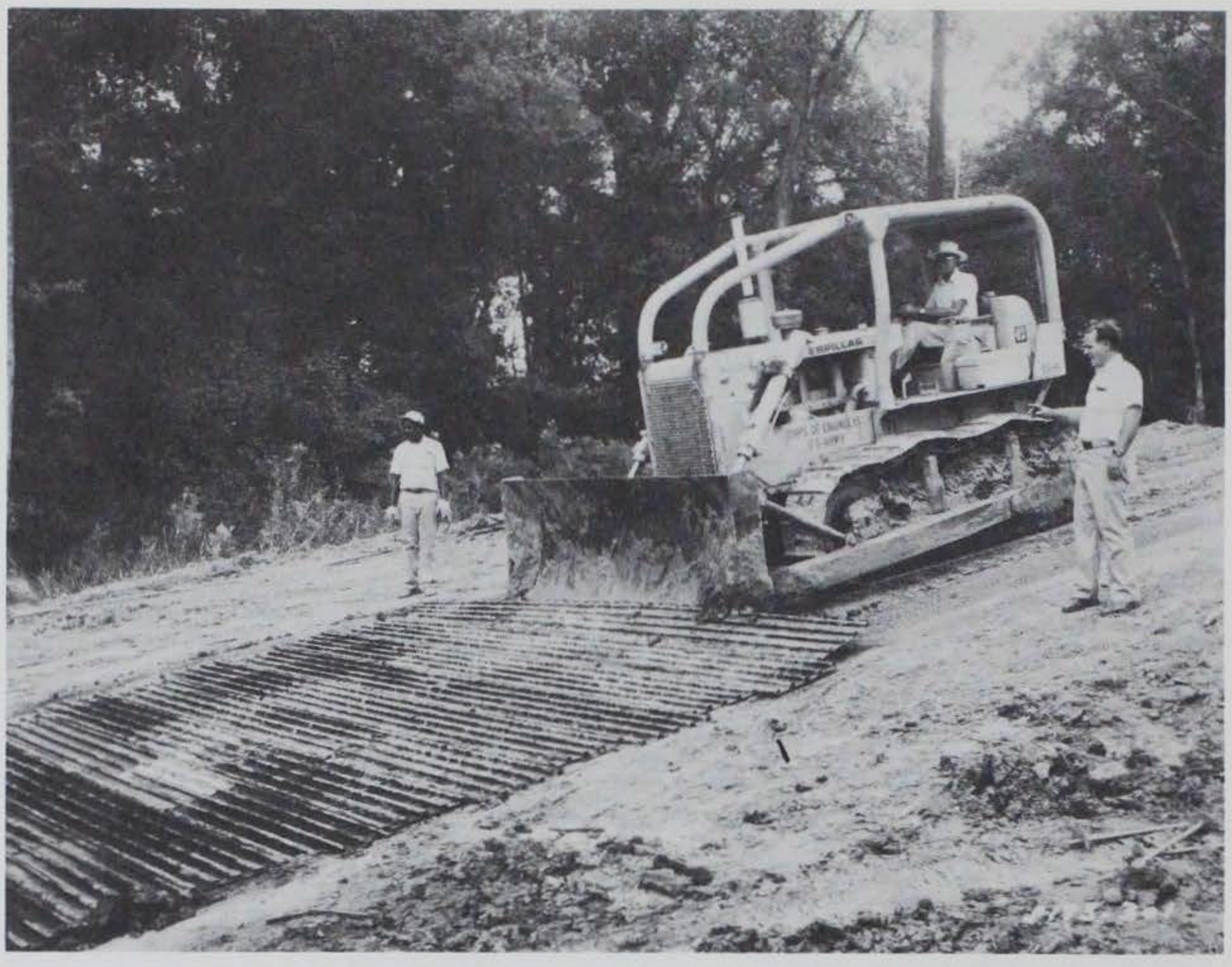
Photo 7. (Sheet 5 of 5)

a. Mat sections inverted to expose raised ridges on bottoms

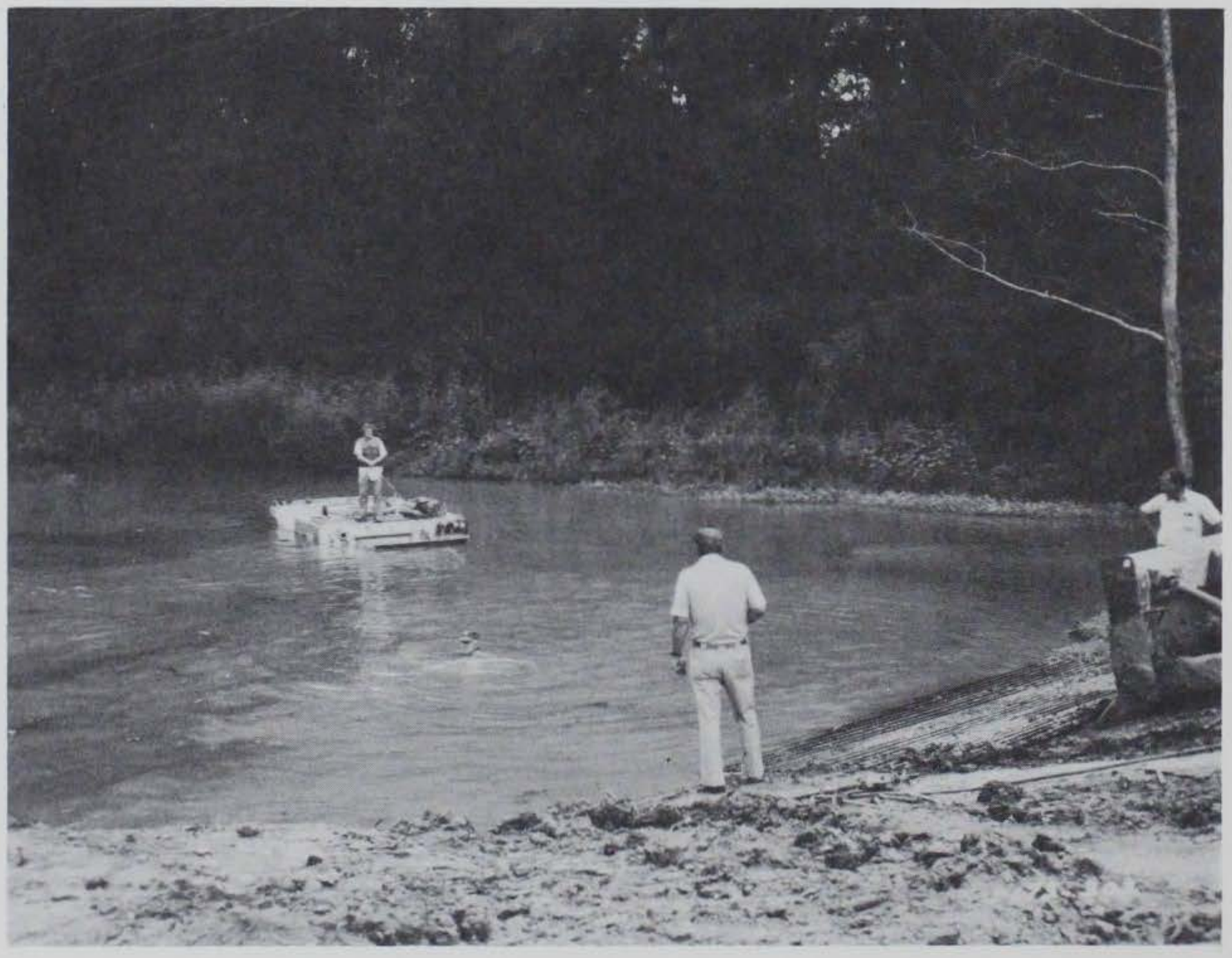


b. Mat sections inverted being pulled unsuccessfully into lake by the M113 APC

Photo 8. M8A1 (upside-down) mat-covered slope tests, Brown Lake area (Sheet 1 of 4)



c. D-6 bulldozer being used to push mat sections downslope into lake



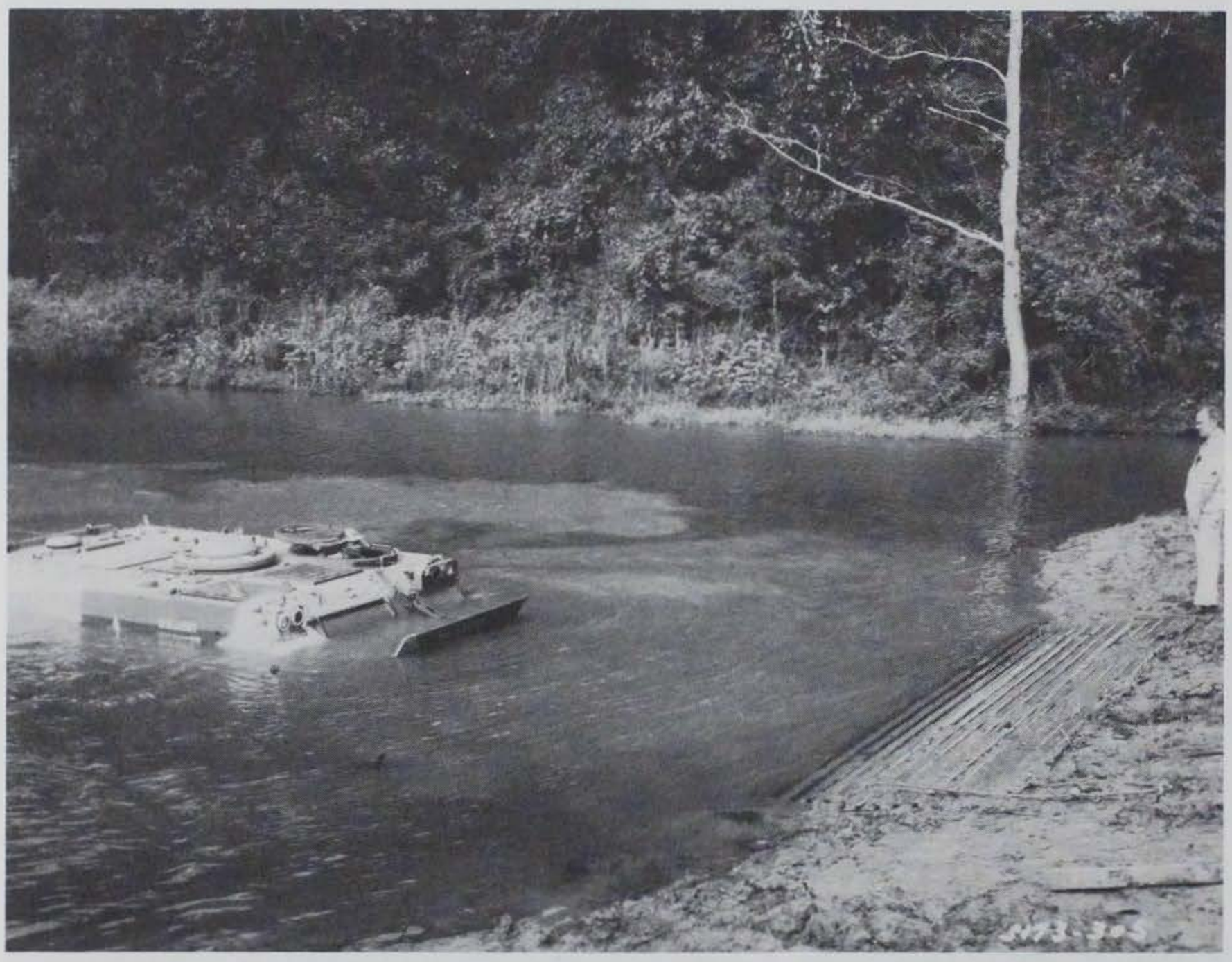
d. Sandbag anchors being placed in lake (note one entangled line being freed by WES personnel)

Photo 8. (Sheet 2 of 4)

e. M113 APC starting upslope on inverted mat

f. M113 APC almost successfully exiting lake (note mat was pulled downslope until "go" condition encountered with mat located as shown in Photo 5g)

Photo 8. (Sheet 3 of 4)



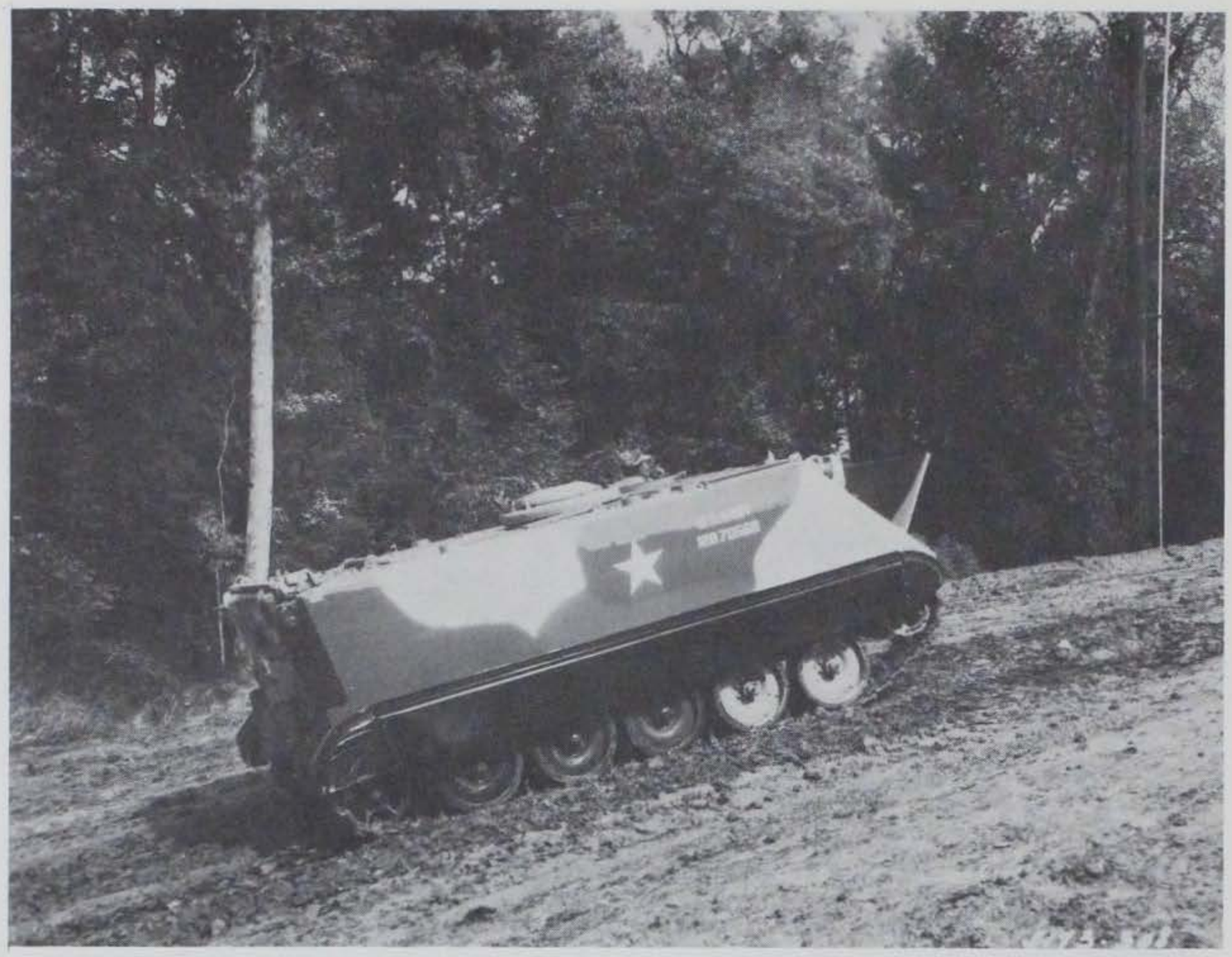
g. Mat anchored at point on slope/lake edge where "go" upslope with the M113 APC was accomplished

Photo 8. (Sheet 4 of 4)

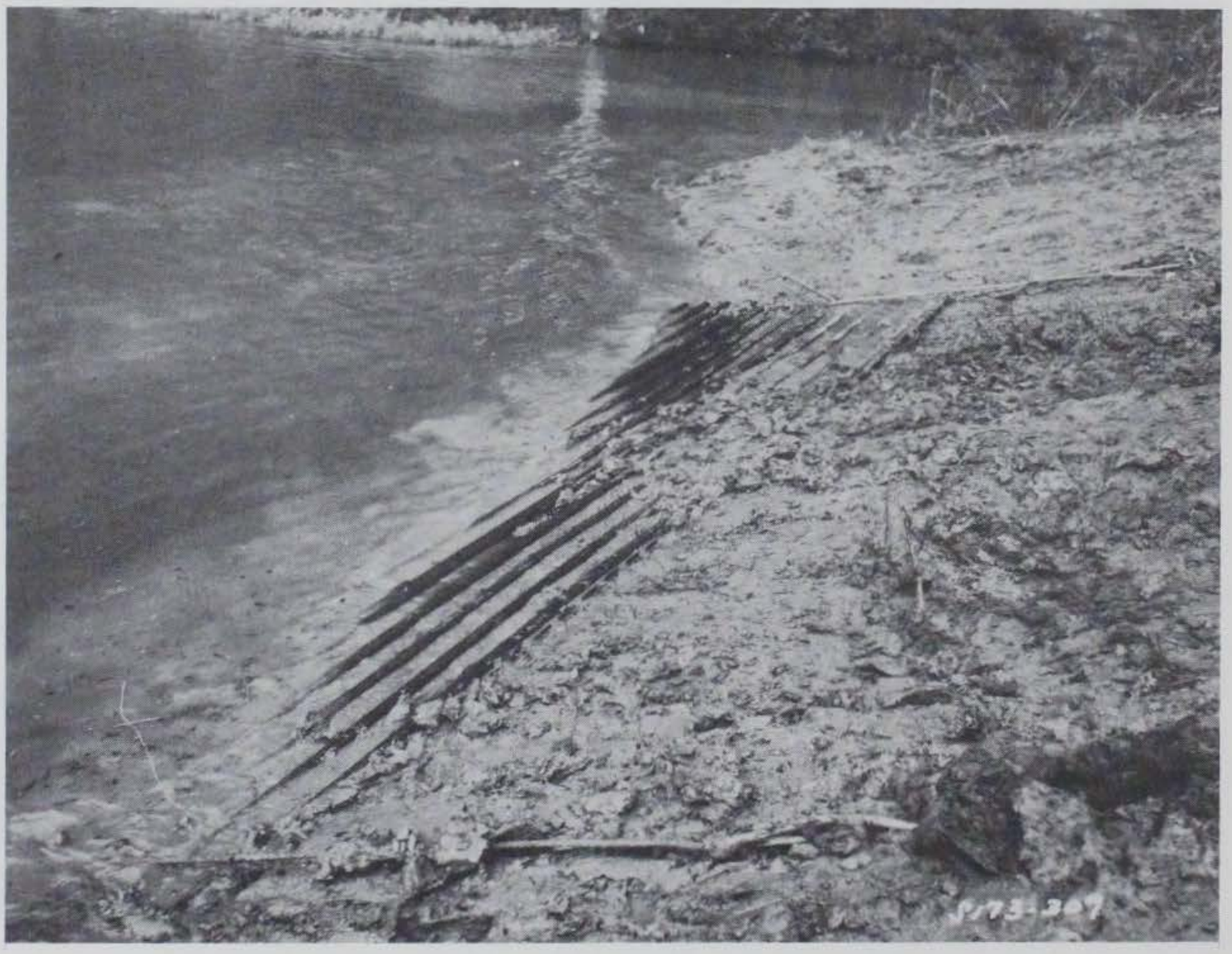
a. M113 APC easing from lake onto mat at slope/water interface

b. M113 APC successfully negotiating mat/slope interface and climbing slope

Photo 9. M8A1 matted water/slope interface tests, Brown Lake area (Sheet 1 of 9)



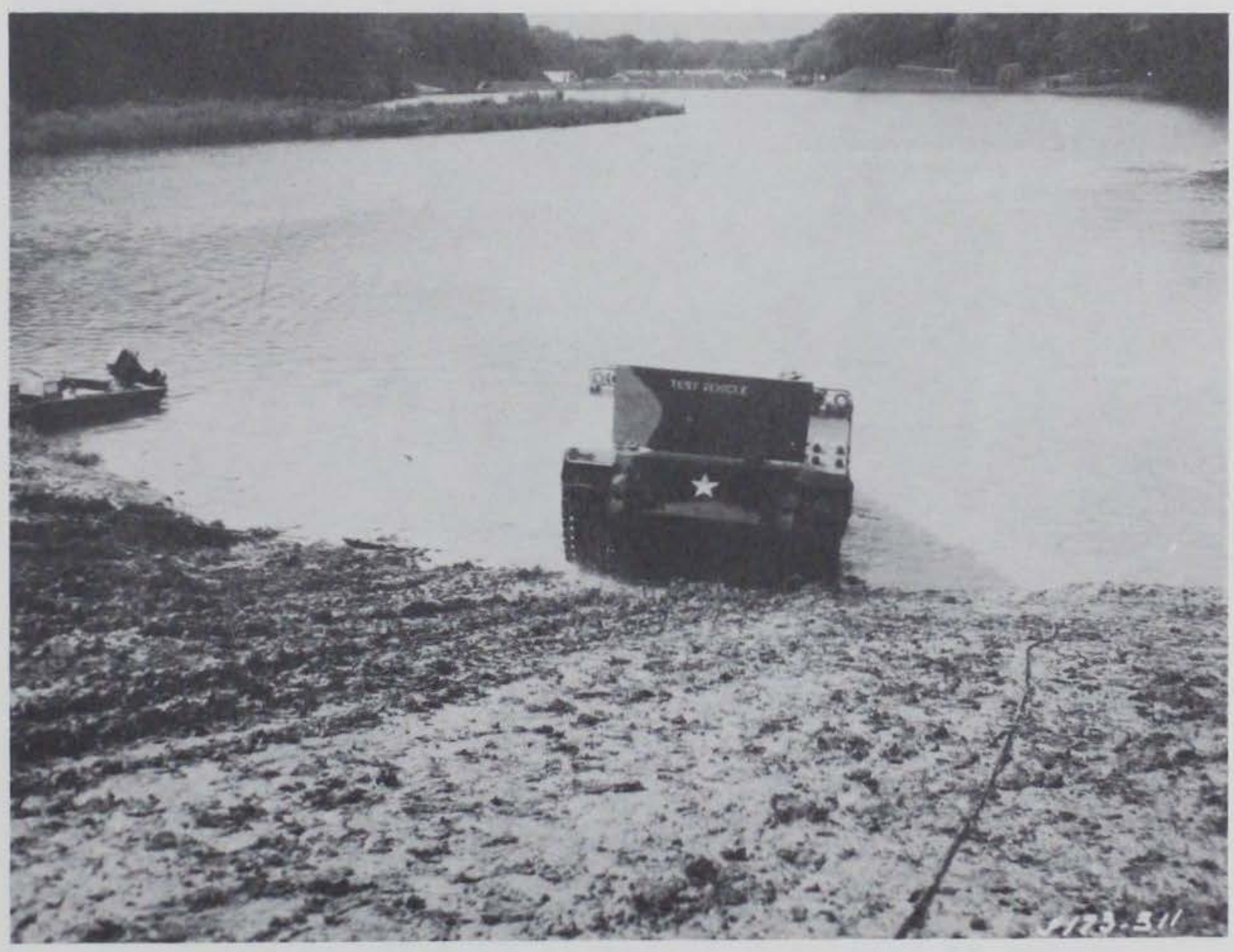
c. M113 APC near top of slope on first "go" condition



d. Mat sections and anchors pulled toward lake and skewed by tractive elements of the M113 APC

Photo 9. (Sheet 2 of 9)

e. Reanchored mat after realignment and reanchoring



f. M113 APC spinning on mat at water's edge

Photo 9. (Sheet 3 of 9)

g. Vehicle negotiating mat and climbing upslope

h. Third pass for vehicle with inverted mat starting at water's edge

Photo 9. (Sheet 4 of 9)

i. Fourth pass upslope with the M113 APC

j. Swimming-climbing technique developed to ensure successful negotiation of slope

Photo 9. (Sheet 5 of 9)

k. Vehicle completing one of last few passes before 25 completions on dry slope

l. Toe of slope after 25 passes with no mat visible at water's edge

Photo 9. (Sheet 6 of 9)

m. First pass with slope being sprayed with water from spray truck

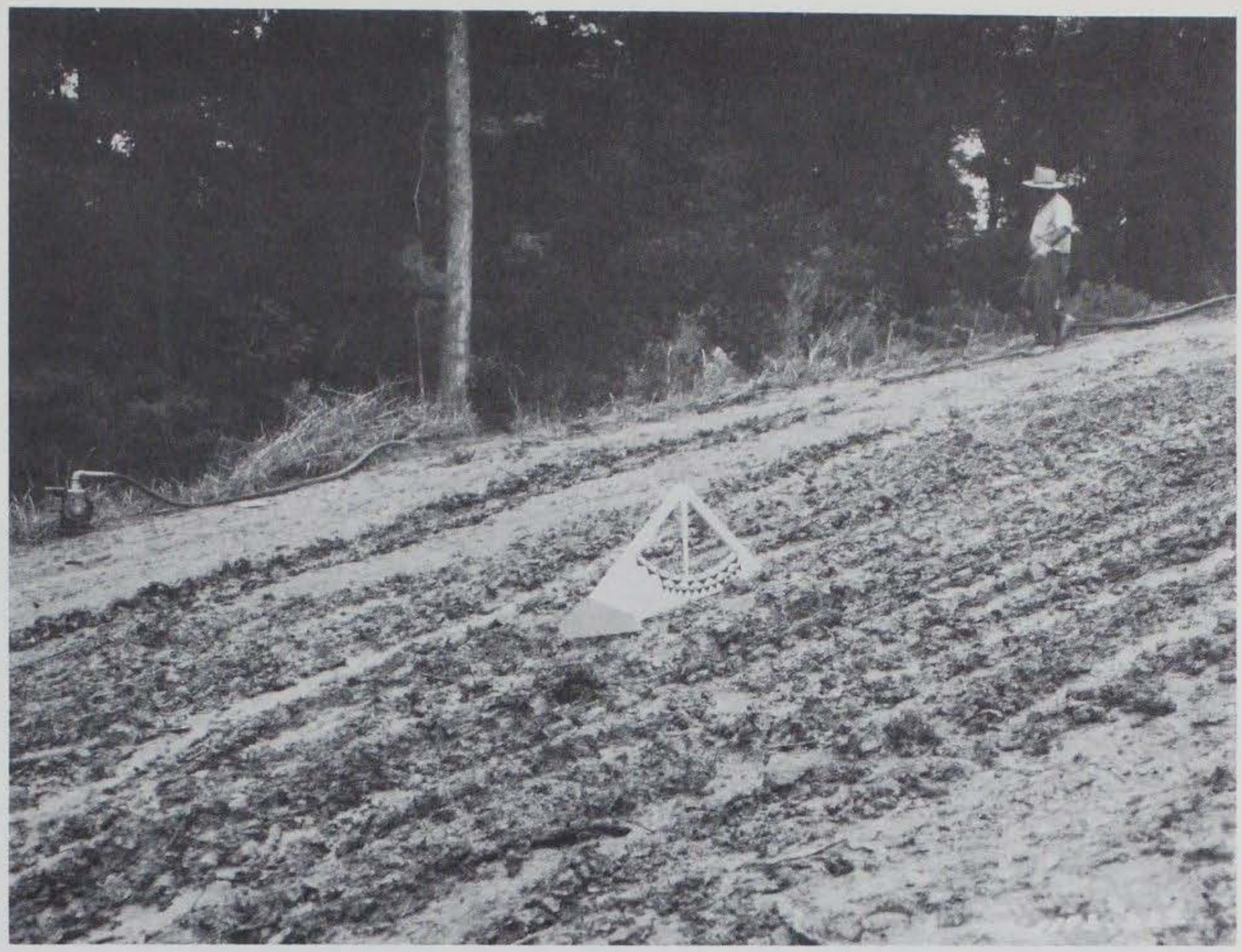
n. Vehicle near top of slope showing water spray from nozzle and bilge

Photo 9. (Sheet 7 of 9)

o. Vehicle completing last pass on mat with wetted slope

p. Slope/water interface after completion of test series

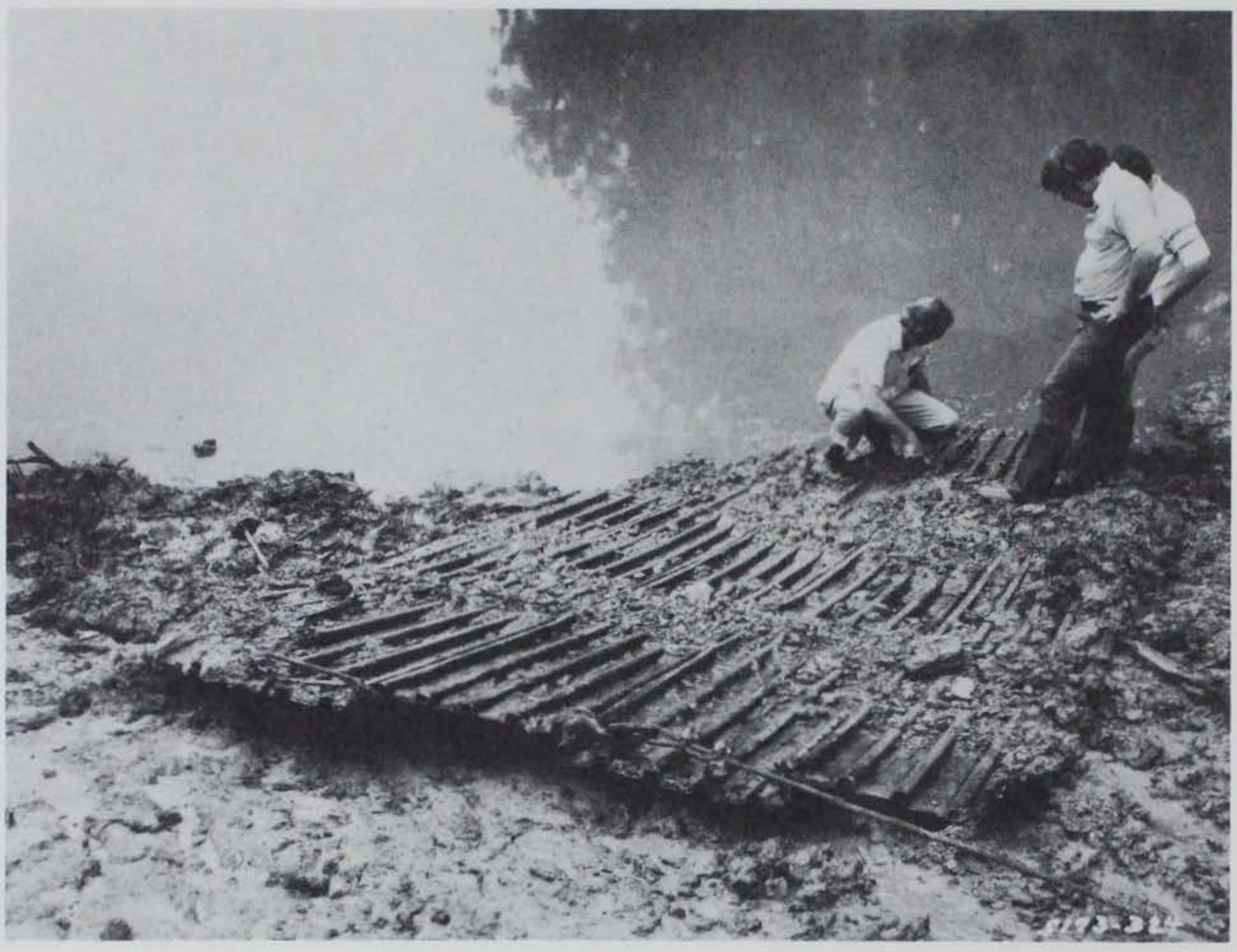
Photo 9. (Sheet 8 of 9)



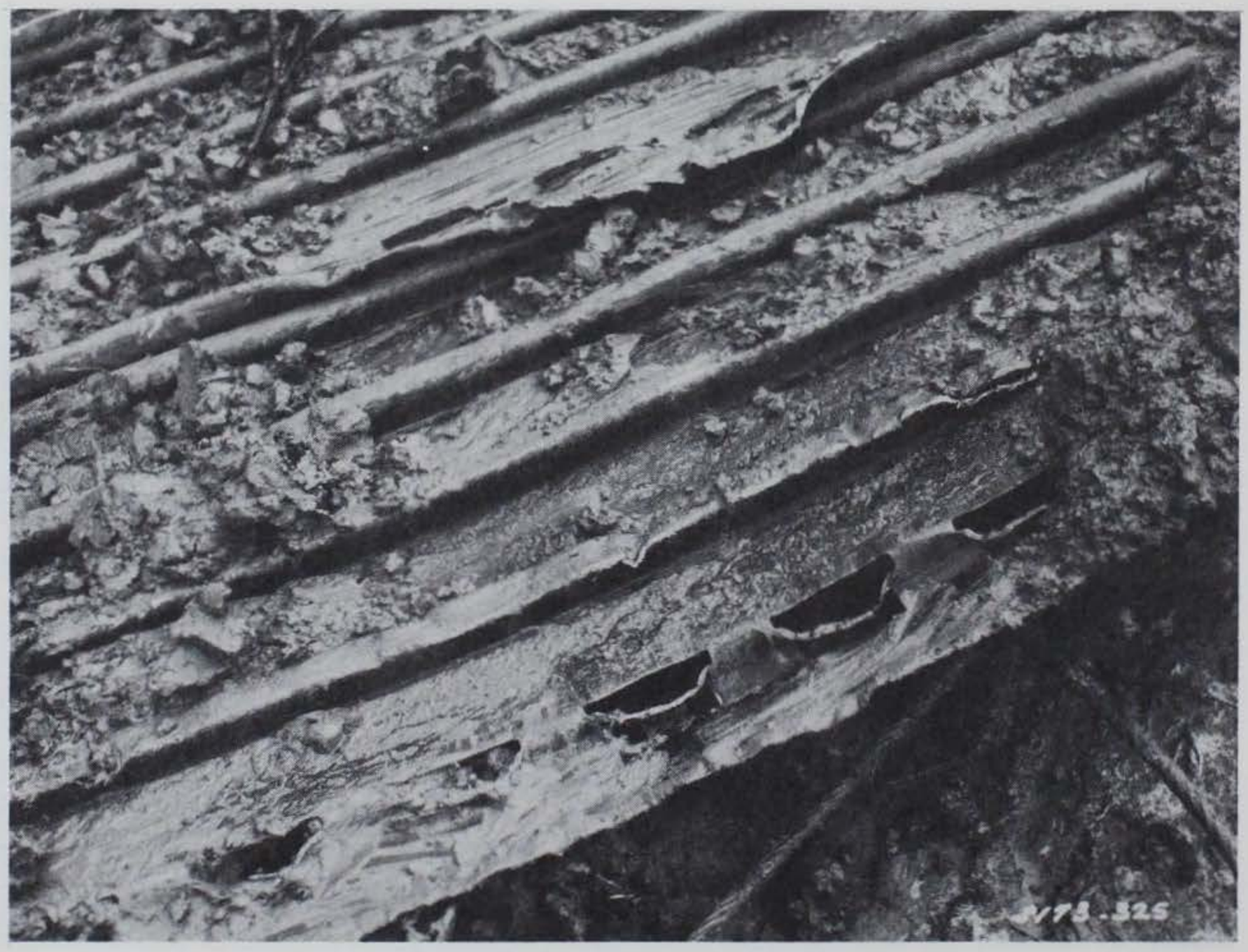
q. Upper slope after completion of test series

r. View of vehicle traveling upslope on wet surface with little or no slippage

Photo 9. (Sheet 9 of 9)

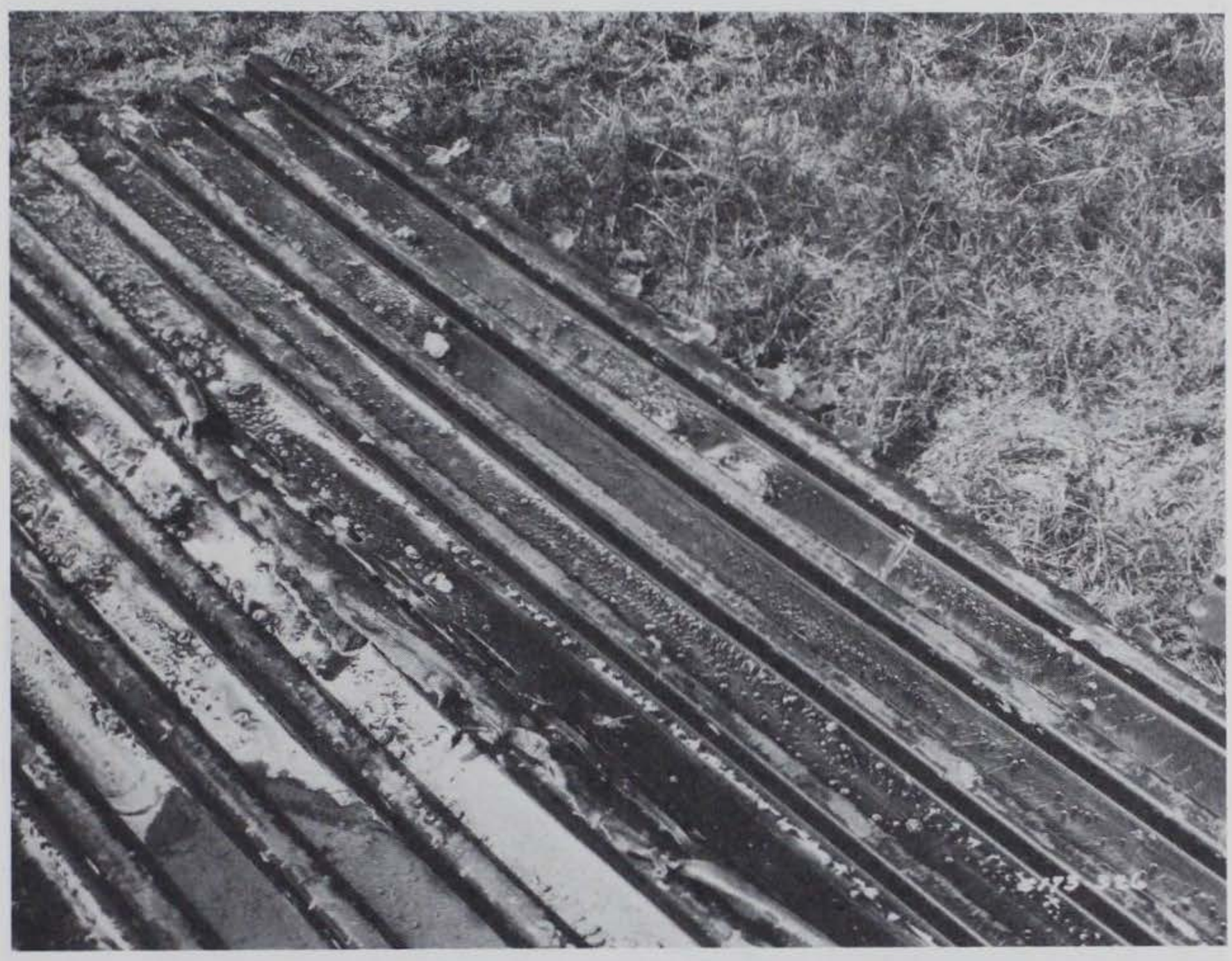


a. View of mat, inverted, rolled edge toward lake, after tests



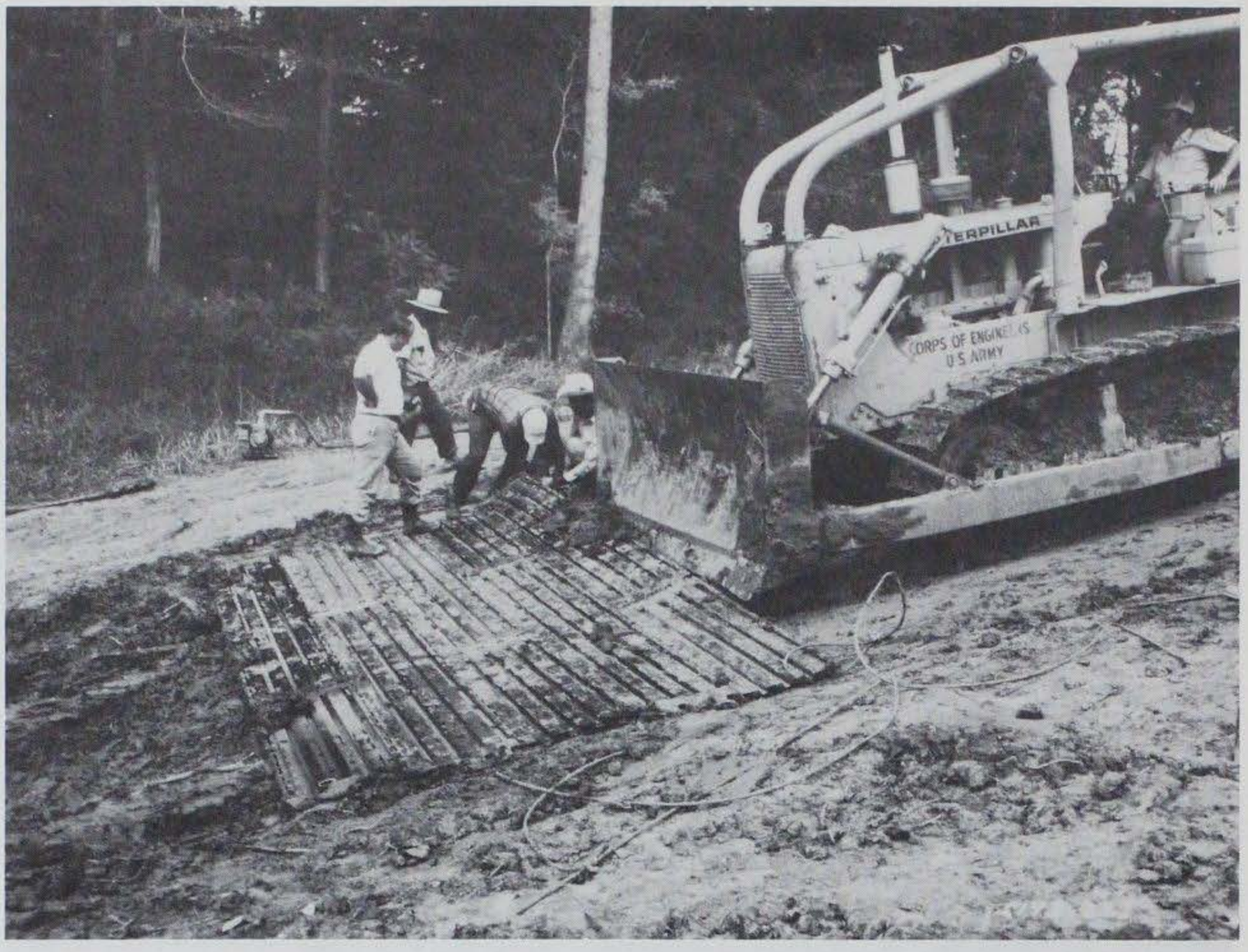
b. Close-up of mat ridges showing damage from track slippage

Photo 10. Damaged M8A1 after vehicle tests
Brown Lake area (Sheet 1 of 2)



c. View showing rolled edge of mat opened by tracks of the M113 APC

Photo 10. (Sheet 2 of 2)



a. Mat right side up with rolled edge downslope being pushed into water by the D-6 bulldozer

b. M113 APC encountering mat in lake near water's edge

Photo 11. M8A1 matted slopes, underwater, Brown Lake area (Sheet 1 of 9)

c. M113 APC attempting unsuccessfully to climb unsurfaced slope

d. M113 APC slipping sideways on mat underwater

Photo 11. (Sheet 2 of 9)

e. M113 APC exiting lake at an angle after edging off end of mat and climbing slope

f. M113 APC encountering mat, which has been flipped from last test (Photo 8e) and placed in lake inverted, hooked edge into lake

Photo 11. (Sheet 3 of 9)

g. Vehicle spinning slightly, then climbing over mat onto slope

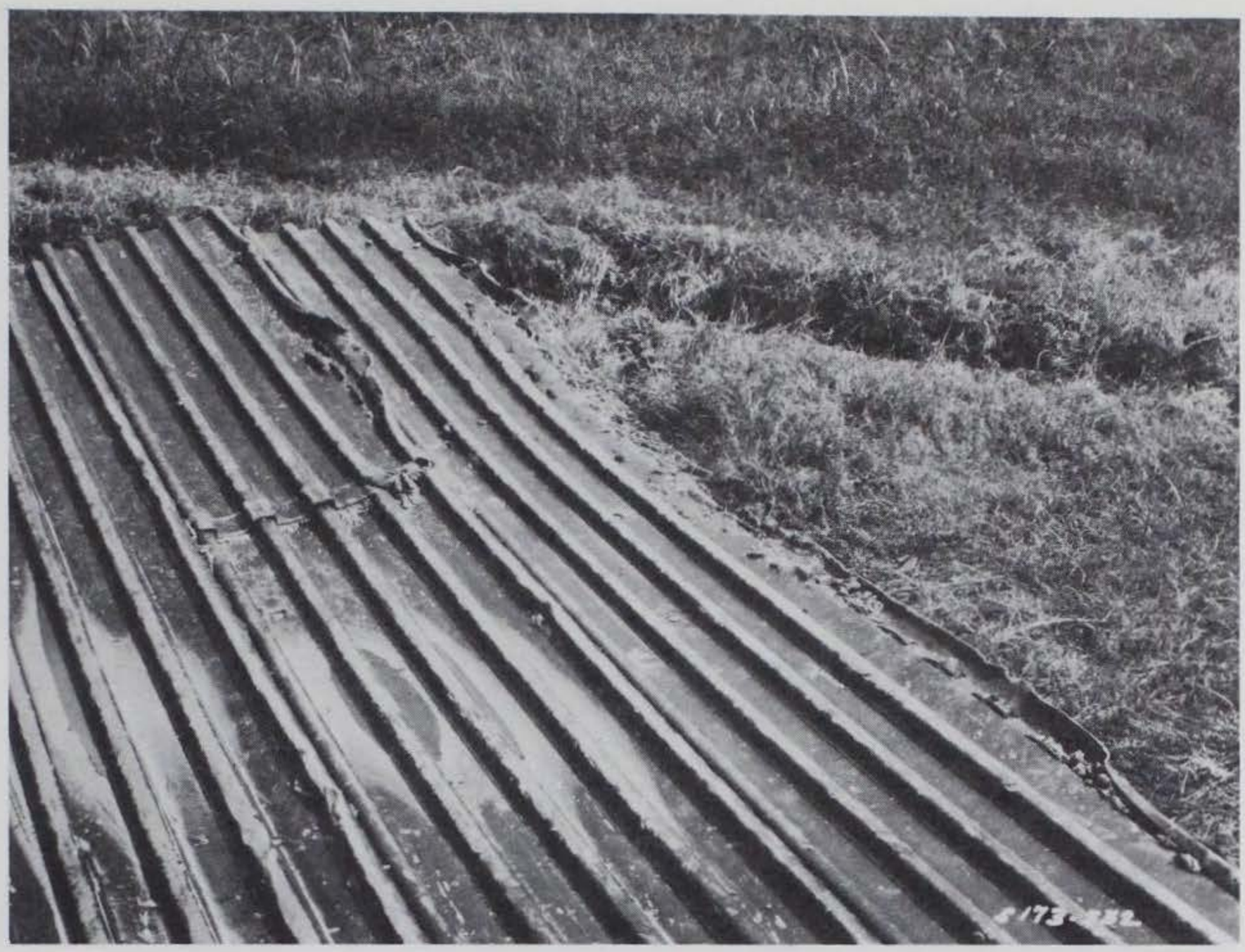
h. Vehicle climbing toward rest of wet slope

Photo 11. (Sheet 4 of 9)

i. View of mat being removed from lake showing distortion of panels with vehicle traffic

j. Two runs of mat, inverted with rolled edge downslope, being pushed into lake for egress test

Photo 11. (Sheet 5 of 9)



k. Views of "unrolled" edge of mat

l. General view of test area

Photo 11. (Sheet 6 of 9)

m. View of vehicle test after mat replaced on slope right side up, rolled edge down

n. Another unsuccessful vehicle test on right-side-up mat

Photo 11. (Sheet 7 of 9)

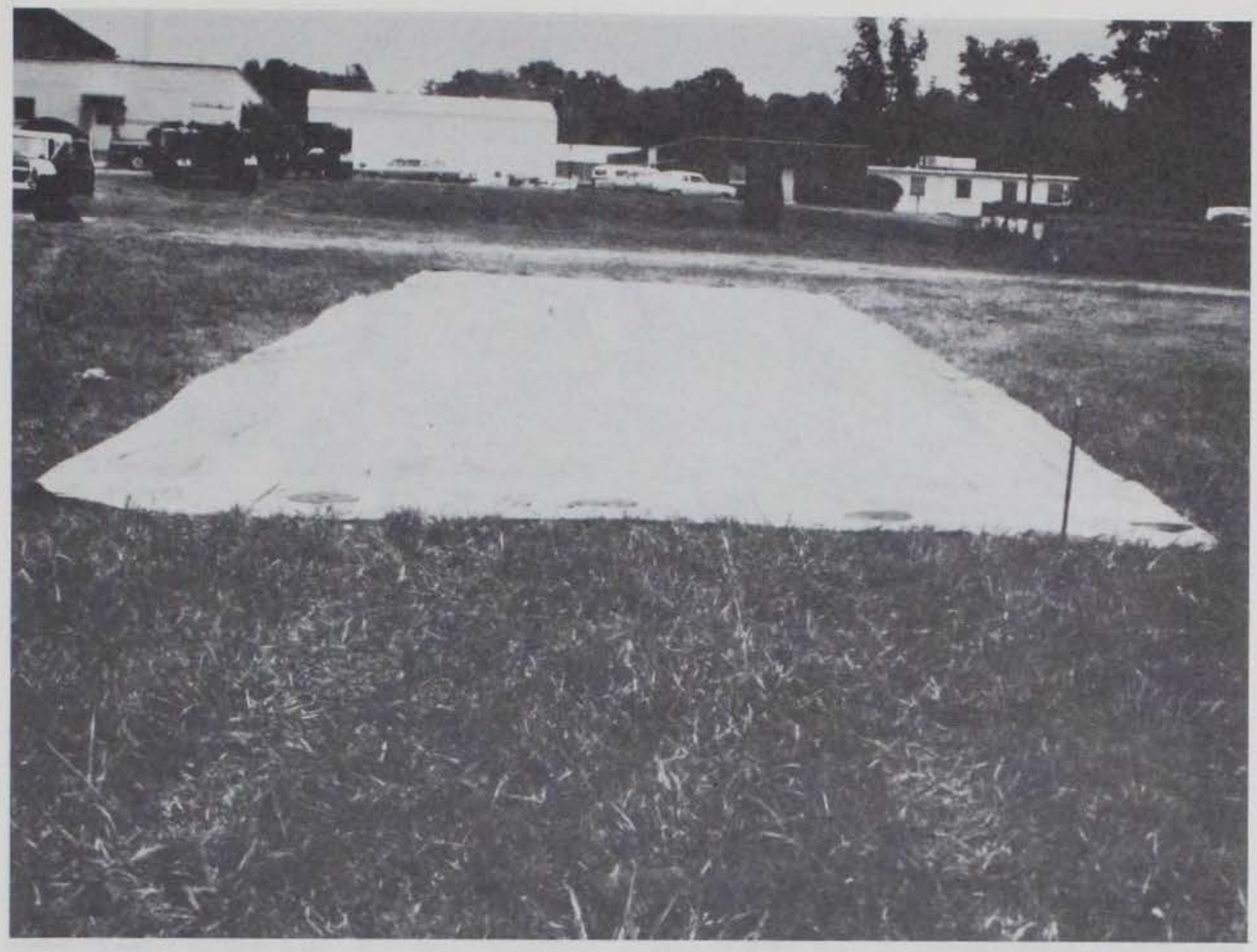
o. Vehicle sliding sideways on right-side-up mat

p. Frontal view of vehicle spinning on mat, underwater, right side up

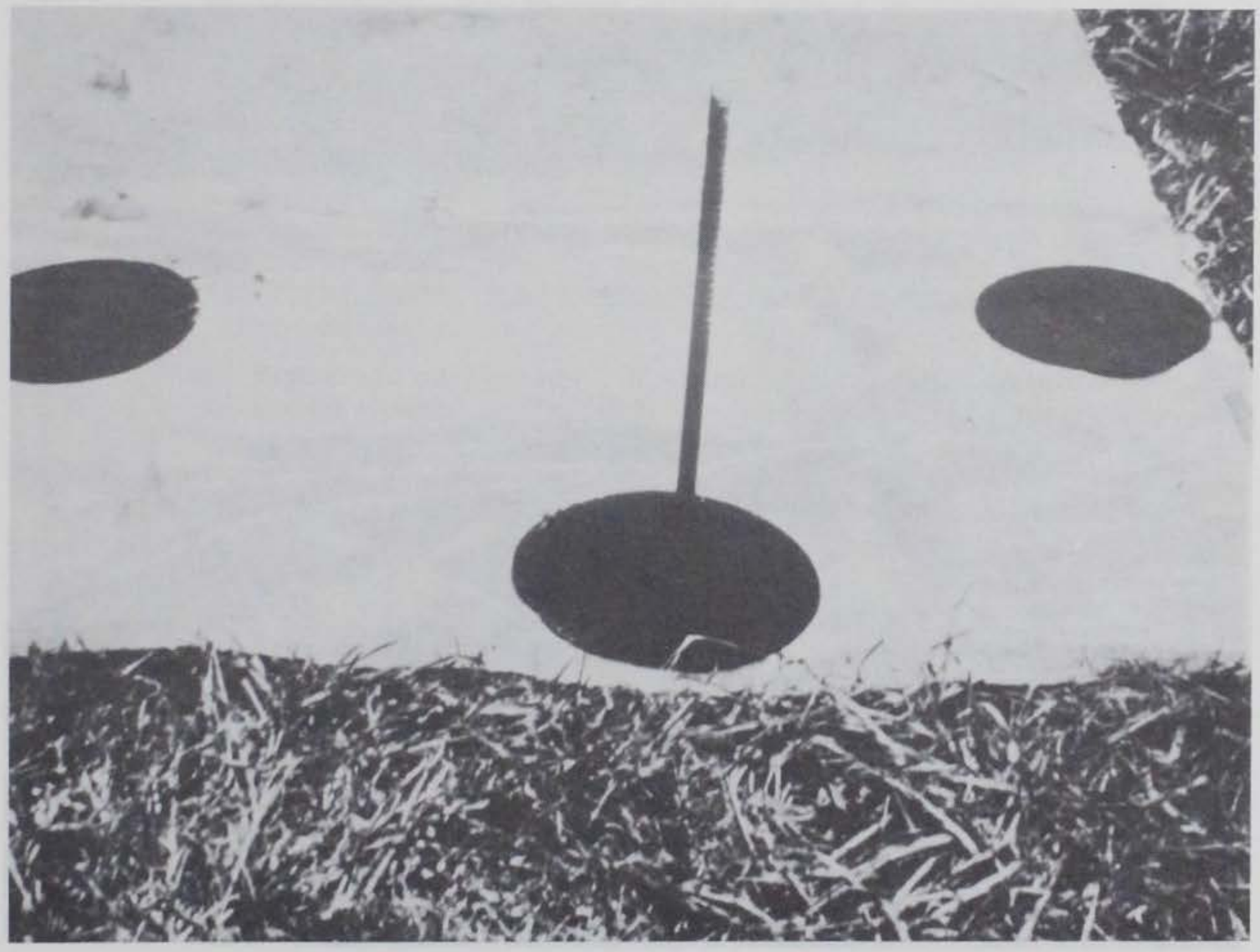
Photo 11. (Sheet 8 of 9)

q. Frontal view of vehicle spinning on mat at water's edge

Photo 11. (Sheet 9 of 9)

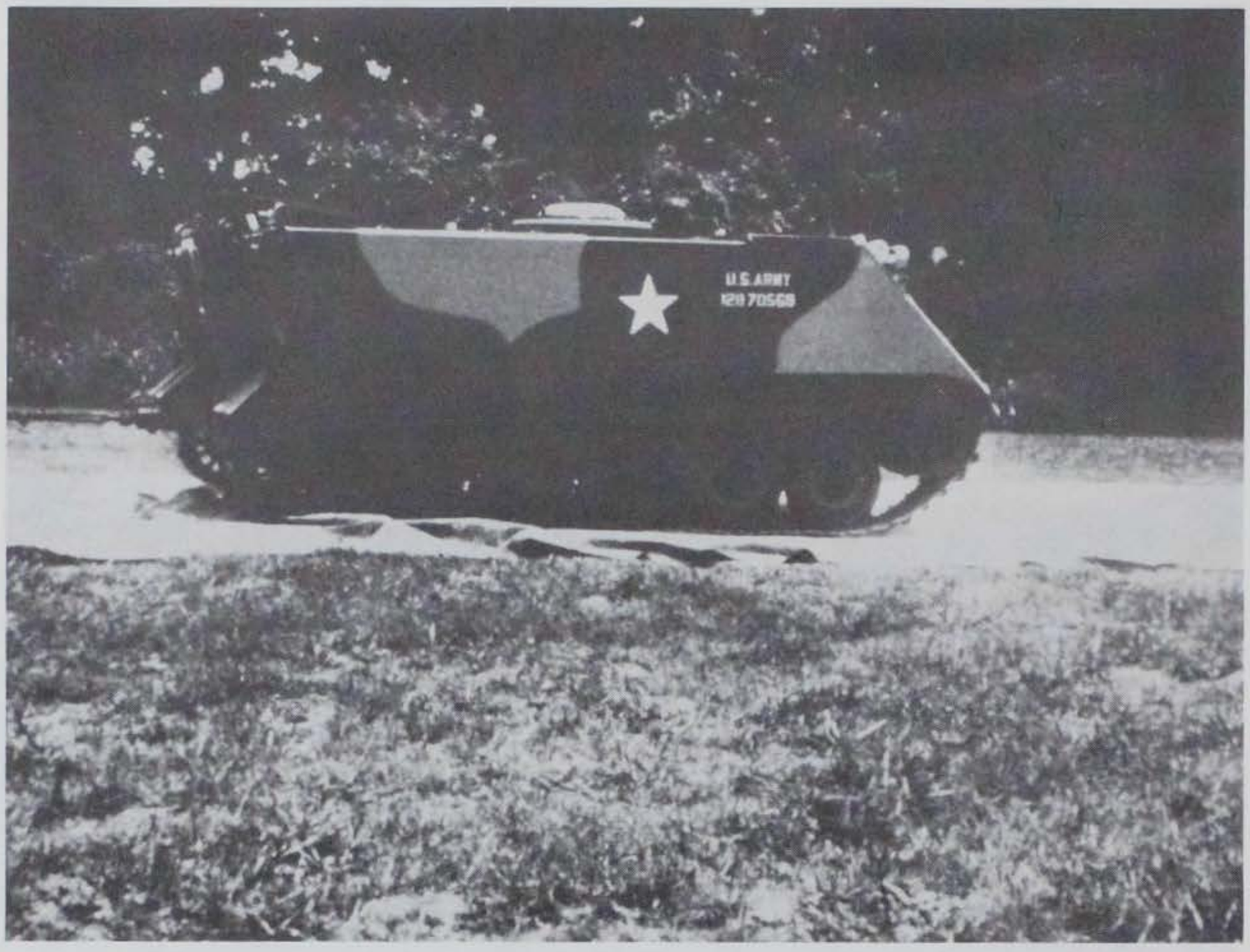


a. View of stretched and tacked T17 membrane on level surface

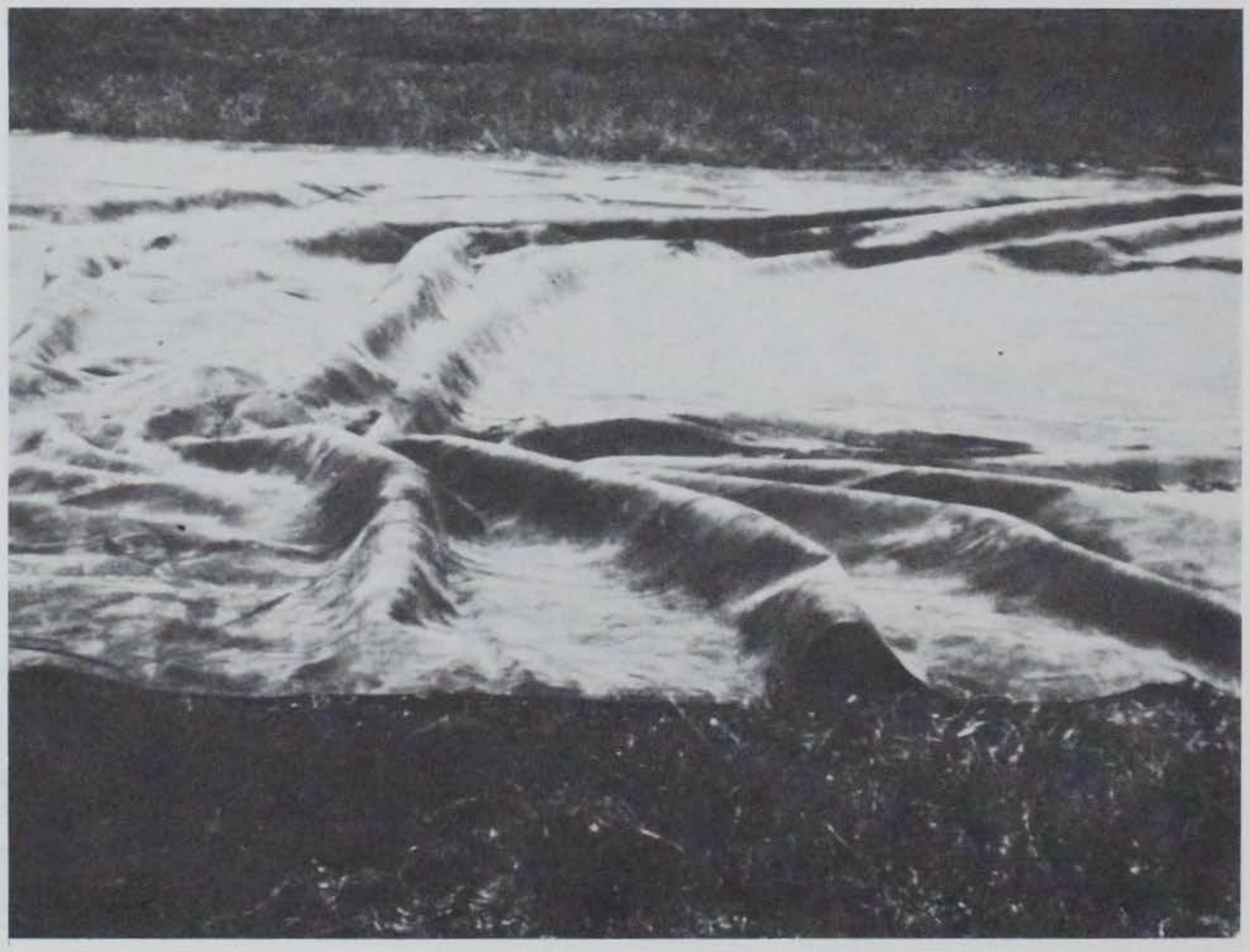


b. View of tack anchors used to secure membrane to soil

Photo 12. Drawbar pull tests on level grass area, WES (Sheet 1 of 2)



c. Drawbar pull test on T17 membrane showing membrane stretching beneath tracks



d. Close-up of stretched T17 membrane from beneath tracks of the M113 APC

Photo 12. (Sheet 2 of 2)