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Remote Determination of Bridging/Fording Sites

Barry Coutermarsh and Sgt. Benjamin Dwinal

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ABSTRACT

Ice that forms in soil voids during the freezing process pushes soil grains apart, reducing particle cohesion and soil strength, and making soil more erodible. This report summarizes 18 experiments to measure erosion rates in a soil that was frozen and thawed once and in the same unfrozen soil. We hypothesized that soil freeze–thaw (FT) processes significantly increase upland hill slope erosion during subsequent runoff events. We selected a frost-susceptible silt to provide an upper bound on this effect. For each experiment, we prepared two identical bins, one as an unfrozen control, the other to be frozen and thawed. We tested three soil-moisture ranges, three flow rates, and two slopes, and measured the cross-sectional geometry of the rills that developed and sediment losses through time for each bin. The cross-section measurements detailed erosion at specific locations along the bins; sediment loss measurements indicated erosion integrated along the entire bin. The results are the first to quantitatively define the differences in sediment loss and rill formation caused by FT cycling. We will analyze data from these experiments and do additional experiments to further define FT effects in the soil-erosion process. (However, these results already demonstrate the importance of FT weakening to soil erosion.) Good regional sediment management in cold climates requires that erosion prediction models accurately account for important processes such as soil-FT cycling to avoid significant underprediction of soil losses on hill slopes and in watersheds in cold climates.

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PREFACE

This report was prepared by Barry Coutermarsh, Research Engineer, U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire, and Sgt. Benjamin Dwinal, Topographic Production Manager, 66th Engineer Detachment, Fort Drum Terrain Team, Fort Drum, New York

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The terrain analysis was performed by members of the Fort Drum terrain team under the direction of Sgt. Dwinal. Members involved in the study were Sgt. Angela Morello, Specialist Alicia Emond, and Pfc. Alfredo Casillas. Chief Warrant Officer II Jerome Papajohn, 66th Engineer Detachment Commander, was the approving authority for the involvement in the project and the scheduling of the terrain analysis portion of the study.

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The Commander and Executive Director of the Engineer Research and Development Center is Col. John W. Morris III, EN. The Director is Dr. James R. Houston.

Remote Determination of Bridging/Fording Sites

BARRY COUTERMARSH AND SGT. BENJAMIN DWINAL

1 INTRODUCTION

The U.S. Army's doctrine of moving to agile, highly mobile, and lighter forces places a premium on force movement. An attacking unit's best weapon may well be its ability to rapidly move where it needs to be, strike hard and fast, and then move quickly to the next point of contact. This will require that units operate efficiently over challenging terrain, including soft and/or slippery soils, difficult geometric obstacles, and water obstacles. A linear feature, such as a river, can be a significant hindrance to an army on the move and can have a substantial detrimental effect on the momentum of an attacking force. To maintain its movement, a force needs to obtain as much information as possible about a river obstacle before it reaches it. This allows effective route planning and efficient allocation of resources to effect the crossing itself. Furthermore, the reconnaissance itself should not slow the execution of the route. To minimize risk and to allow for forward planning, an accurate remote assessment of potential crossing sites that would allow resolution of bank heights and river widths would be extremely valuable.

The U.S. Army Cold Regions Research and Engineering Laboratory performed a study to assess the ability to remotely determine suitable bridging/fording sites using existing technology and procedures typically available to an engineer terrain team. The terrain team from the 66th Engineer detachment stationed at Fort Drum, New York, participated in the study by analyzing two rivers in Vermont and New Hampshire to determine likely crossing areas. We assumed the "hasty" crossing category when evaluating the potential crossing sites. After the remote analysis was performed, the rivers were inspected on-site to determine the suitability of the selected crossing zones and to find any potential crossing zones overlooked in the remote analysis. The field investigations were used to determine the primary factors affecting the determination of a suitable crossing site. The results from this study are baseline data to identify

procedures or technology that would offer a significant improvement to our ability to remotely identify and maintain lines of communication.

Background

A *hasty* crossing is defined in FM 90-13 (1992), *River Crossing Operations*, as “a continuation of the attack across the river with no intentional pause at the water to prepare, so there is no loss of momentum.” Under this category, time is a factor and therefore time for extensive preparation of the actual crossing site is not available. A successful hasty crossing site must allow quick passage of the advance forces with little or no bank preparation or fixed bridging construction. The nature of the hasty crossing category also makes it likely that detailed information about the crossing site itself is gathered by reconnaissance frequently in hostile territory. Contrast this with a deliberate crossing, characterized in FM 90-13 as “... an attack across the river after a halt to make the detailed preparations necessary to ensure success. ...” Time is available for extensive reconnaissance, full-scale rehearsals, development of alternative traffic routes and logistics stockpiling.”

Although the hasty criteria were used in evaluating the suitability of the potential crossing sites, accurate river characteristic data is valuable for any category of crossing operation. Accurate remotely gathered information would also be useful for advance planning and resource allocation in the more permanent crossing site categories.

2 STUDY AREAS

The areas assigned as the crossing zones comprised two rivers in northern New England, in Vermont and New Hampshire. Approximately 85 miles of the Connecticut River between Wells River, Vt., south to Bellows Falls, Vt., and approximately 36 miles of the White River from White River Junction, Vt., north to Rochester, Vt., for an approximate total of 121 miles of river (Figure 1) were studied. The White River joins the Connecticut in White River Junction, Vt.

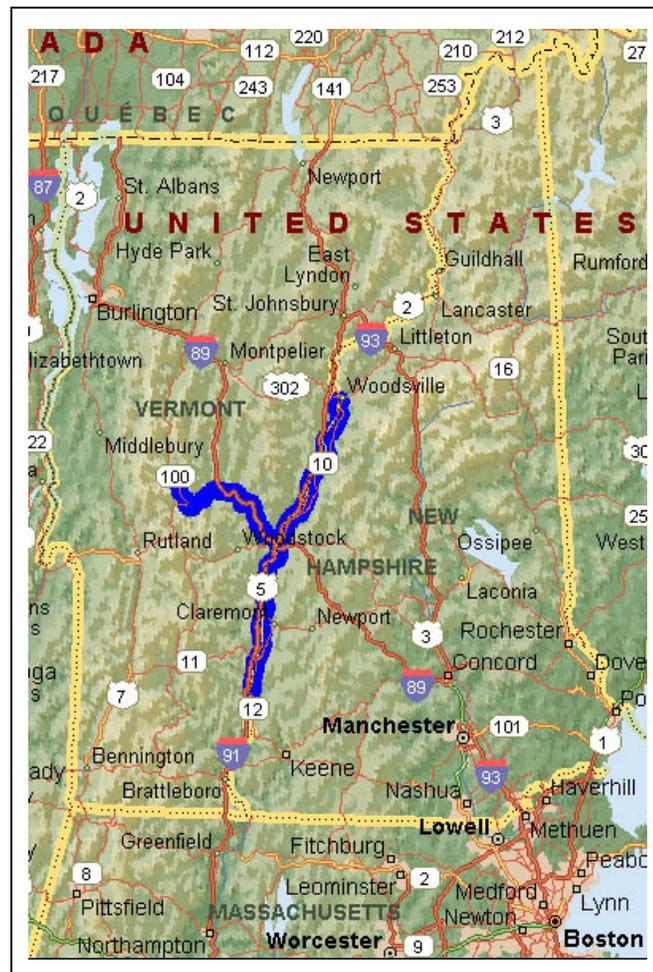


Figure 1. Study area in Vermont and New Hampshire with rivers emphasized in blue.

The physical features of the rivers and surrounding area were formed during the ice age about 14,000 years ago. The area was originally covered in glacier, and as the ice front receded and the surrounding land uplifted, two large lakes – Lake Hitchcock and Lake Upham – formed in what is now the Connecticut River valley. The lakes stretched from about where Saint Johnsbury, Vermont, is now, just north of the beginning of our study area, to Rocky Hill, Connecticut, well south of the southern-most boundary of our study area. The White River formed as a tributary to the Connecticut and drains the mountainous area to the northwest of the river (Lyons 1958, Little 1984).

For convenience, we split the study area into three sections: Area 1 is on the Connecticut River and runs from Wells River, Vt., to the junction of the White River at White River Junction; area 2 extends from there south to the dam at Bellows Falls, Vt.; and area 3 is on the White River and starts at the junction of the White and Connecticut Rivers and runs north to Rochester, Vt.

Connecticut River

As a consequence of the early glacial activity, the Connecticut River valley contains areas of broad flood plain composed of relatively soft soils interspersed with narrow passages where the river cuts through mountainous rocky terrain. At present, the flood plains are generally used as farm land or are developed into urban areas because of the easily built-upon flat topography. The sections where the river cuts through mountains tend to be sparsely developed because of steep slopes and the proximity of the river. U.S. Route 5 in Vermont and U.S. Route 10 in New Hampshire, both major highways, run parallel to the river in the valley as do several secondary roads.

The river bottom elevation at the northern limit of our test area 1 is about 400 ft above mean sea level (msl) descending to 325 ft msl at White River Junction over a distance of about 44 miles. Area 2 descends from 325 ft msl to 260 ft msl over a distance of about 41 miles.

There are two power-generating dams in our study area, one in Wilder, Vt., (area 1) and one in Bellows Falls, Vt., (area 2), that exert a large influence on the river's stage for several miles upstream of each dam. The average depth of the river in study area 1 was about 10 to 20 ft. In area 2, it was about 10 to 15 ft.

White River

The White River is narrower and much more shallow than the Connecticut. Its approximate average depth in the summer is on the order of 2 to 4 ft, with many sections less than that. The adjacent topography is mountainous, with a narrow river valley and fewer broad flood plains than are found on the Connecticut. Study area 3 on the White River descends from about 750 ft msl at the north to 325 ft msl at White River Junction over a distance of about 36 miles.

Two major state highways parallel the river in the valley, state Route 14 in the southern section of the area and state Route 107 in the northern section. There are also numerous secondary roads in the White River valley.

Crossing criteria

We assumed that the first vehicles over the river would be M-1025/26 combat support vehicles (HMMWVs) and Infantry Fighting Vehicles (IFVs) or something similar, because they are relatively light, quick, and maneuverable. These characteristics make them attractive for crossing sites where the banks are not extensively prepared. They would carry the initial troops and light guns across the river to secure the far bank for the following troops and equipment.

In a hasty crossing where the water depth precludes fording, it is likely that time constraints will dictate a rafting operation as opposed to bridge construction. We assumed the crossing means would either be a ribbon raft or an Armored Vehicle Launched Bridge (AVLB). The ribbon raft ramp bay was estimated as having about a 0.3-m (1-ft) to 0.61-m (2-ft) freeboard.

We used the mobility characteristics of the vehicles and the launching and crossing constraints of the ribbon raft and AVLB to determine the allowable bank height and slope that could be successfully traversed without extensive work. We also assumed that the most difficult obstacle in either a fording or bridging situation would be the exit bank. This assumes, depending upon soil type, that a bank on the friendly side of the river that is slightly beyond our vehicle capabilities could quickly be altered using an M-9 Armored Combat Earthmover (ACE) or similar.

Table 1 lists the HMMWV and IFV maximum slope and vertical step capabilities as shown in TM-43-0001-31 (1985) and Vehicle Parameters (1985), Table 2 lists the ribbon raft use constraints, and Table 3 gives the AVLB use capabilities.

	M-2/3 Infantry Fighting Vehicle	M-1025/26 (HMMWV) High-Mobility Multipurpose Vehicle
Maximum up/down slope, % (°)	60 (27)	60 (27)
Maximum side slope, % (°)	40 (18)	40 (18)
Ground clearance, m (ft)	0.45 (1.50)	0.45 (1.50)
Vertical step capability, m (ft)	0.91 (3.0)	0.56 (1.83)
Approach/departure angle	NA	45 (45°)
Maximum fording depth, m (ft)	Swim	0.75 (2.5)

	Free launch	Controlled launch	High bank launch
Minimum water depth, cm (in.)	Ramp bay, 112 (44)	76 (30) recommended, 43 (17) possible	76 (30) recommended, 43 (17) possible
Bank height restrictions, m (ft)	0 – 1.5 (0-5)	0	1.5 – 8.5 (5 – 28)
Bank slope restrictions	0 – 30%	0%	Level ground unless front of truck is restrained.

	Prepared abutments	
Bridge will span, m (ft)		
Prepared abutments	18.3 (60)	
Unprepared abutments	17 (57)	
Bank slope restrictions, m (ft)	Uphill	2.7 (9)
	Downhill	2.7 (9)
	Side slope	0.3 (1)

Based on these parameters, it follows that if the entry bank is greater than 30% then either the bank must be modified to launch the ribbon raft sections or a high bank launch must be used.

The vehicles are capable of 60% slopes straight on and 40% side slopes with a vertical step capability of 0.56 to 0.91 m (1.8 to 3 ft). Depending upon the model, the HMMWV has an approach angle of either 45° or 69° and a departure angle of 45°. The approach and departure angle would control the slope transition

when either entering or exiting the river or when transitioning between the relatively flat surface of the raft and a steeply sloped bank. The vertical step capability determines the negotiable exit bank height after fording or when leaving the raft. Adding this capability to the raft ramp freeboard sets a total maximum negotiable exit bank with a raft of 1.2 to 1.5 m (3.9 to 4.9 ft). This is probably unrealistic, since it does not assume any downward displacement of the raft ramp as the vehicles traverse it. Additionally, as vehicles leave the raft to negotiate a steep bank, it is difficult to keep the raft secure against the exit bank as the vehicle reacts off the ramp. A more desirable bank height is less than 0.91 m (3 ft) to allow for the displacement of the raft. In a fording situation, if the bank is vertical, the vertical step restrictions would govern with the approach and departure angles and maximum slope capabilities governing in the other cases. For this study, we set the maximum acceptable bank height as about 0.91 m (3 ft) and slopes of less than 60%, with less than 45% more desirable.

3 REMOTE ANALYSIS FOR CROSSING SITES

In an actual assignment to locate possible river crossing zones, a terrain team would use all the pertinent information about the river and surroundings it could obtain. This exercise was similar, with the exception of the volumetric flow records that could have been obtained from the two hydroelectric dams situated on the Connecticut River. Those records were not used, because if the dams were located in hostile territory it was felt those records would not normally be available to us. As the analysis turned out, it is doubtful that the information would have affected the selection process. It should also be noted that the rivers were analyzed along their entire length for all likely crossing sites. In an actual scenario, the terrain team might have been tasked with a more narrow geographical area where the forces wished to cross for tactical reasons. Since we wanted to maximize our database, no such constraint was placed upon the selection process. For the same reason, some of the crossing sites we chose would probably not be used for tactical reasons, such as the presence of a hill that could give opposing forces a high vantage point overlooking the crossing site. However, we emphasized the topography in the immediate vicinity of the river to maximize the potential sites.

Two primary data sources were used in the analysis: United States Geological Survey (USGS) 1:24,000- or 1:25,000- scale topographic maps and 1-m orthographic gray-scale aerial imagery. The information available was the best that could typically be obtained by a terrain team in almost any region of the world, with the possible addition of infrared imagery available for some areas. One-meter visible imagery is not available for every area but could be obtained if the justification were sufficient.

The USGS contour maps are used to get a sense of vertical relief around the river, to look for flat areas suitable for staging and launching the river crossing, and to determine road networks pertinent to the crossing operation. They are also used to identify potentially marginal soil conditions, such as marshes, that need to be avoided. The contour information provides the analyst with a sense of slope near the river to eliminate terrain that is too steep for trafficking or for geographical features that would make the crossing unsuitable. The contour interval on the USGS maps for the rivers was typically 20 ft, that is, the elevation data is displayed for every 20 ft of vertical height change.

The 1-m orthographic imagery supplements the maps and is used to determine vegetation locations and road networks and to provide a cross check to the contour map data. Shallow water depths can sometimes be inferred from the

imagery to reveal possible fording locations. Furthermore, as was the case in this study, the maps and imagery are frequently developed at different times and can show a progression of topography changes when viewed together. This difference can also be a source of uncertainty as to what the actual situation is at the time of interest.

Our USGS maps had a vertical datum obtained predominately in 1929, with photographic inspection updates typically in the mid 1980s. The aerial imagery was taken in late winter/early spring of 1994.

Results

Nineteen potential crossing sites were investigated during the study. Area 1 had six remotely identified rafting sites with three sites chosen during the field investigations. Area 2 had two identified rafting sites, one remotely chosen and one picked during the fieldwork. Area 3 had eight remotely identified sites with none chosen during the fieldwork. Of the 15 sites that were remotely identified, three were considered acceptable crossing sites, for a success rate of 20%. Including the sites found during the field investigation results in a 16% success rate in identifying all of the potential crossing sites from the remote analysis.

The Connecticut River in areas 1 and 2 is wider than the AVLB is capable of spanning, so sites there would be either rafting or fording sites. They were most likely to be rafting sites given the depth of the river along most of the river's length. In these two areas, there were five usable rafting sites, only one of which was identified remotely. Bank height and slope were the reasons all the unusable sites were rejected. In area 3, on the White River, we expected more opportunities for crossing because the river is shallower and generally narrower than the Connecticut with more potential for either fording or the AVLB. During a river inspection, the terrain team looks for constrictions in the rivers as these areas offer a high throughput potential, minimizing the crossing force exposure on the river. Six possible AVLB/fording sites and two rafting sites were remotely selected in area 3. Of these eight sites, three were thought to be potential AVLB sites, but on inspection they turned out to be too wide. They were rejected for other types of crossing because of the bank height and slope. Of the remaining five sites, all but two were unusable due to bank height and slope.

Appendix A presents the pertinent information about all the sites selected. Contour map excerpts are matched with aerial imagery and photographs of the actual bank and river conditions. The discussion below presents representative examples of the sites, discusses the reasons they were chosen, and presents actual conditions at the river. In these examples, the contour maps and aerial imagery are arranged with north at the top.

4 DISCUSSION

Unacceptable bank slopes

The predominant reason why crossing sites were unacceptable was the vertical height and slope of the riverbanks. It is nearly impossible to determine vertical height from overhead aerial imagery, and the contour interval of 20 ft on the USGS maps is too coarse for the resolution needed for a river crossing. Figure 2 shows the contour map and 1-m imagery in area 1 that was used to select crossing site 4. The contour map indicates flat ground and gentle slopes next to the river. The 1-m imagery confirms that the areas are fields with sparse vegetation along the riverbanks. For these reasons, it looked to be a potential crossing site.

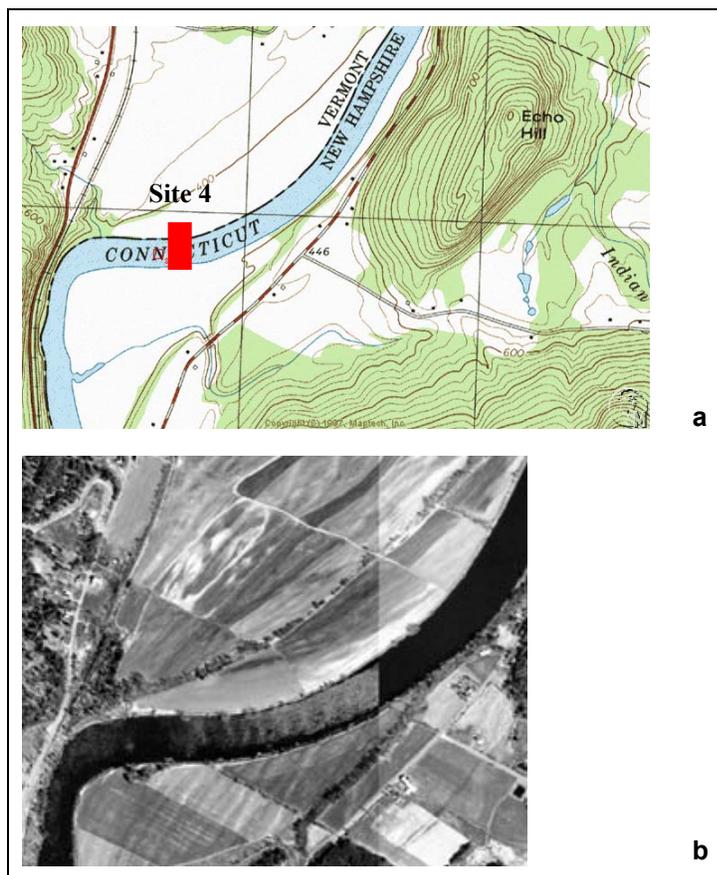


Figure 2. Site 4: Contour map (a) and aerial imagery (b).

Figure 3 shows the east and west banks. It can be seen that there is room between the sparse vegetation for vehicles to move, but the bank has a steep slope, about 45° , and a 10-ft height. The west bank is about a 90° slope with an exposed sandy face between 10 and 15 ft high. Vehicle movement would be impossible on the west bank and very difficult at best on the east bank after the surface got wet and rutted from several passes.

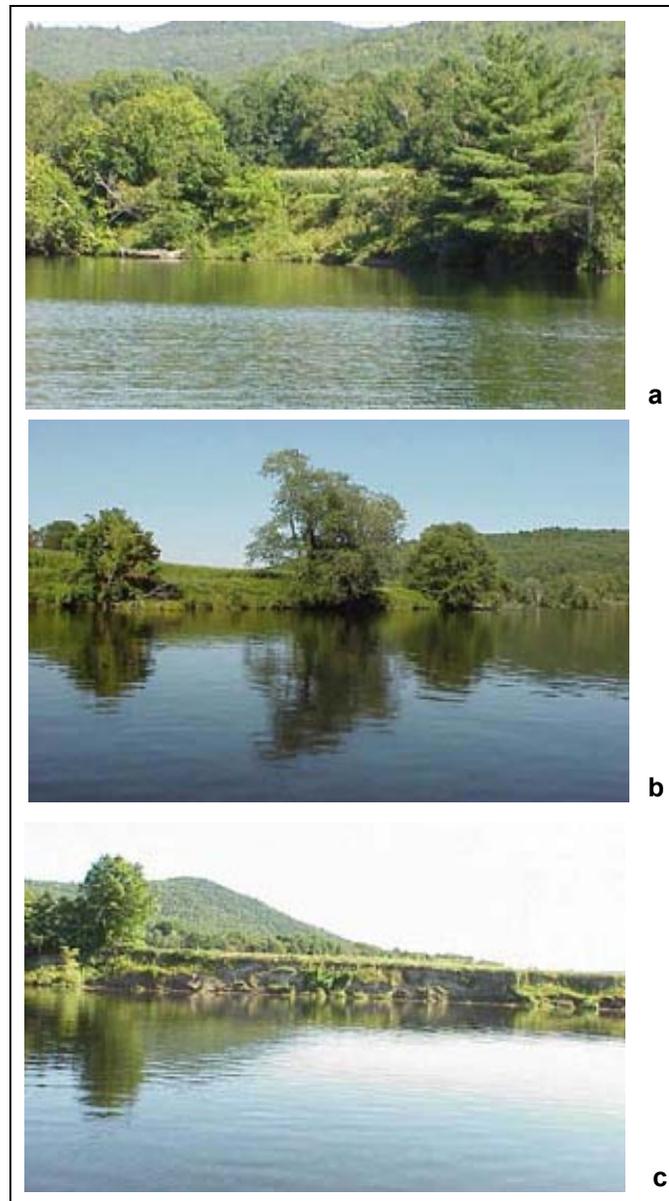


Figure 3. Site 4: East (a and b) and west (c) banks.

Area 2, the southern study area on the Connecticut River, presented more difficult terrain for river crossings. Only one location, site 12 (Figure 4), was remotely identified as a possible crossing site. The contour map indicates a large flat area on both the east and west sides of the river. There is a contour line near and parallel to both sides of the river, but from the map and aerial imagery it is difficult to tell how high a bank there is, if any. A shadow along the west bank indicates some bank height, but the east bank shows no such indication because the sun is shining onto it from the west.

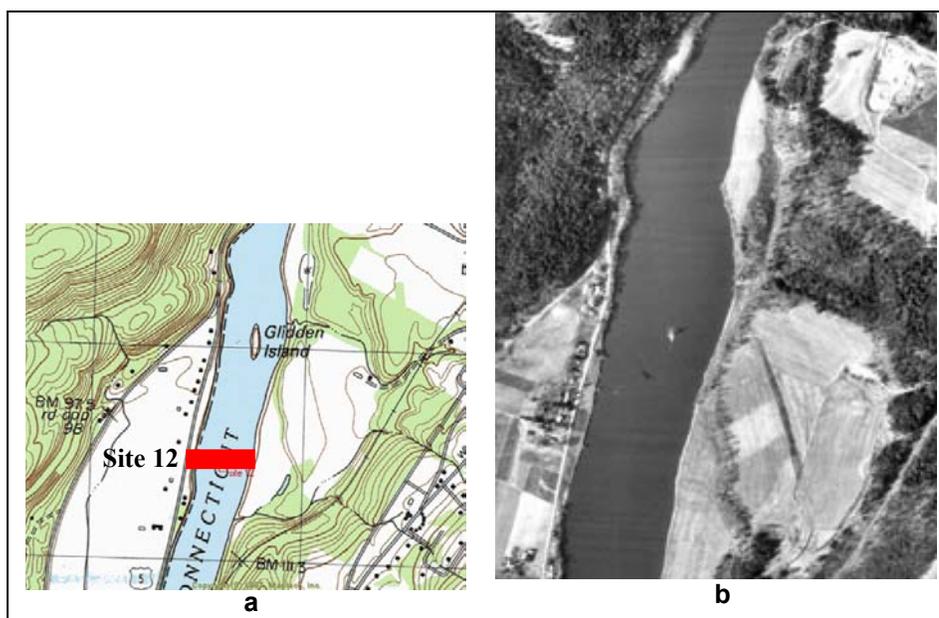


Figure 4. Site 12: Contour map (a) and aerial imagery (b).

Of further interest is Glidden Island, shown on both the USGS map and in the imagery. Field inspection revealed that the island is no longer there.

The field inspection (Figure 5) revealed the east bank to be 10 to 15 ft high at a 90° slope and the west bank to be 8 to 12 ft high at almost a 90° slope.



Figure 5. Site 12: East (a) and west (b) banks.

Figure 6 shows the contour map and imagery for site 13 in area 3 on the White River. The contour map shows a flat area just north of Savage Cemetery on the east side of the river that appeared to be acceptable as a crossing site. The west bank shows vegetation on the USGS map but looks to be relatively flat otherwise. The aerial imagery shows the areas as mostly fields with a sparse tree line behind them. The sun angle reveals the possibility of a bank on the west side of the river, but the east bank is indeterminate. In addition, although it is difficult to see in the shadow, there is a strip of land to the east of the trees on the west bank that was thought to be a corridor to the river.

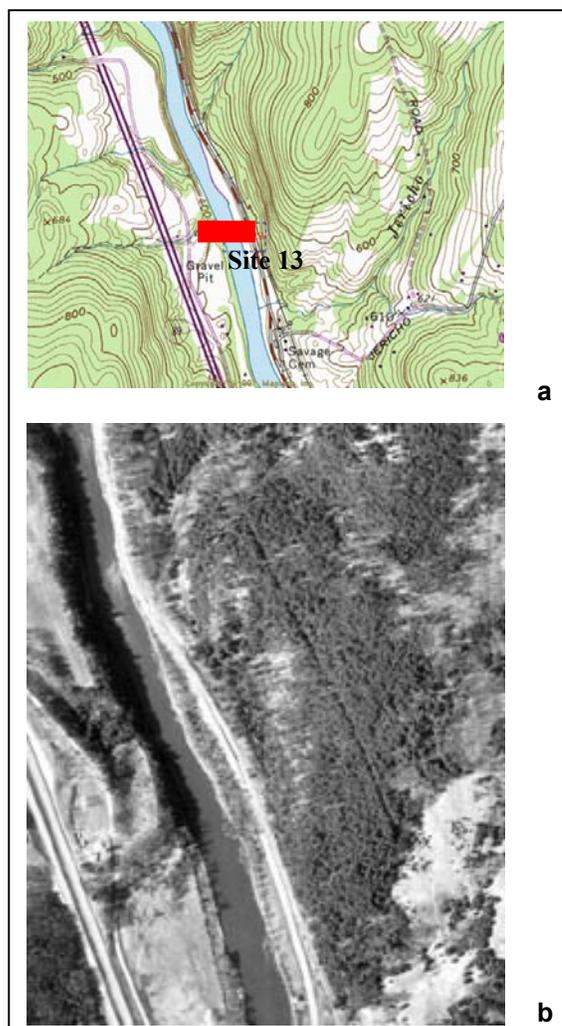


Figure 6. Site 13: Contour map (a) and aerial imagery (b).

Field inspection showed that the initial banks (Figure 7) at this site were of low height with a gradual slope into the river that could easily be trafficked. However, there were secondary banks 8 to 10 ft high and a 70° to 90° slope above the initial banks within the vegetation strip that disqualified this as a crossing site. Along with the inability to determine vertical height from the imagery, the vegetation had substantially filled in areas that were open when the imagery was taken five years before this study.



Figure 7. Site 13: East (a) and west (b) banks. Trees in background of both photos hide steeper secondary banks.

Possible AVLB crossings

Three sites in area 3 – 14, 15, and 17 – were identified as possible AVLB crossing areas because they were at what appeared to be constrictions in the river. The field measurements revealed that all of these sites were too wide for the bridge, and all had bank heights above the capabilities of the AVLB. It is instructive to look at these sites for various reasons.

At site 14, it was thought the AVLB could be deployed between the riverbanks and the smaller island just north of the larger island shown on the map (Figure 8). It can be seen in the aerial imagery that the river has widened the gap between the west bank and the large island. In addition, the smaller island off the northern tip of the large island is now practically nonexistent, essentially just ledge protruding above the water, which shows up as rapids in the imagery.

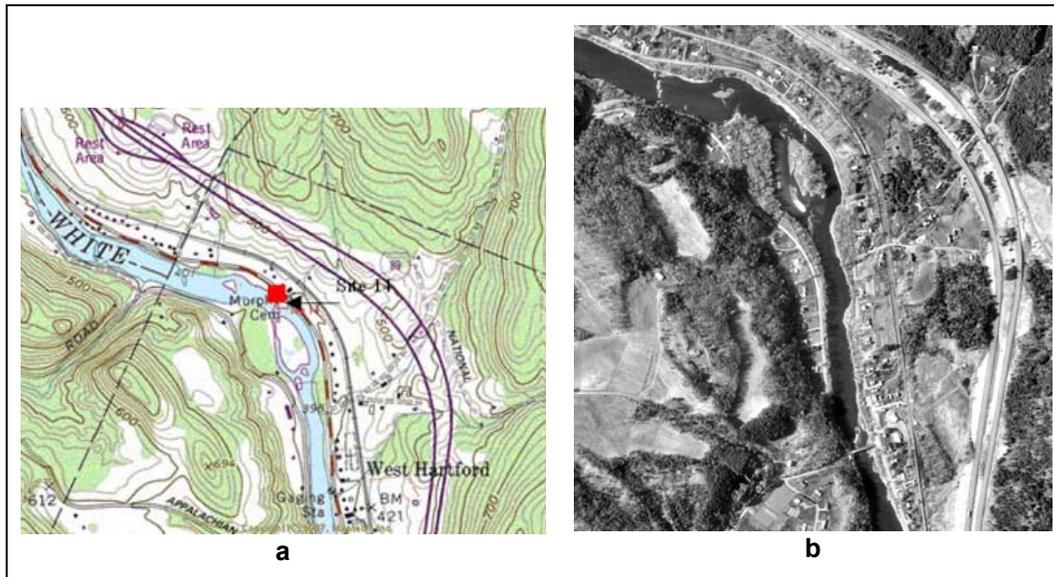


Figure 8. Site 14: Contour map (a) and aerial imagery (b) of possible AVLB site.

Figure 9a was taken looking toward the west bank with the ledge outcropping at the end of the large island visible in the middle of the picture. Measurements showed the distance between the west bank and the outcropping to be 20 to 25 m. The distance between the outcropping and the east bank was 35 to 40 m, both beyond AVLB capabilities. Although the west bank was gradual enough to provide access to the river, the foot of the east bank was jagged ledge outcropping that would be difficult to traverse. The river bottom was too uneven, with alternating deep and shallow spots, to allow either fording or rafting.

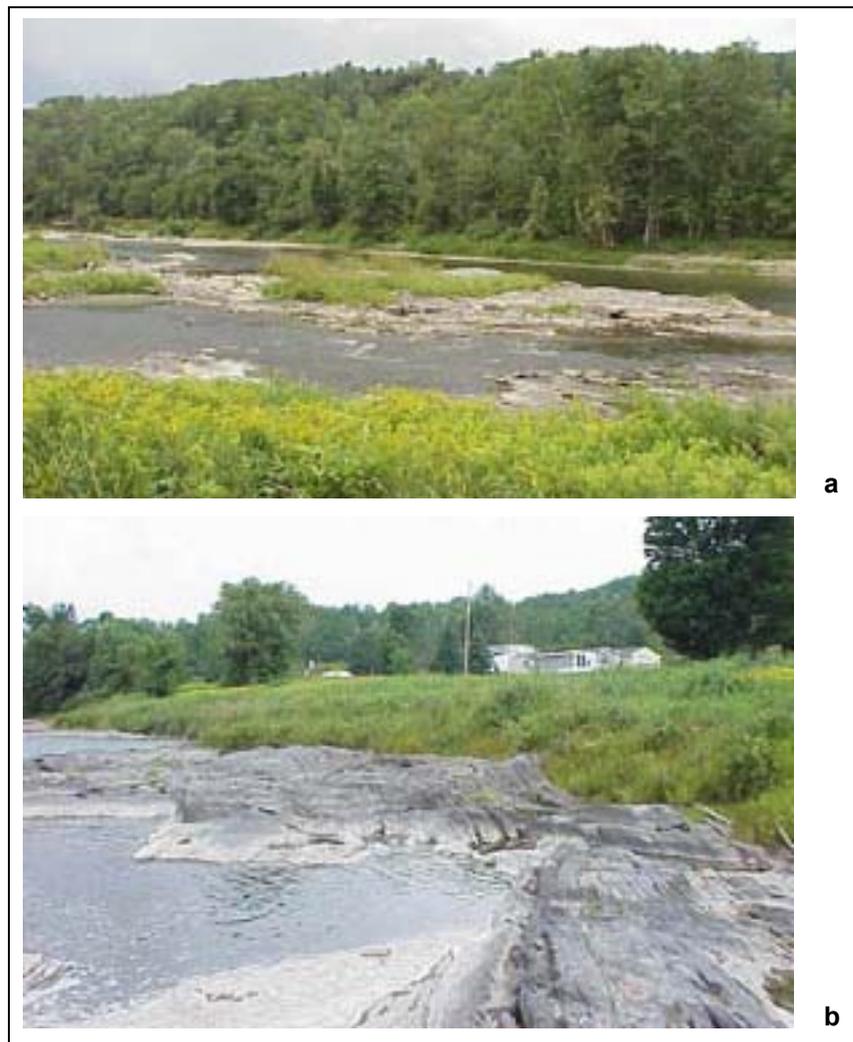


Figure 9. Site 14: East bank (a) and west bank (b) with small island.

The aerial imagery of site 15 (Figure 10) shows an area at the river bend that appears to have a small island and some shallow features crossing the river just to the west of the island. Field inspection revealed that the river is too wide here for an AVLB, with no island or shallow feature present that matched the aerial imagery. Regardless of the river width, the west bank would have been too high an obstacle for crossing here with the AVLB or otherwise.

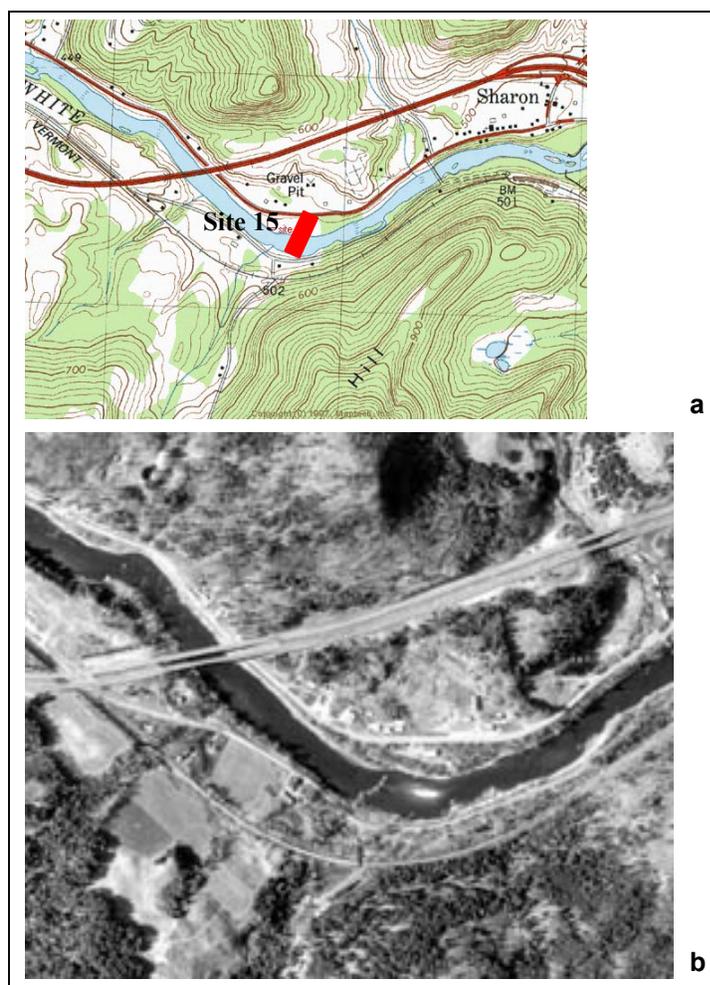


Figure 10. Site 15: Possible AVLB crossing contour map (a) and aerial imagery (b).

There is a gradual slope at the river's western edge (Figure 11a), but then an approximately 10-ft-high secondary bank rises at a 70° to 80° slope to a roadway above. The east bank (Figure 11b) was acceptable at about a 5-ft height and 20° slope at the worst, with small-diameter vegetation. The river bottom was gravel, with areas of exposed ledge that would have made vehicle movement difficult but possible.

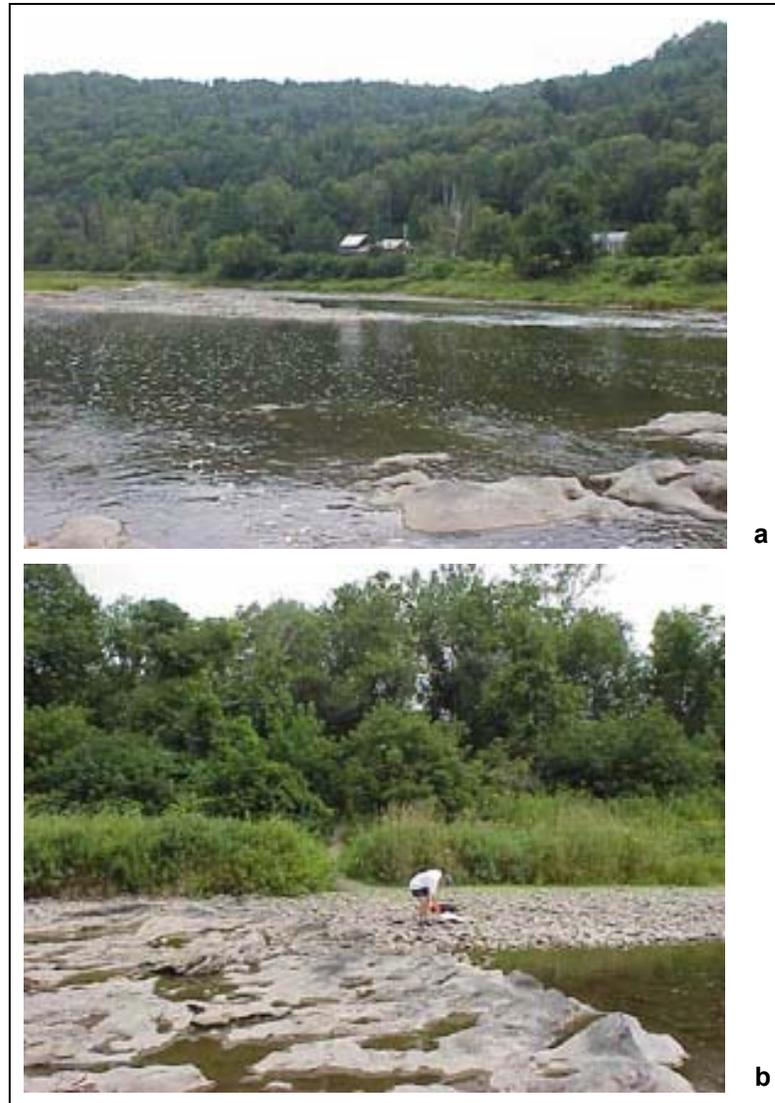


Figure 11. Site 15: West bank (a) and east bank (b).

The map for site 17 (Figure 12) indicates a relatively large flat area on the east side of the river and narrower but still flat west bank at the river. The aerial imagery shows the flat area on the east side of the river to be open fields with little indication of a bank at the river. The west side has vegetation in the area shown on the contour map as an access strip to the river, but roads are visible throughout so the vegetation was not thought to be a major obstacle.

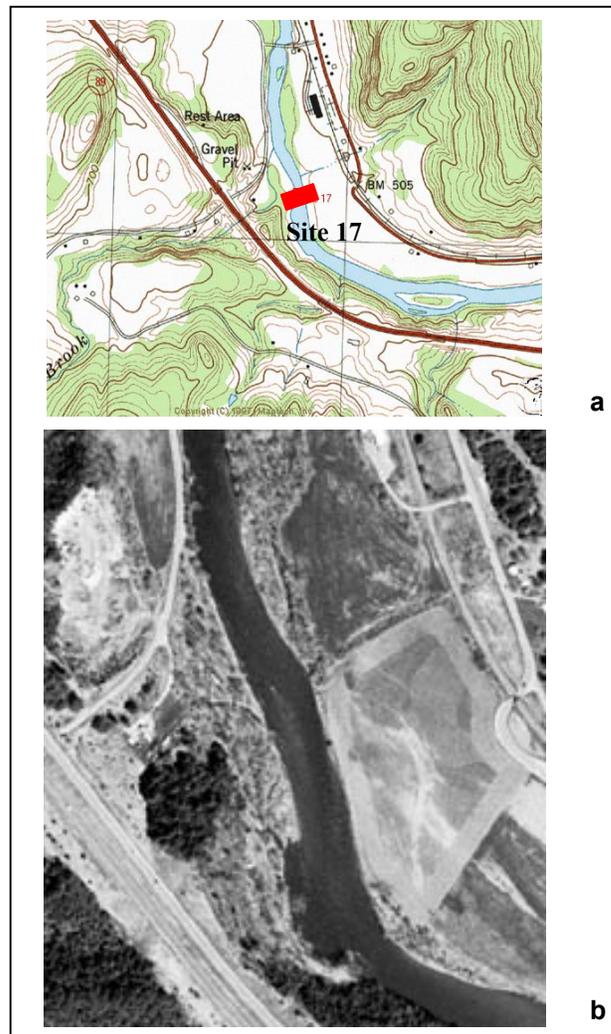


Figure 12. Site 17: Contour map (a) and aerial imagery (b).

It can be seen in Figure 13a that the east bank proved to be a substantial barrier at 8 to 10 ft high and with an 80° to 90° slope. The west bank has a low-slope access to the river with a road/driveway network through sparse trees that would

allow movement. Here again, the problem at this site was the inability to discern vertical height at the river's edge.



Figure 13. Site 17: (a) East bank with west bank access point in background and (b) west bank.

Successful sites identified remotely

For comparison, the successfully identified sites are discussed below. In area 1, on the Connecticut River, site 5 (Figure 14) was considered a successful crossing site. The aerial imagery shows, just to the south of a large building, what appears to be a private road on the east bank leading down to the river. This was thought to be a good access point on the east side of the river, and the contour maps and imagery show the east side to be open fields with little slope.

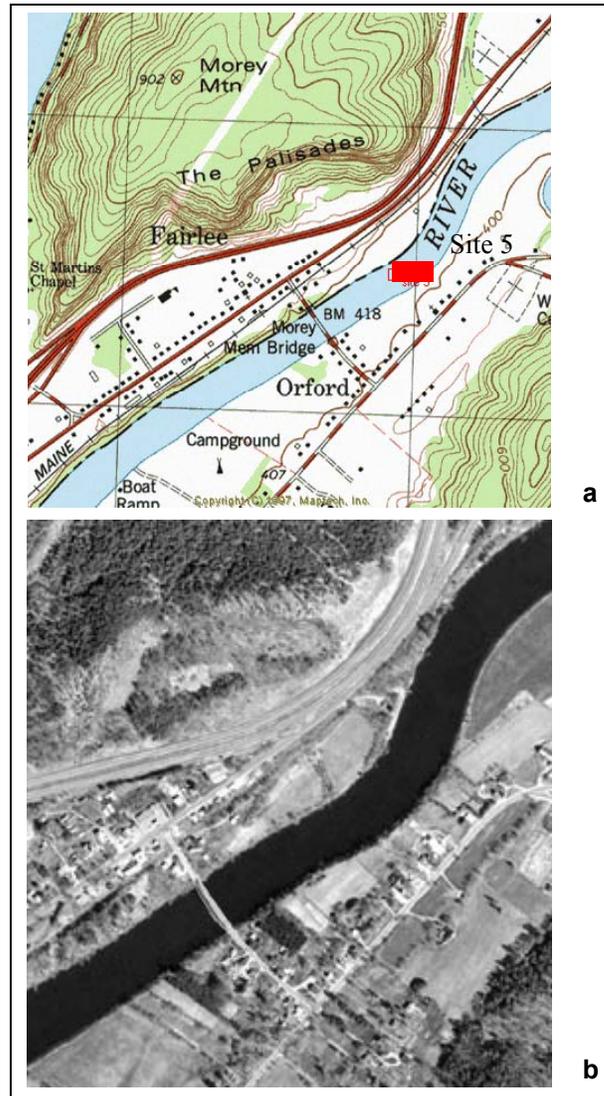


Figure 14. Site 5: Contour map (a) and aerial imagery (b).

On the east bank (Figure 15a), the road leads down to the river; the approach here is good with little bank height at the water. The west bank (Figure 15b) is marginal, with one 10- to 15-ft-wide section of 3- to 4-ft bank height and about a 30° slope.



Figure 15. Site 5: (a) East bank with private road to river and (b) west bank. Actual west bank height is about 3 to 4 ft, but vegetation makes it appear higher.

Site 18 in area 3 (Figure 16) on the White River was another successful crossing site. Note the change in the size and location of the island across from the mouth of the brook on the south side of the river between the date of the USGS map (mid-1980s) and the aerial imagery (1994). Another island, visible at the right hand edge of Figure 16b, has also been created; it does not appear on the contour map. This site was picked because the contour map shows an area of gentle slopes on both sides of the river near the fish hatchery land. The aerial imagery shows fields on the south side of the river with vegetation on the north side. There appears to be some kind of access road to the river on the north side visible just to the west of the island.

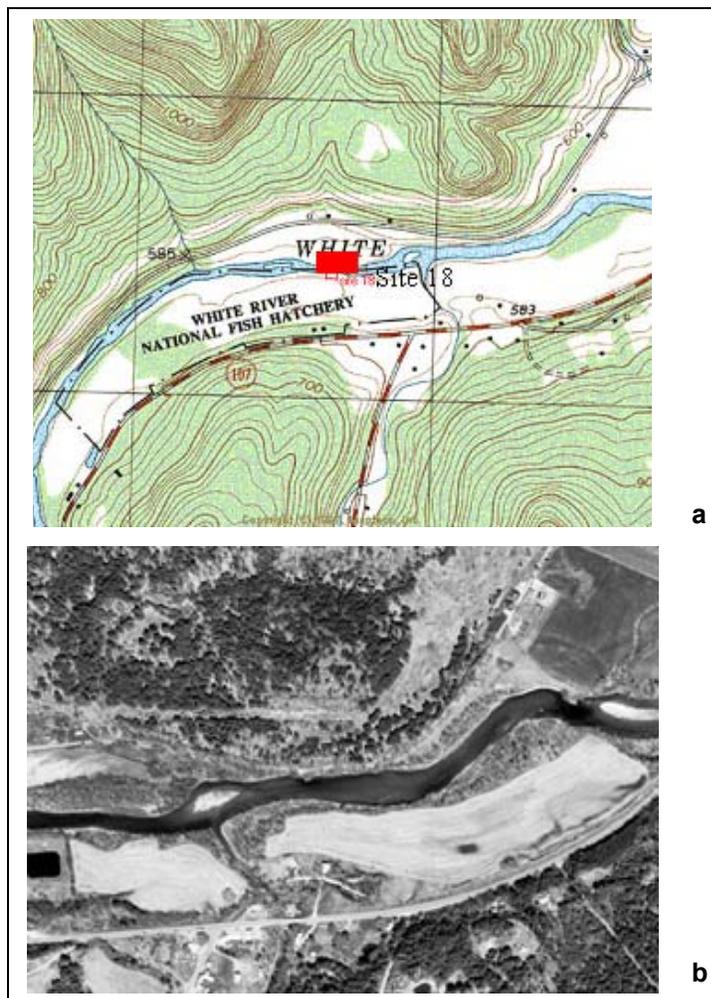


Figure 16. Site 18: Contour map (a) and aerial imagery (b).

The banks at site 18 (Figure 17) are gentle enough to provide good access to the river, with stable soils reinforced by stone. The river itself has a stable bottom with some spots 3 to 4 ft deep but with areas that were fordable. As it turned out, the topography beyond the river on the south side has areas that are steep and covered in mature vegetation leading up to the fields shown in the aerial imagery, so it would be impossible to traffic a direct route to the highway over this terrain.

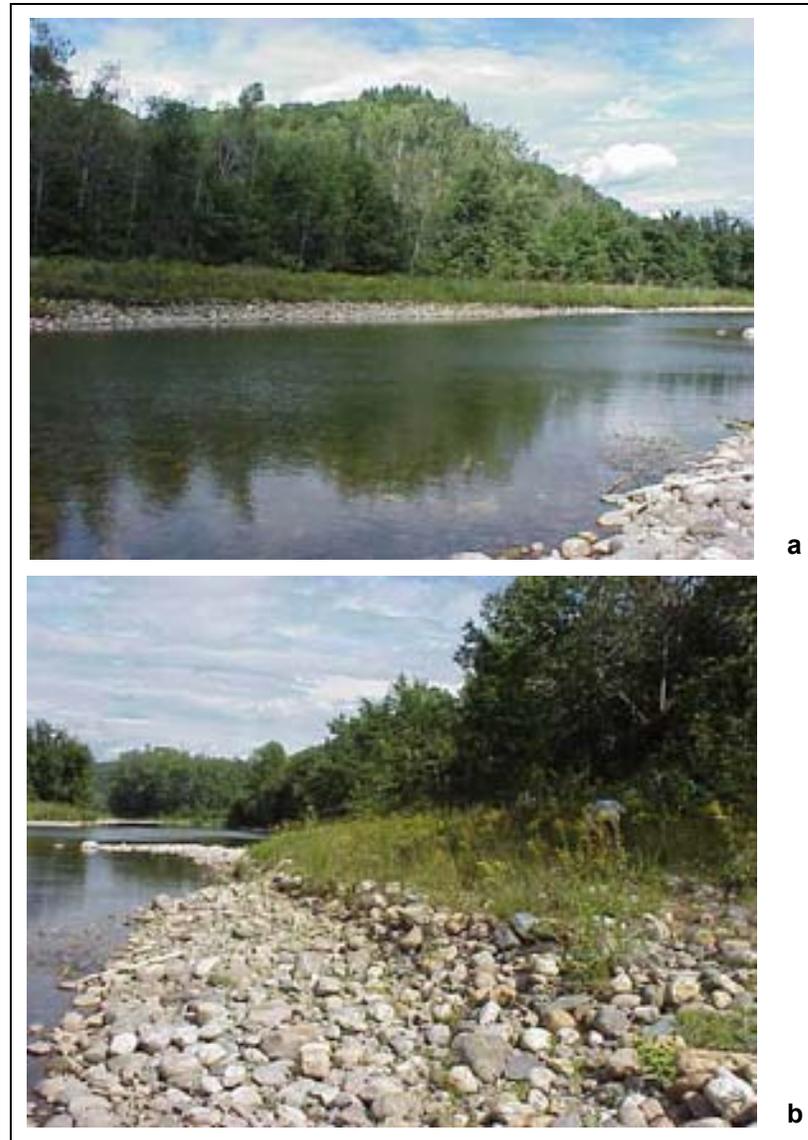


Figure 17. Site 18: (a) North side facing east and (b) south side facing east.

Site 19 (Figure 18) is the final acceptable crossing site identified remotely. It was chosen because the contour map indicates low slopes along the river with roads nearby. The aerial imagery shows the east side of the river as open field behind a vegetation line along the riverbank. The west side of the river had more vegetation but appeared to have open pathways within it.

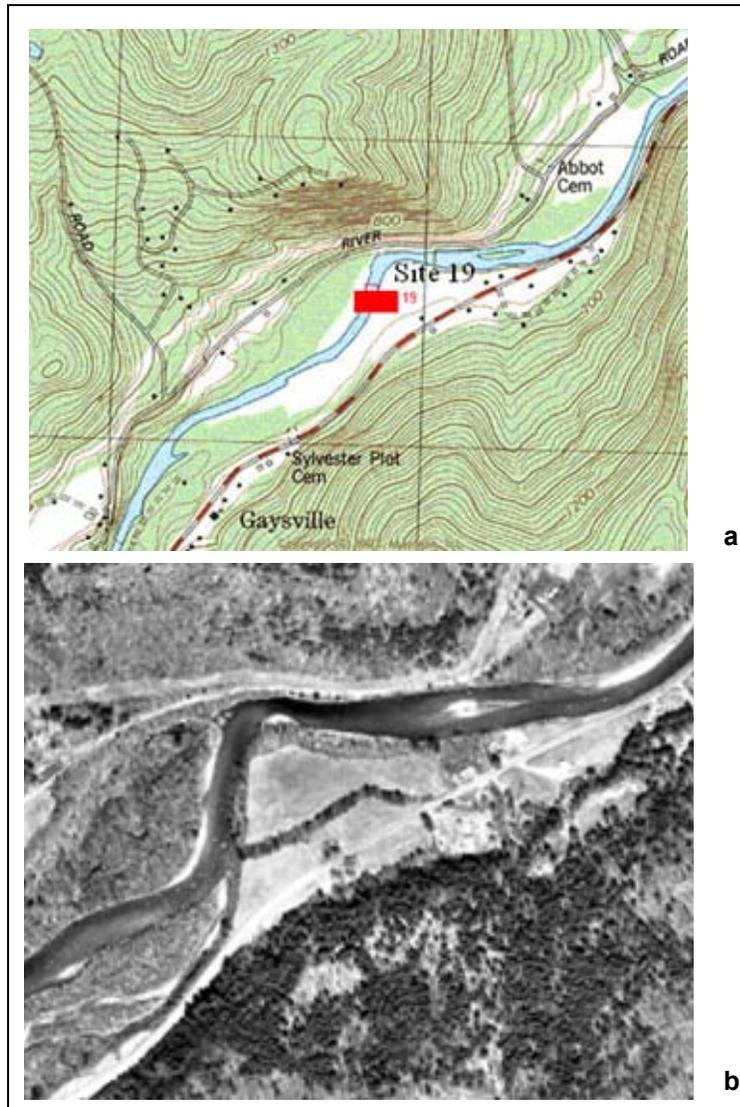


Figure 18. Site 19: Contour map (a) and aerial imagery (b).

The site offers good access to the river on both sides (Figure 19) with low banks but with dense vegetation, mostly small-diameter (2- to 4-in.) trees with some larger trees at intervals that would allow vehicles to pass. The east bank also provides easy access immediately at the river. The bank has less than a 10% slope and is approximately 3 to 4 ft high. As on the east bank, however, the terrain beyond the river is very steep and would be impossible to traffic. Although this was considered a successful site for the purposes of this study, it is doubtful it would be used in actuality because of the difficulty of reaching the roadways beyond the river.



Figure 19. Site 19: (a) East bank (a cliff about 200 m from riverbank adjacent to road would be impossible to traffic) and (b) west bank.

Crossing sites discovered during field verification

Four acceptable crossing sites were found during the river survey portion of the study. These are shown below with discussion as to why they were not identified during the remote assessment. The first two sites – sites 1 and 2 – are near each other at the northern boundary of area 1 on the Connecticut River (Figure 20). Both of these sites were rejected during the remote analysis because of the presence of marsh areas near the riverbanks: just to the northwest of site 1 and just to the east of site 2. This indicates soft ground that could quickly mire vehicles and prevent further progress.

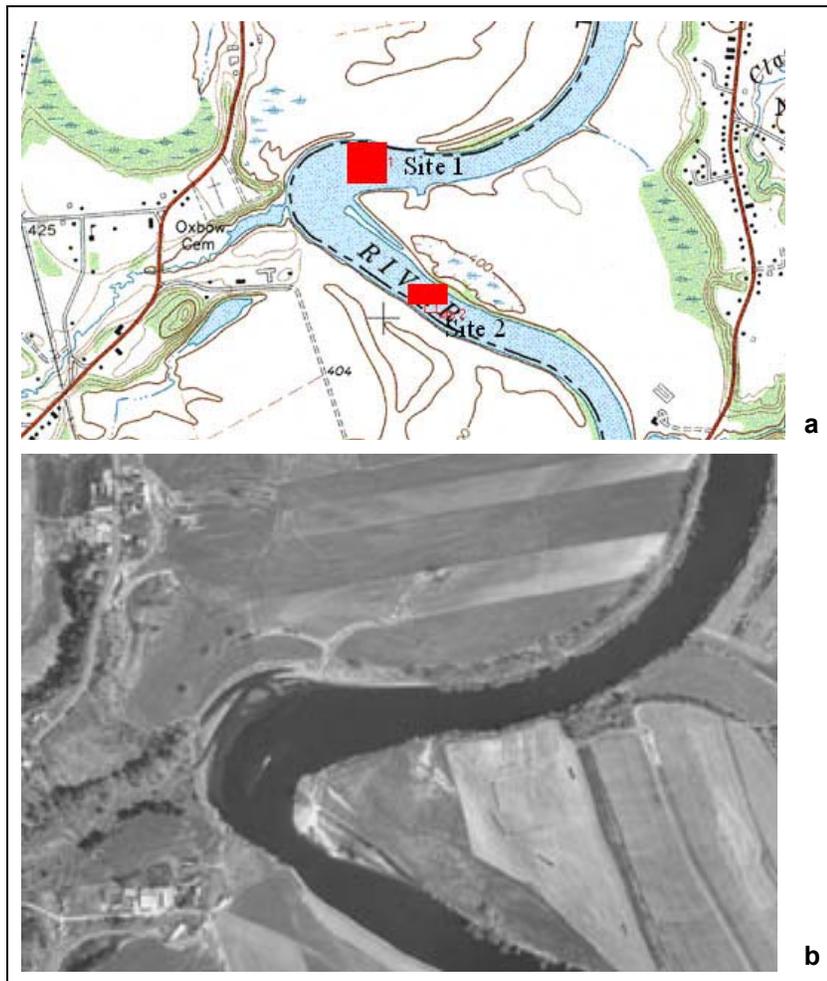


Figure 20. Sites 1 and 2: Contour map (a) (note marsh areas northwest of site 1 and east of site 2) and aerial imagery (b).

It is difficult to see indications of these marsh areas in the aerial imagery. The field inspections showed the land around both sites 1 and 2 was dry enough to support vehicles. If infrared (IR) imagery of the area had been available, it might have shown differences in the ground cover that would have indicated wet or dry conditions.

Figure 21 shows the east and west banks, at site 1, respectively. The east bank offers excellent access to the river with little bank and good soil for trafficking at the water's edge on the inside of the oxbow corner. The west bank has about a 12° slope over a total height of about 5 to 10 ft.



Figure 21. Site 1: (a) East bank looking back at oxbow turn in river and (b) west bank.

Site 2 has a similar east bank with good access to the river and no indication of soft ground beyond, as shown on the contour map. The west bank at site 2 (Figure 22) is interesting in that it is about 15 ft high with about a 26° slope. This is within the vehicle capabilities (see Table 1) but looks to be quite difficult to traffic from a raft. It was included as a crossing site, however, since it did fall within the capabilities.



Figure 22. Site 2: Steep west bank.

The next crossing site found during the field verifications was site 9, also in area 1 on the Connecticut River. It is about 0.6 miles north of remotely selected site 10 (Figure 23). There is no aerial imagery of this site. Site 9 was not chosen because it was thought wet ground might be present on the east bank, as indicated by the stream and small bay just to the north of the site. As it turned out, site 10 had to be rejected because the west bank was too high and steep, and the site 9 location was nearly ideal, with about a 2-ft-high west bank and an east bank with three ramps leading down into the water (Figure 24).

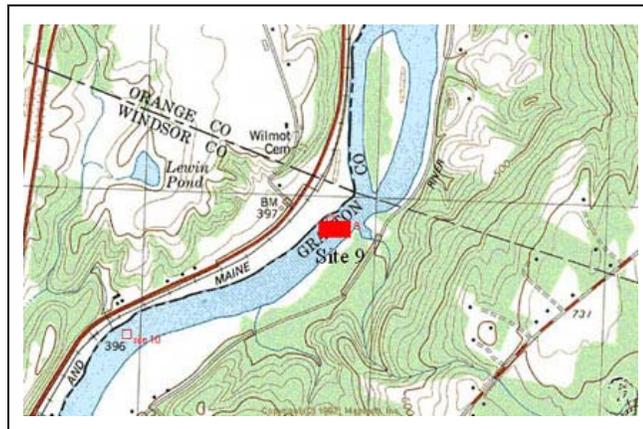


Figure 23. Site 9 found during river survey; just south is remotely selected site 10.

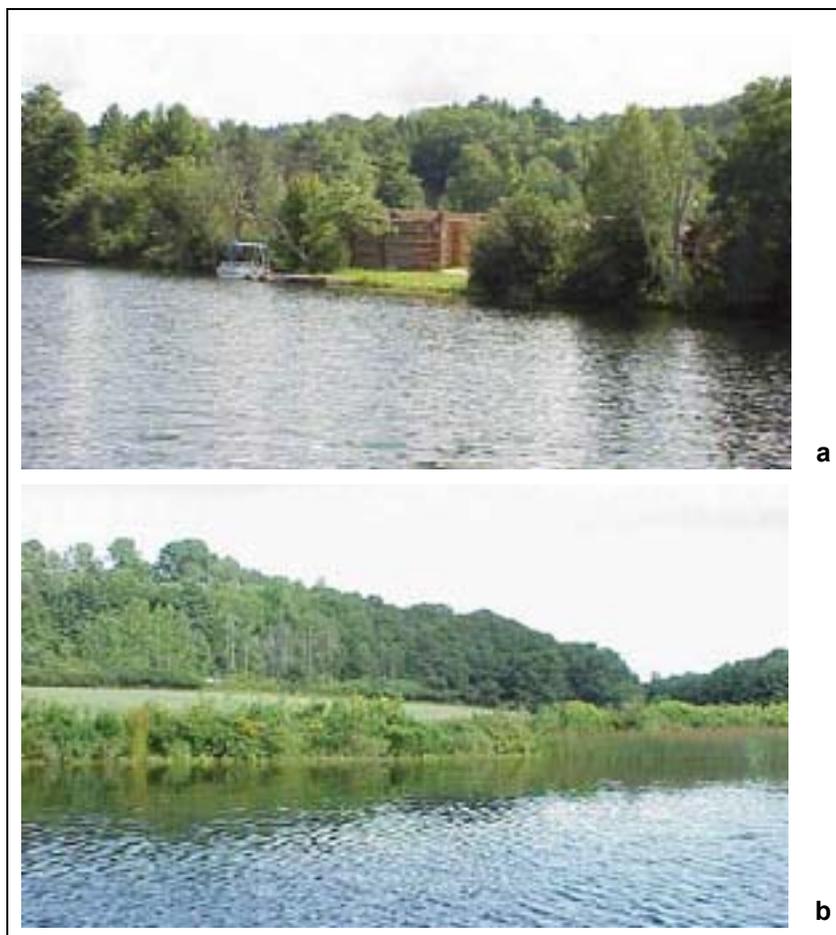


Figure 24. Site 9: (a) East bank, showing one of three ramps leading into river, and (b) west bank, where brush obscures approximately 2-ft-high bank.

The final site picked during the fieldwork was site 11, found in area 2 on the Connecticut River (Figure 25). This site would have been marginal in a real hasty-crossing scenario because the raft would have a distance of 0.4 to 0.5 miles of water to traverse between the approaches. It was chosen, however, because it provides good access to the river and was the only possibility found in area 2. The west bank approach is a paved boat ramp, and the east bank is an open field with a low bank height.

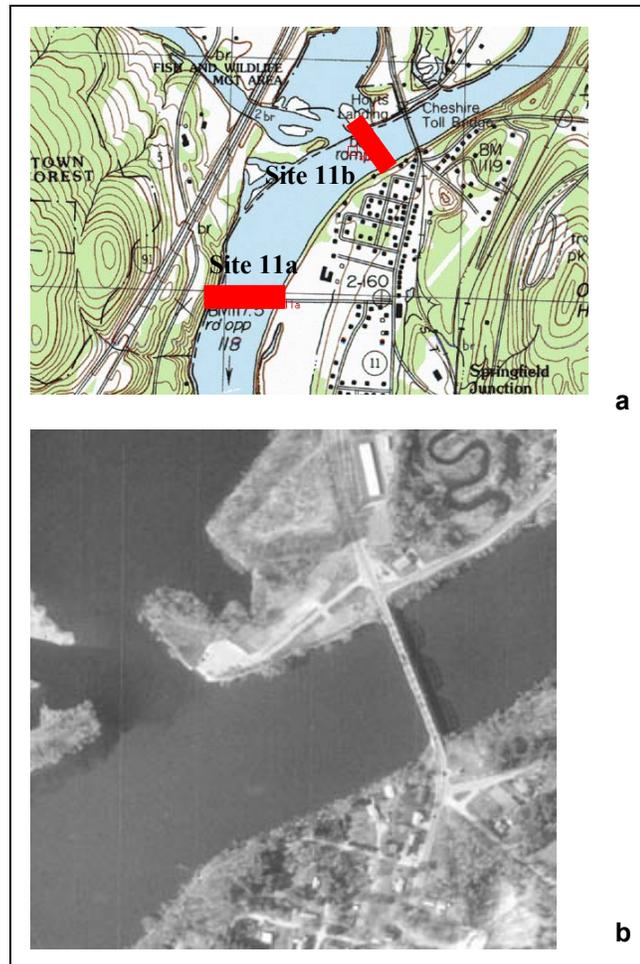


Figure 25. Site 11: Contour map (a) and aerial imagery (b) of east bank approach at boat launch. West bank is just out of view in lower left portion of aerial image.

Contour intervals at rivers

A contour interval of 20 ft makes it difficult, if not impossible, to judge the topography to the resolution necessary for a river crossing. A 2- or 3-ft vertical step that will not be evident within the 20-ft interval can stop a vehicle. This is normally not a problem when maneuvering over open ground. Then the general topographical slope can be determined by looking at the contour interval spacing where more densely spaced intervals indicate steeper ground and vice versa. The vehicle driver can choose to go to the less steep terrain and simply steer around any vertical obstacles that he cannot negotiate. However, a river interrupts the contour spacing and is a linear feature that cannot be steered around and therefore must be negotiated. The contours may indicate the land adjacent to the river is gently sloped, but they do not have the vertical resolution necessary to judge the height from the land to the water surface, especially since contours are not placed at the water surface.

Figure 26 shows a contour (just south of where “New Hampshire” is printed on the river) running roughly parallel to the west bank and close to the Connecticut River in area 1. As the contour runs south, it turns inland from the river’s edge into an area that has a gentle slope. It could easily appear that the contour initially indicates a bank running along the river and that the bank disappears in the location where the contour turns inland.

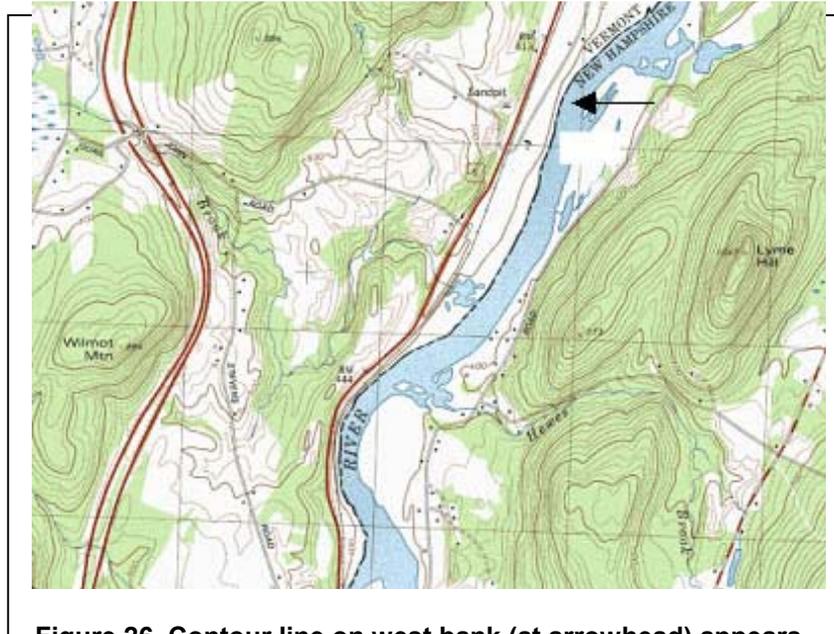


Figure 26. Contour line on west bank (at arrowhead) appears to indicate a bank that gradually disappears from north to south.

In actuality, there are steep banks at both locations (Figure 27).



Figure 27. Steep banks at locations indicated in Figure 26.

River crossings at existing bridge locations

One of the most logical spots to cross a river is at an existing bridge if it has not been destroyed and is adequate for the projected loads. Even if it has been destroyed, crossing at an existing bridge site is advantageous because the existing road network generally offers good mobility on both sides of the river. However, in northern Vermont and New Hampshire this may not be the best choice because of where bridges tend to be constructed. In northern New England, rivers are

prone to ice formation, so bridges tend to be built at high points to keep them above ice jams or flood waters. At these locations, the banks tend to be steep and would be difficult, if not impossible, to traffic in most tactical bridging situations. As an example, Figure 28 is the USGS map of the Morey Bridge and surrounding terrain in area 1 of our study. Figure 29 shows the bridge at the west bank of the river. It is 30 to 40 ft above the water, and the bank angle here is too steep to traffic by the criteria used in this report. This condition is representative of the bridge locations on both of the study rivers.

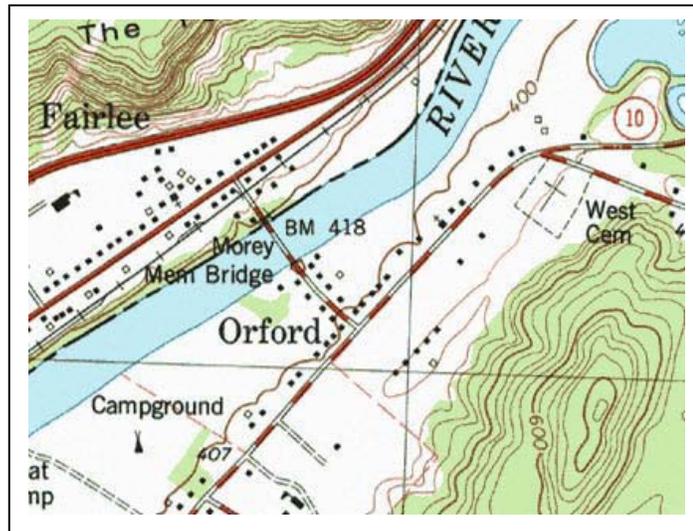


Figure 28. Topographic map of Morey Bridge and surrounding area.

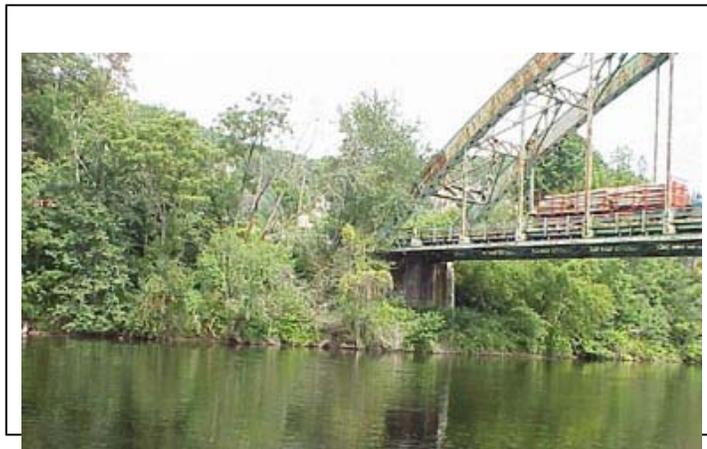


Figure 29. West end of Morey Bridge and bank.

5 CONCLUSIONS AND RECOMMENDATIONS

Using current procedures and tools, our ability to remotely determine suitable river crossing sites is inadequate due to our inability to discern vertical heights to the 1- to 2-ft resolution necessary in a hasty crossing scenario. Aerial imagery does not show vertical heights well. Topographical maps with 20-ft contour intervals miss any vertical changes of less than 20 ft. They can show general slope and are invaluable in determining appropriate overland routes to and from the river, and coupled with aerial imagery they provide important information on staging areas for the crossing itself.

At least one bridging site was missed because of the expectation of soft ground due to marshlands shown on the topographic maps. The aerial imagery was not helpful in more precisely determining the marshland's presence. A method of remotely determining soil type would be very useful. Infrared imagery might have been helpful in this regard because it can show differences in plant type that might or might not indicate marshland; it could also show high reflectance in a vegetated area, which could indicate damp or inundated areas. Unfortunately, IR imagery is not always available to terrain analysts, as was the case in this study.

Vertical resolution of 2 ft or less is not the only parameter necessary to determine bridging/fording sites. A horizontal resolution of about 1 to 2 ft or less is also necessary to judge bank slopes accurately. The water surface must be included in this data.

Some laser-ranging systems currently being used in commercial applications claim vertical resolutions of 10 cm or less. These are normally flown from either fixed-wing or helicopter platforms from near-ground altitudes up to 2000 or 3000 ft. This type of system appears promising in defining to a high degree of accuracy not only potential river crossing sites but also any three-dimensional feature of interest. The utility of these systems is not only in the data resolution during the collection but also in the presentation and flexibility of the output data. For instance, a pictorial three-dimensional image may be of little use at the resolutions necessary for a successful river crossing, whereas a cross-sectional profile representation of the proposed site may be of better use.

These systems require an overflight of the area, which could be difficult in hostile territory, but it could be done by a UAV rather than a piloted aircraft. We are currently investigating these systems for their suitability in a tactical determination of a river crossing site.

It could be argued that the Connecticut River (areas 1 and 2 in our study) is too large an obstacle to be negotiated with a hasty crossing. We feel that advanced high-resolution profiling of linear obstacles would be invaluable for advanced planning no matter whether the crossing is a wet or a dry gap. The advancing force could use this information to focus reconnaissance and/or engineering assets more efficiently.

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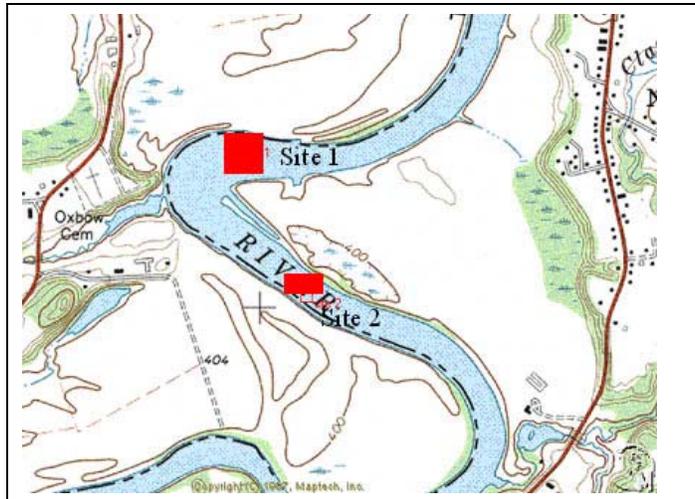
FM 5-34 (1987) *Engineer ford data*. Washington, D.C.: Headquarters, Department of the Army.

FM 90-13/FM 7-26 (1992) *River crossing operations*. Washington, D.C.: Army, Marine Corps, Headquarters, Department of the Army.

APPENDIX A

This appendix contains contour maps, aerial views, and photographs of all the bridging/fording sites investigated in this report.

Site 1



Contour map of site 1.



Aerial photo of site 1.

Sites 1 and 2 were identified on site.



**East bank of site 1,
looking south.**



**East bank of site 1,
looking north.**



**East bank of site 1.
The view is a close-up
of the beach area
shown at the right
central end of the first
photo above. It is
steeper just north of
this view, as shown
above.**



West bank of site 1.

SITE 2

The contour map and aerial photo for site 2 are the same as for site 1.

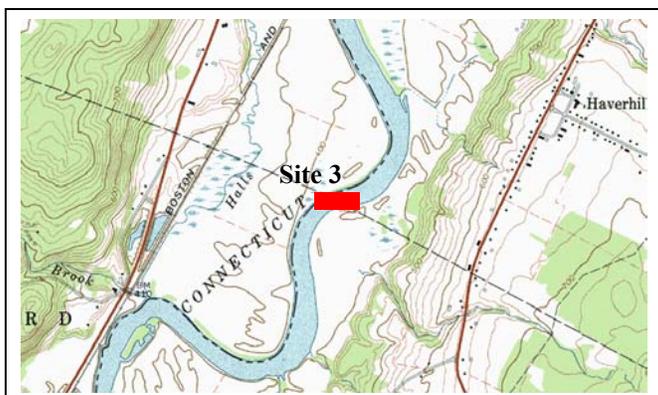


West bank of site 2.

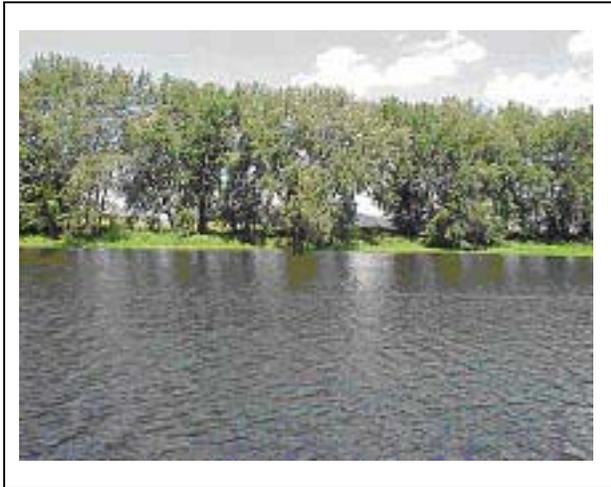


East bank of site 2.

The banks on site 2 looked too steep to traffic, yet they were generally under the 27° maximum up/down slope.

SITE 3**Contour map of site 3.****Aerial map of site 3.**

Identified on site. This site was rejected in remote analysis because of the tree line, which is evident in the photo, and some potential for wet ground shown on the map. On-site inspection showed the trees to be widely spaced with traffic lanes between.

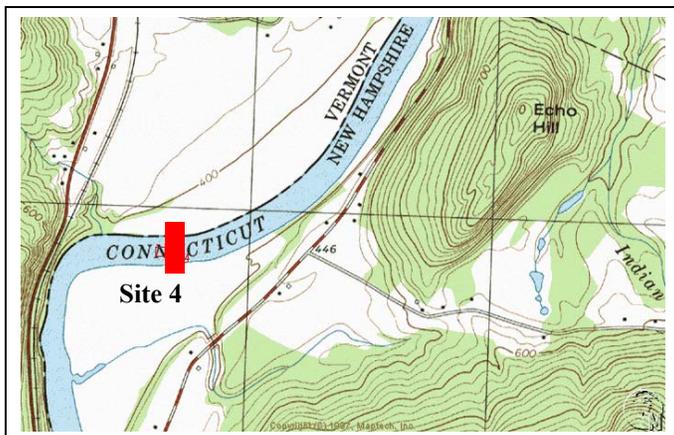


West bank of site 3.



East bank of site 3.

SITE 4

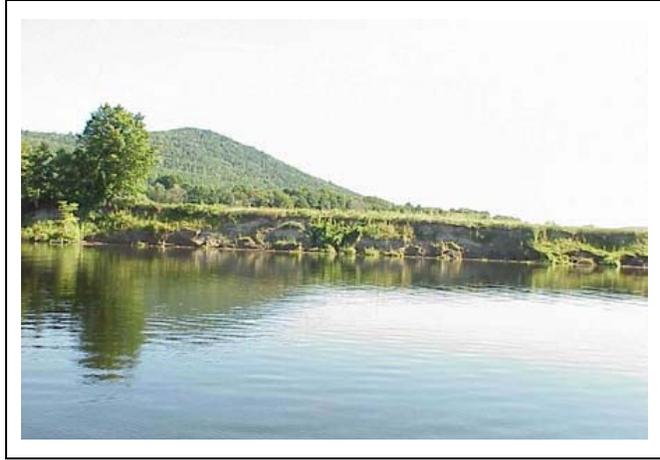


Contour map of site 4.



Aerial photo of site 4.

The banks were too steep and high for crossing.

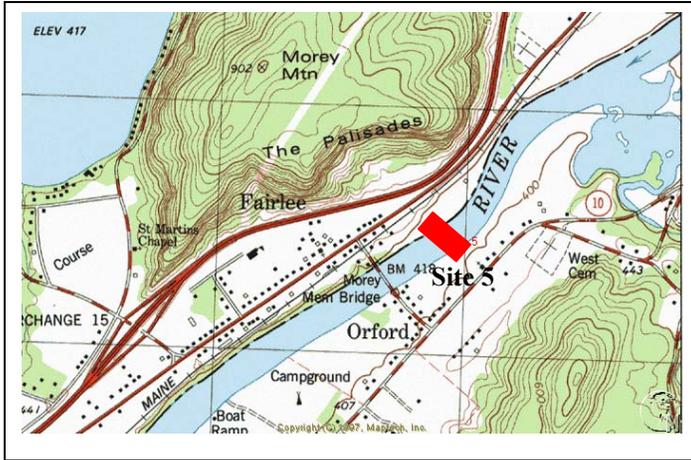


West bank of site 4.

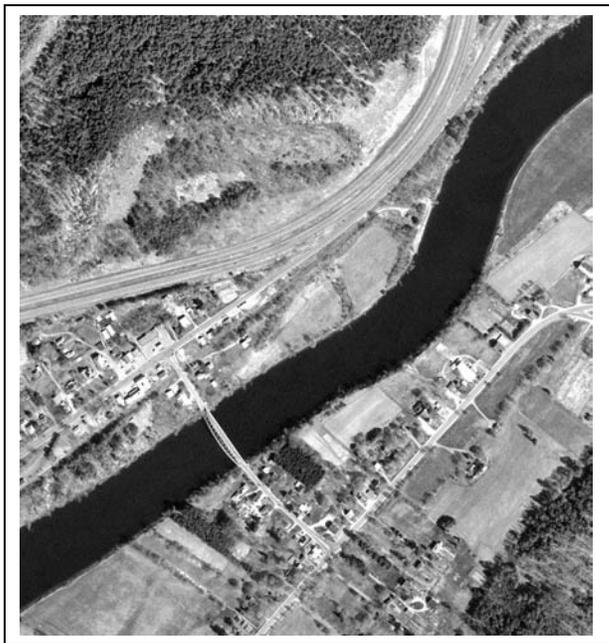


East bank of site 4.

SITE 5



Contour map of site 5.

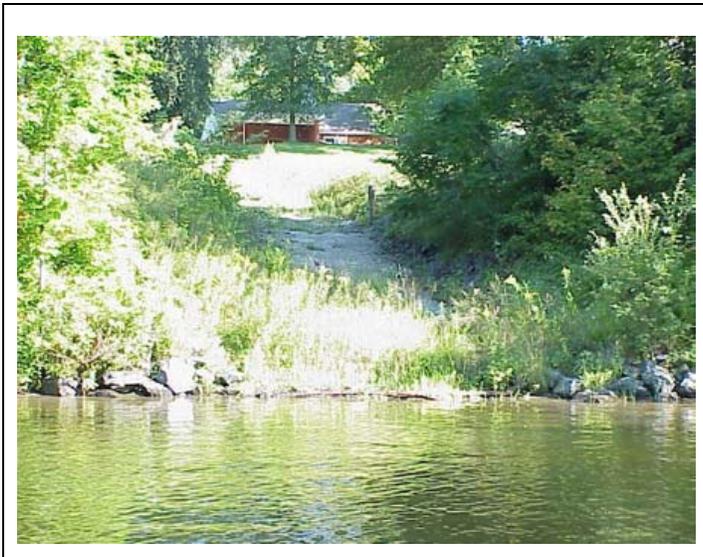


Aerial photo of site 5.

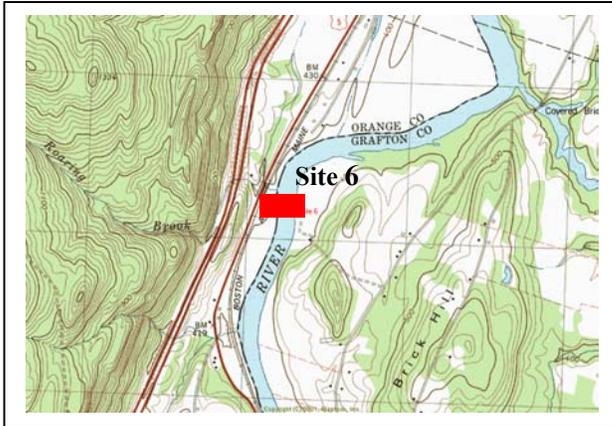
The road leading to the water made this site attractive.



West bank of site 5.



East bank of site 5.

SITE 6

Contour map of site 6.

There is no aerial photograph of site 6.

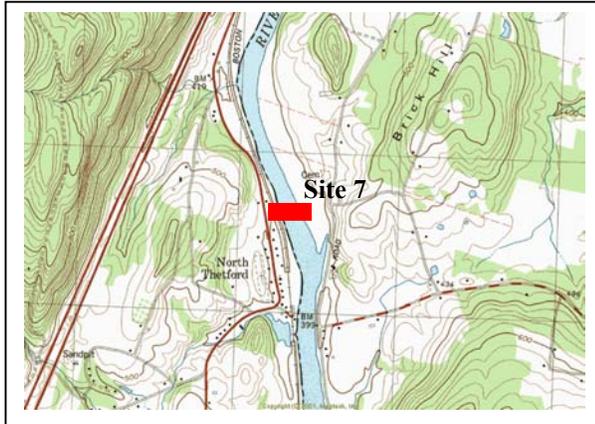


**West bank of site 6.
The bank is 7 to 8 ft
high, nearly straight up
and down.**



**East bank of site 6.
This bank is a gentle
slope with a marsh at
the river's edge and
soft soils beyond.**

SITE 7



Contour map of site 7.

There is no aerial photograph of site 7.

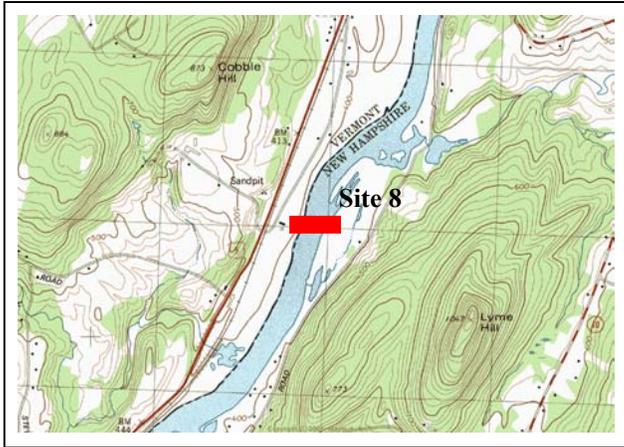


West bank of site 7. The bank is too steep to traffic.



East bank of site 7. The bank is too steep to traffic.

SITE 8



Contour map of site 8.

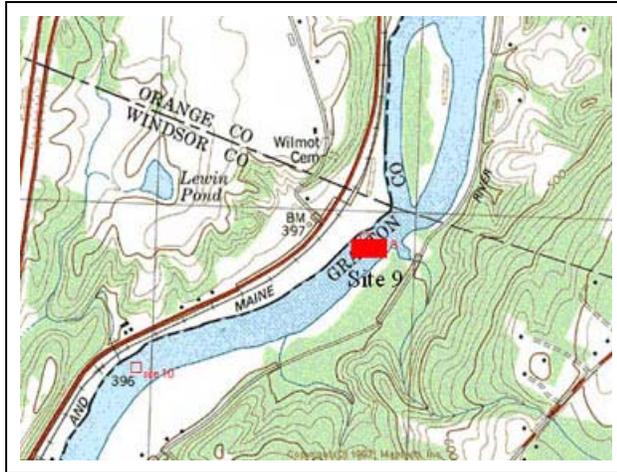
There is no aerial photograph of site 8.



**West bank of site 7.
The bank is steep,
20 to 25 ft high, and
it is low slope and
marsh grass.**



East bank of site 7.

SITE 9

Contour map of sites 9 and 10.

There is no aerial photograph of these sites. Site 9 was found on-site.



West bank of site 9. The west side is a field with about a 2-ft-high bank.



East bank of site 9. This bank has a low-slope cleared section down to the river.



East bank just north of the first east bank picture above. A road leads down nearly to the water's edge.



East bank just south of the first east bank picture above.

SITE 10

The contour map of this site is included in site 9.



West bank north of site 10.



West bank south of site 10. It has an initial 24° slope, then it flattens slightly above.



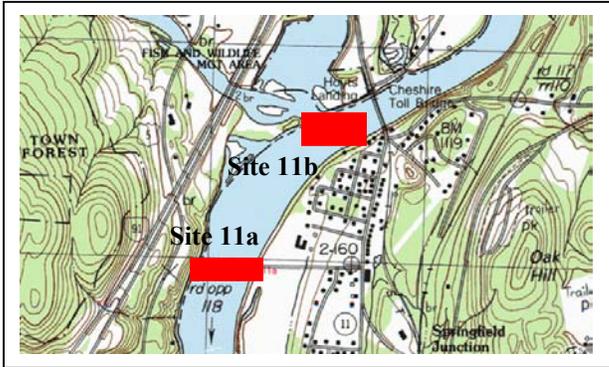
East bank of site 10 looking north.



East bank of site 10 looking south.

Site 10 has a good approach and access with fields and lawns with low banks at the river.

SITE 11



Contour map of site 11.



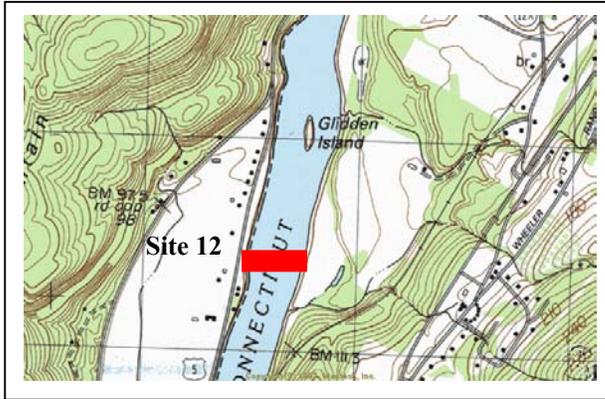
Aerial photo of site 11.



West bank of site 11. The boat ramp is excellent access.



East bank of site 11. Stone riprap is embedded in earth with a height varying from 2 to 6 ft; it would be trafficable in spots. There is a recreation field beyond.

SITE 12

Contour map of site 12.



Aerial photo of site 12. Note how the island's size diminished from the time of the contour map to the time the photo was taken. There was no island evident when we did on-site inspections, just a shallow spot in river where the island used to be.

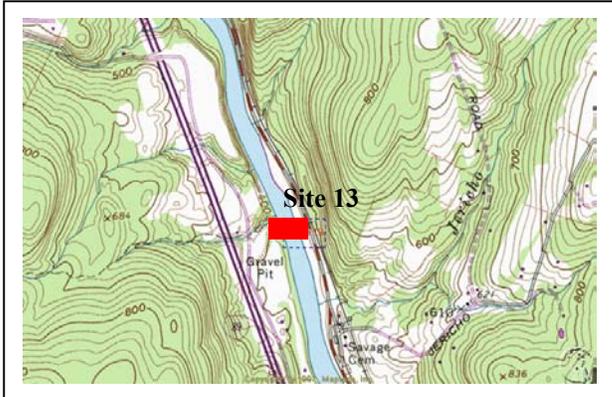


West bank of site 12. It is too steep to traffic.

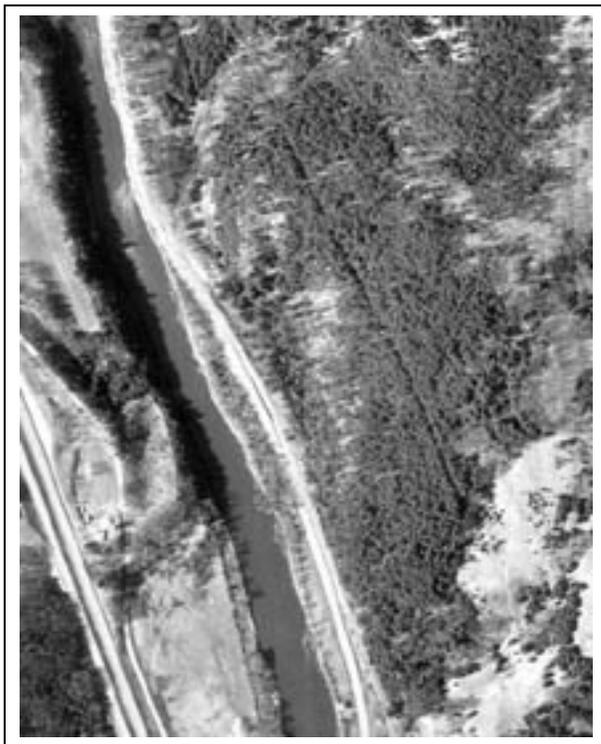


East bank of site 12. It is too steep to traffic – 90° in spots.

SITE 13



Contour map of site 13.



Aerial photo of site 13.



West bank of site 13. There is a steep hill covered with trees.



East bank of site 13. There is a low-slope initial bank, but a secondary bank hidden by trees is 8 to 10 ft high and near 90°.

In the imagery, site 13 looked flat near the river.

SITE 14

Contour map of site 14.



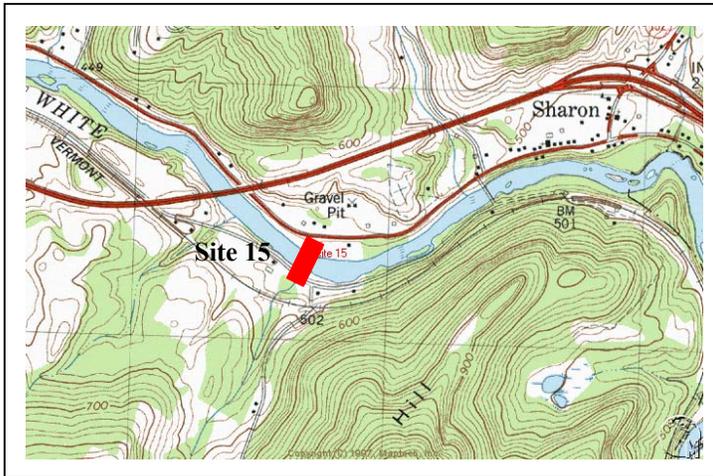
Aerial photo of site 14, which was chosen as a possible AVL B site but proved to be too wide. There is a large amount of ledge outcroppings in the water that are not evident in the aerial photo.



**West bank of site
14.**



**East bank of site
14.**

SITE 15

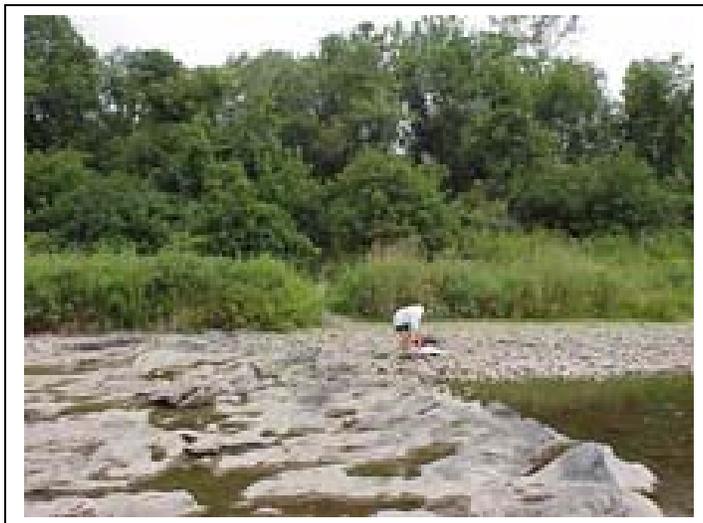
Contour map of site 15.



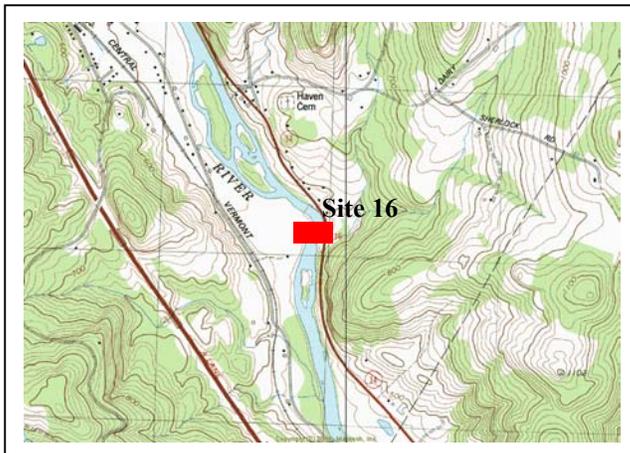
Aerial photo of site 15. The site was chosen as a possible AVLB site, but it is too wide.



West bank of site 15. The initial slope is trafficable, but there is a secondary bank about 8 to 10 ft high and almost 90° leading to a road at top that cannot be negotiated.



East bank of site 15. The bank is about a 20° slope and looks trafficable.

SITE 16

Contour map of site 16.



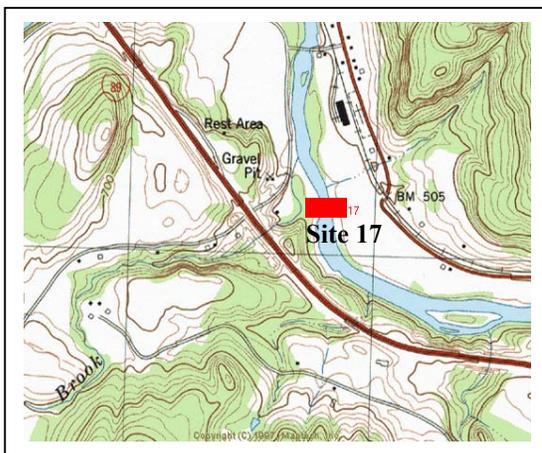
Aerial photo of site 16,
which was chosen as a
possible raft site.



West bank of site 16. It has a good low-slope approach.



East bank of site 16. The bank is not trafficable; it is approximately 15 ft high and very steep, leading to a road at the top.

SITE 17

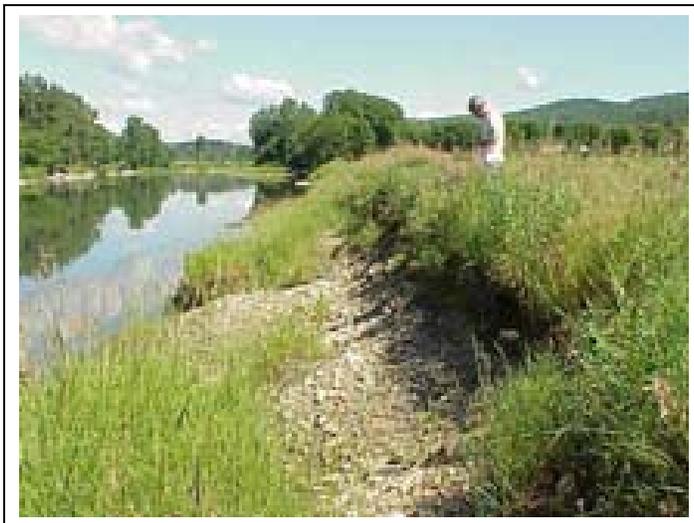
Contour map of site 17.



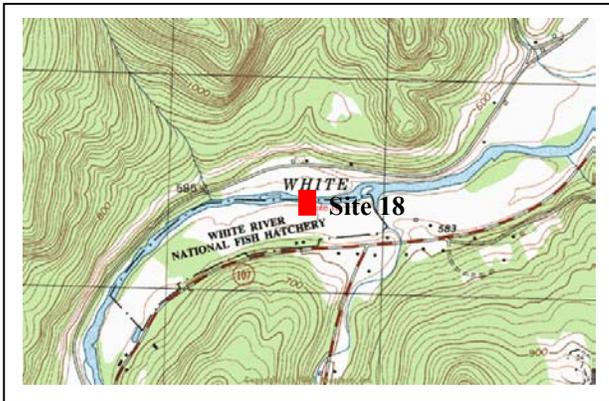
**Aerial photo of site 17.
The site was initially
chose as a possible
AVLB site, but it was too
wide.**



West bank of site 17. The bank starts nearly flat at the water, increases slope to about 19°, then flattens to about 10° with a total height of about 9 ft.



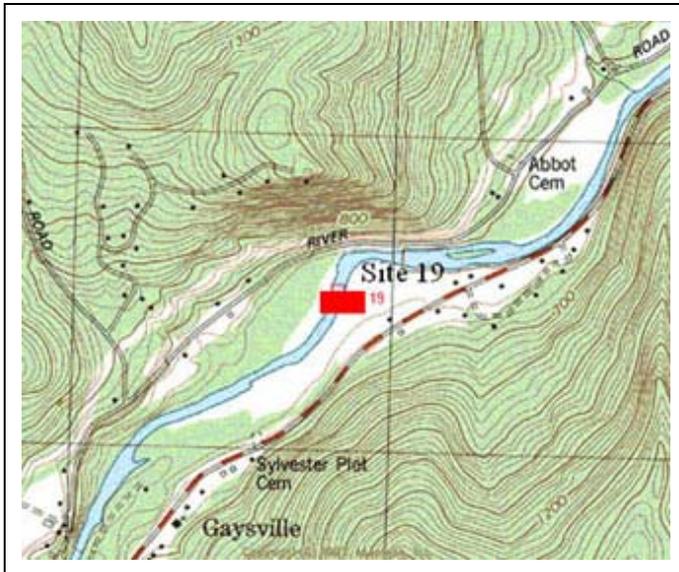
East banks of site 17. The bank is 8 to 10 ft high with some portions 90° at the top.

SITE 18**Contour map of site 18.****Aerial photo of site 18.****West bank of site 18. The land leads into the water with no abrupt bank. The bank has a 24° slope in spots.**



East bank of site 18. The land leads into the water with no abrupt bank. This bank is approximately 20°.

The east and west banks look trafficable, but there could be marginal traction with the cobble and slope combination.

SITE 19

**Contour map of site
19.**



**Aerial photo of site
19.**



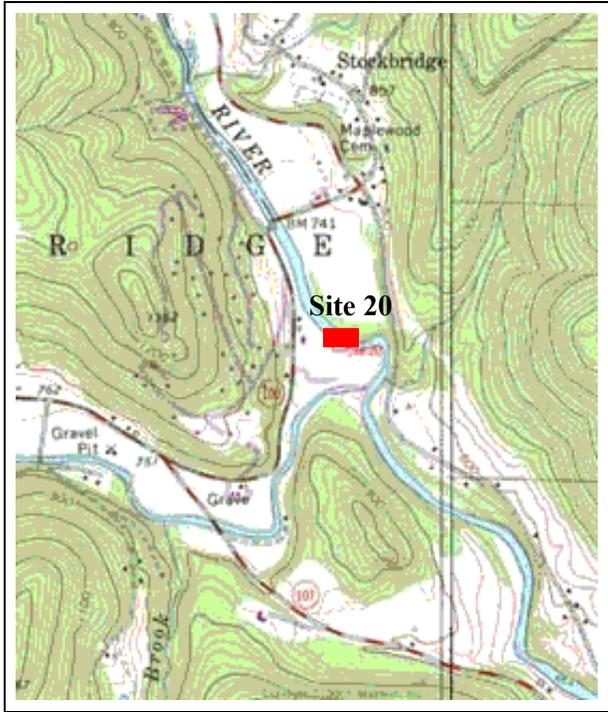
West bank of site 19.



East bank of site 19.

Both slopes at site 19 look below 10° , with lots of cobble. The banks near the river look trafficable, but the terrain away from the river is very steep and forested.

SITE 20



Contour map of site 20.



Aerial photo of site 20.



West bank of site 20 looking north. The initial slope out of the water is trafficable, but the bank has a secondary slope 5 to ft high near 90°.



West bank of site 20 looking south. The initial slope out of the water is trafficable, but the bank has a secondary slope 5 to ft high near 90°.



East bank of site 20 looking north. The bank is trafficable with an initial low slope out of the water, then a 1- to 2-ft-high secondary bank and level beyond.



East bank of site 20, looking just south of the shot above. The bank is trafficable with an initial low slope out of the water, then a 1- to 2-ft-high secondary bank and level beyond.

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14. ABSTRACT Remote analysis of terrain features is invaluable to military units. Prior knowledge of the maneuver geography can be a great force multiplier, allowing accurate forward planning for force projection and placement of assets. The common tools of the Army Terrain Team analyst include geographical contour maps, usually with the best contour interval being 20 ft, and aerial imagery, both visible and infrared. Together, these offer good general information about the terrain adequate for large-scale movement and placement of forces. However, the execution of a river crossing requires detailed knowledge of the topography immediate to the river. Vertical and horizontal resolutions of 1 to 2 ft are necessary, based upon vehicle vertical step and slope negotiation capabilities. This study looks at the capability of the terrain analyst to accurately determine suitable river crossing sites based upon our current remote assessment tools. The 66th Engineer Detachment, Fort Drum Terrain Team, remotely studied 121 miles of river in Vermont and New Hampshire using available contour maps and aerial imagery for suitable crossing locations. The study areas were then inspected on-site to assess the actual suitability of the selected crossing locations. There was a 16% overall success rate for remotely determining bridging/fording sites. The predominant factor in site rejection was the vertical height and/or slope of the riverbanks.						
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