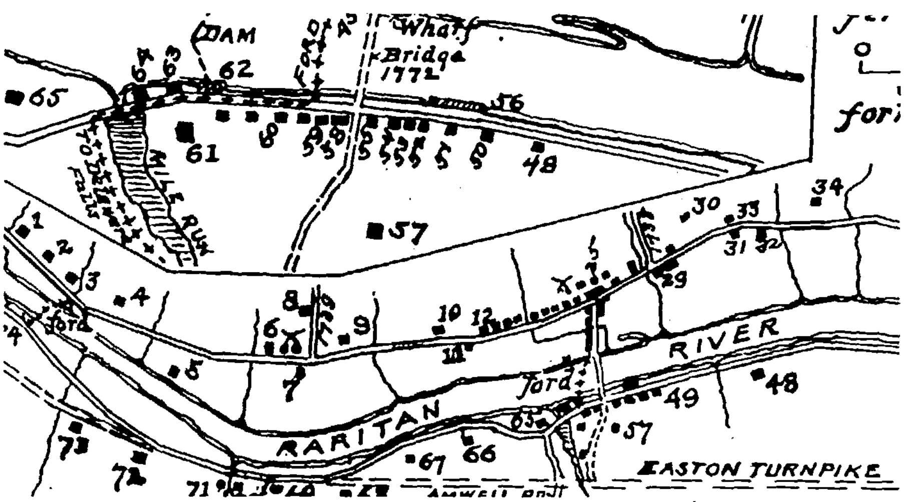
Defining Boundaries and Targeting Excavation with Ground-Penetrating Radar: The Case of Raritan Landing



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In the United States over the last decade, archaeology has become an integrated aspect of large scale and long term environmental study and planning requiring the application of new techniques and approaches to achieve sufficient definition, clarity, and efficiency to meet the decision-making needs of engineers and planners. Although cultural resource management and planning is often perceived as a clash or choice between preservation and progress, the real difficulty stems not

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from any inherent conflict, but instead generally from a lack of information concerning the resources themselves. Difficulties can arise from inadequacies in planning, or from ambiguities as to the nature, extent, or significance of specific prehistoric or historic sites. The following case illustrates the application of advanced technology to overcome the limitations of traditional approaches to the identification, evaluation, and documentation of an archaeological site faced with immediate destruction.

In recognition of the potential destruction of archaeological sites due to our ongoing mining, transportation, and water reclamation programs, a series of new federal and state laws and guidelines mandate that all federally funded or licensed programs take account of cultural resources so as to reduce or avoid loss of these nonrenewable records of our past. Specifically, the National Environmental Policy Act of 1969 (NEPA) and the procedures of the Advisory Council on Historic Preservation call for the evaluation of archaeological resources in terms of the criteria for significance of the National Register of Historic Places. No longer is significance, both in legal and in public perception, based on the aesthetic quality or marketability of artifacts, but instead it is based on current legal and social science perspectives of the relative uniqueness of the physical record and on its potential for providing previously unavailable information on the history or prehistory of a region.

When recognized and evaluated early in the preconstruction phase of a project, the identification of a National Register-eligible archaeological site seldom creates a problem for planners. Instead, once defined in extent and eligibility, it is, as a matter of course, factored into the design process as would be an endangered species, sensitive wetlands habitat, or feature of slope or topography. Although the process sounds tidy on paper, as any official ever involved with the belated discovery of a National Register-eligible archaeological resource in the midst of an ongoing regional water stabilization program knows, the problems posed may be both varied and difficult. The project may be essential for people's health and well-being; it may cost substantial sums to temporarily halt or delay construction; political and financial pressures to ignore or downplay the resources may be considerable; local geography and limitations in information may severely restrict the range of engineering alternatives; traditional archaeological techniques may be inadequate to quickly define or excavate the site in a feasible time frame; the unexpected site may affect other planned projects, thereby involving a broad spectrum of pressures from special interest groups beyond those concerned with the immediate construction project; and finally the legal, scientific, and ethical pressures on the archaeologist to do justice to the site may be equally intense.

Traditionally, the identification of and decisions about the extent and significance of archaeological resources have been based on a combination of researching published accounts and historical documents, and selective test excavations. Five or ten years ago it was not uncommon for archaeological surveys to be limited to fast "walkovers." However, both archaeologists and planners have begun to recognize that biased assumptions, limitations in background information, and inadequacies in accepted field techniques often result in unrecognized sites and information inadequate for well-founded planning and design decisions.

In some regions of the United States, such as the wooded Northeast, extensive ground cover and the depth of man-made landfills have often obscured even large and significant buried archaeological remains from early detection or easy definition and evaluation. As a result, the untimely discovery of a deeply buried archaeological resource in the path of an ongoing construction project may overtax available field or documentary methods, or may prove them to be inadequate for fast problem resolution. While limited subsurface probes or available historical records often suffice to identify the nature and significance of the resource, neither method may be adequate to define the extent, boundaries, or internal variation and relative complexity of a large and deeply buried site. Without these latter categories of information, it is difficult, if not impossible, for the engineer to determine where and how a project should be continued to produce the minimal impact on a significant archaeological resource, as mandated by law. At the same time, without such information, it is equally difficult for the archaeologists to develop an appropriate data recovery or excavation program sufficient to document the range and quantities of cultural information which might be unavoidably lost during construction.

In a recent case in a grass-covered park along the flood plain of the Raritan River in coastal New Jersey, the unexpected discovery of a deeply buried Colonial and Revolutionary port community required the interruption of the nearly completed construction of the last 500 foot link of a 30 mile long sewer force main system funded by the U.S. Environmental Protection Agency. Pressures of time and money and the limitations of traditional archaeological field techniques and documentary sources provided the incentive to apply a new generation of ground-penetrating radar to quickly and accurately define the boundaries and internal complexity of the buried settlement. The enhanced definition provided by the resultant subsurface radar map permitted the engineers to design a minimally destructive construction corridor, and provided the archaeologist with a concrete basis for developing a high speed, target-specific, data recovery excavation program, sufficient to document the range and complexity of information unavoidably lost during construction. Although the site is still under analysis, the combined engineering and archaeological mitigation solution has already demonstrated the problem-solving capabilities of this remote sensing technology to meet the mandates of environmental protection legislation with a minimum of delay and resulting expense.

Raritan Landing As An Archaeological Resource

In the winter of 1978, the U.S. Environmental Protection Agency (USEPA), Region II, was notified by the New Jersey State Museum that ongoing construction by the Middlesex County Sewerage Authority was about to cut through potentially significant archaeological and historical remains located in Johnson Park, Piscataway, New Jersey. In fact machines cutting the trench in which a sewer main was to be laid had advanced to 500 feet on either edge of an important historical site, Raritan Landing.

The historic significance of this community had been first brought to light in the 1920s and 1930s by a Rutgers University geologist and cartographer, Cornelius C. Vermeule (1924, 1928, 1936). According to Vermeule, the Landing began between 1712 and 1720 as two clusters of warehouses, one located next to the river at the south end of Landing Lane and the other at the intersection of the "Great Road" (now River Road) and Landing Lane (Figure 1). By the time of the American Revolution, the Landing was a thriving business community, with at least 57 resident families, two mills, and several large warehouses stretching along the Lane between the river and the larger road. During the Revolution several skirmishes took place at Raritan Landing; portions of the settlement were burned and looted. Commercial activities were suspended during the war and not resumed until about 1790. Developments in transportation at the turn of the century, however, led to the eclipse of the Landing by New Brunswick; the Delaware-Raritan Canal, completed in the 1830s and the railroad in the 1860s, bypassed Raritan Landing. The settlement was abandoned and dismantled by the 1870s.

Based on the earlier writings of Vermeule, particularly in such statements as "... green grass and cattle grazed over the site of Raritan Landing" (1936, p.115), many people assumed that the physical traces of the settlement had long since disappeared. However, the settlement reemerged as an archaeological entity in 1977 as a consequence of an environmental assessment of a proposed bridge replacement at the Landing, done under the direction of Dr. Susan Ferguson for the New Jersey Department of Transportation (NJDOT). These initial subsurface tests revealed the presence of buried historic remains near the river under a one or two foot cap of fill material. Immediately following its initial definition as a possible resource, the site faced impending destruction from three large scale construction projects: a possible bridge, a large highway interchange, and, most immediately, from the ongoing construction of a USEPA-funded 100 million dollar force main system along the river drainage. Although two earlier visual and pedestrian surveys of the proposed sewer route had yielded negative results, the NJDOT subsurface probes towards the river suggested that additional subsurface testing might be warranted. Despite the ongoing construction of this 30 mile long sewer force main, the USEPA, Region II, based on the alert by the New Jersey State Museum that potentially significant archaeological resources might be endangered, requested that the Rutgers Archaeological Survey Office conduct additional tests in the proposed construction right of way.

The purpose of the initial Rutgers field investigations was first to verify the existence of remains in this sector, and second to evaluate their eligibility for nomination to the National Register of Historic Places. The actual pipe laying was nearing completion with two segments, approaching from the north and south, that were to be joined precisely at the northern end of the I-shaped settlement. Because of the rapidly advancing 40 foot wide trenching operations (the machines were 500 feet to the north and south, the archaeological testing had to be completed immediately despite winter weather. An accumulation of 18 inches of snow and ice lay on the ground, temperatures hovered around 20 degrees, and subsurface freezing extended to between 18 and 24 inches below grade.

Overlaying Vermeule's 1936 schematic of Raritan Landing (Fig. 1) onto the construction plans, suggested the general areas thought to contain historic architecture. Because of the frozen soil conditions, a backhoe—in fact, several, as the first few broke—was used to cut a series of five test trenches on either side of the historic roadway. The four trenches on the downriver side revealed the four walls of an L-shaped warehouse (Figure 1, #37) and two strata of primary occupation refuse

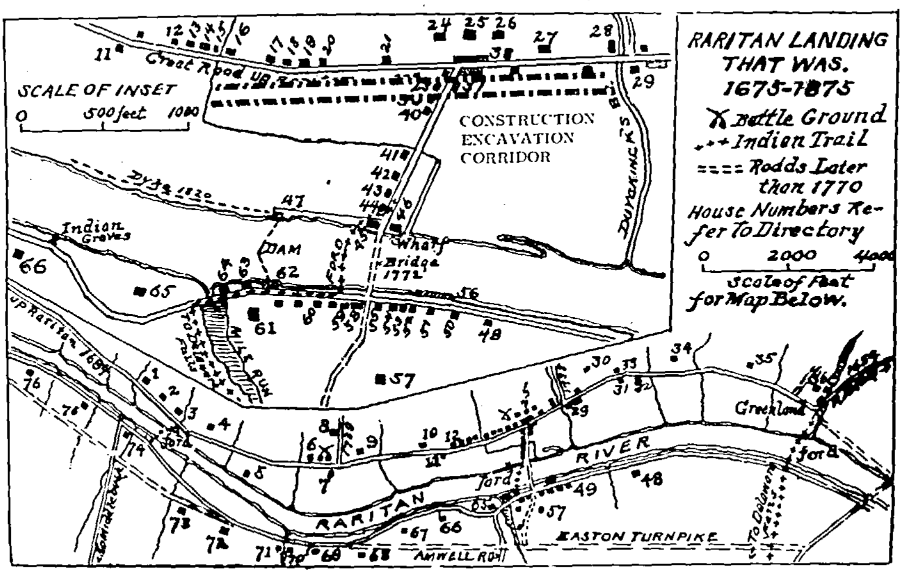

Figure 1 This schematic of Raritan Landing was drawn in 1936 by Cornelius C. Vermeule, a geologist and cartographer from Rutgers University.

under a postoccupation layer of rubble, both sealed and capped by 18 inches of modern fill. However, the historic remains on the opposite upriver side were a bit more difficult to define (Figure 1, #23). Initial backhoe cuts showed the same modern surface overburden, but under it was a bedrock-like deposit of compact shale rock. After repeated attempts to cut through the frozen rock, this apparent bedrock turned out to be historic fill. The backhoe cut revealed four stratigraphic levels of historic remains sealed under three and a half feet of fill and extending to six feet below the surface (Fig. 2).

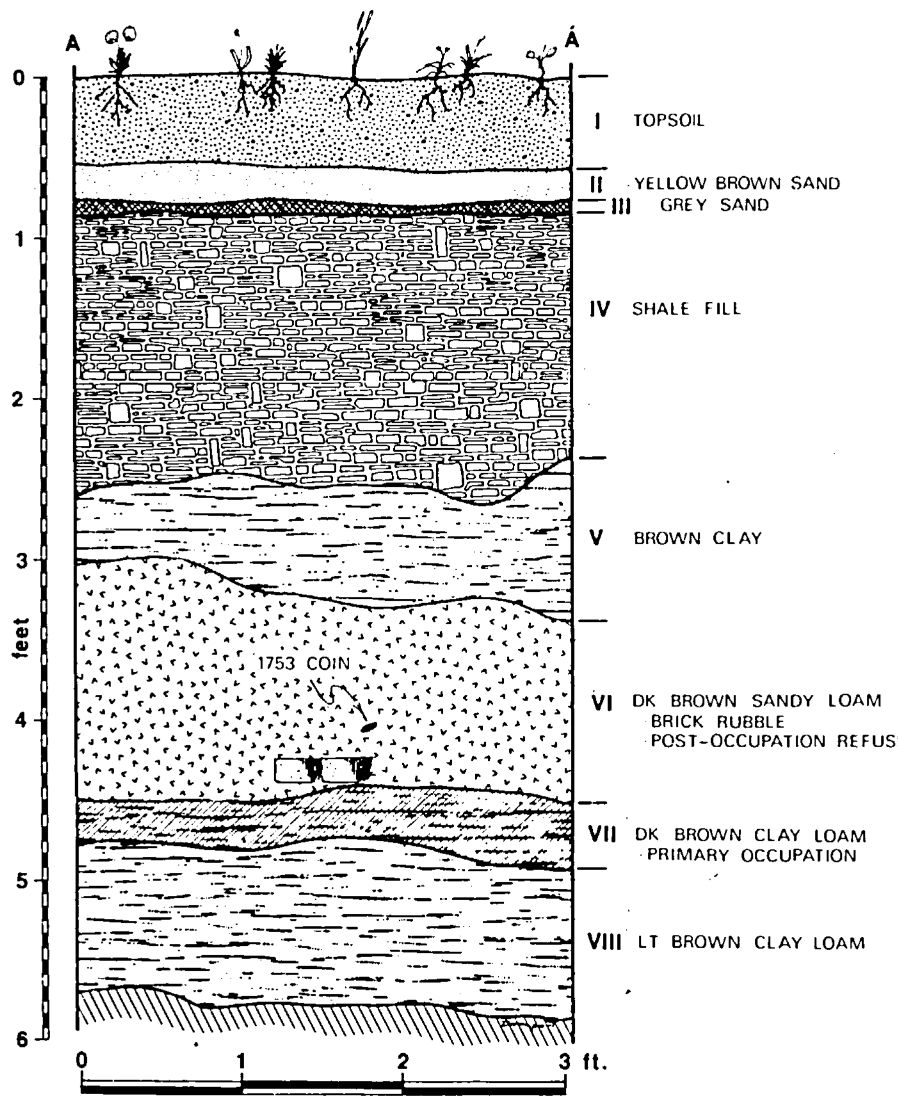

Figure 2 A section profile of a deep backhoe cut shows the multicomponent historic strata sealed beneath 2 feet of shale.

Wall alignments were discovered undisturbed. In addition, a one cubic yard sample of screened cultural refuse yielded a total of 1,600 artifacts. Datable ceramics (Fig. 3) spanned the 18th and 19th centuries, the known period of peak commercial activity at the Landing. The cultural materials reflected a wide range of activities and included large quantities of well-preserved remains of eating utensils, buttons, thimbles, early nails, a 1753 British coin and a 1788 Connecticut coin, and finally a gentleman's cuff links. Wood, leather, food, and plant remains were perfectly preserved. From the perspective of its stratigraphic integrity and diversified remains, the stratigraphic layer cake of the 18th century port community of Raritan Landing represented a sealed environmental time capsule of regional economic history.

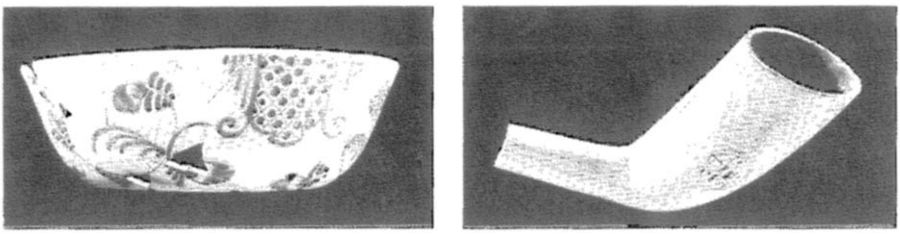

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Figure 3

These ceramics were among the 1,600 artifacts discovered after a one cubic yard sample of cultural refuse was screened. Shown here are an imported 18th century pipe bowl with datable marks of the British maker and a reconstructed "Delft" tin-enamelled earthenware bowl from the pre-Revolutionary levels of strata.

The initial field tests by the NJDOT in 1977 and the more recent probes by the Rutgers Archaeological Survey Office showed a widely spaced distribution of buried historic remains, but these tests threw little light on the extent and density of the buried settlement; little could be said of the boundaries or range of activities reflected by the scattered subsurface remains. Furthermore, the cap of rock shale overburden restricted the feasibility of traditional archaeological testing techniques over such an extensive area. The delicacy of the artifacts further suggested that additional cuts might result in more damage than information.

During the two weeks that followed, the U.S. Department of the Interior declared the site eligible for inclusion in the National Register, and concurrently New Jersey's Department of Environmental Protection (NJDEP) and the USEPA directed the engineers and Sewerage Authority to develop a mitigation program which would facilitate continued construction with a minimum of loss to the site. Although federal and state agencies avoided delays through the mechanism of a speedy "consensus agreement" on the site's significance and National Register *eligibility*, both *formal nomination* to the Register and an adequate mitigation plan required a sound definition of the nature and limits of the site (see Vetter and Coleates 1980). For both the engineer and the archaeologist it was essential to develop a better understanding of the boundaries and internal composition of the site. Without a control of the thickness, complexity, and relative density of the buried remains, the engineer could not decide what to avoid or where the route of least destruction might lie. Without the same information, the archaeologist could not define a realistic time schedule or excavation strategy. The problems were easily defined for both, What were the actual subsurface boundaries, and what was the relative density of archaeological remains within the impending 500 foot construction corridor? Unfortunately the answers were less readily apparent. It was at this point that the limits of traditionally available methods became critically apparent.

The earlier documentary and map reconstruction by Vermeule in the 1930s (Fig. 1) indicated only the approximate location of the primary residences of the more important inhabitants of Raritan Landing. The settlement was clearly a center of diversified activities, but what these were and where they took place was unknown. An intensive investigation into all available property deeds by Richard Porter, a graduate student in history at Rutgers, permitted the definition of some 18th century property boundaries, identified the location of several previously unnoticed residences and structures, and filled in an apparent gap on Vermeule's map with several dwellings and businesses (Fig. 4) unknown to Vermeule. The apparent existence of these structures precluded the design of a bypass. Despite these added insights,

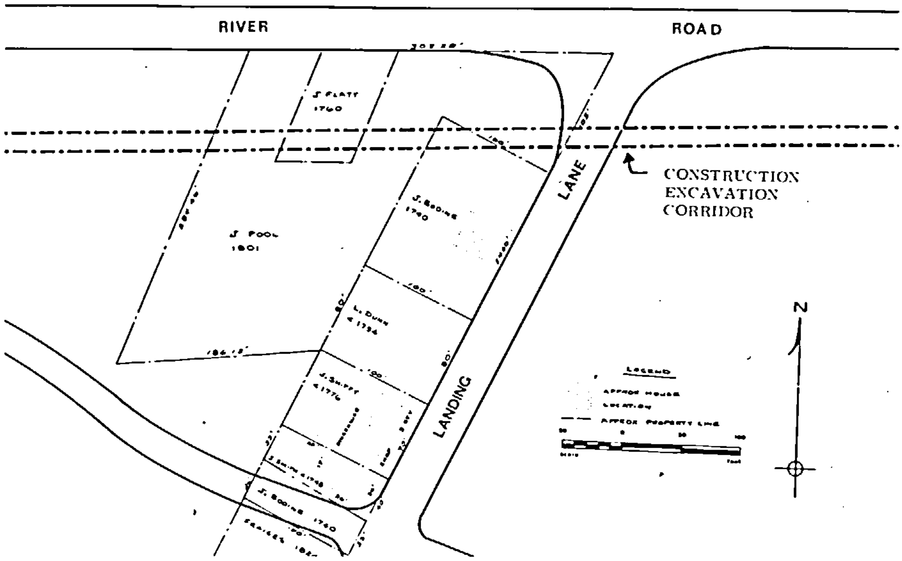

Figure 4 A recent search through property deeds filled in some apparent gaps in Vermeule's 1936 map of Raritan Landing, but there were still unexplained voids, most notably in the area of the historic intersection and the proposed construction.

the resultant map of known structures and property boundaries still showed large gaps, especially in the areas of the primary concentration of businesses and warehouses, where such voids would be least likely within an historic settlement of this magnitude of economic activity.

Thus, the available primary documentary sources could not and did not yield a sufficiently refined level of resolution to provide a basis for decision making for either the agencies or archaeologists involved. The documents did not show the location of secondary businesses or structures, nonresidential work or activity areas, or any of the other features which complete the inventory of known or expected historic archaeological features. Another problem with the documentary sources was that property boundaries were described in relation to the riverbank and to the location of the historic road alignments. Both Landing Lane and River Road have shifted between 20 and 30 feet in either direction since the 18th century, and the Raritan River has also changed its course. Thus, the documentary reconstruction of property boundaries varied in accuracy from 50 to 100 feet from the present reality. In other words, the traditionally available techniques and sources of information were inadequate to meet the legal requirements.

The problem was well defined: how to make a map of the buried historic settlement without having to cut through its cap of rock shale fill. Optical systems were obviously inadequate for the rock: repeated experiments with a Cezium Magnetometer by Dr. Eric Christofferson, a geophysicist at Rutgers, showed that the heavy modern traffic flow around the site area would overwhelm the magnetic sensitivity of his unit.

The potential applicability of ground-penetrating radar was brought to my attention several years before by my colleague, Bruce Bevan of Geosight, Pitman, New Jersey. Over the past ten years low frequency subsurface radar systems, operating generally between 50 and 150 MHz had been applied to a variety of engineering and geological problems. This early generation of radar equipment could shoot a low frequency signal to considerable depths under ideal conditions, but was not suited to resolution near the surface. Ground-penetrating radar was used to detect ice-filled cavities in the permafrost during the construction of the Alaskan pipeline; to detect unmapped utility lines and pipes in urban construction projects; by oil companies to determine if arctic ice sheets were thick enough to support heavy drilling rigs; by NASA for the Apollo lunar system; and recent airborne versions were being tested by the National Science Foundation and the Scott Polar Research Institute to map more than a million miles of Antarctica (Rosetta 1977; Porcello 1974). The potential applicability of this remote-sensing technology to problems in archaeology was demonstrated when Bevan and colleagues at the University of Pennsylvania detected the location and depth of a buried historic wall in Philadelphia (Bevan and Kenyon 1975). About the same time, feasibility studies conducted by Roger Vickers of the Stanford Research Center in conjunction with the Remote Sensing Division of the National Park Service, successfully detected Pueblo buildings buried 1 to 4 meters deep at the Chaco Canyon archaeological complex in New Mexico (Vickers, Dolphin, and Johnson 1976).

However, only in the last few years had a higher frequency, 300 Mhz, antenna become available which was baffled against near-surface static, or "ringback," and refined enough in resolution to be useful at common archaeological depths (between circa 5 inches and 5 feet). Bevan not only suggested that the newer equipment might work in this situation, but raised the possibility of using a new generation of radar then under development by Geophysical Survey Systems (GSS), of New Hampshire. This commercial system, although still in a preproduction wooden box, promised both sufficient penetration and high enough resolution to address the problem at hand. Because of the availability of this equipment, and because there didn't appear to be an alternative, the engineers and I, as the principal archaeologist, decided to use the radar as a basis for providing sufficient information to meet the needs of a well-founded archaeological and engineering plan.

Ground-penetrating radar operates electronically in much the same way that sonar waves record ocean bottom contours through water. For the archaeologist, the difference between the two systems is that the radar signals record a number of superimposed layers and objects in the ground. Multicomponent sites such as Raritan Landing consist of superimposed strata–old surfaces and layers of fill. When the radar signal reflects off some buried feature, e.g., a mound of rubble or a pit, it records an elevation in the first case and a depression relative to

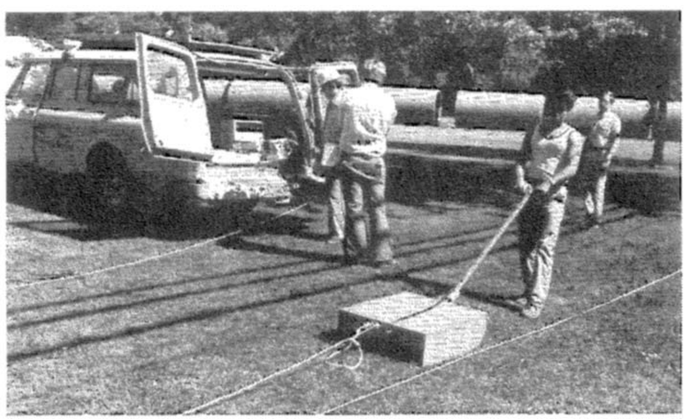

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Figure 5 A 300 MHz antenna developed by Geophysical Survey Systems of New Hampshire became the basis for providing sufficient information about the buried historic settlement to allow engineers and archaeologists to come up with a mitigation plan for continued construction with a minimum of damage to the site. As the radar unit is pulled along a known and measured datum line, it is able to detect a series of buried layers as well as any subsurface anomalies protruding above and below each surface.

a buried surface in the second. Generated in a billionth of a second, rapid radar pulses are constantly being sent and received by the antenna as it moves across the ground surface (Fig. 5). Even when the antenna is being moved it is able to detect a series of buried surfaces as well as any subsurface anomalies protruding above and below each surface. As the antenna is pulled along a known and measured datum line, a computer attached to the radar unit produces a profile printout showing vertical changes in the height across a series of buried superimposed surfaces (Fig. 6). Changes in subsurface stratigraphy can then be plotted with symbols for various echo depths along any given datum line of a site grid (Hranicky 1977; Morey and Harrington 1972; Porcello 1974; Rosetta 1977; Vickers, Dolphin, and Johnson 1976).

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Figure 6 A computer attached to the radar unit produces a profile printout showing vertical changes in the height across a series of buried superimposed surfaces. Here Bruce Bevan scans the radar profiles.

The Radar Survey of Raritan Landing

The primary objective of the application of the radar was to define the boundaries of the site by determining the nature and extent of the buried historic remains. In addition, the radar survey was undertaken to assess the relative density of cultural features in relation to the location of existing and proposed construction alignments through the district.

The subsurface radar survey was conducted over an 11 day period in June 1978 by two members of GSS, in consultation with Bevan, and with technical support from Emerson Frost, a specialist in radar theory and application. This radar team was backed up by an equal number of field archaeologists from the Rutgers Archaeological Survey Office, who provided locational control throughout.

Prior to the actual survey, approximately three-quarters of the site area was covered with an 800 by 500 foot grid system at 5 foot intervals, for a total distance of 10 miles. The spacing of scans at 5 foot intervals on both axes guaranteed that a buried 20 by 40 foot historic foundation would be hit by at least 12 scans—4 in one direction, 8 in another.

Several aspects of radar technology presented special problems at Raritan Landing. The first problem was the rate and depth of pulse penetration under the specific conditions. Basically, could the radar "see" through the rock? The solution to this issue hinged upon two variables (1) the makeup of the fill material, and (2) the presence and concentrations of dissolved salts in the site matrix (Morey 1974; Vickers, Dolphin, and Johnson 1976). The GSS staff had completed some comparative studies of differential penetration in a small range of soil conditions. The radar was shown to penetrate to a depth of 230 feet through an arctic ice shelf, to at least 75 feet in free water-saturated sands of the Massachusetts glacial till, but only to "... five feet in wet clay and less than a foot in sea water" (Morey 1974, p. 223). However, the radar system had not been tested through shale rock fill nor through a series of multicomponent shale and clay fill strata, the situation at Raritan Landing.

An additional problem at the site was presented by the high concentrations of salt, presumably from years of winter deicing operations on the adjacent roadways. The effective penetration depth in any particular area is a function not only of the equipment involved and the parent material, but also of soil conductivity which, in turn, is largely determined by the amount of ions in solution (Morey 1974). The higher the concentration of dissolved salts at a site, the less effective is the ability of the radar to penetrate. Resistivity measurements by Bevan showed that even in the higher and drier portions of the Raritan Landing site, the soil was sufficiently ionized to significantly restrict or attenuate the effective penetration of the radar scans. Instead of the anticipated 6 to 8 foot penetration, the signal appeared to reach only between 3 and 4 feet. This range was critically close to the depth needed to "see" the buried remains under the fill overburden. The high saline levels within 5 feet of the road edge created a virtual electronic shield against radar definition.

Actual calibration was mathematically resolved during the field surveys by Bevan. When the radar beam hits a point target it records a conical trail, much like that of a jet in the air or a ship in the water. Bevan utilized the fact that the shape and width of the echo trail is a function of the velocity of the beam on a point target. He selected a series of point targets in the area of deep fill and, by measuring the relative shape of the echo cones, was able to calibrate the actual depth of each point, and by extension the depths of other anomalies. He thus established that the radar beam velocity in the area of deep shale fill was 0.03 feet/nanosecond. Bevan's calculations showed that the effective penetration of the radar was no less than 3.8 feet or at least

45 inches into and through the shale fill. Based on these calibrations, it was assumed with some certainty that the radar was actually "seeing" at least the upper strata of buried remains beneath and through the shale fill.

Translation and interpretation of the radar data was made difficult by the fact that the radar represented a new visual language with its own vocabulary and rules, most of which still have to be learned. Once the radar scans from each 5 foot datum transect were printed out, matched and cross-coded from the magnetic tape code numbers to specific segments of the actual site grid, it was decided that the most accurate interpretation of the radar graphs could be accomplished through the joint efforts of the engineering staff of GSS and someone familiar with both the subsurface stratigraphy and the documentary evidence on the 18th century settlement. The project historian, Richard Porter, flew to New Hampshire, and in three days, he and Stan Porter, the GSS systems manager who had performed the actual scans, mapped and plotted 10 miles of radar profiles on the 1:10 scale site grid map (Fig. 7).

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Figure 7 — Once the printouts are available, changes in subsurface stratigraphy can be plotted with symbols for various echo depths along any given datum line of a site grid. Here Richard Porter transfers the coordinates of radar echoes onto the site grid system.

Only the most clearly discernible anomalies were plotted on the grid paper; apparent vertical differences of greater than 5 inches to 1 foot above or below an indicated horizontal stratigraphic interface were noted. The resultant radar map, therefore, reflected the location and extent of only the most pronounced features of subsurface stratigraphy. The overwhelming mass of depth information obtained from the graphs was translated into a six-color code that was intended to be comprehensible while reflecting the diversity and complexity of the information. Using the color code, a radar map was made which depicts buried deposits with three different patterns of line and color combinations:

1. zones or areas of parallel lines of one color, reflecting uniform depth along one axis of the grid;
2. intersecting lines of one color within a bounded area, reflecting a common depth along both grid axes; and
3. intersecting lines of various colors within a bounded area, showing different depths along both grid axes. (See Fig. 8)

The first pattern of parallel lines on only one axis is difficult to interpret. It may be due to the uneven conical form of the radar beam which presents a datum axis that is longer than it is wide. Frost suggested that this characteristic of the radar beam could result in a subsurface anomaly being detected in one direction of the grid but not in the other.

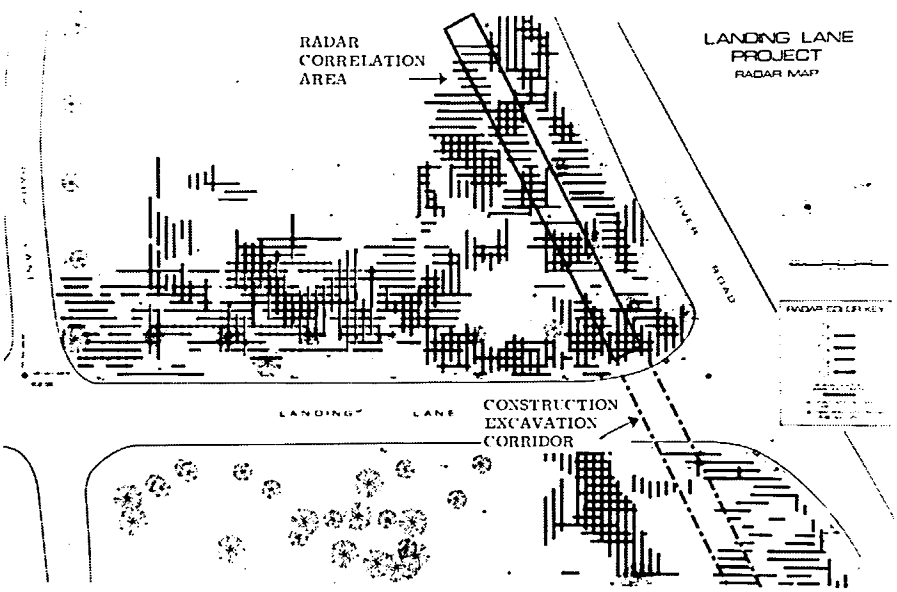

Figure 8 Eventually the overwhelming mass of depth information plotted on grids was translated into a six-color code. The use of color enabled the visual separation of overlapping echo patterns of differing depths. This is a black and white rendition of the resulting polychrome radar map, showing the boundaries and stratigraphic complexity of buried historic remains.

The second and third patterns are less obscure. The second pattern of bounded or enclosed intersecting lines of uniform echo depth were interpreted as all four sides of a continuous subsurface feature. Such a pattern could result from a pit or a raised pile of rubble from a fallen structure. Even originally rectilinear buildings are generally demarcated by an uneven pile of rubble prior to excavation and cleaning. Nevertheless, many of the color patterns on the radar map appeared in form and uniformity of depth and size to suggest probable structures.

The third pattern of intersecting lines of various depth readings within a bounded area can reasonably be interpreted as layers or surfaces of rubble, floors, or fill deposits, commonly encountered within the structural remains of an historic archaeological site.

Information derived from the radar field investigation provided a quantum jump in the knowledge of the nature and extent of subsurface remains present at Raritan Landing. The radar probe identified a density and extent of subsurface remains that had not been indicated in Vermeule's records or in documentary research (Figs. 1, 4, and 8). This previously unavailable information provided a basis for defining the limits and relative densities of the buried historic remains (Grossman 1978), and thus met NEPA's mandate that the loss of a significant archaeological resource through construction be minimized by a joint process of redesign and data recovery of unavoidably destroyed areas.

Mitigation

Based on the level of definition provided by the radar map, a mitigation plan was developed by USEPA and NJDEP in conjunction with the engineering company that was laying the sewer. The mitigation plan combined the redesign of the impact corridor to reduce site destruction with archaeological data recovery within the area of unavoidable negative impacts. Instead of a 40 foot wide open cut through the archaeological district, the sewer construction was confined to a 15 foot wide corridor walled in steel and wood to prevent damage to adjacent remains (Fig. 9).

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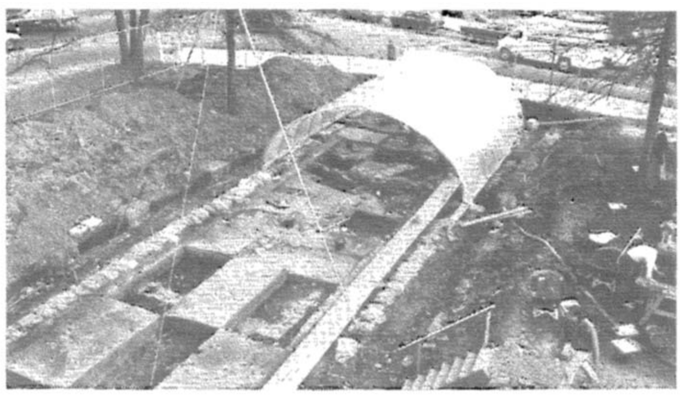

Figure 9

The mitigation plan for laying sewer with the least damage to the historic site called for a 15 foot corridor walled in steel and wood, rather than the originally proposed 40 foot wide open cut. Three 30 foot long, custom-built greenhouse units on movable skids permitted continuous, all-weather excavation in the construction corridor. An overhead bipod camera system (at left) was used to record stereoscopic and photomosaic records as each surface was exposed.

Given the level of complexity indicated by the radar, and the projected density suggested by the initial backhoe cuts, it appeared likely that an excavation using traditional techniques would require six months to a year to complete. Unfortunately construction had to be completed long before then and the archaeologists were requested to prepare a data recovery program of no more than two months in duration. Accordingly, new field procedures were applied by the Rutgers Archaeological Survey Office to document the range and variation of the archaeological remains, and new approaches were applied to enhance the speed, precision, and breadth of the data recovery process.

All distance and elevation measures were made with an electronic infrared transit that could store in memory the vertical and horizontal measurements with a high speed precision of 1/10 of a foot. The use of on-site computer terminals in conjunction with computer-compatible taxonomy developed by the National Capital Team of the National Park Service Denver Service Center permitted the entry of the identity, amount, weight, and location of all recovered artifacts for instant feedback and decision making. Instead of manually drawing artifact patterns or structural features, a RASO-designed self-leveling overhead camera bipod system continuously recorded overhead stereoscopic and photomosaic records as each level or surface was exposed. (Fig. 9). In addition to documenting the complexity of the excavated cultural remains, the precision of the data processing and measurement system also provided a sound basis for evaluating and correlating the radar echo patterns with specific areas or artifact clusters within the buried site.

The Excavation Results

The controlled archaeological excavation revealed undisturbed vertical and horizontal stratigraphy on both sides of Landing Lane. A layer cake of eight distinct strata was exposed under the shale fill on the upriver side. Two living surfaces, each covered with accumulations of refuse and destruction debris, and each sealed by a layer of flood silt, were excavated. The two surfaces were separated by a thick deposit of gravel fill, apparently laid because of problems of wetness and flooding.

This clear, vertical record of changes through time was matched by pronounced contrasts in the spatial distribution, density, and character of cultural materials across the living surfaces. The earliest surface, dated from ceramics to the pre-Revolutionary 1720s-1730s period at the Landing, contained well-preserved *in situ* artifacts and foundations of two early buildings. The upper, apparently post-Revolutionary, surface showed similar horizontal variations in cultural materials as well as the foundation of a building which may have been a replacement for an earlier structure apparently destroyed during the Revolutionary War.

Using the computerized measurement and recording system, a total of 108,885 artifacts and cultural items had been washed, marked, coded, and entered into the computer data bank by early March 1980, two months after completion of fieldwork.

Preliminary Radar Correlations

As illustrated in Figure 10, the precision made possible by the electronic transit permitted the definition of even minor vertical and horizontal undulations across each of the buried surfaces. The applicability of the radar to this and similar situations was demonstrated as soon as the upper floodsilt surface, which sealed the deeper historic strata, was exposed. Before the archaeological work began the shale fill was stripped off the upriver portion of the excavation corridor with a backhoe. The exposure revealed a sharply undulating, silt-covered surface with vertical fluctuations of up to 3 feet. Four distinct mounds in the surface were visible. For the purposes of this discussion, each mound will be numbered, with mound number 1 beginning adjacent to Landing Lane, its peak at grid line 305 (Fig. 10). The crest of each mound ranged between 1 and 2 feet above the norm of the floodsilt surface, and beween 2 and 3 feet below modern grade. The intervening dips between each mound extended to between 3 and 3.5 feet below the modern surface. The range of variation in elevation overlapped the calculated depth penetration for the radar in this sector of the site. The radar signals penetrated down to the top of the silt cap covering the buried historic remains and reflected the gross changes in the subsurface stratigraphy defined by the four silt-capped mounds.

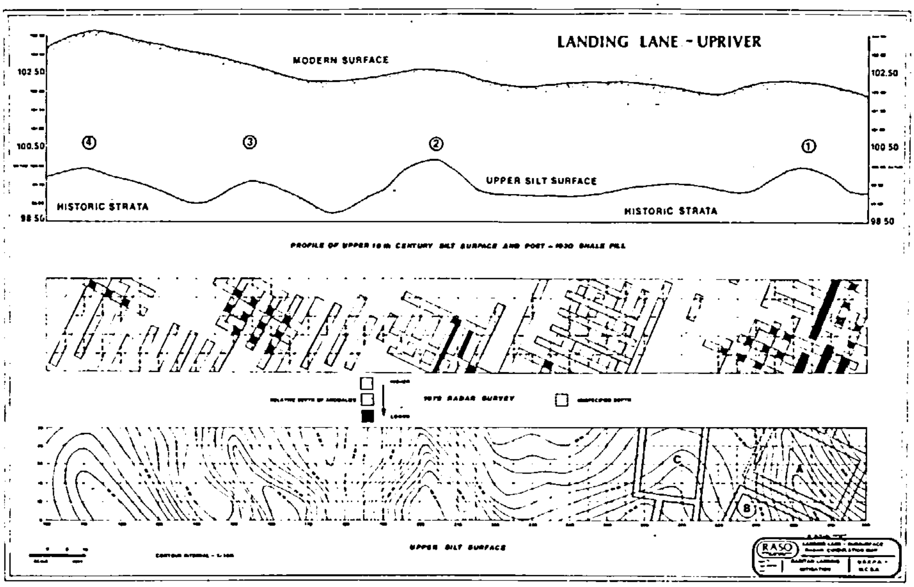

Figure 10 This radar correlation map shows the subsurface topography (bottom) and the vertically enhanced profile (top) of the uppermost historic stratum found under modern fill. The subsurface radar anomaly patterns (center) are shown to scale, overlaid on the 1979 excavation grid.

To facilitate comparison and reproduction, the polychrome color code, initially used to define the relative extent and stratigraphic complexity of buried remains over the entire site, was translated into black and white for the excavation trench (Figure 10). As with the earlier map, which covered the entire site, the anomaly patterns within the construction corridor have been scaled to reflect the approximate width of the radar signal along each of the original 5 foot grid lines. The extent of each band represents the length of either a rise, depression, or change in electrolytic properties relative to a buried surface. The 1978 survey in this area of the site recorded four different echo patterns. For most of the area the patterns suggested buried features, but of unclear relative depth. These patterns of unspecified depth are symbolized by parallel lines. However, for several areas within the impact corridor, the echo patterns along a grid line suggested clear differences in the relative depth of buried anomalies. These differences are here shown as shades of white and black. In Figure 10, near-surface echoes along a grid line are shown in white, medium depths are grey, and the deepest echo patterns are black. It should be noted that the alignment of the different echo patterns differs from that of the actual excavation grid. The original 1978 radar survey grid ran parallel to Landing Lane. The construction corridor and the excavation grid within it crossed the road at an angle. Despite their differing orientations, the location and extent of each radar pattern has been tied to the excavation grid with the electronic infrared transit to a precision of 0.10 feet in 500 feet.

Although detailed analysis of the internal site stratigraphy is only beginning at the time of writing, correlations are apparent between the radar patterns and the gross topography of the exposed silt surface. Four of the criss-crossing radar patterns directly match the location, extent, and surface contour of the mounds in the turn-of-the-century surface exposed during excavation. Even for the western end of the trench where preconstruction blasting had occurred prior to the site being declared eligible on the National Register, the equipment was able to define the subsurface contour with impressive resolution.

The first, third, fourth, and fifth radar patterns correlate with the raised topography of mounds 1, 2, 3, and 4 (Fig. 10). The first radar pattern, between 280 and 310 on the grid, showed overlapping hits of undefined depth covering a 50 by 25 foot strip of the exposed surface. Excavation next to the road revealed the destroyed remains of two buildings (Figure 10, structures A and B), one above the gravel and one below it. The uppermost structural remains lay immediately under the floodsilt cap of mound 1 and consisted of shale foundations covered by a dense concentration of fire-cracked stone from the collapsed structure. The earlier and deeper structural remains, building B, consisted of one corner of a substantially-constructed stone foundation filled with burned rubble and a concentrated brick debris.

The third radar anomaly, defined between 190 and 210 on the excavation grid, showed criss-crossing bands of white indicating relatively shallow echo readings, combined with two bands of deep signal scans. These predominantly high hit patterns correlated in both location and relative depth with a 3 foot high mound, 30 feet wide (Fig. 10, mound 2). A transect trench through this ridge revealed no buried architectural remains but did expose an interior deposit of gravel. The origin of this mound or ridge is as yet unclear. Samples are presently being studied by a geomorphologist. It may be natural, or it may represent the effect of deep blasting or of some unidentified historic activity. Regardless of its origin, both the location and the relative height of mound 2 were detected by the radar survey.

In the west end of the trench, and also in the zone of preconstruction blasting, two separate radar patterns showed circumscribed areas of intersecting echoes of unspecified depth. As suggested by both the microtopography, and by the enhanced profile of Figure 10, both radar anomalies correspond in shape and size with the topography of the upper silt surface. Throughout the area of blasting and directly behind the high mound, the subsurface stratigraphy was less distinctive and more homogeneous than that encountered closer to the road. Beneath the silt covering mounds 3 and 4 was an approximately 1 foot thick matrix of historic refuse consisting of a nearly uniform clay loam deposit. Mound 3 contained no architectural remains, and it appears that the radar was responding to the gross density differences between the clay loam and the overlying shale fill. However, the fourth mound did reveal a deposit of shale blocks, approximately 6 inches below the silt. Exposed in only one 5 by 10 foot excavation unit, this limited deposit of shale suggested the collapsed remains of a former wall immediately outside of the defined excavation corridor. Although this feature was not distinguished by the radar in the blast area, the radar did detect the raised topography of mound 4.

The consistent correlation of four out of the five radar patterns with each of the four subsurface mounds suggests that the electromagnetic signals were responding to the buried topography beneath the shale fill. In addition to these gross changes in subsurface stratigraphy, the radar also appears to have responded to more subtle aspects of the subsurface remains. One of the five patterns, the second from the road between mounds 1 and 2, does not correspond to any discernible discontinuity in the silt surface. The distinctive signature of this anomaly pattern suggests that the radar was reflecting one or several variables beneath the silt, apparently differences in the make-up and distribution of buried cultural materials.

This second radar pattern, between 220 and 265 on the excavation grid, defined an area of superimposed echo lines indicating various depths below the surface. One set of consistent echoes along both coordinates of the radar grid was at an unspecified depth. A second set of overlapping lines on the eastern side of the pattern indicated relatively deeper reflections. Overlaying these two configurations was a single line reflecting a relatively higher subsurface anomaly. The combinations of these patterns suggested buried multicomponent remains.

Excavation in this area revealed a horizontally and vertically diversified record of materials. At least two distinct, superimposed living surfaces were exposed, each with varying concentrations of architectural debris from two periods of occupation. While the second radar pattern corresponds in location with the extent of portions of each of these rubble concentrations, in neither case is the overlap sufficiently inclusive to warrant a direct correlation at this point.

Based on documentary research, at least one foundation had been expected next to Landing Lane. Excavation west of this area in the lowest pre-Revolutionary stratum, however, revealed another foundation, referred to as building C in Figure 10, which was not mentioned in the documents and did not appear on Vermeule's map reconstruction. This pre-Revolutionary stone and brick building had burned and apparently collapsed in place. Extending beyond the outlines of the stone foundation, the densely packed matrix of burned brick and mortar covered a 40 foot area between 245 and 280 on the grid, within the 15 foot wide corridor. While it is possible that the radar was responding to some unidentified structural elements of this buried component, the second radar pattern does not correlate well either with the foundation outline of building C or with the extent of its destruction debris. The deepest echo lines do correspond with the western wall of the building, but the lack of overlap elsewhere suggests that the echo patterns were probably reflecting higher contents of debris on the upper post-Revolutionary occupation surface above these structural remains.

The remains of building C were covered and separated from the later remains by an early floodsilt and then by a humanly-deposited layer of gravel fill. It was on this secondary gravel fill that the next occupation surface formed, and the subsequent refuse and architectural debris accumulated. Although no mound was formed on top of it, two spatially distinct concentrations of debris were evident. Near mound 1 the gravel surface was covered with a spread of brick dust and mortar. Towards the middle of the low area between mounds 1 and 2, the structural debris gave way to a predominantly clay loam matrix containing large quantities of artifacts and high concentrations of marine shells.

Shell and iron objects were densely represented in the upper strata in this area. The upper stratum contained over 68 kilograms of shell. The upper matrix also yielded in excess of 2,000 iron artifacts, over twice the amount encountered in the pre-Revolutionary stratum below. Although other comparable factors may be in operation, these densities alone suggest that the radar was responding in large part to the electrolytically sensitive ions derived from shell and iron concentrations. Just what other electromagnetic properties were being detected is the focus of ongoing research.

This presentation of the radar reflects only a preliminary, first order of comparison. At this stage in the analysis, only the most readily apparent topographic variations in the uppermost surface of the eight buried historic strata, and only the generalized presence and absence of subsurface architectural remains, have been addressed. The next step in comparison will focus on the identification of the discrete stratigraphic and cultural variables which the signals reflected.

A second order of comparison of the radar echo patterns is currently underway based on the data control capabilities of the computerized inventory which amounts to a three dimensional memory bank of the identities, amounts, and specific locations of the over 100,000 artifacts and masses of building materials recovered. Based on this three dimensional control, the various excavated classes of materials and categories of artifacts are being displayed as computer-derived SYMAP density plots across each of the buried surfaces. Once completed, this visual reconstruction of the buried cultural patterns and activity areas will be compared with the recorded radar echo patterns to determine what the echo patterns did or did not reflect in the buried multicomponent site.

Conclusions

In sum, the original polychrome radar map served to define the extent and boundaries of the buried historic site with greater fidelity than was possible through documentary sources. The results presented a picture of archaeological remains more functionally diversified and temporally distinct than could be defined by either the documents or reasonable subsurface sampling of the extensive settlement. Where excavation provided a controlled basis for comparison, the radar appears to have defined two categories of archaeological information. First, consistent with its calibrated depth of penetration, the echo signals responded to either differences in compaction or electrolytic character between the modern shale fill and the undulating surface of the silt cap covering the sealed historic strata. The radar patterns showed clear correlation with marked changes in subsurface topography across this surface. Second, the radar also appears to have detected concentrated remains high in electrolytic properties deeper within the site matrix.

For the planner and engineer, the use of ground-penetrating radar defined a construction corridor of minimal negative impact, as well as facilitated a data recovery excavation program schedule responsive to both political and economic pressures. For the archaeologist, this nondestructive remote sensing technology provided a sufficient level of resolution to develop a target-specific data recovery program which enabled the sampling of the entire range of subsurface anomalies based on insights into the internal variation and complexity of the site, instead of on guesswork.

Note

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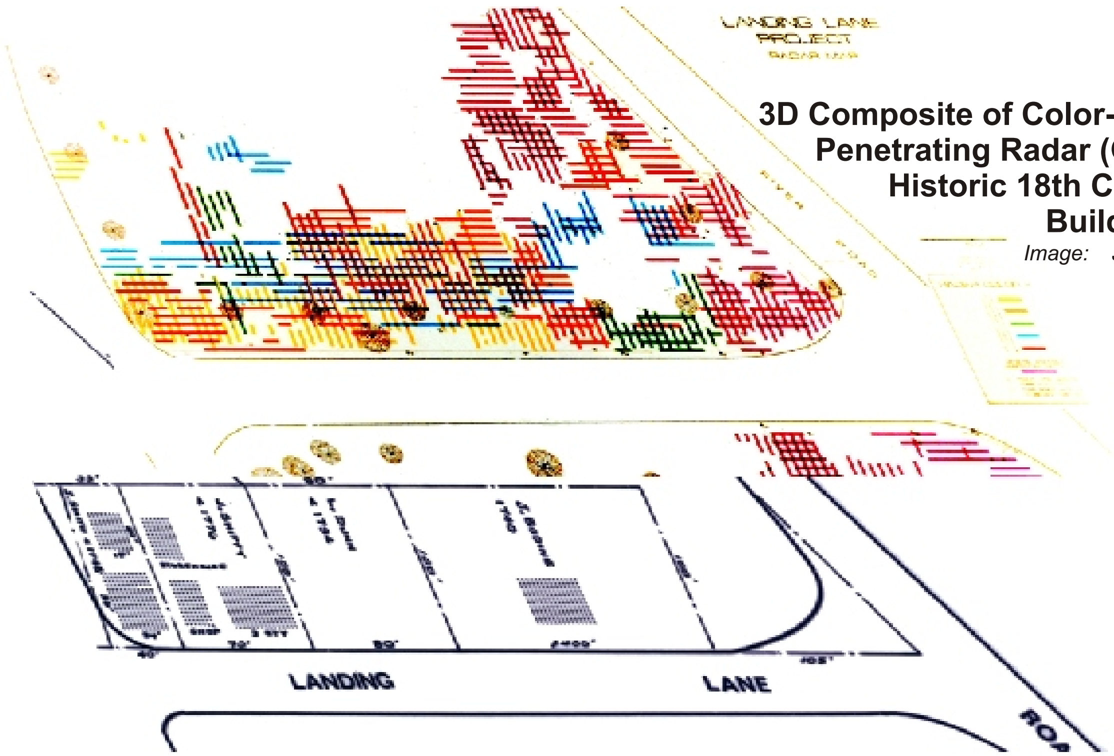
2007 Reconstituted Image Enhancement of original 1979 Underground Radar Map of the Buried 18th C. Port Community of Raritan Landing, New Brunswick, NJ.

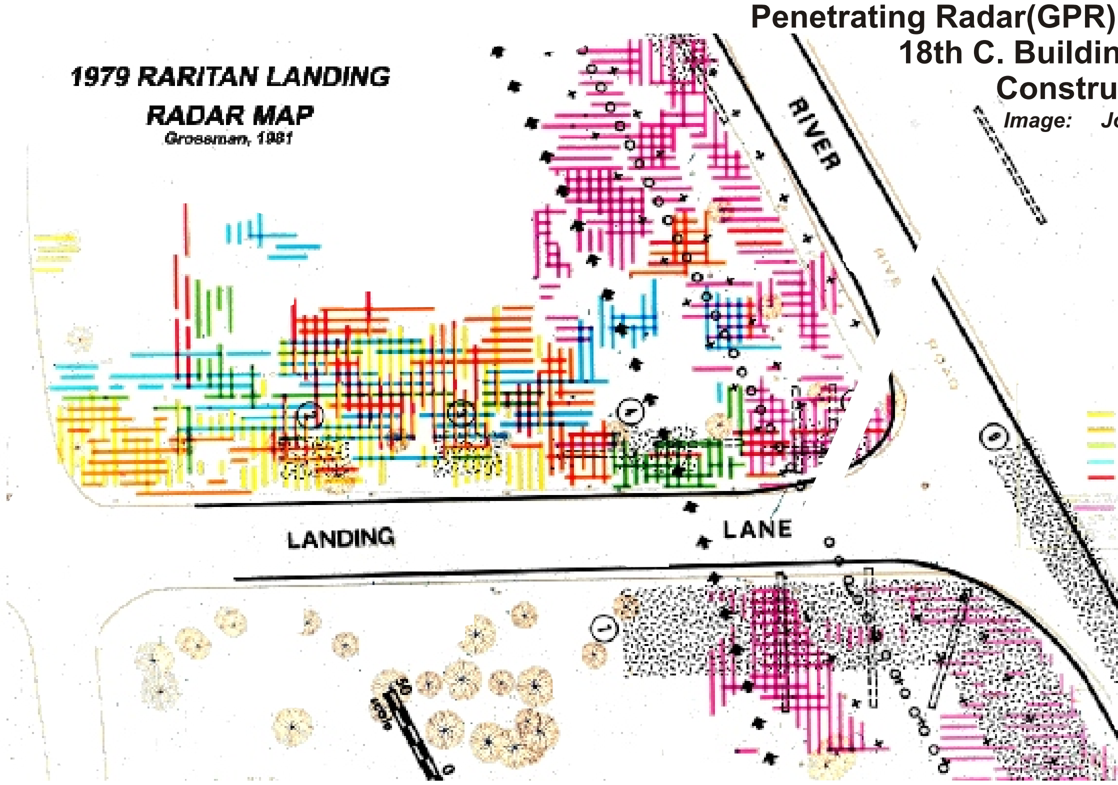
[Note: Each line of Color = 5 ft. Radar Profile Transect; Colors Reflect Relative Eco Depth]

(From Grossman, 1981, Defining Boundaries and Targeting Excavation with Ground-Penetrating Radar: the Case of Raritan Landing. *Environmental Impact Assessment Review, V.1, N. 2, Plenum Publishing.*



3D Composite of Color-Coded Ground Penetrating Radar (GPR) Map over Historic 18th C. Lot Lines and Building Footprints

Image: Joel W. Grossman 2007



2D Composite of Color-Coded Ground Penetrating Radar(GPR) Map of Buried 18th C. Buildings, Relative to Construction Corridor.

Image: Joel W. Grossman 2007

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