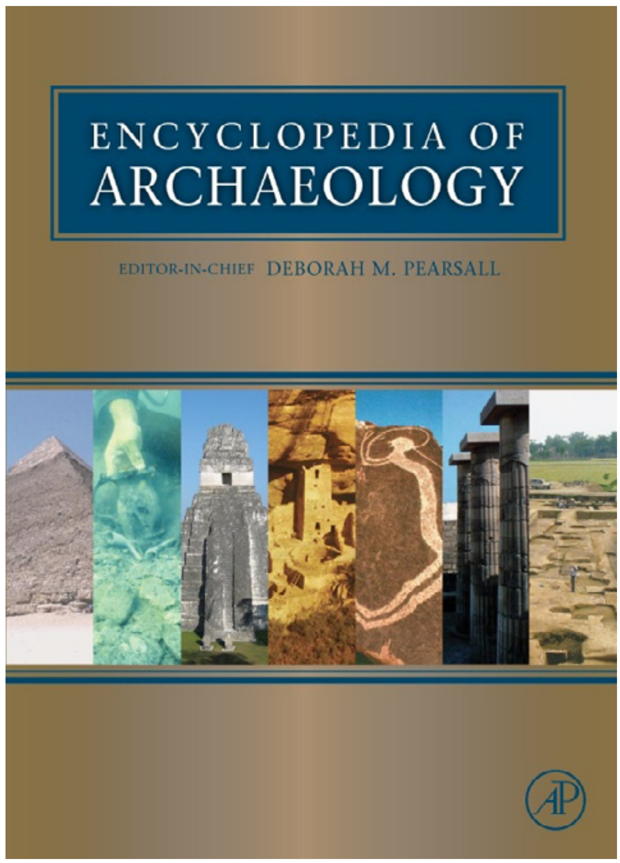
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bring out the contingencies of decision making. Such studies find local-level responses and negotiations that come with asymmetrical interrelations. With globalization, similar forces are influencing the implementation of conservation, preservation, and presentation of the archaeological past. With local responses and decisions varying greatly, the intersection of archaeology and tourism requires sustained exploration and research.

See also: **Ethical Issues and Responsibilities**; **Popular Culture and Archaeology**; **Who Owns the Past?**; **World Heritage Sites, Types and Laws**.

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TOXIC AND HAZARDOUS ENVIRONMENTS

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Glossary

GeoTIFF A public domain metadata (data format) standard that imbeds and links metric and coordinate data to each pixel of a TIFF (Tagged Image Format) digital, or raster, image file.

HAZMAT (Hazardous material) Refers to US Government health and safety regulations for the investigation or clean-up (remediation) of dangerous toxic substances that pose a threat to humans or the environment.

LIDAR (laser-radar or Light-Imaging Detection and Ranging) Near-laser 3D recording technology which records the coordinates and dimensions of objects and surfaces through the measurement of the time it takes for a beam of near-laser light to bounce back from an object or surface.

Photogrammetry A 3D and/or stereoscopic recording technology that uses multiple photographic views of a subject taken with a metric, or flat field, dual or single camera system to compute and extract real-world coordinates or dimensions.

Introduction

The archaeology of contaminated or toxic places can be, and often is, dangerous. It behooves the practitioner to be clear as to why and how it is done. As an arena that permits little room for knee-jerk solutions based on blind adherence to popular theories or paradigms, it also forces the profession, and regulatory agencies, to address some basic questions of feasibility and safety. Are traditional approaches and generally accepted field techniques adequate? Or, are some cases of compliance too difficult, too dangerous, and too costly and beyond the technical and logistical capabilities of the profession? Can the work be done to the highest standards without watering down quality, precision and range of recorded information? The premise of this chapter is, 'Yes', archaeology can be done safely, to the highest standards, and without scientific or regulatory compromise.

This overview will draw from two recent examples of emergency rescue archaeology in extreme settings, one site highly contaminated and the other damaged by natural disaster. Both illustrate the uses of applied technology to provide enhanced levels of data control in restricted time frames so as to do justice to the damaged or soon-to-be-lost resource. While the individual technologies may be transitory and quickly superceded by new innovations, the strategic and tactical reasoning behind them is not. Accordingly, the following case studies will highlight not the specifics of these strategies, but rather the assumptions, mandates and rationale behind their implementation.

Legal and Regulatory Mandates

The archaeological investigation of contaminated or hazardous environments generally takes place because it is mandated by law. As a result, major discoveries, including the two discussed here, were made in heavily developed, disturbed, and contaminated or toxic contexts. It is likely that many of these localities would not have come about without the 'blind eye', or – to be precise – the 'regulatory objectivity of the law'. With the passing of the National Historic Preservation Act of 1966 (NHPA), agencies within the United States began undertaking evaluation studies to guarantee that significant archaeological resources are either avoided or documented before government monies or permits are granted. This early legislation addressed funded or licensed undertakings, but did not specifically mandate the need to address archaeology in contaminated or dangerous places.

The expansion of legal protections for work in dangerous and toxic environments came about between 1976 and 1986 through a series of new laws. In 1976, Congress passed the Resource Conservation and Recovery Act (RCRA) and in 1980 the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) commonly known as 'Superfund', to mandate Federal management, response and funding to address environmental hazards. The Superfund Amendments and Reauthorization Act of 1986 (SARA) provided increased funding and required all Superfund actions to consider existing State and Federal environmental laws and regulations (*see* **Environmental Impact Assessment and the Law**), as well, including, by extension, the need to study the archaeology of contaminated settings. These new regulations mandated that all archaeologists and specialists receive hazardous materials training (HAZMAT) and be medically monitored as a separate set of considerations on top of standard archaeological tasks and guidelines.

In the 1970s and the early 1980s most emergency field situations were due to unexpected 'discoveries under construction'. As of the late 1980s, however, unlikely and often heavily disturbed landscapes became venues of emergency and archaeological excavation in major Superfund projects to remove potentially dangerous chemical and radioactive contamination. The criteria for investigation and evaluation stayed the same: How big is the site? How deep is it? What are its limits? Is it significant under local, regional or national criteria? Can the project be redesigned to avoid or minimize impacts? How these levels of definition were achieved required the adaptation of new approaches and a re-evaluation of the traditional timing and scheduling of archaeological tasks.

These new health and safety mandates added several critical new logistical considerations to the planning and organization of archaeological investigations:

1. The need to work in 'all-weather conditions' regardless of season and temperature,
2. The need to implement 'non-random site testing and definition strategies' that reduce the likelihood of chance encounters with dangerous areas or objects,
3. The need to have immediate data control over number, function and age, as well as the relative conservation and stabilization needs of excavated materials,
4. The need to 'use remote recording' technology to reduce the 'duration, level of exposure, and proximity' of the archaeologist to contaminated and dangerous objects or contexts, and
5. The serous health and safety consequences of bad judgment, poor planning, or inappropriate techniques.

Finally, it can be said that while the structure and standards of archaeology are the same, the time frames for traditional tasks – planning, mobilization, deployment, excavation, data processing, analysis, documentation, and reporting – are generally severely compressed. They are commonly reduced from months or years down to, at times, weeks or days.

Assumptions and Antecedents

The baseline assumption behind each of the technologies and strategies discussed is that archeological evidence and resources are primarily three-dimensional, geospatial and quantified. This 'geospatial' view thus treats an archaeological site as 'a stratified series of geo-referenced planes, deposits, or surfaces', or simply put, as 'a digital layer cake through time'. Given this set of premises, and regardless of the individual technologies involved, the following strategies use Geographic Information Systems (GIS) as the primary organizational framework for the control and analysis of all of archaeological evidence, geophysical results, and existing conditions, surveys, etc., each treated as a layer in a scaled series of superimposed maps (*see* **Remote Sensing Approaches**: Geophysical).

Two archaeological strategies have been consistently applied to facilitate, and expedite, the safe and cost-effective compliance with preservation laws and standards: (1) 'Technologies for safe discovery and definition': GIS and air photo image processing (remote sensing), coupled with, non-random, target-specific geophysical survey to avoid 'flying blind' in dangerous places and (2) 'Technologies for safe remote documentation': High-speed, noncontact, 3D recording to quickly and safely record archaeological resources with minimal or no human contact. Both of these approaches were used to reduce the time as well as the level of on-site exposure and contact during the site 'definition and recording' activities while upholding the care and precision of traditional control of archaeological excavation and exposure.

Each category of applied technology was adopted as lateral transfer from other 'unrelated' disciplines or professions. Only after having been proved to be feasible and effective in nonarchaeological contexts, was it used to expedite and enhance archaeological capabilities. Each illustrates the concurrent deployment of multiple examples of 'technologically integrated, synchronized and partially redundant' classes of applied technology as a buffer against over-reliance on a single brand or category of hardware or software.

Some of the highlighted technologies are mundane or common place, others advanced. Several were initially applied in early emergency rescue archaeology projects dating back to the late 1970s. Although not contaminated, these early 'discoveries under construction' were commonly resolved though the adoption of applied technology solutions that would later continue as 'core' tool sets for the investigation and documentation of hazardous or contaminated sites. These included the 1978 introduction of a high-speed computer transit, or electronic distance meter (EDM), followed in the mid-1980s by the introduction of Total Station survey systems linked to integrated data collectors with built-in data storage and conversion. These early applications also included custom-built all-weather shelters, geophysical survey, and stereo-photogrammetry. Out of the field, these innovations incorporated the introduction of concurrent on-site laboratory processing, analysis, and conservation facilities as well as early micro-computers and early database management systems. Other technologies, including single-camera photogrammetry, advances in 3D geospatial visualization and modeling, satellite image projection software and most recently, laser-radar, represent critical advances in capacity, speed and precision. These in turn provided solutions to logistical challenges that would have been difficult or impossible to address otherwise. In some cases, such as those discussed here, these advances are helping to address difficult compliance issues that are simply beyond the capabilities of normative – and often peer reviewed – method and theory.

Archaeology of Hazardous Places and Natural Disasters: Two Case Studies

Two large-scale emergency archaeological studies, one of a contaminated Civil War site, the other of a National Register District that was damaged by natural disaster, both directed by the author, will be drawn from to describe context and rationale for the choice of applied technology solutions to implement archaeological compliance in toxic or hazardous settings. Both describe the rapid mobilization of small, self-contained, all-weather, multidisciplinary field and laboratory teams in extreme conditions, some natural, and some political, others toxic and all logistically challenging. Each illustrates the concurrent deployment of multiple categories of integrated, synchronized, and partially redundant classes of applied technology.

Both were discovered as significant national resources despite the fact that their existence and significance was counter to accepted theoretical models and the documentary record. At times, these otherwise unavailable lines of evidence contradicted the written record. At others, they filled gaps in critical economic, environmental, or military history: for example, at West Point Foundry, the cadmium-laced archaeological evidence revealed a little-known Civil War R & D program in heavy, rifled 'Super guns'. It also revealed previously unrecognized intelligence operations and capabilities in Lincoln's administration. Similarly, the recent 2004 deep-winter emergency rescue effort in the highlands of New Jersey exposed the unexpected and otherwise undocumented, survival of the earliest engineering dam of the Morris Canal.

The first case comes from the staged, five-year long, archaeological mitigation of the first major US Government-mandated archaeological investigation of a contaminated Superfund site, the Civil War cannon factory of West Point Foundry, located opposite West Point Academy on the Hudson River. In addition to the need to train and equip archaeologists and laboratory personnel in federally mandated HAZMAT procedures and regulations, it underscores the critical role played by all-weather shelters for the protection the crew 'and artifacts' in extreme conditions (Figure 1). It also highlights the importance of concurrent on-site laboratories for decontamination, conservation, and real-time computer inventory of excavated materials, during the excavation, instead of long after, when it is too late to make course-corrections in field strategies.

The second example draws from a recent, 2002–04, emergency archaeological response to a natural disaster, the deep-winter protection-through-redesign and emergency archaeological documentation of flood-damaged historic elements of the Morris Canal Historic District in the highlands of northern New Jersey. It highlights the critical role played by the advent of recently developed high-speed, remote, noncontact, true-color 3D laser-radar, or light detection and ranging (LIDAR) for emergency rescue archaeology in difficult contexts – quickly, remotely and safely. The deep-winter data recovery operation also demonstrated the critical role and utility of GIS, photogrammetry, and satellite image reprojection. Together they enabled the creation

Figure 1 1989–94/Cold Spring, New York. This rescue excavation of the Civil War-era West Point Foundry was the first major archaeological mitigation mandated by the US government at a contaminated 'Superfund' site (Marathon Battery Corp. along the Hudson River). HAZMAT-trained and medically monitored archaeological teams excavated under fixed, all-weather shelters (reinforced, dewatered and heated) to document the 1863 testing facilities for the Parrott rifled cannon.

of emergency base, or planning, maps and remotely recorded metric plans and profiles. Both tools helped avoid time-consuming investment in hardware, engineering, and staff required to deploy and setup elevated or overhead stereoscopic and photogrammetric camera suspension systems.

Finally, these contrasting emergency settings represent polar extremes in organizational and logistical structure. The large multi-year Superfund project was done by a multidisciplinary team of archaeologists, artifact analysts, soils, plant, and animal bone experts, computer aided design (CAD) and database specialists, conservators, scientific illustrators, photographers and fiscal, logistical, and corporate support personnel. All were backed by a dedicated contract administration and budget control staff. In contrast to this concentration of manpower, the deep-winter emergency deployment of the first generation of true-color laser-radar was, with the exception of a temporary field assistant, planned, tasked, implemented, analyzed, and reported by a staff of one.

In emergency or dangerous field situations, 'small' is often better than large. The fewer people there are, the fewer there are to be injured. Similarly, very often-emergency situations are more easily resolved by small, flexible tactical teams, without the institutional controls and constraints of large multilayered private and/or public institutions. None of the technologies or strategies discussed is viable without flexibility and security in budget authorization, indemnification against liability or the institutional and logistical ability to process and facilitate contractual and budget changes without delay.

The Archaeology of a Contaminated Superfund Site: West Point Foundry

Between 1989 and 1995, the US Environmental Protection Agency and Army Corps of Engineers mandated the first large-scale archaeological investigation of a contaminated Superfund site. The cleanup area coincided with the Civil War era cannon factory of the West Point Foundry, situated on the Hudson River opposite the West Point Academy. Dangerous cancer-causing deposits of cadmium from a post-World War II battery factory built over the historic foundry needed to be removed, both from the land and from the marshes bordering the river. As a federally funded and licensed program, historic preservation laws dictated that the cleanup could not begin until significant elements of the historic site, scheduled to be impacted by the superfund program, had been fully documented. The Superfund effort posed critical health and safety constraints and fieldwork needed to be expedited under often adverse all-weather conditions. It also represented a logistical and scientific test case over the ability of archaeology, as a discipline, to meet federal preservation laws in contaminated and potentially dangerous contexts.

The five-year archaeological rescue effort resulted in major discoveries in Civil War military history, including the preserved wood and iron heavy testing platform of Parrott's 30 000 lb. rifled cannon, and beside it, the cannon hoist tower for lifting the new class of heavy rifled ordnance, a buried prehistoric village and the well-preserved workers' housing of some of the Foundry's military engineers and iron workers. Two large caliber '100 pounder' cast iron rifled shells – one a standard exploding piece, the other an example of Parrott's little-discussed binary incendiary shell which was deployed to burn Charleston in 1863 – were probed for traces of explosives with Army ordnance disposal personnel and then, once declared safe, conserved for exhibition. The cannon platform was recorded with 3D photogrammetry, its metal elements conserved, decayed wood elements replicated and then reconstructed for exhibition at the secure Harriman State Park museum complex of the Orange County Historical Society.

A range of applied technology solutions were deployed to facilitate the safe investigation and documentation of the contaminated remains. The buried Civil War cannon testing facilities were initially detected using false-color air-photo image analysis of aberrant vegetation and tree cover patterns of the project area. A patchwork of irregular, 'multicolored', vegetation patterns suggested subsurface traces of past human disturbance within the otherwise unmapped areas. The aerial false-color remote sensing evidence triggered the intensive terrestrial geophysical survey of a football-field-sized shoreline area that was designated for cleanup and land reclamation. Computer transit surveys provided accurate existing conditions maps. Early CAD software was used to plot, define and subtract anomalies caused by modern twentieth century structural debris from the large number of magnetic signals detected by the magnetometers.

The marine portion of the investigation utilized scaled comparisons of historic bathymetric surveys to reconstruct the Civil War era topography of the river channel. Side-scan sonar and marine magnetometer instruments crisscrossed the river in front of the Foundry to identify, avoid and protect any submerged historic ships, barges, and/or historic ordnance dumps prior to dredging. Vertical 'Vibra-core' sediment columns were collected to define the depth of the historic river bottom. Spikes in trace elements of lead and copper, by-products of initial production of brass canon in the 1820s, showed that the former pre-Civil War channel bottom was buried under three feet of more recent river sediments.

Five categories of applied technology and logistics, some mundane and some representing recent innovations and enhancements in capability, were pivotal to the successful and timely completion of the multi-year archaeological Superfund program: (1) the effect of HAZMAT training and procedures, (2) the specialized roles of GIS and geophysical survey in a contaminated context, (3) the importance of blast-proof all-weather shelters, (4) the role of on-contact 3D recording systems (computer transit and photogrammetry) and finally, (5) the critical role played by, and reasons for, on-site laboratories for real-time computer database inventory, decontamination and conservation for 150 000 Civil War era artifacts, concurrent with ongoing field and data recovery tasks (Figure 2).

Figure 2 1989–94/Cold Spring, New York. HAZMAT-trained archaeologist and conservator at on-site X-ray facility – part of concurrent decontamination, inventory, and conservation laboratory at the cadmium-laced Superfund site. Concurrent inventory and stabilization labs provided (1) mandated decontamination before artifacts could be moved and (2) immediate feedback about which areas and artifacts were sufficiently diagnostic or datable to warrant specialized treatment during ongoing fieldwork (rather than long afterwards, when it would be too late or too costly to adjust project resources).

HAZMAT archaeology All crew members were certified in HAZMAT and medically monitored for possible exposure throughout the project. With the new Superfund legislation came the mandate that all field archaeologists and laboratory personnel take a 40-hour HAZMAT course in the use of protective equipment (chemical-proof Tyvek suits, respirators, steel-toed boots, protective gloves, and monitoring instruments) and in the decontamination of people and equipment. The new stipulations brought stringent contractual and liability requirements, and required archaeologists to adhere to government confidentiality and security regulations. In addition to formal proposals, scopes, and budget submissions, archaeological field programs had to plan archaeological tasks in compliance with detailed 'health and safety plans'. These plans, generally developed by outside experts, matched potential areas of exposure, with specific levels of protection (Figure 2).

HAZMAT-certified archaeologists work in four ascending levels of protection, from Levels D to A. The highest level, Level A, is defined by a fully encapsulated suit with supplied air. While Level A was seldom associated with archaeological projects, it was not uncommon for HAZMAT archaeologists to work in toxic environments in levels B, C, and D. The least stringent, Level D, is limited to protective disposable Tyvek suits, disposable gloves and booties, and, depending on conditions, facial dust filter masks. Level C was the same, with the addition of high-quality, 'fit-tested' full-face masks and contaminant-specific filter cartridges capable of protecting against organic vapors, toxic compounds, and radioactive particles. The third, Level B, required supplied air, either in air tanks for via air hoses, from an external compressor.

All levels are distinguished by the signature use of large amounts of duct tape to seal gloves, boots and Tyvek shells. Crew members carried walkie-talkies to guarantee quick rescue and support, and bayonets, taped to the suit, to quickly cut them off in case of a break in the sealed protective outer shell. If that occurs, the exposed members are decontaminated by HAZMAT-equipped rescue personnel with heavy scrub brushes and high-pressure hoses before being medically evaluated.

Finally, aside from the constant threat of heat exhaustion, one of the major logistical drawbacks of having to work in protective HAZMAT equipment had to do with the difficulty of manipulating small instruments through thick layers of protective gloves. This element of reduced dexterity and tactile sensitivity added another consideration to the selection and employment of the different classes of applied technology. The potential systems not only had to be effective and capable of continued operation in adverse climate and field conditions, but were also selected for easy use. What is difficult under normal conditions can become impossible in field situations of extreme physical stress.

The role of geophysics and GIS in dangerous contexts At West Point Foundry, the integrated use of terrestrial geophysical survey and early CAD for digital mapping provided target-specific testing strategy as an alternative to the common practice of relying on statistics-based random sampling to define a testing strategy. Bad testing strategies in 'pure research' environments seldom have real-world consequences. The unnecessary testing of disturbed areas can be wasteful under normal circumstances and often leads to a false sense of scientific accountability. Ill-conceived or random subsurface probes into contaminated contexts, unexploded ordnance, toxic heavy metals, or radioactivity can be dangerous or lethal. At West Point Foundry, there was a high potential for encountering large clusters of unexploded ordnance as well as high concentrations of toxic heavy metals. Terrestrial geophysics and early geospatial mapping were used to develop a non-random, target-specific testing strategy.

Site-specific geophysical remote sensing techniques (e.g., receptivity, magnetometers, and ground penetrating radar) 'can' define the boundaries of a site as well as often isolate the number, location and approximate size of subsurface anomalies. In archaeological contexts that are toxic or dangerous, geophysical survey has emerged both as a means of identifying potentially important subsurface cultural features and as a means of 'avoiding' the 'random' or unexpected contact with potentially dangerous or toxic deposits and features.

GIS are commonly used for the scaled comparison and analysis of different sets or layers of contemporary demographic, environmental, or economic data (e.g., population density of school children relative to community sales of tennis shoes; crop yields relative to regional contrasts in soil chemistry). In archaeology, GIS provides a geospatial framework for the treatment of archaeological data as both contemporary and as diachronic, or chronological, comparisons of modern-to-past conditions. The control of these changes provides a 3D window into the development and changing composition of a site. In hazardous or toxic environments, GIS has also proven to be an essential visual and geospatial framework for the successful deployment and interpretation of terrestrial and geophysical surveys.

Specifically, in these contexts, GIS has proved particularly important as a tool for the correlation and elimination of spurious 'signals' or 'targets' from modern debris or structural remains that could skew or confuse the detection of important subsurface remains. In the context of contaminated or dangerous archaeological environments, scaled comparison of geophysical results as part of a multilayered GIS series of site attributes has emerged as an important a 'non-random' alternative to the inadequacies and uncertainties of relying on 'random sampling' in hazardous and toxic environments. At West Point Foundry, the entire complex was both contaminated and obscured by a mantle of modern industrial debris (elements of collapsed twentieth-century structures, piles of brick, an abandoned used car lot, and sections of old chain link fencing) which obscured and interfered with the identification of archaeological features.

The site was first surveyed and laid out with a reference grid at five-foot intervals. A Proton magnetometer recorded magnetic fluctuations along both axes of the site grid. The results were plotted as both contour and 3D 'terrain models' of the electromagnetic readings. The magnetometer survey identified a large number of 'hits' or electromagnetic fluctuations. It also detected a comparable number of spurious signals responding to modern debris.

To separate and subtract the spurious electronic 'debris' from actual archaeological features, each visible piece of surface metal, piles of bricks, rusted fence sections or cement platform elements were surveyed with the on-site digital transit, or Total Station, and plotted to scale as a separate layer over the geophysical survey map. These scaled cartographic comparisons, or overlays, provided a concrete basis for concentrating subsequent subsurface tests on only those magnetometer anomalies that did not overlap with any of the plotted locations of identified nodes of modern industrial debris. Any anomaly or 'hit' that did not correlate with a node or element of modern debris was deemed of potential archaeological interest and tested for the presence of buried Civil War era remains. Anomaly number 35 on the geophysical map revealed the buried hoist tower and gun platform for the 'proofing' of Parrott's thirty thousand pound rifled cannon. This integrated geophysical and geospatial approach also facilitated the allocation of project resources on only high integrity, and high yield, areas of little or no disturbance, and the avoidance of contaminated and dangerous areas.

All-weather winter shelters Fieldwork was completed in deep winter under heavy custom-built steel-reinforced, blast-resistant, shelters covered with inflated, forced-air-insulated, plastic skins. High volume four-inch pumps operated around the clock to lower the water table to the level of the buried Civil War surface, five feet below. Commercially available greenhouses were customized and retrofitted with skid-like bottom sections so that they could be easily moved. A double layer of plastic sheeting was sealed and inflated to create a low-drag shell that both insulated and withstood heavy gale-force winds. Two person HAZMAT archaeology teams were scheduled to work each night to repair leaks in the protective shells, monitor fuel for heavy dewatering pumps and 400 000 BTU outdoor heaters, connected to each excavation shelter by long sections of insulated ducting. Had the pumps and heaters within the shelters failed, the shoreline excavation would quickly have frozen into a $4 \times 30 \times 60$ ft block of ice, four feet below the water level of the Hudson River (**Figure 1**).

Although safe, dry and warm, the deep winter shelter systems presented the HAZMAT field team with a critical logistical constraint. Earlier projects, involving simple emergencies in uncontaminated contexts, had used a *c.* 18 to 20 ft-high bipod camera suspension system to capture stereoscopic and overlapping photo-mosaic coverage of excavated surfaces. The stereo-camera suspension system had been developed in the 1980s to expedite the documentation of a buried colonial port in New Jersey and the remains of the mid-seventeenth century building foundations and cobble floors of the Dutch West India Company under Lower Manhattan. Weather permitting, the linked sections of 20×30 ft greenhouse units were simply pulled apart to provide a gap with sufficient width to raise the bipod, take several pictures, and then move the portable shelters back into position.

However, forecasts of severe and protracted winter conditions suggested that moving the shelters would not be an option at West Point Foundry. For each targeted area of subsurface investigation, two 30×25 ft custom-built 'greenhouse' shelter units were linked together to form a *c.* 25×60 ft climate-controlled environment. Each was sealed against the elements and guyed down in a fixed position for the duration of the winter. Once sealed and fixed in place, the total height under the shelters was no more than 8 to 10 feet, some 10 feet too low to accommodate the earlier bipod system. A better recording system was needed to provide the high-speed remote recording within winter shelters over the Superfund site.

Non-contact recording: Single-camera photogrammetry This environmentally imposed limitation prompted the adaptation of a more flexible photogrammetric system capable of working within the confines of the fixed position greenhouse shelters. The solution came in the form of a new generation of a single-camera photogrammetric recording developed in the late 1980s by the Rollei Corporation.

The wide angle, 90°, flat-field macro lens of the metric camera captured a high-precision 3D record. Most importantly, it was able to operate at close range with a flexibility of *c.* 20° for each photo view and position. The single camera system had been developed for the documentation of air crash sites, crime scenes, and espionage. A Canadian team had also shown its archaeological utility for remotely documenting and mapping the wide-area distribution of prehistoric pit features and house outlines from the air. It was deployed at West Point together with remotely controlled monopod camera support system for full 360° coverage, both under and outside the shelters.

Even in clumsy HAZMAT protective gear, and within the confines of a winter shelter, this single-camera system permits a field archaeologist to throw a meter scale into the field of view, and quickly snap a series of 'candid' views at various angles in a circular path around the subject – literally in a matter of minutes. Each film image essentially represents a frozen record of embedded coordinate and measurement data that can later be extracted as needed. Desktop computer software correlated and 'rectified' each set of views into a single geo-referenced coordinate system. The system facilitated the safe and rapid metric documentation of the foundry's cannon testing platform and hoist tower in plan and profile. It also enabled the field crew to remotely and safely record, and reconstruct, long stratigraphic profiles throughout the site, despite the proximity of thick bands of highly toxic mineral cadmium in the sidewalls.

However, while the field recording was very fast and could indeed significantly reduce human contact and exposure to toxic contexts, the subsequent photogrammetric coordinate rectification phase was labor intensive and costly. The early software was written in German, tedious to implement and required several days of post-field computer processing for each set of 8 to 12 image captures per subject. This secondary level of effort rendered the system good for rapid data capture, but poor in terms of its ability to quickly produce metrically accurate 3D results. The photogrammetry system was not adequate to address the fast-track emergency response and decision-making requirements for emergency rescue archaeology that would later have to be confronted in the context of a natural disaster.

Concurrent, on-site, laboratory decontamination and data control The pressures of emergency unexpected 'discoveries under construction' and dangerous hazardous environments also affected the timing of the laboratory tasks. Traditional academic practices of delaying tedious laboratory tasks until after the fieldwork was done could not provide the necessary and timely feedback. Beginning with the emergency rescue efforts in the 1980s – and the promulgation of new government standards and guidelines for the proper treatment of archaeological collections – concurrent laboratory facilities and tasks were established on-site and in tandem with the excavation. They provided (1) early chemical first aid and stabilization to fragile artifacts and (2) high-speed feedback as to the nature, number, and implications of what was being uncovered. Funding and review agencies were interested in the amount and nature of the materials being excavated; corporate project managers needed to know immediately how much of the site was disturbed and potentially open to continued construction, and what areas needed to be avoided. In noncontaminated situations, the decision to budget for the concurrent operation of on-site laboratories amounts to good planning. In contaminated or toxic environments, the on-site laboratory is both mandated and a critical component for safe field operations.

With the advent of rescue excavations in contaminated and toxic contexts, archaeologists could no longer remove artifacts without first decontaminating them. Under the new Superfund regulations, transporting 'dirty' artifacts from a Superfund site could create a second Superfund site, which could have serious legal and/or health and safety consequences. These constraints in the timing and feasibility of moving and transporting the excavated materials have emerged as a major logistical consideration in scheduling and staffing of archaeological projects in toxic environments. At West Point Foundry, all excavated materials were cleaned, decontaminated, initially identified and computer-inventoried as a 'first cut' evaluation or 'triage' of material, function and date in the on-site laboratory before being taken off-site for in-depth analysis and curation.

In this case, the on-site laboratory facilities were set up in two 12 × 60 ft trailers with the laboratory tasks subdivided and equipped to sequentially process the artifacts from dirty to clean. At the 'dirty' end were storage and decontamination facilities. The middle section contained artifact sorting, computer inventory, and analysis facilities. At the clean end, dust-free close-up photography and database-enabled portable computers recoded and tabulated the continuous stream of Civil War era cultural materials. Portable X-ray equipment was installed to 'see' through rust and corrosion to determine which artifacts warranted decontamination, conservation and analysis (**Figure 2**).

In addition to six HAZMAT-qualified field archaeologists, a crew of six to ten laboratory technicians – under direction of two conservators – washed, sorted, decontaminated, chemically stabilized, conserved-and the collection of Civil War artifacts at a rate of 2500–5000 per week. Using walkie-talkies, laboratory personnel were able to provide immediate feedback to the field crew on the identity, age, and origins of the cleaned and chemically stabilized artifacts. The early availability of laboratory results provided a concrete basis to also determine within hours which areas or layers of the site were disturbed and which contained high-integrity deposits worthy of more intense investigation. This capability, in turn, resulted in the almost exclusive recovery of significant, 'high integrity' Civil War era artifact associations and deposits. Disturbed contexts of no stratigraphic or structural integrity were abandoned.

These enhanced levels of decision-making and data control also facilitated quick responses to official queries from government officials and corporate managers. They also enabled the timely evaluation and management of budget and resource allocations on an ongoing basis. Highly resolved, task-specific, budgets coupled with real-time data control enabled the quick adjustment of initial budget and labor estimates to accommodate changing artifact yields and conservation needs. Data and laboratory processing tasks and cost estimates were sequentially funded by units of 5000 artifacts. Each time the ongoing database inventory reached this benchmark, a 'change order' was authorized in controlled increments over the initial budget (Figure 3).

High-Speed 3D Documentation in a Natural Disaster: Furnace Falls Dam, New Jersey 2002–04

With the exception of live ordnance and radiation, one of the most dangerous archaeological rescue cases involved the 2002–04 deep winter emergency exposure and documentation of flood-damaged components of the Morris Canal Historic District in the Highlands of northern New Jersey. In the summer of 2000, 1000-year flood levels breached three dams on the Musconetcong River. One dam dated to the 1830s and was significant both as a contributing element to the Morris Canal Historic District and in association with an important northern Civil War era cannon foundry. The flooding destroyed or damaged elements of the historic foundry; a beautiful cut-stone bridge and portions of the modern and historic dams associated with it. The site was also the primary production facility of the Compac Corporation, whose modern factory spanned the river channel and overlay the buried remains of the historic foundry (Figure 3).

Emergency repairs mandated by the New Jersey Department of Environmental Protection for the damaged dam (discovered during fieldwork beneath the 1927 cement spillway) could not proceed until the loss of historic components was either avoided through engineering redesign, or documented through archaeological data recovery. In addition, New Jersey land-use, natural resource, and stream encroachment permit restrictions pushed both the critical dam repairs and

Figure 3 2003–04/Stanhope, New Jersey. Emergency rescue archaeology and high-speed 3D documentation at Furnace Falls Dam took place under severe, sub-freezing, winter field conditions, shown at onset of fieldwork after a storm dumped 8 in of snow in what was reported as "the coldest January since 1977" (CNN). © 2007 Joel W. Grossman, PhD. Published by Elsevier Inc. All rights reserved.

any archaeological work into winter (reported in the local media as the coldest since 1977) to protect fish habitats.

Mitigation through redesign and avoidance The first phase of the mitigation effort involved the development of a background sensitivity study and documentary synthesis of what was already known about the history, layout, and function of buried structural elements within the initially ill-defined area of the Civil War canal system and industrial complex. The mitigation plan used GIS and historic map comparison and reprojection to first define, limit and if possible, avoid potential impacts. Available background information and historic map analysis was used to develop a minimally intrusive – joint engineering/archaeological – Mitigation Plan stressing preservation in place and avoidance through redesign. As an alternative to cutting a 30-foot wide bypass channel through buried elements of the mid-nineteenth-century cannon foundry, the river was diverted overland with six large and environmentally passive siphon pipes. Steel sheet piling across the channel was moved upriver to avoid sensitive components of the historic channel. Only for those elements that could not be avoided through redesign, was it necessary to develop a detailed budget and strategy for documenting the historic site, concurrent with ongoing, deep winter emergency dam and spillway repair, or 'remediation' work.

Logistics of deep winter data recovery At the outset, the project was hampered by five major tactical hurdles: (1) the lack of both accurate digital basemaps for the overall study area and time to contract survey teams and wait for finished drawings, (2) the need to record any and all endangered archaeological features without interrupting critical industrial deliveries to the modern production facility, (3) given the severe winter conditions, a constricted window of access to the exposed and dewatered channel of no more than a day to fully record all historic elements, including the historic dam, (4) the need to operate advanced technology systems near their tolerance levels of 14 °F, and (5) the inability to work on, or next to, the historic structure because of dangerous overhangs and the constant threat of renewed flooding (Figure 3).

Winter field tasks were completed in two steps. Both phases were undertaken as a tightly coordinated logistical collaboration between owner, engineers, contractor and archaeologists, in tandem with, and without delays to, ongoing construction. The archaeological fieldwork was completed by a team of two archaeologists (a Russian-trained Cuban archaeologist and the author) and a three-person team of GPS and LIDAR surveyors and engineers.

The first stage of the field program took place in almost continuous rain. The access road into the factory and into the planned construction staging area were investigated and 'cleared' in six days in October. Two near-surface historic features (a foundation and foundry blast furnace smoke stack base) were excavated and recoded in three days each. The fast-track recording schedule needed to avoid any interruption to military-critical deliveries of raw materials and fuel to the continuously running plant. It also needed to facilitate timely access by heavy equipment for the next stage of site preparation and remediation tasks (Figure 4).

Then, and when the archaeological team returned in December and January after a two-month hiatus during which the contractor prepared the site for the archaeological investigation, the exposed historic dam and channel were documented. This highly focused six day field effort took place while the river was diverted overland and dewatered, in subfreezing conditions, and concurrent with construction and flood control. Construction crews built two large stone gravel causeways along each bank to provide unfettered heavy equipment access along both sides of the historic channel (Figure 4). The most important site preparation task was the design and construction by the contractor of a set of six massive siphon pipes that diverted the majority of the high volume river flow overland, around by the zone of archaeological sensitivity, and without impacting buried historic elements along each bank.

Working with the constant threat of flooding, the fieldwork was planned to permit uninterrupted exposure and recording tasks within a circumscribed, sub-freezing, temperature range of 15 to 30 °F. The selected advanced technology systems and hardware engineered to operate down to temperatures as low as 14 °F. The removal of mud and debris from the damaged dam with heavy equipment left the exposed riverbanks as steep, ice-covered slopes with overhanging cement elements from the dam. Above freezing, mud and debris became dangerous slurry which continuously threatened, and on several occasions did, to burst into the channel and potentially engulf both the site and the field crew. However, at temperatures below 30 °F, the waterlogged debris and the sides of the channel froze into a solid matrix that both stabilized the channel and offset the need for destructive steel safety sheeting. Based on these two parameters, the field effort was designed to take place between 14 and 30 °F to avoid having to install metal sheeting while the historic elements were being documented.

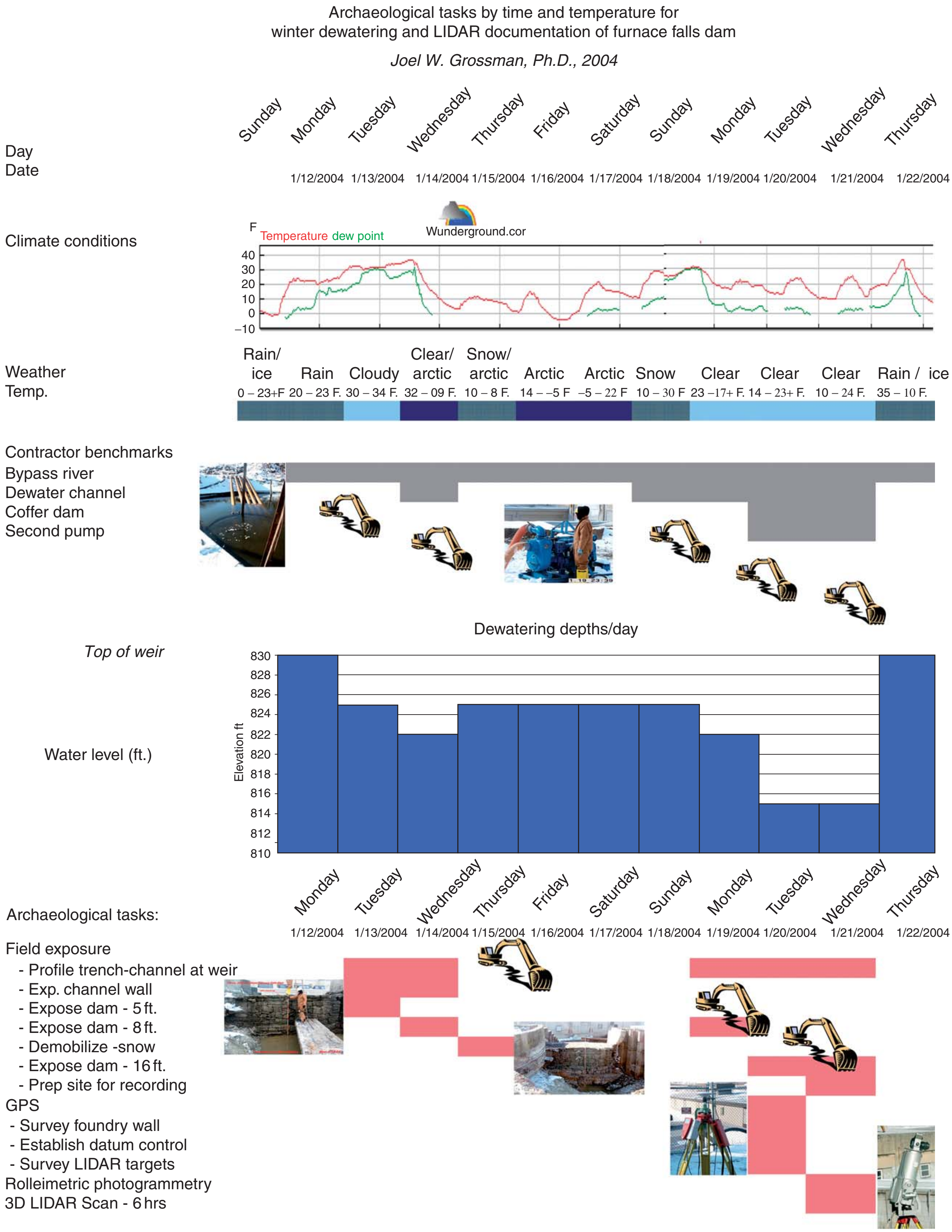


Figure 4 Table of one-week emergency, deep winter archaeological field tasks by time and temperature at Furnace Falls Dam documenting logistics and scheduling of (1) bypass of Musconetcong River using massive overland siphon pipes; (2) heavy equipment and dewatering pumps; and (3) deployment of LIDAR to produce a high-speed, 3D metric color record of the site in severe hazardous sub-freezing field conditions.

The channel was dewatered, cleared of debris and mud over two three-day efforts – interrupted by a blizzard and renewed flooding on the third day – (Figure 4). An earthen coffer dam was built upriver to trap and hold the water in collection basin for pumping. Heavy pumps drained the cofferdam of seepage after the primary gravity-fed siphon bypass system was activated. On the morning of the sixth day, the lowest of the three heavy pumps was removed from the foot of the historic dam, the site brushed of snow, and control targets placed on the dam and along the walls of the channel, surveyed as datum reference points and cleared in preparation for laser-radar documentation. Finally, over a six-hour period in sub-freezing conditions, a new generation of color laser-radar, or LIDAR was deployed from eleven positions to document the historic 1830-era dam and channel in 3D color, to a precision of 6 mm, or *c.* ¼ in. The new equipment worked as advertised, at the temperatures down to 14 °F. Only the batteries for this and other systems failed quickly, in a fraction of their advertised life, in the extreme cold.

3D geospatial solutions In addition to the previously deployed 'core' technologies (computer transits, high-resolution Geospatial Positioning Systems (GPS) and photogrammetry, on-site concurrent lab facilities and data processing), four 'partially redundant, interdependent and synchronized' geospatial site-definition and recording strategies were deployed to overcome the logistical challenges posed by the deep-winter emergency rescue effort: (1) 'Air photo re-projection technology' to create 'on-the-fly' emergency base maps (2) 'Historic GIS' for the scaled reprojection of historic maps to identify, locate and

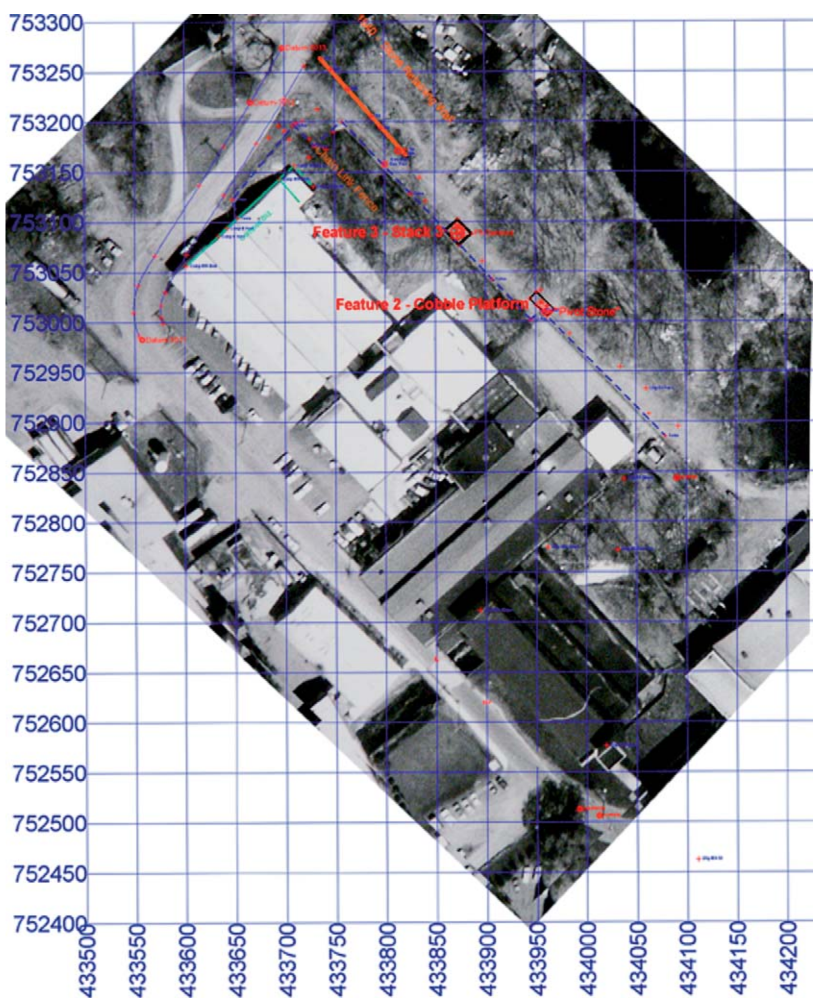


Figure 5 2003–04/Stanhope, New Jersey. At Furnace Falls Dam, emergency base maps were quickly developed from inexpensive digital scans of 1986 black-and-white aerial photo coverage, which was geo-referenced and reprojected to the modern state coordinate and site grid system. This procedure expedited the emergency planning by avoiding delay due to lack of readily available project base maps or the need to delay fieldwork while waiting for outside survey and engineering teams.

target buried archaeological features and to transform candid or oblique metric images into accurately scaled, or rubber-sheeted, 'false-overhead' photographic plan and profile records, (3) 'High-resolution, satellite-linked, GPS' established real-time grid control as the site was being exposed and immediately before the laser-radar scan, and finally, while the river was diverted overland, (4) The latest generation of 'terrestrial color 3D laser-radar', or LIDAR, to produce the first true-color, mm-precise, 3D record of an archaeological site (Figure 5).

Emergency digital base maps As in other such emergencies, no modern digital maps of the entire project impact area were available at the outset of the crisis. There were detailed engineering CAD drawings of the immediate channel section of the project site. None, however, existed for the much larger Civil War era Foundry complex bordering the river. Archived paper surveys from the 1950s did not provide sufficient information to accurately scale and plot archaeological and historic features. To offset the lack of data control and avoid delay, dedicated satellite

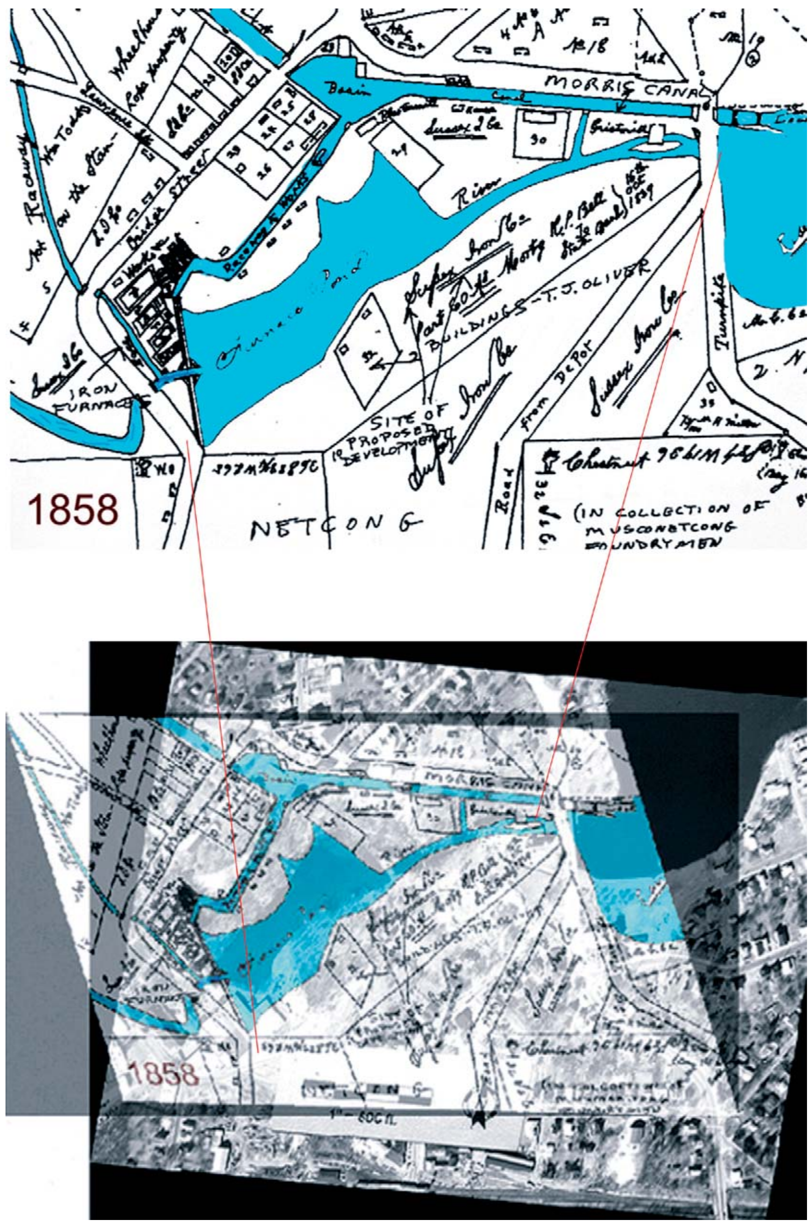


Figure 6 2003–04/Stanhope, New Jersey. An 1858 'Map of Lands Lying in Stanhope, New Jersey and Vicinity', geo-referenced to the modern 1986 air photo of the project area, showed that the original historic dam was not simply a 20-foot spillway, but rather part of an approximately 400-foot long pre-Civil War stone structure that spanned the valley. © 2007 Joel W. Grossman, PhD. Published by Elsevier Inc. All rights reserved.

reprojection software was employed to convert digital scans of low altitude aerial photos into 'on-the-fly' digital base-maps. Commercially available monochrome 1986 Agricultural Extension Service air photos were scanned, geo-referenced and reprojected to the current State Plane coordinate system to produce a high-resolution emergency planning map of the project area (Figure 5).

Targeting with GIS GIS and satellite image reprojection software was also used to scale and align historic maps to define and target the precise location of historic components of the mid-nineteenth-century site. An 1858 map of the area was digitized and geo-referenced to the air photo-derived digital project base map. This example of Historic GIS suggested that the original 1830 dam was (1) significantly longer than the modern spillway spanning the flood swollen river and (2) that it could still be preserved in line with, and directly 'under', the damaged modern (post-1927) cement spillway (Figure 6). The historic map evidence also helped the archaeologists argue against premature demolition of the flood-damaged spillway and what emerged as the underlying 1830 dam – in line with the geo-referenced pre-Civil War map projection – when the channel was later drained.

Similar techniques were also used to locate buried historic elements of the Civil War foundry (Figure 7). Two historic, 1:200 ft. scale, 'Sanborn' Insurance maps from 1886 and 1909 were scaled and overlaid onto the digital air photo-derived emergency base map. The digital reprojection of the historic maps also indicated two near-surface mid-nineteenth century features, one identified as a foundation and the other as one of the foundry's blast furnace smoke stacks. They were later found within five feet of their projected locations. Both were exposed and recorded, in two days each, in plan and profile to 1/100th foot precision on the third day (Figure 8).

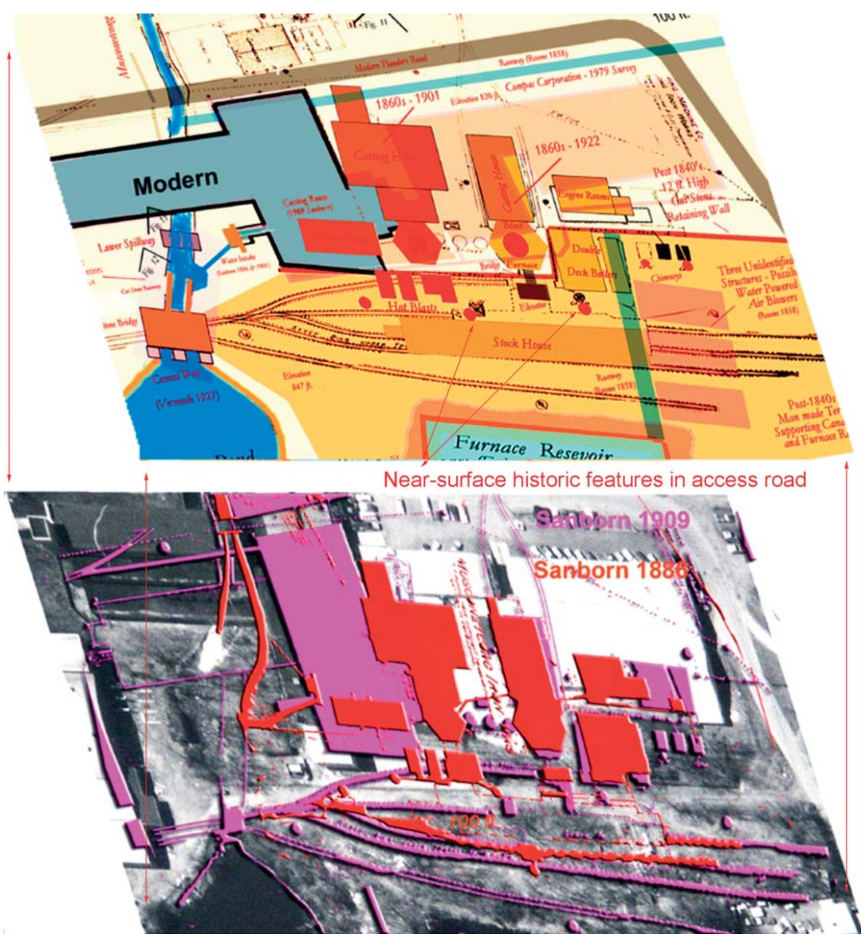
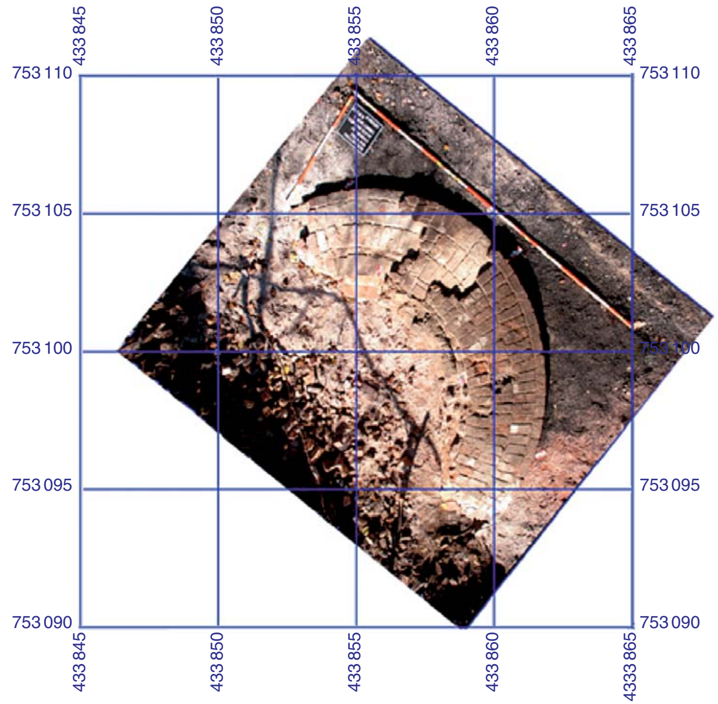


Figure 7 2003–04/Stanhope, New Jersey. As an alternative to random sampling, definition of buried and endangered historical features locations (to within 0–5 ft over the *c.* 1000 foot extent of the site) was targeted from a composite of scaled historic map overlays, geo-referenced from the 1858 Stanhope map, five eighteenth and nineteenth century Sanborn insurance maps (at 10-year intervals), and two modern property surveys of the Civil War-era Musconetcong Iron Works. Excavation revealed that the buried historic features were accurate to within 0 to 5 ft of their indicated locations. © 2007 Joel W. Grossman, PhD. Published by Elsevier Inc. All rights reserved.

Campac access road-geo-referenced feature 3 -Chimney 3
New Jersey state plane coordinate system -NAD83



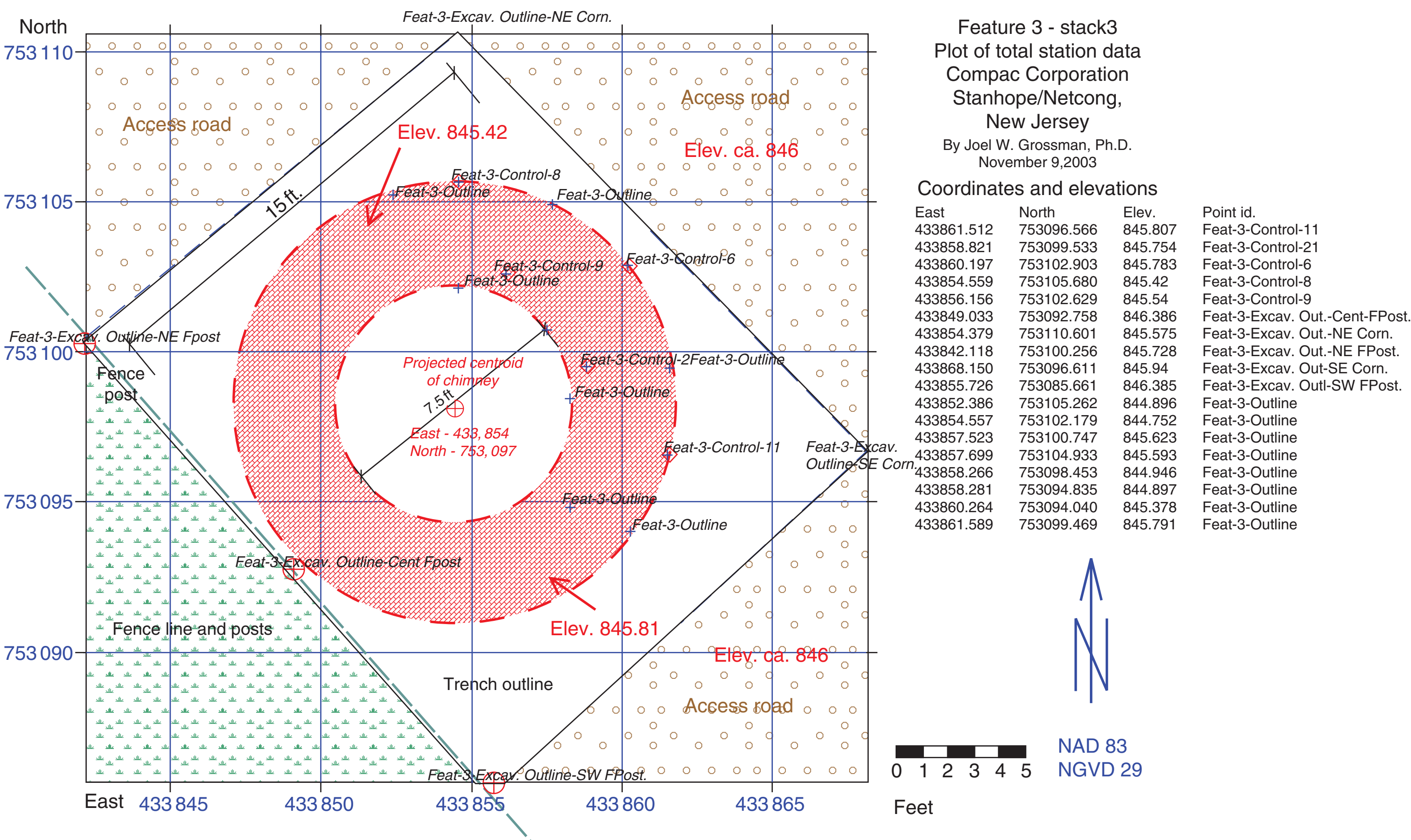


Figure 8 2003–04/Stanhope, New Jersey. Satellite image reprojection software and precisely surveyed targets were used to quickly 'rubber-sheet', or reproject and convert candid perspective metric field photographs of exposed historic features into 'near-overhead' digital plan views. This time saving technique was completed within a two-day window of site access for each excavated feature, without delay or the need to build and implement complex, time-consuming overhead camera suspension systems. © 2007 Joel W. Grossman, PhD. Published by Elsevier Inc. All rights reserved.

Photogrammetric feature documentation As a high-speed alternative to complex and often precarious overhead camera suspension systems, this satellite image projection and coordinate conversion technology was used to produce formal metric plans and profiles from candid, or perspective, metric photographs. A computer transit measured the coordinates of some 15–20 major structural vertices, arc-tangents and corners across each feature. Numbered coordinate control targets were placed at each of these nodes and surveyed to 1/10 in precision. Oblique views were taken at various angles from eight locations around each feature with a film-based medium formed metric camera to provide 360° coverage, both from the ground and at 45° from a 10 ft high wheeled scaffold.

The coordinates of each numbered and surveyed field target were entered into the image reprojection and rectification software as reference points for each of the scanned photographic views. The software then stretched, or 'rubber sheeted', the scans into undistorted and geo-referenced 'false overhead' digital images and saved them in a special raster file format, known as GeoTIFF image files, with all coordinates embedded in the picture, or raster image. From this rectified or stretched digital photographic reprojection of the original perspective views, the location and dimensions of any element of interest can be plotted as line drawings by hand or converted into CAD-compatible output to produce formal measured plan and profile drawings of each feature. The combined exposure and documentation tasks for the 'Access Road' into the site proper were completed within the designated time frame of one week without interrupting or delaying critical deliveries to the modern factory. This high-resolution 3D recording and data reduction, which integrated a metric film camera with digital image-reprojection software, was completed in one day by one person (Figure 9).

Total 3D data capture – color laser-radar, or LIDAR

Antecedents Long used for mapping from aircraft and satellites, laser-radar, or light detection and ranging (LIDAR) has now been engineered to operate from the ground to survey and record high-resolution 3D coordinate information with precision and speed. The newer systems are able to record three-dimensional information from distances of up to *c*. 600 ft without human contact. The idea of using terrestrial laser-radar scanners to document the damaged historic district was as a result of learning that the technology had successfully been used in the defense, oil and movies industries. It was also the only identified technology capable of recording a site of this size and complexity both under dangerous conditions and in a fraction of the traditional timeframe (Figure 9). The development of terrestrial LIDAR provided a remote, non-contact, safe and rapid means to capture the form, dimensions, coordinates, color, and texture of a monument or archaeological resource without extended human contact with the subject.

High-resolution laser-radar scanners and software were first released as a joint venture between Chevron Oil and the United States Defense Advanced Research Projects Agency (DARPA) to record existing conditions, and unmapped hardware additions, on unmapped oil platforms. The technology was first released for public and commercial applications in 1998. Parallel government-supported research and development was also supporting field tests of the new technology on high suspension bridges in Montreal, Canada, and for the mapping of deep caves in France. It was soon also adopted by the Hollywood movie industry, where animated interstellar bugs were precisely positioned onto a large set model of a cave-nest for the science fiction film Star Ship Troopers.

The US Department of Interior had used an early version to capture a monochrome record of the Statue of Liberty and other potentially threatened national monuments after 9/11. The author himself had deployed the initially released 1998 generation of LIDAR in 1999 to address an unexpected archaeological discovery in Albany, New York. While the initial 1999 attempt was not successful, this most recent one delivered excellent results under adverse conditions.

The laser-radar sends out a vertical stream of pulses that create a point cloud of measurements. Each is reflected back to the instrument and recorded as x,y, and z coordinate points, each initially referenced to an arbitrary, or 'floating', grid. Previously surveyed control targets, on the subject and visible in each scan, linked, or 'geo-referenced', the 'raw'-point data to real-world coordinates. The 3D LIDAR software systems integrate the independent point clouds into a single data set of uniform coordinates, and then use the coordinates of the previously surveyed control-targets to 'reproject' the 3D LIDAR data into a uniform map reference system of the operator's choice. The LIDAR reduction software also is able to link the millions of points into a 3D mesh, or surface, model of the subject as well as CAD-compatible vector, or engineering, files.

Benchmarks and criteria This 3D scanning technology has undergone important refinements and enhancements since its original release. The earliest release of this technology was hampered by three

Figure 9 2003–04/Stanhope, New Jersey. The Riegl true-color LIDAR 'laser radar' system at Furnace Falls Dam, shown with integrated, high resolution (6 Mp) digital camera (released only in Summer 2003). This system was deployed for the first time in archaeology to capture a high-resolution (mm-precise), 3D record of a flood-damaged historic site. Single-camera photogrammetry, with Rolleimetric camera and software system (inset), was used in tandem with the LIDAR to record, remotely, difficult-to-access or dangerous archaeological contexts. Real-time datum control and reference targets were provided by (1) independent computer transit, total-station system; and (2) on-site, sub-decimeter, dual calibration GPS; these systems were used to geo-reference the LIDAR scans with real-world coordinates of the site grid (Nad83). © 2007 Joel W. Grossman, PhD. Published by Elsevier Inc. All rights reserved.

technological limitations of relevance to emergency rescue archaeology: set-up time and coverage, data processing limits, and the lack of color.

The first generation of laser-radar was restricted to scan arcs or coverage of only 30–40°. Each scan segment needed to be saved, the LIDAR unit reset and a new file name assigned before the next slice of the horizontal scan sequence could be continued. The short arc coverage of each scan segment meant that each survey station or set-up location would require at least 10–12 scans to attain 360° coverage. This meant that between 50 and 100 operations and independent data sets needed to be processed. In contrast, the newest equipment is able to continuously scan 360° horizontally and 90° vertically from each set-up. This order-of-magnitude increase in coverage and speed drastically reduces the number of equipment set-ups and requires only 1/10th of the previously necessary data processing time. And for this flood emergency, the enhanced capabilities of the 2003 systems for the first time suggested to the client and government agencies that the soon-to-be destroyed historic structure could be documented by these means – to the highest standards and within the restricted time frame imposed by deep-winter emergency repair work.

The first generation LIDAR hardware could record dense 'point clouds' of millions of coordinate points and could extrude the raw data into primitive geometric forms, such as cylinders and blocks, but was unable to convincingly reproduce the subtlety

Figure 10 2003–04/Stanhope, New Jersey. Overlapping digital photo composite of the visible color channel (what the LIDAR 'saw') of the exposed eastern face of the 1830-era Furnace Falls Dam, produced by a Nikon digital camera computer synchronized with the Riegl LIDAR scan. Each color pixel was matched, pixel by pixel, to the 6 mm-precise, LIDAR scanner-derived, coordinate points – rendering the true color, 3D data captures of the formerly submerged dam. Temperature range during this operation: 10–14° F.

and complexity of irregular and often subtle forms of man-made artifacts or structures. Also, although metrically accurate, the early, 1998–2002, software produced false-color (orange to lime-green) image facsimiles that reflected only variations in signal strength, not the surface characteristics of actual color or texture (as can be indicated by speckling or color variations over 3D surface bumps) (Figure 10).

The problem of color was solved in the summer of 2003, six months before the scheduled field program at Stanhope. The second generation of laser-radar integrated a 6 Mega-pixel digital camera that was synchronized with the motion of the scanner. Each pixel of color was matched to a laser-radar coordinate point to produce the first high-precision, true-color 3D record of an archaeological site (Figure 10). The 2003 release of newer hardware and software systems, capable of producing geo-referenced color LIDAR output, also addressed an emerging issue in emergency rescue archaeology and historic preservation.

In a pivotal 2001 article entitled 'Pitfalls of virtual archaeology', Harrison Eiteljorg II raised the scientific and legal issue of 'representation' vs. 'documentation'. He argued that in order to be scientifically accurate and useful, archaeological data-capture and visualization needs to include the full range of data (i.e., color and texture, as well) with sufficient accuracy and detail to enable the scientist to 'query' the model to investigate and document unaddressed aspects at a later point in time. Accordingly, the 'simulation' of projected color or decoration with computer-graphic techniques of 'surface mapping' – the lamination of 'life-like' digital photos or artistic renderings – over the monochrome surface model would not be adequate as 'documentation'. In the context of emergency rescue operations to mitigate the loss of significant cultural resources, this form of embellishment could not offset the loss of the original data. The 2003 release of integrated digital color-LIDAR provided, for the first time, the capabilities to meet Eiteljorg's conditions and criteria (Figures 11 and 12).

The latest generation of 3D color-LIDAR provides a safe and highly accurate means to remotely measure difficult or dangerous structural elements in hazardous environments. It also meets the criteria of being able to later query and investigate unaddressed elements. In this case, because of the threat of collapse within the unstable channel and flood-damaged

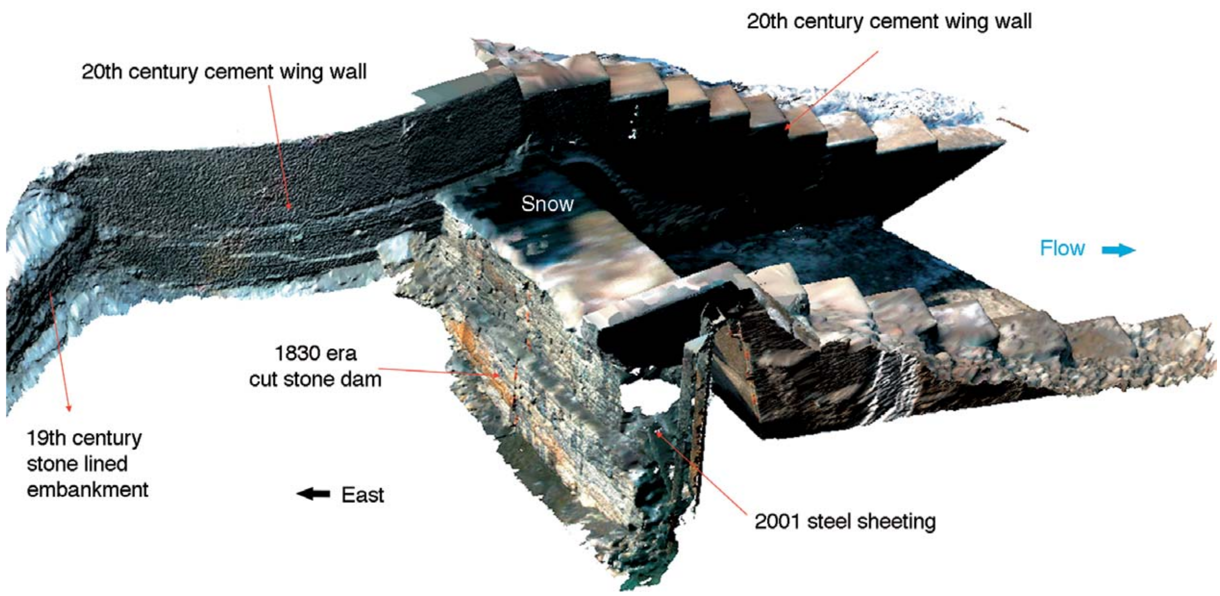


Figure 11 2003–04/Stanhope, New Jersey. Virtual 3D color-LIDAR, or laser-radar scan from *c.* 30 ft. high, birds-eye, perspective view of exposed 1830 Furnace Falls Dam, one of the earliest structures of Morris Canal Historic District, discovered preserved under modern cement spillway after the fast-moving river was diverted overland and dewatered with heavy pumps. The scanner captured a 'point-cloud comprised of millions of coordinate readings and associated color records. Reference to precisely located control targets enabled the 3D record to be geo-referenced to real-world coordinates to produce a rapid, safe 3D metric record without endangering field personnel. © 2007 Joel W. Grossman, PhD. Published by Elsevier Inc. All rights reserved.

cement wing walls, the historic dam was too dangerous work on, or next to, for detailed inspection or measurement. However, once out of the field, the archaeologist was able to 'fly back' into the site to inspect, measure and record from the safety of 'virtual space' (Figures 11 and 12).

Metrics The historic 1830 dam and water control elements of the Morris Canal were scanned and captured in six hours, in eleven equipment set-ups, each – excluding moving and preparation time – lasting about 15 min. Three scans from each position were averaged to produce a total of nine gigabytes of raw data. Each scan episode captured a dense 'point cloud' of coordinates with a resolution of 6 mm (*c.* ¼ in) per point (*c.* 1/100 ft), at an interval of 15 mm (3/4 in) between points and a rate of 12 000 points per second. The geo-referenced color-LIDAR data was saved into several common CAD formats, including AutoCAD and Microstation (dxf, dwg), as well as several 3D modeling file types, specifically 3D color '*.obj' and web-friendly virtual reality modeling language (VRML) (Figures 10–12).

Integrated LIDAR and photogrammetry As the final step of the emergency archaeological recording/mitigation process – and after being scanned by LIDAR – the dam was cross-sectioned and then documented with a combination of photogrammetric recording and LIDAR to yield a geo-referenced measured drawing of the historic structure in profile. Immediately before its destruction, the dam was cross-sectioned under archaeological direction to expose and document its internal structure (Figure 13, bottom). The 90-degree, wide-angle, flat-field macro lens of the single-camera photogrammetric system captured a high-resolution color film record of the cross-sectioned dam. In order to produce the first composite photogrammetric-LIDAR record of an archaeological monument, the photograph was digitized, scanned and geo-referenced to a LIDAR-derived vertical digital profile (Figure 13, top). The dual recording strategies provided a safe and remote means of documenting the damaged historic dam, in 3D, to government standards, with little or no human contact.

Public interpretation and dissemination The ready availability of 3D color imagery and animations of what was captured, by-products of the LIDAR data reduction process, as well as the regular use of digital photography and video as an added bonus helped address some local distress over the lack of public access to the site during the deep-winter fieldwork. The concentration of heavy machinery along both sides of the frozen channel area made such public access too dangerous. The archaeological recording technology inadvertently also provided audio-visual

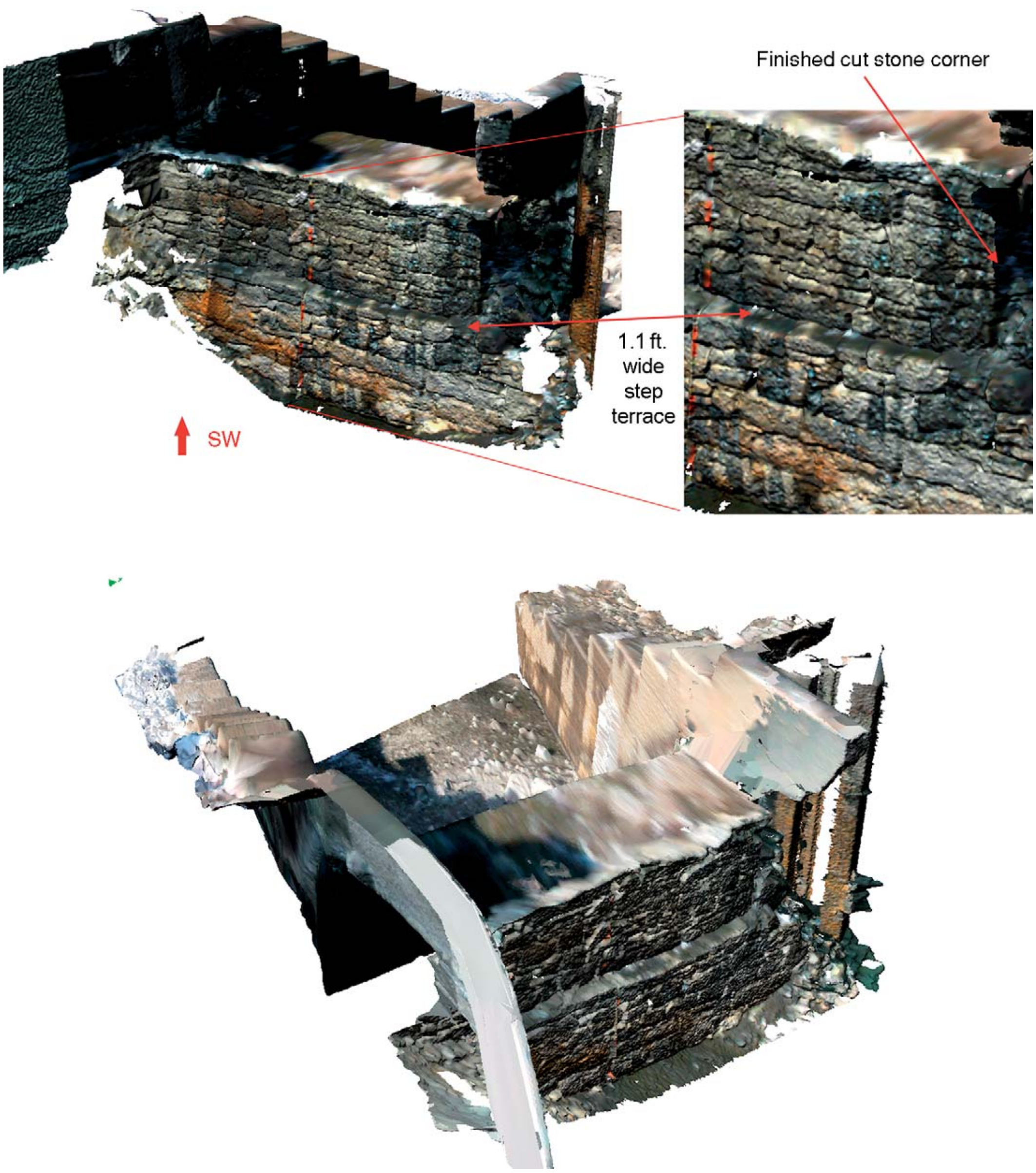


Figure 12 2003–04/Stanhope, New Jersey. Virtual 3D color LIDAR perspective (looking southwest) that highlighted the removed, non-contact recording of Furnace Falls Dam's finished northeast cut-stone corner and inaccessible stone step element of the dam. The ability to 'reinvestigate' the site in geo-referenced 3D color space, once out of the field, provided otherwise unavailable access and proximity to areas of the dam too dangerous to approach during the excavation.

by-products of the documentation and reporting that helped offset these constraits. The results were disseminated among the local communities and institutions (schools, libraries and community groups) on CD Rom. The multimedia disks included a digital copy of the final laser-radar report, a digital-video documentary of the emergency field operations, and 3D animations of the color-LIDAR scans. This effort made both the process and the results transparent and quickly available to the concerned public and preservation community.

Scientific and Regulatory Significance and Implications

While specific categories of applied technology are transitory and often rapidly obsolete, often sometimes with longevity of no more than six months to a year, the underlying 'strategies and capabilities' have been consistently applied with little alteration by the author, initially to address discoveries under construction and then later for archaeological investigation in toxic and hazardous environments. In addition to a 'core' of basic

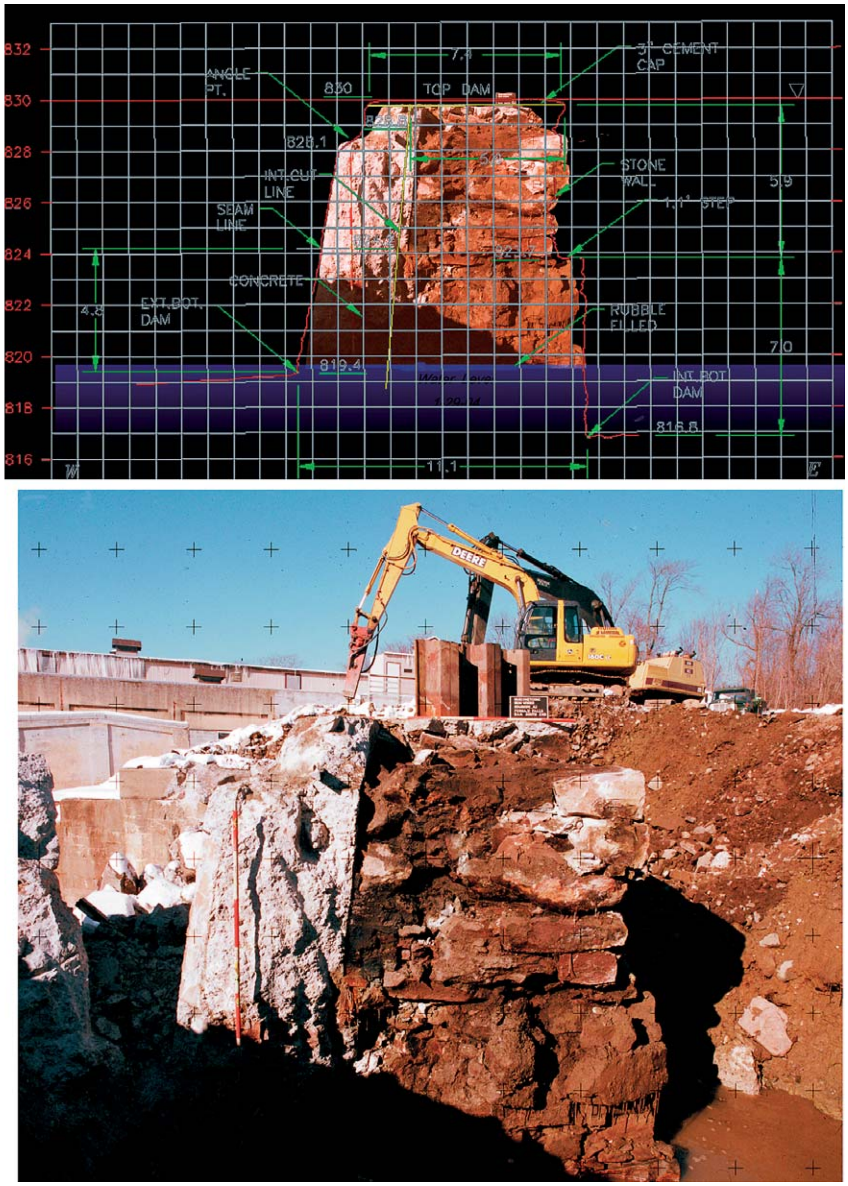


Figure 13 2003–04/Stanhope, New Jersey. (Bottom) Metric photo of sectioned historic dam profile, captured with Rolleimetric camera as the historic dam was sectioned and impounded river water was released to unblock the flood-damaged channel. Note the imbedded calibration marks used to correlate metric photograph with real-world coordinates recorded by the laser-radar. (Top) Digital composite of Rolleimetric photo of cross-section of 1830-era cut-stone dam – the metric photo is scaled, overlaid, and geo-referenced to LIDAR-derived elevation and dimension profile measurements.

archaeological techniques, the investigation of dangerous and/or toxic contexts has consistently relied upon a common set of strategic and logistical approaches and toolkits: (1) the use of geospatial procedures to control existing conditions and provide historic map correlations as well as for the evaluation of terrestrial geophysics to target buried resources, (2) on-site concurrent laboratory data control and conservation, (3) high-speed remote and non-contact 3D recording systems, (4) all-weather environmental control systems, (5) self-contained power, dewatering, heat, and communication systems, (6) adherence to HAZMAT health and safety procedures, through on-site decontamination of artifacts and staff when required, and finally (7) the precondition that all archaeological tasks be defined by highly resolved task-specific budgets, pre-authorized to include data-derived benchmarks, or triggers (e.g., concurrent laboratory-derived increments in artifact totals) for seamless changes in projected levels of effort and budget allocation.

In addition to these shared characteristics, both of the cases presented here demonstrate the integration of a range of applied technology solutions in order to facilitate the safe and rapid investigation of logistically challenging, contaminated or dangerous archaeological settings. The West Point case also proves that the profession of archaeology is able to operate in tandem, and in full compliance, with existing Superfund regulations and constraints, in the context of dangerous or toxic environments and without scientific compromise. The success of the archaeological rescue effort in Stanhope underscores the emerging ability of modern archaeology and new technologies of site recording to jointly do justice to important cultural resources, to the highest standards of the US Department of Interior, even in the face of restricted time frames and difficult conditions. It also demonstrates the ability to mobilize, plan and resolve archaeological emergencies in tight coordination with ongoing emergency repair or rescue activities, under extreme weather conditions and without delay.

At the policy level, the near-total data control provided by the new generation of 3D geospatial recording technologies present cost-effective alternatives to traditional methodological impediments to implementing historic preservation mandates in hazardous situations or natural disasters. Finally, these new, and constantly improving, capabilities also now suggest that the old Hobson's choice (a choice that is not a real choice) of 'history versus progress or', in this case, 'history versus natural' disaster, may no longer apply.

Acknowledgments

The emergency rescue work in Stanhope was conducted under contract with Compac Corporation. The work at Cold Spring was done under contract with Malcolm Pirnie, Inc. under the auspices of, and with funding by, the US E.P.A, with project oversight provided by the US Army Corps of Engineers.

See also: **Cultural Resource Management**; **Environmental Impact Assessment and the Law**; **Remote Sensing Approaches**: Aerial; Geophysical.

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TRACE ELEMENT ANALYSIS

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Glossary

diagenesis The process of chemical and physical change in deposited sediment during its conversion to rock.

Introduction

Evaluation of dietary components and the general health of early peoples has been advanced through the use of analyses of skeletal materials for major, minor, and trace elements. Early work, during the 1970s, optimistically focused on developing new analytical techniques and baseline data. Three basic approaches to trace element studies involved the analysis of single elements (such as lead or iron), multiple elements, and ratios of elements (such as