DESIGNING BORROW PIT CAD SITES: REMEMBER NEWTON'S THIRD LAW!

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ABSTRACT

With the increasing popularity of using borrow pits as confined aquatic disposal sites for contaminated sediment management (e.g., Hong Kong, Boston Harbor, Los Angeles Harbor, Puget Sound), engineers need to remember some lessons learned from past disposal projects when recommending designs for new projects. Results from monitoring at the Bremerton Naval Complex CAD pit demonstrate that one cannot rely on disposal models alone for predicting the fate of dredged material on the seafloor. Disposal of approximately 400,000 cy of contaminated sediment in a borrow pit located in 10 meters of water in Puget Sound was followed by placement of a 5 ft layer of capping material. Grab sampling performed after completion of the capping operation showed elevated contaminant concentrations as far as 300 ft (the farthest distance sampled) from the pit perimeter. A subsequent survey with Sediment Profile Imaging technology showed that material from disposal operations had spread as far as 200 meters from the pit boundary. Periodic monitoring with the proper tools during all phases of the disposal operation is critical to insure that final design criteria and regulatory objectives are achieved.

Failure to remember Newton's Third Law will result in borrow pit CAD projects being perceived of as "failures" by both the general public and regulatory community and will eliminate this valuable disposal alternative as a viable option for future projects. By combining the proper public outreach before the project gets underway and employing the right monitoring protocols as part of the project design, we can insure that borrow pits will continue as a viable disposal alternative in the future for managing contaminated sediments.

Keywords: Disposal modeling, sediment profile imaging, capping.

INTRODUCTION

During the past decade, a popular aquatic disposal option for contaminated sediments has been the use of either historical or newly-created borrow pits; contaminated sediments are placed in the pit initially, followed by a capping layer of clean sediments to bring the level of the pit up to that of the ambient seafloor. One of the more common illusions associated with using borrow pits as opposed to level-bottom areas for capping projects is that the contaminated material will not be spread over as big an area of the seafloor; depending on the depth of water and how disposal operations are conducted, that may or may not necessarily be the case. Despite whatever measures are taken during disposal operations, managers should <u>always</u> plan on finding contaminated material beyond the confines of the borrow pit and take that into consideration for planning their subsequent capping operations.

Borrow pit CAD sites were first used on a large-scale in Hong Kong in the early 1990's associated with the construction of the new Chep Lap Kok airport (Brand et al. 1994) and have since been used in the US for channel deepening in Boston as well as for a demonstration project in Los Angeles Harbor and a remedial action alternative in Puget Sound. An important lesson learned from the Boston Harbor project was to allow sufficient time for the contaminated material to consolidate before cap placement begins; however, an important lesson ignored from all of these projects is that varying percentages of any material placed in a CAD pit (suitable or unsuitable) will not fall within the designated boundaries of the pit. While this paper will focus on the results of the Bremerton CAD project in Puget Sound, there are similar attributes with past disposal projects (both unconfined and confined open-water disposal) that engineers and project managers should keep in mind when designing future borrow pit CAD projects in order to prevent the perception of failure.

Dredging Requirements at the Bremerton Naval Complex

As part of the Navy's plan to provide deeper and wider berths for Nimitz-class nuclear-powered aircraft carriers at the Bremerton Naval Complex (BNC) in Sinclair Inlet, Puget Sound (Washington, USA), during the mid-1990's they earmarked 368,000 cubic yards (cy) of sediment to be dredged from berth areas and turning basins (Foster Wheeler 2002; all the information presented in this initial section about the BNC is taken from this report). Based on chemical and biological testing, approximately 125,000 cy of the sediment was found to be unsuitable for open-water disposal according to the Puget Sound Dredged Disposal Analysis (PSDDA) framework.

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During this same timeframe, but under a separate planning process, the Navy was planning to remediate marine sediments at their facility in Bremerton; studies carried out at their berthing, nearshore, and dry dock areas at the BNC revealed contamination in the top 2 feet of sediment. Approximately 217,000 cy of contaminated sediments were designated for removal.

As part of the Record of Decision (ROD) signed in June 2000, the Navy combined these two projects with the intent to perform mass removal of the PCB-contaminated sediments to accelerate natural recovery. Because the BNC was adjacent to aquatic lands owned by the Washington State Department of Natural Resources, and, for ease of permitting, all sediments earmarked for removal were to stay on Navy property, a subaqueous Confined Aquatic Disposal (CAD) pit was selected as the preferred disposal alternative (Figure 1). The CAD pit was designed and constructed to contain both the unsuitable and CERCLA-contaminated sediments. The CAD pit was created by dredging a subaqueous pit (379,243 cy) within the BNC property lines; the pit was a 600 by 615-ft. rectangle that was 30-ft deep (-66 feet mean lower low water) with a 3:1 (horizontal:vertical) slope on the CAD pit walls, making

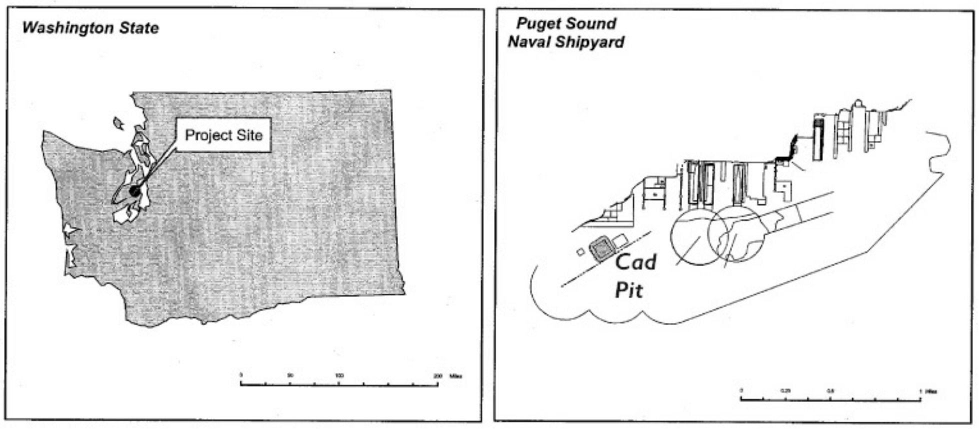

Figure 1. Location of the borrow pit at the Bremerton Naval Complex, Sinclair Inlet, Puget Sound, WA

an effective base of 400 by 415-ft. The surface of the CAD pit was a soft, unconsolidated clayey-silt; as the depth increased, the texture of the material because significantly more firm and consolidated (Foster Wheeler 2002).

Dredging of the CAD pit was done by General Construction Company's derrick barge *Seattle* equipped with a 165-ton duty cycle crane with a 24-cy environmental closed clamshell bucket manufactured by Cable Arm, Inc. Sediment excavated from the CAD pit was taken to three different locations. A total of 35,334 cy was stockpiled adjacent to the CAD pit for use as a finishing layer over the CAD pit cap. A total of 57,343 cy was used as the thick/thin cap for nearshore areas of the BNC requiring remediation, and 286,566 cy was transported to the Elliott Bay Open-Water Disposal Site for disposal; dredging of the CAD pit was completed on August 12, 2000.

Dredging at the CERCLA-contaminated areas began on August 30, 2000 using both 24-cy and 27-cy environmental dredging bucket manufactured by Cable-Arm, Inc.; in those areas where harder sediments were encountered, a 15-cy Hawco conventional bucket was used. All sediment was loaded into 1,500-cy capacity split-hull barges, transported to the CAD pit, and disposed at the CAD pit. The schedule of dredging the CERCLA sediments was determined by berth availability, ship movement requirements, and compliance with environmental windows due to ESA and Tribal Indian Treaty fishing rights. CERCLA dredging was completed on February 9, 2001, and a total of 225,644 cy of sediment was placed in the CAD pit from the CERCLA dredging operation.

Navigational dredging to maintain moorage capabilities for the BNC consisted of dredging in four different pier areas as well as the turning basin/approach channel to the BNC; dredging with both the 24-cy and 27-cy environmental dredging bucket as well as a conventional bucket was carried out between October 19, 2000 and January 17, 2001. A total of 174,360-cy of unsuitable material was transported to and disposed at the CAD pit, and an additional 392,000-cy of suitable material for open-water disposal were taken to the Elliott Bay Disposal site.

Following the completion of contaminated sediment disposal, a cap was required to isolate the contaminated sediments from the water column and biological receptors. The ROD allowed for either sand or native sediment to be used as capping material. In the remedial design, the cap was designed to be a minimum of 3 feet thick and would be achieved by placing imported sand from a hydraulic diffuser deployed at the water surface. After completion of the sand cap, an approximate 1-foot-thick layer of suitable native sediment that had been excavated from the CAD pit and stockpiled adjacent to the CAD pit during construction would then be placed by bottom-dump barge over the CAD pit. The capping plan was modified as the project evolved to beneficially use suitable sediment from the turning basin as part of the capping material. As agreed upon with the regulatory agencies, the CAD pit was constructed in three stages:

- A 1-foot nominal initial sand cap;
- A 2-foot nominal cap of suitable sediment from the turning basin; and
- A 2-foot nominal cover of suitable stockpiled CAD pit sediment.

Filling and Capping of the CAD Pit

Over a period of 5+ months, both CERCLA and unsuitable sediments designated for disposal at the CAD pit were placed in split-hull bottom-dump barges having a capacity of 1,500 cy and towed to the CAD pit by a tugboat. A total of 431 disposal events occurred within the boundary of the CAD pit. Each disposal event averaged 8.2 minutes from opening the split-hull to emptying its contents. The tugboat was equipped with WINOPS software for positioning the bottom-dump barge; horizontal positions were integrated into WINOPS from DGPS equipment onboard the tugboat. Coordinates for each disposal event were recorded, and the CAD pit was filled with the intention of evenly spreading the material within its bounds. The base of the CAD pit floor (400 by 415 feet) was divided into four quadrants for disposal tracking purposes, and the barges rotated disposal loads among the quadrants to provide even distribution of sediment over the CAD pit. Each quadrant was targeted based on progress surveys conducted periodically at the CAD pit. To avoid sloughing of the CAD pit sidewalls, all barge dumping occurred over the floor of the CAD pit while filling, resulting in a 100-foot shoulder (i.e., buffer) inside the CAD pit boundary. Each position of the barge opening, emptying, and closing of the split-hull doors was recorded and plotted. This placement methodology was maintained throughout the course of the CAD pit filling to fulfill the requirements of the EPA WQC and to maintain the structural stability of the side slopes.

A total of 400,000 cy of CERCLA (ca. 223,700 cy), unsuitable navigation sediment (174,360 cy), and Site 1 TOE trench sediment (ca. 1,950 cy) was placed in the CAD pit. Of the total volume contained in the CAD pit, 397,000 cy of sediment was placed prior to February 15, 2001. The remaining 3,000 cy was dredged from the west turning basin and placed in the CAD pit on June 18 and 19, 2001.

The CAD pit cap was created in three stages and was comprised of a nominal 1-foot sand cap (16,567 cy) followed by a 4-foot final cap made of suitable sediment from the turning basin and stockpiled sediment excavated from the CAD pit. Stockpiled sediment was also placed approximately 2 feet thick to a distance of 100 feet from the perimeter of the CAD pit on Navy property (16,934 cy). Stage 1 involved placement of a 1-foot nominal cap of imported sand, which began following a 126-day consolidation period for 99.3 percent (by volume) of the sediment placed within the CAD pit. The remaining 0.7 percent of unsuitable sediment placed June 18 to June 19, 2001, was not considered a concern for cap construction because of the consolidation time achieved. Stages 2 and 3 involved dredging suitable sediment from the turning basin and rehandling the sediment stockpiled during construction of the CAD pit and placing the sediment in the CAD pit to create a nominal 4-foot final cap.

Because of the experience gained from the Boston Harbor borrow pit CAD project, the main concern was that the very soft, fine-grained contaminated sediments placed in the pit would encounter shear failure, resulting in the contaminated sediment being pushed sideways and upwards under the additional weight of the initial sand cap. As required by the EPA WQC, monitoring was conducted to document the temporal variation of consolidation and increases in shear strength of the sediment disposed within the CAD pit; these monitoring tasks included bathymetric surveys, gravity cores, and *in-situ* vane shear tests. With the exception of the bathymetric surveys, problems were encountered with obtaining gravity cores and *in-situ* vane shear measurements due to the soft nature of the sediments in the pit. However, the estimated consolidation settlement in the first 4 months after filling was 1.6 feet. Vane shear measurements done in May and June of 2001 indicated the surface sediment in the CAD pit had sufficient strength by mid-June to support 12 inches of sand, so placement of the initial sand cap started in June, 2001.

Before sand placement began on June 20, 2001, a series of tests were performed by the dredging barge *Portland* to verify the area covered by and the approximate volume of sand placed with each bucket. The *Portland* was equipped with WINOPS software for positioning the bucket over the CAD pit. The plan for sand capping was designed to ensure uniform sand distribution over the entire CAD pit surface. The placement of the sand cap proceeded in a methodical approach, following a grid laid out over the CAD pit area. Each box on the grid corresponded to one "swath" of a full 4-cy bucket of sand. Each crane operator was allowed time to become familiar with the process of evenly distributing the sand. This was done by simulating sand placement from a one-bucket swath by cracking the bucket open a few inches while sweeping it over a flat-deck barge. The distribution of sand was measured to verify uniformity and the operators were required to repeat the process until they were proficient. Once the operators demonstrated proficiency at evenly distributing the sand, placement of the sand cap over the CAD pit proceeded. The placement started along the first plotted lane and moved west to east. The lanes were three bucket "swaths" wide. Over four thousand cycles were required to place 16,567 cy of sand. Sand cap placement activities took a total of 10 days from June 20 to 30, 2001; the sand served as an initial layer between the completion of the CAD filling and the required 60-day minimum consolidation period before the final cap could be placed. Subsequent monitoring by bathymetry, sub-bottom profiling, towed underwater video cameras, and gravity cores confirmed that an average thickness of 1 foot of sand was placed on the top of the CAD pit.

Previous design calculations by Foster Wheeler indicated that the sediment in the CAD pit would settle a total of several feet under the weight of the final cap, and this consolidation would require several years to complete. Therefore, to avoid a depression in the final surface of the CAD pit and comply with the ROD requirements that the final cap be restored to the pre-construction mud-line, the final cap was placed 3-5 feet higher in the center of the CAD pit than at the edges.

Placement of the final cap on the CAD pit was completed using the remaining suitable sediment from the turning basins and the previously stockpiled sediment excavated to build the CAD pit. The dredging barge *Nitro*, equipped with a 40-ton duty cycle crane with a 10-cy environmental bucket manufactured by Cable Arm, Inc., a DGPS, a Hazen Tide Gauge Model HTG 5000, and the WINOPS software for the capping activities was used for this phase of the operation. For placement of the final cap material at the CAD pit, a seven-pocket bottom-dump barge (scow), the *DS-7*, with a capacity of 1,500-cy (215 cy/pocket) was used. The *Nitro* began dredging the remaining suitable sediment from the turning basin on September 10, 2001. The dredged sediment was loaded onto the *DS-7* and taken to the CAD pit by tugboat. The tugboat was equipped with WINOPS software for positioning the pocket scow over the CAD pit. Horizontal positions were integrated into WINOPS from DGPS equipment onboard the tugboat. The seven compartments were opened sequentially, providing for controlled sediment placement over the CAD pit. To expedite the individual barge disposals, the individual pockets remained open until the barge was completely emptied.

For construction of the final cap, the surface of the CAD pit was divided into 211 grid cells. The pockets of the scow were 30 feet by 17 feet, and the grids were set up on a 42-foot by 45-foot pattern to withstand some movement by the tugboat and barge during disposal within the individual disposal target locations. Each grid covered an area of 1,600 to 2,000 square feet. During the placement of material in the perimeter target locations, extra caution was taken by the tugboat captain to stay within the confines of the CAD pit. Final capping activities were completed on October 30, 2001. A summary of the volumes disposed at the CAD pit and the capping layers is shown in Tables 1 and 2:

Table 1. Filling of the CAD Pit

Type of Material/Sediment	Volume Based on Bathymetry or Barge Volume (cy)
CERCLA Sediment	223,689
MCON Unsuitable Navigation Sediment	174,360
Site 1 Toe Trench Sediment	1,955
Total CERCLA and Unsuitable Sediment	**400,004**

Table 2. Capping of the CAD Pit

Type of Material/Sediment	Required Thickness (ft)	Volume Based on Bathymetry of CAD Pit (cy)	Average Thickness Based on Bathymetry (ft)	Volume Based on Sub-bottom Profile[2] (cy)	Average Thickness Based on Sub-bottom Profile[2] (ft)
Capping Stage 1, Sand Cap	1	16,567[1]	1.2	17,205	1.2
Capping Stage 2, Final Cap (turning basin-suitable and stockpile sediment)	4	68,788	4.8	77,161	5.5
Capping Stage 3, Stockpile Sediment (placed 100 ft outside CAD pit)	1	16,934	2.2	NA	NA
Total (within CAD pit boundary)	**5**	**85,355**	**6.0**	**93,919**	**6.6**

1/ Based on barge tickets.
2/ The volume and thickness of the initial sand cap, suiteable sediment cap, and the total CAD pit cap were each calculated independently based on the sub-bottom data; therefore, the total volume and thickness of the cap is not the sum of the initial sand cap and the suitable sediment cap.

The First Hint of Problems

As required by the EPA WQC, sediment grab samples were collected approximately 20 feet from the perimeter of the CAD pit prior to the construction of the CAD pit in June 2000. In August 2001, the sediment sampling was repeated at the same locations following the disposal of the CERCLA and unsuitable sediments and the placement of the initial sand cap. Based on a comparison of the analytical results, the data indicated elevated concentrations of PCBs and mercury outside the CAD pit boundary. As a result of the increased concentrations, additional sampling was performed up to 300 feet from the perimeter of the CAD pit. These analytical results also indicated elevated concentrations of PCBs and mercury.

In response to these elevated concentrations, the regulatory agencies requested some additional effort by the Navy, and the Navy took immediate action to enhance the cap that was originally proposed for the CAD pit. It was mutually agreed that once the dredging of the turning basins was complete, the stockpile material would be placed to a distance of 150 feet from the perimeter of the CAD pit at an average depth of 1 foot on Navy property only because authorization had not been received from WDNR to place material on their property. However, on the morning of October 18, 2001, it became apparent that the placement of the stockpile material would be completed much faster than anticipated, and that direction by the Navy regarding the placement of the stockpile material on the CAD pit was needed immediately. After discussion with the Navy on October 18, 2001, it was agreed that material would be placed only up to 100 feet from the perimeter of the CAD pit. It was also decided that the material needed to cap up to 100 feet on WDNR property would be kept as reserves in the stockpile area for capping at a later date.

Another phone conference was held on October 23, 2001, with the regulatory agencies to develop a course of action for dealing with the elevated sediments outside the CAD pit. Based on the schedule for completion of capping at that time, it was mutually agreed that the 2,500 cy of stockpile material would be placed within 100 feet of the perimeter of the CAD pit, excluding WDNR property, and the remaining material originally planned for capping the elevated sediments on WDNR property would be placed on the CAD pit to fill in low areas.

Representatives from the federal and Washington state regulatory agencies presented the results of the August 2001 BNC CAD pit sampling at the annual Sediment Management Annual Review Meeting (SMARM) held in the Puget Sound area each spring (April-May time frame) and expressed surprised to find elevated concentrations of sediment contaminants "as far as 300 feet" from the perimeter of the CAD pit. Follow-up discussions with these regulators pointed out that these sorts of results have been found previously in other areas of the world with both level-bottom capping projects as well as other borrow pit CAD projects, and it was quite likely that the disposed material had spread much further than 300 ft (91.4 meters) beyond the CAD pit perimeter. Germano & Associates had just completed a series of sediment profile imaging (SPI) surveys as part of the Los Angeles Harbor Borrow Pit demonstration project conducted by the US Army Corps and found contaminated material as far as 300 meters away from the pit boundary immediately after disposal. As a follow-up to the SMARM presentation, EPA authorized additional monitoring to be carried out by Germano & Associates using SPI technology to document the lateral spread of dredged material beyond the CAD pit boundary.

Verification Monitoring Using SPI

SPI was developed almost two decades ago as a rapid reconnaissance tool for characterizing physical, chemical, and biological seafloor processes and has been used in numerous seafloor and disposal site monitoring surveys throughout the United States, Pacific Rim, and Europe (Germano 1983; Germano and Rhoads 1984; Rhoads and Germano 1982, 1986, 1990; Revelas et al. 1987; Valente et al. 1992). The sediment profile camera works like an inverted periscope. A deep-sea 35mm camera mechanism with a 50-ft bulk film cartridge is mounted horizontally inside a watertight housing on top of a wedge-shaped prism. The prism has a Plexiglas® faceplate at the front with a mirror placed at a 45° angle at the back. The camera lens looks down at the mirror, which is reflecting the image from the faceplate. The prism has an internal strobe mounted inside at the back of the wedge to provide illumination for the image; this chamber is filled with distilled water, so the camera always has an optically clear path to shoot through. This wedge assembly is mounted on a moveable carriage within a stainless steel frame. The frame is lowered to the seafloor on a winch wire, and the tension on the wire keeps the prism in its "up" position. When the frame comes to rest on the seafloor, the winch wire goes slack (Figure 2) and the camera prism descends into the sediment at a slow, controlled rate by the dampening action of a hydraulic piston so as not to disturb the sediment-water interface. On the way down, it trips a trigger that activates a time-delay circuit to allow the camera to penetrate the seafloor before any image is taken. The knife-sharp edge of the prism transects the sediment, and the prism penetrates the bottom. The strobe is discharged twice with each lowering to obtain two cross-sectional images of the upper 20 cm of the sediment column. After the two replicate images are obtained at the first location, the

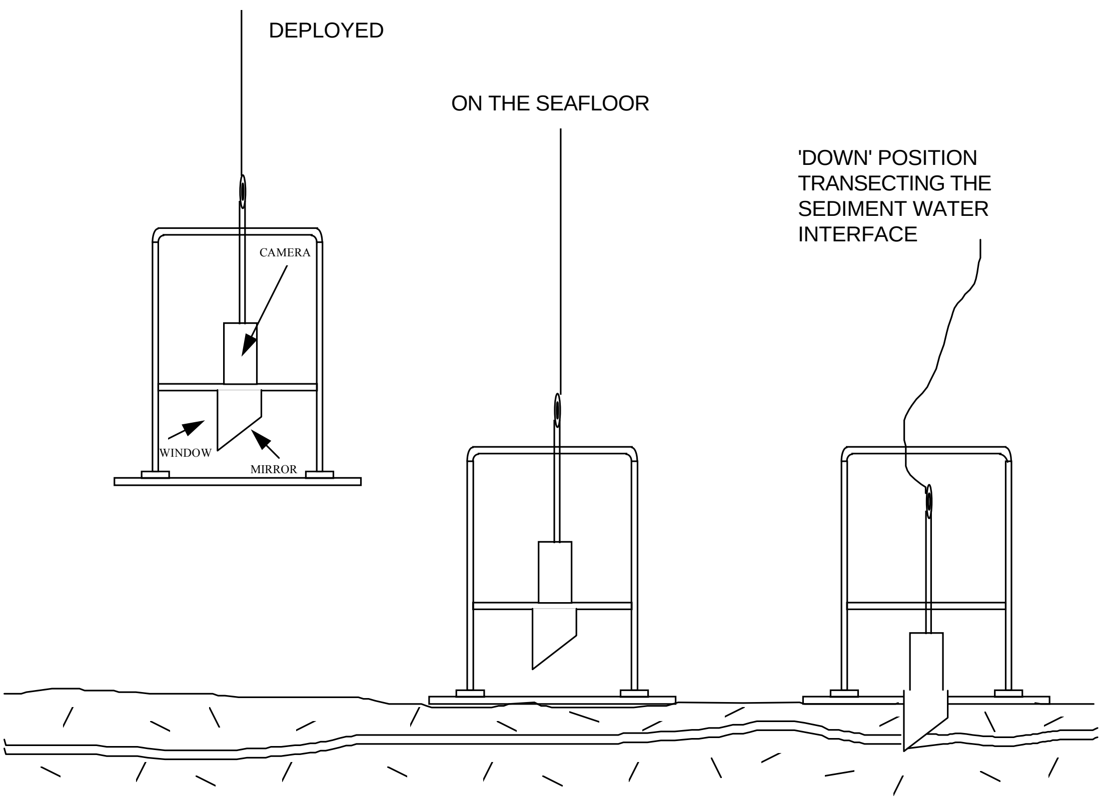

Figure 2. The central cradle of the camera is held in the "up" position by tension on the winch wire as it is being lowered to the seafloor (left); once the frame base hits the bottom (center), the prism is then free to penetrate the bottom (right) and take the photograph.

camera is then raised up about 2 to 3 meters off the bottom to allow the strobe to recharge. The strobe recharges within 5 seconds, and the camera is ready to be lowered again for another two images. Surveys can be accomplished rapidly by "pogo-sticking" the camera across an area of seafloor while recording positional fixes on the surface vessel. The resulting images give the viewer the same perspective as looking through the side of an aquarium half-filled with sediment.

To document the spread of dredged material at the BNC borrow pit CAD site, a series of transects radiating from the site perimeter were occupied with stations placed every 50 feet (Figure 3). The SPI survey was carried out on July 31 and August 1, 2002, approximately 9 months following completion of the final capping operation. Kodak Ektachrome® color slide film (ISO 200) was used throughout the entire survey. At the beginning of the survey, the time on the sediment profile camera's internal data logger was synchronized with the internal clock on the computerized navigation system. Two camera lowerings (four replicate images) were taken at each of the 90 stations surveyed; water depths ranged from 8 to 13 meters. Each SPI replicate was identified by the time recorded on the film and on disk along with vessel position. Even though multiple images were taken at each location, each image was assigned a unique frame number by the data logger and cross-checked with the time stamp in the navigational system's computer data file. The field crew kept redundant sample logs, and all film taken was developed in the field at the end of each completed roll to verify successful data acquisition; strict controls were maintained for development temperatures, times, and chemicals to insure consistent density on the film emulsion. The final report was submitted to EPA one week following completion of field sampling operations.

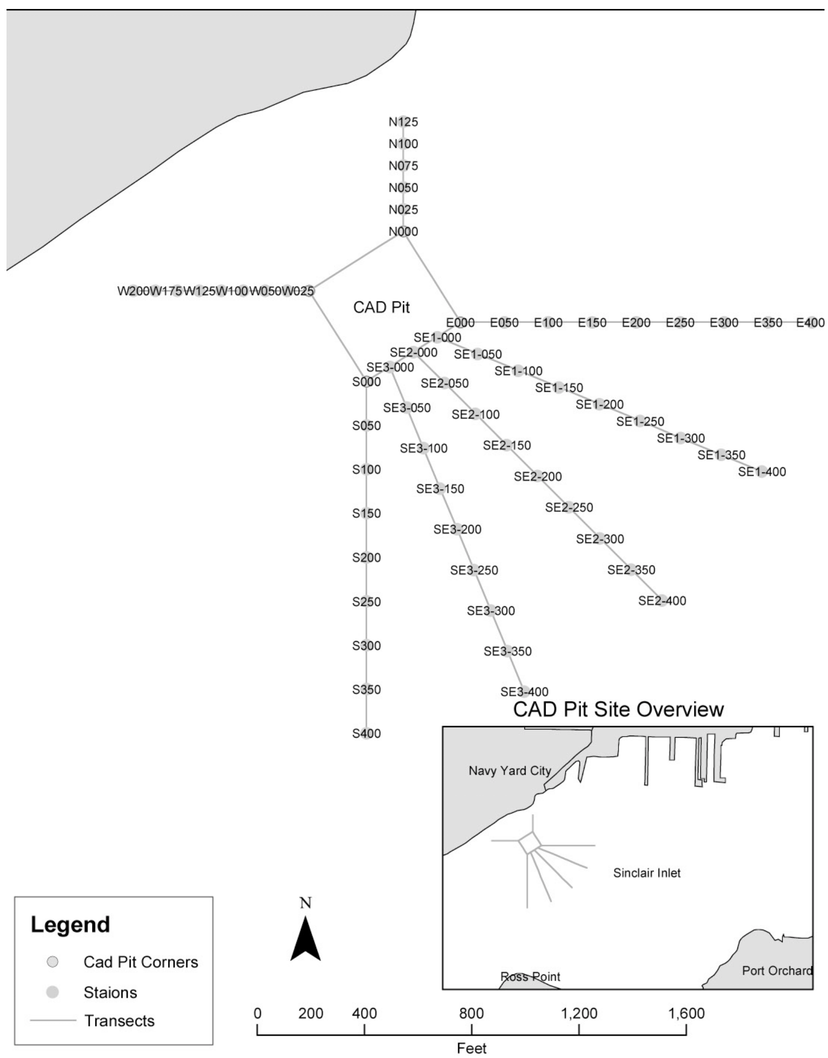

Figure 3. Location of the SPI sampling stations for detection of disposed material footprint

RESULTS

While the survey was extremely successful as far as detecting the presence or absence of dredged material in the area outside the CAD pit, the optical signature of the dredged material was not as obvious as we have found in other locations when we were able to perform the survey either immediately after or within 1-2 weeks following disposal operations. The optimal time to map the extent of dredged material deposits using a combination of acoustical and optical survey techniques is within 1-4 weeks after completion of the disposal operation. However, the dredged material still had a distinct fabric and texture that allowed us to distinguish it from the ambient sediments.

The sediment grain-size major mode was in the silt-clay range (> 4 Φ) at all stations except for station N125, where there was a thin surface layer of very fine sand at this shallow location. There was no evidence of the sand cap at any of the stations sampled either outside or inside the designated CAD boundaries; two stations (CP 01 and CP 02) were sampled inside the CAD pit with the camera stop collar settings deliberately put in a position so that the prism would over-penetrate in the hopes of detecting some of the sand layer signature. Despite successfully over-penetrating the sediment surface (the camera easily went in at least 30 cm based on the mud clinging to the prism upon retrieval), the camera did not penetrate far enough to detect the sand layer. However, the surface deposit of fine-grained dredged material, while having an identical grain size distribution to the ambient sediments, had a distinct fabric and higher shear strength compared with the more fluid, ambient, fine-grained sediments. The dredged material within the CAD boundaries and closer to the pit perimeter was more cohesive and resembled modeling clay (Plasticine) in texture, while the ambient sediments had a much higher water content and a "cake batter" appearance.

Dredged material of varying thickness extended beyond the CAD pit boundary in all directions surveyed, sometimes as far as 200 meters (Transect SE-2; see Figure 4). At numerous stations (N0, N025, N050, E0, E25, S0, S050, S100, W0, W025, W050, SE1-0, SE1-050, SE2-0, SE2-050, SE3-0, SE3-050, NE0, NE025, NE050, NE075, NE100, NE200, SW0, SW025, SW050, SW075, CP01, and CP02), the layer of dredged material was thicker than the penetration depth of the sediment profile camera prism in one or both replicate images, making it impossible for us to state the absolute thickness of the dredged material layer(s) at these locations (while coring would be required at these locations to determine the absolute thickness of the cap, it would be extremely difficult at this point to visually distinguish the dredged material from the underlying sediment because of the consolidation that occurs with coring). At several stations (N075, S050, S100, S115, W0, SE2-115, SE2-130, SE2-200, SE3-115, SE3-130, SE3-150, SW050, SW075), multiple layers of dredged material were detected, representing different depositional events during the course of the disposal operation.

The trailing apron and end of the deposit could be distinguished along each transect except for the NE transect sampled on the second day (dredged material was detected all the way out to NE200, although the thin 6.6 cm layer at NE150 hints that the thicker deposit detected at NE200 may have been from the stockpiling operation done during the CAD construction).

The other notable feature from all the images in this survey was the degree of recolonization by the local infauna and the amount of bioturbation that has occurred since the disposal operation has stopped. Without exception, there was evidence of mature, infaunal deposit-feeding activity at all the stations where dredged material was detected; the local fauna had recolonized the stations outside the CAD pit either through upward burrowing and re-establishing themselves near the sediment-water interface or from lateral migration. Given the depositional nature of the site and rate of bioturbational activity, I would predict that within another 6-12 months it would be impossible to distinguish the optical characteristics of the dredged material layer from the ambient sediment using SPI technology.

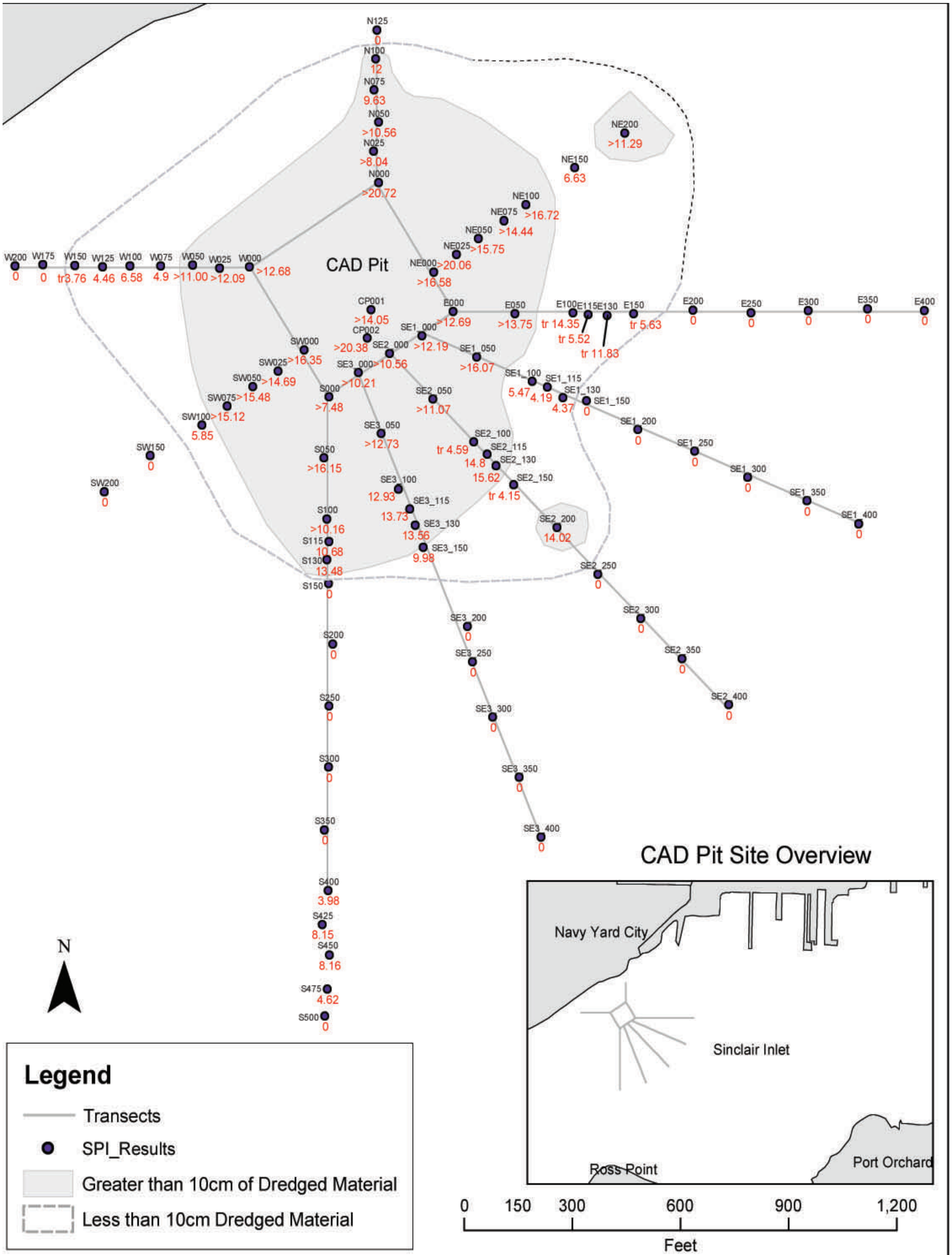

Figure 4. Footprint of dredged material surrounding the CAD Pit as detected with SPI technology

CONCLUSIONS

The results from the SPI survey at the BNC borrow pit CAD site confirmed similar results found at both unconfined and confined open-water disposal sites during the past 2 decades: that a substantial volume of fine-grained dredged material can spread out in a thin apron beyond the disposal point. While the amount of spread can be controlled somewhat by careful disposal operations (such as was the case at the BNC borrow pit site), Newton's third law on the conservation of momentum cannot be ignored. Early studies in the Army Corps' Dredged Material Research Program (DMRP) carried out in the 1970's showed that dredged material goes through three phases following release from a surface barge: convective descent, dynamic collapse, and passive dispersion. The first two phases happen within the initial seconds/minutes (depending on water depth) following release of material. Because we know that Force = Mass x Acceleration, given the mass of sediment in a disposal barge and the acceleration caused by gravity over the distance traveled through the water column, the resulting force is translated laterally (conservation of momentum) once the slug of sediment hits the bottom. This means the downward force vector of convective descent is translated horizontally to the lateral force vector of dynamic collapse; the downward momentum is conserved by the horizontal translation of material until the force is diminished due to friction – in other words, disposed material can travel quite far from the release point depending on the volume in the barge and the height of the water column through which it falls.

Recent work done during the capping demonstration at the Palos Verdes site has illustrated this phenomenon quite convincingly (McDowell et al. 2002). A series of bottom tripods with acoustic sensors placed at experimental disposal cells show the surge of dredged material moving outward in an annulus following impact with the bottom in a period of minutes (Figure 5), but the surge had lost most of its horizontal momentum by a few hundred meters away from the disposal point.

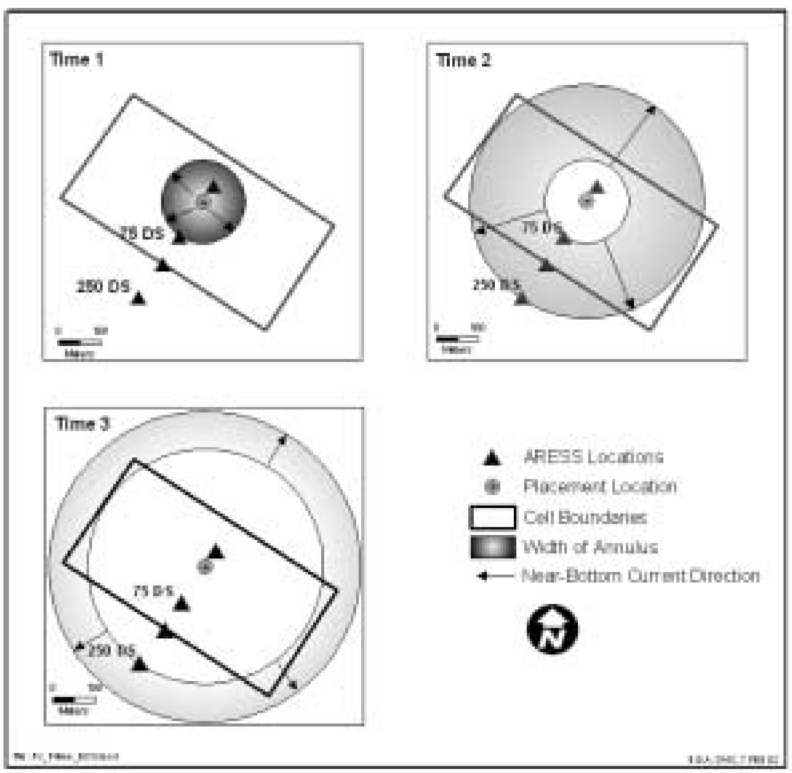

Figure 5. Detection of near-bottom surge from dredged material release at Palos Verdes site (from McDowell et al, 2002)

Some of the initial results from level-bottom disposal in Long Island Sound (Germano 1983) showed that a layer of dredged material can extend as far as 750 meters beyond the disposal point in relatively shallow (20 meters) water; the deeper the water column at the disposal point, the further the material will spread during the dynamic collapse phase. However, the basic conservation of momentum is controlled by the F=MA relationship, and it is important to remember when planning CAD disposal operations that, given the volume of material typically released in a split hull barge, the force is sufficient to have the dredged material travel “uphill” and slosh out over the sides of the borrow pit. Material was spread far beyond the CAD pit boundary from SPI monitoring results at the Los Angeles Disposal site as well as the CAD pits in Hong Kong used during the Chep Lap Kok airport construction.

Because this was not anticipated during the BNC borrow pit CAD project, the detection of elevated sediment contaminant concentrations outside the pit boundary was highlighted as a botched project by the media; the local paper reporting on the project carried the headline, “**THE NAVY, A TOP POLLUTER, BOTCHED CLEANUP**” (Seattle Post Intelligencer, November 18, 2002 issue). Proper planning and confirmation monitoring with the appropriate tools are needed during each phase of a borrow pit CAD project – from the initial borrow pit excavation to immediately following contaminated disposal as well as confirmation monitoring after cap placement. Public outreach and education is needed during the planning phases to inform concerned stakeholders that the physics of dredged material disposal are well-understood and the final footprint of contaminated material can be accurately detected and subsequently covered with clean capping material. A combination of both acoustical (bathymetry, sub-bottom) and optical (sediment profile imaging) survey techniques are needed following each phase of the disposal operation to guide the successful completion of the project.

As with so many things in life, when it comes to successful borrow pit CAD projects, the “devil’s in the details”; if project managers remember Newton’s 3rd law and employ proper engineering design as well as appropriate monitoring technology during all phases of the capping operation, practitioners will be able to insure that borrow pits will be the disposal alternative of choice for managing contaminated sediments for both environmental and economic reasons.

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