CONTAINED AQUATIC DISPOSAL (CAD) – A REVIEW OF MONITORING PROGRAMS

David L. Palmerton, Jr., The Palmerton Group, LLC, Syracuse, New York , USA

ABSTRACT
Contained aquatic disposal (CAD) is one of several containment-type options for managing contaminated sediments. The author has researched several CAD projects in the U.S. and abroad to identify methods of monitoring and post-construction performance evaluation. An overview of the use of CAD and a summary of project specific pre- and post-construction monitoring is presented. The search for alternatives to expensive and limited upland disposal of contaminated sediments has led to the development of CAD as a viable remedial alternative. The CAD alternative provides a disposal option with adequate disposal volume, below navigable depths, near the existing source of contaminated material, and that can be designed to reduce the migration of contaminants (Palmerton et al., 2002). The CAD performance effectiveness relies in part upon the physical and chemical containment of the contaminated material while limiting losses of material during placement and capping. Monitoring is typically performed before, during and after construction. Monitoring programs range from the simplistic to the complex. Monitoring programs typically measure specific design components for effectiveness. However, obtaining data that can "demonstrate" effectiveness can be difficult. A summary is provided of case histories for completed CAD projects with particular emphasis on monitoring programs, their methods, degree of success, and their limitations and complexities.

RÉSUMÉ
La disposition aquatique contenue (DAO) est une des méthodes de confinement disponibles pour disposer des sédiments contaminés. L'auteur a recherché plusieurs projets de DAO aux ETATS-UNIS et identifié à l'étranger des méthodes d'évaluation des performances de surveillance et de post-construction. Une vue d'ensemble de l'utilisation de la DAO et un sommaire de projets spécifiques de surveillance pré et de post-construction sont présentées. La recherche de solutions de rechange à la disposition coûteuse et limitée de grande quantité de sédiments contaminés a mené au développement du DAO comme alternative réparatrice viable. La DAO fournit une alternative pour la disposition adéquate de volumes, sous le niveau des profondeurs navigables, près de la source existante de matériaux contaminés, et cela peut être conçu pour réduire la migration des contaminants (Palmerton et al., 2002). L'efficacité d'exécution de la DAO compte en partie sur l'isolation physique et chimique du matériel contaminé tout en limitant les pertes de matériel lors de la mise en place. La surveillance est typiquement effectuée avant, pendant et après la construction. Les programmes de contrôle s'étendent du simpliste au complexe. Les programmes de contrôle mesurent typiquement les composants spécifiques de conception pour l'efficacité. Cependant, il peut être difficile d'obtenir les données qui peuvent "demontrer" l'efficacité. Un sommaire est fourni des histoires de cas pour des projets réalisés de DAO en insistant particulièrement sur les programmes de contrôle, leurs méthodes, degré de succès, et leurs limitations et complexités.

1. INTRODUCTION

Disposal of dredged material has long been a topic of considerable debate, especially with regard to its potential impacts on the environment. The search for alternatives to expensive and limited upland disposal of contaminated sediments has led to the development of Contained Aquatic Disposal (CAD) as a viable remedial alternative. The CAD alternative provides a disposal option with adequate disposal volume, below navigable depths, near the existing source of contaminated material, and that can be designed to reduce the migration of contaminants (Palmerton et al., 2002).

The U.S. Army Corps of Engineers (USACE) has been for long a pioneer in the concept of CAD as an innovative method of placement of dredged material. The attractiveness of the CAD is that it can be performed with conventional dredging equipment and can be designed such that the dredged material is placed in the near vicinity of the dredging location. Thus, this technique allows for minimal transportation costs and the "containment" of the perceived threat to the environment in a specific zone. However, the CAD performance effectiveness relies in part upon the physical and chemical containment of the contaminated material while limiting losses of material during placement and capping.

Monitoring is typically performed throughout the CAD process: beginning with cell construction and continuing through dredging, transport, placement, capping, and post-project stages. Tied to the design objectives, monitoring can be used to evaluate the physical, chemical, and biological components. However, obtaining data that can "demonstrate" effectiveness can be difficult.

With this in mind, the author has researched several CAD projects in the U.S. and abroad, in order to identify the types of monitoring, and at what stages monitoring was performed. The results are presented in this paper.

2. THE CAD CONCEPT

Contained aquatic disposal is one of several containment-type options available for managing contaminated sediments. This containment technology can be implemented in various ways. CAD is the subaqueous deposition and capping of contaminated materials in natural or manmade pits or depressions. In some cases, CAD relies on engineered berms for lateral confinement. (See Figure 1.)

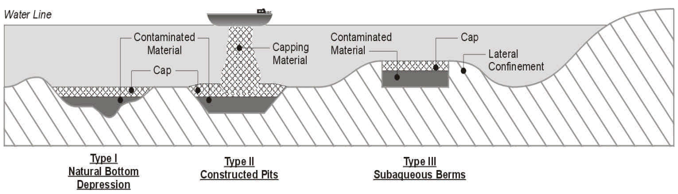

Figure 1 - CAD Configuration Types

The use of CAD depends on the effective capping of deposited materials by using clean material to isolate the contaminants. Open water capping of contaminated sediment sites has been used frequently since the 1970's. Advancements in capping and armoring design during the 1980's and 1990's have shown that capping can provide effective chemical and biological isolation of the contaminants. The USACE has developed guidelines for CAD planning, site selection, design, equipment selection, placement, capping, and monitoring (Palermo, 1991a, 1991b, 1991c, and 1997, and Truitt, 1987). Proper CAD design can reduce the transportation of contaminated material and the quantity of cap material, which as a result, reduces costs.

Although the application of CAD has been limited, many of the completed projects are significant in terms of size, planning, design, and construction. For example, in the early 1980's one of the first large CAD projects completed was in Rotterdam Harbor, The Netherlands. Rotterdam Harbor was a major CAD design and construction project, which has a combined CAD disposal capacity of almost 3 million cy.

The recent CAD studies in the U.S. have concentrated on using "in-channel" disposal options, when contaminated materials are encountered within navigational channels. One such project is the Boston Harbor CAD project (Murray et al, 1998; Fredette et al, 1999; Myre et al, 2000), which proved the environmental and cost-effectiveness of using CAD's in such setting.

Three USACE offices (New England Division, New York District, and Seattle District) have been the primary proponents of CAD. The U.S. Army Engineer Waterways Experiment Station in Vicksburg, Mississippi has pioneered much of the research and development from permitting to guidance for CAD construction.

3. CASE STUDIES EVALUATED

The project specifics for eight CAD projects are individually summarized in Tables 1 through 8. These projects are completed and the information included in the tables originates from the available published data that could be located during a literature review. Project specifics include the location, description, year of construction, construction technology types used, disposal capacity, contaminant types, water depth, monitoring and lessons learned. The monitoring sections are subdivided into baseline, cell construction, dredging, placement, cap, and post construction to identify the stage at which monitoring was performed. Additional documentation for the existing projects may exist; however, it was not available for use in this paper.

4. MONITORING

Contained aquatic disposal is an effective and implementable technology for providing environmental isolation for contaminated material. If contaminated material must be removed and disposed, CAD provides a cost-effective method of disposal near the source of material, which is usually preferred by environmental and citizen groups.

A major limitation of CAD is the potential loss of contaminated material during placement. However, in those cases where placement was adequately engineered, there were few or no difficulties. Conventional means of placement such as bottom dumping from barges and hopper dredges has generally been shown to be effective. In some cases, such as at Hong Kong Harbor, relatively deep water and high tidal currents caused losses of up to 10% when using either bottom dumping or pipe-discharge methods. While the use of tremie pipes or diffusers (for submerged discharge) can potentially reduce such effects, they could significantly increase the project costs.

The goal of sediment management using CAD is the reduction of human health and ecological risks. Therefore the goal of the monitoring program is to identify the success at protecting human health and protecting or restoring the environmental resource at risk.

Monitoring plays a key role in assuring that CAD provides an effective means of containment. Some of the difficulties encountered with CAD are the placement of dredging material without unacceptable losses beyond the CAD area, accurate placement of the cap material, and placement of cap material over the less dense contaminated material. Proper planning and design has been shown to reduce or eliminate these difficulties. Monitoring programs can be used to evaluate these and other design objectives. Monitoring can be used before, during, and after placement of contaminated materials. For the monitoring program to be effective there should be performance standards and "monitoring should be tied to testable hypotheses." "The monitoring program should be multi-tiered, with thresholds, testable hypotheses, sampling design, and management options (should the thresholds be exceeded) defined for each tier." (Palermo 1997)

A three-pronged approach for monitoring remedial effectiveness has been recommended by the US Navy (Apitz 2002) that can be applied to CAD:

1. Monitor to assess effectiveness of remedial action in achieving ultimate goal, i.e. protection or recovery of the resource at risk.
2. Identify interim goals and monitor to evaluate the effectiveness of the remedial action achieving those interim goals.
3. Monitor implementation of the remedial action to evaluate effectiveness of meeting both engineering and environmental protection goals.

Over the last few decades national and international guidelines for managing dredged materials have been worked out to limit contaminant releases. In the U.S. the Environmental Protection Agency and U.S. Army Corps of Engineers have developed numerous guidelines for monitoring and managing contaminant releases from dredging projects. Although there is a large body of research and guidance for water and sediment testing and risk assessment; there is no comprehensive guidance for the types of monitoring or stages to be monitored for CAD construction and use. Each CAD project has project specific and site specific issues that need to be addressed on a case by case basis.

The components of monitoring identified in the case studies fall into three general categories: physical, chemical, and biological. Site specific factors to be considered when developing a monitoring program include many of the same siting factors presented by Palermo (1997):

- Single site vs. series of sites
- Water depth
- Distance from dredging areas
- Hydrodynamics
- Sediment characteristics
- Water quality
- Biological resources
- Existing infrastructure
- Previously impacted areas

Only a handful of CAD projects exist that have published information regarding their environmental monitoring programs. None were found that presented monitoring costs. A few of the cases reviewed have very limited published information about monitoring in general. However, others such as the Boston Harbor CAD project have a significant amount of published monitoring information. Of the cases reviewed, most rely on "event driven" monitoring, as opposed to regular time-sequence monitoring. The monitoring for most of these cases has focused on the dredging or placement events.

The case studies identify a variety of monitoring types:

- Bathymetric mapping
- Turbidity testing
- Side Scan Sonar (SSS)
- Water column monitoring
    - -total suspended solids (TSS)
    - -chemical concentration
    - -dissolved oxygen (DO)
- Bioassay tests
- Bioaccumulation tests
- Sediment core collection for chemical and/or biological assessment
- Sediment Profile Imaging (SPI)
- Acoustic Doppler Current Profilers (ADCP)
- Satellite imagery (SPOT)
- High- and low-level color photography
- Ecology surveys (grab samples and REMOTS seabed camera system)
- Chirp seismic profiling
- Video and diver assisted visual observation

The most complete environmental and cap monitoring program reviewed was the Boston Harbor Navigation Improvement Project (BHNIP) which utilized a number of the monitoring techniques identified above in one or more stages of its development. The BHNIP took advantage of an initial pilot project (Phase 1) that produced monitoring data that was later used to better design Phase 2. This project was monumental in terms of its size, complexity, and use of innovative techniques.

As in most of the other case studies, the major focus of the BHNIP monitoring was on disposal into the CAD cell. Monitoring included real-time tracking of turbidity and the collection of water column samples down current of the disposal cell for chemical analysis. It also included a limited amount of biological testing and fisheries monitoring.

In all cases, TSS and turbidity measurements are the primary screening tools used to determine the potential for adverse sediment dispersion. Predictive modeling is often used to estimate the potential for elevated water column suspended solids and water quality criteria exceedences following placement of contaminated material. In all cases, actual TSS measurements were said to have shown no adverse impacts beyond the immediate disposal area. The TSS and turbidity measurements are often collected contemporaneously with water column chemical concentration data. The relationship between the chemical concentration and the TSS and turbidity data is often relied upon throughout the dredging and placement stages of CAD often without the benefit of additional chemical concentration data (e.g., only TSS and turbidity measurements are made). As noted in the BHNIP Phase 2 Summary (ENSR 2002), "…more effective monitoring could include periodic monitoring of all aspects focused on real-time measurements…with sampling and analysis focused on significant suspended solids plume events…" This is an apparent need in all the cases reviewed. For the Newark

Bay site, TSS is only measured if there are visible plumes outside of the containment facility. Otherwise, TSS is measured at the entrance channel to measure "transit effect" of the scow/tug as they pass. In the case of Rotterdam Harbor, maneuvering of large vessels during contaminated material placement at Rotterdam Harbor resulted in high turbidity.

Monitoring to determine cap thickness was a primary focus for all sites once placement and capping was complete. In at least three cases bottom surges were identified during cap monitoring long after the event occurred. Recognition of the potential for bottom surge and the use of real-time monitoring designed to identify surges could have provided early information about placement techniques and the potential need to remove contaminated surge deposits.

Cap thickness is a typical performance objective. However, the BHNIP researchers recognized the need for something other than cap thickness as a measure of success of a capping effort. The researchers note: "A matrix could be developed to score the performance of a given cap which could be compared against a 'goal' for successful capping that takes into consideration the level of contamination of the material within the cell, the similarity of the material within the cell to surrounding harbor bottom, movement of water over and through the cell, expected deposition over the cell, and proximity to specific habitats of concern." (ENSR 2002) This is an example of setting more rigorous site specific performance standards.

Although not often considered, groundwater discharges through bottom sediments or releases of contaminants from the CAD to groundwater can be limiting effects. At Rotterdam, the potential for contaminant migration to groundwater was a major concern. As a result, a groundwater monitoring program was initiated prior to construction to assist in the design process.

The case studies reviewed provide information on the types of monitoring performed at various stages of CAD. Several "lessons learned" are presented for each case that may help future CAD planning. The data on monitoring of CAD are limited. Published data on the various monitoring approaches and techniques and costs are needed in order to further develop and improve CAD as a remedial technology.

5. SUMMARY

The intent of this paper is to provide a summary of CAD projects and references that can be used when evaluating CAD as an alternative for disposal of contaminated sediments and dredged material. Eight project profiles are provided. These projects identify a variety of techniques and approaches to monitoring. Each CAD project should be evaluated on its own merits and designed for the site specific conditions and the nature of the contaminated materials to be disposed. Additional research and publication of future CAD monitoring information will help to improve future guidance documents.

6. REFERENCES

Apitz, S.E., J.W. Davis, K. Finklestein, D.L. Hohreiter, R. Hoke, R.H. Jensen, J.M. Jersak, V.J. Kirtay, E.E. Mack, V. Magar, D. Moore, D. Reible and R. Stahl. 2002 *Critical Issues for Contaminated Sediment Management,* MESO-02-TM-01, http://meso.spawar.navy.mil/docs/MESO-02-TM-01.pdf

Brand, E.W., J.B. Masey, and P.G.D. Whiteside. 1994. Environmental aspects of sand dredging and mud disposal in Hong Kong, *Proceedings of the First International Congress on Environmental Geotechnics*, July 1994, Edmonton, Canada, pp. 1-10.

d'Angremond, K., A. de Jong, and C.P. de Waard. 1984. *Dredging of Polluted Sediment in the First Petroleum Harbor, Rotterdam* Third United States - The Netherlands Meeting on Dredging and Related Technology*.* pp. 169-190.

ENSR, 2002. Boston Harbor Navigation Improvement Project Phase 2 Summary Report. Contract DACW33-96-D-004 Task Order 51. Document No. 9000-278-000. Prepared for U.S. Army Corps of Engineers and Massachussetts Port Authority.

Fredette, T.J., P.E. Jackson, P.M. Murray, D.A. Hadden, and D.L. Bell. 1999. Preliminary Monitoring Results from the Phase II Boston Harbor Confined Aquatic Disposal Cells, *Proceedings of the Western Dredging Association; Nineteenth Technical Conference Thirty-first Texas A&M Dredging Seminar, Louisville, KY, May 1999,* pp. 255-275.

Kleinbloesem, W.C.H., and R.W. van der Weidje. 1983. A special way of dredging and of disposal of heavily polluted silt in Rotterdam, pp. 509-526, Proceedings *of the 10th World Dredging Congress*, Singapore. London Commission Publication.

Knoesel, E., M. Masters, T.H. Wakeman, and P. Dunlop. 1998. Operation and Management of a Subaqueous Confined Disposal Facility for Dredged Material in Newark Bay, New Jersey. *Proceedings of the 15th World Dredging Congress.* Dredging into the 21st Century & Exhibition, Vol. 1, Las Vegas, NV, July 1998, pp. 367-375.

Matthews, G.P., E.C. Knoesel, J.J. Nocera, and T.H. Wakeman, III. 1999. Operating the Newark Bay Confined Disposal Facility, *Proceedings of the Western Dredging Association Nineteenth Technical Conference; Thirty-First Texas A&M Dredging Seminar*, Louisville, KY, May 1999, pp. 475-482.

Murray, P.M. 1999. Monitoring Results from the First Boston Harbor Navigation Improvement Project Confined Aquatic Disposal Cell. Prepared by Science Applications International Corporation by New England

District, U.S. Army Corps of Engineers. Disposal Area Monitoring System (DAMOS) No. 124.

Murray, P., T. Fredette, P. Jackson, and S. Wolf. 1998. Monitoring Results from the First Boston Harbor Navigation Improvement Project Confined Aquatic disposal Cell, *Proceedings of the 15th World Dredging Congress*, Vol. 1, pp. 415-430.

Myre, P., P. Walter, and M. Rollings. 2000. Geotechnical Evaluation of Sediment Data Collected in Boston Harbor Confined Aquatic Disposal Cells, *Proceedings of the Western Dredging Association -Twentieth Technical Conference Thirty-Second Texas A&M Dredging Seminar*, No.372, pp. 303-316.

Nilson, S, D. Hadden, and P. Giard, Jr. 1998. The Boston Harbor Navigation Improvement Project: Dredging Today for a Deeper Tomorrow. Proceedings of the 15th World Dredging Congress, Vol. 2, pp. 783-797.

Palermo, M.R. 1997. Contained Aquatic Disposal of Contaminated Sediments in Subaqueaus Borrow Pits, *Proceedings of the Western Dredging Association 18th Technical Conference and 30th Annual Texas A&M Dredging Seminar*, pp. 249-262.

Shaw, J.K., P.G.D. Whiteside, and K.C. Ng. 1998. Contaminated Mud in Hong Kong: A Case Study of Contained Seabed Disposal. Proceedings of the 15th World Dredging Congress, June 28-July 2, 1998, Vol. 2, pp. 799-810.

Shields, F.D. and R.L. Montgomery. 1984. Fundamentals of Capping Contaminated Dredged Material. Proceedings of the Conference Dredging '84. American Society of Civil Engineers, Vol. 2, pp. 446-460.

Sumeri, A. 1996. Dredged Material is Not Spoil: A Report on the Use of Dredged Material in Puget Sound to Isolate Contaminated Sediments. Proceedings of the Western Dredging Association Seventeenth Technical Conference and Twenty-Ninth Annual Texas A&M Dredging Seminar June 1996, pp. 207-251.

Truitt, C.L. 1986. The Duwamish Waterway Capping Demonstration Project: Engineering Analysis and Results of Physical Monitoring. Technical Report D-86-2. Long-Term Effects of Dredging Operations Program. Vicksburg, Mississippi: U.S. Army Engineer Waterways Experiment Station.

U.S. Army Corps of Engineers, Los Angeles District. 1999. Coastal Resources Studies Los Angeles County - Marina del Rey and Ballona Creek Feasibility Study. Dredged Material Management Plan, Aquatic Disposal and Capping. *San Pedro Bay Aquatic Disposal and Capping Sites Descriptions.*

U.S. Navy. 2000. Puget Sound Naval Shipyard. Confined Aquatic Disposal of Contaminated and Unsuitable Marine Sediments. OU B Marine Remedial Action and FYCO MCON Project P-338. http://enviro.nfesc.navy.mil/erb/erb_a/support/rits/presentations/2000-10-puget.pdf.

U.S. Navy. 2000A. Puget Sound Naval Shipyard's Installation Restoration Environmental Cleanup Award. http://web.dandp.com/n45/pp_2000/psnsclea.pdf.

Whiteside, P.; K-C Ng, and WP Lee. 1996. Management of Contaminated Mud in Hong Kong, Terra et aqua, No. 65, pp. 10-17.

TABLES

Table 1
CAD Case Study
Boston Harbor, MA

Location:	Boston Harbor, MA
Description:	Boston Harbor Navigation Improvement Project (BHNIP). Two phases of construction in the Federal navigation channels of the Boston Inner Harbor.
Year of Construction:	1997 Phase I - Single CAD cell. 1998 Phase II- Eight CAD cells.
Construction Technology:	CAD excavation in navigation channel using level cut/environmental clamshell for surface silts and open-toothed bucket for native clay.
Disposal Capacity:	Phase I - 23,000 cy of surface silts from Conley Terminal Berths 11 and 12. Phase II – 1 million cy maintenance material disposed.
Contaminant Types:	Various contaminants including heavy metals, PCBs, and PAHs.
Water Depth:	Approximately 50 feet.
Monitoring:	
Baseline	Phase I data generated chemical, biological, and physical data. Predictive modeling of suspended solids impacts.
Cell Construction	Limited fisheries observation.
Dredging	Limited turbidity tests. No significant suspended solids impacts.
Placement	Real-time tracking of turbidity. Water column samples for contaminants. Monitoring revealed limited transport of suspended solids and no exceedences of water quality criteria. Bioassay tests showed no impacts. Bioaccumulation tests showed no apparent impacts. Dissolved oxygen tests showed no apparent impacts.
Cap	Bathymetric, sub-bottom, and side-scan sonar surveys. Core collection for chemical concentration. Video performed for Phase I. Phase I showed significant cap thickness variability and insufficient consolidation prior to cap. Final Phase II showed complete cap coverage and no significant mixing of cap with contents.
Post Construction	Collection of 10-foot cores, surface samples, and performance of sediment profile imaging. No significant changes to the cap. Biological assessment showed recolonization by Stage I organisms with community similar to surrounding harbor bottom.

Table 1 (Continued)
CAD Case Study
Boston Harbor, MA

Lessons Learned: An independent observer successfully resolved conflicts between the contractor and regulatory agencies. Real-time turbidity monitoring provided a good indication of the potential transport of material away from the disposal area. An experienced monitoring team was deemed cost effective when compared to potential work stoppage costs due to permit exceedences.	Operational aspect of dredging (cycle time, scow washing, and operator experience) l kely outweighed the equipment aspects in terms of potential effects on the water column. A more effective monitoring could include periodic monitoring of all aspects focused on real-time measurements to estimate suspended solids with sampling and analysis focused on significant suspended solids plume events or specific concerns about the dissolved constituents. A bottom surge was created by denser material placed on top of lighter material causing the deposition of a small amount of disposed material to be pushed outside the cell.
References:	Nilson 1997, Murray 1998, Murray 1999, Fredette et al 1999, et al and Myre et al 2000 et al, ENSR 2002

Table 2
CAD Case Study
Duwamish Waterway, WA

Location:	Lower Duwamish Waterway, Seattle, WA
Description:	Pilot study CAD to evaluate removal of shoaled contaminated sediment with disposal in a subaqueous depression (borrow pits) and capped with sand.
Year of Construction:	1984
Construction Technology:	Conventional clamshell dredge.
Disposal Capacity:	1100 cy contaminated fine, sandy, clayey silt plus 4000 cy cap material.
Contaminant Types:	Heavy metals, PCBs, Aldrin and others.
Water Depth:	Approx. 72 feet
Monitoring:	
Baseline	Bathymetry and tidal current monitoring. Background water quality including chemical, salinity, temperature, and density data. Sediment samples (surface and cores) analyzed for chemical constituents. Samples also analyzed from reference site. Side-scan sonar (SSS) used for monitoring.
Cell Construction	Not applicable.
Dredging	Water column samples for contaminants and total suspended solids (drawn from near-surface, mid-depth, and near-bottom). SSS monitoring. Continuous turbidity monitoring. Sediment samples for contaminants.
Placement	Water column samples for contaminants and total suspended solids (drawn from near-surface, mid-depth, and near-bottom). SSS monitoring. Continuous turbidity monitoring. Sediment samples for contaminants. Multi-tiered settlement plates.
Cap	Turbidity monitoring. SSS monitoring. Multi-tiered settlement plates. Visual confirmation by divers. Hydrographic survey.
Post Construction	SSS monitoring. Vibracore samples for chemical analysis. Water samples 1 meter above sediment upstream and downstream. Samples from borings at 2 weeks, 6 and 18 months, 5-year and 11-year. Predictive contaminant migration modeling. Data shows the cap has effectively isolated the contaminants.

Table 2 (continued)
CAD Case Study
Duwamish Waterway, WA

Lessons Learned: Monitoring showed a bottom surge displaced some material outside the cell. Clay balls of contamination found in the capping material. Slight migration of contaminants into the cap. 1995 study verified the applicability of the use of the RECOVERY model to assess long-term effectiveness of the cap. High level of acoustic background noise makes application of the SSS more difficult and time consuming.	SSS was successfully used to monitor disposal. The use of the SSS to determine limits of the cap was successful, but use of the sub bottom profiler was only marginally successful at determining cap thickness. Standard hydrographic survey depth sounder best tool for determining sediment thickness. Monitoring for 18 months and at the 11-year post-cap monitoring period showed no mixing of contaminated sediment with cap material and moderate to fair sediment quality for benthic in fauna.
References:	Truitt 1986, Truitt 1987, Sumeri 1996, Ruiz and Schroeder 2001

Table 3
CAD Case Study
East Sha Chau, Hong Kong

Location:	East Sha Chau, Hong Kong
Description:	An overview of Hong Kong's contaminated mud management program, including the construction and operation and maintenance of their contaminated mud pits. Five pits contaminated mud pits (CMP) in use in 1994.
Year of Construction:	Beginning in 1992
Construction Technology:	Grab and trailer dredge
Disposal Capacity:	Approximately 13 millon cy disposed from 1992 to 1996.
Contaminant Types:	Various contaminates including metals, organic pollutants (PCB, PAH) and sewage waste
Water Depth:	Approximately 65 feet
Monitoring:	
Baseline	Chemical testing of sediment various locations.
Cell Construction	Chirp seismic profiling.
Dredging	Suspended sediment surveys using satellite imagery (SPOT), high-level fixed-wing and lower-level helicopter color photography. Water sampling, turbidity meters, Acoustic Doppler Current Profilers (ADCP). Data shows sediment plumes decay rapidly with distance and not damaging the environment. Seabed ecology surveys using grab sampling and REMOTS seabed camera system.
Placement	ADCP surveys and turbidity meter measurements.
Cap	Unknown
Post Construction	Water, sediment and biota monitoring.

Table 3 (Continued)
CAD Case Study
East Sha Chau, Hong Kong

Lessons Learned : Environmental and ecological monitoring have indicated that the operation of the mud pits appear to have no noticeable environmental impact. Sediment losses were negligible when disposal takes place during slack current conditions. On-site supervision and automatic self-monitoring devices that register barge position have eliminated the disposal of contaminated sediments outside of the designated area.	Sediment plumes from sand dredging decay rapidly with distance with visible remnants rarely beyond approximately 3000 feet from the dredging location. Chirp seismic profiling was used to monitor construction. An experimental disposal of clean sediment into empty seabed pits resulted in sediment losses of up to 10%. The deep water (approximately 65 feet) and high tidal currents were thought to be the cause of these losses.
References :	Brand et al 1994, Whiteside et al 1996, Shaw et al 1998

Table 4
CAD Case Study
Newark Bay Confined Disposal Facility, NJ

Location :	Newark Bay, NJ
Description :	Construction of the Newark Bay Confined Disposal Facility (NBCDF).
Year of Construction :	1997
Construction Technology :	Bucket dredge (26 cy closed environmental bucket). Placement with split-hull scow.
Disposal Capacity :	NBCDF has an estimated disposal capacity of 1.5 million cubic yards. The L berty State Park Project disposed approximately 27,000 cubic yards.
Contaminant Types :	Category 2 material, as classified per NY Harbor practice (i.e., material with no significant toxicity but potential for bioaccumulation)
Water Depth :	5 to 20 feet at high tide
Monitoring :	
Baseline	Unknown
Cell Construction	Unknown
Dredging	Unknown
Placement	Total suspended solids sampling beyond perimeter after disposal events. Samples collected at six inches from surface and at 20-foot depth with control samples. Bathymetric surveys performed periodically and after each 10-foot lift of disposed material.
Cap	NA
Post Construction	Bathymetric surveys performed periodically and after each 10-foot lift of disposed material. Vibracore sediment samples collected for geotechnical data.
Lessons Learned : Environmental sampling results indicate proper disposal of sediments can take place at the NBCDF with no adverse effects to the immediate aquatic environment.	Communication among all parties involved in a sediment disposal is essential throughout the disposal process. Sediment disposal should be performed under favorable hydrodynamic conditions to minimize potential environmental impacts.
References :	Matthews et al 1999, Wakeman et al 1996, Knoesel et al 1998

Table 5
CAD Case Study
One Tree Island Marina, WA

Location :	Olympia, WA
Description :	Design of CAD to dispose of chemical constituent-containing sediments removed during deepening of the marina.
Year of Construction :	1987
Construction Technology :	Clamshell. Placement of material by bottom-dump barges.
Disposal Capacity :	Not available
Contaminant Types :	Lead, copper, zinc, cadmium, arsenic, and PAHs
Water Depth :	5 to 20 feet
Monitoring :	
Baseline	Sediment sampling and analysis for chemical constituents.
Cell Construction	Unknown
Dredging	Unknown
Placement	Unknown
Cap	Post construction sediment cores collected for chemistry.
Post Construction	No immediate post-cap chemical monitoring to establish baseline. Sediment cores collected for chemistry. Surface sediment samples and an off-site reference sample were collected to evaluate recolonization of benthos.
Lessons Learned :	Two years after CAD completion, sampling indicated a relatively diverse assemblage of benthic organisms. There was no evidence that the cap was being contaminated by the underlying sediments upon sampling the sediments two years after CAD completion.
References :	Sumeri 1996

Table 6
CAD Case Study
Rotterdam Harbor (Phase I), Netherlands

Location :	Botlek Harbor, Rotterdam, The Netherlands
Description :	Construction of subaqueous disposal pits to dispose of contaminated dredge material.
Year of Construction :	1981-1982
Construction Technology :	Contaminated material dredged by two trailing suction hopper dredges and transported to Botlek Harbor. Placement material transported by scow. Material discharged by a modified suction dredge through a submerged diffuser.
Disposal Capacity :	1.8 million cy (only 1.1 million cy actually disposed)
Contaminant Types :	Chlorinated hydrocarbons, pesticides
Water Depth :	Approximately 95 feet
Monitoring :	
Baseline	None
Cell Construction	Turbidity measurements.
Dredging	Pre-dredging chemical testing of contaminated sediment cores. Turbidity measurements.
Placement	Turbidity measurements and sediment transport evaluation.
Cap	Unknown
Post Construction	Unknown
Lessons Learned :	Experimental pilot testing preceded the work and provided valuable insight. Dredging temporarily raised the level of suspended sediment concentration in the project vicinity. There was no noticeable dispersion of contaminated sediment during discharge activities. However, maneuvering with large vessels lead to high peak values for turbidity in the project vicinity (i.e., 200 to 400 mg/L vs. Normal 40 mg/L).
References :	Kleinbloesem et al 1983, d'Angremond et al 1984, Truitt 1987

Table 7
CAD Case Study
Rotterdam Harbor (Phase II), Netherlands

Location :	First Petroleum Harbor, Rotterdam, The Netherlands
Description :	Construction of subaqueous disposal pits to dispose of highly contaminated dredged material.
Year of Construction :	1983
Construction Technology :	Disposal pits dredged by a bucket ladder dredge. A suction head was mounted to a dismountable cutter suction dredge for contaminated sediment dredging. Placement by pipeline to submerged diffuser mounted on a suction pipe.
Disposal Capacity :	Approximately 600,000 cy was disposed
Contaminant Types :	Chlorinated hydrocarbons, pesticides
Water Depth :	Approximately 15 feet
Monitoring :	
Baseline	None
Cell Construction	Turbidity measurements.
Dredging	Pre-dredging chemical testing of contaminated sediment cores. Turbidity measurements.
Placement	Turbidity measurements and sediment transport evaluation. Groundwater measurements.
Cap	Unknown
Post Construction	Unknown
Lessons Learned : Advanced preparation and modeling may reduce the need for modifications during the project. A de-gassing system was used during dredging to minimize turbidity from gas bubbles and problems with pumping (vacuum problems, reduced head).	 Monitoring and feedback are essential during dredging work in case dredging methods need to be modified mid-operation in order to meet sediment removal goals. Dredging and disposal of contaminated sediment can be performed without causing excessive turbidity.
References :	Kleinbloesem et al 1983, d'Angremond et al 1984, Truitt 1987

Table 8
CAD Case Study
Puget Sound Naval Shipyard, WA

Location :	Sinclair Inlet, Seattle, WA
Description :	Construction of CAD pit for combined disposal of contaminated sediment and navigational dredged material.
Year of Construction :	2000
Construction Technology :	Barge mounted 25 cy environmental clamshell bucket. Placement using split-hull bottom dump barges controlled by GPS positioning.
Disposal Capacity :	377,000 cy
Contaminant Types :	PCBs, PAHs, metals and other contaminants
Water Depth :	Approximately 50 feet
Monitoring :	
Baseline	Extensive marine studies. Water column chemical concentration data collected. Biological assessment.
Cell Construction	Chemical and biological tests on sediment samples. Daily bathymetric survey. Water quality monitoring (In Situ STD, oxygen, turbidity). Current profiling.
Dredging	Pre-dredge side-scan sonar. Bathymetric survey. Water quality monitoring (In Situ STD, oxygen, turbidity). No exceedence of water quality criteria so TSS and turbidity used without chemical data. Current profiling.
Placement	TSS and turbidity.
Cap	Intermediate cap placed first. No monitoring required for clean cap placement.
Post Construction	Collect and analyze marine sediments and marine tissues to monitor changes in concentrations of chemicals. Sediment profile imaging (SPI) used to determine location of bottom surge deposits.

Table 8 (Continued)
CAD Case Study
Puget Sound Naval Shipyard, WA

Lessons Learned: Bottom surge deposits discovered post-capping requiring additional attention. Water quality monitoring could have been better located and timed to measure potential bottom surge effects. Area selected is protected from prop wash. Pre-dredge side scan for debris. Planned habit layer using existing clean material.	$30 Million savings reported in transportation costs (versus disposing at upland sites). Navy ownership of property was an important factor for approval. Over 85,000 cy of clean sediment approved for cap natural recovery enhancement, and beneficial use for near shore habitat enhancement.
References:	US Navy 2000, US Navy 2000A.