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# INTERNATIONAL REVIEW OF APPLICATION OF SUBAQUEOUS CAPPING TECHNIQUES FOR REMEDIATION OF CONTAMINATED SEDIMENTS

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NWRI Contribution No. 99-246

# INTERNATIONAL REVIEW OF APPLICATION OF SUBAQUEOUS CAPPING TECHNIQUES FOR REMEDIATION OF CONTAMINATED SEDIMENTS


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## MANAGEMENT PERSPECTIVE

Along the general business line of "nature", priorities dealt with are human health impacts on ecosystems. This work was done to further document and divulge world wide investigations into subaqueous capping for an international audience. NWRI's capping project of 1995 in Hamilton Harbour is referred to, which was funded by the Great Lakes 2000 Cleanup Fund.

The application of sand, gravel and dredged non-cohesive natural sediments have been tried with apparent success in different aquatic environments. Comprehensive guidelines exist for the design of projects using this low-cost remedial technology. A need exists to investigate sediment and porewater geochemistry for better understanding of fluxes and transport of contaminants through subaqueous in-situ caps.

With the knowledge gained from international projects on the use of sand and similar material, the suitability of chemically-active, low-cost materials for capping (e.g. rock flour or clays) should be investigated. This could be done through laboratory tests to a full-scale application. Existing experience with fine-grained caps has been very limited so far.

N.B. The Managementment Perspective and Abstract are currently being translated into French.

## ABSTRACT

Subaqueous capping is a relatively new method for isolating contaminated sediments from the overlying water and biota. In its simpler form, capping represents the placement of a layer of clean, sandy or silty sediment, which is evenly spread over contaminated sediments. Among the advantages of capping, we can point out its significantly lower costs relative to other sediment remedial techniques; its suitability for isolating both organic and inorganic contaminants; and the intrinsic advantages of being an *in situ* technique. Capping can also be a viable alternative for disposal of contaminated sediments that have been dredged and placed in another subaqueous location. Several countries (e.g. USA, Germany, Japan, Australia, Norway, and Canada) have engaged in capping projects. However, because capping projects started in the late 1970s, this technique is still in its infancy. At the present time, several research groups are trying to solve scientific questions and develop technical improvements related to the capping methodology.

# 1 DESCRIPTION OF CAPPING TECHNIQUE

Aquatic environments have been severely affected by the fast population and industrial growth during the last few decades. Sediments, with long residence times, can act both as source or sink of contaminants to water bodies (Förstner & Wittmann 1981). Toxic substances in the sediments are slowly released into the overlying water column or assimilated by bottom dwelling organisms, thereby having a strong negative effect on the whole aquatic ecosystem. In recent years, several treatments have been used to deal with severely contaminated sediments. However, no particular method is ideal or problem free for all circumstances.

Subaqueous capping, a relatively new method, has become an attractive concept for isolating contaminated sediments. Subaqueous capping is the placement of a layer of clean (i.e. suitable for unrestricted open-water disposal) material over contaminated sediments. The capping layer isolates the sediments both physically and chemically from the overlying water column and biota. An important role of a subaqueous cap is the transfer of the zone of active bioturbation from the contaminated sediment into the clean cap. An important distinction should be made between *in situ* capping and dredged material capping that involves sediment removal by dredging, transport to another location, and subsequent covering of dredged material by a cap (Palermo 1997). This manuscript will be primarily concerned with *in situ* capping.

Most *in situ* capping projects carried out to date have used capping material that was either dredged from nearby waterways or obtained from upland sources including commercial quarries. Sand is usually employed as capping material, as it is much easier to place in a layer of uniform thickness and it is more resistant to erosion due to bottom currents. Both laboratory experiments and field experience convincingly demonstrate that, when properly designed, placement of a relatively coarse-grained cap does not disturb or mix with underlying very soft fine-grained sediments.

The cap can consist of one or more layers of sand-sized or silt-sized material. In more dynamic aquatic environments, a top armour layer can be incorporated into the cap design. The guidance on the hydraulic design of an armour layer subjected to physical stresses such as bottom currents or propeller wash in navigation channels is available (Palermo 1997). Pervious geotextile fabric can be also incorporated into the cap design in conjunction with granular materials (Instanes 1994). Low-permeability geotextiles are unsuitable as these may induce cap instability due to gas and porewater flow.

In order to determine the required cap thickness, the chemical and biological characteristics of both the contaminated sediment and the capping material must be evaluated. Also, potential impacts of local benthic community and other aquatic burrowing organisms must be taken into consideration. A conservative estimate of required cap thickness, based on laboratory reactor tests is about 50 cm, where 30 cm acts as a chemical barrier and remaining 20 cm provide allowance for the maximum bioturbation depth (Brannon et al. 1985; Gunnison et al. 1987). The laboratory test on which this value is based used relatively mobile, non-adsorbing chemicals (dissolved oxygen, ammonium nitrogen, and orthophosphate phosphorus) as tracers. Laboratory and field experience shows that primary contaminants of concern, namely heavy metals and persistent organic compounds, are less mobile (Sturgis & Gunnison 1988). Recent research at Louisiana State University found that much thinner caps can be successful in isolating organic contaminants for long periods of time.

The most favourable conditions for an *in situ* cap location are in sediment depositional areas with low bottom currents, no navigation traffic, and where no maintenance dredging is required. Many sites are not suitable because of dredging requirements, strong underwater currents, steep bottom gradients, and significant groundwater seepage. The other considerations pertaining to the applicability of *in situ* capping include the change in water depth, and the potential impacts on the future use of the site (e.g. flooding, navigation, and recreation). Comprehensive environmental assessment of each capping project is typically required by regulatory agencies.

## 2 REVIEW OF SOME FIELD CAPPING EXPERIMENTS

Capping projects have been carried out world-wide in riverine, nearshore, and estuarine environments. However, many of those projects were associated with the handling of contaminated dredged material removed from navigation channels (Palermo 1997). The following information is related to well documented *in situ* subaqueous capping projects.

### 2.1 Puget Sound, Washington, USA

At the Denny Way *in situ* capping project in Puget Sound, a sand cap was placed in early 1990 over a contaminated nearshore area of about 1.2 ha, with water depths ranging from 6 to 18 m below mean lower low water (MLLW) datum (Sumeri et al. 1991; Sumeri 1995). Contaminants in bottom sediments included lead, mercury, zinc, low and high PAHs, and PCBs. The cap consisted of about 15,300$m^3$ of uniformly graded sand (mean diameter 0.4 mm). A bottom dump barge sand spreader was used for cap placement. A 55 m long by 15.3 m wide split-hull barge was used. Sand spreading was accomplished by opening the hull of the barge 6-8 degrees, allowing the gradual release of the sand in a sprinkling manner. Two 800-horsepower tugs controlled location and speed of the barge. Positioning during capping was accomplished by a laser positioning system following a prism mounted on the side of the barge.

At the Eagle Harbor project in Puget Sound, the 28 ha large area contaminated with PAHs and mercury was remediated by *in situ* capping between September 1993 and March 1994 (Sumeri 1995). The cap consisted of sandy dredged material suitable for open water disposal. The capping site was divided into two clean-up areas based on the type of bottom sediment and the type of placement technique to be used. Area 1 (about 10 ha), with bottom sediments consisting predominantly of fine to medium sands, was capped from bottom-dump barges towed closely behind a tug. In Area 2 (about 18 ha), the contractor placed the cap by washing dredged material off flat-deck barges with a high-pressure water jet. A Differential Global Positioning System (DGPS) was used for positioning of the barge, the tug and the track line.

## 2.2 The Great Lakes-St. Lawrence River Region

In the summer of 1995, Environment Canada carried out a pilot-size demonstration project of sand capping contaminated sediments in Hamilton Harbour, Lake Ontario (Zeman & Patterson 1997). The sediments from the selected site (1 ha) exceeded the Ontario Ministry of Environmental and Energy sediment quality guidelines at the severe effect level for Zn, Cu, Pb, Cr, Ni, Cd, As, Hg, and PAHs. Water depths at the site range from about 12 to 17m (International Great Lakes Datum 1985). The sand cap (35 cm) was placed by means of a specially designed multiple tremie tube system attached to a feed hopper. A rotating paddle, located between the hopper and the tremie tubes, distributed the sand (mean diameter 0.5 mm) through each tube. The spreader barge was positioned by means of four-point mooring system and the position control of the barge was achieved by two tugboats. Horizontal and vertical position of the barge was tracked and recorded by a DGPS with an accuracy of 0.1 m. A significant consolidation of about 14 cm occurred in the uppermost one meter of sediment. Assessment of the porewater after one year of capping of the contaminated sediments showed a significant reduction (up to 80%) in the vertical fluxes of all trace elements (Azcue et al. 1997).

*In situ* capping in a riverine environment has been demonstrated at a PCB-contaminated Superfund site in Sheboygan Falls, Wisconsin, USA (Eleder 1992). This project involved placement of a composite cap with layers of gravels and geotextile to cover several smaller contaminated areas in the shallow water (less than 1.5 m deep) and floodway of the Sheboygan River. A total area of about 0.4 ha was placed with land-based construction equipment and manual labour.

PCB-contaminated sediments at the General Motors Superfund site in Massena, New York, USA were removed from the St. Lawrence River by dredging. The remedial objective of the site was 1 μg/g, but areas remaining at concentrations >10 μg/g after repeated dredging attempts were capped. An area of approximately 0.7 ha was covered with a composite 3-layer cap consisting of 15 cm of sand, 15 cm of gravel, and 15 cm of armour stone (Palermo et al. 1996).

## 2.3 Japan

*In situ* capping of contaminated sediments has been demonstrated at a number of sites in Japan. Most Japanese *in situ* capping projects were carried out primarily on fishery grounds in the inner bays and lakes of Japan. The primary purpose of these projects was to control release of nutrients from polluted sediments and to mitigate undesirable eutrophic effects on the water quality. Demonstration projects carried out at Hiroshima Bay evaluated various types of placement equipment. Specialized equipment for the placement of *in situ* caps developed in Japan include a barge unloader sand spreader (Kikegawa 1983), a conveyor unloading barge with a telescopic tremie tube (Togashi 1983), and a sand dispersal platform vessel used in shallow water in the Biwa Lake project (Toa Construction 1990). A numerical model was developed to predict the effect of *in situ* capping on the improvement of seawater quality and seabed sediment, and on the recovery of marine animals (Horie 1987; Horie, 1991). The model was tested by comparing the computed changes with the measured values at sand-capped sites in Kure Bay, a part of the Seto Inland Sea.

## 3 DISCUSSION OF APPLICABILITY AND LIMITATION OF *IN SITU* CAPPING

Capping, as all other treatment techniques, is not problem free nor ideal for all circumstances. The main requirements and limitations that should be considered when choosing the *in situ* capping technique include: bathymetry, currents, water depths, water column density stratification, bottom sediment characteristics, and operational requirements (Palermo 1991).

One of the major concerns in capping applications is the potential for erosion by waves and currents, and the disturbance of very soft sediments during cap placement (Zeman 1994). The ideal area for *in situ* capping would be sheltered from high erosive forces or upwelling from porewater. The stability of the cap material has to be well investigated and different hydrodynamic conditions should be tested. General guidelines for capping recommend that a capping site be located within a relatively low energy environment (Palermo 1991). Geotextiles and silt screens can be used to reduce resuspension of material during placement and to improve sediment-bearing capacity (Dolinar et al. 1990). However, these materials are not widely used in most capping projects because of numerous practical difficulties associated with their application.

The effects of shipping are especially important in design considerations for capping projects because bottom stresses due to propeller wash and/or direct hull contact are typically of a greater magnitude than the combined effects of waves and currents (Truitt et al. 1989). Therefore, areas with considerable ship traffic could represent a limitation to capping projects. Freeland et al. (1983) used a Seaflume (a bottom-resting flume) to determine the critical shear stress necessary to resuspend sediments and thus to predict the erosion threshold of the sediments at dredged material dump sites.

The perfect capping material should be suitable for unrestricted open-water placement, and it should come from an area close by the site. Three types of capping materials can be used: inert, chemically active, and sealing agents. Sand is usually employed because it is much easier to place in a layer of uniform thickness, it is more resistant to erosion due to bottom currents, and it is less apt for resuspension after deposition than fine-grained material. Occasionally, large gravel or stones may be required as an armour layer (Clausner & Abel 1987). Although a sand cap will allow a greater consolidation of the underlying material, the flux of porewater should be determined and in some cases an impermeable cohesive cap may be required.

The selection of the proper cap thickness is a crucial point in the planning of capping projects. The chemical and biological characteristics of both contaminated sediment and capping material must be evaluated together with their financial implications. The type of benthos whose habitat is normally in that area must also be taken into consideration. The cap thickness required is determined by the sum of the thickness needed for a chemical seal plus the allowance for bioturbation (Sturgis & Gunnison 1988).

A complete capping project should include a monitoring program. The monitoring program must address contaminant migration and physical and biological condition of the site over time. The physical impacts of the capping operation, such as sedimentation and change in grain size, drive biological and chemical changes in the area. Physical monitoring (bathymetry, side-scan sonar, and submarine profiler) at chosen locations, is also required (Truitt et al. 1989). Visual inspection of the cap, by divers, is performed to get an understanding of the recolonisation of the cap. Other biological monitoring that can be carried out includes bioassays and tissue analysis of resident fauna to determine bioaccumulation and the chemical isolation of the capped material (Zarull & Reynoldson 1992). Palermo (1997) recommended intensive monitoring to be carried out immediately after the placement of the cap, followed by long-term monitoring at less frequent intervals. He also suggested that the costs and effort involved in long-term monitoring and potential management actions should be evaluated as part of the initial feasibility study.

## 4 FUTURE AREAS OF RESEARCH

Because *in situ* capping is a relatively new technique, there is a definitive need for further research. Among the main topics requiring further development, we consider the following ones as priority areas of research:

- Selection of capping materials. One of the main novelties of the capping technique is the possibility of developing pollutant-specific barriers. The cover material could consist of substances able to immobilize or degrade specific pollutants during their upward diffusion. The cover materials could in part consist of industrial or domestic waste substances that meet criteria for open-water disposal and that exhibit characteristic properties applicable for immobilizing or degrading specific pollutants.

- Develop computer models to evaluate long-term fixation of contaminants. While laboratory and field work can provide insight into the driving physical and chemical mechanisms, the long-term scales involved prevent extensive laboratory and field testing to compare alternative capping techniques. Numerical models, as long as validated with field and laboratory data, are attractive tools to conduct experiments on capping alternatives.

- Laboratory tests, especially sediment and porewater geochemistry. Negligible changes in sediment composition often cause noticeable variations in the quality of sediment porewater. The sediment porewater chemistry can help explain many diagenetic processes, as well as fluxes and transport of contaminants.

- Seasonal effects. In order to properly design a capping alternative, it is paramount to establish the seasonal effects on benthic fluxes and to establish the response of the system to any further inputs.

- Biological monitoring. Special attention should be paid to the development of techniques to help biological recolonisation of the capped sediments.

- Field experiments. There is a definitive need to carry out more field capping experiments using similar methodologies in different environments. This allows us to equate the results and assure that the selected techniques could be applied in different environmental conditions.

## 5 CONCLUSIONS

Subaqueous *in situ* capping is a relatively new method that has become an attractive concept for isolating contaminated sediments. Capping, as all other treatment techniques, is not problem free and ideal for all circumstances. Among the advantages of *in situ* capping is its simplicity and significantly lower costs than removal and treatment of contaminated sediments. Further, it is suitable for isolating both organic and inorganic contaminants. Major concerns in capping applications are the potential erosion by waves and currents and disturbance of contaminated sediments during placement. The selection of a proper cap thickness is a crucial step in the planning of capping projects. Capping projects have already been carried out in different environments throughout the world, such as USA, Canada, Japan, and Norway.

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