Environmental Applications for Sub-Surface Dredging (SSD)

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ABSTRACT

Capping, as a major remediation alternative, is sometimes precluded during feasibility studies because it reduces water depth. Reduction of water depth is often not allowed in Federal Channels, floodways, or in shallow water bodies due to possible adverse impacts. Acquisition and transport of capping material is expensive, amounting to a large fraction of the total remediation cost. Where clean, cohesionless sediment underlies the bed, Sub-Surface Dredging (SSD) can be the answer.

Recently several successful pilot projects using Sub-Surface Dredging were conducted in the Netherlands. Two major dredging contractors individually optimized and innovated the SSD-concept. The pilot projects were accompanied with extensive environmental monitoring program of which this paper gives a record. The monitoring program had high ambition levels and revealed only minute environmental impacts.
SSD-technology involves penetrating with lances through surficial sediment to underlying cohesionless (sandy) sediment. Deeper sand is carefully dredged and transported to the surface. The SSD-techniques yield free sand, and a subsided bed.

This paper describes how this technology can be used for remediation, habitat mitigation and natural resources restoration with a variety of examples including:

1 Using the dredged sand as a cap over the newly-subsided contaminated surficial sediments while maintaining pre-remediation water depths.
2 Capping flood plain contaminants without breaking the artesian seal of the surficial fine-grained sediments, and without reducing the floodway.
3 Diversifying habitat in riverine or estuarine conditions. Where no contamination is involved, a mud flat environment can be diversified by dredging underlying sand and placing it nearby, deepening part of the habitat while building a base for an adjacent island.
4 Deepening a wetland, thereby changing its role in nutrient processing and creating more diverse wetlands.

Keywords: Sub-Surface Dredging, SSD, remediation, capping technique, environmental dredging

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INTRODUCTION

Capping, as a major remediation alternative to counteract the dispersal of contaminants to the environment, is sometimes precluded during feasibility studies because it reduces water depth. Reduction of water depth is often not allowed in Federal Channels, floodways, or in shallow water bodies where reducing depth has adverse impacts on passage of floodwaters, habitat quality, water and land uses, navigation, and natural resources.
Acquisition and transport of capping material is expensive, amounting to a large fraction of the total remediation cost. Where contamination is underlain by clean, cohesionless sediment, Sub-Surface Dredging (SSD) with integrated sand cap placement can be the answer. SSD-technology involves drilling with lances through contamination to underlying cohesionless (sandy) sediment (see Figure 1).

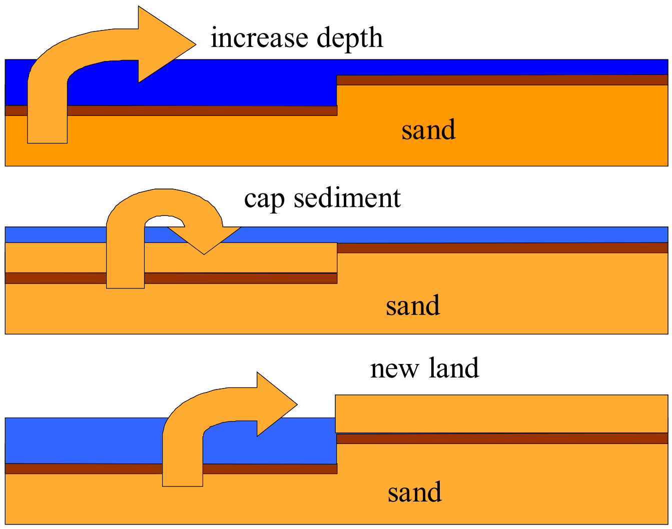

Figure 1. Application Sub-Surface Dredging (SSD).

Deeper sand is carefully dredged and pumped to the surface. The SSD-principle is similar to stationary suction devices for sand mining on land and offshore, where sand is produced by a propagating breaching or subsiding process. However, the SSD-technology must realize a homogeneous subsidence of the sediment-water interface to prevent resuspension of the contaminated layer. This is done by controlling the progressive failure of breaching that creates the dredged cave. The dredged sand can then be either (i) used commercially when only increase in water depth is required, or (ii) can be used for capping the contaminated layer or (iii) as fill to make land or diversify habitat .
The SSD technology yields:

- Free sand,
- A newly placed sand cap,
- Isolated contaminated sediment,
- No significant reduction in depth or elevation of the waterway, shallows, or floodplain, and
- Potentially, excess sand that can be used as construction material.

Competing technologies that can achieve pre-remediation bathymetry include dredging and surcharged capping.
Advantages of SSD include:

- Free capping sand
- Limited disruption of geo-hydrological conditions
- No transportation or disposal costs,
- No risk of spreading contamination by transportation
- No double handling costs,
- No short-term impacts by dredging on air emissions or water quality, and
- Faster completion.

SUB-SURFACE DREDGING TECHNIQUES

At present two types of subsurface dredging techniques were developed independently in the Netherlands:

- **“BeauDredge”:** Royal Boskalis Westminster developed the “BeauDredge”, which is a single suction device with an active excavation method by means of hydraulic jets (see Figure 2);

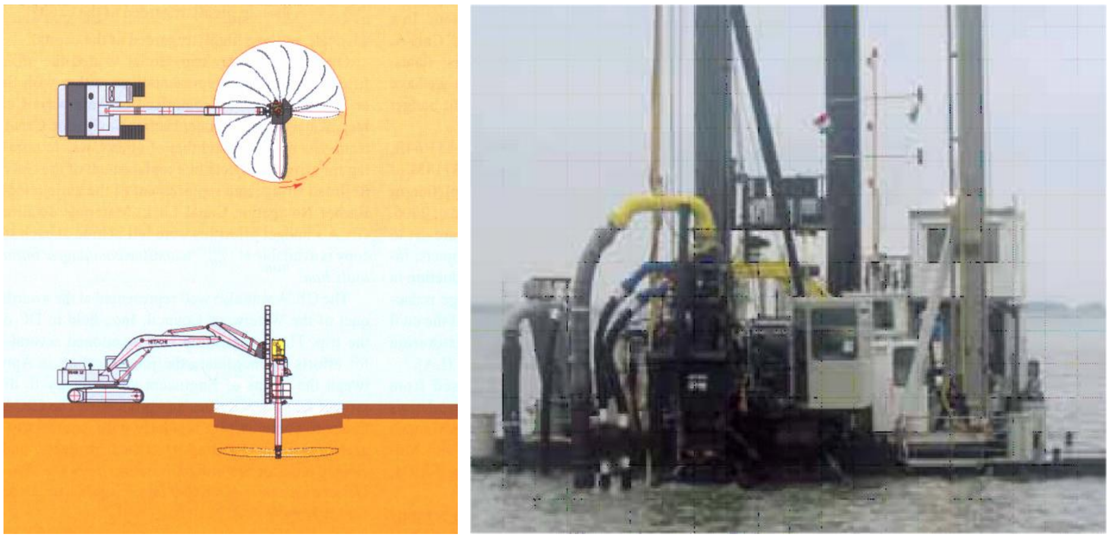

Figure 2. SSD “BeauDredge” (Boskalis): Outline and offshore plant

The “BeauDredge” is excavating the sand with horizontal hydraulic jets creating a circular cave. The hydraulic jet erodes the sand and creates a sand-water mixture that is flows towards the suction mouth in the centre. The hydraulic jets of the “BeauDredge” will create excess pore water pressure in the excavated area.

- **“Sub-o-Suction”:** Ballast-Van Oord Grondstoffen VOF developed the “Sub-o-Suction”, which is a multiple suction device with a passive excavation method by using a water ejector pump at the base of the suction pipes (see Figure 3).

Figure 3. SSD “Sub-o-Suction” (Ballast-VanOord): Outline, drill head and offshore plant

The “Sub-o-Suction” is based on the breaching process (see Mastbergen et al., 2003), which is similar to the process in traditional sand mining with a stationary suction device. The breaching process in the “Sub-o-Suction” is an autonomic erosion process of a sand slope, where a steep distortion in the slope moves upward and creates a sand water mixture that flows down the slope. The required additional water (blue arrows Fig.3) is supplied below the suction inlet (yellow arrows Fig.3). The "Sub-o-Suction" may result in negative or excess pore water pressure.

In both methods the pore water pressure needs to be controlled in order to prevent eruption of the surface or blowout. By applying key instrumentation and control of the water supply and pressure within the excavated area, water can: (i) partially support the cave, (ii) eliminate blowouts, (iii) fluidize the excavated sand to flow to the pump, and (iv) remove the sand.

Moreover a system of multiple suction pipes will minimize the differential settling in order to prevent collapse and resuspension of contaminants, and to realize a homogeneous subsidence up to the sediment-water interface (see Figure 4). The excavated sand can then be placed over the superficial sediments using a variety of proven methods like diffusers or pontoon spreaders.

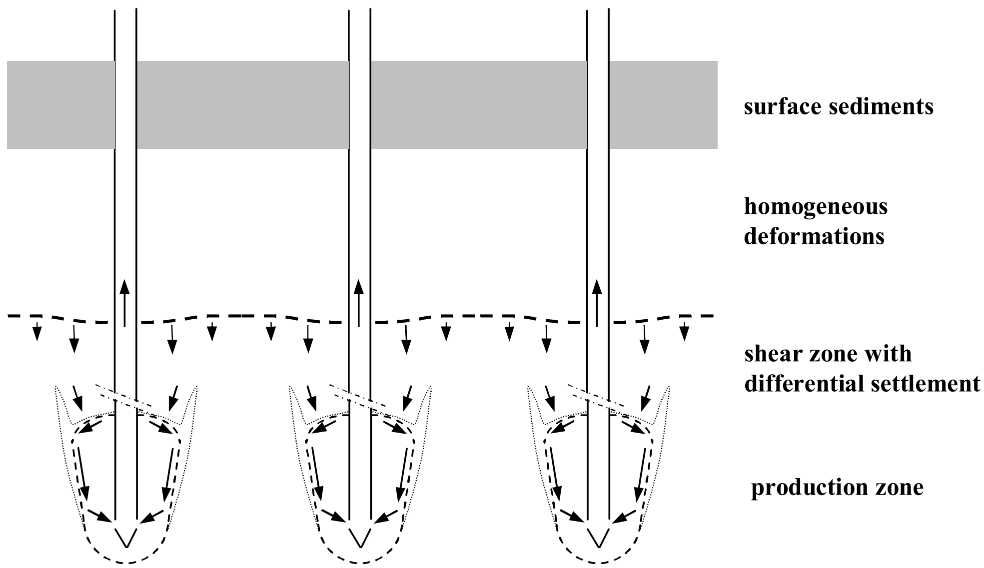

Figure 4. Multiple system in "Sub-o-Suction" for homogeneous subsidence.

LABORATORY TEST

The feasibility of a homogeneous subsidence up to the sediment-water interface has been investigated at a scale of 1:4 in the Dredging Flume at WL | Delft Hydraulics (see Figure 5).

Figure 5. Experimental set-up in Dredging Flume WL | Delft Hydraulics

Behind a glass wall 9 suction pipes with water ejector pumps were installed in a sand bed 2 m thick. Two different grain sizes (D50 = 130μm and 350μm) and two packing conditions (loose and dense) were tested.
The tests showed that after an uniform surface subsidence of about 20 cm (i.e. 10% of the total depth) the top bed profile is still the same. Resumption of subsurface dredging finally caused a short cut to the surface resulting in an undulating surface profile.

FIELD TEST FULL SCALE

After the phase of design, development, lab testing, prototype testing and redesign, a pilot project was organized by Rijkswaterstaat (Ministry of Transport, Public Works and Water Management of the Netherlands) in lake Ketelmeer (see Figure 6), in which both SSD-methods were tested (test location in red). The objective of the pilot project was to prove the applicability of SSD as an alternative for increasing water depth in a potentially contaminated area, while producing clean sand. In view of the contamination, an important issue in these tests was the environmental impact of the dredging technique, so both pilot projects were implemented with extensive, identical environmental monitoring programs.

The mined sand layer is located between depths of -6 m to -9 m below the waterbed. At -3 m depth the sand is overlain by clay, peat and contaminated soft clay. The surface sediment (upper 0.2 m) is very soft "clean" clay with contaminants below maximum allowable levels.

Both methods were applied with a single suction device and therefore the obtained results are without the beneficial effect of a multiple suction system. Nevertheless, the results showed that the bathymetry changes were within the required specification of plus and minus 0.5 m.

Figure 6. Pilot test location in lake Ketelmeer, The Netherlands (red area).

ENVIRONMENTAL MONITORING PROGRAM

The lay-out and scope of environmental monitoring program was based on:

(i) monitoring the top layer of slightly contaminated, fine-grained that functioned as a surrogate for more contaminated sediment,

(ii) with the lack of data on the environmental impacts of SSD, since this was its maiden trial;

(iii) a desire to try new monitoring techniques and environmental parameters.

The monitoring program for both pilot projects consisted of:

- surface water quality
  - suspended matter
  - translucency
  - chemical contamination
  - temperature, oxygen content, salinity and pH
- sediment layers
  - preservation of the discrete strata
  - mobilization of contaminants
  - stress level on the bed flora
  - closure of the bore holes
- subsurface
  - ground water pressures
  - ground water contamination

A number of stations were installed to house clusters of the various sensors that continuously kept track of the basic environmental parameters (suspended matter, temperature, oxygen content, pH, salinity, flow velocity and direction, water level, wind intensity) throughout the control area (see figure 6) and the groundwater pressure was logged on several places. Before the pilot projects, an inventory was made of the amount and diversity of the benthic community. Water samples and sediment cores were taken at regular intervals throughout the period of the pilot projects at important locations. In the Sub-o-suction pilot project, grass matting was put on the waterbed in order to monitor the bed surface deformation. This monitoring was done by scuba divers.

As a new test, LISST (Laser In-Situ Scattering and Transmissometry) instruments were deployed to fingerprint the turbidity and determine its origin.

Apart from these continuous measurements, special detail measurements were carried out when localized impact was suspected

ENVIRONMENTAL MONITORING RESULTS

The monitoring program proved to be founded on a worst-case impact scenario, because during the entire study, the environmental impacts were extremely low to non-existent.

- No vertical mixing of the surrogate contaminated layer was observed with other layers.
- Soil strata remained intact.
- Groundwater pressure changes proved to be local and temporary.
- Contamination concentrations (metals, nutrients, PAK, PCB's, OCB's) in ground water and surface water were below detection limits.
- The Sub-Surface Dredging activities did not affect the oxygen content of the surface water.
- Turbidity in a 25 m radius from the SSD, increased by no more than 5 mg/liter (background turbidity level ranging form 10 to 40 mg/liter; mean value 35 mg/liter).
- Under flow conditions of approximately 5 to 20 cm/s, no erosion of the dredged area was observed.
- Turbidity fingerprinting with the LISST-instruments was not detected because of the minute resuspension of sediments.
- No effect of any substance on the benthic live was recorded. Biologic communities remained intact.
- Trials under the placed grass matting proved that it is possible to decrease the waterbed level under layers that are reinforced with aquatic plant roots.

The turbidity produced by the Sub-Surface Dredge is compared in Figure 7 with other dredging equipment by means of the S-parameter, which is defined as the amount of kilograms of dry solids per m^3 of in-situ dredged material that is released into the surface water (Pennekamp et al., 1990, 1996).
Figure 7 shows that the subsurface dredge technique with $S < 0.1$ kg/m^3 can be designated as an environmental friendly dredging technique.

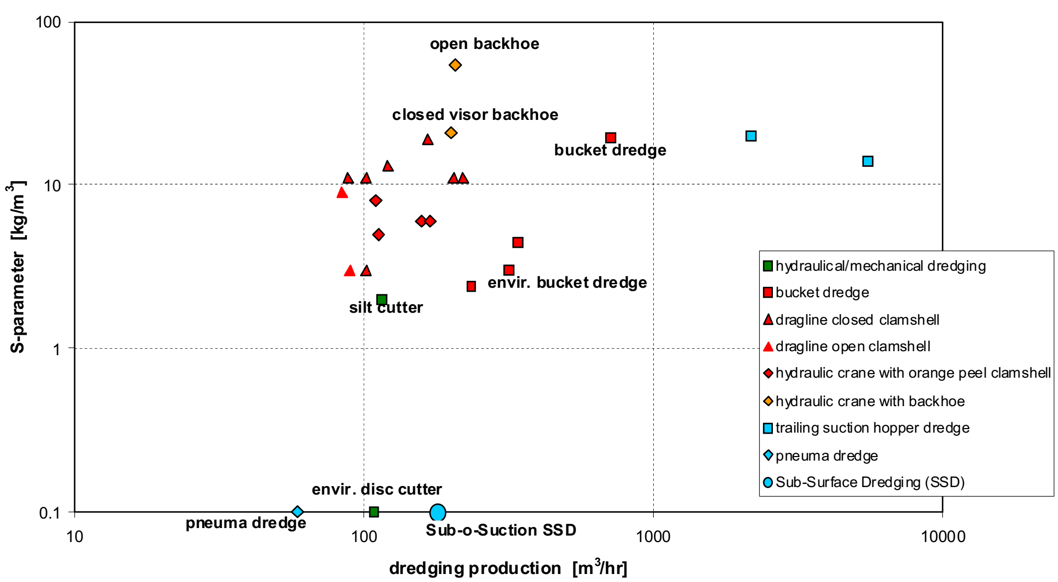

Figure 7. S-parameter for different dredging techniques.

APPLICATIONS

SSD offers numerous advantages with respect to environmental dredging/capping that translate well to the following conditions if underlain by cohesionless sediment:

1 ***Sites where water depth needs to be maintained***. By preserving or deepening the original water depth, SSD can be applied in
   - channels whose depth are navigationally controlled,
   - near polders where geo-hydrological conditions must be maintained,

- o floodplains where floodway elevation are controlled, and
- o wetlands where depth affects nutrient cycling, mobility and habitat performance.

2 ***Sites with near surface toxic chemicals***. These chemicals can be isolated from the bioactive zone with a cap, allowing reestablishment of the active and healthy benthic or aquatic plant rooting zone without toxic influences.

3 ***Sites where nutrients need to be reduced***. SSD isolates the high nutrient (e.g. Phosphorus) layer, taking the nutrients out of the cycle and improving water quality.

4 ***Sites that need deepening but contain important aquatic plant or benthic communities***. For example, traditional wetland deepening requires stripping of the established wetland soils prior to removal of underlying mineral soils. With SSD, the surficial biota can remain intact.

5 ***Sites where transportation or disposal of dredged material is infeasible***. SSD eliminates transportation and disposal and their associated costs.

6 ***Sites of high land value***. Urban centers; busy ports; touristic, historic, and natural areas; where sediment disposal or transport, air emission, turbidity and heavy industrial work may cause adverse impacts.

7 ***Sites of high aquatic values***. In areas with sensitive flora and fauna, turbidity needs to be minimized.

8 ***Sites where construction material is in short supply***. With SSD, clean sand can be extracted and used in construction.

9 ***Sites that require revenue for economic feasibility***. By producing clean sand, revenue can be generated to off-set costs of construction, improving the economic feasibility of publicly funded projects.

With currently scaled equipment, the top layer to remain in place can be up to 3 meters thick. SSD requires a dredge target layer of saturated cohesionless material that is 3-5 times the thickness of the Top Layer to be subsided. These are general guidelines and should be determined on a site-specific basis depending on the goals of the project. For example, on projects where resuspension of sediment and turbidity from placement of dredged sediment containing silts and clays are acceptable short-term effect, there will be greater flexibility on the conditions where SSD can be applied. The more restricted these goals become; a cleaner and thicker underlying layer becomes more important.

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