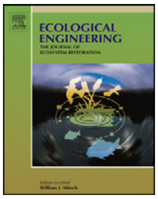
Ecological Engineering 35 (2009) 1523–1528

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng



# Dewatering of contaminated sediments: Greenhouse and field studies

K.E. Smith[a,*], M.K. Banks[c], A.P. Schwab[b]

[a] *Department of Math, Science and Technology, University of Minnesota-Crookston, 2900 University Ave., Crookston, MN 56716, United States*
[b] *Department of Agronomy, Purdue University, West Lafayette, IN 47907, United States*
[c] *Department of Civil Engineering, Purdue University, West Lafayette, IN 47907, United States*

ARTICLE INFO

*Article history:*
Received 1 October 2008
Received in revised form 15 June 2009
Accepted 18 July 2009

*Keywords:*
Transpiration
Dewatering
Dredged sediments
Contaminants
Plants

ABSTRACT

Water management of dredged sediments in Confined Disposal Facilities (CDFs) is an issue for the United States Army Corps of Engineers (USACE). Removing water from contaminated dredged sediments in CDFs is desirable because water removal can reduce the volume occupied by the sediments and can create the aerobic conditions needed for the microbial degradation of many contaminants found in the sediments. The objective of the current study was to identify plant species that could be used to dewater saturated sediments contaminated with PCBs and PAHs. A greenhouse study revealed that wetland plants (54–67% water removed) were able to dewater contaminated sediments more than unvegetated (28% water loss) or treatments with terrestrial plant treatments (39% water removed). Three promising species (*Scirpus fluviatilis*, *Spartina pectinata*, and *Carex aquatalis*) from the greenhouse study were tested in the field. In the field trials, wetland plants again were able to dewater sediments effectively. Some of the same species selected in the greenhouse study were the best dewatering species in the field study (*S. fluviatilis* and *S. pectinata*); however, the *S. fluviatilis* dewatered the sediments past its own permanent wilting point (0.323 g water/g soil). By the end of the final growing season, the *Salix nigra* (0.161 g water/g soil) and *S. pectinata* (18.4 g water/g soil) were able to dewater the sediments without negative impacts on the plants and are recommended for dewatering applications.

## 1. Introduction

The waterways of the United States would become non-navigable without the removal of accumulated sediments. The United States Army Corps of Engineers (USACE) has the responsibility of keeping shipping channels open, usually through dredging operations. When dredged sediments are found to be contaminated, they are placed in Confined Disposal Facilities (CDFs). However, the number of CDFs is limited, and they are reaching their holding capacity (Fredrickson et al., 1999). To accommodate ongoing dredging, existing CDFs need to be transformed into recycling centers for contaminated sediments in which the sediments that have been placed in them are remediated and removed.

Immediately after dredging, sediments are supersaturated with water and often have a very low redox potential (Price et al., 1999). They must be dewatered to allow aerobic degradation of organic pollutants (Vermeulen et al., 2003). Sediment dewatering involves three processes: (1) sedimentation; (2) consolidation and (3) “ripening.” The first two are relatively fast processes; however, ripening can take several years and involved physical, chemical and biological processes (Vermeulen et al., 2003). Ripening is the process of initial soil formation that results from drainage of waterlogged sediments and has been achieved through the use of plants by many authors. Löser et al. (2002) used hemp (*Cannabis sativa*) to ripen metal contaminated sediments; the hemp would germinate, but within 1 week the seedlings became discolored and ultimately 95% of the plants died. Those seedlings that survived were shorter and produced less biomass than their counterparts grown in uncontaminated soil (Löser et al., 2002). Helophytes have been used successfully to evaporate large amounts of water and transport oxygen into sediments (Löser and Zehnsdorf, 2002; Klee and Hofmann, 1987; Gerth and Grosser, 1996). As sediment moisture content decreased, the volume of the sludge also decreased. These plants also reduced organic substances and inorganic compounds found in the sediments (Klee and Hofmann, 1987).

Establishing plants in saturated sediments may increase dewatering while accelerating oxidation. When plants open their stomata to allow carbon dioxide to enter for photosynthesis, they lose water to the atmosphere through transpiration (Kramer, 1983). Various plant species have evolved ways to reduce the water loss to the atmosphere during photosynthesis because, in many environments, water loss is detrimental. However, some plant species have evolved in environments where water is never a

---

* Corresponding author. Tel.: +1 218 281 8262; fax: +1 218 281 8250.
*E-mail address:* katys@umn.edu (K.E. Smith).

0925-8574/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.ecoleng.2009.07.002

limiting factor. For these plants, mostly wetland species, continuously open stomata are an asset because this maximizes photosynthesis (Pisek and Berger, 1938).

Leaf area; root/leaf area ratio; leaf orientation; leaf size and shape; leaf surface characteristics; leaf anatomy; and stomata number and size have been shown to affect the transpiration rate of plants (Kramer, 1983; Kramer and Boyer, 1995). In addition, the transpiration rates vary widely by species and by plant type. Transpiration also can be affected by diseases and some pollutants (McFarlane and Pfleeger, 1991; Pfleeger et al., 1991); therefore, it is critical to evaluate transpiration rates in the presence of contaminants. Transpiration rates in plants can range from 4.8 mm/day in buffalograss (*Buchloë dactyloides*) (Shearman, 1989) to 45.4 mm/day in the purple nutsedge (*Cyperus rotundus*) (Brezny et al., 1973). Wetland plants generally have higher ET rates than grasses (Euliss et al., 2005; Tsao, 2003; Brezny et al., 1973; Kim and Beard, 1988; Shearman, 1989; Bowman and Macaulay, 1991). Leaf surface area also is a key factor in determining the most efficient dewatering species.

Many classes of contaminants found in dredged sediments degrade aerobically, including lower chlorinated polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) (Field et al., 1995). Oxygen needs to be introduced as a terminal electron acceptor before the remediation of many recalcitrant compounds can begin (Keuth and Rehm, 1991; Walter et al., 1991; Tiehm and Fritzshe, 1995). Through dewatering, plants create an aerobic environment in which organisms aerobically degrade many contaminant classes such as PAHs (Keuth and Rehm, 1991; Walter et al., 1991; Tiehm and Fritzshe, 1995). Wetland plants also oxidize the soil in contact with their roots by translocating oxygen into the rhizosphere via their aerenchyma (Armstrong, 1979; Evans, 2003).

For the purposes of dewatering the sediments, plant species with the highest evapotranspiration rate are needed. The objective of this study was to screen various plant species for their ability to remove water from contaminated sediments. Water loss (evapotranspiration) from greenhouse pots containing PCB contaminated sediments was quantified, and the results were applied to a field study where dewatering progress was monitored on PAH-contaminated sediments by monitoring the moisture content of the sediments over time on a CDF in Milwaukee, WI.

## 2. Experimental

### 2.1. Description of study

Dredged sediments for the greenhouse study were obtained from the Kinnickinnic River in Milwaukee, WI during December of 2001. A NEESKAY sampling boat (Great Lakes WATER Institute) was used, employing box-core casts to grab sediments. Kinnickinnic sediments were used to ensure that the results obtained in the greenhouse would be applicable to the field site at the Confined Disposal Facility in Milwaukee, WI. Greenhouse and field sediments were analyzed for basic chemical and physical properties (MDS Harris Laboratory, Lincoln, NE) (Table 1).

### 2.2. Greenhouse study

The sediments to be used in the greenhouse study were found to contain low concentrations of PCBs (Alpha Analytical Laboratories, Westborough, MA). Transformer oil containing Arochlor 1260 was obtained from Safety-Kleen Corp (Twinsburg, OH), and mixed with acetone to obtain a final concentration of 1000 mg/L Arochlor 1260. One hundred milliliters of this acetone/Arochlor mixture was uniformly sprayed onto 5 kg of the sediment to obtain a total PCB concentration of approximately 20 mg/kg. This procedure was repeated for each of the 120 pots used for this study.

**Table 1**

Physical and chemical properties of sediments used in the greenhouse study Methods of determination: organic matter by loss on ignition; phosphorus by Bray-1; bulk density by clod method; exchange properties by $NH_4OAc$; texture by hydrometer.

| Property | Greenhouse value[a] | Field value[a] |
|---|---|---|
| pH | 7.5 | 7.6 |
| Organic matter (%) | 3.7 | 4.2 |
| Phosphorus (mg/kg) | 30 | 74 |
| Bulk density ($g/cm^3$) | 1.0 | 0.8 |
| Water soluble: | | |
| Salts (dS/m) | 2.20 | 1.2 |
| Sulfate-S (mg/kg) | 547 | 272 |
| Nitrate-N (mg/kg) | 64 | 2 |
| Boron (mg/kg) | 0.7 | nd[b] |
| Exchange properties ($cmol_c$/kg): | | |
| Cation exchange capacity | 22 | 18 |
| Potassium | 2 | 2 |
| Magnesium | 4 | 5 |
| Calcium | 14 | 10 |
| Sodium | 2 | 1 |
| DTPA-extractable (mg/kg): | | |
| Zinc | 8 | 4 |
| Manganese | 14 | nd |
| Copper | 2 | nd |
| Iron | 13 | nd |
| Texture: | | |
| Sand (%) | 34 | 34 |
| Silt (%) | 61 | 61 |
| Clay (%) | 5 | 5 |

[a] Results from MDS Harris Laboratory Analysis.
[b] Not determined.

The sediments were placed in 7.6 L (2 gal) pots (dimensions 25.4 cm × 22.86 cm) with a plastic bag liner. Prior to planting, all pots were saturated and incubated for 3 days. The saturation point was 51% moisture by weight, determined using the paste method (Rhoades, 1982). After the incubation period, the vegetation treatments were established: no plants, River bulrush (*Scirpus fluviatilis*), Eastern gama grass (*Tripsacum dactyloides*), Lake sedge (*Carex aquatalis*), and Prairie cord grass (*Spartina pectinata*). One plant was established per pot, and all were planted from plugs. Plugs were obtained from Ion Exchange (Harpers Ferry, IA) for all species except the Eastern gama grass that was planted as rhizomes obtained from a living plant at the Feldun Purdue Agronomy Farm (Bedford, IN). All treatments (5 vegetation treatments) were arranged in a randomized complete block design with 4 blocks arranged across the temperature gradient in the greenhouse. The combination of 5 vegetative treatments, three scheduled destructive events, and 4 blocks/replicates yielded 60 pots. All pots were fertilized once per month at 2.5 mg/kg K and 6.25 mg/kg N.

### 2.3. Gravimetric determination of dewatering efficiency in greenhouse

Dewatering efficiency was monitored gravimetrically (Kramer, 1983) by weighing all 60 pots on a weekly basis. The sediments were brought to the saturation point and monitored for water loss for a period of 3 weeks. At the end of the third week, the pots were watered again to the saturation point and the cycle was repeated twice for a total of three cycles.

### 2.4. Infrared gas analyzer for dewatering efficiency in greenhouse

Dewatering efficiency also was evaluated with an Infrared Gas Analyzer (IRGA) (LCA-4, Dynamax, Inc. Houston, TX, USA). The IRGA