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Beneficial Use of Illinois River Sediment for Agricultural and Landscaping Applications

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List of Abbreviations

Abbreviation	Meaning	Abbreviation	Meaning
Al	Aluminum	N	Nitrogen
As	Arsenic	Ni	Nickel
B	Boron	P	Phosphorous
BAP	Benzo(a)pyrene, a polycyclic aromatic hydrocarbon	PAH	Polycyclic aromatic hydrocarbon
C	Carbon	Pb	Lead
Ca	Calcium	PRI	Prairie Research Institute
Cd	Cadmium	RM	River Mile, on Illinois River measured from Grafton North
CDF	Confined disposal facility	S	Sulfur
CL	Clay loam	SFWA	State Fish and Wildlife Area
Cr	Chromium	SiC	Silty clay
Cu	Copper	SiCL	Silty clay loam
DTPA	Diethylenetriamine pentaacetic acid	SiL	Silt loam
Fe	Iron	SOM	Soil organic matter
FWA	Fox Waterway Agency	ISWS	Illinois State Water Survey
HREP	Habitat Rehabilitation and Enhancement Project	TACO	Tiered Approach to Corrective Action Objective (IL Admin. Code)
IDNR	Illinois Department of Natural Resources	UIUC	University of Illinois at Urbana-Champaign
ISTC	Illinois Sustainable Technology Center	USACE	U.S. Army Corps of Engineers
ISWS	Illinois State Water Survey	USEPA	U.S. Environmental Protection Agency
K	Potassium	USGS	U.S. Geological Survey
Mg	Magnesium	USX	Former U.S. Steel South Works Facility in Chicago
Mn	Manganese	Zn	Zinc
MSL	Mean Sea Level		

Executive Summary

Sediment behind navigation dams in backwaters and side channels of the Illinois River has accumulated to the point that economic, recreational, and habitat uses of the river are impaired. The State of Illinois has studied this matter for decades and has partnered with various agencies to address the problem. One such effort involved evaluating the potential for beneficial uses of dredged material, especially in the Lower Peoria Lake near Peoria, IL. Cores taken in the lake show varying depths of material including a top layer of soft sediment likely deposited since major changes to the river began in 1900. Lower layers often include original river bottom or floodplain soil. Dredged material from the Peoria Lakes and several reservoirs is similar to native topsoil. Discussion of contaminant levels in the sediment is beyond the scope of this report; however, levels varied by location and increased upstream of Peoria.

Mechanically dredged sediment from Lower Peoria Lake was transported by barge to several locations including a former steel mill site in Chicago. The sediment was cohesive and did not require containment. It dewatered rapidly and could be tilled and seeded within a few months. Within a year after placement it developed a typical soil structure, especially after freezing and thawing. Given that sediment from different layers varied in quality, mixing or tilling sediment after placement provided a more homogenous sediment-derived soil.

A variety of methods were demonstrated for handling the material. Demonstrations showed that displacement pumps and conveyors could handle the soft sediment layers. Minimizing excess free water when loading barges was essential for maintaining cohesiveness and keeping the shipping weight low. Sediment was easily transferred to trucks. On dumping, the sediment usually flowed from the trucks without difficulty, except for a few occasions when transporting deeper, sticky dredged material.

Sediment from the Peoria Lakes region of the Illinois River tends to be dominated by silts and clay, with typically about 2–6 percent organic matter and a pH of 7 or more. These parameters are close to those of good quality Illinois topsoil. However, the sediment clay content is generally higher than optimal from a management perspective. Greenhouse experiments showed that the sediment could be improved by adding organic matter such as compost or biosolids. Field experiments sediment placed onto sandy soil dramatically improved the native sandy soil quality and crop response. These studies did not consider mixing dredged sand with fine-grained sediment. Our recommendation for mixing sandy and fine-textured sediment to make an acceptable topsoil would be to first dewater the sediment and mix it with an equal volume of sand. If desired, adding an organic amendment such as biosolids to make up 10–20 percent of the dry volume would be a further enhancement.

Sediment-derived soil can be used in numerous applications, ranging from landscaping to rehabilitating old industrial sites and strip mines. Beneficial uses of this dredged sediment could also prevent the practice of native soil being removed from some areas to supply needs in others. Moving sediment by barge removes truck traffic from highways and local neighborhoods. Dredging of sediment from navigation channels has long been a federal priority. It is reasonable to consider giving similar priority to restoring backwater habitat choked with fine sediment. The dredged material could be used to create habitats, improve disturbed soils such as strip mines or industrial sites, and possibly restore coastal marshes. There is a need to review policies and regulations that impede the beneficial use of dredged material.

Introduction

This report is a review of the sediment beneficial use project coordinated by the Illinois Sustainable Technology Center (ISTC), which became known as the “Mud to Parks” project. This document focuses on published and unpublished results and insights that researchers developed between the late 1990s and 2017. It is not intended to be a comprehensive technical review of sediment beneficial use, and therefore, includes references to a limited number of publications by other researchers. Although it mainly involves Illinois watersheds, potential applications of results and insights will likely be useful in other areas. Although much of the effort was centered on fine-grained sediment, a large part of the project involved placing sediment on sandy agricultural soil. The Sand Farm Project is reviewed in detail in Appendix B. ISTC was previously housed in the Illinois Department of Natural Resources (IDNR), and is now a division of the Prairie Research Institute (PRI) at the University of Illinois, Urbana-Champaign (U of I). The name Mud to Parks originated when the first large project took fine-grained dredged material from Lower Peoria Lake to Chicago to provide soil for a lake-front park (Figure 1). In reality, the project dealt with many aspects of potential beneficial uses of dredged materials from a number of sources.

This document is organized into sections dealing with various aspects of the project. The motivation for the project is covered first, followed by a description of early work to determine the ability of the dredged material to be readily transported, and whether it would develop an acceptable soil structure. This section also describes equipment demonstrations. Specific beneficial use projects are covered in the next section. Soil fertility and physical characteristics are then covered along with a discussion of greenhouse and field studies of sediment from the Peoria Lakes and Illinois water supply reservoirs. Information and data from the soil studies are provided in the appendices, which are largely excerpted from published material. The final section contains some of the authors’ thoughts and speculations on potential uses of material dredged to restore depth in navigation channels, wildlife habitats, and reservoirs.

Sediment, especially sand, has been dredged from channels for hundreds of years to maintain an adequate navigation depth in waterways. The impetus within IDNR for beneficial reuse dates back to the 1960s when sedimentation was becoming increasingly recognized as contributing to aquatic habitat degradation in addition to loss of recreational depth, water storage capacity, and other useful features. In reservoirs and navigation pools, fine-grained sediment gradually covered other types of bottom substrate, greatly decreasing habitat diversity.

For many years, dredged material was simply placed wherever it was convenient and legal to do so. This was frequently in backwaters, wetlands, and low-lying areas of adjacent floodplains. This too altered or eliminated riparian habitat, adversely impacting environmental conditions and associated economic and recreational activities such as boating, hunting, fishing, and nature photography. Public pressure, including litigation, eventually led to requirements that dredged material be placed in less environmentally sensitive areas including upland locations and confined disposal facilities (CDF).

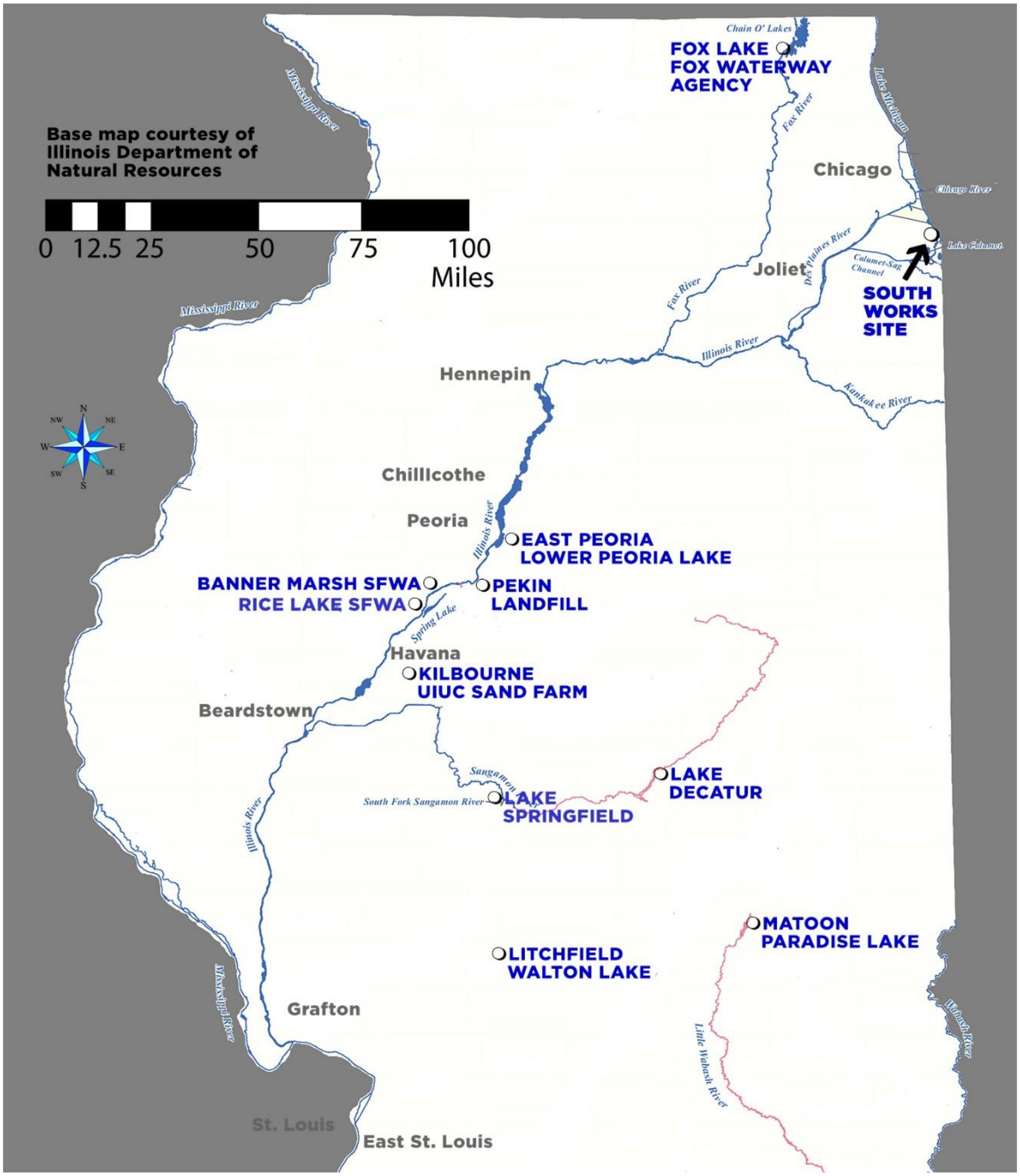

Figure 1. Rivers and project locations. Dots indicate locations of study areas and projects. Dredged material for the South Works site left East Peoria in barges and followed the Illinois and Des Plaines Rivers and Calumet Sag Channel to Lake Michigan.

In Illinois and much of the Upper Mississippi River Basin, the sediment impacting the commercial navigation channels on large rivers is primarily sand. The relatively heavy sand particles drop out of suspension before the lighter silt and clay particles. Fine-grained material tends to stay in suspension until water velocity is slower than in the main channel. Therefore, deposition of fine-grained material is usually more of a problem in backwaters and side channels as well as in marinas. Exceptions include areas where a tributary transports and deposits sand away from the main channel, often forming deltas. Illinois reservoirs typically have no navigation channel, and the location of deposited sand and fines within them varies depending on site-specific considerations. For the most part, the sediment has eroded from farmland and stream banks and beds, although urban runoff contributes.

There is growing public awareness of the need to address poor soil quality or absence of soil at locations such as strip mines and old industrial sites including brownfields in order to support desirable healthy vegetation. There is also a demand for topsoil in urban areas where homeowners and landscapers are attempting to grow grass and gardens in areas where much of the topsoil was removed by developers, prior commercial/industrial owners, or erosion due to poor management. Soil loss from agricultural land has long been recognized as an issue needing attention. Highway and other construction projects also require topsoil to support ground cover.

A variety of other options for meeting this demand are under consideration, including moving soil from one area to another, various formulations of soil amendments, and manufactured soil. These may include mixtures of biosolids, compost, sediment, wood byproducts, and other materials as well as subsoil and sand. Dredged material has the potential to play a large role in this effort. Mary Landin, an early advocate of beneficial use of dredged material, compiled considerable information on the concept (USACE, 1985).

Mud to Parks was initially focused on the Peoria Lakes, which historically were wide spots in the river and low floodplain along the Illinois River channel near Peoria, but eventually included backwater lakes between Beardstown and Hennepin, IL. The construction of the Lake Michigan Diversion at Chicago in 1900 and locks and dams in the late 1930s increased the size and depth of the lakes. IDNR's primary concern was the loss of water depth, ecological diversity, and habitat in the backwaters and side channels, which was primarily caused by sedimentation (Mills et al., 1966; Bellrose et al., 1983). The project ultimately included several water supply and recreational reservoirs in Illinois, which were also mainly impacted by fine-grained sediment.

A study by Demissie et al. (1992a) documented that backwaters, which originally had a depth suitable for a variety of recreational and habitat uses, had lost an average of 72 percent of their capacity by 1990. The sediment also eliminated aquatic habitat diversity for benthic organisms by covering the bottom of the pools with a layer of fine-grained material. Adjacent floodplains lost much of their topographic diversity when dams raised the water level.

The Mud to Parks project focused on removal and the beneficial use of sediment as a means of restoring habitat. This included investigating ways to provide deeper water in some backwater areas and increased land elevation in other selected areas. Projects of the U.S. Army Corps of Engineers (USACE), state agencies, and non-government organizations (NGOs) dealt with other potential issues including erosion control, stream stabilization, reconnection of floodplain backwaters to the channel, moist soil units for waterfowl, and repurposing agricultural levees (Bhowmik et al., 2000; USACE, 2007).

By the mid-1980s, restoring depth in much of the Peoria Lakes, especially Lower Peoria Lake, was a priority of interest groups in the surrounding communities. A number of studies and reports addressed the issue (Demissie and Bhowmik, 1986; Bhowmik et al., 1993; and USACE, 2003a). In the 1950s the lakes were relatively deep and heavily used for recreation including water skiing. By 1990, up to 14 feet (4.3 m) of sediment had accumulated in some areas and other areas were less than 2 feet (0.6 m) deep. By 2000, even small fishing boats had trouble navigating the lakes and the backwaters along the river. Larger recreational boats were mainly limited to the navigation channel in the two lakes, and access to marinas was seriously impacted. Initial public and technical concerns about the beneficial use of sediment centered on potential contaminants and the agronomic properties of the sediment. Other considerations included dredging techniques, access to land for sediment placement, potential beneficial uses, ownership of the sediment, likely partners and collaborators, and of course, funding.

Given that the lakes contained millions of cubic yards of mostly fine-grained material and that much of the shoreline was developed, it was apparent that restoration of depth would require finding sites for permanent sediment placement or use at some distance from the lakes. Numerous sites have over 100 acres (49 ha) of open land within 10 miles (16 km) of the lakes. However, they were not seriously considered at the time because there was a prohibition on purchasing land for projects. The highly developed area immediately surrounding Lower Peoria Lake was not a likely candidate for placement of massive quantities of sediment-derived topsoil, especially since the surrounding farmland generally had adequate high quality soil. Additionally, the local commercial market for topsoil was limited. The researchers focused on regional uses of sediment for a variety of purposes such as landscaping soil, agricultural soil amendment, landfill cover, remediation of strip-mined land, and construction activities.

The Chicago and St. Louis metropolitan areas contain a considerable amount of distressed former industrial land, including brownfields and old landfills, which would benefit from the addition of good quality topsoil. The feasibility of moving large amounts of sediment to these cities by barge received early consideration because handling would be limited to loading and unloading barges and final placement. If sediment quality proved suitable, it was thought that it might be commercially viable to market sediment as topsoil, either by itself or mixed with biosolids, composted yard waste, or other materials.

In 1998, the project team became aware of efforts to revitalize the old U.S. Steel South Works site (often referred to as USX) on Lake Michigan in Chicago (Figures 2, 3). The site included 570 acres (230 ha) and had undergone environmental cleanup and removal of buildings and other structures. It had its own marine slip at the end of the Illinois Waterway at river mile (RM) 333. The City of Chicago and its partners planned to develop the site and were looking for a source of topsoil for much of the site. Rock-like slag, a byproduct of steel production with no value as soil, covered the site. Approximately 100 acres (40 ha) along Lake Michigan were proposed to be turned over to the Chicago Park District. This site appeared to be an ideal location for a large project using sediment-derived topsoil.

The IDNR received a state grant of $500,000 in 1998 to begin evaluating Peoria Lake's sediment quality, looking into dredging technology, sediment handling and processing, beneficial use, and related matters. The following pages will cover some of the highlights and lessons learned during that effort. Note that unless otherwise specified, the sediment used in these projects came from the Peoria Pool, mainly Lower Peoria Lake. Sediments from other locations and watersheds may handle differently, depending on their characteristics.

Figure 2. The largest Mud to Parks project took sediment to the old U.S. Steel South Works site on Lake Michigan in Chicago. The Illinois Waterway (Calumet Sag Channel) is at the bottom of the photo, Steelworkers Park is above the waterway and south of the slip. Sediment was placed along its lakeside edge. The unnamed park is northeast of the slip in the center where barges were unloaded.

Figure 3. Steelworkers Park before sediment placement was a slag field. Greenery in the distance is a demonstration plot for biosolids. The concrete ore wall is in the background.

Investigation of Soil Formation and Sediment Handling

An early question was how quickly mechanically dredged fine-grained sediment would form soil structure and how well it would hold up to the erosive force of rainwater. To determine this, wet sediment was collected from the lake with a hand auger and placed in buckets. It was relatively cohesive and had little tendency to flow rapidly, having about 50 percent moisture content by the wet weight method. It was then placed in greenhouse trays, sprinkled with grass seed, and allowed to dry both in and out of doors. The sediment began to crack and form small geometric shapes called polygons almost immediately. Wind and rain caused the seeds to fall into the cracks. The surface of the polygons dried and hardened rapidly, and only a few seeds germinated on the surface. However, seeds readily germinated in the cracks, and the roots followed the moisture gradient downward as the cracks expanded. Raindrops initially dimpled the wet sediment surface, but even after drying, the hard polygons lost little material to rain. After a few weeks, the grass was several inches tall (Figure 4) and soon covered the material. These results indicated that rapid vegetation growth and erosion resistance were achievable on fresh sediment.

In field demonstrations, truckloads of mechanically dredged fine-grained sediment, when end-dumped, formed mounds about 2.5 feet (0.8 m) high and 20 feet (6 m) in diameter (Figure 5). The material was initially cohesive enough to withstand rainfall with little noticeable erosion. Grass seed germinated and grew similarly to that in the small tray demonstrations. Roots followed the cracks to obtain moisture, and the blades soon grew to protect the material from wind and rainfall. Areas that were not seeded soon developed seedlings of cottonwood and common weeds from blown-in seeds or seeds in the sediment or on the surface where the sediment was placed. It was also observed that after a few days the cracks were large enough to contain a considerable amount of rain without runoff. Rainwater did not rewet the polygons back to their previous high moisture content. The result was that erosion was not initially a problem at the placement sites, even though no berm or other containment was provided.

As the sediment polygons further dried and weathered, soil structural units (i.e., small peds) began to form. They generally stayed within the placement site because the cracks between polygons prevented water from flowing off site. Freezing and thawing overwinter resulted in more breakdown of the polygons into smaller soil aggregates. At that point, the sediment-derived topsoil was subject to erosion and would benefit from a vegetative cover to minimize soil loss. The undisturbed soil was also resistant to wind erosion. Presumably, if silty sediments were overworked by tillage when under dry conditions, they would be susceptible to wind erosion, as would any silty soil. As discussed later, the sediment generally proved to be an excellent medium for plant growth.

The time required for soil structure formation varied with conditions, especially initial sediment depth. Sediment about 14 inches deep placed at the Paxton 1 landfill in Chicago had granular and platy structure over much of its depth one year after placement (Figure 6). The roots of grass seeded on it penetrated the entire depth (Figure 7). At other sites where sediment was placed three or more feet (1 m) deep, after a year there was well-developed soil structure for about the first foot. Below that were polygons and then pasty, wet sediment. Over time, all of the material dewatered and had a relatively conventional soil profile, as evidenced by the granular structure at the surface with a polygonal structure below. The process of wet sediments evolving into more recognizable soil-like material is called ripening. It involves an irreversible loss of its initial high moisture content and development of soil structure, as is commonly observed with dewatered and aged/weathered fine-grained sediments (Lafrenz et al., 2013).

Based on these demonstrations and the cohesiveness of delivered sediment, no containment berms were constructed for the initial phases of the USX project. The sediment formed piles and grass seed grew in the desiccation cracks between the soil polygons (Figures 8, 9). Within two months, the grass was tall enough to completely cover the polygons, even though the surface remained bare.

The Dredging Depth Issue

Navigation dredging is fairly straightforward, requiring a 9-foot (3 m) depth across the navigation channel. Dredging to increase depth in backwaters and side channels for habitat enhancement or recreation poses some additional challenges, especially if hydraulic dredging is not a viable option. Areas requiring deepening are often far from on-shore infrastructure such as roads, and are also relatively far from the main channel. Assuming that access rights on shore are obtainable, it is likely to be difficult to mobilize equipment without disrupting adjacent vegetation and traversing difficult terrain. Access from a navigation channel could require digging a channel to the work site deep enough for equipment that may require 9 or more feet (2.7 m) of depth. In many situations, this access channel may not be ecologically desirable or economically feasible. Additionally, the material excavated to reach the site would have to be handled and placed somewhere. Various types of equipment were considered to address this situation and are discussed below.

The Illinois State Water Survey (ISWS) collected sediment cores reaching as deep as 8 feet (2.5 m) in the study area (Figure 10). For example, core 197 was taken midway between the navigation channel and East Port Marina in Lower Peoria Lake near RM 164 (Figure 11). The core illustrates how certain physical and chemical properties vary with depth. In the lake the layer of soft, fine-grained sediment, which was usually ideal for use as topsoil, varied in thickness from 2 to over 14 feet (0.6–4.3 m). Generally, this layer was thicker close to the main channel and tapered off closer to shore. This material frequently overlaid less desirable stiff material with a low organic matter content that was likely in place before the dams were constructed (Figure 12). In some situations, it is desirable to remove only soft sediment or dredge less than the standard barge depth for habitat creation or other purposes. However, conflicts can arise when some interests desire a deeper dredging for boat access or other purposes.

For the Mud to Parks projects in Lower Peoria Lake, the solution was relatively simple given that the main objective was reclaiming topsoil from the lake. In the process, the channel to marinas would be restored. A barge-mounted crane began digging from the edge of the channel into the adjacent soft sediment and placed dredged material into standard hopper barges for transport. As the operation approached shore, a stiffer, light-colored material was encountered. It was added to the barge as long as it was not the predominant material (Figure 13). It was agreed that the operation would move to another location if the lighter material became excessive. In retrospect, the deeper material at this location formed an acceptable soil for most purposes, especially when mixed with the overlaying soft material, and was superior to that at the distressed placement sites. However, it was more difficult to handle. Where deep, soil-quality sediment exists near a navigation channel, this method can be used to obtain large quantities with minimal handling. Ultimately, a method is needed to remove sediment without excavating to the standard barge depth.

Sediment Handling Approaches

Over the years, several types of equipment were considered for dredging, transporting, and handling primarily fine-grained sediment. Some were either demonstrated or observed in the field and others were simply discussed. In the absence of readily accessible areas for settling ponds and drying sites, mechanical and other high solids options were investigated. Minimizing loading and unloading was a major consideration as there are costs associated with each handling operation. The general cost of using the different methods was not determined as costs are often controlled by factors such as ownership of facilities and equipment, local regulations, labor rules, the sponsoring entity, and the relationships between contractors. The following sections cover several of these options, some of which were used for projects and others were demonstrated or observed.

<u>Hydraulic Dredging</u>

Hydraulic dredging is economical and desirable in many, if not most, situations in which a settling and dewatering basin can be constructed nearby (Figure 14). In some situations, it is possible to pump the material tens of miles using booster pumps, although this adds costs. Return flow must often meet water quality standards, which may vary by jurisdiction. Beneficial reuse of the material is then largely dependent upon the distance from the dewatering basin to the point of use or the nearest appropriate transportation option. If possible, for large-scale reuse the material should be dewatered near the point of use or a rail or barge connection for efficient loading and transport. Trucking reclaimed soil from a dewatering basin to a transfer facility involves relatively high handling and labor costs. If used near the basin, trucks can readily carry material to local sites.

Material leaving the dredge pipe tends to settle out in the receiving basin by particle size. Sand and gravel accumulate near the discharge pipe, while silts and clays move a much greater distance (Figure 15). The resulting material may have to be mixed to produce a more uniform reclaimed soil. If sediment is to be reclaimed, it may be useful to divide the dewatering area into sub-basins. That way, dewatered material can be removed from one while others are filling. Assuming most clients prefer dry soil, it may be desirable to stockpile dry material.

Figure 4. When placed on trays of fresh sediment, grass seed grew in the cracks as it dried.

Figure 5. Dredged material was cohesive and formed piles when dumped from trucks in Chicago.

Figure 6. After one year sediment developed granular structure about 8 inches deep over polygons of consolidated material.

Figure 7. One year after placement, sediment exhibited excellent soil structure and grass roots penetrated the entire layer.

Figure 8. Grass seed scattered on a pile of fresh sediment at USX was knocked or blown into cracks by rain or wind as the surface dried.

Figure 9. The same pile a month later shows grass growing in the cracks. Roots follow the moisture gradient as the material dries.

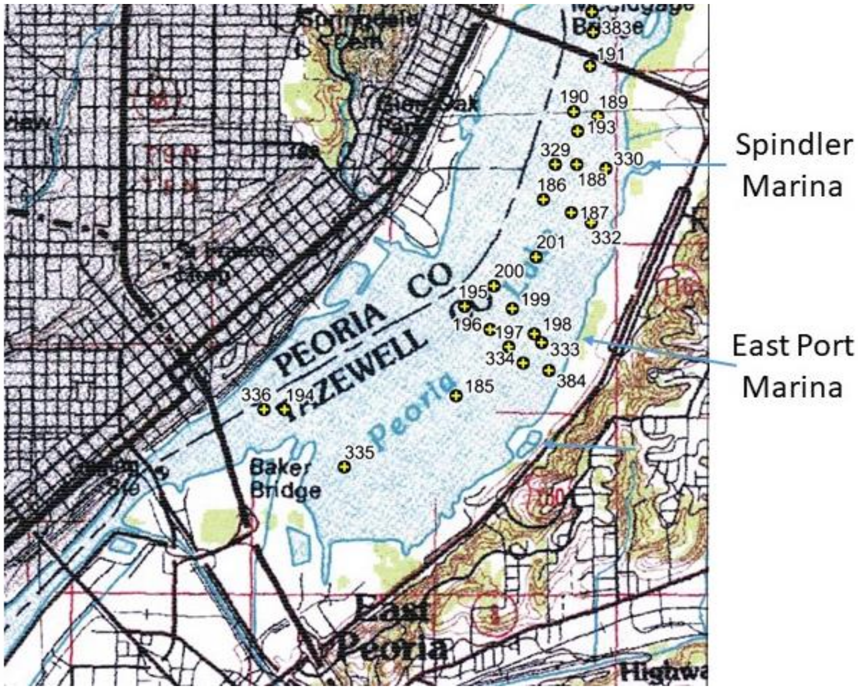

Figure 10. Location of cores taken in Lower Peoria Lake for physical and chemical analysis. The bulk of the sediment used in projects came from two marina channels, East Port near RM 164 and Spindler near RM 165. Data for some cores are included in Appendix D.

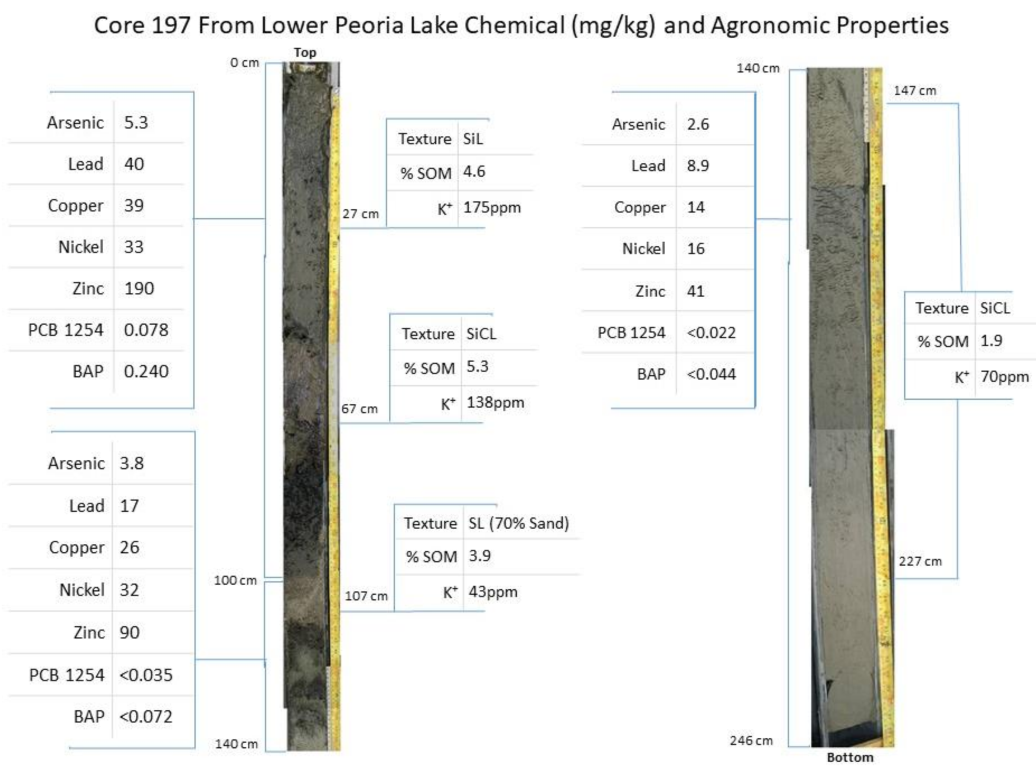

Figure 11. Sediment core showing physical and chemical attributes at various depths.

Minimizing Excess Water and Spillage

Mechanical dredging can usually bring up sediment with little excess free water. To reduce handling, mechanically dredged material was usually transported to the placement site while wet. Preventing excessive free water from entering the barge and mixing with the dredged material was, therefore, an important consideration for holding down transportation costs and avoiding leakage during truck transport. This was best accomplished by heaping or overfilling the dredge bucket so that it was completely filled to the point that little excess water remained. Where water was entrained and streaming from inside a bucket, it was often allowed to drain before the load was released. The operator then lowered the bucket into the barge and placed the sediment rather than dropping it from a height. This minimized the mixing of any free water into the dredged material. The sediment was normally somewhat cohesive, tended to mound in the barge, and oozed rather than flowed freely.

Hopper barges were used for long-distance transport and usually contained little free water after loading (Figures 16, 17). Occasionally pumps were used to remove some accumulated water on site. During transport, rainwater occasionally accumulated in barges. This was removed with pumps at the unloading site. In Chicago, the pumped water was discharged in vegetated areas near the slip and did not flow into Lake Michigan. This prevented increasing turbidity in the lake or introducing invasive species. The consistency of material dumped from trucks in Chicago varied depending upon how much water was mixed with the sediment during barge loading (Figures 18, 19). However, none of the loads were fluid enough to cause serious handling problems.

When deck barges were used for short hauls, water in the bucket was less of an issue. Buckets were still heaped to minimize the amount of turbid water flowing off the deck. Barriers, such as jersey barriers, were used to help contain mounded sediment on deck barges, although in most cases, the material had little tendency to slump during short movements. Using barriers also allowed more material to be loaded. Material was often in barges about a week before being unloaded into trucks. It was usually somewhat cohesive and initially mounded in the trucks. However, conditions often varied, and it was necessary to make sure that gates on all trucks could seal tightly, usually with the aid of clamps. It was not necessary to use special liners. At some sites, or if too much water was introduced during operations, the material was more fluid and drivers had to be careful not to allow it to slosh around within the truck bed.

Dredging Buckets

A number of conventional clamshell buckets (Figure 20) were used with cranes on Illinois River projects. They were particularly useful in locations where dense material required removal along with the overlying soft sediment. In these instances, the teeth allowed greater penetration. Given the length of their booms, they had a greater reach than some other equipment and could dig deeper. Sediment would sometimes stick to the outside of a bucket and fall into the water or chunks would spill over from the top. A conventional crane with a Hawco bucket was used to unload barges into trucks in Chicago during the first phase of Mud to Parks. It closed tightly and did not drip material into the lake.

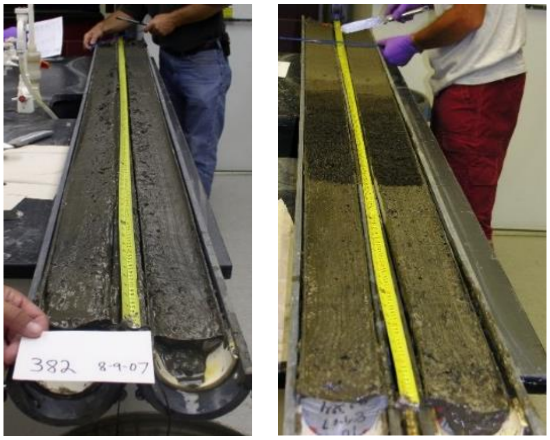

Figure 12. Sediment core on left has uniform color; on the right three layers are visible, indicating different physical properties.

Figure 13. Loaded barge shows darker soft sediment between chunks of dense light material. They usually stayed separate during transit.

Figure 14. Dewatering basin for the Lake Decatur water supply reservoir dredging project.

Figure 15. Sand and gravel settles out near the pipe at Fox Waterway Agency setting basin.

Figure 16. Crane operator has allowed very little free water to enter this barge.

Figure 17. Excessive water in a barge where the hydraulic bucket is not draining adequately prior to placing sediment.

Cable Arm™ clamshell buckets (Figure 21) were used on some projects in Lower Peoria Lake. They are designed to remove contaminated sediment without allowing spillage and were particularly useful in areas with deep, soft sediment (Marlin and Darmody, 2005a). The buckets known as "navigation" buckets worked best. They filled well and had screened ports that expelled excess water without losing material. This minimized turbidity from material falling from the bucket during swings. They also make a level cut on the bottom. Best results were obtained with heavier buckets; however, they were not suitable for removing dense material. Cable Arm™ has developed a bucket for use with hydraulic excavators.

Hydraulic clamshell buckets (Figure 22) on large excavators were used on several occasions. They allowed precise movement and could be pushed into the sediment to enhance filling. They could also be readily cracked open to drain water with minimal loss of material. Their short arm length often limited their usefulness to relatively shallow dredging locations.

A hydraulic clamshell was used to unload barges for the second and third phases of the project at the U.S. Steel site. It could be readily maneuvered within the barge and could easily position its bucket to drop material into trucks. A skid steer was placed into barges to scrape the last of the load into piles, which the buckets could then grab.

Conventional open buckets (Figure 23) on excavators worked well in locations where water was shallow and their reach was not an issue. Their ability to drain water was limited, especially if they were not fully filled.

<u>Displacement Pumps</u>

Displacement pumps, which push material through pipes, are commonly used to place concrete at construction sites. They are increasingly used to handle dredged material. They come in a variety of sizes and capacities and can be mounted on trailers, barges, trucks, and other types of equipment. They have few moving parts and discharge little or no excess free water. The pipe can extend a great distance over water, up slopes, and over land.

The Dry Dredge™ was demonstrated in Upper Peoria Lake in 2001 (Marlin, 2002) to determine its ability to place material for creating islands and elevated landforms. This self-contained dredge is stabilized with traveling spuds and can operate in as little as 26 inches (65 cm) of water. It uses a sealed clamshell bucket to place sediment in a hopper feeding the pump. The material is then discharged from a pipe. The demonstration involved excavating soft lake sediment and pumping it through 120 feet (37 m) of pipe. The operator was instructed to minimize the amount of free water entering the hopper and mixing with the sediment in order to stay as close as possible to the *in situ* moisture content. The dredged material was placed at several locations on a nearby island and in shallow water. The material exiting the pipe was quite stiff and had no free water. Sixteen samples were taken that showed the dredged material had essentially the same moisture content as the *in situ* sediment. The discharged material was much firmer than expected and made piles with a slope of about 9:1. When an attempt was made to fill a wooden form 18 inches (46 cm) high and 8 feet (2.4 m) square, the material stacked up to the height of the pipe lip instead of flowing across the form.

Figure 18. Material deposited at USX from most barges was cohesive and formed piles.

Figure 19. Material from the few "wet" barges was more fluid but not enough to cause concern.

Figure 20. A conventional bucket with sediment heaped does not carry much free water.

Figure 21. Screened ports on Cable Arm ™ buckets drain water while preventing sediment from falling back into the lake.

Figure 22. A hydraulic clamshell bucket depositing drained material in a barge.

Figure 23. Heaped excavator bucket. Note color differences in this stiff material from below the soft sediment layer at Rice Lake.

The dredge successfully filled four 15-foot (4.6 m) circumference geotextile tubes, which when full were about 1 foot above water level. The discharge pipe was placed inside the tube ports, filling them without discharging any free water. The tubes were placed in a trapezoidal pattern to create an outline of a small island. The pipe was then placed over the west tube, and sediment was pumped into the enclosure (Figures 24, 25). The only difficulty encountered was that the dredged material was so stiff that it did not flow all the way over to the east side, a distance of about 35 feet (11 m). In order to fill the east side of the small island, water was then added to the hopper to increase the flowability of the discharge. In an actual operational situation, the pipe would have been moved or extended to avoid adding water. This demonstrated the ability of the dredge to move cohesive material through a pipe to a placement site. No debris was encountered that threatened the pump. The sediment consolidated and dried to the point where it could be walked on. It was subject to frequent flooding and wave action. Over several years, the tubes flattened and lost some height. It was not possible to determine whether this was due to consolidation, the fine-grained material passing through the tube walls, or the tubes sinking into the underlying soft sediments. In some locations, all three may be factors.

In 2002, IDNR tested the ability of an unmodified Putzmeister BSF32-16 concrete pumping truck with a 105-foot (32 m) placing boom to handle wet sediment. The sediment came from Whightman Lake, a backwater near Lacon. It was stiff and similar to that in Lower Peoria Lake (Figure 26). As with the Dry Dredge™, the pump and placing boom experienced no difficulty with the material. The remote-controlled boom was able to spread the material over an area at various thicknesses and place it at precise locations. When held in place to see how high the sediment would stack, it produced a cone that maintained itself 1.85 feet (0.56 m) high with a radius of 10.3 feet (3.1 m.) (Figure 27). No debris was encountered that threatened the pump; however, in a large project it would be wise to screen the material and watch for debris (Marlin, 2002 and 2003b).

The Midwest Foundation Corporation (Midwest) constructed stage 1 of the Peoria Riverfront Ecosystem Development Project of the Rock Island District of the USACE in Lower Peoria Lake. Project purposes included improving water depth diversity, aquatic habitat, and water quality by deepening some areas and creating a 21-acre (8.5 ha) island with the dredged material. The project site was in shallow water, and the future island was ringed with geotextile tubes to protect it from waves and retain the dredged sediment. Midwest obtained a modified Putzmeister 14,000 HPD positive displacement pump with a capacity of 300 cubic yards (229 cubic meters [m^3]) per hour and mounted it on a barge. A mud hopper was used to screen material before it entered the pump. The pump filled the tubes and then began pumping sediment into the ring (Figures 28, 29). The equipment worked well in soft sediment. When hard clay-like material was encountered, it proved impossible to break up enough to pump. At that point, conventional cranes and excavators dug up the material and it was taken to the island by deck barge. This increased the amount of handling.

Conveyors

Conveyor belts are used to move many types of material, usually in situations where they can remain in place. Special applications such as loading trucks or moving construction material to various heights can justify moveable units. Conveyors will likely be proven useful for moving dredged material over shallow water, in various loading and unloading operations, and at locations where it is stockpiled for beneficial use.

The ability of a truck-mounted conveyor commonly used to move concrete, gravel, and other construction materials was demonstrated in 2002 (Marlin, 2003b). A Putzmeister TB105 telebelt truck-mounted telescoping conveyor was used. It has a maximum reach of 105 feet (32 m), and is capable of moving up to 350 cubic yards (268 m^3) of material per hour. Material is placed in a hopper that feeds a 40-foot (12.2 m) feeder conveyor that carries material to a transfer point on top of the truck where it moves to the main conveyor (Figure 30). The transfer point is covered to prevent splattering of materials.

These hoppers are designed to handle concrete and coarse material up to 4 inches. (10 cm) of gravel. Hoppers are narrow and sit close to the belt. The thick, moist sediment bridged over the bottom opening of the hopper rather than falling rapidly through it onto the moving feeder belt. Shovels were used occasionally to push material through the hopper. When the hopper was raised several inches with boards, the moving belt pulled large dollops of material from the bottom. These sediment chunks moved readily up the feeder belt, through the transfer point, and onto the main belt. The material was flattened as it passed under the transfer point's cover, but maintained its consistency. The sediment occasionally hit guides, causing some splatter. This appeared to be a minor issue that can be addressed without difficulty. A modified hopper and some changes in fittings designed for concrete would likely resolve the problem. Splatter was not an issue on the main belt.

The bulk of the material for the conveyor demonstration was pumped into the hopper through the placing boom of the pump truck. After pumping, this material was less cohesive than that loaded from the skidder bucket. However, it presented no serious problems on the feeder belt, transfer point, or main belt. When placed directly on the feeder belt, the pumped material stayed centered on the belts, eliminating most splatter. The belt scrapers adequately cleaned both belts of sediment and no carry back was observed. When elevated, the extended conveyor transported material up an incline of about 30 degrees without difficulty. The material did not liquefy or slide on the belt, although this may be a concern if sediment with a higher moisture content is conveyed, especially over longer distances. Like the placing boom, the conveyor was able to place material in precise patterns. A remote control allowed the operator to stand near the end of the extended conveyor and move it horizontally and vertically. The truck could be used to place dry or wet material on fields or slopes at landfills, highways, or other sites.

Figure 24. Cohesive dredged material forming a mound as it comes from Dry Dredge™ pipe.

Figure 25. East Port Marina material is placed in a hopper in front of the excavator on the dredge. The displacement pump is below the deck.

Figure 26. Material dredged the day before was used in the pump and conveyor demonstrations.

Figure 27. Sediment leaves the placing boom, which can be moved to spread the sediment.

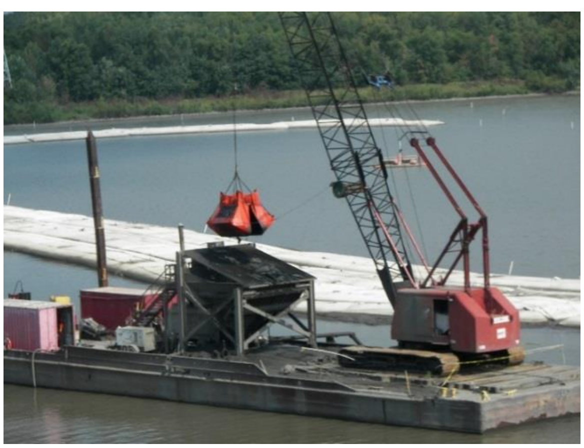

Figure 28. Soft sediment is placed in a mud hopper feeding a displacement pump during island construction on Lower Peoria Lake.

Figure 29. Material is pumped into geotextile tubes forming a ring that was later filled with sediment to form the island.

A similar conveyor could be mounted on a workboat or barge for loading or off-loading. The truck would not be necessary in an ongoing operation where owned equipment could be attached to a power source and dedicated to specific tasks. IDNR arranged a test in the spring of 2002 in which sediment freshly excavated with a 0.5-yard (0.4 m^3) clamshell was placed on conveyors at a sand and gravel pit with river access (Marlin, 2002). A 10-foot deep layer of sediment was excavated at *in situ* moisture content from Upper Peoria Lake and carried on a deck barge about 8 miles through rough water. The sediment held its shape during the trip and did not liquefy.

The sediment was taken to a gravel pit near Spring Bay on Upper Peoria Lake. There, various amounts of sediment were placed directly on a 36-inch conveyor belt with a clamshell bucket. The sediment traveled about 50 feet (15.2 m) and dropped 7 feet (2.1 m) through the first transfer point, was conveyed 100 feet (30.5 m) up a 6 percent slope, and then transferred to a 50-foot (15.2 m) stacking conveyor with a 25 percent slope. A variety of conditions were tested including dropping sediment on a moving belt and on stationary wet and dry belts, and as a load with extra water added. In a separate test, an end loader bucket carried sediment to a 600-foot conveyor. The sediment was conveyed that distance and stopped on an incline. The material kept its shape and did not slide down the belt.

The conveyors and transfer points used in the test worked well with wet sediment, even though the equipment was configured for sand, which has significantly different physical properties. As expected, there was some drag back of sediment as it dropped off the end of dry belts that had no scrapers. However, at the first transfer point, most of the material fell onto the second conveyor after hitting a baffle (Figures 31, 32). At the second transfer point with no baffle, much of the material missed the stacking conveyor hopper. This material, which had lost much of its cohesiveness, was later collected by an end loader and placed directly into the stacking conveyor hopper. That conveyor was then started and the entire load was successfully conveyed up the 25 percent slope.

During the test, the sediment maintained a reasonably solid consistency over the belt idlers and across the transfers. It did not liquefy. Minor slumping occurred on the belt, but the sediment cross section remained constant. The sediment did not exhibit excessive stickiness or build up on the belts or chutes after eight runs. The use of belt scrapers and transfer points designed for the sediment could address the issues of splatter and drag back by the return belt. The sediment traveled an incline greater than that likely necessary to load a barge from a floating conveyor. The test demonstrated that, with some modifications to hoppers and transfer points, local sediment could be handled by conveyors.

Floating conveyors may prove useful in situations in which barges need to be loaded with material dredged mechanically at a relatively shallow depth. A crane or excavator operating in shallow water could feed a conveyor mounted on floats or work barges. The conveyor could fill a barge positioned in the main channel, within a marina channel, or in a purposely excavated access channel. A few hundred feet of conveyor operating sequentially on two sides of an access channel could reach a large area. Conveyors could also carry dredged material from backwaters separated from the channel by levees or interfering woody vegetation.

IDNR and Caterpillar visited a site in California where a large floating conveyor (Figure 33) transported gravel (Marlin, 2002). A smaller system could operate on the Illinois River system. Careful consideration would need to be given to wave action if a long conveyor were envisioned. In near-shore locations, it may be possible to convey dredged material directly to shore for transport or processing. Pipe conveyors are designed to carry material on a belt that folds over on itself, forming what is essentially a pipe. The belt opens out at the receiving and discharge ends. This device can move thick slurries, has considerable flexibility, and can handle inclines (Figure 34). Another option is a modified version of the small rail-mounted conveyors used to convey concrete onto bridge decks during construction (Figure 35).

Slurry Pumps

In 2001 representatives from Caterpillar Inc., IDNR, and Kress Corporation journeyed to Florida to observe slurry pumps unloading barges at the Jacksonville and Tampa ports. In both locations, Cable Arm™ buckets were used to excavate fine-grained sediment with minimal resuspension. The stiff material was taken to a nearby confined disposal facility (CDF). At Jacksonville, a TOYO pump suspended by a crane emptied the barge in about an hour. During the process, water was added to thin the sediment for pumping. It was pumped to shore and discharged into a CDF. It flowed like molasses into the containment and did not mound up near the pipe (Figures 36, 37). The situation was similar at Tampa. There, the CDF was partially constructed of geotextile tubes. A Dragflow™ pump was used. Again, water was added, making this material more fluid than that at Jacksonville. It readily flowed into the CDF and did not accumulate near the discharge.

This type of pump, along with others such as the Eddy Pump™, could potentially be used to empty sediment barges directly to placement sites, including marsh areas in need of nourishment. The amount of water added could be adjusted to meet local conditions. The pumps also have the potential to dredge material from backwaters and reservoirs and place it on farm fields or marsh restoration areas with minimal added water.

Figure 30. A truck-mounted telebelt typically used to convey concrete demonstrates its ability to handle wet sediment.

Figure 31. Sediment transiting a transfer point designed for sand during a demonstration at a gravel pit.

Figure 32. Soft sediment on a conveyor belt after dropping through a transfer point.

Figure 33. A large floating conveyor in a gravel mine in California.

Figure 34. A pipe conveyor belt folds over itself allowing material of various consistencies to move uphill without spilling or blowing away.

Figure 35. Specialized conveyors come in a variety of sizes, some of which could operate on floats or barges to convey dredged material.

Highlighted Projects

Spindler Marina

This project dredged the recreational boat channel from Spindler Marina to the navigation channel on Lower Peoria Lake at about RM 165 during the spring of 2000. Although this was not a Mud to Parks project, it provided an opportunity to test concepts and observe soil formation. The fine-grained material was initially removed with a conventional crane and clamshell bucket and placed on deck barges. The dredged material was stiff and remained where placed on the barge (Figure 38). It was then barged about 5 miles and unloaded to trucks. During the project, a Cable Arm™ bucket was successfully demonstrated.

Semi-trucks took the material to two urban locations. The first was an open field on the lake shoreline at East Peoria that was previously occupied by a power plant. The area was highly compacted. Trucks dumped most material while moving, making long rows of sediment, which held its shape and did not flow (Figure 39). Some material was simply dumped in piles. Wet sediment depth varied from about 6 to 18 inches (15 to 46 cm). A heavy rain fell soon after it was placed, but the sediment did not erode (Figure 40). After two months, the material had dried, forming hard soil polygons (Figure 41). The material gradually developed some soil structure as it weathered over the summer. By fall, the field was disked and, over the winter, freezing and thawing caused the sediment to develop typical granular soil structure. Researchers observed the site for several years. It supported vegetation and was transformed into a riverfront park (Figure 42). The material provided a layer of soil over the original compacted clay base (Figure 43).

The second site was a gravel pit in Peoria. The material lost some of its cohesiveness while in transit, but did not splash out of the trucks. It was dumped over the side of the pit and then spread slowly across the bottom as more sediment was added. Within a year, researchers identified 53 species of plants in the pit that were common in early successional, disturbed wetlands along the Illinois River (Marlin, 2002). Plants likely grew from seeds that were blown in or arrived with the sediment. Cottonwood and other moisture-tolerant trees quickly established. By October 2002, researchers were able to excavate over 6.5 feet (2 m) down and observed a typical soil structure and root penetration. Sediment-derived topsoil from this site was used in the Sand Farm Project. By 2004, the Spindler Channel was again largely filled with sediment. This was expected since deep, soft sediment was on both sides of the narrow channel, which received a constant input of fine particles resuspended by waves, boat passage, and fish.

Paxton 1 Landfill

In late 2002, the USACE Rock Island District provided grant funding to send a partial barge load of sediment from the edge of the Spindler Marina channel to the Paxton 1 landfill near Lake Calumet Harbor in Chicago, which was in need of cover soil (Marlin, 2003a). A number of contractors and shippers cooperated to get the barge to Chicago for unloading prior to the end of the fiscal year. This was the first local test of the feasibility of moving wet sediment over that distance. This test was crucial because the results would determine whether the Chicago Park District, City of Chicago, and U.S. Environmental Protection Agency (USEPA) among others, would agree to use sediment-derived topsoil at South Works and other sites.

The barge arrived at the unloading site with little free water on the sediment. It rained during the first day, making the landfill too wet for trucks to traverse. Four loaded trucks were then diverted to William Powers State Park and unloading was suspended for a day. The trucks dumped their loads on a slag area at a former Nike missile base. Two truckloads were placed while moving, forming narrow lines 12 to 18 inches deep. An end-loader bucket was used to smooth it to a thickness of about 6 inches. Two truckloads of sediment were left in piles, where in the following years turtles laid their eggs. Forty loads of the remaining material were taken to a level area of the landfill and dumped close together in a triangular shape that varied from 12 to about 32 inches (0.30–0.81 m.) deep (Figure 44). Two samples of the dredged material were taken from different loads in the clamshell bucket prior to being placed in the barge. The moisture content on a dry weight basis was 92.8 and 91.0 percent, respectively. The percentage of the material passing through a standard 200-mesh sieve was 91.4 and 93.8 percent. Six samples of the material were taken minutes after being placed by trucks at the Powers site. These samples had an average moisture content of 97.5 percent (range 92.6 to 102.3 percent) on a dry weight basis calculated as weight of water divided by dried soil weight.

Representative samples were taken from eight truckloads shortly after dumping at the Paxton 1 site. They had an average moisture content of 94.7 percent (range 84.6 to 99.5 percent). It rained during the time the material sat in the barge with 1.4 inches of rain recorded within 12 miles of the dock. The following spring grass seed was placed on the Paxton 1 plots, which had not experienced erosion, and some prairie plants were added. No fertilizer or other treatments were used. The plants grew well (Figure 45) and by fall, the soil structure formed to a depth of over 12 inches and roots penetrated to the clay liner in many spots. The project demonstrated that the sediment could be moved from Peoria, placed, and vegetated, thus paving the way for the larger project at South Works.

U.S. Steel South Works Site (USX)

In April 2004, the first barge load of sediment left Spindler Marina channel for the old U.S. Steel South Works site on Lake Michigan (Marlin, 2004; Marlin and Darmody, 2005b). The project was funded by an IDNR grant to Chicago. Artco Fleeting Service, an Archer Daniels Midland subsidiary, was the prime contractor. The company fleeted the barges about 5 miles (8 km) from the dredging site prior to sending them north. The distance traveled was about 165 miles (265 km). Sixty-eight barges transported 102,000 tons of wet mud to the site with the last arriving in July. Initial placement was on a 15-acre (6 ha) slag field south of the barge slip, which would become Steelworkers Park (Figure 46). Mining trucks were loaded with sediment at the slip and deposited it on the slag fields.

The first loads dumped were cohesive, formed mounds and did not flow across the field. Thus, it was determined that earthen berms were not needed to contain the sediment. A bulldozer spread the material to an approximate 14-inch (35 cm) depth. Bulldozer tracks and mining truck


Figure 36. Water is added to a barge load of fine-grained dredged material at Jacksonville, Fla., for pumping by a slurry pump.


Figure 37. Material the consistency of thick molasses flowed from the pipe and spread across the CDF without blocking the discharge point.


Figure 38. A deck barge filled with soft sediment from the Spindler Marina channel in 2000.


Figure 39. The Spindler material was dumped from moving trucks in April 2000 on level compacted ground at a former power plant.


Figure 40. A heavy rain filled cracks and spaces in the sediment-covered field, but did not cause the material to erode.


Figure 41. In June the material had dried and formed polygons as seen in the rear. A disk was used to break them up and level the field.

Figure 42. By fall of 2000 the site supported a healthy growth of volunteer vegetation. The area is now East Peoria's Riverfront Park.

Figure 43. A core in the park shows the dark sediment layer full of plant roots over the compacted clay base of the former power plant.

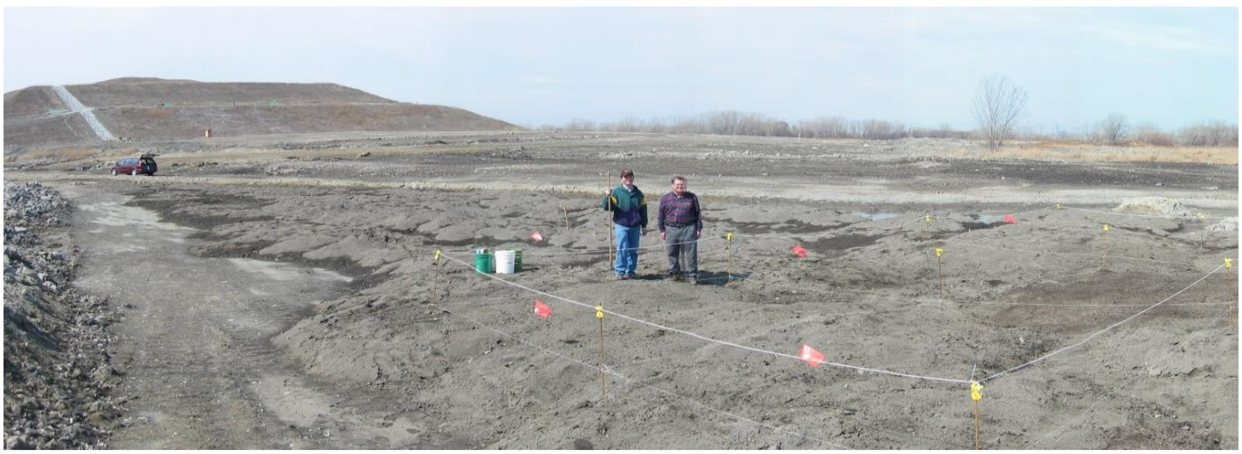

Figure 44. A demonstration plot of sediment placed at the Paxton 1 landfill in Chicago in October 2002. The granular structure caused by freezing over the winter is visible.

Figure 45. By August 2003 the Paxton 1 plot was covered with planted and volunteer vegetation. The gray areas are the landfill's clay cap.

wheels left furrows in the sediment, which aided in drying (Figure 47). As it dried, it was pushed to a height of up to 8 feet (2.4 m) to make room for additional sediment. After a few weeks, it was necessary to push material into piles after minimal drying (Figure 48). The top layer dried and cracked quickly while the lower material remained wet. Grass and alfalfa seed scattered on the sediment grew several inches within weeks (Figure 49) as did weed seeds blown in from the neighborhood. Some weed patches were over 8 feet (2.4 m) tall by fall.

In May, the operation moved to the north side of the slip where about 20 acres (8 ha) would be covered. Given that this area was not slated for development for several years, trucks dumped the sediment in adjacent piles as close together and as deep as possible. It was seeded with grass and alfalfa as soon as the crust would support researchers. Weed and tree species also germinated within weeks. Almost no debris was found in the sediment at the site except for occasional beverage cans, a few pieces of cable, and small tree parts.

In the fall, the field south of the slip was bulldozed to level the area, leaving sediment-derived soil varying in depth from 2 to 4 feet (0.6–1.2 m). It was then seeded with grass, which was established before winter. The north side was left alone. By spring, the top several inches of material on both sides of the slip had developed a granular soil structure due to weathering. Additional sediment was taken to the site, mainly from East Port Marina's channel, during the summer of 2007, when more funding became available. Barges were filled with both cranes and hydraulic excavators. The sediment was placed north of the slip adjacent to material from 2004. A hydraulic excavator unloaded the sediment into semi-trucks. It was seeded and left to dry. A third project transporting material to the north side of the slip began during the summer of 2012. It was decided to build a berm about 4 feet (1.2 m) high along the Lake Michigan edge of the site. "Soil" from a local site was trucked in to begin the berm, but it contained considerable foreign material including glass, pipe, concrete, and other rubble. It was used as the base of part of the berm and was covered with sediment, which was used to construct it from that point on.

A hydraulic clamshell was used to excavate material from the East Port channel in Lower Peoria Lake. Initially, soft sediment was encountered, which was handled without problems. As the dredge barge came closer to shore, stiffer light gray material was excavated below the softer material. It was cohesive and did not readily mix with the darker soft material in the barges. This material was more difficult to handle as it stuck to the unloading equipment and truck beds. It tended to slide out of trucks like chunks of clay instead of flowing or oozing out (Figure 50). Occasionally a small excavator was needed to scrape truck beds clean. Sticky material of this type is likely to cause problems on conveyors and in hoppers. When this material began to dominate loads, it was decided to move the operation to the Spindler channel where soft dark material was available (Figures 51, 52). The darker and lighter material sometimes ended up side by side on the field (Figure 53).

Bulldozing material into temporary piles of a generally uniform height had the desired effect of mixing material originating from different sediment layers. This resulted in more uniform soil. However, if the blade was set too low, it also brought up small amounts of slag and other material from the field and mixed it with the sediment. In areas where material was dumped in close piles without bulldozing, the lighter and darker material within truckloads was initially somewhat segregated. When it was bulldozed after several days of dewatering, it mixed well. Leveling and tilling the material prior to overwintering or seeding was also beneficial.

Over the years, the sediment-derived topsoil has performed well at the South Works site. The southern field is now Steelworkers Park and supports trees, grassy areas, and large plots of native wildflowers (Figure 54). The north side supports healthy vegetation and is awaiting development as a park (Figure 55). The Park District added some biosolids to the area. The northern area is covered with a mixture of grass and volunteer vegetation. It should be noted that the lighter colored material supports healthy vegetation and formed a soil far superior to what was originally present at the site.

Banner Marsh SFWA

The IDNR's Banner Marsh State Fish and Wildlife Area near Banner, IL consists primarily of strip-mined land. Much of the land is overburden with poor soil quality. Artco Fleeting and the Office of the Lt. Governor funded two barge loads of sediment from Spindler Marina to be placed there in July 2004. Hopper barges moved the material 18 miles, and semi-trucks hauled it the remaining 8.5 miles to the site. The sediment was dumped from moving trucks in closely aligned rows on a flat field and allowed to dry (Figure 56). It formed dry polygons, which were subjected to freezing and thawing over the winter. By spring, soil formation was well underway and the soil was largely mounds of granular peds. The field was disked and leveled in the spring. It was then planted with various crops for wildlife, including sunflowers, which grow far better on the sediment-derived topsoil than on the overburden.

Pekin Landfill

Several barge loads of sediment were taken from Lower Peoria Lake to the Pekin Landfill in 2007 to provide cover soil for the clay cap. Material was transported about 8 miles (12.9 km) by deck barge and then by semi-trailer about 17 miles (27 km) of state and county highways. There were no notable issues of sediment dripping from trailers. The material was dumped in piles that were pushed together by a small bulldozer and left to dry. It supported vigorous vegetation the following spring (Figure 57).

Fox Waterway Agency

The Fox Waterway Agency (FWA) manages 15 interconnected lakes, which make up the Fox River Chain O'Lakes and 30 miles of the Fox River stretching from the Wisconsin State line to Algonquin, IL, as well as their tributaries and over 40 miles of navigable channels. The system operates a number of mechanical and hydraulic dredges to maintain channels. The sediment in the system is fine-grained and has excellent soil characteristics. Mud to Parks funding assisted in development of the Cooper Farms Sediment Dewatering Facility, which has two connected basins for receiving hydraulically dredged material. This allows flexibility in meeting water quality standards while settling solids. It also provides the ability to remove dewatered sediment from one basin while the other is filling or decanting.

Sediment is periodically removed from the basins and stockpiled (Figures 58, 59). Unlike the wet material barged from Peoria Lake, it is allowed to dry and is screened to remove debris. It is then ready for use. Using Mud to Parks funds, sediment-derived topsoil was taken from the FWA to two sites being developed by the Chicago Park District. It was delivered by semi-trailers and could be spread and seeded like any other dry topsoil. The FWA is now marketing over 15,000 cubic yards (11,468 m^3) of sediment-derived topsoil in bulk per year.

East Port Marina

The East Port Marina on Lower Peoria Lake is owned by the City of East Peoria. The marina's depth, like that of its channel, was seriously impacted by sedimentation. To address this issue, the city purchased the Dry Dredge™ to dredge the marina on an ongoing basis as weather permits using a displacement pump. The marina area was once marshy, and there are seams of peat in the sediments. Water was occasionally added to the hopper as this peaty material had more resistance in the pipe than did the mud. The material was pumped directly into a semi-trailer and taken to a field where it dried for later use or to locations where it was placed wet (Figures 60, 61). The truck had a tight sealing gate with rubber seals and screw clamps. This system has been in place for about 10 years. It is part of the marina's regular budget and is primarily run by one employee. The dredged material thus comes in annual increments rather than as a high-profile, big-budget project every decade or so. The harbormaster estimates they have removed more than 70,000 tons of soil in 10 years of operation.

Rice Lake SFWA Boat Access

Like many IDNR boat launch locations, the one at Rice Lake State Fish and Wildlife Area near Banner, IL periodically fills with sediment to the point at which recreational boats have great difficulty operating. In this instance, the channel needs to extend from shore out into the lake far enough for boats to gain enough speed to proceed over the shallow lake. It was too far a reach for excavators and there was limited space for dewatering hydraulically dredged material. Superior Seawalls & Docks completed the project using an excavator on a small barge that filled small hopper barges that could hold 20 cubic yards (15 m^3) of material when fully loaded.

The material had a rather firm consistency in the channel and could completely fill or heap in the bucket. Small ports also allowed water to drain. The barges were pushed with a small boat to a ramp where a second excavator on shore unloaded them into trucks. The sediment was then taken about 6 miles (10 km) to Banner Marsh. The first trucks used did not seal tightly, and wet sediment dripped onto the highway, causing a halt in operations. Trucks with screw clamp seals were obtained that worked well, allowing the project to proceed without further incident. Unlike the prior Banner Marsh project, this material was dumped on a slope largely composed of strip mine overburden. This sediment was less cohesive than much of the Peoria Lake sediment, but still formed piles and did not flow down the slope. As with Lower Peoria Lake, the more recent sediment was usually darker than the material from the original bottom, which

Figure 46. Placing sediment south of the slip at USX in March 2004.

Figure 47. A bulldozer and mining trucks left furrows in the sediment, which aided drying.

Figure 48. When more space was needed for placement, partially dried sediment was pushed up to 8 feet high to make additional room.

Figure 49. On the north side, sediment out of the water about three months supported sunflowers, seeded grass, and volunteer plants.

Figure 50. In 2012, material dredged where the East Port channel neared the shore was light colored and sticky. It was difficult to handle.

Figure 51. On 6-5-2013, sediment from Spindler Marina near the navigation channel handled easily and was essentially friable.

Figure 52. In July 2013, dark-colored Spindler sediment gently flowed from trucks and was easy to handle.

Figure 53. On the north side of USX in 2013 dark and light sediment sit side by side. They were somewhat mixed during tilling and leveling.

Figure 54. South side of USX eight years after receiving sediment sports grasses, prairie plants, and trees and is now Steelworkers Park.

Figure 55. A year after last sediment-derived topsoil was placed, the north side of USX supports lush vegetation.

Figure 56. Sediment from Rice Lake poured in long lines from moving trucks onto strip mine overburden at Banner Marsh SFWA.

Figure 57. Volunteer vegetation did well on sediment-derived topsoil covering part of the Pekin landfill. The clay cap is in the foreground.

was also stiffer. The contractor brought up as little of this older, light colored material as possible. The sediment was left to dry overwinter and did not erode. By spring, it had developed a considerable granular soil structure and was then lightly graded to level and gently mix it. This sediment-derived topsoil dramatically outperformed the adjacent overburdened areas with no sediment when both were planted with sunflowers (Figures 62, 63).

Lake Decatur

Lake Decatur in central Illinois was impounded in 1922. Sedimentation plagued it for decades and its upstream arms had lost over 50 percent of their capacity by 1983. The dam's height was increased and several dredging projects restored considerable capacity. Hydraulically dredged material is pumped to a 523-acre site that holds the city's sedimentation basin. A Mud to Parks grant provided for removing some dewatered sediment from the basin. An excavator was able to dig material to a depth of about 10 feet (3 m) and load it onto trucks without encountering excessive moisture. It was then delivered to an old landfill near the dam. It handled like typical soil and was spread over the landfill. It was later planted with grasses for energy production and ringed with a planting of native wildflowers. A pamphlet about potential beneficial use of the Lake Decatur sediment was published (Agricultural Watershed Institute, 2005).

Walton Lake

Walton Lake at Litchfield, IL was impounded in 1874 and is currently part of the Litchfield Park System. The spillway was damaged by excessive flow after hurricane Harvey and the lake was drained for repair. In 2011 a Mud to Parks grant was made available for excavating sediment from the lake while it was drawn down. The Park District took the initiative and successfully excavated a small arm of the lake with a shore-based excavator, which placed firm, but moist, material into tandem trucks. In November 2012, an excavator with a long reach went onto the dry lakebed supported on timbers (Figure 64). The excavated material was soft and moist below the crust, but had no free water and no tendency to flow.

Most of the sediment went to a new city water treatment plant that needed topsoil to cover a poorly vegetated slope. Trucks dumped the material with no trouble, and then an excavator smoothed it to a thickness of about 10 inches (25 cm) like icing on a cake (Figure 65). The sediment-derived topsoil dried, developed a soil structure, and was vegetated with grass in 2013. Some sediment was used for projects in the parks and other municipal locations.

Figure 58. Hydraulically dredged sediment is loaded onto trucks from a dewatering basin by the Fox Waterway Agency.

Figure 59. Dried and screened sediment-derived topsoil available for shipment at the FWA processing facility.

Figure 60. The Dry Dredge™ operating at East Port Marina. Sediment is forced through the pipe by a displacement pump.

Figure 61. The Dry Dredge™ directly loads sediment from the river into trucks for placement at various locations.

Figure 62. Sunflowers planted in strip mine overburden at Banner Marsh SFWA show stunted growth.

Figure 63. Sunflowers in sediment-derived topsoil placed on overburden immediately adjacent to those in Figure 62 show vigorous growth.

Figure 64. A long stick excavator removes sediment from temporarily drained Walton Lake at Litchfield, Ill.

Figure 65. Sediment from Walton Lake is placed at the Litchfield water treatment plant and smoothed to the desired thickness.

Dealing With Dredged Sediments as Topsoil

Sediments have a wide range of physical and chemical properties. Physically their texture can vary from clean sand to mostly clay. Organic matter content also ranges from essentially none to peat, which is predominately composed of organic matter. Sediment soil fertility correlates well with finer textures and organic matter content. Contamination of sediments is a concern where there is a possibility of pollutants being added to the water body. We have considerable experience dealing with sediments from Illinois reservoirs and in particular, from the Illinois River near Peoria as a resource out of place (Appendix A). Our understanding of the applications and limitations of beneficial uses of dredged sediments is covered in the other Appendices as excerpts of our sediment-related research publications together with some unpublished data sets.

General Sediment Physical Properties

Most of our experience with using sediments as topsoil substitutes has involved finer-textured, fairly organic-rich sediments. Moisture contents in sediments are quite high when extracted from the river bottom, but with time, they dewater and form more acceptable physical soil properties. Sediment moisture contents vary by dredging methods and are exacerbated by the use of hydraulic dredging. Disposing of excess water accompanying hydraulically dredged or transported sediments is a challenge. In terms of textural attributes, an application of fine-textured dredged sediment significantly improved the productivity of native sandy soils as revealed by our experimental plots at the University of Illinois Sand Farm. There, we conducted a multiple-year research project involving sediments as an amendment to sandy soils and the subsequent response in corn and soybean growth (Appendix B). Sandy soils in other locations and situations would also benefit by the application of similar sediment amendments. The converse has not been tested; that is, mixing sandy sediment into high clay content soils to improve their desirability. There is much controversy in the literature about this concept. Generally, while adding a small amount of sand to clayey soils likely makes the situation worse, soils with 50 percent or more sand added begin to acquire properties that improve soils excessively high in clay-sized particles (Appendix C). More desirable soil texture ranges include a sand content of 10–60 percent, a silt content of 10–70 percent, and a clay content of 10–35 percent (see Figure C1).

In terms of U.S. Department of Agriculture (USDA) soil texture class names, poorer topsoil textures include clay, silty clay, and sandy clay for their excessive clay content. Problems associated with clayey soils include poor root penetration, potential compaction, and tilth, or workability. Conversely, poor topsoil textures also include coarse sand, sand, fine sand, very fine sand, and loamy sand textures for their excessive sand content. Problems associated with sandy soils include low fertility and in particular, low soil moisture holding capacity. Sediments we have worked with from Peoria Lakes tend to be fine-textured, with 0–27 percent sand content, mostly < 10 percent sand and mostly fine sand, and 22–55 percent clay. The higher clay content sediments should benefit from adding to the desired range of 10–60 percent sand and < 35 percent clay. One of the complications with using sediments as topsoil in Illinois is that the bar is set high in terms of soil quality. Illinois is generally blessed with some of the best soils in the world for agriculture. Most of the state is blanketed with loess, which imparts the highly desirable silt loams and silty clay loams as surface soil textures. The less desirable, very sandy upland soils are confined to limited areas, such as adjacent to larger floodplains, as are the heavily clayey soils also found in some floodplains or other specialized locations.

ISWS Reconnaissance Sediment Sampling and Analysis in the Illinois River

The Illinois State Water Survey (ISWS) collected sediment samples in Lower Peoria Lake on the Illinois River at East Peoria in 2004 (Figure 10), and we analyzed a subset of those samples (Appendix D). Core SWS 194 was unique because it was taken from the Farm Creek Delta and contains considerable amounts of sand. The other five cores were taken farther from that delta, roughly at RM 164 in the area of East Port Marina, and were predominantly composed of silt and clay. Dredging later occurred in this general area and near to Spindler Marina to collect sediments for delivery to the USX project (Appendix E). For lab analyses, the cores were sub-sampled by depth, and contiguous sub-samples with similar texture and color from individual cores were combined before analysis.

In general, sediment chemistry is closely linked to its physical properties. Finer textured sediments are typically higher in all measured parameters due to the high surface area of silt and clay. The pH of all the samples was high due to the presence of bioaccumulated carbonates (i.e., mollusk shells) and from primary carbonates in some of the original sediment sources. This would be in the pH range desirable for most crops, but too high for some iron-sensitive plants. Organic matter content was generally high in the sediments, particularly in the finer textured samples. With these samples, the organic matter level was about the same as in the typical highly productive topsoils in Illinois, 2–6 percent. Sandy samples had lesser amounts of organic matter, and the highest organic matter content was found in a sample identified as a peat (SWS 198 - 87). The extractable major nutrients, sulfur (S), phosphorus (P), calcium (Ca), magnesium (Mg), and potassium (K), and the other extracted micronutrients generally followed the organic matter trends (i.e., higher in the finer textured samples). In general, with the macronutrients, more is better. Ca, Mg, S, and P are at levels generally considered sufficient for crops, and K is somewhat below optimum. Soils derived from these sediments would benefit from additional fertilizer, as would any high quality topsoil. None of the micronutrients or other extractables are at levels that should cause significant concern. Total C and nitrogen (N) generally follow the soil texture. Total N is a rough guide to the amount of N in the soil, the nutrient that is typically most limiting to crop growth. The C:N ratio in the cores increases with depth, which is typical in soils and is related to the stage of decomposition of soil organic matter.

Metal contents of soils and sediments can be determined in several ways. To assess the potentially plant available metal forms an organic extractant, such as DTPA is used. Levels of extractable metals in the ISWS sediment core samples again followed the soil physical properties with finer textured sediments having higher levels. Metal levels were well correlated with a strong relationship between the concentrations of most metals, especially arsenic (As), which has a correlation coefficient > 0.9 with lead (Pb), nickel (Ni), and chromium (Cr). The levels of extractable metals were generally within the range of DTPA extractable metals from "uncontaminated farm soils" (Wolnik et al., 1985).

Sediments Delivered to the USX Site

In addition to the ISWS cores, some sediments delivered to the USX location in Chicago were sampled. These included samples from several rather homogeneous barge loads of darkcolored sediment delivered in 2004. In 2012, barges containing dredged material with different characteristics were sampled by dominant color, i.e., black, yellowish, or mixed/gray (Appendices D, E). Sediment colors varied, indicating different sources. The darker material was from shallower, more recently sedimented areas and depths, and the lighter colored materials most likely were from older sediments at greater sediment depths. Shallow-water sediments typically are very fine-grained and coarse fragments (i.e., >2 mm) and are rare in the samples. Where present, coarse fragments were composed of fine gravel or fingernail clamshells. The sand (2–0.05 mm) found was fine or very fine sized (0.25–0.05 mm). One sample had 27 percent sand; the others typically had < 10 percent. Sandy sediments are rare in the backwaters of the Illinois River, except where higher energy tributary streams flow into it, as is the case with the Farm Creek delta. USDA soil texture classes were commonly Silty Clay (SiC) or Silty Clay Loam (SiCL) with clay (< 0.002 mm) contents ranging from 13 to 55 percent, averaging 37 percent. These fine textures are ideal for storing plant-available water, which will likely make irrigation of land reclaimed with these sediments less critical. Two individual samples were very high in silt and classified as Silt Loam (SiL). The higher sand content sample was classified in the Clay Loam (CL) texture class. The higher clay content sediment (i.e., Silty Clay textured, such as similar Illinois soils), may present a challenge for use and management due to stickiness and restricted permeability. Care should be taken to avoid compacting these finer grained sediments. The more desirable textures would be the Silt Loam or Silty Clay Loam. The high silt and clay content of the sediments, in particular the black samples, indicates that the locations where the samples were dredged were distant from any sand sources or turbulent water. When averaged by sediment color, the black samples had the finest texture, with clay contents ranging from 27 to 55 percent, averaging 42 percent and only 7 percent sand. These samples were grouped into the Silty Clay (SiC) USDA texture class. The mixed and yellow samples both averaged 13 percent sand with clay ranging from 22 to 44 percent, averaging 29 percent. They both fell into the Silty Clay Loam (SiCL) USDA soil texture class. This supports the hypothesis that the dark-colored samples represent shallower, more recent deposition in the river. In practice, upon delivery, sediments tended to be mixed as a result of handling and grading, thus their properties tended to average out somewhat.

Adding organic materials along with sand to excessively clayey soils, which are sometimes referred to as "gumbo," is generally seen as important in improving those soils, if done correctly. Such organic materials may include compost, sawdust/wood chips, and biosolids. One concern with organic materials is their carbon and nitrogen content. When expressed as a ratio, C:N, materials with a ratio above 20 are known to cause nitrogen unavailability due to microbial competition precluding N uptake by higher plants. Woody materials (i.e., chips and sawdust) have C:N contents of 100–500:1, which will depress N availability. Well-managed compost has a C:N content of about 30:1, similar to biosolids, which are within a reasonable C:N range. The

C:N ratio of the sediments we measured ranged from 74 to 10, with a mean of 22 for 27 samples taken from Peoria Lake. A combination of materials mixed to produce a desirable C:N ratio is beneficial.

Sediments can be rich in plant nutrients; the finer textured ones tend to have higher levels of extractable and plant available nutrients, including S, P, Ca, Mg, K, boron (B), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), and aluminum (Al). All are necessary plant nutrients or micronutrients, except Al, which is toxic to most plants at high concentrations in low pH soils. Given that the sediments in Illinois have high pH and low Al contents, that is not a problem. The other extractable elements can be toxic at higher concentrations, including Zn, Cu, B, and Mn, but, although some are elevated above background levels for Illinois topsoils, none are at toxic levels in the lower Peoria Lake sediment samples we measured to date. Zn is of particular interest because it is somewhat elevated in sediments due to an industrial source upriver from Peoria. However, Zn is a micronutrient in Illinois topsoil that might be deficient in some locations.

Specific soil fertility attributes from the USX sediments also revealed an association with color. The samples described as "black" in the field at sampling had soil organic matter (SOM) contents ranging from 2.6 to 9.0 percent and averaging 4.2 percent. Those described as "yellow" had SOM ranging from 0.1 to 1.1 percent, averaging 0.9 percent. The "mixed" samples had SOM ranging from 0.18 to 3.4 percent, averaging 2.0 percent. Extractable Ca in the "yellow" sediments was high, and ranged from 10,000 to 12,000 mg kg^{-1}, and the Zn content was low, 1–2 mg kg^{-1} in keeping with its ancient origins in contrast to the "black" samples, which had low Ca and high Zn concentrations up to 99 mg kg^{-1}, indicating recent contamination by industrial metals.

With sediments, the possibility of contamination from undesirable metals or organic compounds is often a concern. This is particularly important where wastewater treatment, industry, or agriculture might have polluted the waterway. Recent improvement in water quality efforts have resulted in measurable improvements in the pollutants contained within sediments as evidenced by sediment cores exhibiting lower contamination levels in the shallower core depths. Our work indicates that both the dark and light sediment layers have concentrations of metals that are below levels of significant concern. The elevated metal levels are associated with the finer-textured sediments. Our field work with growing plants in sediments indicated that plant uptake of problematic metals was not a concern, in part due to the high pH of sediments which makes most metals less plant available (Appendices F, G). This finding was verified with sediment/biosolids/compost mixtures in our greenhouse studies (Appendix F). When assessing metal contaminant levels in a soil material, the methodology has a profound impact. Methodologies include total, near total, and various extractable techniques, which yield progressively lower values. Further complicating metal analysis is the need to determine actual plant uptake and potential toxic concentrations. However, plant uptake is complicated by differential uptake associated with growth stage, plant part, and species, as well as soil chemistry issues including pH and competing ions. In addition, there is no consensus on the lower limit of critical levels of all metals in soil or plants.

Sediment as Topsoil Summary

The ISWS reconnaissance sampling of the Illinois River sediments near Peoria indicated that the sediments generally are dark colored, with low sand and high silt, clay, and organic matter contents. Restoration of the USX South Works site that once was a large steel-making facility in Chicago demonstrated the potential utility of unamended Lower Peoria Lake sediments as a topsoil substitute. Adding modest amounts of organic materials such as biosolids and compost enhanced crop response to sediments in the greenhouse and in a sandy soil in the field, even without organic matter additions in the field study. Adding biosolids to fine-textured sediments may be particularly advantageous, both from a physical/handling point of view and from a microbiological view (Kelly et al., 2007; Baniulyte et al., 2009).

Our recommendation for mixing sandy and fine-textured sediment to make an acceptable topsoil would be to first dewater the fine-textured sediment and then mix it with an equal volume of sand. Adding an organic amendment such as biosolids to make up perhaps 10–20 percent of the dry volume would be a further enhancement. This general recommendation is applicable to sediment as topsoil whether in bulk or bagged. However, bagged sediment-derived topsoil mixtures need to be carefully screened and may require blending with organic matter sources to optimize the “curb appeal” of the product.

Insights and Speculations on Beneficial Use and Related Matters

There are a number of topics that were considered over the years that can best be handled in a general category covering some brief observations and considerations.

Contaminants

The Illinois River watershed includes the Chicago and Peoria metropolitan areas and numerous industrial sites in between that have released contaminants that remain in river sediments. An analysis of this topic is beyond the scope of this report. The test results for metals and a variety of organic compounds show that contaminant concentrations tend to vary with the sediment depth and distance from the Chicago region. For example, in core 197 near RM 164, lead in the first hundred centimeters was present at 40 parts per million (mg/kg) and benzo(a)pyrene (BAP) was at 0.240 mg/kg. In the lower 100 cm, lead was 8.9 and BAP was less than 0.044 mg/kg (see Figure 11). Our focus was in Lower Peoria Lake on the channels leading to the East Port Marina near RM 164 and the Spindler Marina at RM 165. Many samples were taken in these areas. Other locations were sampled at a lower density between Hennepin and Beardstown, IL. Most samples were taken to ascertain the quality of sediment beyond the main study area. Basically, contaminant levels were higher above the RM 166.5 at the Narrows separating Upper from Lower Peoria Lake (Zou and Zheng, 2015).

Cahill (2001a) published an analysis of several sampling efforts in the Peoria Lakes and concluded, “Some metal concentrations exceed the U.S. EPA sediment screening values, but none approach the TACO values.” TACO (Tiered Approach to Corrective Action Objectives) is an Illinois Regulation (Illinois Administrative Code, no date) that, among other things, sets soil remediation objectives for chemicals in soils at residential and commercial sites. Cahill (2001a) also reported, “Pesticides, volatile organic compounds, semi-volatile organic compounds, and chlorinated pesticides were usually not detected.” Polycyclic aromatic hydrocarbons (PAH) were found at levels exceeding consensus-based probable effect concentration (MacDonald et al., 2000) for aquatic invertebrates, but the results were method dependent. Cahill also states that more research was needed to understand the fate and distribution of PAH compounds in the sediments. PAHs are associated with combustion of fossil fuels, including coal, diesel, and gasoline.

Contractors and developers of properties in urban areas had great difficulty meeting the original TACO objectives for PAH. Subsequent sampling in urban areas throughout Illinois showed that levels of the PAH benzo(a)pyrene (BAP) exceeded TACO residential soil remediation goals of 90 micrograms per kilogram (µg/kg) in urban areas. The rules were amended to incorporate new objectives that generally allow 1300 (µg/kg) in Chicago and 2100 (µg/kg) in “metropolitan areas.” Similar adjustments were made for other PAHs. These were determined to be background levels in those areas.

The Lower Peoria Lake sediments were determined to be acceptable for use in Chicago. Five samples along the East Port Marina channel collected in 2004 had an average of 270 µg/kg of

BAP (range 200–340). However, the Illinois Department of Transportation (IDOT) did not accept them for rural highway usage. IDOT was concerned that if sediment-derived topsoil was used on a right of way that later needed to be moved, it might not meet remediation objectives for the new location. Samples in Upper Peoria Lake and backwaters as far as Hennepin showed widely varying levels of PAH (often exceeding TACO objectives), other compounds, and some metals (Cahill et al., 2008). Sampling at specific locations prior to dredging will be necessary to determine if levels of contaminants are acceptable for the proposed beneficial use.

Use of Historic Maps

Very little foreign material was discovered at the dredging areas in Lower Peoria Lake. A few lengths of cable, wood planks, and logs were found along with some cans and similar material such as an occasional tire. Other areas may not be so clean. Project planners could look at historic maps and photos for evidence of prior uses that may impact sediment recovery. For example, several areas in the Peoria Pool were logged prior to impoundment, and large stumps may be in the sediment now covering the previous floodplain. The Woermann maps show floodplain forest that existed at the time of the Lake Michigan Diversion (Woermann, 1905).

Older maps and soundings can be used to estimate the thickness of sediment layers over the pre-impoundment surface behind the dams as well as the current water depth. By comparing the two, it is possible to determine locations with deep soft sediment or whether it is necessary to excavate the original bottom to gain access for equipment. Maps can also indicate the location of former islands (Figure 66) that may either adversely impact dredging or provide a firm base for restored islands (Marlin, 2001).

Islands and Elevated Floodplain

The use of islands to permanently contain sediment is a double-edged sword. It is important to remember that the sediment filling the lakes came from outside the floodplain, and that returning it to the land or to the Mississippi delta is desirable. Every acre of water surface converted to islands in an effort to save lakes decreases the size of the lake. In order to justify building islands, the amount and benefits of aquatic and terrestrial habitat created, enhanced, or restored must be substantial. This is particularly true in locations where the rate of sedimentation is high and dredged habitat areas may refill quickly. Increasing the topographic diversity on the floodplain should also be considered. Creating additional low floodplain land that is similar to the majority of existing floodplain land is questionable. What is needed is land that is high enough to support trees and other species adapted to infrequent flooding that occurred on portions of the floodplain prior to the construction of the Lake Michigan Diversion and locks and dams.

The best location for islands and other elevated areas may well be in shallow backwaters, on or adjacent to existing islands, on low floodplains, or within leveed areas converted to wetland and other habitat uses. These areas can be selected for minimizing erosion by wave action and current. Totally filling leveed areas with sediment is not a particularly good environmental option, as this would essentially permanently eliminate those portions of the floodplain. Placing islands in locations that were islands or vegetated floodplain prior to 1930 may provide a relatively firm base (Marlin, 2001). This could avoid some of the issues related to islands "sinking" when placed on deep deposits of soft sediment. This concept was used by the USACE, constructed for a barrier island in Upper Peoria Lake near Chillicothe (RM 178.5–181.0) as part of a habitat rehabilitation and enhancement project (HREP) completed in 1997. "The Barrier Island is an earthen embankment constructed by mechanical excavation of adjacent sediment. It is approximately 1 mile long and 182 feet wide at the base. It has a 50-foot-wide crown, side slopes of 6H:1V, and a top elevation of 446.0 MSL. The island follows historical high ground that was shown on surveys made in 1903. During construction the top 4 feet of sediment was spoiled on the riverside of the Barrier Island to create the Overburden Island. This material was beneficial in protecting the Barrier Island from wave wash erosion" (USACE, 2001). It should be noted that the barrier island itself was composed of the firm material below the recently deposited soft sediment. It has retained much of its original shape, although considerable material has washed away from its crown, exposing tree roots. The overburden island has also remained largely intact (Figure 67).

Constructing islands with fine-grained sediment in the Peoria and LaGrange pools is more difficult than anticipated in our earlier papers. The long wind fetch in the Peoria Lakes and many backwaters allow large waves to form. When water is high, they strike the islands with great force. Waves washing over the tops of islands as the water rises and falls can lap at the soil surface and erode the island and expose tree roots (Figure 68). The interpretation of policies, rules, and regulations that prevent the USACE and other entities from creating islands that are high enough for floodplain hardwoods to survive frequent floods should be reviewed. It is possible that some regulations designed to protect a resource type that was threatened 40 years ago are so broadly interpreted that they are now blocking needed restoration efforts in other situations.

If such islands are to remain in place as valuable habitat, a means of protecting them must be developed. Designing them in lifts such that a wide, low border area supports rapidly growing water-tolerant trees such as willow may initially break the force of waves. Farther back, material at a higher elevation may then be able to withstand the attenuated waves. Investigating the use of sand or other coarse material from local deltas as part of the island structure may also prove useful. A row of geotextile tubes, Hesco™ units, or other materials could protect the base of the higher lift. A multidisciplinary team with experience in a number of watersheds should evaluate the island and floodplain elevation projects in the Mississippi Basin to develop guidance for future projects.

Geotextile Tubes

Geotextile tubes have been used in many successful water resources projects, especially when filled with sand. Our earlier papers were overly optimistic in terms of the ability of Geotextile tubes to maintain their shape and position in the Peoria Lakes. In Illinois applications using fine-grained sediment in locations subject to wave action, the tubes have a tendency to flatten and sometimes shift position. When placed over soft sediment, they can displace it and settle at a lower elevation. Riprap, which may also sink, is often necessary to protect the tubes, which can be torn and lose material. This is especially true where waves can push ice flows into the tubes and tear them.

Despite some shortcomings, however, the tubes have made possible some useful restorations, including an island in Grass Lake in the Fox Waterway (Figure 69). The island is on a lake and is not subjected to the same current and wave action as the Peoria Lakes. The tubes are protected by riprap and have flattened, but the island is largely intact after more than a decade of exposure. Memorial Park at Hudsonville, TN includes a project by the USACE Nashville District. Goetextile tubes on the Drake's Creek arm of Old Hickory Lake were filled with mostly fine-grained material using a displacement pump. Tree seedlings were planted in cuts in the tubes, creating a vegetated breakwater that reduces the amount of sediment entering an area dredged for aquatic habitat (Figure 70).

Geotextile tubes confine the sediment used to construct the island completed in 2013 at the upper end of Lower Peoria Lake near RM 166. The tubes and island ring are primarily filled with fine-grained sediment, and much of the island rests on the same. Some of the tubes sank a foot (0.3 m) or more into the sediment. Waves have caused some of them to roll. Riprap was placed in front of the tubes around the perimeter to provide some protection. Several of the tubes were torn by ice or other means and lost considerable material, causing them to flatten (Figure 71). During frequent floods, the island is underwater and is subject to wave action as water rises and falls. This is more pronounced than expected given that the protective tubes have flattened and in some areas sunk. This has eroded or displaced some of the sediment that makes up the island (Figure 72).

The tubes have great potential for enclosing portions of floodplain or islands that are being elevated to provide topographic diversity. The enclosure can then be pumped full of nearby sediment or sand. They can then potentially protect soil within the enclosure from direct wave action. If soil moisture conditions are right, trees and other vegetation can be planted in cuts in the fabric. More research is needed to determine how geotextile tubes perform in areas with high-energy waves, ice flows, and other conditions when filled with material of varying grain sizes.

Hesco™ Units

Hesco™ Units are essentially collapsible wire baskets lined with various fabrics depending on the desired use. They link together, making a rather rigid structure that can then be filled with sand, sediment, or other materials (Figures 73, 74). They are used by the military for defensive barriers and can be rapidly deployed to make floodwalls. They have potential utility in beneficial use applications where durable barriers are needed to hold material in place. For example, they could be used to enclose a floodplain area that is to be elevated for growing hardwood trees. Sediment could then be placed inside the area, protected from high water waves. The units could also be used to hold marsh restoration materials in place. Given that they are composed of many cells, the failure of one will not necessarily cause a major breach in a protective barrier.

Figure 66. A U.S. Geological Survey map from about 1890 shows three islands in Upper Peoria Lake near Spring Bay.


Figure 67. Artificial island near Chillicothe, Ill., built on a former high spot on the floodplain that was flooded by the Peoria Lock and Dam.


Figure 68. Periodic high water overtopping islands allows waves to erode soil and expose tree roots.

High Water Dredging and Placement

In some potential restoration locations, such as a floodplain that is now permanently or intermittently flooded, there is a need to provide water depth in some areas and elevation above normal pool in others. Accomplishing this without digging deep access channels is a challenge. An option to consider is entering a backwater during high water with a small towboat and shallow draft deck barges. Sediment could then be excavated from preselected areas mapped with GPS to be deepened and placed on a barge. The barge can then proceed to the coordinates of an area to be elevated and push the dredged material overboard. The receiving area could be partially ringed with geotextile tubes or another barrier material. Alternatively, excavated material could be moved from the dredge boat to the placement site by displacement pump or floating conveyor. It could also be deposited where it could be collected on dry land after flood waters recede. These techniques can also be used to remove soft sediment near shore without collecting the underlying lower-quality material. This was done in 2004 when high water allowed dredging the entrance to Spindler Marina without excavating to a 9-foot (3 m) depth.

Figure 69. Students stand on a geotextile tube protecting an artificial island from waves at FWA. Riprap protects the tubes from ice and debris.

Figure 70. Trees and other vegetation were planted in geotextile tubes in a sheltered inlet on Old Hickory Lake in Tennessee.

Figure 71. On Lower Peoria Lake geotextile tubes lose material after being torn. Protective riprap is in the foreground.

Figure 72. Sediment forming the artificial island in Lower Peoria Lake is eroded when waves overtop the torn or flattened geotextile tubes.

Figure 73. Hesco Units™ near Ft. Pike in La. survived Hurricane Katrina. They have the potential for marsh restoration and habitat enhancement.

Figure 74. Hesco Units, shown here near New Orleans, come in several sizes and can be placed at various heights and in different patterns.

Maintenance Dredging of Aquatic Habitat
The government appropriations process routinely reflects the fact that navigation channels are in a dynamic environment and collect sediment, especially sand. It is time to give similar consideration to the backwaters and side channels that are also subjected to sedimentation that diminishes their ecological value and decreases habitat diversity. The situation is usually exacerbated where dams slow the current, preventing natural flushing of sediment. Habitat projects and their local sponsors are required to bear most of the cost of restoring depth to these areas even though the dynamics are quite similar. Allocating resources to maintain depth in areas outside the navigation channel on a regular basis will benefit fisheries, aquatic recreation, habitat diversity, and other uses.

Projects for restoring aquatic habitat depth, like those for navigation depth, can be accomplished on a continuous basis over river reaches. For example, a dedicated crew can remove sediment for something like overwintering habitat from several widely spaced locations over a river reach during a given year. During subsequent years, other locations could be deepened. Then the cycle could be repeated by removing newly accumulated sediment in the first areas. If this removal of fine-grained material is coordinated with dredging sand from the channel, the potential for manufacturing soil exists. Similarly, both materials might be used to elevate some floodplain areas for hardwood growth.

Mixing Sediment and Biosolids
At the Paxton I site ISTC and the Metropolitan Water Reclamation District of Greater Chicago mixed batches of dried biosolids and weathered sediment on a windy day. The sediment was brought to the mixing area by an end-loader and placed on the ground. It looked like typical granular soil, and it had little tendency to blow in the wind. The biosolids were dumped from trucks and had considerable fine material that generated clouds of dust. The two materials were mixed by bucket load on a volume basis with the operator using the bucket to stir and blend the material. Any large-scale mixing should be accomplished with suitable measures to control dust (Figure 75). Prior to drying, biosolids are quite fluid, and it may be difficult to mix them proportionally in that form with sediment and other materials (Figure 76). Additional information on biosolids/sediment mixtures is in Appendix F.

Placing Sediment on Farms and Other Land
Throughout much of the world, sediment deposition on bottom ground is recognized as an excellent source of soil and nutrients. Dredged material has the potential to be added to farmland by several methods, depending on its distance from the river source. A cooperative agreement with a farmer could also provide a placement site.

A traditional type of settling basin constructed on farmland that is leased for the net value of the crops foregone during dredging and dewatering is an option. Once filled by hydraulic dredge or other means, the basin can be dewatered. At that point, crops can be planted on the dredged material if provisions are made for drainage and the material is suitable. Alternatively, the sediment-derived soil can be spread over adjacent farmland to a desired depth by low ground pressure equipment. The end result would be a completed dredging project and improved farmland with additional soil at no cost to the farmer.

In areas with flat land, a very low berm could be pushed up around a field, or a number of low cells could be constructed. Material could be put in these cells to a desired depth using a hydraulic dredge, a slurry pump, or a displacement pump. It would be necessary to control turbidity in any water leaving the cells. Leveling and disking would follow dewatering. “Rainbowing,” or pressure spraying of sediment/water mixtures, could be used. Displacement pumps might also prove feasible. This may be particularly desirable where farmed levee districts are adjacent to bays or backwaters filled with sediment. Similar techniques may prove useful at locations with special conditions such as levee breaks, gumbo soil, or strip mines. However, it may be necessary to barge in dredged material if a nearby source does not exist.

There is increasing global interest in energy crops, carbon sequestration, and the threat posed by desertification of arable land. Dredged material used as soil or a soil amendment could enhance plant growth in a number of areas with poor soil or deficient moisture. For example, along a desert edge, sediment could increase the soil’s water-holding capacity and help establish grasses and other vegetation to hold soil in place. A number of options for transporting the material exist including new or existing pipelines, backhaul by coal unit trains, or other vehicles that currently return empty for loads.

Louisiana Delta Enhancement

Using sediment from the Peoria Lakes to help address the loss of the Mississippi River Delta in Louisiana was one of the more unusual parts of the Mud to Parks effort. Between 2004 and 2006, Illinois representatives made several trips to Louisiana. A number of options for using sediment were discussed particularly since fine-grained material spread over the delta during flood events was historically a major component of delta soil development. Fine-grained material can come from many locations along the waterway system other than Peoria. Because of the large sizes of tows operating on the Mississippi, getting the material to the delta by barge could be economical when the benefit to the marsh is considered, especially given the lack of such material in the delta region. Illinois and Louisiana Departments of Natural Resources developed a plan to test the concept, but the cost of marine work and equipment use after hurricane Katrina made it cost-prohibitive.

There are numerous locations throughout the delta region, including urban areas, along the Gulf Intracoastal Waterway, and various passes where open water spots occur in marsh areas. Examples include a number of ponds and embayments, including Grand Coin Pocket, between Bay Jaune and The Rigolets near Fort Pike (Figure 77). They expand as wave action and other processes erode the edge or kill vegetation. Sand obtained from the Mississippi River or other nearby locations could be dumped or pumped into some of these areas to bring up the bottom elevation. Fine-grained material could then be pumped over the sand to the desired depth. This would minimize the amount of fine-grained material needing to be shipped in from distant locations.

Dredged channels and open areas associated with pipelines and other facilities built long ago are present in many areas and are widening and facilitating erosion of surrounding marshland (Figure 78). These are often near the Mississippi or other waterways over which barges could deliver sand. Barges could be unloaded with pumps or excavators. Floating pipes could carry sand for miles into these areas filling them to a desired depth. Fine-grained material could then be pumped over the sand using a variety of techniques including displacement or slurry pumps. The sediment and or sand could also be mixed with suitable amounts of water and pressure sprayed, or "rainbowed," over areas. Another option is to place material from barges or suction dredges into the discharge from diversion structures. This could be done in a manner to minimize the impact of fresh water on the salinity of receiving waters. An example would be opening the diversion when dredged material is available to be placed. A comprehensive report on long-distance conveyance of dredged material for use in coastal restoration was issued by the USACE (Welp and Ray, 2011).

Over the years, millions of tons of rock have been barged down the Mississippi and placed along shorelines to protect marshland and channels. The rock frequently sinks into the soft substrate and is periodically replaced at what has been considered a reasonable expenditure of funds by proponents. Perhaps it is time to experiment with transporting fine-grained sediment to the delta region as an alternative or a complement to the current management protocol.

In locations where sand is being dredged from the channel, it should be possible to pump it over levees or transport it miles to locations where it can reinforce or expand what is left of nearby marshland. Fine-grained material used to cover it can be barged in or captured from the river's flow. In the long run, restored marsh would help protect the channel. This option would require rethinking what constitutes a least-cost alternative in terms of the value of the marsh to the channel, its habitat value, and its importance to the overall economy of the region.

The volunteer plants found growing in sediment-derived topsoil were not a threat to the local Illinois ecosystems because they are commonly found in the placement areas. In anticipation of sediment from Lower Peoria Lake being used for marsh restoration in Louisiana, the USACE Engineer Research and Development Center evaluated Illinois data on the plant species found at Mud to Parks sites. They concluded that the "data presented herein indicate that new introductions of species of concern to Louisiana are highly unlikely as a result of a mud-to-marshes project because they either do not occur in Illinois, or they do not presently occur in areas where sediments will most likely be dredged" (Shearer, 2008). The report recommended monitoring and testing if a restoration project is initiated. Sediment dredged from Mobile Bay and the Mississippi could be used to restore and enhance barrier islands. Using material from the bay could reduce the need for expanding confined disposal areas. Fine-grained material may or may not be appropriate to enhance vegetative growth, but it is available.

Insights on Marketing and Processing

A formal marketing study for the use of sediment-derived topsoil would be beneficial. It is apparent that topsoil for many local residential and commercial uses is needed in quantities of a relatively few truckloads. Persons purchasing this soil are often residents or owners who insist on material that meets their perception of a good quality soil. This often comes from nearby development sites where contactors commonly “mass grade” an area by scraping all topsoil into piles. The minimum required by local ordinance (where such exist) is then replaced after construction is complete and the rest is sold or made available for other sites. Sod in many new developments is laid on subsoil or minimal topsoil. This raises the concern about the amount of water needed to keep lawns green in places such as the Chicago suburbs where water availability is an issue. In some areas, developers are allowed to take topsoil directly from farmland. The overall ecological and resource costs to society of this practice are likely negative. The cost of transporting manufactured soil or that containing dredged material will frequently exceed the short-term cost of local materials, but a life-cycle analysis will likely show long-term benefits.

The situation is somewhat different for projects in need of large quantities of soil. They often end up with “urban soil” or “soil material” from a number of sources with varying quality (Figures 79, 80). Given the lack of accepted definitions of topsoil, contractors can provide whatever the client is willing to accept. This may be material that is mostly subsoil from an excavation. Sometimes it is provided at no charge. In other cases, the material may contain debris, crushed brick, broken glass, wood fragments, rebar, bricks, concrete, and similar refuse items. Such material can be used as a “subsoil” to be buried beneath higher quality soil. This can lead to problems when digging is required for infrastructure or landscaping and when erosion or frost heaving causes the exposure of undesirable items.

For dredged material and mixtures that constitute manufactured soil to come into common use, several things must happen. First, the public, institutions, and agencies must accept these soils as safe and suitable for the intended use. This will require a reasonable amount of testing, demonstration, and comparison to alternatives and existing soil in urban and rural areas. Policies and regulations of various entities need to adapt to facilitate beneficial uses of clean dredged material and allow for different end uses. Issues such as liability, adequate testing, transfer of ownership, interagency cooperation and coordination must also be addressed. Another issue is determining the appropriate use of federal and other public funds for efforts that may begin as maintenance dredging and end with soil delivered to private property. Finally, the costs of handling and transporting the admixtures and the final product must be reasonable in relation to the social and environmental benefits.

The main Mud to Parks project succeeded because a large number of government entities collaborated with the Office of the Illinois Lt. Governor through several administrations. Direct action and ownership was all within Illinois with no direct expenditure of federal funds. The Fondulac Park District and City of East Peoria obtained permits to have their channels dredged and agreed to relinquish the dredged material. The City of Chicago and Chicago Park District received the material. State agencies cooperated with details and IDNR administered state grant funds and bond funds appropriated for sediment beneficial use.


Figure 75. Dry biosolids are dumped from a front loader to be mixed with dried sediment.

Figure 76. Wet biosolids are seen pouring from a truck onto a drying bed in Chicago.


Figure 77. Shallow openings eroding in the marsh near Ft. Pike, La., and other locations could be filled with sand covered with fine-grained sediment.


Figure 78. Various innovative techniques could be combined to place dredged sand and fines into Mississippi Delta marsh areas.


Figure 79. So called "urban soil" is often laced with foreign objects such as glass, brick, and metal.


Figure 80. "Urban soil" on the left adjacent to sediment-derived topsoil at USX.

A long-term vision for sediment beneficial uses may involve a public-private partnership. This would include the ability to stockpile dredged material at convenient locations where it can dewater and be efficiently accessed by contractors or mixed with other appropriate products to manufacture a topsoil. The concept anticipates transporting large volumes of sediment to locations such as the Chicago and St. Louis metropolitan areas where it can be stored until needed. Smaller areas such as Peoria, Quincy, and the Quad Cities could support similar operations. Currently for large projects, the dredging and use of sediment must occur in the same timeframe and be logistically simple. The ability to stockpile would greatly simplify matters. Other considerations include whether large-scale processing is best accomplished in metropolitan areas with potentially high demand, or if some or part of it can be done at other locations along the river.

Ants and Elephants

Elephants are symbols of power and can rapidly make changes to their local environment. Ants, on the other hand, are diminutive, but excavate vast quantities of soil annually, one grain at a time. Major projects such as reservoirs require a large outlay of money and resources up front during construction. Then resources to maintain the project typically remain unavailable for decades, while sediment accumulates particle by particle. Eventually, it is necessary to raise money and mobilize equipment and resources for a major dredging effort, a new dam, or higher spillway. Essentially, elephants are used for both construction and maintenance.

An ant analogy may be useful for maintenance of some projects. For example, if reservoirs in an area are accumulating 100 acre feet (123,348 m^3) of sediment per year, a small-scale dredging and reuse project removing that amount annually may be feasible. It could be a small part of an annual budget with the work executed by municipal workers or local contractors. A relatively small area could handle the dewatering, and the annual volume of dredged material would not be as intimidating. In central Illinois, many cities with water supply reservoirs are seriously impacted by sedimentation. The cities could initiate a cooperative agreement with a contractor who could then dredge portions of each water body sequentially over time. The cycle could be repeated based on varying needs and the ability to place dredge materials. Each location would have its own pipes and dewatering basin. The concept can be extrapolated to ports, channels, aquatic habitats, and other facilities.

Rapid advances in solar power, robotics, and remote sensing create the potential for innovation in sediment management options. Devices operating independently of fossil fuel and the electrical grid could dredge or collect sediment and place it into a marsh, storage area, containers, or transport system. Such devices could operate intermittently, charging batteries as needed or waiting for sufficient sunlight. Operated independently, over time, these devices could collect large amounts of material. Technicians could provide routine maintenance and respond to problems detected by sensors.

Appendix A. Sediments and Sediment-Derived Soils in Illinois: Pedological and Agronomic Assessment

Excerpted from: Darmody, R.G., and J.C. Marlin. 2002. Sediments and Sediment-Derived Soils in Illinois: Pedological and Agronomic Assessment. Journal of Environmental Monitoring and Assessment 77(2): 209-227. DOI: 10.1023/A:1015880004383.

Abstract
Dredging sediments from water bodies in Illinois is done to preserve reservoir capacity, maintain navigation and recreation channels, and restore habitats, but the fate of the sediments is an issue. In anticipation of a major sediment dredging operation in Lake Peoria in the Illinois River, a retrospective study of sediment placement operations was performed. Sediments previously dredged from reservoirs and placed in retaining ponds were sampled along with adjacent upland soils which served as references. Sediments from the Illinois River above Peoria were sampled from islands, river bottom, and adjacent floodplain. Dredged sediment retention ponds initially support wetland vegetation. After dewatering, the physical properties of sediments tend to become similar to upland soils and the retention basins are then able to support conventional agriculture. Sediment organic matter content was similar to local reference surface soils, and soil pH of the sediments was neutral or above. Sediment textures are dominated by silts and clays, with the Lake Peoria samples being most clayey. Calcium was the dominant cation in all the samples, and micronutrients measured were in adequate supply for plant growth. However, because the Illinois River watershed includes industrial inputs, river sediments contained elevated levels of some metals, but they were generally below levels of regulatory concern. Results indicated that properly handled dredge sediments could make high quality agricultural soils. In addition, sediment placement on poor soils could improve their productivity.

Introduction
Sedimentation is a significant problem in reservoirs and other water bodies in watersheds impacted by erosion from farmland, urban areas, and stream banks and beds. Sediment reduces water depth and quality, and impacts such uses as water supply, recreational boating, and fish and wildlife habitat. Illinois water supply reservoirs are expected to lose approximately 1.2×10^8 m^3 of useful storage capacity between 1990 and 2030 due to sedimentation (Singh and Durgunoglu, 1990). A prime example is Lake Decatur in central Illinois which lost an average of 0.53% of its capacity annually between 1922 and 1983. During this time, its average depth decreased from 3 to 2 m (Fitzpatrick *et al*., 1987). Sediment also impacts rivers by filling in backwaters and side channels. The adverse impact of sedimentation in the Illinois River was summarized by Talkington, 1991. Bellrose *et al*. (1983) conducted a detailed evaluation of backwater lakes along a 370 km reach of the river between Grafton and Utica Illinois and found that water depth in most backwaters averaged less than 60 cm. Demissie (1997) estimated that on average bottomland lakes in the Illinois River valley lost 72% of their water storage capacity to sedimentation by 1990.

Dredging is employed to remove sediment from water supply reservoirs and navigation channels. Sediment from commercial navigation tends to be coarse-textured because propellers on towboats resuspend smaller particles which are then preferentially moved out of the channels. However, the bulk of sediment in water supply reservoirs and river backwaters is generally fine-grained, silts and clays. In some situations, contamination of sediments is a concern due to pollution. Placement of dredged sediment has traditionally been considered disposal or spoiling, regardless of sediment quality. Typically, sediments removed from reservoirs are deposited in constructed basins or ponds where they are allowed to dewater and consolidate.

In the Peoria Lakes on the Illinois River, resource managers are considering construction of artificial islands from dredged sediment as part of an ecological restoration project. Placement of sediments takes up land in the case of sediment ponds or surface area of the water body as in Lake Peoria. It would be desirable to find a beneficial use for sediments. In recent years the difficulty of placing large amounts of material dredged each year has led to a national search for beneficial uses of sediment (Landin, 1997). Sediment is now being used in a number of applications including fill, beach nourishment, wetland creation, and as landscaping soil. Potential uses of sediment are dependent upon its physical and chemical properties. Previous work in Illinois has shown that dredged sediments may be utilized for agriculture. For example, material removed from Lake Springfield and from Lake Paradise in central Illinois was shown to have potential for increasing crop yields on eroded soils (Olson and Jones, 1987; Lembke *et al.*, 1983a, b). However, contamination of sediments with industrial and municipal pollutants can occur even in relatively weakly industrialized and urbanized watersheds (Martin, 2000), so site-specific assessment is warranted.

The work reported here was done to investigate selected physical and chemical properties of sediments derived from rivers in Central Illinois. This is in anticipation of the dredging of the Peoria Lakes, which are wide, show-moving portions of the Illinois River with a normal pool elevation maintained by a navigation dam. The lake area has experienced the deposition of over $115 \times 10^6\ m^3$ of sediment that reduced water depth over much of the lakes from greater than two meters to less than 60 cm.

Methods and Materials

<u>Site Selection</u>

Research sites were chosen from reservoirs that were recently dredged, specifically Lake Springfield, Lake Decatur, and Lake Paradise near Mattoon, Illinois (Figure A1). These dredging projects were completed at Springfield in 1991, at Decatur in the mid-1990s, and at Mattoon in 1981 to increase the volume of water stored in the municipal water supply reservoirs. At each site, local upland soils within 100 m of the sediment sites were collected to serve as reference samples. Additional samples were collected from Woodford County, Illinois, in and near Upper Lake Peoria in the Illinois River where the proposed dredging will likely occur.

The Decatur sampling site was within an extensive sediment impoundment covering about 200 ha used to store 1.6 x 10^6 m^3 of dredgings. The confining berm was 2–7 m high and the sediment was 1–6 m deep. At the time of sampling the site had not been reclaimed, water content of the sediment was high, and there were volunteer hydrophilic plants covering the site. Two adjacent natural upland cultivated soils that formed in loess, a Typic Argiudoll and an Aquic Hapludalf (Soil Survey Staff, 1999), served as references. At Mattoon, the sediments were dry and in a small impoundment that had been reclaimed and was supporting a wheat (*Triticum aestivum*) crop. The sediments were thin, <1.5 m, and the confining berm had been graded onto the surface of the sediments to facilitate agricultural activities. An adjacent upland cultivated Typic Hapludalf formed in loess served as a reference. At Springfield, the sediments were dewatered and in a large impoundment covering about 200 ha, that was currently cultivated, supporting corn (*Zia mays*) and soybean (*Glycine max*) crops. The confining berm was 2–7 m high and the sediments were 1–6 m thick. The sediments had been graded in 1993 to improve drainage in anticipation of agricultural use of the area. An adjacent cropped Typic Argiudoll formed in loess served as the reference. Woodford County sample sites in the Illinois River upstream from Peoria included three Typic Fluvaquents on natural wooded islands, one from an island constructed from dredged sediments, and a grab sample from the river bottom. Three Woodford County reference sites in natural alluvium from the adjacent floodplain of the river included; a Typic Fluvaquent from a currently flooded farmed wetland, an Aquic Udifluvent from an unmanaged pasture, and a Typic Udifluvent from a mowed grass lawn, in order of increasing distance from the Illinois River.

Soil Sampling

Soils were collected as continuous 6.4 cm cores to a depth of 122 cm with a truck- mounted Giddings Soil Probe where possible. Inaccessible sites were sampled by hand with a 4 cm soil probe to 122 cm. Cores were wrapped in plastic and described by standard methods (Soil Survey Staff, 1993). The cores were then sectioned by horizon and air-dried prior to laboratory analyses. Buried soils were found beneath the sediments at Springfield and Mattoon. At Mattoon, because the sediments were covered by material derived from the confining berm that was graded onto the sediments after they dewatered, the results are skewed and are generally not included in the discussion. The Illinois River – Lake Peoria bottom grab sample was collected from about 60 cm of water by hand with a bucket auger. A shovel was also used to collect the dredge sediment island samples.

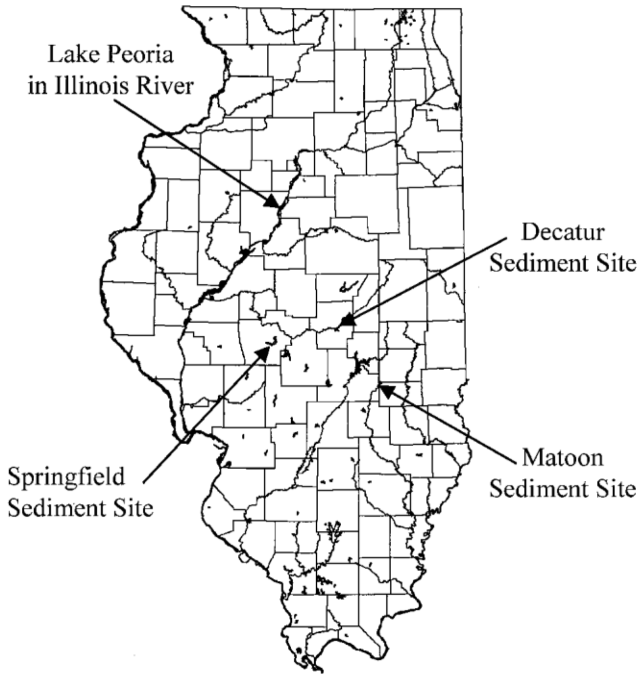

Figure A1. Sediment sampling sites in Illinois.

<u>Laboratory Analyses</u>

All laboratory analyses followed standard methods as appropriate (Klute, 1986). Particle size analysis was by sieving for the sand fractions and by hydrometer for the silt and clay fractions. Extractable elements were determined in a Mehlich 3 extracting solution (Mehlich, 1984). Analysis for total recoverable metal content was by USEPA method 3050. The soil fertility and metal analyses were done at Brookside Labs Inc. of New Knoxville, Ohio. Statistical comparisons were done at the α = 0.05 level.

Results and Discussion

<u>Physical Properties</u>

Soil Strength

Freshly deposited sediments tend to have low soil strength that varies little with depth, as seen in the penetrometer data from the wet sediment pond at Decatur (Figure A2). This was due to the high water content of the sediment, absence of contrasting compacted layers, and lack of coarse fragments. Because of the low strength from high initial water content, trafficability is a problem and may indicate future differential settling as they dewater and consolidate. The sediment retention basins as Springfield and Mattoon were dewatered and consolidated, and currently support conventional row crop farming activities. The sediment soil strength increased sufficiently to allow normal farming operations. The penetrometer resistance of the reference upland Hapludalf soil exceeds that of the sediment samples. It has been farmed continuously with heavy equipment and shows evidence of compaction at 20 cm, a problem not yet seen in the farmed sediments that have been cultivated only a few years. As long as they are strong enough to support equipment, lower soil strength in sediments can be an advantage because excess compaction in agricultural soils can inhibit plant growth (Dunker *et al*., 1995).

Soil Texture

Due to the nature of sediment transport and deposition, dredge sediments tend to be fine textured with silt and clay dominating and without significant amounts of coarse fragments. The texture of natural sediments on floodplains tends to become finer toward the surface due to stream hydrodynamics. In addition, floodplain soils tend to be more coarse textured on natural levees and terraces. At the Woodford floodplain sites, the soil textures follow these typical sedimentation patterns (Table A1). The floodplain soils sampled became finer textured upwards in the profile. For example, sand content ranged from 81% at 101 cm to 35% at the surface. The Illinois River island sites, in contrast, acted more like levees. Soils there tended to have more sand toward the surface due to recent deposition of sandy alluvium; sand content increased from 9% at 111 cm to 88% at the surface. Clay content of these alluvial samples tended to be moderate, ranging from about 2–21%. Underwater grab samples from the Lake Peoria – Illinois River bottom were very clayey at 63–73% clay, even more clayey than samples from a dredge sediment island that ranged in clay content from 42–52%. The difference in clay content could be due to the method of dredging or the sediment source. Different portions of the river bottom can be expected to vary in texture due to proximity to variable sediment sources and to water depth and velocity.

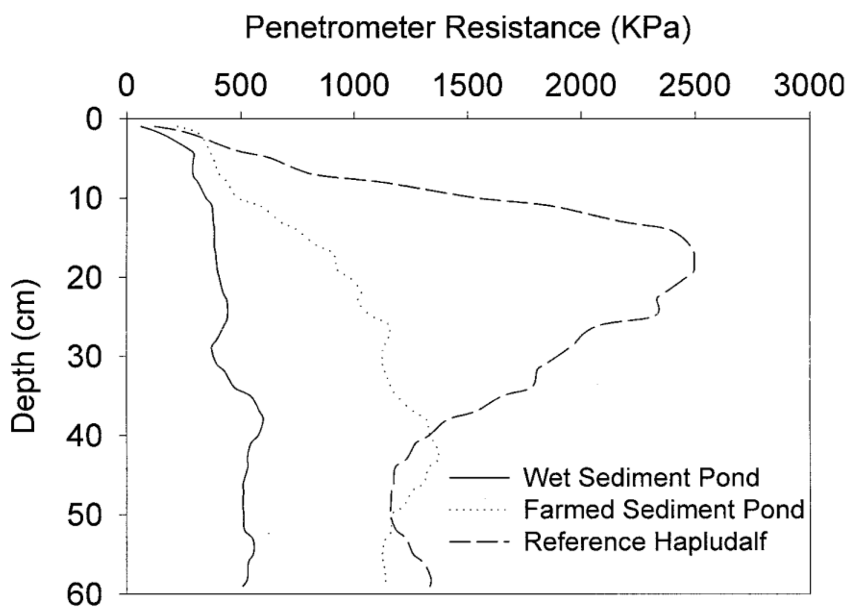

Figure A2. Penetrometer resistance of soils at selected sediment research sites, means of 15 determinations per site. The wet sediment pond and the reference Hapludalf are from Decatur, the farmed sediment pond is from Springfield.

Soils from the dredging impoundments at Springfield, Decatur, and Mattoon were silt loams, silty clay loams, and silty clays, generally with 30–50% clay and <5% sand. There were essentially no coarse fragments (data not shown). This fine texture reflects the sediment source, the methods of dredging, and the placement of the material. As expected with hydraulically deposited sediments, the textures varied randomly with depth, unlike the natural reference soils, which show an accumulation of clay in the B horizon. The natural reference soils are primarily developed in loess, which generally has silty textures similar to many of the dredge sediments.

When plotted on a texture triangle (Figure A3), the differences between natural alluvial sediments and those from sediment storage basins are apparent. Because most of the sediment samples were from low-energy bodies of water, they tend to have much less sand and more clay than the natural alluvial samples from better-drained floodplains and islands that require higher energy flows before they receive sediments. The two most clayey samples are the grab samples from Lake Peoria.

<u>Chemical Properties</u>

Soil Fertility

Illinois soils are naturally fertile and the samples analyzed had high pH and extractable nutrient levels (Table A2). Calcium was the most abundant of the extracted nutrients in all samples, and sediment samples had higher extractable Ca than reference samples. The reference samples, generally being from uplands, were naturally leached of their carbonates. In addition, the sediments are rich in Ca due to bioaccumulation by mollusks, as evidenced by clamshells distributed throughout the sediments, and possibly due to calcareous loess and till contributions to the sediment. At Decatur, for example, extractable Ca was over 5000 mg kg^{-1} in the sediments and about 2000 mg kg^{-1} in the reference soils that presumably have been limed. Shell fragments in the sediments also contributed to the CEC as measured because the technique used did not allow for discrimination of Ca contributed by dissolution of biogenic calcite. This Ca trend was followed at the other sediment sites and contributed to the high pH of the sediment relative to the upland reference soils that were naturally leached of Ca, particularly in their upper horizons. For the major plant nutrients P and K, the sediments had levels as high as or higher than the reference highly productive agricultural soils. This indicates that the potential for supporting vegetation is good, although most sites tested, particularly the reference sites, had less than optimum levels of P and K for row crop production and like most soils could benefit from fertilizer additions (University of Illinois Extension, 1998).

Table A1. Soil texture at selected sediment research sites.

Horizon	Depth cm	Class [a]	Sand	Silt	Clay	Horizon	Depth	Class [a]	Sand	Silt	Clay
Decatur Sediment Pond						Decatur Reference Alfisol					
A	7	SiC	1	57	42	Ap	12	SiL	7	73	20
Cg1	19	SICL	2	62	36	BE	27	SICL	4	60	36
Cg2	35	SICL	2	61	37	Btl	48	SiC	1	54	45
Cg3	54	SICL	2	59	39	Bt2	71	SICL	1	61	38
Cg4	75	SICL	1	60	39	2Bt3	87	SiL	2	72	26
Cg5	96	SICL	1	62	37	2BC	106	SiL	2	76	22
Springfield Sediment Pond						Springfield Reference Mollisol					
Ap	8	SiC	1	56	43	Ap	10	SICL	3	67	30
Cl	21	SiL	2	71	27	A	27	SICL	3	66	31
Cg1	42	SiC	3	48	49	Ab	43	SICL	2	63	35
Cg2-1	81	SiC	3	54	43	Bt1	61	SiC	1	55	44
Cg2-2	122	SICL	6	56	39	Bt2	82	SICL	1	59	40
Cg3	151	SICL	8	54	38	Bt3	103	SICL	1	62	37
Cg4	177	SiC	0	50	50						
Illinois Reference Floodplain Soil						Illinois River Peoria Lake Island Soil					
Ap	5	SiL	35	50	15	C	9	FS	88	10	2
A	19	SiL	36	50	14	A	29	FSL	68	23	9
Bw1	37	SiL	35	51	14	Bgl	51	L	46	44	10
Bw2	59	L	40	45	15	Cg1	71	SiL	24	66	10
2Bw3	82	FSL	67	23	10	Cg2	92	SiL	16	72	12
2C1	101	LS	81	12	7	Cg3	111	SiL	9	70	21
Peoria Lake Dredge Sediment Island						Peoria Lake Bottom Sediments					
Cg1	5	SiC	6	51	43	Cg1	10	C	25	12	63
Cg2	22	SiC	5	53	42	Cg2	60	C	3	20	77
Cg3	38	SiC	3	45	52						

a. Texture classes (USDA): SiL, silt loam; SiCL, silty clay loam; SiC, silty clay; C, clay; L, loam; FSL, fine sandy loam; FS, fine sand; LS, loamy sand; L, loam (Soil Survey Staff, 1993).

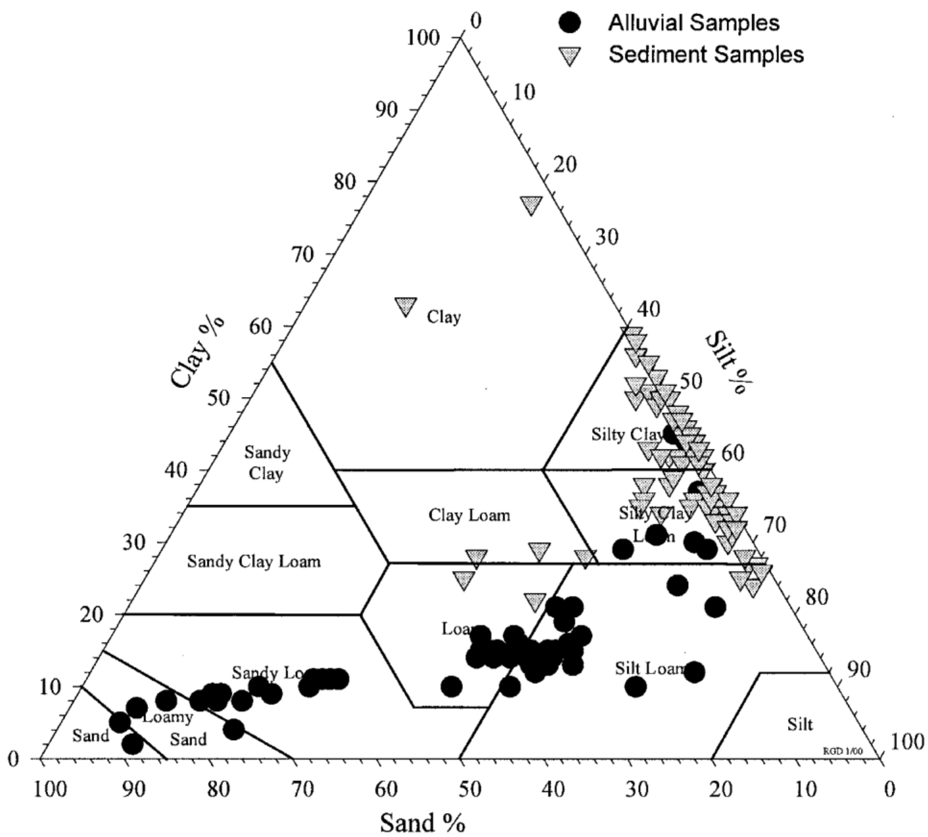

Figure A3. Texture of sediment and alluvial samples plotted on a USDA texture triangle. Alluvial samples include those from the natural islands and floodplain of the Illinois river, the sediment samples include dredged sediments from impoundments at Decatur, Springfield, and Mattoon as well as those from the Lake Peoria dredged sediment island and from the river bottom.

Table A2. Soil fertility parameters at selected sediment research sites.

Horizon	Depth cm	CEC meq 100g^{-1}	pH	SOM %	S	P	Ca	Mg	K	Na	B	Fe	Mn	Cu	Zn	Al
					------------------- Extractable (mg kg^{-1}) --------------------											
Springfield Reference Mollisol																
Ap	10	18	5.9	4.0	25	26	2380	341	178	12	0.5	130	64	2.5	2.9	441
A	27	22	5.9	3.6	23	16	2405	434	108	13	0.6	156	44	2.8	1.3	581
Ab	43	22	5.9	3.0	23	10	2081	526	104	17	0.4	137	27	2.4	0.6	660
Bt1	61	26	5.9	2.3	35	8	2546	854	144	27	0.5	118	35	2.1	0.6	760
Bt2	82	21	5.9	1.8	38	9	2129	814	117	22	0.4	94	40	1.7	0.6	752
Bt3	103	19	6.6	1.5	37	11	2204	894	124	28	0.4	93	61	1.7	2.7	712
Springfield Sediment Pond																
Ap	8	29	7.7	3.5	46	44	4497	758	200	20	0.7	271	90	5.4	5.1	422
Cl	21	17	7.6	1.7	36	47	2402	509	104	23	0.6	310	80	3.1	2.9	424
C2	29	31	7.5	3.2	69	47	4712	793	170	30	0.7	296	57	4.3	5.4	405
Cg1	42	30	7.5	3.3	103	51	4515	835	188	34	0.7	303	51	4.0	5.1	439
Cg2-1	81	25	7.6	3.0	138	58	3624	712	160	29	0.7	319	55	2.9	4.4	442
Cg2-2	122	23	7.5	3.0	183	63	3399	696	165	35	0.8	325	65	2.5	4.5	445
Cg3	151	33	7.1	3.8	160	58	4480	1160	234	50	0.9	310	193	5.0	4.4	496
Cg4	177	31	7.3	3.1	83	29	4060	1200	203	48	0.7	303	234	3.0	2.7	586
Difference[a]		–	s	–	s	s	s	s	s	s	s	s	s			r
Decatur Reference Alfisol																
Ap	12	9	6.1	1.8	32	32	1328	281	81	11	0.2	126	136	2.0	1.5	509
BE	27	23	4.9	1.4	32	12	1032	390	69	17	0.1	120	49	2.1	0.9	780
Bt1	48	31	5.2	1.9	52	7	2013	1036	99	22	0.2	99	59	2.3	0.8	852
Bt2	71	23	7.3	1.8	38	4	2201	1357	87	32	0.3	61	141	2.2	1.0	598
2Bt3	87	21	8.0	1.2	34	5	2092	1240	59	27	0.3	53	118	1.6	0.9	370
2BC	106	22	8.2	0.9	36	4	2358	1225	64	26	0.3	59	169	1.5	1.5	352
Decatur Sediment Pond																
A	7	35	8.0	4.4	65	44	5380	886	272	19	0.7	281	41	5.2	5.6	338
Cg1	19	34	7.9	3.6	62	28	5302	821	117	17	0.8	292	35	4.3	4.1	357
Cg2	35	34	7.9	3.3	74	25	5262	826	97	20	0.8	291	30	4.1	3.6	392
Cg3	54	36	7.8	3.4	113	24	5473	950	113	22	0.7	289	39	4.8	3.6	456
Cg4	75	35	7.8	3.8	135	22	5413	942	115	22	0.7	290	42	4.5	4.0	435
Cg5	96	33	7.7	3.4	177	22	5156	849	108	22	0.7	293	46	4.0	3.8	405
Difference[a]		s	s	s	s	s	s	–	s	–	s	s	r	s	s	r

a. Statistically greater at natural reference sites (r), natural island sites (i), floodplain sites (f), or sediment sites (s) at a location.

Table A2 continued. Soil fertility parameters at selected sediment research sites.

Mattoon Reference Alfisol																
Ap	5	12.0	6.0	2.0	43	30	1470	320	97	14	0.1	140	117	1.3	1.8	490
Bt1	14	14.0	5.3	1.2	34	9	1042	387	85	12	0.1	104	60	1.4	1.2	643
Bt2	26	18.4	5.2	1.4	48	5	1084	584	91	23	0.1	91	47	1.3	0.7	706
Bt3	53	12.7	5.9	1.2	37	5	1210	707	84	24	0.1	94	64	1.8	0.9	505
Mattoon Sediment Pond																
Ap	6	14.5	7.9	1.8	24	50	2108	416	170	7	0.5	84	142	1.6	1.9	352
C1	27	21.1	8.1	1.0	24	9	3358	471	105	18	0.5	77	130	1.6	1.0	364
2C2	52	18.6	7.9	2.7	26	47	2804	514	97	18	0.5	288	33	3.8	4.8	415
2C3	74	20.4	7.8	2.9	26	54	3102	536	131	16	0.8	300	24	4.2	6.0	456
2C4	93	18.7	7.8	2.6	28	56	2838	507	107	10	0.8	308	27	3.5	5.5	438
2C5	113	11.2	7.6	1.9	20	16	1609	351	83	12	0.0	117	129	2.3	1.5	497
Difference[a]		–	s	–	r	s	s	–	–	–	s	–	–	s	–	r
Illinois River Reference Floodplain																
Ap	5	15.4	7.6	3.5	22	18	2036	568	175	11	1.0	103	153	5.5	5.5	285
A	19	15.3	7.9	2.1	18	12	2216	478	81	11	1.0	130	148	4.3	2.7	335
Bw1	37	23.2	8.2	1.7	19	6	3785	483	86	12	1.1	114	120	4.9	1.5	266
Bw2	59	25.6	8.0	1.4	19	4	4190	526	89	14	0.6	94	83	3.8	0.9	112
2Bw3	82	20.0	7.9	0.6	21	6	3300	393	74	14	0.6	87	49	2.9	1.2	141
2C	101	10.8	8.1	0.4	13	14	1654	286	48	12	0.5	90	45	1.9	1.0	193
Illinois River Lake Peoria Natural Island																
C	9	15.3	8.1	0.8	53	61	2568	259	54	38	0.7	364	84	2.5	77.1	138
A	29	18.1	7.6	3.9	80	81	2671	511	70	79	1.1	404	61	3.4	79.5	217
Bg	51	21.6	7.6	3.1	83	49	3089	655	80	102	1.1	326	122	4.4	145.2	267
Cg1	71	24.9	7.9	1.9	88	25	3807	628	77	104	1.0	284	175	4.6	97.5	216
Cg2	92	28.8	8.1	2.3	120	27	4337	762	86	132	1.1	291	166	4.8	86.0	115
Cg3	111	35.2	7.8	2.6	155	30	5175	998	107	171	1.7	225	125	5.4	164.2	183
Illinois River Lake Peoria Dredge Sediment Island																
Cg1	5	35.5	7.8	4.3	47	44	5227	1031	154	76	1.4	403	28	5.8	19.4	380
Cg2	22	38.3	7.5	4.7	75	65	6019	886	165	80	1.1	390	30	10.5	67.4	373
Cg3	38	33.5	7.5	4.9	73	62	5226	804	148	65	1.1	421	31	7.7	52.0	400
Illinois River Lake Peoria Bottom Sediments																
Cg	2	34.5	7.5	3.4	213	71	5633	665	150	84	1.0	470	107	5.9	63.1	284
Difference[a]		s.i	f.i	s.i	s.i	s.i	s.i	s.i	s.i	s.i	-	s.i	f.i	s.i	s.i	-

a. Statistically greater at natural reference sites (r), natural island sites (i), floodplain sites (f), or sediment sites (s) at a location.

Secondary and minor nutrients including S, Fe, Mg, Mn, and B were also in adequate supply (University of Illinois Extension, 1998), and tended to be in greater concentration in the sediment samples than in the upland reference soils. The reference sites at Decatur and Mattoon may have been slightly deficient in B. Potentially problematic elements Al and Na in the sediments tended to be at concentrations lower or equal to those in the upland reference soils. Soil organic matter content tended to be greater in the sediments than in the reference soils due to the sedimentary additions and biogenic accumulation in the aquatic environment.

One striking difference among the samples is the Zn and Cu content of the Illinois River island soils. Extractable Zn ranged from 60–170 g kg^{-1} on the islands but was closer to 4 mg kg^{-1} on the adjacent floodplain. This is similar to the samples analyzed from the other reference sites. The differences were not as striking with Cu, but it was also more abundant in the island soils than elsewhere. The concentration of Zn and Cu did not systematically decrease with depth in the island soils; therefore, there is no indication that they represent recent additions. Given the vigorous vegetation at the island sites, neither Cu nor Zn appeared to be inhibiting plant growth. Copper and Zn tended to be elevated in the other sediment samples tested, as compared to their reference soils, but the concentrations and contrast with their reference samples were not as great. From a micronutrient view, the soils at all the reference sites may be deficient in Zn whereas all the sediment sites had adequate Zn. Again, the Cu and Zn content of the sediments does not appear to be at a level to cause concern or inhibit plant growth.

The grab sample from the river bottom and the samples from the sediment islands had chemistry similar to the natural island soils, except the organic matter content tended to be greater in the grab and sediment island samples than in the reference floodplain samples.

The overall impression given by the fertility data is that the sediments are generally rich in plant nutrients and potentially could make a good agricultural soil, particularly for crops that are tolerant of relatively high pH, fine textured soils. Although micronutrient levels measured in the sediments were more than adequate, levels of P and K were below optimum for maximum row crop yields (University of Illinois Extension, 1998). This is similar to normal agricultural soils that are routinely fertilized with N, P, and K as part of accepted agricultural practices to maximize row crop yields.

Metal Content

Total recoverable metal analyses included As, Ba, Cd, Cr, Pb, Ni, and Se (Table A3). While it is difficult to determine levels at which sediment metal concentrations are important, there are lists of reference values from surveys and from regulatory agencies. All metals tested were within ranges commonly found in soils and sediments in Illinois with few exceptions. Cd levels tended to run slightly higher than the Illinois EPA statewide soil mean (0.97 mg kg^{-1}) and background soils (0.6–0.5 mg kg^{-1}) but were generally below the EPA elevated sediment levels (5 mg kg^{-1}) (Table A4).

Table A3. Total recoverable metals (mg kg^{-1}) in selected sediments from research sites.

Horizon	Depth	As	Ba	Cd	Cr	Pb	Ni	Se
Springfield Reference Mollisol								
Ap	10	6	153	2	8	21	10	0.1
A	27	7	157	3	9	22	12	0.1
Ab	43	8	136	3	10	18	12	0.1
Bt1	61	11	136	4	13	26	17	0.1
Bt2	82	12	139	5	14	29	21	0.1
Bt3	103	11	131	5	14	26	21	0.1
Springfield Sediment Pond								
Ap	8	9	147	4	14	28	24	0.2
Cl	21	6	101	3	10	19	12	0.1
C2	29	8	142	4	13	26	15	0.2
Cg1	42	9	132	4	13	29	16	0.2
Cg2-1	81	8	135	3	13	24	14	0.2
Cg2-2	122	7	122	3	12	23	14	0.2
Cg3	151	9	161	4	15	28	16	0.2
Cg4	177	18	297	8	30	50	33	0.3
Difference[a]–	–	–	–	–	–	s		
Decatur Reference Alfisol								
Ap	12	5	92	2	6	21	6	0.1
BE	27	8	84	3	11	28	9	0.1
Bt1	48	12	127	4	15	28	21	0.1
Bt2	71	11	269	5	15	28	34	0.2
2Bt3	87	8	176	3	10	20	18	0.2
2BC	106	6	125	3	9	18	16	0.3
Decatur Sediment Pond								
A	7	8	110	3	12	24	14	0.2
Cg1	19	9	131	4	14	26	16	0.2
Cg2	35	8	103	3	11	21	14	0.2
Cg3	54	10	129	4	14	26	16	0.2
Cg4	75	8	110	3	12	22	14	0.2
Cg5	96	8	105	3	11	22	13	0.2
Difference[a]		–	–	–	s	s	–	s
Mattoon Reference Alfisol								
Ap	5	5	51	2	7	19	9	0.1
Bt2	26	8	64	3	12	20	19	0.1
Bt3	53	9	107	4	14	23	22	0.1

a. Statistically greater at natural reference sites (r), natural island sites (i), floodplain sites (f), or sediment sites (s) at a location.

b. Below detection limit.

Table A3 continued. Total recoverable metals (mg kg^{-1}) in selected sediments from research sites.

Mattoon Sediment Pond								
Ap	6	7	47	2	8	17	14	0.2
C1	27	6	59	3	10	19	16	0.3
2C2	52	7	94	3	11	27	13	0.2
2C3	74	8	75	2	9	23	12	0.1
2C4	93	6	81	2	9	23	11	0.1
2C5	113	4	67	2	7	15	10	0.1
Difference[a]		–	–	–	–	–	–	–
Illinois River Reference Floodplain								
Ap	5	2	33	<3[b]	5	<10	9	<0.2
A	19	2	36	<3	5	<10	8	<0.2
Bw1	37	3	39	<3	6	13	10	<0.2
Bw2	59	4	41	<3	6	11	9	<0.2
2Bw3	82	3	26	<3	5	11	6	<0.2
2C	101	2	14	<3	4	<10	5	<0.2
Illinois River Lake Peoria Natural Island								
C	9	3	30	<3	6	11	10	<0.2
A	29	3	40	3	9	20	12	<0.2
Bg	51	5	56	4	10	26	17	<0.2
Cg1	71	5	69	4	8	18	15	<0.2
Cg2	92	4	83	4	10	22	18	0.2
Cg3	111	4	104	6	14	31	22	0.2
Illinois River Lake Peoria Dredge Sediment Island								
Cg1	5	6	127	7	26	50	28	0.4
Cg2	22	15	135	7	42	100	28	0.4
Cg3	38	12	141	7	38	90	29	0.3
Illinois River Lake Peoria Bottom Sediments								
Cg	2	10	123	8	39	72	28	0.4
Difference[a]		s	s	s,i	s,i	s,i	s,i	s

a. Statistically greater at natural reference sites (r), natural island sites (i), floodplain sites (f), or sediment sites (s) at a location.
b. Below detection limit.

Pb levels in the Illinois River sediments were also higher than the unpublished statewide mean for soils of 24–49 mg kg^{-1} from the Illinois State Geological Survey and the Illinois EPA, and are higher than those levels considered elevated in sediments. These values should not be a concern because they are not, with the exception of the Illinois River samples, statistically different from their reference samples, and are well below the U.S. EPA 503 pollutant ceiling regulation levels (85 mg kg^{-1} for Cd and 840 mg kg^{-1} for Pb) (U.S. Environmental Protection Agency, 1995), and only slightly higher that the Cd probable effect concentrations (MacDonald *et al.*, 2000). The regulations for placement of sediment on land have not been developed, and the use of the 503 regulations, which were designed for the placement of biosolids on farmland, may not be appropriate for applications of dredged sediments.

At Springfield, the metal concentrations in the sediment pond samples were generally typical for the state (Table A4) and statistically similar to their reference samples with the exception of Se, which was slightly higher in the sediments, but still considerably below U.S. EPA 503 ceiling pollution levels (100 mg kg^{-1}). Metals tended to be distributed uniformly through the sediment column, but the deepest sample had higher metal levels and may represent an isolated situation because a second sample from the sediment pond did not show this condition (data not shown). Although the metals in this particular sample stand out, they are not of concern because they are only slightly higher than the probable effect concentration (MacDonald *et al.*, 2000) and considerably lower than the U.S. EPA 503 levels. In addition, they are buried about 170 cm below the soil surface and only represent a small volume.

At the Mattoon research area, the sediment metal contents were statistically indistinguishable from their reference soils. At Decatur, the Cr, Pb, and Se concentrations were slightly but statistically greater in the sediments than in their reference samples. Again, the Cd levels tended to run slightly higher than the IPA mean for the state, but they and all the metal tested were less than the U.S. EPA 503 pollutant ceiling levels. Given the comparable values in the reference and sediment sites, metal contamination is not a concern in these sediments.

Illinois River sites generally ran the highest among the soils tested, and the metal content increased in proximity to the river with all metals tested being statistically greater in the sediments than in the reference floodplain samples (Table A3). The texture of the reference soils tended to be somewhat coarser than the other samples. Consequently, the CEC level was somewhat lower than the other soils which in part accounts for the low metal content. The Illinois River samples tended to have the highest metal contents in the study. The samples from the sediment island and the river bottom had higher As, Cd, Cr, Pb, and Ni levels than the IEPA statewide mean, and the Cd, Cr, and Pb levels in the sediments were high enough in most of the samples to be considered elevated (Table A4). Apparently, the elevated metal levels are associated with geologically recent Illinois River sedimentation, and are possibly anthropogenic in origin. This finding is similar to rivers studied in Germany, where elevated metal levels were found toward the surface in sediments of the Lahn River, despite its predominantly rural catchment (Martin, 2000). The floodplain represents an older Illinois River sediment deposit that has not received metals, as indicated by the relatively low metal content of the floodplain soils.

Table A4. Reference values for some metal contents of Illinois soils and sediments [a].

As	Ba	Cd	Cr	Pb	Ni	Se	Ref.
0.4	5500	78	390	400	1600	390	1
7.2-5.2	110-122	0.5-0.6	16.2-13	36-20.9	13-18	0.37-0.48	2
10.1	545	<1	59	23.6	23.6	<1	3
6.7	130	0.97	17.3	49.2	16.8	0.5	4
75	-	85	-	840	420	100	5
<8-43	81-211	<1.3-11.6	9.4-99	<8-99	-	<0.9-2.1	6
70	-	9.6	370	218	52	-	7
700	-	10	270	600	-	-	8
4.1-<14	94-<271	<5	13-<27	14-<59	14.3-<31	-	9
14-<95.5	271-<397	5-<14	27-<49	59-<339	31-<43	-	10
9.79	-	0.99	43.4	35.8	22.7	-	11
33	-	4.98	111	128	48.6	-	12

a Compiled from various unpublished US EPA, Illinois State Geological Survey, and Illinois EPA sources.

1. Illinois EPA TACO Regulations soil remediation objectives for ingestion exposure route-specific values
2. IEPA Background soils concentrations (urban – non-urban)
3. Illinois State Geological Survey statewide mean (total digestion)
4. Illinois EPA statewide mean (method 3050)
5. USEPA 503 Regulations, ceiling concentrations
6. ISGS Peoria Lake sediments survey
7. USEPA sediment screening
8. USEPA apparent effects threshold (high)
9. IEPA Sediment concentrations normal
10. IEPA Sediment concentrations elevated (greater values are considered highly elevated)
11. Consensus-based sediment quality guidelines threshold effect concentration (MacDonald et al., 2000)
12. Consensus-based sediment quality guidelines probable effect concentration (MacDonald et al., 2000)

The general decrease in metal content toward the surface of the Illinois River island soils indicates that the metal content of the sediment supplied to the islands may have fallen off recently. Although this interpretation is complicated by the generally decreasing CEC toward the surface on the island, it is supported by results from undisturbed cores taken from the river bottom (R.A. Cahill, ISGS, personal communication). Given the luxurious vegetative cover on the islands, the metal content does not seem to be inhibiting plant growth. In addition, even though the metal levels exceed the statewide mean and their reference site values, they should not be a significant concern because they do not exceed U.S. EPA 503 pollutant levels. Given the high pH of the soils, it is doubtful if the metals are readily available to plants. Research involving plant uptake tests should be done to determine if plants grown on these sediments develop significant metal concentrations.

Conclusions

The physical characteristics of the dredged sediments evaluated are similar to naturally productive, fine textured agricultural soils in Illinois. Their potential water storage capacity is high and their coarse fragment content is low. After the sediments dewater and age, they can develop good tilth that is associated with productive agricultural soils. The trafficability of sediment impoundments should not be a problem after dewatering occurs and natural soil structure develops. There is no indication in the physical data that these sediments should present a problem for agricultural utilization given proper handling, tillage, and fertility treatments.

Metal levels in the Illinois River sediments were somewhat elevated compared to the other sediments and to their reference soils. This may be of some concern if the sediments are used undiluted to grow vegetables for direct human consumption. However, there are no consistent criteria for judging the significance of a soil's metal content. Regulatory agencies have not reached a consensus in this area. What should serve as a reference level is not well defined (Martin, 2000), and critical values are not universally recognized (U.S. EPA, 1995, 1997; IL EPA 1997). The high pH, fine texture, and high CEC would indicate that metals would be tightly held in the sediments and not move. This would indicate a potential beneficial use of the sediments on sandy soils which would increase their water holding capacity while decreasing leaching of pollutants. Additional research into plant uptake would help in determining if these metal levels are significant for any of the many possible uses for the sediments.

Beneficial use of sediments should be evaluated as part of dredging projects, particularly when the potential for contaminants is low. Many sediments are basically derived from clean upland soils and are perhaps more appropriately viewed as a resource out of place than as a disposal problem. The work reported here indicates that the dredged sediments in the study sites may serve useful purposes. Their high fertility and water holding capacity indicate a number of beneficial possibilities such as; agricultural or landscaping soil, or as cover for undesirable substrates found in abandoned industrial areas, highly eroded or sandy soils, abandoned surface mines, or scalped highway rights-of-way.

Appendix B. Dredged Sediment:
Application as an Agricultural Amendment on Sandy Soils

Excerpted from: Darmody, R.G., and D.R. Diaz. 2017. Dredged Sediment: Application as an Agricultural Amendment on Sandy Soils. ISTC Reports. TR-066. Illinois Sustainable Technology Center, Champaign, Illinois, 102 pp. http://hdl.handle.net/2142/97824

Abstract

This study proposed using sediments dredged from the Illinois River to enhance sandy soils. Sediments often have high nutrient levels and physical properties that are desirable for agricultural production. Dredged sediments may greatly improve extensive areas along the Illinois River that have sandy soils with poor physical properties. We built research plots using Peoria Lake sediment at 0, 7, 15, and 30 cm (0, 3, and 12 in.) thicknesses applied to Bloomfield Fine Sand. Corn and soybean plants were grown on the plots for four years. An analysis of chemical and physical properties of soil treatments revealed a significant improvement in water holding capacity, cation exchange capacity, and the nutrient content of the soil. A significant plant response was observed where the sediments were applied. In corn, higher vegetative growth and grain yields occurred in plots treated with sediment. With soybeans, vegetative growth was greater on sediment plots; however, treatment effects were not as dramatic as with corn. Concentrations of metals in soils and plant tissues were within normal levels. However, molybdenum (Mo) levels in soybean grain were found above levels considered safe for livestock fodder if the copper (Cu) content is low in ruminants' diets. This is a common problem in certain soils in the US, and is easily solved by providing Cu feed supplements. Polychlorinated biphenyl (PCB) levels in soybeans were below the detection level (17 μg kg^{-1}) for four of six samples from the sediment plots. The other two had levels of 21 and 22 μg kg^{-1}. We concluded that Peoria Lake sediments hold promise as a topsoil amendment when applied to sandy soils.

Introduction

Given their high soil fertility, organic matter content, and water holding capacity, adding dredged sediments to poor soils could greatly benefit agricultural production. Olson and Jones (1987) found that dredged sediments had a similar total porosity and higher water retention compared to local topsoil, as well as other characteristics significantly favorable for plant growth. Silty sediments from the Potomac River, when applied in a layer 1–2 m thick, supported exceptional growth of corn in Virginia (Daniels et al., 2007). Lembke et al. (1983) found that dredged sediments from central Illinois had a much darker color than local topsoil, indicating a higher organic matter content. In addition, plant growth was significantly higher in sediment treatments compared to reference soils, and plots with sediment showed less moisture stress, attributed to the greater water holding capacity (Lembke et al., 1983). Typically, the texture of sediments from the Peoria Lake portion of the Illinois River is silt loam to silty clay, similar to the texture of productive Mollisols in Illinois (Darmody and Marlin, 2002).

Considering their texture, water holding capacity, cation exchange capacity (CEC), and fertility, sandy soils are generally less favorable for agricultural production. Adding dredged sediment to soils with poor agricultural characteristics could increase productivity enormously. Canet et al. (2003) conducted greenhouse experiments to evaluate the improvement of local sandy soils using dredged sediment from Albufera Lake in eastern Spain, obtaining significant improvements in characteristics such as soil water retention, CEC, and nutrient content. In addition, lettuce yield and nutrient content increased with sediment application (Canet et al., 2003). Dredged lake-bottom sediment has been applied to an agricultural soil, which led to increases in N, P, and K uptake in corn, soybeans, and sunflowers that were proportional to the amount of sediment mixed with sandy soils (Woodward, 1999).

Compared to typical Illinois topsoil, Peoria Lake sediment had higher concentrations of most common soil elements, especially Ca and Mg, which are biologically magnified by mollusks. Industry-related metals (Cd, Zn, and Pb) were also present in relatively greater concentrations (Darmody et al., 2004). However, metal levels were below the U.S. Environmental Protection Agency (USEPA) 503 regulations regarding concentrations for biosolids applied to land (Darmody and Marlin, 2002). Metal uptake measured in tomatoes grown on Peoria Lake sediments was not significantly different from that in plants grown on natural topsoil in greenhouses or local gardens. Levels of metals in barley, snapbeans, lettuce, and radishes were relatively higher in sediment than topsoil, but were not considered excessive (Darmody et al., 2004). Likewise, vegetables grown on sediment from the Lower Peoria Lake reach of the Illinois River did not contain excessive levels of metals (Ebbs et al., 2006). Inherent properties of dredged sediment from the Illinois River such as high pH, fertility, and fine texture could contribute to the low mobility and plant availability of metals, reducing the possibility of plant uptake or leaching of pollutants once applied to land (Darmody and Marlin, 2002).

Poor water holding capacity and low fertility are some of the main limitations of very sandy soils for agricultural production, but widely used irrigation and fertilization (often as fertigation) allow the use of this soil type for row crops (Calsyn, 1995). However, crop production levels in sandy soils are relatively low compared with typical fine-textured Illinois Mollisols. We tested the efficacy of sediment amendments to improve sandy soil agricultural productivity.

Methods

Sediment and Research Plots

Dredged sediment was obtained from the Lower Peoria Lake on the Illinois River at East Peoria, Illinois (river mile 165). The experiment was performed on a Bloomfield fine sand soil series (sandy, mixed, mesic Lamellic Hapludalf). The project research plots were located at the University of Illinois Sand Farm (hereafter, the sand farm), near Kilbourne in Mason County Illinois. The sediment was removed from the river by a clamshell dredging bucket in May 2000, then transported to an abandoned gravel pit near Peoria where dewatering and some weathering occurred. In May 2001, 89 tons of sediment was trucked to the sand farm (Figure B1). No pretreatments were applied to the sediment prior to use. Plots were established by applying the sediment to the existing sandy soil in a replicated design (Figure B2). An unanticipated complication was that the sediment as used was contaminated with foreign matter such as coal, tar, chunks of concrete, rebar fragments, and asphalt due to handling and storage. During the experiment, some of the foreign matter was removed from the plots by hand, as time permitted. However, results were not significantly impacted by this situation.

SOIL AND CROP SAMPLING AND ANALYSIS

Soil samples were obtained at five different depths (0–7, 7–15, 15–30, 30–45, and 45–60 cm). Analyses of nutrient status were performed, including pH, organic matter, soluble sulfur (S), extractable P, K, Ca, Mg, K, Na, B, Fe, Mn, Cu, Zn, and Al by standard methods (Mehlich, 1984). Metal analyses of soil samples and plant tissues was near total for the soils and total for the plant samples by standard methods; USEPA Method 3051 (USEPA, 1994a). Soil physical analyses also followed standard methodology (Klute, 1986; Gee and Bauder, 1986; Kember and Rosenau 1986; Blake and Hartge, 1986). Crop development was monitored throughout the growing season and yields were measured at the end of the growing period.

Results and Discussion

Soil Characteristics

Sediment and the native sandy soil properties differed greatly. Sediments had poor structure initially, but provided better nutrition for crops than sandy soil and produced remarkably better plant growth. Local sand and sediment textures were quite different; the sandy soil was predominantly sand-textured (97 % sand, 1% silt, and 2% clay), sediment was silty clay loam (11% sand, 60% silt, and 29% clay), typical of highly productive soils. The mix of sediment and local sandy soil was expected to produce a texture more desirable for agricultural production than the sandy soil alone, an expectation that was observed in the study period (Figure B3).

Water Holding Capacity

Soil water holding capacity was significantly increased by the addition of dredged sediment. This soil property is one of the most important limiting factors for agricultural. Improvement of this soil property would reduce crop production costs by minimizing the amount of irrigation needed on sandy soil. The water retention curve (Figure B4) demonstrates the substantial difference between the original soil and the sediment-amended soil. Plant-available water in the sand (control) plots ranged from 1.5% to 3.5% moisture, indicating a very low water retention capacity. In contrast, values ranged from 10.5% to 20% moisture in sediment-treated plots, giving a field capacity of 9.5% and providing almost five times more water available for plants than the control plots.

Soil Temperature

In this experiment, soil temperature was measured at a 10 cm depth during the growing period for all treatments. The highest and lowest temperatures were observed in the control sandy soil. The ideal soil temperature for corn and soybeans is between 25 and 30° C; growth ceases at temperatures above 35° C (Brady and Weil, 2002). Addition of sediment moderated soil temperature fluctuations (Table B1).

Figure B1. Soil materials used at the Sand Farm research site: A, sediment as delivered to site; B, Bloomfield Sand core showing thin, weak A horizon on right; C, Bloomfield sand core with 30 cm applied sediment; D, 30 cm sediment core showing some mixing at the interface.

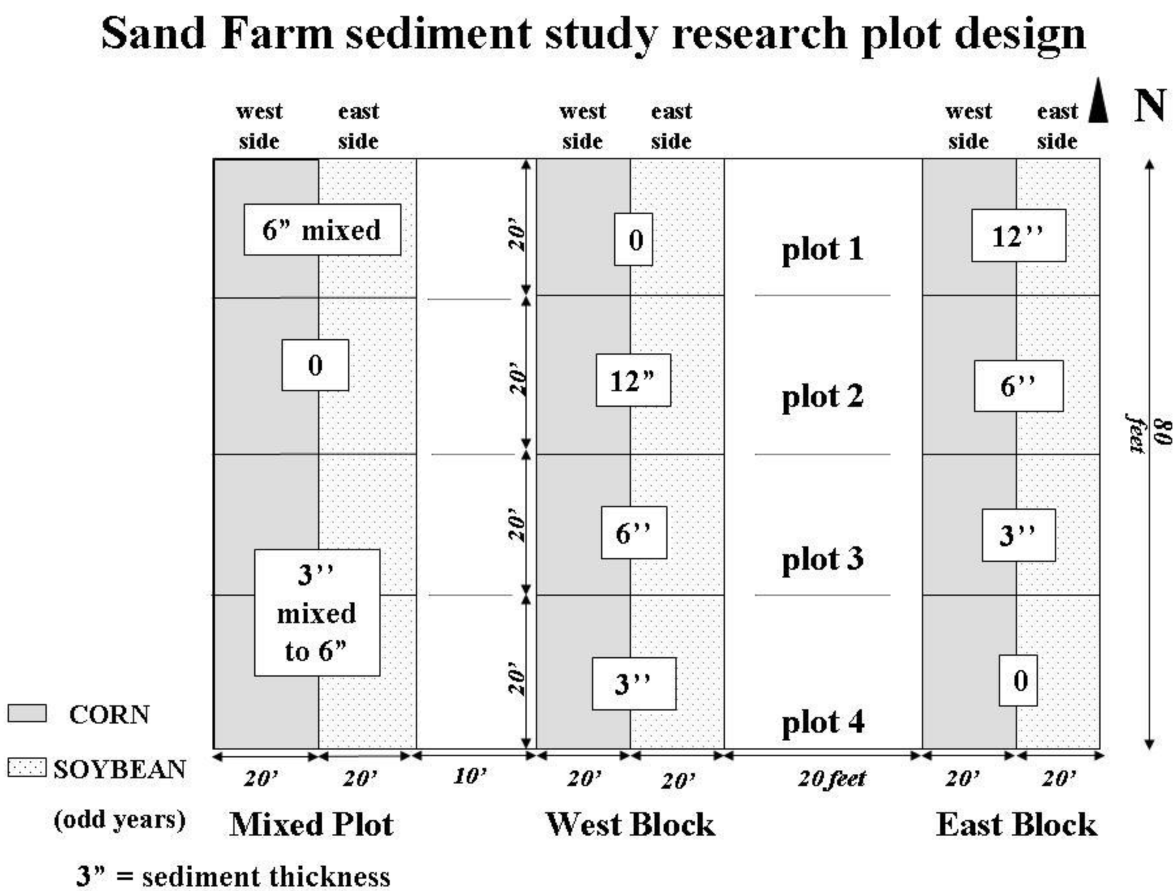

Figure B2. Final experimental plot design at the sediment research site at the University of Illinois Sand Farm.

Figure B3. Sand Farm sediment research plots: A, early season view showing sediment treatments and irrigation system; B, late season view showing crop response to sediment addition.

Nutrients and Fertility
Soil fertility was improved by adding sediments. Sediments were calcareous and raised the soil pH from ~5.4 to ~7.4 (Table B2). Levels of organic matter (OM) also increased dramatically with the added sediment. The native soil had ~0.1-0.5% OM, whereas sediments had a range of ~2.7-3.0 % OM.

Sediment Metal Content
Acceptable levels of pollutant metals in sediments intended for land application have not been formally established; instead, pollutant limits for land application of sewage sludge from Part 503 (USEPA, 1994b) are used here as a reference. None of the elements measured exceeded one-eighth of the ceiling levels established by the USEPA (Table B3).

Plant Growth and Crop Yield
Differences in plant height were not statistically significant in the first half of the growing period; however, in the second half, a clear treatment effect was observed, especially in corn (Figure B5). Yields of both crops were very low in the first two years, attributed mainly to damage from wild animals and poor rainfall distribution, therefore, no clear treatment effects were observed. However, yields in subsequent years were considered a direct effect of experimental treatments, given that herbivory was minimized through the erection of fences and the plots were irrigated. Corn yield showed a direct positive response to sediment treatments; the sediment plots produced significantly higher yields than the control sandy soil, however, response of soybeans was not as clear cut (Table B4).

Metal Uptake by Soybeans
Soybean metal content, in general, was higher in sediment-treated plots (Table B5), but levels were still low enough not to be considered problematic. Metal values were for plants from individual plots therefore, no statistical analysis could be done. Instead, noticeable trends are described. Levels of Be, Se, Ag, and Tl were below the limit of detection (LOD) in soybean tissue for all treatments and plant parts. Concentrations of B, Cu, Zn, Cd, and Hg were higher in plants grown on sediment-amended soil than in the control sandy soil. This trend is for both leaves and grain. The level of Mo followed the same trend; however, a marked difference could be observed between plant leaves and grain, with concentrations of Mo up to 10-fold greater in the grain.

Concentrations of Ti, V, Cr, Ni, As, and Pb were similar for all treatments. In contrast, levels of Mn, Co, and Ba were consistently higher in plants grown on the control sandy soils, despite lower levels of these elements in the control soil. Levels of B, Cu, Zn, Mo, and Cd increased with sediment application, as was expected. Levels of Hg were very low and inconsistent (at the lower limit of detection), increasing with sediment application in the leaves, but not varying in the grain.

Properties of the soil, such as pH and the presence of competing ions, influence metal uptake. In addition, the growing stage, health, and biomass of a plant influences contaminant concentrations in plants. In general, the element levels analyzed were considered sufficient or

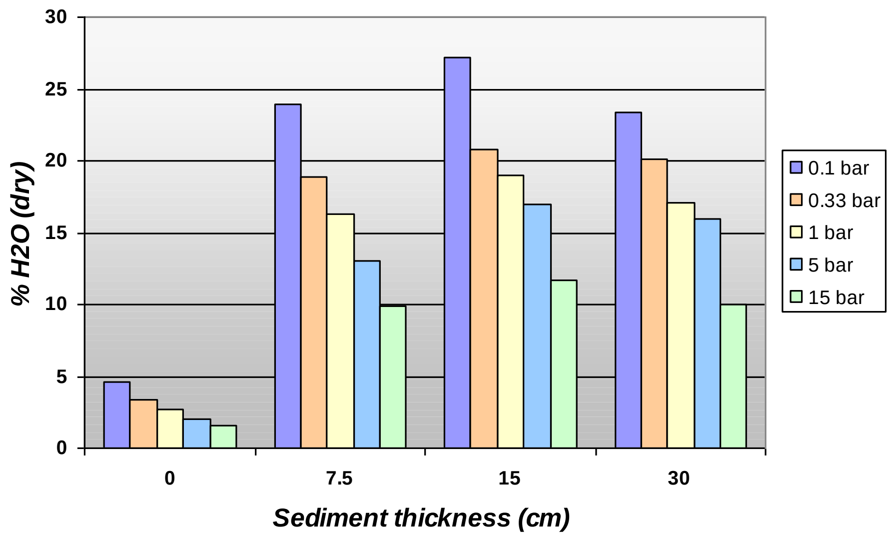

Figure B4. Soil (0-7 cm) moisture holding capacity by sediment treatment at five suction levels.

Table B1. Soil temperature during the third corn growth period measured at 10 cm depth.

Treatment	Temperatures (°C)			
	Max	Min	Average	Range
30 cm	28.9	3.0	17.1	25.9
15 cm	29.3	2.8	17.0	26.5
7 cm	34.7	1.6	17.8	33.1
0 (Sand)	34.8	1.4	18.5	33.4

Table B2. Least square means of soil nutrients of 0-60 cm, by treatment (2001, 2002).

Treatment (cm Sediment)	OM (%)	pH	TEC cmol kg^{-1}	P	Ca	Mg	K
				----------------mg kg^{-1}----------------			
30	1.7 a†	7.4 a	20 a	90 a	3720 a	365 a	100 a
15	1.3 b	7.2 a	16 b	89 ab	2606 b	272 b	84 ab
7	1.0 b	6.8 b	12 c	101 a	1936 c	195 c	71 b
0	0.2 c	5.4 c	2 d	87 b	292 d	47 d	44 c
	Na	B	Fe	Mn	Cu	Zn	Al
	------------------------------------mg kg^{-1}------------------------------------						
30	26 a	1.0 a	343 a	47 a	3.5 a	29.0 a	264 b
15	16 b	0.9 a	318 a	44 ab	2.8 b	9.4 b	272 b
7	13 bc	0.8 a	285 b	39 b	2.2 c	9.3 b	324 a
0	8 c	0.5 b	146 c	34 c	0.9 d	1.5 b	342 a

† Values in a column followed by the same letter are not significantly different, e.g. in P, 90 is the same as 101, but is more than 87, 89 is not different from 101 or 87.

Table B3. Total recoverable metals in sediments and soils after one season (mg kg^{-1}).

Treatment	Depth	Cd	Cr	Cu	Pb	Ni	Zn
0	0-7	2.8	4.5	2.2	9.5	6.4	21.0
	7-15	2.9	5.7	2.3	13.4	7.7	17.8
	15-30	3.4	5.8	2.4	14.4	7.2	16.0
	30-50	2.8	6.0	2.3	14.5	9.0	14.8
	50-60	3.1	5.3	1.9	15.3	7.7	13.7
	60-80	3.6	5.6	2.6	14.1	8.6	14.0
	80-100	3.4	6.0	2.1	11.4	9.5	14.2
	Mean	3.1b†	5.5c	2.3c	13.2b	8.0b	15.9c
7.5	0-7	5.9	19.8	18.1	35.1	28.6	101.3
	7-15	5.1	13.9	11.2	17.9	17.6	63.6
	15-30	4.4	5.7	2.5	11.3	7.1	22.9
	30-50	3.6	5.3	2.3	10.4	8.6	16.2
	50-60	3.5	5.5	2.0	9.6	7.7	14.2
	60-80	3.1	5.4	2.2	12.9	9.0	14.6
	80-100	2.9	6.3	2.1	14.7	9.7	15.9
	Mean	4.1a	8.8b	5.8b	16.0ab	12.6a	35.5b
15	0-7	5.7	18.8	20.5	35.0	26.5	103.5
	7-15	6.8	22.3	25.7	29.6	30.2	114.6
	15-30	3.0	8.2	6.6	17.6	8.8	35.7
	30-50	3.0	5.9	2.9	10.8	6.4	20.3
	50-60	2.8	5.2	2.9	13.4	6.9	15.1
	60-80	2.9	6.2	3.4	10.7	8.6	24.6
	80-100	3.0	4.8	2.3	10.0	9.5	15.6
	Mean	3.9a	10.2a	9.2a	18.2a	13.8a	47.1a
30	0-7	5.3	17.7	18.4	30.3	27.2	98.1
	7-15	6.1	19.8	20.5	32.9	29.3	110.2
	15-30	3.4	14.4	9.7	11.5	14.0	53.9
	30-50	2.8	4.7	5.6	13.9	6.9	21.9
	50-60	2.8	4.9	3.8	10.2	7.0	42.3
	60-80	2.6	4.0	1.7	9.6	7.4	12.3
	80-100	3.0	4.0	2.8	9.9	8.7	14.8
	Mean	3.7ab	9.9ab	8.9a	16.9ab	14.4a	50.5a
Mean	0-7	4.9a	15.2a	14.8a	27.5a	22.2a	81.0a
	7-15	5.2a	15.4a	14.9a	23.5a	21.2a	76.6a
	15-30	3.6b	8.5b	5.3b	13.7b	9.3b	32.1b
	30-50	3.0b	5.5c	3.2c	12.4b	7.7b	18.3c
	50-60	3.1b	5.1c	2.7c	12.5b	5.2b	21.3c
	60-80	3.0b	5.3c	2.5c	11.8b	8.4b	16.4c
	80-100	3.1b	5.3c	2.3c	11.5b	9.4b	15.1c
	Mean	3.7	8.6	6.5	16.1	12.2	37.3

† Values within a group followed by different letters are statistically different ($\alpha = 0.05$).

Figure B5. Crop response to sediment addition: A, view of plots showing strong response of corn and weak response of soybean to sediment addition; B, corn height at mid-season in sediment plot; C, corn height on check plot.

normal (Kabata-Pendias and Pendias, 1992). However, excessive Mo was found in the soybean grain grown in sediment-treated plots, rendering it unfit for use exclusively as a feedstock for ruminants. A minimum ratio of Cu to Mo of 2:1 in feed is recommended to avoid Cu deficiencies in ruminants (McBride et al., 2000; Mattioli et al., 1996). The problem with Mo in plants is essentially a theoretical one, considering that the materials would pose a potential problem only if they were the only food available to the target animals. Where natural soils present this problem, feed supplements are routinely used (McBride et al., 2000).

In addition to the metal content, the potential uptake of organic contaminants in the sediments was also a potential problem. We conducted a limited analyses of PCB content of soybean grain (six samples from the sediment plots), and detected only two congeners of the PCB Aroclor-1254 slightly above the detection limit of 17 µg/kg at 21 and 22 µg/kg.

Table B4. Mean soybean and corn grain yields from sediment-treated plots, last two years of the project.

Treatment	Yield (g per plot)	
(Sediment cm)	Corn	Soybeans
0	889	858
8	2,790	878
15	2,567	1,058
30	3,094	932
Average	2,335	931

Table B5. Metals in soybean leaves and grain grown at the sediment research site. †

Material	Sediment (cm)	B	Ti	V	Cr	Mn	Co	Ni	Cu
		mg kg^{-1}							
Leaves	0	19	6	0.1	0.5	190	0.2	0.7	2.0
Leaves	15	40	5	0.1	0.5	86	0.1	0.5	3.2
Leaves	30	34	5	0.1	0.5	46	0.1	1.6	3.4
Grain	0	10	10	0.02	0.05	55	0.2	2.4	3.7
Grain	15	30	11	0.02	0.08	30	0.1	3.0	9.4
Grain	30	34	10	0.02	0.08	28	0.1	2.6	8.2

Material	Sediment (cm)	Zn	As	Mo	Cd	Ba	Pb	Hg
		mg kg^{-1}						
Leaves	0	9	0.17	0.1	0.1	114	0.9	0.016
Leaves	15	42	0.19	2	0.5	11	0.7	0.015
Leaves	30	38	0.19	4	0.5	10	0.9	0.056
Grain	0	24	0.02	2	0.1	19	0.02	0.001
Grain	15	40	0.02	23	0.3	3	0.03	0.001
Grain	30	40	0.02	21	0.4	2	0.06	0.001

† Be, Se, Ag, and Tl are below the limit of detection (LOD) for all treatments and materials.

Conclusions

The overall conclusions were based on soil analyses and plant performance from four years, but extensive plant damage from animals in the first two years significantly altered the measured plant parameters, especially yield. Data from the third and fourth years were likely more representative of the actual findings because the worst impacts of dry weather and damages from animals were largely controlled in those years by better fencing and addition of irrigation.

Analyses of chemical and physical soil properties suggested that the addition of dredged sediment to sandy soils significantly improved the overall quality of the soil for crop production. Outstanding improvements were observed in the water holding capacity of the soil, a property that may be one of the most relevant for this region, given that application of irrigation water represents one of the highest production costs. Soil nutrient levels increased significantly with the added dredged sediment, as well as desirable properties such as cation exchange capacity and organic matter content.

Despite the higher surface compaction observed in the sediment-treated plots, no negative effects were observed in any of the crops grown on the sediment treatments. Levels of metals in the soil increased with the added sediments. For example, the total concentration of Cd in soil in some of the sediment-treated plots were above suggested normal values, but the rest of the element levels were considered normal for US soils.

Corn growth was directly proportional to the amount of sediment applied, with the best plant height and yield found in the 30 cm sediment treatments. This was also supported by higher values of SPAD chlorophyll-meter readings, suggesting greater nutrient levels in the plant, especially N. In soybeans, greater plant growth was observed in treatments with 30 cm sediment; however, plant lodging occurred at harvest in this treatment in 2003, perhaps because of excessive vegetative growth or high winds. Treatments with 15 cm of sediment produced higher soybean yields, but note that soybeans did not show a constant yield response to the application of sediment, in contrast to the stronger response of corn. Metal concentrations in soybean tissue were, in general, within normal suggested values for US soil; however, levels of Mo in soybean grain require care if it will be used exclusively for ruminant feeding, for which there are standard protocols. The overall conclusion of the research is that sediments improved the physical, chemical, and crop growth properties of Bloomfield soils without significantly adding bioavailable contaminants to the soil.

Appendix C. Topsoil: What Is It and Who Cares?

Excerpted from: Darmody, R.G., W.L. Daniels, J.C. Marlin, and D.L. Cremeens. 2009. Topsoil: What Is It, and Who Cares? Proceedings America Society of Mining and Reclamation, 237-269. DOI: 10.21000/JASMR09010237

Abstract
Topsoil means many things to many people, but to everyone it represents the best part of the soil from a plant-growth perspective. Many activities alter the soil profile including surface mining, agriculture, and urban development. Of these, mining is subject to state and national regulations for protection of soil and the USDA has a series of programs to protect topsoil from erosion. The extensive use of mass grading to remove topsoil from entire subdivisions during construction will likely create pressure for additional standards and regulations governing topsoil protection and replacement, as will national efforts to restore abandoned industrial areas. Topsoil is the subject of mine reclamation regulations and is viewed as something to be protected and preserved, but also something that regulators will allow, in certain situations, to be removed or buried and replaced by a topsoil substitute. When there is a need for a suitable growth medium to support vegetation at a site that has lost its native topsoil due to mining or other earth-moving activities, a wide range of materials can be used as topsoil, including subsoil or selected overburden materials or manufactured soil materials. The Surface Mining Control and Reclamation Act (SMCRA) was the first federal statute to specifically define operations involving the handling, storage, and substitution of topsoil. A wide range of organic and mineral wastes and residual products can be beneficially used for either *in-situ* soil reconstruction or on-site remediation. Similarly, many waste materials can be successfully combined with organic composts to produce commercially viable manufactured topsoils. This paper will review the authors' experience with "topsoil," both in a scientific and practical, applied sense.

Introduction
Topsoil means many things to many people, but to everyone it represents the best part of the soil from a plant-growth perspective. It is often the subject of federal and state regulations and something to be protected and preserved. Topsoil is also something that regulators will allow, in certain situations, to be replaced by a topsoil substitute. When there is a need for a suitable growth medium to support vegetation at a site that has lost its native topsoil due to mining or other earth-moving activities, a wide range of materials can be used as topsoil, including subsoil or selected overburden materials. While regulators may recognize that "Mother Nature knows best" when it comes to topsoil, the regulations allow other materials as substitution for topsoil in certain circumstances. Examples include B or C or even R horizons if soft materials like shales or saprolite meet the chemical and physical requirements. For example, Texas soils are often better after mine reclamation when deeper C horizon materials are used instead of local sodic topsoils (Askenasy et al., 1997). Likewise, in mountainous regions, where the native topsoil may be thin and difficult to recover, the material placed on the top of a reclaimed area may be more appropriately referred to as "cover soil" and may include blasted hard rock spoils, saprolite, decomposed shale, fly ash, or many other fine-grained materials (e.g. water treatment plant

sludge, biosolids, river sediment dredgings, etc.) that are available and do not pose a soil or water quality threat. In general, topsoil substitutes must first be carefully selected to avoid acid- forming or other deleterious materials and to provide sufficient rooting depth and associated water holding capacity. Ideally, these materials will break down mechanically during the replacement activities to a loam or silt loam texture to maximize water-holding capacity. Nutrient deficiencies are usually readily met via routine fertilization.

Topsoil substitutes made primarily from materials on-site minimize the costs associated with transport of large volumes of imported materials, and in addition, the off-site damage associated with “borrowing” natural topsoil is eliminated. Furthermore, manufacturing “topsoil,” rather than removing it from a borrow area, may offer the advantage of a beneficial use of material that would otherwise need disposal, such as biosolids, fly ash, dredged sediment, etc. Furthermore, many of these residuals may be highly effective at mitigating or minimizing soil phytotoxicity or water quality threats on highly contaminated sites (EPA, 2007).

Concerning soils manufactured from some waste materials, dealing with excesses of soluble salts or other potentially plant growth limiting constituents is more difficult, and many industrial byproducts must be diluted with relatively inert material. Contract specifications in these cases generally include requirements related to the ability of the cover soil to support plant growth, including ranges of essential soil properties such as texture and available nutrients, but not about the materials used *per se* in the cover soil. One potential complication with mixing materials to manufacture “topsoil” may be a patent infringement. Patents have been awarded for manufactured “topsoil” that is composed of mixtures of clay, organic compost, sand, or other materials. However, this has not proven to be a problem in practice. The narrow legal view is that the patent only protects someone making a nearly identical product from exactly the same kind of material, and any deviation from this in materials or mix eliminates that concern.

Topsoil in a retail sense is anything bought by the truckload or in a bag labeled “Topsoil.” To our knowledge, there are no regulations controlling what is sold as topsoil in the US. Commercial topsoil is available from a wide variety of sources, and ranges from native materials removed and trucked from construction sites, to industrial waste products, and to carefully controlled manufactured topsoils. States and localities vary widely in how these materials are regulated. For example, in Virginia, topsoil *per se* is not regulated and labeled, but any product that is offered as a horticultural growing medium, soil conditioner, or soil amendment must be tested, labeled, and periodically inspected. One very successful manufactured topsoil product from Virginia is described in detail in a later section. We have also analyzed a few randomly selected bags of topsoil offered for sale in Illinois and found that overall the fertility and texture were favorable and compared well against high quality Illinois natural topsoil. However, the bags did not identify what the source material was and there was some foreign matter, such as small pieces of plastic and glass, included in the mix. This paper reviews the authors’ experience with “topsoil” both in a scientific and practical, applied sense.

Definitions of "Topsoil"

Topsoil is one of those things that are hard to define, but you know it when you see it. Generally, it is recognized as the surface few cm or more of soil darkened with organic matter, often mechanically and chemically manipulated by farmers to control weeds or enhance desirable plant growth. Oftentimes, its importance is recognized in regards to its superior ability to support plants, thus warranting protection from erosion or other degradation. Various definitions are offered for topsoil. According to Wikipedia (http://en.wikipedia.org/wiki/Topsoil): "Topsoil is the upper, outermost layer of soil, usually the top 2 to 8 inches. It has the highest concentration of organic matter and microorganisms and is where most of the Earth's biological soil activity occurs. Plants generally concentrate their roots in and obtain most of their nutrients from this layer. A variety of soil mixtures are sold commercially as topsoil, usually for use in improving gardens and lawns, or for ideal growing conditions in container gardens, by using potting soil, for example." The standard text used in many university introductory soil classes is The Nature and Properties of Soils (Brady and Weil, 2004). In it, "topsoil" is defined as "The organically enriched A horizon at the soil surface." The Soil Science Society of America, in their Glossary of Soil Science Terms (https://www.soils.org /sssagloss/index.php) defines "topsoil" as: "(i) The layer of soil moved in cultivation. Frequently designated as the Ap layer or Ap horizon. (ii) Presumably fertile soil material used to top-dress road banks, gardens, and lawns." In addition, they define "surface soil" as: "The uppermost part of the soil, ordinarily moved in tillage, or its equivalent in uncultivated soils and ranging in depth from 7 to 25 cm. Frequently designated as the plow layer, the surface layer, the Ap layer, or the Ap horizon."

These definitions are not particularly technical, a deficiency not mitigated in the more technical literature. For example, the field soil scientist bible, Soil Taxonomy (ftp://ftp-fc.sc.egov.usda.gov/NSSC/Soil Taxonomy/tax.pdf), does not include the term "topsoil" nor is "A horizon" defined. However, it does define the Epipedon, a Diagnostic Surface Horizon: "The epipedon (Gr. epi, over, upon, and pedon, soil) is a horizon that forms at or near the surface and in which most of the rock structure has been destroyed. It is darkened by organic matter or shows evidence of eluviation, or both. An epipedon is not the same as an A horizon. It may include part or all of an illuvial B horizon if the darkening by organic matter extends from the soil surface into or through the B horizon."

The take home message is that topsoil is a common sense, lay term, that is not well defined anywhere, and is roughly synonymous with epipedon, or A or Ap horizon. It forms in place via pedogenesis over the course of several scores to several thousands of years, supports most of the biological activity in the soil ecosystem, and provides mechanical support and nutrients to plants. Removing it and placing it in another location may alter some of its desirable characteristics such as its generally favorable granular structure. Any other "soil material" intentionally placed at the surface might better be termed "cover soil" or "surface soil," or manufactured topsoil, and not "topsoil" in the natural sense, but even that material may or may not be the subject of reclamation or other regulations. What is in the bags labeled "topsoil" at Walmart or other retailers is anybody's guess.

Evaluation of Soil Reconstruction Material for Drastically Disturbed Areas

Evaluation of soil material for use as soil in reclamation of disturbed areas is included in the NRCS Soil Interpretation Guide (http://www.itc.nl/~rossiter/Docs/NRCS/620nsh.pdf). When the soil materials are properly used in reconstruction, a rating of good means that vegetation is relatively easy to establish and maintain, that the surface is stable and resists erosion, and that the reconstructed soil has good potential productivity. Material rated fair can be vegetated and stabilized by modifying one or more properties. Topdressing with better material or applications of soil amendments may be necessary for satisfactory performance. Material rated poor has such severe problems that revegetation is very difficult and costly.

What Is Topsoil Worth?

Soil erosion is a big concern all over the world because loss of topsoil changes the capacity of the soil to function and restricts its ability to sustain future uses. Erosion, like surface mining or urban development, or other anthropogenic disturbance, removes or redistributes topsoil, the layer of soil with the greatest amount of organic matter, biological activity, and nutrients. The ability of a plant community to recover after topsoil is lost is restricted. The NRCS estimated the value of in place topsoil in terms of 1997 dollars (Table C3). This is a crude evaluation and does not include the full cost of sedimentation or full cost of reclamation of an area that has lost its topsoil (Figure C1).

Table C1. Soil reconstruction material for drastically disturbed areas.

Property	Limits			Restrictive Feature
	Good	Fair	Poor	
1. Sodium adsorption ratio	<4	4-13	>13	Excess sodium
2. Salinity (mmhos/cm)	<8	8-16	>16	Excess salt
3. Soil reaction (pH, 0-40")	5.0-8.5	4.0-5.0	<4.0	Too acid
3a. Soil reaction (pH, >40")	---	<4.0	---	Too acid
3b. Soil reaction	---	---	>8.5	Too alkaline
4. Available water capacity (in. /in.)	>0.10	0.05-0.10	<0.05	Droughty
5. Erosion factor (k)	<0.35	>0.35	---	Erodes easily
6. Wind erodibility group	---	---	1, 2	Soil blowing
7. Texture	---	SCL, CL, SiCL	C, SiC, SC	Too clayey
7a. Texture	---	LCoS, LS, LFS, LVFS	CoS, S, FS, VFS	Too sandy
8. Weight % 3-10"	<25	25-50	>50%	Too cobbly
8a. Weight % >10"	<5	5-15	>15	Too stony
9. Layer thickness (in.)	>40	20-40	<20	Thin layer
10. Organic matter (%)	>1	0.5-1.0	<0.5	Low fertility
11. Clay activity (CEC/clay)	>0.24	0.16-0.24	<0.16	Low fertility
12. Calcium carbonate eq. (%)	<15	15-40	>40	Excess lime

Source: http://www.itc.nl/~rossiter/Docs/NRCS/620nsh.pdf

Bagged Retail Topsoils

Bagged topsoil is available seasonally in many locations in 40 lb. (18 kg) bags. To the best of our knowledge, there are no legal definitions of topsoil, or regulations about what is sold in bulk as topsoil off of trucks, or in bags labeled "Topsoil." We analyzed material in triplicate from bags of three brands of "topsoil" purchased at various locations in central Illinois. The bags did not list their ingredients, but they appeared to be made up of a mixture of actual soil material plus some organic compost-like material. There are no regulations in Illinois concerning bagged topsoils, and as far as we know, this situation is typical. The physical analyses of the topsoils indicated that the texture varied within the brands of topsoil. The overall texture class from all samples was a desirable loam (Table C4). Sand contents ranged from 16-67%, silt from 17-55%, and clay from 16-29%, all within a reasonably good range.

Soil fertility of the bagged topsoils was generally comparable to a grab sample of a typical east central Illinois natural topsoil (Table C4). The cation exchange capacity (CEC), pH, soil organic matter (SOM), and extractable S, P, Ca, Mg, K, Fe, were all higher than the reference natural soil. The extractable Na is higher in the bagged topsoil, but probably not enough to be a concern.

Table C2. Estimated value (1997 dollars) of topsoil in place.

Item	Cost/ton
Cost by the bag	$40 - $80
Cost by the truckload	$15
Cost to replace soil functions and remedy off-site damage	$19*
Cost of erosion to downstream navigation	$0 - $5
Cost to human health	$3
Cost to return soil to its original, non-eroded condition	Priceless

Source: http://soils.usda.gov/sqi/concepts/soil_organic_matter/som_value.html

Table C3. Texture of bagged topsoil.

Topsoil Bag	Class[1]	Sand	Silt	Clay	VCoS	CoS	MS	FS	VFS	CoSi	FSi
BRN A	CL	26	46	28	2	4	6	9	5	24	22
BRN B	SiCL	16	55	29	1	3	4	4	3	28	27
BRN C	CL	22	50	28	2	4	6	6	4	26	24
Mean	CL	21	50	28	2	4	6	7	4	26	24
GRN A	L	42	41	17	0	1	3	20	18	28	13
GRN B	L	38	42	20	0	1	3	15	19	27	15
GRN C	L	33	48	19	0	0	1	9	23	32	16
Mean	L	38	44	19	0	0	2	14	20	29	15
RED A	FSL	67	17	16	1	2	15	36	12	8	9
RED B	L	29	45	26	2	7	14	5	2	20	25
RED C	SL	65	17	18	1	2	36	25	2	6	11
Mean	SL	54	26	20	2	3	22	22	5	11	15
Overall Mean	L	38	40	22	1	3	10	14	10	22	18

1. Analyses by the hydrometer method (Gee and Bauder, 1986).

Performance parameters of a suitable growing media, or topsoil substitute, based on chemical properties include: a) meeting plant nutrient requirements over the course of a growing season and in successive years; b) having no extremes of nutrient content or pH that are either phytotoxic (excessive) or deficient; and c) do not produce plants that contain potentially excessive levels of toxic elements. Soil materials with excessive levels of undesirable chemical properties should be excluded. Low pH levels are easily corrected with lime. Unusually high pH is more difficult to deal with, but can be corrected with sulfur and other amendments. Deficiencies in nutrients can be eliminated with amendments (bulk fertilizers).

Ideal texture of manufactured topsoils would be “loamy” providing good soil moisture holding capacity (Figure C1). Compost materials may consist of on-site or imported, properly composted plant materials (bark, sawdust, shredded leaves, municipal chipped plant debris) and/or composted biosolids that meet EPA Part 503 Grade A “exceptional quality” requirements (free of pathogens and odors). Sawdust may not be used alone, and when used with other organic materials must be free of arsenic and chromium often used in pressure-treated lumber. All organic materials must be properly composted and screened to less than 1 in. (2 cm), and free of any foreign materials such as plastics, metal fragments, and concrete fragments, a potential problem with urban-sourced compost.

In general, topsoil on a landfill cover must meet contradictory requirements, it must meet surface and slope stability requirements while minimizing erosion and water infiltration, and at the same time support healthy vegetation. This is a tall order for any soil.

Table C4. Soil fertility[1] of bagged topsoil; means of four samples per bag.

Sample	CEC	pH	SOM	S	P	Ca	Mg	K	Na	B	Fe	Mn	Cu	Zn	Al
			%	------------------------------- Extractable (mg kg^{-1}) ---------------------------											
GRN	19	7.8	5.8	44	127	2,583	470	807	84	1.2	333	67	3	9	48
BRN	36	6.7	9.2	840	698	5,729	721	388	144	4.9	265	53	5	48	178
RED	23	7.8	10.0	107	238	2,571	706	1,354	112	1.8	298	31	2	10	63
Overall Mean	26	7.4	8.3	330	354	3,627	632	850	113	2.7	299	50	3	22	96
Typical Illinois Mollic Epipedon	18	5.9	4.0	25	26	2,380	341	178	12	0.5	130	64	2	3	441

1. Analyses done by Brookside Labs, Inc. Mehlich III weak acid extractions, water pH, CEC by summation.

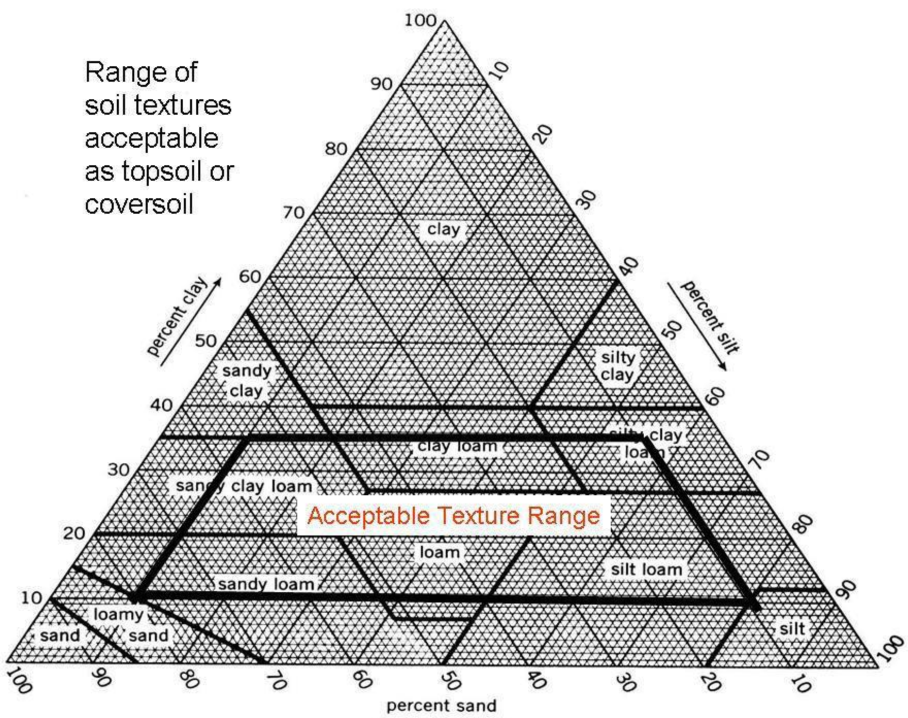

Figure C1. Acceptable texture ranges for material used as topsoil or cover soil.

Case Studies
Typically, manufactured topsoils can be made from low cost, readily available materials including native soil with added materials such as slag, ash, and organic materials with added lime or fertilizer if necessary. The organic materials may include chipped trees and brush from land clearing operations, biosolids, straw, sawdust, etc. to add organic matter.

The “ideal soil” for most turf establishment and landscaping applications is loamy in texture to ensure adequate water holding and aeration without being sticky and plastic when handled and graded. Beyond that, the soil should be moderate in pH (between 6.5 and 7.5) to ensure maximum beneficial biological activity, and moderate to high in plant available nutrients such as calcium (Ca), magnesium (Mg), potassium (K) and phosphorus (P). Good topsoils contain small but adequate amounts of plant essential micronutrients like iron (Fe) and copper (Cu), but should also be low in soluble salts and sodium (Na) which can damage soil structure and harm plants. Finally, the ideal soil will contain approximately 3 to 6% organic matter that serves as a long-term source of plant nutrients (especially nitrogen-N), maintains biological activity, and greatly enhances physical properties such as water holding. Perhaps most importantly, the ideal soil for turf and landscaping applications will be consistent over time in all of the above properties that so that the user will not have to “fine tune” establishment and management protocols for each batch of soil received.

The most successful manufactured topsoil product to date in Virginia and the mid-Atlantic region is the Greene topsoil product manufactured by Luck Stone from granitic saprolites, paper mill compost, and mineralized igneous rock dust at their Greene mine just north of Charlottesville. This topsoil provides balanced levels of plant available micronutrients (e.g. B, Cu, Fe, Mn, and Zn).

<u>Dredged River Sediment as Topsoil Substitute</u>
Sediment removed from Lower Peoria Lake on the Illinois River provided topsoil for final vegetative cover on the clay cap of the Pekin Landfill in Central Illinois. The project also benefited two nearby marinas by removing sediment from their access channels. The sediment deposits in the lake are over ten feet deep near the commercial navigation channel, making it possible to load barges directly with a barge-mounted crane (Figure C2-A). The sediment was the consistency of toothpaste and was placed on deck barges for a six mile (9.6 km) trip to a downstream dock. From there it was loaded into semi-trucks with a hydraulic clamshell excavator. The trucks traveled 17 miles (27 km) to the landfill. Normal trailers with tight sealing gates were used and spillage and leaking from the trailers was not a problem. Once there, it was end-dumped onto the cap (Figure C2-B), and if necessary, pushed into place with a bulldozer. The material stayed in place without containment and was left in a stockpile for later distribution over the cap. The sediment was placed in September of 2007, too late for grass seed to become well established. It dried and cracked over the next few months (Figure C2-C) and freezing and thawing cycles hastened the development of soil structure. By spring, the upper layer was granular to a depth of three to six inches (7.5 to 15 cm) and had not experienced excessive erosion. Planted annual rye and volunteer weeds germinated and the sediment stockpile was quickly vegetated. Soil formation continued through the summer with

granular material filling desiccation cracks around massive polygons. Figure C2-D shows the contrast between the sediment pile and an adjacent landfill cap in August of 2008.

The Banner Marsh State Fish and Wildlife Area largely consists of pre-law strip-mined land adjacent to the Illinois River. In July of 2004, two barge loads of sediment removed from Lower Peoria Lake were placed on a field with very poor soil planted in alfalfa. The material was shipped about 20 miles (32 km) by barge and then loaded on semi-trucks for the remaining five miles (8 km). Figure C3-A shows the consistency of the material as it was loaded into the trailers. There were no issues with spillage on roads. At the site, the sediment was dumped in adjacent rows on a field with the crown of the row 12 to 18 in. (30 to 45 cm) deep. Within a month, the sediment had largely dewatered and formed polygons (Figure C3-B). The material was not planted. By fall, soil formation was progressing as polygons cracked due to wetting and drying. By spring, freezing and thawing had largely reduced the polygons to granular material (Figure C3-C). The field was left unplanted again in 2006 and it supported volunteer plants. In the spring of 2006, it was disked and planted in sunflowers to provide a food plot for doves and other wildlife. Figure C3-D shows the immature sunflowers adjacent to the alfalfa on the untreated portion of the field. The sediment developed good soil structure and performing as an excellent topsoil.

Figure C2. Sediment application as a topsoil substitute at Pekin, Ill., Landfill: A, clam shell bucket loading Peoria Lake sediment onto a deck barge; B, stockpiling sediment on top of Pekin Landfill clay cap; C, drying sediment one month after placement; D, volunteer vegetation thriving on sediment, unvegetated foreground is landfill clay cap, one year later.

Figure C3. Sediment application to Banner Marsh State Fish and Wildlife Area: A, Truck receiving sediment from barge for transport to Banner Marsh pre-law strip mine area; B, Sediment drying one month after placement: C, frost shattered sediment polygons the following spring; D, Planting of sunflowers thriving on sediments after tillage, foreground is untreated.

Conclusions

Topsoil is universally recognized as vital in ecosystem health, landscape hydrology, and revegetating disturbed lands including abandoned industrial areas, landfills, mined lands, and lawns in urban areas. However, topsoil presents conflicting requirements and goals. The common practice of borrowing it from one place to restore another creates a topsoil deficit in the borrow area, while requiring expensive transport of large amounts of the dense material. Placement of topsoil often involves heavy machinery that compacts it to the detriment of plant growth. Compacted soils have been identified as the limiting factor in reclaiming prime farmland mine soils in Illinois (Dunker et al. 1995). Ironically, trees growing on mine soils often do better where soils have not been replaced, again due to compaction (Gorman et al., 2002). A related problem often associated with topsoil application is the lack of appreciation of the subsoil's importance on water supply to plants. Because of the expense, topsoil is often applied in a thin layer over compacted or scalped surfaces. This is especially true in urban and suburban developments (Craul, 1999).

Sediment will likely become an increasingly important source of soil material and as a topsoil substitute for landscaping, restoration, and redevelopment as dredging and handling options become more efficient. The nation's reservoirs and waterways hold vast quantities of sediment, much of it fine grained and relatively uncontaminated. Removing the sediment realizes recreational and ecological benefits, restores water storage capacity, and can provide soil material that is currently a resource out of place. When a planned dredging project can be matched with a soil placement project, both projects may benefit economically. In locations where it can be delivered by barge, it also keeps thousands of trucks from moving soil over urban highways and through neighborhoods. The technology exists to ship wet or dry sediment to areas needing fine-grained material by rail or by slurry pipelines. In Illinois the authors have used sediment as topsoil material in several studies and demonstration projects including moving sediment 165 miles (270 km) for a lakefront park in Chicago (Marlin, 2004, Marlin and Darmody, 2005a; 2005b). The sediment is from the Illinois River and is for the most part eroded from farmland and stream banks. The sediment was quite similar to native Drummer-Flanagan topsoil and performed well in greenhouse and field studies. It has also been mixed with biosolids and compost (Darmody, et al, 2004; Kelly et al, 2007) and used as an amendment on sandy soil. The Great Lakes Commission maintains an extensive bibliography on the beneficial use of sediment (Great Lakes Commission, 2004).

When it comes to revegetating a disturbed site, topsoil, or a high quality topsoil substitute, in sufficient thickness and appropriate density is paramount in achieving success. No matter where it comes from, or what you call it, the upper skin of the earth is vitally important in maintaining a healthy, functioning ecosystem that we both love to look at and depend on for water, fiber, and food.

Appendix D. Analysis of Sediment Core Samples Collected by the Illinois State Water Survey (ISWS) from the Illinois River Near Peoria[1]

Table D1. Agronomic characterization of chemistry of ISWS core samples.

ISWS Core Sample	Depth[2] (cm)	TEC	pH	% SOM	Mehlich-3 Extractable (ppm)													Total %		
					S	P	Ca	Mg	K	Na	B	Fe	Mn	Cu	Zn	Al	Mo	C	N	C:N
194 Farm Creek	7-87	21	7.5	0.6	105	45	3798	191	32	27	0.7	374	61	1.4	5	36	0.11	1.8	0.1	18
194 Farm Creek	127	16	7.3	0.2	35	14	2975	143	23	20	0.5	278	93	1.1	2	7	0.07	1.2	0.1	12
194 Farm Creek	167-207	30	7.6	2.7	206	60	4868	563	114	44	1.2	378	91	4.4	36	231	0.13	3.2	0.1	32
195 (WP11)	7-247	37	7.4	4.4	305	130	5905	762	161	71	1.2	303	75	7.0	78	320	0.19	3.8	0.3	13
196 (WP9)	27-67	39	7.5	4.5	413	93	6281	829	177	84	1.1	290	91	7.0	46	251	0.18	4.0	0.3	13
196 (WP9)	107	36	7.4	5.4	586	38	5823	729	147	62	1.1	333	73	4.2	44	366	0.17	4.1	0.3	14
196 (WP9)	147	35	7.5	5.1	417	37	5576	772	156	53	1.1	332	75	2.8	31	433	0.14	3.7	0.3	12
196 (WP9)	187	44	7.9	0.7	42	12	8125	387	63	21	0.6	245	42	3.3	2	12	0.03	3.3	0.1	33
197 (WP7)	27	40	7.5	4.6	339	78	6410	799	175	90	1.0	286	82	6.2	41	274	0.15	3.8	0.3	13
197 (WP7)	67	37	7.4	5.3	390	143	5914	818	138	58	1.2	289	70	7.7	89	392	0.18	4.1	0.3	14
197 (WP7)	107	125	8.0	3.9	89	10	23372	933	43	35	0.8	204	145	1.3	2	11	0.07	12.0	0.2	60
197 (WP7)	147-227	42	7.9	1.9	80	19	7569	458	70	24	0.8	295	123	3.3	2	36	0.09	4.4	0.1	44
198 (EP6)	7-47	39	7.5	4.4	479	126	6326	833	166	85	1.0	281	68	6.0	51	272	0.19	4.0	0.3	13
198 (EP6)	87	32	7.5	21.7	360	32	4948	813	60	61	1.8	280	7	2.0	4	92	0.16	11.6	0.9	13
198 (EP6)	127-147	52	7.4	14.0	143	23	8985	856	67	60	1.5	218	29	3.3	4	88	0.17	11.0	0.8	14
198 (EP6)	167-247	33	7.9	1.8	51	13	5848	413	66	29	0.7	306	87	3.8	2	54	0.11	4.4	0.1	44
199 (EP5)	7-47	36	7.5	4.2	361	112	5717	745	162	69	1.1	291	74	7.9	75	329	0.23	3.8	0.3	13
199 (EP5)	87-207	34	7.4	5.8	399	38	5507	661	138	43	1.2	330	63	3.7	34	375	0.18	4.0	0.3	13
199 (EP5)	247	25	7.8	1.3	79	27	4432	344	63	24	0.8	360	67	2.9	5	55	0.14	2.9	0.1	29
200 (EP4)	7-47	39	7.4	4.4	333	106	6224	805	179	89	1.1	281	70	7.1	53	338	0.21	3.8	0.3	13
200 (EP4)	87-247	41	7.3	4.7	446	124	6873	767	164	62	1.3	292	85	7.8	95	440	0.22	3.1	0.3	10

1. Unpublished data collected by the Illinois State Water Survey and in unpublished report, Darmody 2006a. Core locations shown in Figure 10.
2. Two cm of sediment were taken every 40 cm of core length. Similar contiguous sub-samples were combined. Because the water-sediment interface was difficult to define at the top of the core, cores were measured from the bottom, and the topmost sub-sample may be either 7 or 27 cm from the top of the core. For example, core 194 has sub-samples at 6-8 plus 46-48 plus 86-88 cm combined into the first analytical sample, the second analytical sample is from 126-128 cm deep in the core, and the third analytical sample is 166-168 plus 206 -208 cm combined. (Unpublished data collected by the Illinois State Water Survey).

Table D2. DTPA extractable metals from ISWS core samples.

ISWS Sample	Depth (cm)	DTPA Extractable (ppm)					
		As [1]	Cd	Cr	Pb	Ni	Se
194 Farm Creek	7-87	< 0.0312	0.0468	< 0.0312	1.03	0.136	< 0.0625
194 Farm Creek	127	< 0.0312	0.0240	< 0.0312	0.60	< 0.125	< 0.0625
194 Farm Creek	167-207	0.0486	0.6421	0.0324	6.10	1.892	< 0.0625
195 (WP11)	7-247	0.1294	0.0213	0.0446	11.69	4.138	< 0.0625
196 (WP9)	27-67	0.0810	0.0235	< 0.0312	7.90	1.748	< 0.0625
196 (WP9)	107	0.0588	0.4887	< 0.0312	12.65	2.475	< 0.0625
196 (WP9)	147	0.0491	0.3278	< 0.0312	7.59	1.609	< 0.0625
196 (WP9)	187	< 0.0312	0.1080	< 0.0312	0.90	0.152	< 0.0625
197 (WP7)	27	0.0727	0.0204	< 0.0312	8.18	1.713	< 0.0625
197 (WP7)	67	0.1455	0.0236	0.0649	15.98	6.189	< 0.0625
197 (WP7)	107	< 0.0312	0.0943	< 0.0312	0.24	0.585	< 0.0625
197 (WP7)	147-227	< 0.0312	0.1099	< 0.0312	1.48	0.537	< 0.0625
198 (EP6)	7-47	0.1160	1.4144	0.0388	11.88	4.239	< 0.0625
198 (EP6)	87	< 0.0312	0.2452	< 0.0312	1.44	1.212	< 0.0625
198 (EP6)	127-147	< 0.0312	0.2897	< 0.0312	1.61	1.116	< 0.0625
198 (EP6)	167-247	< 0.0312	0.1102	< 0.0312	1.01	0.406	< 0.0625
199 (EP5)	7-47	0.1152	1.8260	0.0538	13.93	4.375	< 0.0625
199 (EP5)	87-207	0.0521	0.4105	< 0.0312	10.44	1.533	< 0.0625
199 (EP5)	247	< 0.0312	0.1160	< 0.0312	1.11	0.359	< 0.0625
200 (EP4)	7-47	0.0730	1.2140	0.0354	9.25	1.810	< 0.0625
200 (EP4)	87-247	0.1435	2.4063	0.0660	15.89	3.001	< 0.0625

1. Values below minimum detection limit (MDL) indicated as < MDL. (Unpublished data collected by the Illinois State Water Survey. Core locations shown in Figure 10.)

Table D3. Physical properties of ISWS core samples.

ISWS Sample	Depth (cm)	Property [1]				
		Munsell Color	USDA Texture	Consistence	Penetration	Notes
194 Farm Creek	7-87	10YR 4/3	Sand	ML	-	medium sands, no gravel
194 Farm Creek	127	2.5Y 4/3	Sand	ML	-	medium sands, no gravel
194 Farm Creek	167-207	2.5Y 3/1	SiCL	Soft	Too soft	15% fine sand
195 (WP11)	7-247	5Y 2.5/2	SiCL	Fluid	-	Almost no sand, very uniform
196 (WP9)	27-67	5Y 2.5/1	SiC	liquid	-	No sand
196 (WP9)	107	5Y 2.5/1	SiC	liquid	-	No sand
196 (WP9)	147	10Y 2.5/0	SiC	soft	-	No sand
196 (WP9)	187	2.5Y5/2	L	soft	-	-
197 (WP7)	27	5Y2.5/2	SiL	Liquid	-	no sand
197 (WP7)	67	5Y2.5/1	SiCL	very soft	-	no sand
197 (WP7)	107	5Y2.5/1	SL	very soft	-	70% sand
197 (WP7)	147-227	2.5Y4/1	SiCL	firm	-	no sand
198 (EP6)	7-47	2.5Y3/1	SiL	Liquid	Liquid	
198 (EP6)	87	10YR2/1	MPt	Spongy	Soft	
198 (EP6)	127-147	10Y3/0	SiCL	Soft	-	
198 (EP6)	167-247	5Y3/1	SiC	Soft	0.1 kg/cm^2	
199 (EP5)	7-47	5Y2.5/2	SiCL	liquid	-	no sand
199 (EP5)	87-207	5Y2.5/1	SiCL	very soft	-	no sand
199 (EP5)	247	5Y5/1	SL	VFR	-	
200 (EP4)	7-47	2.5Y3/2	SiL	Liquid	-	no sand
200 (EP4)	87-247	5Y2.5/1	SiCL	very soft	-	no sand

1. Key: Texture: L=Loam; SiL=Silt Loam; SiCL=Silty Clay Loam; SiC=Silty Clay; SL=sandy loam; MPt=mucky peat. Consistence: VFR=very friable; ML=moist loose. All analyses are field estimates. Core locations shown in Figure 10.

Appendix E. Properties of Sediments Used at Chicago USX Former Industrial Site

Table E1. Particle size of sediment samples collected at the USX sediment site, fall 2012.

USX Sample	Color	Texture Class	% >2mm*	Sand	Silt	Clay
1	Black	SiCL	0.7§	1	72	27
3	Black	SiCL	-	1	63	36
6	Black	SiCL	-	0	64	36
8	Black	SiC	0.2§	14	42	44
10	Mixed	SiCL	-	16	51	33
14	Yellow	SiL	0.4†	25	53	22
15	Mixed	SiCL	0.0	12	55	33
16	Black	SiC	0.6§	6	44	50
18	Black	SiC	0.2	2	43	55
20	Mixed	SiCL	0.5†	9	63	28
21	Mixed	CL	12.2†	27	44	29
22	Mixed	SiC	0.5†	6	50	44
23	Mixed	SiCL	0.0	4	57	39
24	Black	SiCL	-	13	57	30
25	Black	SiC	0.0	6	40	54
26	Yellow	SiCL	0.3	5	67	28
27	Black	SiC	0.0	8	50	42
28	Black	SiCL	5.7†	18	47	35
31	Black	SiC	0.4§	13	42	45
33	Yellow	SiCL	0.6†	5	67	28
34	Mixed	SiL	0.3†	17	60	23
35	Black	SiC	0.0	3	49	48
36	Black	SiC	0.0	5	47	48
		Maximum		27	72	55
		Minimum		1	40	13
		Average		10	54	36

* Material > 2mm is termed as coarse fragments in this case they include; § fingernail nail clams; † gravel. Much of the sand detected was fine sand.

Table E2. Texture of USX sediment samples averaged by color.

Color	Sand	Silt	Clay	Texture Class
Black	7	51	42	Silty Clay
Mixed	13	57	30	Silty Clay Loam
Yellow	13	62	30	Silty Clay Loam

Table E3. Particle size of samples from buckets of sediments collected at the USX sediment site.

Barge	Texture Class	% Sand	% Silt	% Clay
AT 510B	SiCL	3	70	27
XL 153	SiL	4	71	25
XL 164	SiCL	3	70	27
AT 505B	SiL	2	75	23
AT 510B	SiCL	2	70	28
AT 519B	SiL	16	60	24
XL 163	SiL	3	74	23
	Max	16	75	28
	Min	2	60	23
	Avg.	5	70	25

Table E4. DTPA extractable metals from USX sediment bucket samples.

Bucket	Barge	DTPA Extractable (ppm)					
		As	Cd	Cr	Pb	Ni	Se[1]
BUC-1	AT 510B	0.1097	0.0207	0.0569	15.5250	4.7106	< 0.0625
BUC-2	XL 153	0.0957	0.0231	0.0486	10.3750	2.1960	0.0707
BUC-3	XL 164	0.0818	0.0230	0.0475	11.2500	3.0006	< 0.0625
BUC-4	AT 505B	0.0961	0.0208	0.0596	17.4000	5.2226	< 0.0625
BUC-5	AT 510B	0.0881	1.7765	0.0499	12.5000	3.8287	< 0.0625
BUC-6	AT 519B	0.0787	0.0206	0.0439	10.6125	2.4339	< 0.0625
BUC-7	XL 163	0.0851	0.0215	0.0501	13.2000	3.9082	< 0.0625
Max		0.11	1.78	0.06	17.4	5.2	-
Min		0.08	0.02	0.04	10.4	2.2	-
Avg.		0.09	0.27	0.05	13.0	3.6	-

1. Values below minimum detection limit (MDL) indicated as < MDL.

Table E5. Agronomic characterization of chemistry of sediment samples collected at the USX site, fall 2012.

USX Sample	meq/100 g TEC	pH	% SOM	Extractable (mg/kg)											
				S	P	Ca	Mg	K	Na	B	Fe	Mn	Cu	Zn	Al
1	32.1	7.4	4.0	442	74	4,827	707	161	80	1.2	421	48	11.7	99.2	376
6	33.5	7.5	3.8	269	58	4,985	758	175	104	1.2	439	70	6.1	65.1	253
8	26.7	7.6	2.9	180	42	4,086	561	118	59	0.9	521	71	5.4	37.0	249
10	29.8	7.8	2.8	152	29	4,193	872	98	64	1.0	530	52	1.3	12.0	257
14	55.1	8.2	0.7	14	8	9,675	566	44	32	0.1	216	60	3.3	1.8	6
15	27.6	8.0	1.5	54	32	4,046	714	85	52	0.7	485	70	4.2	5.6	133
16	28.8	7.6	3.0	227	38	4,229	703	132	76	1.0	532	64	3.5	43.5	351
18	36.4	7.0	9.0	218	29	5,127	1,022	112	83	1.4	421	19	1.8	5.0	304
20	91.3	8.0	1.5	34	9	16,380	719	63	36	0.4	199	90	3.8	4.5	6
21	36.6	8.1	2.3	208	26	5,546	851	129	54	1.1	426	142	3.5	23.2	548
22	27.7	7.7	3.4	87	31	3,754	882	101	66	1.0	523	45	1.4	14.7	143
23	25.6	8.1	1.5	31	24	3,922	569	84	44	0.5	458	78	4.0	2.8	34
24	27.3	7.9	2.6	94	40	3,880	777	80	57	0.9	522	79	2.3	14.2	92
25	32.3	7.7	4.5	85	32	4,175	1,168	99	65	1.1	456	26	1.9	8.6	280
26	61.9	8.2	1.1	17	13	10,913	604	61	33	0.3	247	82	4.2	1.9	5
27	27.9	7.8	4.1	25	111	4,394	511	229	19	0.9	402	21	5.3	41.2	223
28	34.5	7.6	5.1	77	301	5,501	594	246	27	1.2	296	74	10.1	74.8	519
31	36.2	7.6	3.2	263	40	5,486	785	162	96	1.1	402	58	7.2	66.2	302
33	67.0	8.2	1.0	11	9	11,850	637	55	41	0.2	175	70	2.7	1.0	5
34	62.1	8.3	0.8	18	3	11,145	506	34	37	0.1	183	71	2.2	0.7	8
35	32.5	7.6	4.1	374	26	4,805	772	181	86	1.0	446	55	3.7	41.3	222
36	30.7	7.5	3.9	266	56	4,612	688	155	78	1.1	412	54	6.2	73.1	196
Max.	91.3	8.3	9.0	442	301	16,380	1,168	246	104	1.4	532	142	11.7	99.2	548
Min.	25.6	7.0	0.7	11	3	3,754	506	34	19	0.1	175	19	1.3	0.7	5
Avg.	39.3	7.8	3.0	143	47	6,251	726	118	59	0.8	396	64	4.4	29.0	205

Table E6. Agronomic characterization of chemistry of sediment samples collected at the USX site, fall 2012, average values by color.

Color	**meq/100 g**	**pH**	**%**	**Extractable (mg/kg)**											
	TEC		**SOM**	**S**	**P**	**Ca**	**Mg**	**K**	**Na**	**B**	**Fe**	**Mn**	**Cu**	**Zn**	**Al**
Black	32	8	4	210	71	4,676	754	154	69	1.1	439	53	5	47	281
Mixed	43	8	2	83	22	6,998	730	85	50	0.7	401	78	3	9	161
Yellow	61	8	1	14	10	10,813	602	53	35	0.2	213	71	3	2	5

Table E7. Agronomic characterization of chemistry of USX sediment bucket samples.

Barge	**TEC**	**pH**	%	Mehlich-3 Extractable (ppm)													Total (%)		
			SOM	**S**	**P**	**Ca**	**Mg**	**K**	**Na**	**B**	**Fe**	**Mn**	**Cu**	**Zn**	**Al**	**Mo**	**C**	**N**	**C:N**
AT 510B	39	7.5	4.3	434	107	6252	777	171	81	1.3	299	75	5.5	76	342	0.21	1.8	0.2	9
XL 153	42	7.6	4.2	371	105	6660	894	180	92	1.3	300	78	5.2	46	303	0.20	3.8	0.2	19
XL 164	39	7.5	4.3	324	93	6232	822	157	84	1.3	316	72	5.5	46	302	0.20	2.7	0.2	14
AT 505B	39	7.5	4.0	414	99	6408	776	177	85	1.5	297	91	7.6	71	418	0.24	4.6	0.2	23
AT 510B	39	7.5	4.3	408	92	6433	776	179	78	1.4	310	81	5.1	57	314	0.24	1.9	0.2	10
AT 519B	36	7.5	3.7	458	83	5930	712	150	85	1.2	332	70	4.6	49	320	0.23	2.0	0.2	10
XL 163	37	7.5	4.1	351	88	6091	730	163	72	1.2	325	77	4.7	57	296	0.23	2.1	0.2	11
Max	42	7.6	4.3	458	107	6660	894	180	92	1.5	332	91	7.6	76	418	0.24	4.6	0.2	23
Min	36	7.5	3.7	324	83	5930	712	150	72	1.2	297	70	4.6	46	296	0.20	1.8	0.2	9
Avg.	39	7.5	4.1	394	95	6287	784	168	82	1.3	311	78	5.5	57	328	0.22	2.7	0.2	14

Appendix F. Illinois River Dredged Sediment and Biosolids Used as Greenhouse Soil Mixtures

Excerpted from: Diaz, D., R.G. Darmody, J.C. Marlin, G.A. Bollero, and F.W. Simmons. 2009. Trace Metal Bioaccumulation and Plant Growth on Dredged River Sediments and Biosolids Mixtures. Water Air Soil Pollution. DOI 10.1007/s11270-009-0108-7.

Abstract
The objective of this study was to determine if mixtures of dredged sediment with other materials, including biosolids, yard waste compost, and horse manure could serve as topsoil substitutes. The greenhouse experimental design included eighteen different mixtures of those materials. Barley and snapbeans were grown in the mixtures and plant growth, total biomass, and heavy metals content were analyzed along with the physical and chemical properties of the soil mixtures. The experiment was carried out twice using the same soil material. Plants grew well in all treatments, except snapbeans were stunted by salts in unleached biosolid mixtures. The highest overall yield for barley was obtained in the treatment composed of 50% sediment and 50% biosolid. For snapbean, the highest yield was the treatment composed of 70% sediment and 30% biosolid. Heavy metals in plant tissue were within ranges considered normal, except for Mo in snapbean, which is at a level of concern if the plants were used exclusively as animal fodder. Addition of biosolids to sediments decreased Mo plant availability. Compost did not have a significant effect on yield, but did significantly increase Mo uptake in snapbeans. Based on our results with this limited greenhouse experiment, the dredged sediment we used has no inherent chemical or physical properties that would preclude use as topsoil substitute. Adding dredged sediment to unleached biosolids improved plant growth and an optimum ratio of sediments to biosolids might be 80:20 to 70:30 in most situations. However, salt in unleached biosolids might be a problem initially for salt sensitive plants.

Materials and Methods
The experiment was carried out in a controlled environment greenhouse, with two common crops; snapbeans (*Phaseolus vulgaris* var. Bush Blue Lake 274), a legume, and Barley (*Hordeum vulgare*), a small grain. The crops were growth in plastic pots of 5 inches standard and 6 inches standard, respectively, for barley and snapbean. The materials for the soil mixtures included dredged sediment, biosolids, municipal yard waste compost, and horse manure. The dredged sediments were collected from the Peoria Lake portion of the Illinois River. Biosolids were obtained from the Metropolitan Water Reclamation District of Greater Chicago; compost was from the Urbana Illinois municipal yard waste facility, and horse manure from a local farm. Materials were passed through 10 mm mesh sieves to disaggregate clumps and to remove coarse debris that may have been present in the materials.

<u>Methods</u>
The sediment was dredged with a clamshell bucket from Peoria Lake in May 2000, loaded on dump trucks, and transported for storage in a gravel pit near Peoria. About 100 gallons of dried sediment were collected by hand from the pit in November 2002. By then the sediment had

dried to a depth of about 3 ft. (1 m), with signs of weathering, iron oxidation, soil structure formation, etc. due to dewatering and exposure to the environment. Biosolid used was class "A," which passes the regulatory requirements established by the U.S. Environmental Protection Agency (USEPA) (National Research Council, 2001). The materials were mixed on a volume basis, producing 17 mixtures (Table F1). A standard greenhouse soil mix, a mixture of soil, perlite, and compost in equal proportions, served as the control. The soil mixtures were placed in plastic pots and placed on a table in the greenhouse.

Pots were seeded and irrigated as needed. No fertilizers or other amendments were applied; therefore, crop growth depended on the inherent fertility of the mixtures. Pest control was performed as needed. After germination and establishment, the number of plants per pot was thinned to one plant for snapbean and 3 plants for barley. Plant heights were measured periodically and were allowed to grow until flowering (6-7 weeks). Plants were harvested with special care to avoid contamination with soil, since heavy metal content in plant tissue is one of the parameters measured.

The experiment was repeated a second time using the same soil material after removing plant residues, mixing, and relocation into new pots. This allowed leaching of salts that were observed efflorescing on the pots with treatments that included biosolids. The experimental procedure was followed in the same way as with the first batch of samples.

Table F1. Soil mixtures used in experiment, % by volume.

Treatment #	Sediment	Biosolids	Compost	Other†
1	100	0	0	-
2	80	10	10	-
3	60	20	20	-
4	40	30	30	-
5	20	40	40	-
6	70	30	0	-
7	50	50	0	-
8	30	70	0	-
9	50	0	50	-
10	0	100	0	-
11	80	20	0	-
12	70	20	10	-
13	0	0	100	-
14	80	0	0	20 h
15	70	0	10	20 h
16	-	-	-	100 s
17	60	0	10	30 p
18	60	15	15	10 p

† h = Horse Manure, s = Standard Greenhouse Mix, p = Perlite

Three soil sample sets were collected; before planting, after the first harvest, and after the second harvest. Soil texture of the initial materials was determined by hydrometer and sieving. Soil fertility-related characteristics were determined at Brookside Labs of New Knoxville, OH, using standard methodology including Mehlich III extractable extraction (Mehlich, 1984). Oven dried above ground plant mass was used to determine growth and for samples for metal analyses by standard methods (Richards, 1993) as determined by the Illinois Waste Management and Research Center using US EPA Method 3051 (USEPA, 1994).

Statistical Analysis

Data was analyzed using Proc Mixed procedure in SAS statistical program (SAS Institute, 2000). For the analysis, the model used a repeated measured in time (Littell et al., 1996; Littell et al., 2002) using the factor time as repeated to take into account the effect of using the soil repeatedly on the treatments. Unless otherwise noted, significance was reported at $\alpha = 0.05$.

Results

Soil Compaction and Resistance

A concern with utilization of dredged sediments for agriculture is their undesirable propensity to hard-set upon drying, which makes water and plant root penetration difficult. This appears to be only a temporary phenomenon. Because the sediments we used had gone through several drying and wetting cycles and were weathered in the field for a few years, they had developed some soil structure that gave them relatively low soil strength as measured by surface penetration. In general terms soil compaction cannot be considered as a limiting factor for plant growth in any of the mixtures produced for this experiment.

Texture

The mixtures are rather similar in texture; most of them are silt loam or silty clay loam. Pure sediment used is silty clay loam, biosolid is silt, and the compost is silt loam, with the mixtures being intermediate (Table F2). The greenhouse mix is the coarsest because of the added sand. Typical highly productive Mollisols in Illinois have silt loam or silty clay loam textures, which are very desirable for agricultural production, and similar to our mixtures.

Water Holding Capacity

Water holding capacity (WHC) is an important criterion for soil agricultural productivity. The biosolid had the highest water holding capacity as it was enhanced by its high organic matter content. Standard greenhouse mixture and the sediment have similar WHC while the compost has an intermediate value. Compared to a reference silty clay loam Mollisol from Illinois (Drummer, Fine-silty, mixed, superactive, mesic Typic Endoaquolls) (upper 17 cm) the WHC of the treatments are very good.

Table F2. Soil texture of greenhouse mixtures.

Treatment	Class*	Sand†	Silt	Clay	VCoS	CoS	MS	FS	VFS	CoSi	FSi
1	SiCL	4	61	35	-	-	-	-	-	17	44
2	SiCL	5	63	32	-	-	-	-	-	23	40
3	SiCL	7	62	31	-	-	-	-	-	24	38
4	SiL	9	69	22	-	-	-	-	-	40	29
5	SiL	11	70	19	-	-	-	-	-	47	23
6	SiL	4	70	26	-	-	-	-	-	32	38
7	SiL	4	76	20	-	-	-	-	-	44	32
8	SiL	4	83	13	-	-	-	-	-	62	21
9	SiCL	13	60	27	2	3	3	3	2	24	36
10	Si	6	83	11	-	-	-	-	-	76	7
11	SiCL	3	65	32	-	-	-	-	-	25	40
12	SiCL	5	62	33	-	-	-	-	-	24	38
13	SiL	25	53	22	4	4	7	7	2	30	23
14	SiCL	6	59	35	-	-	-	-	-	19	40
15	SiCL	7	62	31	-	-	-	-	-	23	39
16	L	34	44	22	5	8	14	6	1	18	26
17	SiCL	7	61	32	-	-	-	-	-	21	40
18	SiCL	8	63	29	-	-	-	-	-	26	37

* USDA soil texture class names: SiCL, silty clay loam; SiL, silt loam; Si, Silt; L, loam.

† Content (%) of soil separates in USDA texture classes including: VCoS, very coarse sand; CoS, coarse sand; MS medium sand; FS fine sand; CoSi, coarse silt; FSi, fine silt.

Salt Content

The level of soluble salts as contributed by the biosolids was one of the main factors that appears to have had a negative influence on plant growth during the first experimental run. Salt toxicity was a problem only in the first planting because the salts leached out before they were used for the second experimental run. This rapid leaching in a greenhouse, where the excess water caries away the salts onto the greenhouse floor, would not be replicated in the field where the salts can be expected to persist much longer. Salt levels in compost and sediments are low. Unlike sediments from more saline environments, salt is not a concern for plant growth in sediments from the Illinois River. Diluting biosolid with dredged sediment reduced the levels of salts and the associated damage to plants caused by the salts in biosolids.

Soil Chemistry

The pH of the mixtures is related to the proportion of sediment and biosolid. Dredged sediment from the Illinois River has pH values in the range of about 7.5 to 8.1 (Darmody and Marlin, 2002), a result of the presence of free carbonates i.e. mollusk shells, etc. (Darmody et al., 2004). Soil pH in the greenhouse mixtures ranged from 6.0 for 100 % biosolids to 7.6 for 100 % sediment. The higher pH value were for compost, with values up to 8.2, this exceeded the pH values found for dredged sediment.

Biosolids generally have a higher level of plant nutrients than sediments. Sediment organic matter (OM) content was 4.5%, about the same as highly fertile Illinois topsoil. Biosolids had 30% OM, and mixtures of the two had intermediate contents of OM. Compost came in at 17 % OM and treatments with horse manure in the composition had about 7% OM.

Soluble sulfur is also more concentrated in biosolids, 100% biosolids had about 2,826 mg kg^{-1} S, compared to 167 mg kg^{-1} in the sediment and 646 mg kg^{-1} in the control. Soluble S dropped after leaching, down to 1,297 mg kg^{-1} in the 100% biosolid treatment. Levels of phosphorus are also considerably higher in biosolids with values of 2,247 mg kg^{-1}, compared to 144 mg kg^{-1} for sediment, and 318 mg kg^{-1} for the control and 352 mg kg^{-1} for compost. Iron content is higher in sediment while Ca is high in all materials. Levels of Mg, K, Na, B, Mn, Cu, Zn, and Al are higher in biosolids than sediments. Some of the chemicals in biosolids are concentrated from the original sewage, and some may be added as part of the sewage treatment process. Additives to sewage can include clarifying agents, i.e. flocculants, which remove particulate matter from the waste stream so that the resultant effluent is as clean as possible so that it can be discharged into water bodies. Anything left behind ends up in the sludge to become an attribute of the biosolids.

Metal Content

Selected soil mixtures sampled before planting were analyzed for metal content. Metals reported here are equivalent to a total recoverable analysis, which is essentially, but not quite the true total metal content, and is the accepted US EPA method for this type of analyses. Biosolids had higher concentrations of Cr, Ni, Cu, Zn, As, Se, Mo, Ag, Cd, Ba, Pb, and Hg, than the other materials tested (Table F3). In sediments, levels of Mn and Be are higher than the rest of treatments. Levels of Ti, V, and Co were significantly higher in mixture of sediment and horse manure (80%-20%), most likely increased by the addition of horse manure, especially for Ti and V. Levels of metals found in the soil mixtures do not exceeded ceiling concentration limits established in the Guide for Land Appliers on the requirements of the federal standards for the use or disposal of sewage sludge, 40 CFR Part 504 (EPA, 1994). Typical metal contents gleaned from the literature are given in Table C4 for comparison.

Metals in Snapbean Tissue

Trends of heavy metal contents in snapbean tissue are similar to those observed in the soil mixtures; however, this is not true for all elements analyzed. Levels of Ni, Cu, Zn, and As, originally high in the biosolid, are also present in snapbean tissue in high levels (Table F5). Mn and Be, initially high in 100% sediment, were not accumulated in the plant, instead, these elements are in highest concentration in treatments with 100% biosolids. Ti and V, high in soil mixtures with horse manure in the composition, also shows higher concentrations in plants grown on biosolids. No differences among treatments were found in the concentrations of Cr, Ag, Pb, and Hg.

According to published concentrations of trace elements in mature leaf tissues generalized for various species of plants (Kabata-Pendias and Pendias, 1991), most metals analyzed in snapbean tissue are in the range considered normal. However, levels of Mn and Zn observed in plants grown on biosolids are considered excessive. Levels considered excessive for Mo were also observed in plants grown on 100% sediment, 100% compost, the mixture of both (50-50), and sediment mixed with horse manure (80-20).

However, this ratio was not met for any of the snapbean tissues analyzed, including plants grown on the control standard greenhouse mix. This problem is routinely dealt with by the addition of supplements to animal feed.

METALS IN BARLEY TISSUES

Concentrations of metals found in barley tissue are, in general, lower than those in snapbean (Tables F5, F6). Levels of B, Ti, Mn, Ni, Cu, Zn, and As are higher in plants grown on biosolids, Mo and Ag levels are higher in barley grown on compost. High concentration of Ba, V, and Hg were found in barley grown on the mixture of sediment and compost (50-50). No difference between the treatments were found for Cr and Pb. B was found at levels >100 mg kg^{-1} DW in plants grown on 100% biosolids and 100% compost, which can be considered excessive or toxic (Kabata-Pendias and Pendias, 1991; Davis et al., 1978). However, all other elements are within normal levels. Plants grown on 100% compost and the 50-50 mixture of compost-sediment did not meet the minimum ratio Cu to Mo of 2 for ruminants, the rest of treatments show values above the minimum.

SNAPBEAN YIELD

Snapbean yield was measured as the total dry biomass at 6-7 weeks after planting (Table F7). Lower yields were observed for the first harvest in general with a very poor growth and some mortality of the plants in the 100 % biosolids. This is attributed to the high levels of salt in the biosolids. Yields increased in the second harvest particularly in the treatments with high amounts of biosolids. Treatment 10 (100% biosolids) went from the lowest yield in the first harvest to one of the highest in the second harvest. The 100% sediment treatment (Trt. 1) did not change significantly between harvests while the control (Trt. 16) exhibited a small decrease in snapbean yield. Large differences in yields between harvests are primarily due to salt contents; however, small differences can be attributed to slightly different environmental conditions in the greenhouse because the experimental runs were sequential, not simultaneous. Overall, the second snapbean crop out-yielded the first (Table F7).

Yield increase between harvests was also observed in compost treatments, in particular treatment 13 (100% compost). Adding large amounts of fresh organic matter such as horse manure, biosolids, or compost, in some situations, may pose problems for plant growth. In our experiment, in addition to the beneficial effects of salt leaching, decomposition of the organic rich materials during the first growing cycle apparently lead to higher plant growth during the second growth period. This was observed in the mixtures with large amounts of compost, manure, and biosolids, but not in the sediment or control treatments. Considering the treatments with sediments and biosolids only, the treatment with the highest average combined snapbean yield was composed of 70% sediment and 30% biosolid.

Table F3. Total recoverable metal contents of selected soil treatments.

Treatment	Sediment	Biosolid	Compost	Be	B	Ti	V	Cr	Mn	Co	Ni	Cu
	--------------%--------------			-------------------------------------mg kg^{-1}-------------------------------------								
1	100	0	0	1.2 a†	28 d	214 b	43.0 b	65 de	826 a	10.0 ab	50.3 ab	42 e
3	60	20	20	1.2 a	37 dc	256 ab	43.7 b	96 cd	773 ab	9.3 ab	49.3 bc	95 d
6	70	30	0	1.3 a	30 dc	226 b	43.7 b	105 c	800 ab	9.9 ab	51.7 ab	104 d
7	50	50	0	1.4 a	39 dc	201 b	43.7 b	173 b	756 abc	9.8 ab	54.7 ab	202 c
8	30	70	0	1.3 a	41 bc	206 b	41.3 bc	198 b	676 bc	9.3 ab	51.0 ab	236 b
9	50	0	50	1.1 a	36 dc	236 ab	42.7 b	48 ef	746 abc	8.1 bc	38.7 d	37 e
10	0	100	0	0.9 ab	51 ab	189 b	31.0 d	296 a	618 dc	8.5 ab	55.3 a	376 a
13	0	0	100	0.5 b	61 a	256 ab	29.0 b	20 f	520 de	5.5 d	15.0 e	19 ef
14	80	0	20‡	0.8 ab	36 dc	328 a	58.0 a	62 de	753 abc	10.3 a	44.3 c	36 e
16	control			0.5 b	7 e	240 ab	33.3 cd	19 f	470 e	6.4 cd	10.3 e	10 f

Sediment	Biosolid	Compost	Zn	As	Se	Mo	Ag	Cd	Ba	Tl	Pb	Hg
--------------%--------------			-------------------------------------mg kg^{-1}-------------------------------------									
100	0	0	270 d	13.0 a	< 3	0.8 f	1.0 bcd	3.5 cd	190 cd	0.6 a	66 de	0.24 cd
60	20	20	356 c	12.0 a	< 3	2.9 de	5.1 abc	3.6 c	207 c	0.6 ab	78 cd	0.35 c
70	30	0	386 c	13.0 a	< 3	3.2 d	5.6 ab	4.0 c	220 c	0.6 ab	85 c	0.38 c
50	50	0	587 b	12.3 a	2.1 b	7.5 c	4.4 abcd	5.0 b	273 b	0.5 ab	120 b	0.68 b
30	70	0	646 b	11.3 ab	3.1 b	9.9 b	4.5 abcd	5.3 ab	290 b	0.5 ab	126 b	0.74 b
50	0	50	206 d	9.5 b	< 3	0.9 ef	1.0 bcd	2.9 d	163 d	0.5 bc	50 f	0.15 cd
0	100	0	886 a	13.3 a	5.8 a	17.3 a	6.4 a	5.7 a	333 a	0.4 c	160 a	1.24 a
0	0	100	70 e	6.5 c	< 3	0.9 ef	0.1 d	0.4 e	116 e	0.2 d	26 g	0.06 d
80	0	20‡	212 d	12.3 a	< 3	1.0 ef	0.7 cd	3.5 cd	193 cd	0.6 a	59 ef	0.19 cd
control			33 e	5.6 c	< 3	0.4 f	0.2 d	0.2 e	111 e	0.2 d	13 g	0.02 d

† Values in a column with different letters are statistically different.
‡ Horse manure.

Table F4. Typical metal content of surface soils.†

Element	Range	Mean	Element	Range	Mean
	--------mg kg^{-1}--------			-------mg kg^{-1}--------	
As	< 1 - 93	7	Mn	20 - 3000	600
B	2 - 200	80	Mo	0.02 - 5	-
Ba	200 - 1500	675	Ni	< 5 - 150	19
Be	0.04 - 2.54	0.54	Pb	< 10 - 70	26
Cd	0.4 - 0.5	-	Se	< 0.1 - 4	0.3
Co	1 - 70	8	Ti	500 - 10000	3000
Cr	7 - 1500	50	Tl	0.02 - 2.8	-
Cu	1 - 40	9	V	0.7 - 98	-
Hg	0.02 - 1.5	0.17	Zn	10 - 300	50

† Compiled from Kabata-Pendias and Pendias (1992) and Havlin et al. (1999).

Table F5. Total recoverable metal content (mg kg^{-1}) in snapbean tissue for selected treatments.

Treatments		B	Ti	V	Cr	Mn	Ni	Cu	Zn
1	(100-0-0)†	30 c§	16 ab	0.06 bcd	0.34	13 d	3.6 ab	5.1 cd	31 de
3	(60-20-20)	61 b	11 ab	0.06 cd	0.35	19 cd	1.5 b	5.8 bc	43 cd
6	(70-30-0)	39 c	13 ab	0.06 d	0.24	20 cd	2.0 b	5.5 bcd	52 bc
7	(50-50-0)	48 bc	13 ab	0.06 bcd	0.18	44 cd	3.6 ab	6.5 b	58 b
8	(30-70-0)	68 b	17 ab	0.08 ab	0.21	140 b	4.0 ab	6.2 bc	61 b
9	(50-0-50)	97 a	6 b	0.08 bc	0.18	22 cd	4.3 ab	4.4 de	29 def
10	(0-100-0)	117 a	20 a	0.11 a	0.28	433 a	8.0 a	8.6 a	101 a
13	(0-0-100)	106 a	4 b	0.08 abc	0.29	24 cd	0.8 b	2.7 f	17 f
14	(80-0-20‡)	39 c	4 b	0.11 a	0.15	13 d	1.5 b	2.8 f	20 ef
16	control	48 bc	10 ab	0.08 bcd	0.21	95 c	2.1 b	3.2 ef	22 ef
		As	Mo	Ag	Cd	Ba	Pb	Hg	
1	(100-0-0)	0.22 b	15 bc	0.10	0.23 b	11 bc	0.81	0.0036	
3	(60-20-20)	0.19 b	6 cd	0.12	0.19 bc	5 d	0.38	0.0025	
6	(70-30-0)	0.22 b	5 d	0.06	0.19 bc	3 d	0.29	0.0027	
7	(50-50-0)	0.19 b	5 d	0.09	0.14 c	3 d	0.26	0.0017	
8	(30-70-0)	0.23 b	6 cd	0.07	0.14 c	3 d	0.30	0.0022	
9	(50-0-50)	0.30 b	25 a	0.03	0.19 bc	17 a	0.81	0.0020	
10	(0-100-0)	0.71 a	9 cd	0.08	0.24 b	3 d	0.68	0.0033	
13	(0-0-100)	0.21 b	19 ab	0.05	0.05 d	13 b	0.40	0.0013	
14	(80-0-20‡)	0.12 b	13 bcd	0.06	0.35 a	10 bc	0.44	0.0014	
16	control	0.18 b	7 cd	0.06	0.05 d	8 c	0.34	0.0014	

† (%Sediment - % Biosolid - % Compost).
‡ Horse manure.
§ Values in a column with different letters are statistically different.

Table F6. Total recoverable metal content (mg kg^{-1}) in barley tissue for selected treatments.

Treatments		B	Ti	V	Cr	Mn	Ni	Cu	Zn
1	(100-0-0) †	18 b‡	8.4 de	0.11 ab	0.25	12 d	0.60 ab	5.4 def	43 b
3	(60-20-20)	37 b	8.9 de	0.11 ab	0.21	18 d	0.48 ab	6.9 dc	44 b
6	(70-30-0)	20 b	8.2 de	0.05 b	0.24	23 cd	0.51 ab	6.0 cde	46 b
7	(50-50-0)	31 b	10.7 cd	0.06 b	0.30	39 bc	0.73 ab	7.5 bc	64 a
8	(30-70-0)	89 a	13.0 bc	0.05 b	0.21	55 b	0.83 ab	8.9 ab	75 a
9	(50-0-50)	97 a	7.5 e	0.05 b	0.22	13 d	0.61 ab	4.6 ef	32 bc
10	(0-100-0)	108 a	18.7 a	0.11 ab	0.23	79 a	1.18 a	10.5 a	67 a
13	(0-0-100)	105 a	6.4 e	0.16 a	0.24	13 d	0.20 b	3.9 f	31 bc
14	(80-0-20*)	25 b	7.7 e	0.16 a	0.23	12 d	0.39 b	5.9 cde	45 b
16	control	27 b	13.7 b	0.06 b	0.26	89 a	0.42 ab	4.6 ef	21 c
		As	Mo	Ag	Cd	Ba	Pb	Hg	
1	(100-0-0)	0.20 b	1.8 de	0.08 ab	0.7 a	8.5 a	0.32	0.0021 c	
3	(60-20-20)	0.18 b	3.2 bc	0.08 ab	0.7 a	2.4 c	0.23	0.0023 c	
6	(70-30-0)	0.47 ab	3.6 abc	0.05 b	0.7 a	1.4 c	0.30	0.0024 bc	
7	(50-50-0)	0.27 ab	4.2 ab	0.10 ab	0.8 a	1.5 c	0.30	0.0029 ab	
8	(30-70-0)	0.27 ab	3.8 abc	0.06 ab	0.5 b	1.1 c	0.23	0.0032 ab	
9	(50-0-50)	0.20 b	3.2 abc	0.08 ab	0.4 b	9.2 a	0.49	0.0041 a	
10	(0-100-0)	0.64 a	3.8 ab	0.07 ab	0.1 c	0.8 c	0.26	0.0028 ab	
13	(0-0-100)	0.33 ab	4.7 a	0.13 a	0.1 c	8.7 a	0.55	0.0038 ab	
14	(80-0-20*)	0.14 b	2.7 cd	0.10 ab	0.8 a	8.4 a	0.34	0.0027 ab	
16	control	0.13 b	1.1 e	0.09 ab	0.2 c	5.8 b	0.27	0.0031 ab	

† (%Sediment - % Biosolid - % Compost).

* Horse manure.

‡ Values in a column with different letters are statistically different.

Table F7. Yield of plants (g per pot) grown in sediment mixtures, first and second harvest.

Treatment	Barley			Snapbeans		
	First	Second	Both	First	Second	Both
1	1.95 def	2.49 gh	2.22 ef	2.55 abc	2.35 gh	2.46 def
2	2.17 cde	5.01 de	3.59 cd	2.86 a	6.30 abc	4.58 a
3	2.29 cd	5.00 de	3.65 cd	1.60 bcdef	4.84 cde	3.22 bcde
4	1.95 def	7.29 ab	4.62 abc	2.44 abc	6.48 ab	4.46 ab
5	1.67 efg	7.87 a	4.77 ab	1.88 abcde	6.72 ab	4.30 ab
6	2.88 b	6.60 bc	4.74 ab	2.40 abcd	7.03 ab	4.72 a
7	3.43 a	7.56 ab	5.50 a	2.37 abcd	5.68 bcd	4.03 ab
8	2.90 b	6.59 bc	4.75 ab	1.41 def	5.52 bcd	3.47 abcd
9	1.66 efg	2.35 gh	2.01 ef	2.10 abcde	2.25 gh	2.18 ef
10	1.97 def	7.24 ab	4.60 abc	0.64 f	6.91 ab	3.77 abc
11	2.55 bc	7.02	4.78 ab	1.95 abcde	7.43 a	4.69 a
12	2.67 bc	6.52 bc	4.60 abc	2.48 abc	6.06 abcd	4.27 ab
13	1.21 g	3.42 fg	2.31 ef	1.58 cdef	3.48 efg	2.53 cdef
14	1.25 g	3.51 fg	2.38 ef	1.32 ef	3.16 fg	2.24 def
15	1.63 fg	4.28 ef	2.96 de	1.85 bcde	4.56 def	3.20 bcde
16	1.97 def	1.33 h	1.65 f	2.18 abcde	1.56 h	1.87 f
17	1.99 def	1.72 h	1.85 f	2.14 abcde	2.77 gh	2.46 def
18	2.69 bc	6.05 cd	4.37 bc	2.59 ab	6.15 abc	4.37 ab
Mean *	2.16	5.10	-	2.02	4.99	-

† L.S. Means of 5 reps per treatment, values in a column followed by the same letters are not statistically different.
* Overall L.S. Means, first and second harvests are statistically different for both plants.

A ratio of Cu to Mo of 2:1 in forages is the minimum recommended for ruminants diet in order to avoid Cu deficiencies caused by high Mo levels (Molybdenosis) (McBride et al., 2000).

Barley Yield

Barley yield trends were similar to snapbeans, with an increase in the second harvest especially for the treatments with biosolids in the composition; there was also a yield increase for the treatments with compost and horse manure in the mix (Table F7). As with snapbeans, addition of perlite in the composition (treatments 17 and 18) did not increase crop yields.

We attribute most of the yield increase in the second harvest to the leaching and weathering of the mixes, particularly those with biosolids. Barley is also more affected by the level of Nitrogen than snapbean, so as we mention before the C:N ratio in biosolid could contribute to a good amount of N to be release as organic matter is decomposed in the second run. The relative increase in barley yields were not as marked as with snapbean because of the greater salt tolerance of barley. Treatment 7 (50%- 50% sediment-biosolid) produced the highest yield when both growing cycles were included. Similar to snapbeans, standard greenhouse mix (control) produced the lowest yield, most likely because fertilizer was not applied; which is the usual practice with this soil mixture.

Conclusions

In terms of standard agronomic parameters such as plant growth, our results confirm previous work that established that sediments from the Peoria Lakes reach of the Illinois River make excellent topsoil material. Both legume and grass plants grew well in all sediment mixtures and improved the plant growth potential of unleached biosolids. The quantity of biosolids available to mix with sediments is essentially limitless. Chicago alone produces 190,000 dry tons of biosolids per year (Tom Granato, 2004, personal communication). Although sediment tested was well suited as topsoil substitute alone, it may be worth the cost of mixing biosolids with sediments. This could be accomplished in the field with tillage equipment or with soil blending devices. In addition to providing an outlet for some portion of the biosolids produced, combining biosolids with sediment mitigates some of the problem with growing plants directly in sediments or biosolids. Pure sediments may initially have poor physical characteristics, under some field conditions. Pure biosolids have excessive salts that inhibit plant growth, particularly legumes, as evidenced by death of some snapbean plants on 100% biosolids. The sediments may experience improved tilth and higher plant nutrient content under field conditions when mixed with biosolids. The biosolids release less of their load of potentially toxic heavy metals and the injurious salt content is diluted by sediment addition. Mo uptake from sediments is decreased by biosolid addition.

Elevated Mo in some plants grown on pure sediments is not a real problem in most situations where sediments may be utilized as topsoil. The unlikely situation when it may be a problem would be where legumes are grown on pure, unamended sediment as a forage to be fed exclusively to ruminants. Under these conditions, addition of gypsum to the sediment may have a favorable effect on Mo uptake and supplemental dietary Cu should mitigate any potential for Mo toxicity. Under the more likely scenario where sediment is for topsoil in parks, lawns, or other areas where the use is more recreational and less agricultural, it is doubtful if Mo would be important. Direct ingestion by humans of large quantities of legumes grown on pure sediments to the exclusion of other food is difficult to imagine, and Mo toxicity is more of an issue with ruminants than with humans. An optimum sediment to biosolid mix in the field we feel would be about 80:20 to 70:30 sediments:biosolid on a volume basis. This mixing ratio was also shown to reduce uptake of metals by crops, perhaps due to dilution as well as to modifications of soil properties, such as pH.

Appendix G. Dredged Illinois River Sediments: Plant Growth and Metal Uptake

Excerpted from: Darmody, R.G., J.C. Marlin, J. Talbot, C. Stohr, R. Green, and E.F. Brewer. 2004. Dredged Illinois River Sediments: Plant Growth and Metal Uptake in Illinois River Sediments. Journal of Environmental Quality 33: 458-464. DOI:10.2134/jeq2004.4580.

Abstract
Sedimentation of the Peoria Lakes reach of the Illinois River in central Illinois has greatly diminished it. Consequently, a large dredging project has been proposed to improve its wildlife habitat and recreation potential, but disposing the dredgings presents a challenge. Land placement is an attractive option. Previous work in Illinois has demonstrated that sediments are potentially capable of supporting agronomic crops due to their high natural fertility and water holding capacity. However, Illinois River sediments have elevated levels of heavy metals, which may be important if they are used as garden or agricultural soil. A greenhouse experiment was conducted to determine if these sediments could serve as a plant growth medium. A secondary objective was to determine if plants grown on sediments accumulated significant heavy metal concentrations. Our results indicated that lettuce, barley, radishes, tomatoes, and snap beans grown in sediment and a reference topsoil did not show significant or consistent differences in germination or yields. In addition, there was not a consistent statistically significant difference in metal content among tomatoes grown in sediments, topsoil, or grown locally in gardens. In the other plants grown on sediments, while Cd and Cu in all cases and As in lettuce and snap beans were elevated, levels were below those considered excessive. Results indicate that properly managed, these relatively uncontaminated sediments can make productive soils and that metal uptake of plants grown in these sediments is generally not a concern.

Introduction

The Illinois River is a major tributary of the Mississippi River. Prior to major modifications of Midwestern drainage patterns caused by glaciation during the Pleistocene, the lower Illinois River channel was the path of the upper Mississippi River. Consequently, the river is underfit for its valley, and for much of its length the river is sluggish and has a broad flood plain. It drains about 75,000 km^2, flowing for 680 km from the Des Plains River out of Chicago to the Mississippi River. A more recent modification of the river occurred about 100 years ago, when the Chicago Sanitary and Ship Canal was constructed in part to channel the city's waste water away from Lake Michigan by sending it down the Des Plains River and into the Illinois River. At about the same time, navigation projects in the Illinois River were initiated, culminating with the construction of a lock and dam at Peoria designed to pool water for navigation. Over the same period, changes in land use converted much of the Illinois River watershed from natural forests and prairies to the modern mixture of urban and rural uses. Row crops, stream channelization, urban storm water runoff, and other factors have increased erosion and sediment loads to the river.

Sedimentation is a significant problem in lakes and reservoirs anywhere surface water bodies are impacted by soil erosion. Because of rapid sedimentation into Illinois surface water impoundments, removal and utilization of sediment is a concern. Previous work in Illinois has shown that agricultural use of dredged sediments is a possibility (Darmody and Marlin, 2002). Their high fertility and favorable moisture holding capacity are beneficial for plant growth. Similarly, sediments removed from Lake Springfield and from Lake Paradise in central Illinois were shown to have potential for increasing plant growth on eroded soils (Olson and Jones, 1987; Lembke et al., 1983a, b).

The work reported here is in anticipation of the dredging of the Peoria Lakes portion of the Illinois River to restore habitat diversity and recreation (Bhowmik et al., 2000). The project could produce as much as $119x10^6$ m^3 of sediments needing environmentally and economically sound management (Demissie and Bhowmik, 1986). An extensive sampling program recently documented levels of some metals in the sediments as somewhat elevated above background soil levels (Cahill, 2001a). Sediment quality issues typically involve concerns about water pollution or the impact on aquatic ecosystems; but here we are concerned with beneficial agricultural utilization. The fertility and general suitability of sediments to serve as agricultural soils has been demonstrated elsewhere (Darmody and Marlin, 2002), however, there is no long term agricultural track record or clear regulatory tradition of sediment utilization as there is for biosolids (Gaskin et al. 2003; McBride, 1995). The primary intent of this research was to determine suitability of the sediments from the Peoria Lakes region of the Illinois River as a growth medium for selected plants. Secondarily, we wanted to obtain preliminary data on uptake of metals by those plants.

Materials and Methods

<u>Experimental Design</u>

Sediment samples were collected in the Peoria Lakes between Peoria and Chillicothe where the proposed dredging will occur. These included “fresh” and “weathered” sediments. The fresh sediment was collected from the upper 60 cm of sediment where the water was about 75 cm deep in the lake. Weathered sediment was collected at 0-25 cm from an island constructed of dredged sediments by the U.S. Army Corps of Engineers. It is located within the Woodford State Fish and Wildlife Area and was built in 1994. A reference natural topsoil was a mixture of Drummer and Flanagan silty clay loam, common, highly productive topsoils in East Central Illinois. Horticultural grade perlite was added to the materials to enhance aeration and drainage. The mixtures were placed into 15 cm greenhouse clay pots.

Plants grown in sediments in greenhouse pots included: cardinal barley (*Hordeum vulgare*), snap bean (*Phaseolus vulgaris* var. *humillis*), cherry belle radish (*Raphanus sativus*), black seeded simpson lettuce (*Lactuca sativa*), and patio type cherry tomato (*Lycopersicon lycopersicum*). The snap beans were inoculated with the appropriate Rhizobium species. Agronomic parameters measured included germination, dry mass yield, and where appropriate, number of fruit. Plants were watered as needed. Each pot was fertilized with Peters 20-10-20 at a rate of 200 mg kg^{-1} N each week after thinning. After the plants grew for four to five weeks, they were harvested and dried overnight at 60°C to determine dry mass yield. Fresh tomato fruit were used for evaluation of metal uptake, and tomato fruit from residential vegetable gardens in Champaign and Peoria Counties, Illinois served as reference samples. Dried, aboveground portions of the bean, lettuce, and barley plants were also analyzed for total metal content and used in the uptake evaluation. The stems and leaves were not washed, but had little or no visible soil on them. This would more closely mimic a situation where vegetables are eaten right out of a garden. Whole radishes were harvested and the roots washed prior to drying and analysis.

Laboratory Analyses

All laboratory soil analyses followed standard methods as appropriate (Klute, 1986). Extractable nutrients were determined in a Mehlich 3 extracting solution (Mehlich, 1984; Mc Lean, 1982). Metal contents of the materials were by standard methods (USEPA SW846 microwave digestion Method 3051A; USEPA, 1998). Statistical comparisons were done at the $\alpha = 0.05$ level using ANOVA (SAS Institute Inc., Cary, NC, USA).

Results and Discussion

Soil and Sediment Fertility

The Peoria Lake sediments used were typical of the fine-silty textured sediments from that portion of the Illinois River (Darmody and Marlin, 2002; Cahill 2001a), and they were similar to the topsoil used in the experiment. Silt contents were 65, 69, and 62%, and clay contents were 30, 28, and 28% for the topsoil, fresh sediment, and weathered sediment, respectively. The sediments had a water pH of 7.5 and organic matter content of about 2.65%, about the same as the topsoil (Table G1). However, compared to the reference topsoil, the sediments were more fertile. They were higher in exchangeable bases and most extractable nutrients. Although extractable K and Mg were about the same in the sediments as in the topsoil, the sediments had a greater amount of extractable P, Na, and particularly Ca. The weathered sediment had the highest P content, perhaps because large numbers of birds frequented the site. The greater Ca content in the sediments was largely due to biogenic accumulated Ca in the form of mollusk shells. The sediments also had more Na, but not so much as to be an agronomic concern (University of Illinois, 1998). The general conclusion from the soil fertility data is that the sediments have high natural fertility, as good as or better than the naturally fertile and productive top soils of Illinois from which they are largely derived.

Soil Metal Content

Metal levels in sediments from the Illinois River will vary with location in the river and sediment sample depth (Cahill, 2001). The sediments used in this study had total recoverable metal contents typical of Peoria Lake (Table G2) (Cahill, 2001). In general, compared to the topsoil, the sediments had higher levels of most elements measured, particularly Ca and Mg, which are biologically magnified in the sediments by mollusks, etc., and greater concentrations of some of the industry related metals, such as Cd, Zn, and Pb. When compared to the fresh sediment, the weathered sediment had somewhat lower Ca and Mg contents, but was generally somewhat higher in the other elements measured. Concentration of metals in perlite was very low with the exception of Na, K, Ca, and Al. Addition of perlite generally had only a small impact on the total recoverable metal content of weathered sediment. A dilution effect can be assumed because of the lower concentrations shown in the samples with perlite; however, because of the very low density of perlite (~0.03 g cm^{-3}) its effect on a weight basis is small. Na is an exception; it is increased by the addition of perlite. However, because these are total metal levels, not plant available, the impact of perlite on the chemistry is not considered biologically significant.

Table G1. Soil fertility of materials used in greenhouse experiment.

Material	CEC	pH		SOM	P	K	Mg	Ca	Na
	cmol/kg	Water	$CaCl_2$	------------- extractable (mg/kg) ----------------					
Topsoil	20	6.4	6.9	2.9	13	137	616	2758	26
Fresh sediment	42	7.5	7.2	2.6	35	164	729	7020	73
Weathered sediment	38	7.5	7.2	2.7	74	123	688	6390	77

Table G2. Total recoverable metals (mg/kg) in the materials used in the greenhouse experiment.

Material	Cr	Ni	Cu	Zn	As	Se	Ag	Cd	Ba	Pb	Na	Mg	Al	K	Ca
Perlite	1	2	<1	7.5	<1	<1	<1	<1	2.1	<1	5750	61	690	1060	1060
Topsoil	29	22	20	60	8	1.1	<1	<1	183	18	134	5 500	24600	4600	5000
Fresh sediment	48	38	43	241	7	<1	1.2	3.4	157	40	301	17100	19900	4550	35 500
Weathered Sediment (no perlite)	65	41	45	306	11	1.3	<1	4.4	218	56	284	13900	28400	6580	22500
Weathered Sediment (with perlite)	61	36	43	293	11	1.4	<1	4.4	200	54	1110	13000	24000	5890	19900

Material	Fe	V	Mn	Co	Mo	Ti	Sr	Zr	Cs	La	Ce	Th	Ga	Rb	Y
Perlite	500	<1	258	<1	<1	9	<1	<1	<1	<1	<1	<1	<1	4	<1
Topsoil	21300	54	687	9	<1	383	23	14	3	19	40	<1	8	47	12
Fresh sediment	22800	40	637	9	1	210	54	12	3	16	32	8	6	39	11
Weathered sediment (no perlite)	23300	59	527	11	1	376	45	18	4	19	37	9	9	58	13
Weathered sediment (with perlite)	28100	53	569	10	1	343	44	14	3	17	32	8	8	50	12

There are no generally agreed upon standards for metal contamination in sediments intended for land application (Darmody and Marlin, 2002). One approach would be comparison with background soil levels. The only potentially toxic heavy metals that we found that exceeded a national survey of uncontaminated agricultural soils were Cd, at 4.4 vs. 2.0 mg kg^{-1}, and Zn at 306 vs. 264 mg kg^{-1} (Holmgren et al., 1993). Based on a statewide survey of Illinois soils (Illinois EPA, 1994), with the exception of K in the weathered sediment, none of the metals in the sediments exceeds concentration ranges observed. Another approach would be to look at the USEPA critical values for metal contaminants in its 503 regulations for the land disposal of sewage sludge (USEPA, 1995). Under those regulations, none of the metals in the sediment exceeds regulatory levels. Other regulations include the Illinois' Tiered Approach to Corrective Action Objectives (TACO), which provide industrial site cleanup standards for a variety of chemicals (Illinois EPA, 1997). While these TACO standards do not apply to sediment, they are frequently referenced in discussions about potential use of sediment. Metals in Peoria Lakes sediments meet the TACO standards. Another approach is simply statistical; the Illinois EPA classifies an analyte in sediments as “elevated” if its concentration is between one and two standard deviations above the state-wide mean and as “highly elevated” if it is greater than two standard deviations above the mean (Mitzelfelt, 1996). By this measure, the sediments we used had “elevated” levels of Ni and “elevated” to “highly elevated” levels of Cr and Ag. With any approach, the method of determining the metal levels, total, recoverable, or by some extractant, is critical and not necessarily a good predicator of plant uptake (Singh et al., 1996; Vandecasteele et al. 2002a).

Plant Growth and Metal Uptake

There were no statistically significant differences in seed germination among the soil treatments with any of the plants grown. Plants grew well in all the soil treatments. Barley growth was no different among the perlite-treated samples. Barley yields were highest in the non-perlite fresh sediments, but there was no statistically significant barley yield difference between the reference topsoil and the weathered sediments. The perlite/no perlite comparisons for barley growth are not directly comparable because they were grown at different times, but they indicate that perlite additions were not necessary to achieve good plant growth in the sediments.

Lettuce growth showed some statistical differences. It grew best on weathered sediment and reference topsoil. Radish yield did not differ among the materials. Snap beans produced the same quantity of fruit on all three materials and the total plant mass produced also did not differ among growth media. The number of tomato fruits produced did not differ on the materials, but the fruit mass produced was least from the topsoil.

The metal content of tomatoes grown on different media varied and did not present clear trends, although values from the sediment-grown plants indicate that metal uptake was inhibited, possibly due to the higher pH of the sediments or to the presence of less available forms of the metals (Table G3) (Tack et al. 1996). There were few statistically significant differences in the metal contents. The lowest concentration of Cd was found in the plants grown in the topsoil. However, Cd content of the tomatoes from local gardens had about the same amount of Cd as the plants grown on the sediments in the greenhouse, and Cd levels measured were within the uncontaminated range (Wolnik et al., 1985). Tomatoes grown on the topsoil had the statistically highest content of Co, while Co levels from the growth media did not differ. Barium content was highest in tomatoes from the topsoil and the reference gardens and lowest in the weathered sediment samples. Likewise, Mo was highest on the topsoil and lowest in the weathered sediment tomatoes. Selenium contents were highest with the fresh sediment and lowest with the topsoil. Only one sample, from a topsoil pot, had detectable Hg (0.001 mg kg^{-1}). Cr was only found in two samples, one tomato grown in Champaign garden soil (3.4 mg kg^{-1}) and one grown in topsoil (3.3 mg kg^{-1}). Overall, metals detected in tomatoes grown in the sediments were all at a very low levels and within typical levels observed in agricultural crops (Sharp, 1987).

Other plants analyzed for metal content were only grown in reference topsoil and weathered sediment, because of the similarities of the two sediments, and most elements did not differ by soil type. However, when averaged over all plants, Ba and Mn were statistically lower, and As, Cd, Cu, Se, Tl, Zn, and Mo were statistically higher in the plants grown in sediment than in the reference topsoil. These differences are not necessarily important because the levels remain below those considered excessive (Kabata-Pendias and Pendias, 1994; Förstner, 1995) and are within normal ranges observed in plants (Pais and Jones, 1996; Sharp, 1987), although Wolnik et al. (1983) report an upper limit of 1.9 mg kg^{-1} Cd for lettuce grown in uncontaminated soils. Despite the “elevated” levels of Ni and “highly elevated” levels of Cr and Ag in the sediments, none of these metals showed an increase in plant uptake over the topsoil.

Table G3. Metal content (mg/kg) of tomato fruit grown in dredged sediment and reference materials.

Material	**Cd†**	**Pb**	**Co**	**Cu**	**Ba**	**Mn**	**Mo**	**Ni**	**Se**	**Ti**	**Zn**	**Sr**	**Zr**
Topsoil	0.1b	0.5	0.16a	13	1.6a	9	6a	2	0.1c	18	26	2	0.3
Fresh sediment	0.4ab	0.4	0.08b	12	1.0ab	10	3c	1	0.5a	20	25	2	0.3
Weathered sediment	0.5a	0.3	0.04b	8	0.7b	7	4b	1	0.2b	19	21	1	0.2
Peoria garden	0.4ab	0.2	0.08b	10	2.4a	10	2d	1	0.5ab	19	20	2	0.2
Champaign garden	0.2ab	0.9	0.12b	21	1.4a	11	2d	13	0.2ab	18	21	2	0.2

Cadmium showed the greatest consistent increase in the plants grown in sediments compared with those grown in topsoil. Increase in concentrations over the topsoil control ranged from 5.5 times background for barley to 4.8 times background for snap bean. Lettuce grown in sediment showed the highest overall concentration of Cd at 2.40 mg kg^{-1}. Leafy vegetables like lettuce are well known accumulators of Cd, but we found no published standards for unacceptable Cd levels in vegetables. Published Cd concentrations in plant materials range from 0.2-0.8 mg kg^{-1} for normal and from 5-30 mg kg^{-1} for contaminated plants (Kabata-Pendias and Pendias, 1994), so by this metric, the plants we grew were not contaminated.

Conclusions

Sediments from the Peoria Lakes of the Illinois River are essentially equal to highly productive natural topsoils from central Illinois in terms of fertility and plant productivity in the greenhouse. Because of their initially poor soil structure and fluid consistency immediately after dredging, crusting and sealing of the surface may be a problem at first, but should become less of an issue after weathering or tillage. Addition of materials to improve tilth, such as perlite, compost, biosolids, or similar materials, may be helpful in the development of soil structure and the avoidance of compaction. Plant metal uptake, as indicated by tomato fruit and barley, snap bean, lettuce, and radish plants grown on sediments in the greenhouse, was not excessive. Metal levels, although elevated in some of the plants relative to those grown in topsoil, were below levels considered excessive, and well below those from more industrial areas (Tack et al. 1996; Vandecasteele et al. 2002a, b). In summary, we found no chemical or physical reason that these relatively uncontaminated dredged sediments from Peoria Lakes, properly managed, should not make an excellent plant growth medium.

Appendix H. Bibliography of Sediment-Related Literature

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