TECHNOLOGY OVERVIEW

CHEMICAL STABILIZATION
PHOSPHATE AND BIOSOLIDS TREATMENT

August 2010

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ITRC (Interstate Technology & Regulatory Council). 2010. *Chemical Stabilization: Phosphate and Biosolids Treatment*. Washington, D.C.: Interstate Technology & Regulatory Council, Mining Waste Team. www.itrcweb.org.

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1. INTRODUCTION

Chemical stabilization using phosphate for treatment of solid mining wastes has proven effective at reducing the mobility of divalent heavy metals both ex situ and in situ. This technology has been used as a permanent remedy. Ex situ treatment has been much more widely used than in situ and is usually used in conjunction with off-site disposal. In situ treatment has been used in mines as a coating on exposed ore surfaces. In situ phosphate treatment has been tested and proven effective but not widely implemented at stabilizing lead-contaminated soil in residential settings. Chemical phosphate treatments have used a variety of phosphate species, but phosphoric acid has been demonstrated to be the most effective. Organic sources of phosphate such as biosolids or composted animal wastes have also been used to stabilize, reclaim, and revegetate barren mine and mill wastes.

The primary mode of action of phosphate treatment chemical stabilization is a chemical reaction with phosphorous and divalent metals, including but not be limited to lead (Pb), zinc (Zn), cadmium (Cd), copper (Cu), iron (Fe), and aluminum (Al), which form various species of metal phosphates. Metal phosphates, especially pyromorphites (i.e., a family of lead phosphate minerals with varying monovalent anions), are highly insoluble and stable across a wide range of pH. The stable nature of the compound dramatically reduces mobility and bioavailability of the heavy metals.

2. APPLICABILITY

Chemical stabilization using phosphate and biosolids can be used in the following ways:

- to treat solid waste
- to treat high or low volume of materials
- in remote, rural, or urban areas
- as a stand-alone technology or in conjunction with other technologies

Chemical stabilization using phosphate treatment is an innovative technology and can be designed to address soil, sediment, or mine tailings at remote, rural, and urban locations and can be used for small and large volumes of wastes. Phosphate treatment can be used by itself as an interim or final remedy or in conjunction with other technologies. Most applications to date have been in conjunction with off-site disposal. Research on in situ stabilization has demonstrated effectiveness at reducing the bioavailability of heavy metals (mainly lead) and providing a relatively nontoxic growth medium for previously barren mine/mill waste.

The potential applicability of phosphate, as phosphoric acid, biosolids (composted municipal wastewater treatment sludge), and buffered phosphate are discussed in examples below, including the Oronogo-Duenweg Mining Belt Superfund site; the Palmerton Zinc Smelter

Superfund site in Palmerton, PA; the Upper Arkansas River Operable Unit 11 of the California Gulch Superfund site in Leadville, CO (USEPA 2005a, 2005b); the Bunker Hill Superfund site in Coeur D'Alene, ID (USEPA n.d.); the Ore Hill Site in White Mountain National Forest, NH (USFS n.d., Daniels et al. 1998).

2.1 Phosphoric Acid and Related Amendments

At the Oronogo-Duenweg Mining Belt Superfund site, located in Jasper County, southwestern Missouri, contamination was deposited by wind dispersion onto residential yards near a primary lead smelter. Phosphate treatment was tested as an alternative to excavating contaminated residential yards. Remedial strategies for addressing the risk from exposure to lead at the site included excavating contaminated soil in residential yards with concentrations of lead over 800 mg/kg, backfilling with clean soil, and disposal of contaminated soil at a nonresidential area of the site. The U.S. Environmental Protection Agency (USEPA 2005a) performed time-critical removal and/or remedial actions at approximately 2,600 residences at a cost of $29 million. In situ phosphate treatment, using phosphoric acid to reduce bioavailability of lead in residential yards was identified as an alternative and more economical treatment if research demonstrated its effectiveness as noted in a EPA Region 7 Record of Decision dated August 1, 1996.

In a Five-Year Review Report for the site dated August 27, 2007, the treatability studies for phosphate application were completed over a period of six years and showed a reduction in the bioavailability of lead of up to 40% in soil from the addition of phosphate. Additionally, a follow-up exposure study from the Missouri Department of Health and Senior Services at the conclusion of residential yard physical soil removal indicated that EPA exceeded its goals for reduction of blood-lead levels. EPA Region 7 determined that phosphate treatment of yards below 800 milligrams per kilogram was not warranted given that site goals were met, blood lead levels were reduced, and that given the current economic conditions, the cost of phosphoric acid treatment exceeded the cost of physical soil removal and disposal activities. Neither EPA Region 7 nor the Missouri Department of Natural Resources has implemented phosphoric acid treatment at any other sites in the region at the time of this technology overview.

In situ phosphate treatment using a combination of calcium diphosphate, phosphoric acid, and phosphate rock was tested at a battery recycling site near Jacksonville, FL (Melamed et al. 2003). Phosphate treatment reduced Toxicity Characteristic Leaching Procedure (TCLP) for lead (Pb) from 82 mg/L to below EPA's regulatory limit of 5 mg/L. Researchers found the mixture of phosphoric acid and phosphate rock to be effective in immobilizing Pb with minimum adverse affects associated with pH reduction in the soil.

2.2 Phosphate Rock and Buffered Phosphate

Phosphate rock, apatite, and buffered phosphate have been tested as a metal stabilization agent. Typically, the metal phosphate reactions take place at a slower rate with lower short-term effectiveness. However, in low-pH environments phosphate rock can be a more desirable amendment due to a reduction in short-term leaching of metals and phosphate.

At the Ore Hill site in New Hampshire, 36,000 cubic yards of contaminated soil and tailings was excavated from the White Mountain National Forest during May–November 2006. Copper-, lead-, and zinc-contaminated waste rock and tailings were excavated, treated with a chemical stabilizer (Enviroblend), and placed in an on-site repository. Due to the limitations of excavation equipment, a thin layer of contaminated tailings was present at the base of the excavation on top of the bedrock. These tailings were sprayed with the chemical stabilizer prior to backfilling. Lead and zinc treatment goals were set to be protective of groundwater using the synthetic precipitation leaching procedure. Goals of <0.1 and <0.18 mg/L, respectively, have been met.

2.3 Biosolids Using Organic Phosphate

For the Oronogo-Duenweg site, biosolids initially worked well to establish plant growth. Approximately 40–60 tons/acre dry weight of biosolids was applied to select site areas. Revegetation was highly successful over the next several growing seasons after biosolids application. However, over time in areas with the lowest rates of biosolids application, the plants used up the nutrient content of the biosolid material and were unable to sustain long-term growth. In a future application, biosolids were added to select areas at rates up to 150 tons dry weight per acre, plus 50 tons/acre of other organic waste (yard waste compost), and long-term growth appears to be maintained. Any application at this rate would likely require a special permit near any residences due to exceedances of standard nutrient loads. Additionally, the material was not able to be used near residences unless composted due to odors. Smaller municipalities are often reluctant to compost given the additional cost.

According to Peter S. Machno and Peggy Leonard (http://www.wef.org/biosolids/), tests at Palmerton, PA; Leadville, CO; and Bunker Hill, ID demonstrated that biosolids mixtures can restore soils and vegetation. Biosolids combined with a calcium carbonate material, such as lime or wood ash, create a fertile soil and vigorous, self-sustaining plant growth. Iron and phosphates in biosolids adsorb lead and convert it to an insoluble compound, chloropyromorphite. Wood ash raises soil pH and prevents Zn from being taken up by plants or leached. Biosolids supply nutrients and organic matter for rebuilding soil and soil microbial communities.

According to EPA Region 3 (USEPA n.d.), full-scale implementation of the revegetation of Blue Mountain (Palmerton Zinc, Operable Unit 1, Blue Mountain [USEPA n.d.]) began in 1991, preceded by several years of pilot testing. From 1991 through 1995 a mixture of fly ash, sewage sludge, and a combination of grass and tree seeds was placed on approximately 1,000 acres of the mountain.

In 1998 EPA began a soil amendment/revegetation demonstration project on fluvial mine waste deposits adjacent to the Arkansas River (USEPA 2005b). Four demonstration sites covering 10 acres were treated with biosolids during the summer of 1998. In 1999, an additional 20 acres was amended with lime and organic matter consisting of biosolids pellets, cow manure compost, wastewater treatment plant compost, or a combination of these amendments. Based on results from the 1998–2000 work, additional soil amendments and seeding were conducted in 2003 on fluvial mine waste deposits with negligible or insufficient vegetation growth. During the summer, wood chips, dolomite, and pond sediments from the Mount Massive Lakes Estates ponds were added to several of the demonstration sites.

In 1999, a study was conducted to evaluate the effectiveness of biosolids and lime treatment in reducing metals availability, increasing pH, and promoting vegetation growth. In 2003, a second efficacy assessment, based primarily on observations of vegetative growth, was conducted. The fluvial mine waste deposits within OU 11 cover approximately 2.8 million square feet and have an estimated volume of 2.7 million cubic feet. Thirty of the 65 acres has been treated as part of the demonstration project.

Biosolids application was also implemented in a mining area of Upper Silesia, Poland. Upper Silesia is a highly industrialized Pb, Zn, and coal mining and smelting region in southwestern Poland centered near the city of Katowice. Zinc smelter wastes were treated with biosolids and lime during 1994–1995. Highly contaminated zinc smelter wastes were treated with a variety of lime or calcium oxide and sewage sludge applied at rates of 5–30 and 75–300 tons/hectare, respectively. These application rates were applied on 0.5-hectare test plots and seeded with zinc- and salt-tolerant grass species.

3. ADVANTAGES

- long-term effectiveness and permanence
- flexibility
- cost-effectiveness for ex situ treatment
- turns waste into useful by-product

3.1 Long-Term Effectiveness and Permanence

At the Oronogo-Duenweg site, phosphate treatments using phosphoric acid were tested by dosing treated and untreated soils to immature swine. Pigs are thought to be a better model for humans than rats due to relative similarities in size, diet, feeding habits, and digestive tracks. To test the permanence of the chemical treatments at reducing the bioavailability of lead, soils were dosed to pigs over a period of several years after treatment. Soils dosed 2.5 and 6.5 years after treatment actually had lower or equivalent bioavailability as soils dosed within weeks to 1.5 years after treatment. The conclusion of this study is that the metal chemical formed by phosphate stabilization is stable over time.

Biosolids application rates at the Oronogo-Duenweg site determined long-term effectiveness. In areas where 40–50 tons dry weight per acre of biosolids was applied, plants depleted the nutrients relatively rapidly and did not maintain long-term growth. In areas where 200 tons dry weight per acre was applied, the plants were observed to maintain long-term growth.

3.2 Flexibility

In addition to in situ treatment described above, there are a wide variety of chemical phosphate applications. The technology can be modified to suit a variety of needs. Phosphoric acid can be used to stabilize excavated soils to facilitate achieving TCLP requirements for disposal. Additionally it can be used to reduce the bioavailability of metals in soils in residential yards.

Biosolids can be used not only to stabilize metals but also to facilitate revegetation. Additionally, amendments can be added to biosolids to buffer or blend to account for site-specific treatment conditions.

3.3 Cost-Effectiveness

Short- and long-term cost estimates for the multiple phosphate technologies were not available for this technology overview at the time of development. However, for ex situ treatment, excavated soil that fails TCLP can be stabilized quickly and is available for disposal within a few hours or days, which may equate to reasonable lower costs.

For in situ treatment, residential soil treatment may take longer than excavation, and the cost of phosphoric acid varies. Soils tested within three weeks of treatment showed reduction in bioavailability. For in situ treatment, the cost to treat over time and the resulting performance to meet site goals may exceed the cost to excavate and dispose. Biosolids are effective at relatively rapid revegetation, which reduces runoff. However, reduction in metal mobility and bioavailability within the soil will likely take time to occur. Maintenance and reapplication may be required.

3.4 Waste Stream Reuse

Biosolids are generated at all waste water treatment plants and are readily available for use. Biosolids application beneficially uses a waste material that may otherwise be required to be disposed of in a landfill, thereby using valuable landfill space. More information can be found in TerraCycle Technologies 2000, Brown et al. 2002, and USEPA 2007.

4. LIMITATIONS

- variable cost for in situ treatment
- some limits on applicability
- nutrient loading
- limited implementation

4.1 Variable Costs

Ex situ phosphate treatment costs are very favorable when compared to disposal at a hazardous waste facility, but vendors have driven the cost of in situ treatment high enough to be not cost-effective when compared to conventional excavation and disposal methods. Biosolids application costs are highly variable and driven by local markets, availability of organic matter, and transportation distance.

4.2 Limits on Applicability

Chemical stabilization as a whole has a wide range of applicability; however, there are limitations. Ex situ treatment is applicable only to mine waste or contaminated soils that would be transported to a hazardous waste disposal facility. In situ treatment to reduce bioavailability has primarily been investigated for residential yard remediation purposes, mainly limited to lead. In situ phosphate treatment of lead-contaminated material has been demonstrated to reduce the bioavailability of Pb by a maximum of 43%. Therefore, it is useful for only relatively low concentrations of lead, less than 1200 parts per million in high baseline bioavailability settings or lower baseline bioavailability soils of higher concentrations. Other metals have been successfully treated using phosphate, but extensive bioavailability studies have not been conducted on metals other than Pb.

Phosphate rock and buffered phosphate are expected to be effective in the long term and in low-pH soils or waste rock but are limited in applicability where rapid reductions in bioavailability are required. Biosolids application is applicable to rural areas, where other permanent disposal options are not available. Due to odor problems, biosolids application is not recommended adjacent to heavily populated areas. Thick deposits of mine/mill waste over 2 m deep may not be conducive to biosolid applications if shallow groundwater or water existing at the soil/mine waste interface is problematic as a contamination source.

4.3 Nutrient Loading

Nutrient runoff in both in situ phosphate stabilization and biosolids application is a possibility. In situ phosphate treatment requires supersaturation of soil with phosphorous because phosphorous is readily sorbed to clay, organic matter, and aluminum and iron hydroxides in the soil. Supersaturation ensures that enough phosphorous is available to react with Pb and other heavy metals. There is the potential for excess phosphorous runoff and contamination of surface water. However, leaching tests performed on soil treated with 10,000 mg/kg showed minimal phosphorous penetrating through a 1 m column. Adding phosphate rock and other liming agents such as buffered phosphate reduces phosphate leaching potential.

Since phosphorous tends to bind to soil, the main threat for nutrient runoff is erosion of treated soil. Standard storm-water best management practices should be sufficient to prevent nutrient problems. Biosolids have higher potential to cause nutrient problems than in situ treatment. Similarly biosolids application involves very high application rates to build soil from barren mine waste and to supply sufficient phosphorous to bind metals. Unlike in situ chemical phosphate treatment, biosolids also contains high nitrogen content.

Large-scale biosolids application has been implemented in floodplains of streams without nutrient loading/runoff problems. Care in best management storm-water controls may be sufficient to prevent this unintended consequence. Permits may be required to apply larger volumes of material.

4.4 Limited Implementation

Although ex situ phosphate treatment has been widely used, biosolids and in situ phosphate treatment has had limited implementation. Several vendors, such as Metal Treatment Technologies (MTT), SCE Environmental Group, Sevenson Environmental Services, and UFA Ventures, have used proprietary phosphate at mining and other heavy metal–contaminated sites to reduce the solubility of metals. Biosolids have been applied in several locations covering significant acreage. However, it has not been standardized as a normally applied technology; therefore, questions about effectiveness and implementability still remain. At the end of 2009, in situ phosphate treatment has not been implemented in a full-scale application in a residential setting.

5. PERFORMANCE

5.1 Phosphoric Acid and Related Amendments

In Situ Treatment

In situ phosphate treatment has been tested in a handful of settings. The most comprehensive testing of its effectiveness at reducing the bioavailability of lead-contaminated soil has been conducted at the Jasper County, MO Oronogo-Duenweg site. Smelter-contaminated soil and mill waste–contaminated soil (5,000–2,500 mg/kg Pb) were treated with a variety of phosphate amendments and subjected to bioavailability testing using immature swine as a model. Most of the bioavailability testing was conducted on smelter-contaminated soil treated with phosphoric acid, potassium chloride, and calcium hydroxide. Heavy application rates were used, with the most effective treatment tested being 1% phosphoric acid. Phosphoric acid reduced the bioavailability of lead up to 43%. The reduction in bioavailability was maintained in periodic testing over a 6.5-year period.

The bioavailability of Jasper County soils was high relative to other sites tested nationwide. This study at the Oronogo-Duenweg site concluded that phosphate treatment would be effective only for relatively moderately contaminated soils (less than 1000 mg/kg). The concentration that can be effectively treated is highly dependent on the untreated bioavailability of the lead. Less bioavailable soils can be treated at higher concentrations.

The various forms of phosphate treatment have varying degrees of proven effectiveness. Ex situ stabilization has been used widely and has much evidence of effectiveness. Biosolids treatment has less widespread application but has shown to be effective at revegetating barren mine waste and reducing bioavailability. In situ treatment has never been selected as a remedy for a site in a residential setting, but treatability study testing has proven effectiveness for moderate levels of contamination. Performance measures include the protection of human health and ecological environment in the reduction of contact with contamination, reduction of contaminant migration and subsequent restoration of downgradient water bodies, and promotion of a healthy wetland ecosystem.

Ex Situ Treatment

Ex situ treatment has been used effectively at multiple heavy metal–contaminated sites by a variety of vendors. Use of ex situ treatment is much more widespread at nonmining hazardous waste sites. Sites include the St. Louis Courthouse, St. Louis, MO; U.S. Coast Guard Tongue Pt. facility in Astoria, OR; National Park Service near Hot Springs, SD; U.S. Marine Corp facility in Yuma, AZ; the City of Dallas, TX; and a metals recycling facility in Towanda, PA. In all cases this treatment has been very effective at stabilizing metal contamination to concentrations below the TCLP test. Maximum TCLP reduction from 3,320 mg/L lead before treatment to nondetect after treatment. Minimum TCLP reduction results were 15–30 mg/L lead before treatment to 0.3 mg/L to nondetect post treatment. This treatment technology is typically used in conjunction with excavation and disposal.

5.2 Rock Phosphate and Buffered Phosphate

Surface water monitoring data at the Ore Hill Site and U.S. Forest Service sites in New Hampshire indicate that dissolved metals of concern have been reduced by approximately 80% as a result of the 2006 work (USFS n.d.). Results are as follows:

- Aluminum in surface water before the Removal Action averaged 2.21 ppm and has averaged 0.16 ppm since the end of October 2006. Aluminum in the background surface water averaged 0.07 ppm.
- Copper in surface water before the Removal Action averaged 0.23 ppm and has averaged 0.06 ppm since the end of October 2006. Copper in the background surface water was nondetect.
- Lead in surface water before the Removal Action averaged 0.35 ppm and has averaged 0.08 ppm since the end of October 2006. Lead in the background surface water was approximately 0.00 ppm.
- Zinc in surface water before the Removal Action averaged 8.11 ppm and has averaged 1.98 ppm since the end of October 2006. Zinc in the background surface water was approximately 0.03 ppm.

5.3 Biosolids Treatment

Biosolids treatment has been demonstrated to reduce the mobility of metals on the pilot scale in Jasper County, MO; Palmerton, PA; Coeur d'Alene, ID; Leadville, CO; and Upper Silesia, Poland. Metal stability results vary at these sites. The limiting factor at these sites is the amount of biosolids that can reasonably be applied. Some sites where only limited amounts of biosolids were applied due to steep slopes and runoff concerns (Palmerton Zinc Smelter and Bunker Hill) were successful for a short period of time until organic matter was consumed. These types of sites may require repeated application of a small amount of biosolids.

- The Oronogo-Duenweg site used different biosolid types and application rates applied to approximately 200 acres of mine-contaminated land in 1997–98.

- The Creek Bottom site was located in a floodplain wetland and was monitored for water quality before, during, and after application. The site received an average of 50 tons of biosolids per acre. There was significant revegetation success with high diversity, and nutrient runoff was within acceptable limits. An ecological risk evaluation of the site by the EPA demonstrated that metals no longer present an unacceptable risk. Ten years after treatment some of the areas with highest zinc and lead contamination (>10,000 mg/kg and >2,000 mg/kg, respectively) are poorly vegetated. In these areas the organic matter was consumed without stable vegetation being formed. In other areas stable and diverse vegetation has been established with a sustained soil profile. The recommendation from this pilot study was that in areas of the highest contamination, higher application rates are needed. The recommendation was for 100 tons/acre of biosolids with 50 tons/acre of additional organic matter to form the appropriate carbon:nitrogen (C:N) ratios. Optimal C:N ratios are approximately 20:1 to reduce the potential for nitrogen runoff. Lime addition may also be necessary to stabilize pH. At the Jasper County site, lime was added at a rate of 10 tons/acre.

- The Palmerton Zinc site included approximately 1,000 acres which has been successfully revegetated with grasses. However, fungal disease, competition with plants, and foraging animals have hindered tree seed growth. An additional 1,000 acres remain to be revegetated, and efforts may need to be made to grow trees and other larger types of vegetation on all of the approximately 2,000 acres in the Blue Mountain OU.

- The Upper Arkansas River Site, Leadville, CO, the barren tailings areas were successfully revegetated with 100 tons/acre biosolids and lime amendments. However, attempts to quantify performance results in 1998–99 failed to show statistically significant differences. EPA observed trends in the data and made inferences about the effectiveness of the treatment. EPA observed that biosolids application appeared to reduce the availability of contaminants of concern (COCs), based on a decrease in extractable metals in treated tailings, including water-leachable, exchangeable, weak acid–extractable, TCLP, and multiple extraction procedure metals in treated tailings. Biosolids appeared to improve soil quality, based on an increase in pH, total organic carbon, water-holding capacity, total nitrogen, phosphorous, and other secondary anion and cations. In the treated tailings, there was a decrease in salinity, limestone requirement, and available metal nutrients and an increase in plant and soil microbial activity. The plant community was established one year after treatment; however, the soil microbial community was still recovering. While data from the fungal, bacterial, and protozoan communities in treated tailings indicated that these communities were not balanced, the high biogeochemical activity of the soil was an indicator of active recovery of the soil microbial community. EPA found reduced soil toxicity, based on the results of plant and earthworm assays, with the exception of one distinct area of tailings. However, all treated tailings showed significant sublethal effects on plant root biomass, and the concentrations of the COCs in plants and earthworms in these tailings were higher than those found in the reference soils. EPA did find that biosolids reduced the dietary exposure risk for higher trophic organisms, based on the results of several preliminary dietary exposure models; however, it was determined that there may be a risk to the mammal and avian communities from specific metals (USEPA 2005a, 2005b).

- The Upper Silesia, Poland (USEPA 2000) revegetation was successful on smelter wastes that contain near neutral pH (6.9); moderate salinity (as measured by electrical conductivity = 7.3 deci-Siemens per meter [dS/m]); and mean Zn, Cd, and Pb concentrations of 30,900; 540; and 7,900 mg/kg, respectively. However, revegetation initially failed on waste with a pH of 3.6; high salinity (electrical conductivity = 16dS/m); and mean Zn, Cd, and Pb concentrations of 75,100; 2,310; and 23,820 mg/kg, respectively. The solubility of all metals and salinity was reduced for treatments except for Cd in the moderately saline waste. However, soluble metals and salinity in the highly saline waste were not reduced below phytotoxic levels by the biosolid and lime or calcium oxide amendments. A subsequent reapplication of a 15 cm lime cap followed by 300 tons/hectare biosolids resulted in 75%–80% revegetation success. However, plant roots penetrated into the underlying smelter waste to a depth of only 2 cm.

One important factor to be considered in biosolids application is the degree that material has been composted. In general, the more thoroughly composted the material, the more effective the application. Noncomposted or moderately decomposed material has increased odor concerns, carried higher potential for nutrient runoff, and is harder to handle.

6. COSTS

The costs of phosphate treatment are highly variable, depending on market conditions and transportation rates. requirements at the treatment facility.

6.1 Phosphoric Acid and Related Amendments

In Situ Treatment

In situ residential treatment initially was considered a cost-effective remedial alternative. In Jasper County, costs were estimated at $4,000 per residential yard versus approximately $10,000 per residential yard for traditional excavation and soil replacement. However, the supply of phosphoric acid has recently been reduced, and the cost of the reagents has significantly increased, which has affected the cost of this technology. Phosphoric acid was formerly the principal component of chemical fertilizer and was readily available. Recently, the trend has been to use other forms of phosphate in the manufacture of phosphate fertilizer. This has decreased the availability of phosphoric acid and increased the cost of this technology.

Melamed et al. (2003) have shown success in an aqueous application of calcium di-phosphate and phosphoric acid without tilling reagents into a non-mining-related lead-contaminated soil near Jacksonville, FL. This is an important step in increasing the cost-effectiveness and the acceptance of this technology. Rototilling reagents and revegetating soils are a major cost component of in situ treatment. Other nonresidential settings of phosphate treatment are considered highly cost-effective.

Ex Situ Stabilization

Most ex situ stabilization is dominated by specific vendors who have patented formulas for their reagents. These proprietary applications tend to be significantly more expensive than the main raw ingredients that can be purchased independently. However, as for in situ treatments, vendors advertise 50%–95% cost savings compared to other remedial methods.

6.2 Biosolids

In some cases biosolids can be very inexpensive. Biosolids are a waste product that in some cases an industry or municipality must pay for disposal. In many instances biosolids produced from municipal wastewater treatment facilities are a liability for those municipalities. If a location for disposal, which may include a contaminated mine site, is located within a reasonable haul distance from that municipality, it may be possible to get biosolids applied for free, or for the cost of transportation alone.

However, other sources such as composted manure or other waste from confined animal feeding operations are increasingly seen as a product that comes at a cost. Haul distances from biosolid sources to the mining site become the controlling cost consideration. In addition, large amounts of biosolids are often needed, which tend to magnify the transportation costs.

7. REGULATORY CONSIDERATIONS

Regulatory permits or approvals which may be needed include, but are not limited to, a Clean Water Act (i.e., National Pollution Discharge Elimination System) permit. Significant information for the regulatory authorities may be needed for biosolids treatment application. The rates of application necessary are significantly higher than most agronomic application rates. Normal regulatory limitations may be waived if the application is undertaken in the broader context of site remediation or under a separate regulatory authority. Institutional controls may need to be placed on the property if concentrations of COCs exceeding the cleanup levels are left in place or to prevent certain future activities, such as digging near the repository or installing a drinking water well.

8. STAKEHOLDER CONSIDERATIONS

Phosphate treatment has some limitations in its public acceptance. Biosolids treatment can have serious odor concerns that will definitely limit its use to rural settings. In situ phosphate treatment results in destruction of vegetation in the yard temporarily and restricted access for a number of days. Residents may not want their yard destroyed despite its status of contamination. However, the alternative is excavation of the yard, which is a more destructive alternative.

9. LESSONS LEARNED

9.1 Phosphoric Acid and Related Amendments

In Situ Treatment

Research has shown that phosphate treatment, as an agent to reduce the bioavailability of lead to reduce human health exposure, is effective at only moderate concentrations (<1,200 mg/kg). Higher concentrations of lead and other heavy metals could be treated with in situ phosphate if human health protection (i.e., ecological risk or threats to groundwater) is not the primary focus. Phosphate treatment is most effective in the treatment of Pb, but the mobility and bioavailability of other heavy metals, including Al, Barium (Ba), Cd, Cu, Fe, Mercury (Hg), Selenium (Se), Uranium (U), and Zn, have also been demonstrated.

More implementation is necessary to assess the applicability of in situ treatment. Although the most effective treatment was at very high application rates of 1% phosphoric acid, more testing should be conducted on lower application rates of 0.75% phosphoric acid. Other reagents, such as triple super phosphate, may be used to reduce costs and increase the ease of implementation. In addition, a noninvasive application method such as aqueous application of phosphate amendments in residential settings would increase the cost-effectiveness and the acceptance of this technology. While phosphoric acid-based treatment is the most effective in the long-term for stabilizing heavy metals in soil, it can cause short-term leaching of other metals (e.g., Cd and Zn). Therefore, a buffering agent is needed to return soil pH conditions to neutral if other more soluble metals are of concern.

9.2 Rock Phosphate and Buffered Phosphate

Rock phosphate and buffered phosphate may have limited effectiveness in the short term. However, in areas where low pH conditions are present it may be the most effective option. Rock phosphate used in conjunction with phosphoric acid or other low pH amendments may be a very effective treatment due to the buffering capacity of phosphate rock.

9.3 Biosolids

Winter time or cooler weather application are helpful in biosolids treatment. Application in cooler weather reduces the odor and ensuing neighbor complaints. Extensive education is normally necessary for the Clean Water Act permitting authority. Very high application rates are necessary in barren or sparsely vegetated environments: 100–150 tons/acre of biosolids. Where lower rates have been used (25–50 tons/acre) revegetation success has been minimal in five or ten years after application.

10. CASE STUDIES

Table 10-1. Case studies using chemical stabilization as a treatment technology

Oronogo Duenweg, MO
Ore Hill Mine, NH

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