In-Place Precipitation Immobilization: Technical And Economic Assessment At The Former A.Y. McDonald Foundry Site, Dubuque, Iowa

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ABSTRACT

Remedial action alternatives at hazardous waste sites containing significant concentrations of heavy metals have, in the past, concentrated on waste excavation and relocation to provide the most certain solution for site closure. The extent of waste removal has been guided mainly by the results of soil metal concentration guidelines or EP Toxicity test results. This paper presents the results of a detailed evaluation of the technical and economic effectiveness of in-place precipitation immobilization (IPI) of lead at the former A.Y. McDonald foundry site in Dubuque, Iowa. The complete assessment involved the consideration of six alternative remedial actions on the basis of performance, reliability, implementability and safety. The collection of detailed subsurface geological and geochemical information as well as the performance of laboratory treatability studies were used to demonstrate that IPI would provide long-term control of lead release from the site at substantial cost savings in comparison to more standard approaches.

INTRODUCTION

The former A. Y. McDonald foundry site in Dubuque, Iowa was initially placed on the NPL in early 1985 after the disclosure by the company in mid- 1983 that foundry sand wastes from casting operations and Pangborn dust from air pollution control equipment had been deposited across the eastern portion of the site during the operating history of the foundry. As a result of operational waste stream classification by A.Y. McDonald Industries, Inc., these wastes had been determined to be hazardous under RCRA since they exhibited the characteristic of EP Toxicity due to high leachable levels of lead.

The site is located northeast of the intersection of east 12th and Pine Streets approximately 0.2 mi. east of downtown Dubuque and 0.25 mi. west of the Mississippi River (Fig. 1). This location is east of an area of one of the largest concentrations of lead mining activity in the United States. A.Y. McDonald originally had developed an iron foundry at the site in 1896, converting it to a brass foundry in 1951 until its closing in 1983 after nearly 90 years of operation. The Iowa Department of Transportation (IDOT) subsequently purchased the site to provide l and for an approach embankment to a bridge crossing the Mississippi River as part of the U.S. Highway 61 relocation project.

The eastern area of the site (Fig. 2), over which the foundry wastes had been placed in piles or spread out evenly over the surface, encompasses about 5.5 acres and contains approximately 5,000 yd.[3] of lead-containing foundry wastes. Since the adverse human health effects from lead ingestion are well documented, there is great concern at the site for limiting human contact with the waste materials. The potential pathways for migration of lead off-site include airborne dispersion, surface water runoff or leakage into subsurface groundwaters.

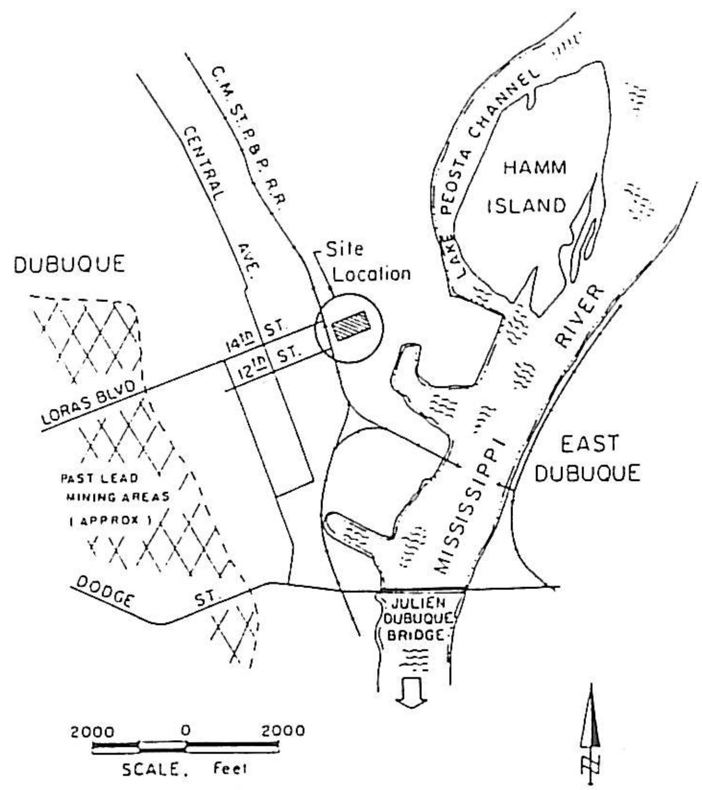

Figure 1
General Site Location of A.Y. McDonald Foundry

The purpose of this paper is to present the results of a detailed evaluation of possible remedial action alternatives for site closure. These alternatives included standard excavation practices as well as the option of leaving the wastes on-site and mixing in buffering additives to reduce the leaching lead solubility. The data gathered during site characterization and analysis indicated that natural solubility controls were in process beneath the site and that enhanced in-place precipitation immobilization should be given serious consideration as the permanent means of controlling long-term lead release.

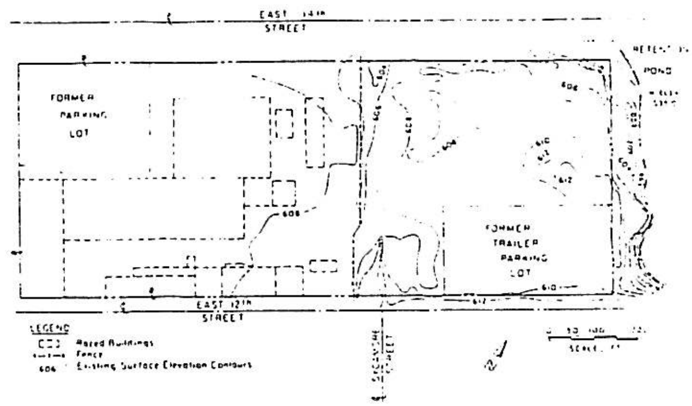

Figure 2
A.Y. McDonald Foundry Site Layout Plan

SUBSURFACE CONDITIONS

The site is located on the alluvial plain of the Mississippi River with natural subsurface soil deposits consisting of unconsolidated gravels, sands, silts and clays horizontally stratified in layers, lenses and channels characteristic of alluvial deposition. A carbonate bedrock of the Platteville formation underlies the site at depths ranging from approximately 40 ft. on the western edge to greater than 50 ft. along the eastern border.

The vertical and horizontal distribution of subsurface materials and groundwater conditions was determined from information gathered from 32 exploratory borings, 12 monitoring well installations, test pits and surface material sampling. As shown in Fig. 3, the site generally is covered by approximately 10 to 14 ft. of miscellaneous black slag, sand, building rubble and rubbish fill materials. Over much of the eastern portion (Fig. 2), approximately 1 to 3 ft. of relatively homogeneous, black to light tan foundry sand is encountered at the surface.

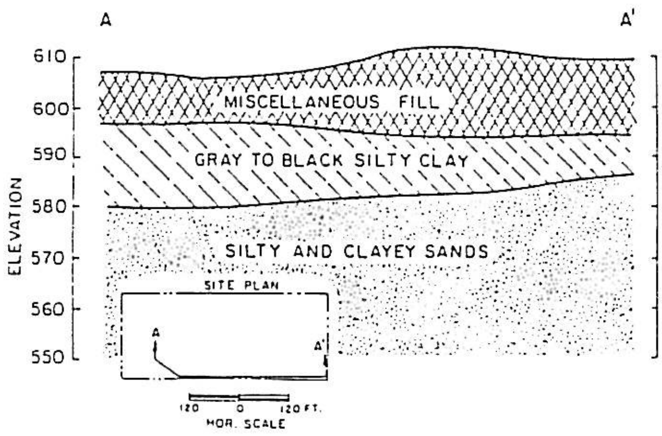

Figure 3
Generalized Subsurface Stratigraphic Profile A-A'

In general, these upper fill materials are separated from deeper interstratified natural granular layers by a relatively low permeability black to gray silty clay. This silty clay layer acts as a hydrologic separator at the site, creating two distinct groundwater systems. The upper water table system within the miscellaneous fill is perched on the natural clay confining layer, resulting in a somewhat irregular potentiometric surface through the heterogeneous fill. The lower groundwater system in the underlying natural sands is confined, with the potentiometric surface indicating that discharge is directly eastward towards the Mississippi.

The drinking water is supplied through municipal sources which in turn get their water from a well field approximately 1 mile northwest (up-gradient) of the site. The municipal wells draw their water from the alluvial aquifer system at a depth of 150 to 200 ft. There are no known down-gradient wells screened in the alluvial sand system due to the site's close proximity to the Mississippi River. Groundwater discharge from the former A.Y. McDonald site has been calculated to be on the order of 0.25 $ft.^3$/min., with the average flow in the Mississippi River at this location yielding a dilution ratio of 1:11,088,000[2].

WASTE CHARACTERIZATION

A total of 105 material samples has been collected at the site by four separate organizations for the specific purpose of determining the extent and severity of lead contamination. Geophysical electromagnetic conductivity and resistivity surveys were performed across the site prior to the bulk of the sampling effort to gain preliminary information on areas of high conductivity indicative of buried foundry-type materials. This information was used to select test pit locations more efficiently, particularly in the western one half of the site where surface evidence of foundry waste deposition had been obscured by past operations.

Ninety-seven of the samples taken have been analyzed for EP-toxic concentrations of lead, while eight were analyzed for total compositional lead only. Of these tests results, 30 samples had lead concentrations equal to or greater than the regulatory threshold of 5.0 mg/l. Of these materials that classified as hazardous, all were obtained from the eastern portion of the site and about two-thirds were collected from depths less than 2.5 ft. below the ground surface. These test results support the conclusion that the bulk of site materials containing the characteristic of lead EP toxicity are restricted to the thin surficial layer or discrete piles of foundry sand present over the eastern portion of the site.

These surficial foundry sands were used in the molding and casting operations for the production of brass products. Due to bentonite clay and chemical additives mixed with the sand to enhance mold formation during the casting process, these materials exhibit a higher than expected cation exchange capacity and are generally well buffered, with an acid neutralizing capacity (ANC) ranging from 18 to 33 meq/100gr. and an aqueous pH typically between about 7.5 and 8.5.

The distribution of total compositional lead measured across the eastern portion of the site indicates that total lead concentrations

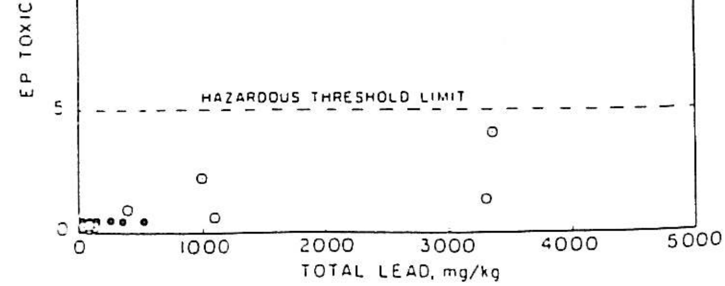

Figure 4
Relationship Between Total Compositional Lead and EP Toxicity for Samples Tested

as high as 4890 mg./kg. were found in the surficial foundry sand. However, it is apparent from the scattered relationship between measured total compositional lead concentrations in the waste and the relative leaching potential of lead as measured by the EP Toxicity test (Fig. 4) that variations in existing foundry sand composition as reflected in the measured pH, ANC and percent clay can significantly influence lead leaching characteristics.

GROUNDWATER GEOCHEMICAL ASSESSMENT

The concentration of dissolved lead in groundwaters and surface waters typically is low under most natural conditions due to its ability to form compounds of low solubility with some of the major anions of natural waters such as hydroxides, carbonates, sulfates or phosphates [1]. A comparison between site-specific groundwater quality data obtained from monitoring well samples taken over a 2 yr. period [2] and an equilibrium-based lead solubility model [3,4] is shown in Fig. 5. The values of pH and total aqueous lead are plotted against the theoretical solubility relationship for the carbonate lead mineral, cerrusite ($PbCO_3$) for the selected representative site groundwater total alkalinity of 360 mg/l as $CaCO_3$. As shown in the figure, the measured site values tend to cluster around the theoretical lead carbonate solubility line, indicating that the presence of cerrusite is controlling the total aqueous lead concentration in the system.

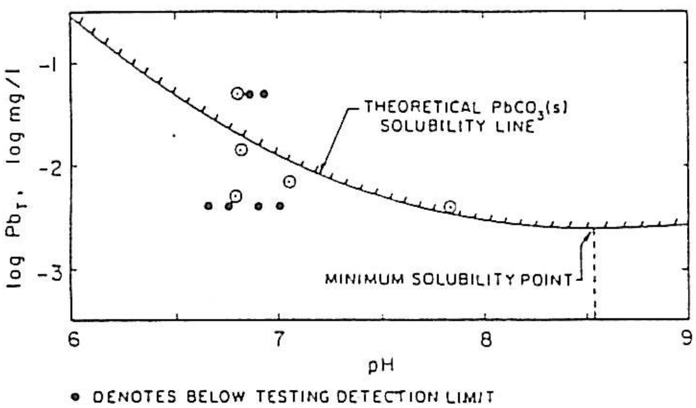

Figure 5
In Situ Aqueous Lead Concentrations
Versus Theoretical Solubility for Site Conditions
with Average Total Alkalinity of 360 mg/l As $CaCO_3$

The control of lead solubility through high alkalinity levels is not a surprising result considering that the city of Dubuque, Iowa, located in the center of one of the richest lead-bearing regions of the United States, is not plagued with high levels of lead in its drinking water due to the location of the lead deposits within carbonate bedrock sequences. Testing of city supply wells near the site by the U.S. EPA indicated there were no metals that exceeded the U.S. EPA Primary Drinking Water Standards (PDWS).

Theoretical equilibrium solubility calculations [3] have shown that the total alkalinity of the leaching groundwater may be no less than 43.2 mg./l. as $CaCO_3$ in order to control lead solubility by the formation of cerrusite to below the proposed U.S. U.S. EPA PDWS of 0.02 mg./l.

LABORATORY TREATABILITY STUDIES

In conjunction with the geochemical assessment of the site, laboratory treatability studies were performed to quantify the leaching behavior of treated and untreated foundry sand wastes at varying pHs. Both batch-type and column-type leaching tests were conducted on a composite foundry sand sample containing 2400 mg./kg. of total lead judged to be representative of expected overall worst case site conditions.

One series of batch tests used to quantify the relative leachability of treated mixtures is shown in Fig. 6. The foundry sand was mixed with 0.0, 5.0, 10.0, 15.0 and 20.0% lime ($Mg(OH)_2$ and $Ca(OH)_2$) by dry weight and analyzed for the characteristic of lead EP Toxicity. The results indicate that the total leachable lead concentration decreased by a factor of about 185 when 10 to 15% lime by weight was added. This reduction in leachability is a direct result of the buffering effect that the lime additive had on the leaching pH of the foundry sand during EP toxicity testing. As seen in the figure, the optimum leaching pH range appears to be between about 8.5 to 10 for this particular additive strategy.

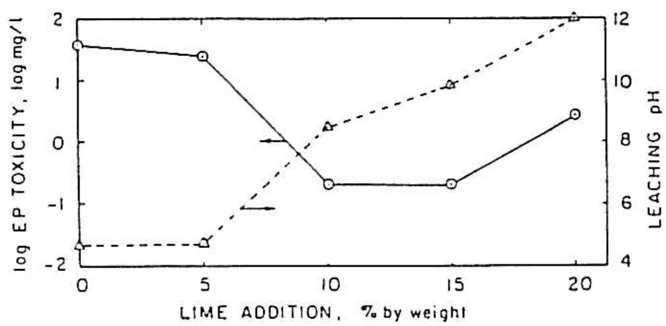

Figure 6
Lead EP Toxicity of Lime-Treated Composite
Foundry San Sample Containing
2400 mg./kg. of Total Lead

A different series of 24-hr. batch tests was performed to further quantity the relative effect of the leaching pH on the concentration of lead released from the sand[5]. In these tests, the adjustment of the untreated foundry sand pH between values of 3 to 12 using either acetic acid (to decrease pH) or sodium hydroxide (to increase pH) indicated again that maintaining the pH in the range of 8 to 10 minimizes the amount of soluble lead released.

The batch test results in general conform with the theoretical solubility line included in Fig. 6 that shows minimum solubility for the lead carbonate occurs at a pH of about 8.53. Although useful for providing an indication of relative reductions in leachable metal concentration under specific test conditions, batch tests results, including EP toxicity, are affected by many variables (e.g. solid/solution ratio and test duration) and cannot be used for predicting in situ leaching concentrations because they fail to duplicate the actual in-place transient geochemical and groundwater flow conditions[5]. Column leaching studies were performed to more closely duplicate in-place influent geochemistry, material soil/solution ratio and flow conditions.

The results of selected column tests are summarized in Table 1. A simulated acidic rainwater with a pH of 4.6 and a chemical composition based upon data developed by the National Atmospheric Deposition Program (NADP) considered representative of acidic precipitation falling on eastern Iowa was used as the permeant. In general, the results indicated that the inherent acid neutralizing capacity present in untreated foundry sand due to the addition of alkaline materials during casting processes was able to buffer the flowing permeant for many thousand pore volumes in a pH range that yielded total aqueous lead concentrations near the proposed U.S. EPA PDWS for lead. Raising the leaching pH above the optimum range by adding lime resulted in higher lead levels in the column effluent. Total alkalinity measurements of the effluent samples indicated flow rates were such that lead was at its equilibrium solubility limit with respect to the lead carbonate mineral. This indicated that reaction kinetic constraints had not influenced the measured lead concentrations.

Table 1
Results of Columns Testing at pH 4.6 on Leachate Composition

Test No.	% Lime Addition by Weight	Sampling Pore Volume	Sample pH	Total Aqueous Lead Concentration mg/liter
1[a]	0.0	1	10.68	0.039
1[a]	0.0	30	7.79	0.006
1[a]	0.0	4000	7.23	0.019
2[b]	0.0	5	8.28	0.015
3[c]	1.0	5	12.47	4.35
3[c]	1.0	1000	8.35	0.011

[a] sample length 1.0 in.
[b] sample length 5.0 in.
[c] sample length 2.0 in.

ALTERNATIVE EVALUATION

The NCP 40 CFR 300.68 (i) requires the selection of the cost-effective remedial action that effectively mitigates and minimizes threats to and provides adequate protection of public health, welfare and the environment. Based on the previously discussed site characterization and the associated health effects concerns, it is apparent that it is desirable to take response actions which will reduce the potential for contamination migration from the site, enhance site appearance and stability and reduce future maintenance. The principal concerns regarding the site are:

- The prevention of groundwater contamination by lead in excess of drinking water standards
- The prevention of direct receptor contact with the foundry sands
- The prevention of dust transport and erosional surface run-off into the adjacent storm water retention basin (Fig. 2).

Various response action alternatives were chosen based upon their applicability to the site conditions, contaminant characteristics and health endangerment considerations mentioned above. These alternatives were then assessed and compared with regard to their performance, reliability, constructability, short- and long-term environmental and safety impacts and other relevant considerations in compliance with sections 121(a) and 121(b) of the SARA. The alternatives were developed to cover the full range of options at the site, even though extreme options (e.g., "No Action" and "Clean Closure and RCRA Cap" Alternatives) are not considered viable, but only establish boundaries for the discussion of more viable options.

The first alternative evaluated was "No Action." While there have been no measurable adverse impacts on public health from the site, the no action alternative is ineffective in preventing direct receptor contact and future contaminant migration via the runoff, erosion or air pathways. In addition, there would be no monitoring over the long term to check for possible unexpected conditions which are not evident at this time. This alternative therefore is considered inappropriate.

The second alternative considered required contouring the foundry sand surface to enhance drainage, in-place compaction, establishing a vegetative cover and a post response maintenance and groundwater monitoring program. This alternative takes advantage of the existing acid neutralizing capacity of the foundry sand to restrict subsurface migration, minimizes direct receptor contact and provides for a post-response program. This alternative merited serious consideration because it was the most cost-effective solution considered which can achieve the degree of clean-up required under SARA and was compatible with future site use. The U.S. EPA Region VII, however, rejected this alternative based upon their concern for long-term stability of the cover and potential variation of ANC within the foundry sand.

The third alternative required recontouring the foundry sand surface followed by in-place precipitation immobilization (IPI) of lead by addition of a suitable fixing agent into the top 8 to 12 in. of foundry sand. The site then would be covered with a 2-ft. compacted clay cap and a 2-ft. vegetative/drainage layer to reduce infiltration through the foundry sand and restrict the waste exposure to wind surface water erosion and direct contact. This action is complimented by a post-response maintenance and groundwater monitoring program. This option significantly enhances the protective level of the second alternative by increasing the acid neutralizing capacity of the foundry sand materials. In addition, the clay cap and vegetative cover provide substantial increased protection from direct contact with the foundry sand, increased erosional protection and significantly reduced the percolation through the underlying waste materials. This alternative also is compatible with future site use and is the response action that has been selected.

The fourth alternative considered parallels the action required by alternative three augmented by a full RCRA cap as prescribed by current U.S. U.S. EPA guidance. This guidance includes a synthetic liner to further minimize percolation through the underlying waste materials. Because of the substantial acid neutralizing capacity of the foundry sand and the use of IPI, the complete prevention of infiltration is not necessary at this site. Therefore, the increased costs associated with this alternative are not warranted.

Other alternatives evaluated include partial (waste above 500 mg./kg. total lead) or total off-site removal of the foundry sand followed by the capping of the site. These alternatives result in increased potential for receptor contact with the waste due to material handling, transportation and disposal. In addition, it exposes the owner to potential future CERCLA liability associated with off-site disposal. Finally, these alternatives are many times more costly than other assembled alternatives providing equivalent environmental benefit.

Metal reclamation has been evaluated at this site by both the owner and the Iowa State University Center for Industrial Research and Services (CIRAS). Studies have focused on the quantity of metals present in the foundry sand and surficial waste materials as well as the ability to segregate and recover these metals. These studies have concluded that metal reclamation is not economically feasible at this site.

The results obtained from the geochemical assessment and laboratory treatability studies undertaken in the development of alternatives three and four support the conclusion that the maintenance of leaching pH in the range of 8 to 10 with high alkalinity levels should limit the long-term release of soluble lead to near or below the proposed U.S. EPA PDWS. Based on this, in-place

Table 2:
Economic Analysis of Potential Remediation Processes

Alternative	Capital Cost $	Annual O & M Cost $
1. No action	0	0
2. Contour, topsoil	200,400	7,100
3. IPI, clay cap, and monitor	781,000	7,100
4. IPI, RCRA cap and monitor	1,423,000	7,100
5. Partial off-site removal, clay cap and monitor	2,760,000	7,100
6. Clean closure RCRA cap and monitor	35,912,000	7,100

precipitation immobilization alternatives were developed consisting of the addition of 5% by weight calcium carbonate in the form of crushed limestone into the upper 1.0 ft. of the surficial foundry sand. Economic comparisons (Table 2) between the IPI alternatives and standard remedial action options involving partial or complete off-site removal indicated that the use of IPI would substantially reduce the cost of site clean up.

CONCLUSIONS

Site groundwater data suggest that there has been no significant lead migration into the groundwater beneath the former A.Y. McDonald foundry site since the presence of the $PbCO_3$ mineral, cerrusite, currently is controlling the dissolved lead concentration to levels near or below the proposed U.S. EPA Primary Drinking Water Standards. The evaluation of an in-place precipitation immobilization alternative that requires carbonate addition to the lead-containing surficial foundry sands indicates that the use of IPI is significantly more cost-effective than either partial or complete removal alternatives at the site. The IPI technique also should provide a technically sound permanent solution for controlling lead release from the site to acceptable levels.

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