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FEASIBILITY OF IN SITU SOLIDIFICATION/STABILIZATION OF LANDFILLED HAZARDOUS WASTES

by

J. Bruce Truett
Richard L. Holberger
Kris W. Barrett
The MITRE Corporation
McLean, Virginia 22102

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Project Officers

Wendy J. Davis-Hoover
Donald E. Sanning
Solid and Hazardous Waste Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to prevent and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and is a most vital communications link between the researcher and the user community.

The application of solidification/stabilization technology to uncontrolled hazardous waste sites is considered a possible solution to the problem of toxic discharges from landfilled hazardous substances. This report summarizes research that has been conducted to determine if current technology is suitable for in situ application at landfills as a solution to the problem.

Francis T. Mayo
Director
Municipal Environmental
Research Laboratory

ABSTRACT

This study investigates the feasibility of solidifying or stabilizing hazardous industrial wastes that are already in place at a landfill. Solidification methods considered include (1) incorporating the waste in solids formed by cement, lime, or lime/siliceous materials, organic polymers, or thermoplastic materials such as bitumens; (2) fusing the waste with soil to form a vitreous solid, and (3) isolating the waste by enclosing it in impermeable, inert envelopes (surface encapsulation) or smaller capsules (microencapsulation), or by constructing an impermeable barrier of grout or other material that completely surrounds the entire mass of landfilled waste. Other waste stabilization methods that do not involve solidification were also considered (e.g., neutralizing or destroying hazardous constituents by chemical reaction or immobilizing toxic ions by ion-exchange mechanisms). The neutralizing or immobilizing agents can be applied most effectively by injection into the fill or surrounding soils.

None of the solidification methods appears generally applicable to large landfills containing mixed industrial wastes, although two methods (injection of reactive chemical agents and vitrification), appear promising for some specific applications.

The more promising methods were examined for possible application at a specific landfill--the 8.5 acre LaBounty site at Charles City, Iowa. This fill poses several problems for in situ remedial actions, including a diversity of chemical constituents that are located partially below the water table and in contact with highly-fractured bedrock containing an important aquifer system. None of the solidification/stabilization methods appears suitable for in situ application as a principal means of pollution control at this site because of large variations in the permeability of the fill material and the diverse chemical composition of the wastes.

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SECTION 1

INTRODUCTION

Purpose

The principal purpose of this report was to investigate the feasibility of solidifying or stabilizing hazardous industrial wastes that are already in place at a landfill. An ancillary purpose is to investigate the potential applicability of solidification/stabilization methods to the specific conditions at one waste disposal site--the LaBounty site at Charles City, Iowa.

Background on In Situ Solidification/Stabilization Technology

Since the early 1970's, the U.S. Environmental Protection Agency (EPA) has been involved in research, development, and demonstration of methods for the proper management of hazardous wastes. This activity was given added impetus by the passage of the Resource Conservation and Recovery Act of 1976 (RCRA) or Public Law 94-580, which amended the earlier Solid Waste Disposal Act and focused attention on problems relating to hazardous wastes and the need for improvement in hazardous waste management techniques.

EPA's Municipal Environmental Research Laboratory (MERL) has sponsored much of the research and development on methods for managing solid and hazardous wastes. One of the approaches investigated by MERL involves incorporating or encapsulating the waste in an inert solid material in such a way as to prevent the release of hazardous components to the environment, or to limit the

rates at which hazardous materials are released (through leaching or other mechanisms).

A number of techniques have been developed for stabilizing liquid, semi-solid, or solid wastes in this manner. Some are patented, and several are currently in commercial use. Under contract to MERL, the Army Corps of Engineers Waterways Experiment Station has surveyed the various solidification/stabilization methods, described the procedures involved, identified the relative advantages and disadvantages of each method, and prepared a "Guide to the Disposal of Chemically Stabilized and Solidified Wastes."[17]

With few exceptions, the methods developed thus far have been designed to pretreat hazardous wastes before final disposal in landfills or by other means. The wastes can be classified by size (if appropriate), and thoroughly mixed with fixative agents under controlled conditions. The materials being processed can be tested at various stages to insure that chemical reactions are complete and the product will have the desired properties of hardness, resistance to leaching, etc.

MERL is interested in the feasibility of applying solidification/stabilization methods to hazardous wastes already deposited in landfills without first removing the wastes and treating them by conventional solidification/stabilization technology. One solidification method has been designed for in situ application: thermal fusion caused by passing an electrical current through the mixture

of waste and soils, and followed by vitrification upon cooling of the fused materials. This report discusses the feasibility of in situ application of this and other methods.

Selection of the LaBounty Demonstration Site

Chemical wastes from a manufacturer of veterinary pharmaceuticals and agricultural chemicals had been deposited at the LaBounty site in Charles City, Iowa, from 1953 until the site was closed in 1977. Following field investigations conducted in 1978, EPA Region VII and State agencies concluded that contaminated leachate from the site was entering the groundwater and the Cedar River in the vicinity of the site. Remedial actions were proposed by the generator who placed his wastes at the site. At the request of EPA Region VII, and in response to a Congressional mandate, the LaBounty site was surveyed by research personnel of the Municipal Environmental Research Laboratory, and the site has been considered as a possible demonstration site for in situ stabilization techniques.

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SECTION 2

CONCLUSIONS

Conclusions are presented here concerning the feasibility of in situ solidification/stabilization in general, and its application to the LaBounty site in particular.

General Feasibility of In Situ Solidification/Stabilization

- A number of methods are available for effectively solidifying or otherwise stabilizing a great variety of hazardous wastes, particularly inorganic wastes, but also an increasing number of organics. Some of these methods have been demonstrated and are commercially available for large-scale applications. All of the demonstrated methods require thorough mixing of the waste and solidification/stabilization agents.

- The effective use of existing solidification methods for in situ application to wastes buried in landfills is technically infeasible (with one possible exception) at the current state of technology. The possible exception--vitrification by electrical energy--is economically infeasible for large-scale use with most industrial hazardous wastes.

- Effective in situ application of existing stabilization methods that do not involve solidification is feasible for landfilled wastes under certain conditions where simple neutralization and/or oxidation-reduction reactions are possible.

- No actual examples of large-scale applications of in situ solidification or stabilization in the U.S. were identified during the present study.

- Two commonly encountered characteristics of industrial landfills that militate against the in situ application of solidification/stabilization technology are:

  - Large variation in permeability of the landfilled wastes (and intermixed soils) from one part of the fill to another.

  - Diversity in the chemical constituents of the wastes and variations in their concentration from one part of the fill to another.

- Chemical components of some wastes may interfere with the desired action of certain solidification/stabilization agents, whether they are applied before deposition of wastes in a landfill, in situ, or after the wastes have been removed. There appears to be no generally available base of quantitative data on how various concentrations of specific interfering substances affect the performance of specific solidification/stabilization agents.

Feasibility of In Situ Solidification/Stabilization at the LaBounty Site

- Identified solidification/stabilization methods are infeasible for in situ application at the LaBounty landfill, principally because of four conditions at this site:

  - Large variations in permeability of the chemical fill and soils from one part of the fill to another;

  - The diverse chemical composition of the landfilled wastes and their heterogeneous distribution within the fill;

  - The suitability of the principal hazardous constituents of the site to currently available in situ methods; and

  - The highly fractured condition of bedrock underlying the site.

SECTION 3

METHODS OF IN SITU SOLIDIFICATION/STABILIZATION

This section identifies methods for solidifying and stabilizing hazardous waste materials and discusses their characteristics that might affect their practicality for use with wastes in landfills.

The terms "solidification" and "stabilization" are used in EPA's Guide to the Disposal of Chemically Stabilized and Solidified Wastes[17] to refer to treatments that (a) improve waste handling and physical characteristics, (b) decrease the surface area across which transfer or loss of contained pollutants can occur, and (c) limit the solubility or detoxify any hazardous component of the waste. Solidification implies that the treated wastes will be contained in a solid mass, whereas stabilization implies that the hazardous components of the waste will be rendered insoluble or otherwise immobile or that their hazardous characteristics (e.g., toxicity) will be neutralized. Both the solidification and stabilization approaches to waste treatment generally involve the addition of materials to effect hardening or neutralization.

Most of the methods for solidification/stabilization were developed for use with liquid, semi-solid, or solid wastes before deposition in landfills or other disposal sites. Whether such methods can be applied effectively to landfilled wastes in situ is discussed in Section 4.

Whether the application of a given solidification/stabilization method to a specific landfilled waste should be considered to be an

in situ application is not always clear. Before specific solidification/stabilization methods are described in this section, the scope of in situ treatment will be discussed.

Scope of In Situ Waste Treatment

In this report, the term in situ treatment of landfilled waste materials means that the treatment is applied to the landfilled waste while located within the fill. It is not used to mean treatment of wastes excavated from the fill, irrespective of whether the waste is excavated as a total mass or removed in increments, and irrespective of whether the solidified, stabilized product is replaced in the original landfill or otherwise disposed of. Whenever the solidification or stabilization process occurs external to the fill, the application is not considered in situ in the present report. Methods of non-in situ solidification/stabilization of wastes have been adequately described in other EPA documents,[17,18,21] vendor publications,[19,30] and the open literature.[20] These methods do not require extensive treatment in this report.

There are two borderline cases that require clarification. One occurs when the stabilization is effected by injection of a treatment agent into the buried mass, producing a polluted leachate while leaving the original waste in a stabilized, non-hazardous condition. The basic approach--injection of a stabilizing agent into the buried mass--qualifies as an in situ procedure, although subsequent treatment of the leachate (or perhaps gaseous byproduct), if pumped

or otherwise removed from the fill, is not considered to be in situ treatment.

Another borderline case that could logically be classified as in situ stabilization is that of isolating the waste from any driving force that would cause the release or dispersal of hazardous components to the environment. In the case of an existing landfill, this approach could involve sealing the entire mass of the fill--top, bottom, and sides--by impermeable (or highly impervious) barriers that prevent the infiltration of precipitation or the flow of groundwater through the fill, thereby precluding the formation of polluted leachate or the movement of pollutants from the site.

Several problems arise if macro-scale isolation is considered as a form of in situ stabilization. The foremost among these is that, in most practical situations, complete physical isolation of the waste mass is not undertaken as an initial remedial step.[18,19,20] Instead, partial barriers such as upgradient cut-off walls, surface caps, or bottom seals are installed sequentially until the desired limitation of pollutant release is achieved. These separate steps cannot logically be considered as either solidification or stabilization. Second, this approach does not appear to fall within the purview of those sections of the Environmental Research and Development and Authorization Act of 1981 (PL 96-569) that pertain to in situ solidification. Third, this approach does not fall directly within the definition of in situ solidification/stabilization given in EPA's guidance documents on solid waste treatment.[17,18]

However, because the isolation/barrier approach to pollution control can be used in conjunction with certain types of waste solidification techniques, and since in its ultimate form it is a type of in situ stabilization, this approach is discussed in the present report. The feasibility of installing partial barriers or enclosures that do not effect complete isolation is not evaluated.

Isolation of the hazardous materials can also be approached on a less massive scale, in the form of "surface encapsulation" and "microencapsulation" techniques. For the present study these techniques will be considered as forms of solidification, and are discussed further in that context.

Solidification Methods

In most of the solidification techniques, the waste is chemically or mechanically bound within a solid in such a way that pollutants are not readily released upon exposure to air, water, soil, or the mild acids commonly encountered in the atmosphere or naturally occuring aquatic environments. Some of the methods can produce solid blocks, pellets, or other forms that can be stored or used in a load-bearing landfill. Other methods produce a slurry that can be placed on a landfill to harden into a surface with relatively high load-bearing capabilities.

The principal types of solidification/stabilization techniques are outlined below. Most of these techniques have limits on the proportion of organic pollutant species that can be included within the mix. These summary descriptions

are based mainly on earlier EPA publications,[17,18,21] to which reference is made for more complete descriptions of the respective methods.

Crystalline Matrix Methods

One type of solidification process is based on the formation of crystalline structures such as the hydrated limestone-type crystals formed by portland cement. Processes of this type usually involve mixing a solution or slurry of the waste material with the solidifying agent, which may be lime, portland cement, various siliceous materials, or other inorganic materials that set up to form a rigid crystalline or semi-crystalline substance. Vendors for some of the patented solidification processes assert that ionic components of the waste (e.g., metallic ions) are incorporated within the crystal structure. This method is generally limited to wastes with low organic content, especially when the organic material is in liquid form. Various sources quote limits of organic content ranging from 5 to 20 percent.[10,28] The allowable percentage could reasonably be expected to depend on the type of solidifying agent, the type of organic material, and the desired properties of the solid product.

Organic Polymer Methods

Another type of solidification process involves dispersing the waste within a liquid organic monomer, then adding an agent that causes the monomer to polymerize, forming either a dense, rigid solid (as from an epoxy monomer) or foam-like mass (as from urea-formaldehyde) in which particles of the waste are trapped or

enclosed. The urea-formaldehyde polymer system sometimes used in this type of process is more susceptible to shrinkage or degradation during long-term environmental exposure than solidification systems employing polymers such as polyesters or styrenes.

Thermoplastic Matrix Methods

A third type of solidification process involves mixing the waste with a bituminous material such as asphalt or other thermoplastic organic materials such as paraffin. The mixing may be accomplished by stirring the waste with the molten thermoplastic material, or by mechanical blending and compression of the waste with the thermoplastic in solid or semisolid form. Depending on the type of thermoplastic and the conditions of mixing, the product will be a thermoplastic material that can be extruded, spread on surfaces, or cast into blocks. Products of this type are generally highly impervious to water.

Encapsulation Methods

A fourth type of solidification process involves placing the waste in an inert, impervious coating. In one such process, sometimes termed "surface encapsulation", the waste is solidified into blocks by processes as described in the preceding paragraphs, and the blocks are coated with a heavy, seamless, impermeable layer of a polymeric material such as polyethylene. A second process of this type encloses much smaller quantities of the waste in a manner

described as analogous in concept to pharmaceutical-type capsules, although not of the same size or geometric shape. In this method, sometimes termed microencapsulation, the waste is enclosed in a stable, inert material or in a degradable material which releases the waste material to the environment at a slow, controlled rate.

Thermal Fusion and Vitrification

A fifth type of solidification process involves vitrification of the wastes by application of heat. In the case of in situ applications, the heat could be generated by passing electric current through the mass of waste material. At sufficiently high temperatures, any soil or rock components of the waste will melt, most organic materials will decompose, and many metallic components will either fuse or vaporize. Gases and vapors may require recovery and/or treatment, depending on the composition of the wastes. Upon cooling, the fused mass will solidify into a glassy or crystalline product that has about the same chemical stability as granite;[30] however, the physical and chemical properties of the solid product might reasonably be expected to depend on the composition of the rock and soil.

Stabilization Methods

Stabilization by Addition of Chemically Reactive Agents

Some specific chemical constituents in wastes may be neutralized, immobilized, or rendered less harmful by specific additives

that react chemically with the hazardous constituent. A strongly acidic (or alkaline) waste could be neutralized by the addition of an alkaline (or acidic) material, or its level of acidity (or alkalinity) could be controlled by an appropriate buffering agent. A simple toxic species such as a cyanide might be de-toxified by reaction with a strong oxidizing agent such as the hypochlorite ion. Heavy metal ions may be immobilized by reaction with an additive that forms a precipitate of very low solubility, or may be rendered less harmful by reaction with a sequestering or chelating agent, although the resulting chelate might pose a separate problem.

In general, each individual pollutant (or in some cases, classes of pollutants such as heavy metal ions) in the waste could require different chemical agents to render it non-hazardous. Moreover, a particular chemical added to cope with one hazardous constituent might cause antagonistic or counterproductive reactions with other constituents. Thus the addition of an oxidizing agent intended to destroy a specific organic compound might also change the valence state of a metallic ion making the metal more toxic or mobile.

Stabilization by the Action of Ion Exchange Resins

Wastes containing heavy metals and certain organic compounds can produce leachate contaminated by toxic cations (e.g., heavy metals) and anions (e.g., cyanide). When such leachates contact selected ion-exchange resins under appropriate conditions, the toxic ions in the leachate will attach to the resin while releasing an

innocuous ion into the leachate. This approach has been applied for the detoxification of certain hazardous wastes in equipment designed for contacting the liquid waste within the resin. An alternative approach that might prove useful in landfills is to inject into the landfilled wastes or the surrounding soil, a fluid containing ion-exchange materials and a material that will polymerize or form a gel. Under appropriate conditions, the polymer or gel will form in situ and will be imbedded with the ion-exchange resin. The solid component (e.g., the polymer or gel, or a matrix of these materials and soil) will tend to impede movement of leachate through the soil while immobilizing toxic species in the leachate through the mechanism of ion exchange. Laboratory experimentation with this process indicates it to be technically feasible, but field demonstrations have not yet been reported.[29]

Advantages and Disadvantages of Selected Methods

The principal advantages and disadvantages of several classes of solidification/stabilization methods, including those outlined above, are summarized in Table 1. A listing of possible constituents of the treated wastes which might adversely affect the use of each technique is given in Table 2. The information in this table is entirely qualitative. Although individual vendors have information about the quantitative effects of specific interfering substances on the setting characteristics of grouts and the performance of specific solidification agents or techniques, information of this nature does not appear to be available in the open literature.

TABLE 1

ADVANTAGES AND DISADVANTAGES OF SELECTED SOLIDIFICATION/STABILIZATION TECHNIQUES CONSIDERED FOR POTENTIAL IN SITU USE

Advantages	Disadvantages
CRYSTALLINE MATRIX METHODS	
Cement-Based Methods	
- The amount of cement used can be varied to produce high load bearing capacities (making the waste concrete good subgrade and subfoundation materials) and low permeability in the product.	- Extensive pretreatment, more expensive cement types or additives may be necessary for waste containing large amounts of impurities such as borates and sulfates that affect the setting or curing of the waste-concrete mixture.
- Raw materials are plentiful and inexpensive.	- The alkalinity of cement drives off ammonium ion as ammonia gas.
- The technology and management of cement mixing and handling is well known, the equipment is commonplace, and specialized labor is not required.	- Relatively large amounts of cement are required for most treatment processes (but this may partly be offset by the low cost of material). The weight and volume of the final produce is typically about double those of other solidification processes.
- Extensive drying or dewatering of waste is not required because cement mixtures require water, and the amount of cement added can be adapted through wide ranges of water contents.	- Uncoated cement-based products may require a well-designed landfill for burial. Experience in radioactive waste disposal indicates that some wastes are leached from the solidified concrete, espcially by mildly acidic leaching solutions.
- The system is tolerant of most chemical variations. The natural alkalinity of the cement used can neutralize acids. Cement is not affected by strong oxidizers such as nitrates or chlorates. Pretreatment is required only for materials that retard of interfere with the setting action of cement.	- Organic wastes, especially oils, may interfere with setting or may affect properties of resultant solid.
- Leaching characteristics can be improved where necessary by coating the resulting produce with a sealant.	
Lime/Siliceous Methods	
- Product is generally a solid with improved handling and permeability characteristics.	- Lime and other additives add to the weight and bulk to be transported and/or landfilled.
- The materials are often very low in cost and widely available.	- Uncoated lime-treated materials may require specially designed landfills to guarantee that the material does not lose potential pollutants by leaching.
- Little specialized equipment is required for processing, as lime is a common additive in other waste streams.	- There is no evidence that it will fix organics.
- The chemistry of lime-pozzolanic reactions are relatively well-known. Sulfate does not cause spilling or cracking.	
- Extensive dewatering is not necessary because water is required in the setting reaction.	

TABLE 1
(continued)

Advantages	Disadvantages
ORGANIC POLYMER METHODS	
- Less treatment reagent is required for solidifying the waste than in other systems. The waste-to-reagent ratio is usually about 30% greater for a UF organic polymer system than with cement.	- No chemical reactions occur in the solidification process that chemically binds the potential pollutants. The particles of waste material are trapped in an organic resin matrix, and breakdown or leaching of the matrix will relese many of the waste materials.
- The waste material treated is usually dewatered, but it is not necessarily dried as in thermoplastic processes. (The finished, solidified polymer, however, must be dried before ultimate disposal.)	- Catalysts used in the UF systems are strongly acidic, and the waste-UF mixture must be maintained at pH 1.5 $\pm$ 0.5 for solidification to occur in a rapid manner. The low pH can put many waste materials into solution. If the pH is not lowered to 1.5, the polymerization is slow; solids will thus settle out, and the waste material will not be trapped effectively.
- The organic resin used is consistently less dense (specific gravity is approximately 1.3) than cement. The low density reduces the transportation cost related to the reagents and to the treated products.	- Uncombined or weep water is often associated with polymerized water. This must be allowed to evaporate to produce a fully-cured polymer. This weep water may be strongly acidic and may contain high levels of pollutants.. Waste-UF mixtures shrink as they age and will produce weep water during aging.
- The solidified resin is nonflammable, and high temperatures are not required in forming the resin.	- Some catelysts used in polymerization are highly corrosive and require special mixing equipment and container liners.
	- The reaction producing the resin may release fumes that can be harmful or disagreeable even in low concentrations.
	- Some cured resins, especially UF-based systems, are biodegradable and have a high chemical oxygen demand.
	- Secondary containment in steel drums is a common practice in the use of organic resins, which increases the cost of processing and transportation.

TABLE 1
(continued)

Advantages	Disadvantages
THERMOPLASTIC METHODS (including Bitumens)	
- The rates of loss to contacting fluids are significantly lower than those observed with cement-based and pozzolon systems.	- Expensive, complicated equipment requiring highly specialized labor is necessary for processing.
- By disposing of the waste in a dry condition, the overall volume of the waste is greatly reduced.	- The plasticity of the matrix-waste mixtures may require that containers be provided for transportation and disposal of the materials, which greatly increases the cost.
- Most thermoplastic matrix materials are resistant to attack by aqueous solutions, and microbial degradation is minimal.	- The waste materials to be incorporated must be dried, which requires large amounts of energy. Incorporating wet wastes greatly increases losses through leaching.
- Most matrices adhere well to incorporated materials.	- These systems cannot be used with materials that decompose at high temperatures, especially citrates and certain types of plastics.
- Materials embedded in a thermoplastic matrix can be reclaimed if needed.	- There is a risk of fire in working with organic materials such as bitumen at elevated temperatures.
	- During heating, some mixes can release objectionable oils and odors causing secondary air pollution.
	- Some organics are readily leached.
	- The incorporation of tetraborates of iron and aluminum salts in bitumen matrices causes premature hardening, and can clog and damage the mixing equipment.
	- Strong oxidizers usually cannot be incorporated into organic materials with the occurrence of oxidizing reactions. High concentrations of strong oxidizers at elevated processing temperatures can cause fires.
	- Dehydrated salts incoporated in the thermoplastic matrix will slowly rehydrate if the mixture is soaked in water. The rehydrated salt will expand the mixture causing the waste block to fragment and increasing its surface area greatly.

TABLE 1
(continued)

Advantages	Disadvantages
SURFACE ENCAPSULATION METHODS	
- The waste material never comes into contact with water, therefore, soluble materials such as sodium chloride can be successfully surface encapsulated.	- The resins required for ensapsulating are expensive.
- The impervious jacket eliminates all leaching into contacting waters as long as the jacket remains intact.	- The process requires large expenditures of energy in drying, fusing the binder, and forming the jacket.
	- Polyethylene is combustible, with a flash point of 350°C, making fires a potential hazard.
	- The system requires extensive capital investment and equipment.
	- Skilled labor is required to operate the molding and fusing equipment.
THERMAL FUSING AND VITRIFICATION METHODS	
- The process is assumed to produce a high degree of containment of wastes.	- Some constituents (especially metals) may be vaporized and lost before they can bind with the molten silice if high-temperature processes are used.
- The additives used can be relatively inexpensive (syenite and lime).	- The process is energy-intensive. The waste-silicate charge must be heated (often up to 1350°C) for melting and fusion.
- Can be performed without close contact between workers and waste materials.	- Specialized equipment and trained personnel are required for this type of operation.
	- No experience with organics, potential to create dioxin and other hazards.
IN SITU INJECTION OF NEUTRALIZING CHEMICALS	
- When the chemistry and circumstances are such that a hazardous material is amenable to chemical control, chemical injection may be a cost-effective method to correct a problem due to leaching.	- The fact that the source of the problem is buried deeply in the ground introduces many uncertainties such as the dimensions of the affected landfill volume, the concentration gradients in the system, whether any causative material is retained in drums only to continue to propagate the problem, etc.
- The method could potentially control a hazardous situation in which no other alternative is feasible.	- Some displacement of the pollutant, perhaps to environs outside of the landfill, will occur due to the injection of the added volume of the chemical solution.

TABLE 1
(concluded)

Advantages	Disadvantages
ISOLATION BY BOTTOM SEALING AND SURFACE CAPPING	
Bottom Sealing	
- Grouting has been a standard practice for many years and is very effective in gravel and sand.	- Drilling through the fill or waste material may be difficult because of unknown materials.
- Construction is relatively easy and can be performed at any time of year.	- The grout-take may be erratic when uncharted pockets of fine-grained soils are encountered.
	- Methods of determining that all voids between boreholes have been effectively grouted are not readily available. After installation, an ungrouted void would be difficult to locate.
	- Overdesign of the grout barrier is almost unavoidable because of the uncertainties involved in creating a solidified mass beneath the landfill to prevent seepage.
	- Bottom sealing has not yet been used on landfills and leachate may have a deleterious effect on the grout integrity.
Surface Sealing	
- Surface seals can be installed easily and economically.	- The cover and seal are subject to settlement and/or subsidence within the landfill.
- Contractors with equipment for major earthmoving projects are available throughout the United States.	- Vegetation will require maintenance until it has become firmly established (1 to 2 years).
- Cover material may be available free of charge.	- Specific sealing materials:
- Soil-cement and lime-stabilized soil construction is relatively inexpensive and can be accomplished with locally available equipment	a) Natural clay deposits may not be available. b) Fossil-fueled energy stations are not located in all parts of the country to supply fly ash c) Heavy metals in fly ash used as cover material can be mobilized by precipitation and cause pollution d) Soil-cement caps may rupture with settlement of the landfill. e) Membrane materials are expensive.
- Soil-cement seals do not have to be covered with soil.	
- Lime-stabilized soils can withstand some settlement without rupture	
- Bituminous paving can be used to cover large areas rapidly.	
- In landfills where subsidence potential is minor (i.e., those with shallow old well-compacted wastes), no further maintenance will be required.	- Large quantities of borrow materials may be necessary to establish required slopes on the landfill surface.
- Long service life is anticipated.	- Gas venting must be provided with all surface seals.
- Membrane seals can withstand some settlement.	

Source: Adapted from Reference 17.

TABLE 2

COMPATIBILITY OF SELECTED WASTE CATEGORIES WITH DIFFERENT WASTE SOLIDIFICATION/STABILIZATION TECHNIQUES

Waste Component	Treatment Type					
	Cement Based	Lime Based	Thermoplastic Solidification	Organic Polymer (UF)[a]	Surface Encapsulation	Thermal Fusion and Vitrification
Organics:						
1. Organic solvents and oils	Many impede setting may escape as vapor	Many impede setting may escape as vapor	Organics may vaporize on heating	May retard set of polymers	Must first be absorbed on solid matrix	Wastes decompose at high temperatures, may form undesirable pyrolysis products
2. Solid organics (e.g., plastics, resins, tars)	Good--often increases durability	Good--often increases durability	Possible use as binding agent	May retard set of polymers	Compatible--many encapsulation materials are plastic	Wastes decompose at high temperatures
Inorganics:						
1. Acid wastes	Cement will neutralize acids	Compatible	Can be neutralized before incorporation	Compatible	Can be neutralized before incorporation	Can be neutralized and incorporated
2. Oxidizers	Compatible	Compatible	May cause matrix breakdown, fire	May cause matrix breakdown	May cause deterioration of encapsulating materials	High temperatures may cause undesirable reactions
3. Sulfates	May retard setting and cause spalling unless special cement is used	Comaptible	May dehydrate and rehydrate causing splitting	Compatible	Compatible	Compatible in many cases
4. Halides	Easily leached from cement, may retard setting	May retard set, most are easily leached	May dehydrate	Compatible	Compatible	Compatible in many cases
5. Heavy metals	Compatible	Compatible	Compatible	Acid pH solubilizes metal hydroxides	Compatible	Compatible in many cases
6. Radioactive Materials	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible

[a]Urea-Formaldehyde resin.

Source: Reference 17

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SECTION 4

FEASIBILITY OF APPLYING SOLIDIFICATION/STABILIZATION METHODS TO LANDFILLED WASTES

This section outlines the conditions needed for effective solidification or stabilization of hazardous wastes by the methods identified in Section 3, and draws conclusions concerning the prospect for successful in situ application.

Factors Relating to the Feasibility of In Situ Solidification/Stabilization

All except one of the methods for waste solidification discussed in the preceding section require two conditions for successful in situ application. The exception is the fusion/vitrification method in Section 3. These conditions are:

- The composition of the waste must be known.
- The waste must be thoroughly mixed with the solidification agent(s).

Information on waste composition is needed to determine whether waste components will interfere with the proper "setting up" of the solidification material by crystallization, polymerization, gelling, adhesion, or other setting mechanisms. It is also needed to permit formulation of the proper additives for neutralization or detoxification, if this approach is used. The required level of detail concerning waste composition and physical characteristics differs for the various solidification methods.

In some processes such as containment of the solid within a bituminous material, the efficiency of the process (in terms of amount of waste contained per unit of solid formed) depends on the

thoroughness of the mixing. In cases where the waste participates directly in the chemical reactions that form the solid product (as in providing water of hydration in a cement-setting process) or when two or more additives must be blended (as with a polymerizing agent and a monomer in addition to the waste), the thoroughness of the mixing and blending is critical to the formation of a solid with the desired properties.

In the discussions that follow, it is assumed that the required information about the landfilled waste material, surrounding rock and soil, and groundwater, is available or can be determined at the required level of detail by established methods of sampling and analysis. This information may include chemical composition and physical characteristics of the waste; quantities and spatial distribution of the wastes; types and characteristics of surrounding and intermixed soils, rocks, and other geologic materials; and rates and directions of groundwater movement. Methods for acquiring these types of information are described in a variety of manuals, handbooks, and other sources (References 22 through 25, for example) and their use is demonstrated in the case study of the LaBounty disposal site (Section 5 and Appendix A).

The second requirement--that of providing a sufficient degree of mixing or contact between the landfilled wastes and the solidifying agent(s)--presents a more fundamental and difficult problem in the general case of multiple-constituent wastes buried and intermixed with soils of different textures and hydraulic conductivities.

Examination of the literature included in the References to this report (Section 6) reveals that the degree of mixing or contact that can be expected to occur when a solidification/ stabilization agent is applied in situ to a given landfilled waste is dependant on a large number of parameters. Several parameters that influence the degree and rate of contact are:

- viscosity of the applied agent
- permeability* of the waste material
- permeability* of surrounding soils (if they are contaminated)
- porosity of the waste material and soils
- degree of saturation of waste material and soils
- spatial distribution of the waste material relative to soils, rocks, and other surrounding materials
- setting time for solidification agents.

Methods of Applying Solidifying/Stabilizing Agents In Situ to Landfilled Wastes

The number of in situ application methods identified in the referenced literature or in vendor publications is very limited. These include:

*It is recognized that "permeability" involves the penetration of one substance (soil or waste) by another (usually a liquid). In standard soil determinations, the liquid is considered to be water. Permeability is sometimes reported in different units, depending on the method of determination. Here, permeability is considered synomymous with hydraulic conductivity and is reported in units of distance/time, since these are units used in the case study measurements in Section 5.

- Injection of the solidifying/stabilizing agents in liquid, slurry, or possibly gaseous form into the mass of landfilled wastes. Injection could be by means of porous tube(s) that penetrate the fill at strategic locations to the depth required, with the injection liquid under pressure, as required.[21]

- Application of the stabilizing agent to the surface of a fill, with infiltration by gravity into the (shallow) fill.

- Application of electrical energy by electrodes placed at strategic locations within the fill.

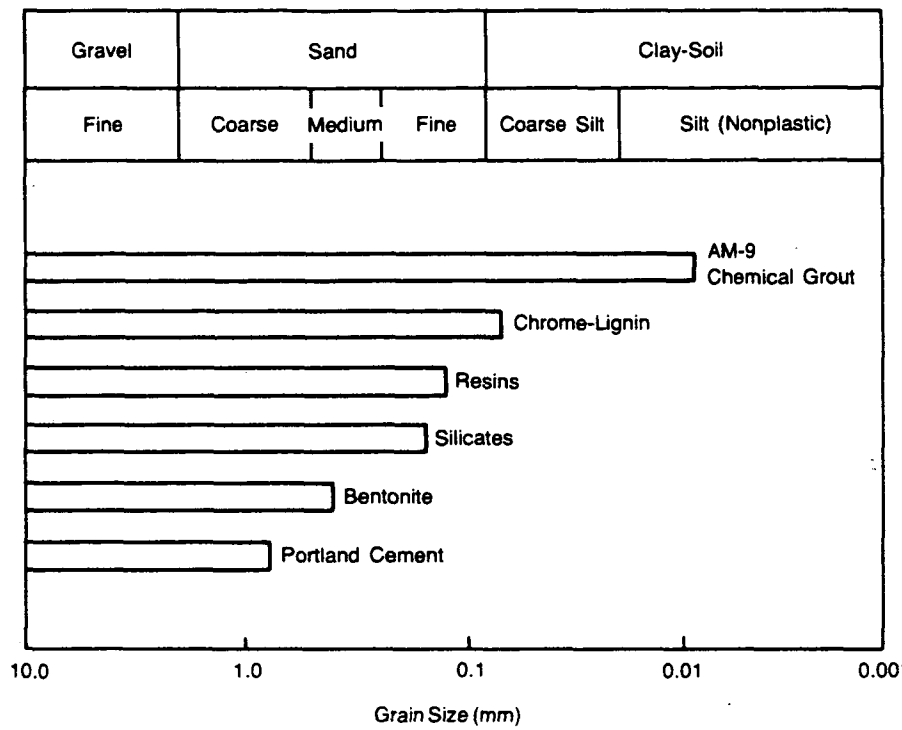
None of the referenced sources proposes methods of in situ mechanical mixing of a stablizing agent with buried solid wastes.

Injection of Solidifying/Stablizing Agents

Conditions under which chemical agents can be successfully applied by injection are limited by the extent to which the fill will be penetrated by the injected agent. The referenced literature contains few quantitative guidelines for determining degree or extent of penetration from a knowledge of properties of either the fill or the surrounding (or intermixed) soils.

One such guideline is available from the relationship shown in Figure 1. The upper part of this figure indicates the textural classes of soils in which various types of grouts with widely different viscosities can be successfully applied.

It must be carefully noted that the "limits for injectability" shown in Figure 1 relate to the injection of grout material into soil for the purpose of forming a seal or other solid structure. They are not designed for determining permeation into non-soil



Source: Reference 21

Figure 1. Soil Limits of Grout Injectability

materials such as chemical wastes, and do not indicate the degree to which such material will be incorporated, enclosed, or otherwise solidified or stabilized by the grout. The graph provides only general guidelines as to the textural classification of solid wastes (insofar as this parameter might be related to the particle size distribution of the waste materials) that can be penetrated by grouts of the types indicated. There is no implication of chemical compatibility of the waste and grout material, or of the effect of the waste on grout setting characteristics.

However, the figure does provide substantive guidance about conditions where injection should not be undertaken. For example, it would contraindicate the use of a siliceous-type material for solidifying wastes with textures finer than that of fine sand (with grain size of about 0.15 millimeters), or a lignin gel with wastes of finer texture than coarse silt (or about 0.04 millimeters grain size).

Surface Application

The stabilizing agent can be applied to the landfill surface in solid or liquid form and allowed to penetrate the waste materials by infiltration, provided the landfill is sufficiently permeable (and provided a chemical applied to the surface in solid form is dissolved or otherwise transported by rainfall or wetting).

Surface application would be appropriate primarily for very shallow, permeable, loosely-packed fills in which simple chemical

reactions are used for rendering a specific waste component less hazardous. This type of application does not appear generally useful where a buried waste is to be incorporated or enclosed in a rigid solid mass.

Application of Electrical Energy

This approach uses electrical energy at a rate sufficient to heat a mass of buried wastes to temperatures above the fusion point of surrounding soils and rocks. The energy is applied through electrodes inserted in the landfill on either side of the wastes (or portions thereof) to be melted. The electrodes are placed in the ground or fill by drilling or other appropriate means, and a strip of graphite in contact with the fill material is connected across the electrodes to act as a "starter" in melting the fill. A cover is placed over the surface of that portion of the fill which will be fused at a given placement of the electrodes. The cover is intended to capture gases released during the fusion. Captured gases are ducted to a treatment unit as necessary. The real world limitations of this technique have not been ascertained at this time.

Feasibility of In Situ Application of Solidification/Stabilization Techniques

All of the methods for waste solidification or stabilization outlined in Section 3 have been reviewed for in situ applicability to landfilled solid wastes. Our conclusion is that none of the methods are generally applicable to all situations, although two of them--chemical injection and vitrification--appear applicable in

certain specific situations. Some of the solidification methods appear useful if employed with other means of pollution control. These conclusions are based on either technical or economic considerations, or some combination of these.

Feasibility of Stabilization Methods Not Involving Solidification

Stabilization by injection of chemical agents into a landfill appears to be a technically and economically feasible approach to pollution control only in specific, limited cases where the following conditions exist:

- The waste contains a homogeneous waste stream that can be neutralized, chemically decomposed, or otherwise rendered harmless by relatively simple reactions with a single stabilizing agent.
- The pollutant components are either in solution or are in the form of a solid that is highly permeable* to the stabilizing agent (presumed to be in liquid form).
- Soils intermixed with the waste material (and contaminated soils which surround the waste and which must also be neutralized) are highly permeable to the stablizing agent.

The cost of stabilizing a hypothetical 10-acre landfill containing about 180,000 cubic yards of cyanide-polluted waste by injection of sodium hypochlorite solution has been estimated to be about 15 to 30 percent of the cost of excavating this quantity of fill[21]. Here the cost of excavating does not include the cost of neutralization, transporting, or reburial.

*Here, "highly permeable" is used to mean a permeation rate similar to that of clean sand to water--about 10^1 to 10^{-3} cm/second. The term is used only as a rough indication of the soil or waste permeability to the stabilization agent.

In cases where chemical injection is considered as a feasible method of stabilization, the following restrictive factors should be considered. First, the procedure is pollutant-specific. Second, long-term effectiveness of the procedure is predicated on the condition that the pollutant neutralized is not generated by continuing chemical or biological processes within the fill. Third, if the specific pollutant is in an undissolved solid form, the concentration of the stabilizing agent and the contact time must be adjusted to allow the reaction to proceed to completion. Fourth, the neutralizing agent, if not completely reacted, may itself be considered a pollutant.

Feasibility of Stabilization by the Action of a Solidifying Agent

No situations were identified in this study where in situ solidification of a landfilled waste by the action of crystallizing, polymerizing, or gelling agents appeared technically feasible. This approach to solidification requires intimate mixing or blending of the waste and the agent, or thorough dispersion of the waste throughout the solidifying agent. Thorough mixing or dispersion is difficult to insure through in situ application.

The two principal impediments to the use of this type of in situ stablization are (1) non-homogeneity of the landfilled wastes, with respect both to physical properties and chemical properties, and (2) the possible presence of waste components (not necessarily pollutants) that would interfere with proper setting of the solidification agent.

Feasibility of Soldification by Fusion/Vitrification

In situ vitrification of landfilled hazardous inorganic wastes appears technically feasible in concept, but very expensive relative to the other methods discussed in this report (with the possible exception of excavation-treatment-reburial, which is not considered an in situ method). Its technical feasibility for use with wastes containing materials that form toxic gases or vapors at high temperatures (for example, arsenic, mercury or organic materials that produce dioxins) depends on the effectiveness of the vapor-capture cover and vapor/gas treatment equipment.

The description of this method in a vendor brochure[30] indicates that it has been demonstrated in tests involving the fusion and solidification of 100 pounds of contaminated soil. The method was later demonstrated in tests involving over ten tons of soil.[31] Although the results of the latter tests were not available for review at the time this report is being written,* it is the tentative assessment of the authors that tests of this magnitude cannot be conservatively interpreted as demonstrating that this method is suitable for large-scale applications involving complex mixtures of wastes, such as the case-study landfill containing 350 million pounds of chemical sludge and 2.3 billion pounds of underlying or surrounding soil (as described in Section 5).

*Results are expected to be available in June 1982.

The estimated cost of fusion/vitrification falls in the range of $10 to $70 per cubic foot (1981 dollars), of which about 12 percent is for energy, 10 percent for equipment, and the remainder for labor. As with many developing technologies, the cost is expected to decrease greatly as experience is accumulated and improved techniques and equipment are developed. Comparison of these estimated costs of fusion/vitrification with those of several alternative methods for controlling pollution from landfills (as presented in Reference 21 and updated to 1981 dollars) suggests that most of the alternatives, with the possible exception of complete excavation-treatment-reburial, are substantially less costly. The cost differential depends strongly on types of waste and other site-specific factors (including labor costs).

If, for either technical or economic reasons, the fusion/vitrification method should not prove feasible for use with large-scale landfills containing complex mixtures of chemicals, it may nevertheless prove to be appropriate and cost effective for treatment of lesser quantities of highly hazardous wastes in landfills, especially if the removal of the wastes would present severe problems of environmental contamination or threats to the health of personnel involved in excavation and treatment.

Solidification/Stabilization Used in Combination with Other Pollution Control Measures

The materials produced by some of the solidification/stabilization methods discussed in Section 3 are suitable for use in the

construction of cover caps or cutoff walls for controlling rainwater infiltration or groundwater flow through a landfill. For example, the slurry produced by incorporating certain inorganic wastes with portland cement will set up to form a solid with load-bearing characteristics similar to that of conventional concrete and with low leachate-forming characteristics. The specific characteristics of the solidified materials depends on the nature of the waste, the proportion of waste to cement, the use of other additives, the thoroughness of mixing, and possibly other factors. An appropriately blended slurry could be used to form a strong, rigid, low-permeability, slow-leaching, upgradient barrier to direct groundwater flow around a landfilled area and thus reduce the quantity of leachate formed in landfill.

In general, a cement-, lime-, or silicon-based solidification agent incorporates inorganic wastes more successfully than organic, especially if the latter are of an oily nature. Some bitumen-based agents can accommodate many organic as well as inorganic waste materials. A stabilized waste formed by mixing with bituminous materials or fly ash might also be used to construct a slow-leaching, upgradient barrier or surface cover.

Regardless of the solidification/stabilization method applied to produce materials for use in groundwater diversion structures or surface covers, the wastes to which these methods are applied would have to be first removed from the fill and then processed in

equipment capable of effecting the required degree of mixing or blending. Hence the process(es) would not be in situ applications according to the definitions in Section 3. Nevertheless, combined approaches of the types mentioned here do provide a possible means of on-site treatment that can reduce the amount of materials to be transported and can reduce the amount of unstabilized waste that remains in the fill. The portions removed and stabilized could be selected to include the most hazardous, or most soluble (leachable), or most highly concentrated portions of the landfill, as appropriate.

SECTION 5

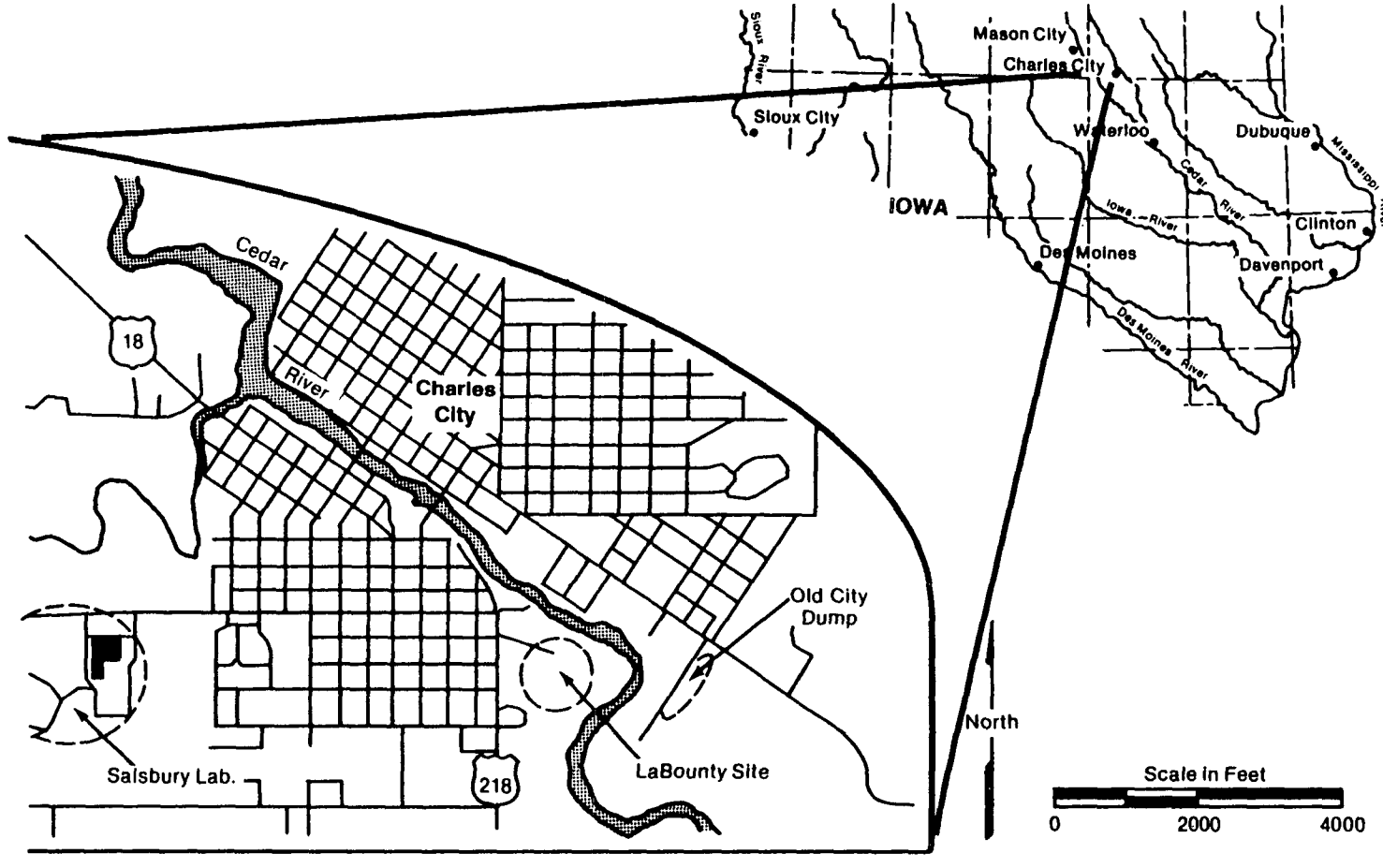
DATA AND OBSERVATIONS RELEVANT TO IN SITU STABILIZATION AT THE LABOUNTY SITE

The LaBounty waste disposal site was identified as a source of chemical pollutants in the groundwater and in the Cedar River through an extensive sequence of field investigations. Some of the principal investigations are outlined in Appendix A.

This section briefly describes the prominent geophysical and hydrogeologic characteristics of the LaBounty site and presents data relating to its suitability for a case study of in situ stabilization techniques. The general location of the site is shown in Figure 2.

Geological Characteristics

The site is located on the west side of the Cedar River in the alluvial deposits which include the floodplain and a low terrace. The northeastern one-third of the site overlays a portion of an abandoned channel of river. The alluvium is characterized by various combinations of clay, silt, sand, and gravel and typically becomes coarser at greater depths. For example, the coarser cleaner sands are generally located near the alluvial-bedrock and the finer sands, silts, and clays are closer to the alluvial surface. Underlying the alluvium is a fractured bedrock unit consisting primarily of limestone, with dolostone and shale, the Coralville members of the Cedar Valley formation. The upper few feet of the member has weathered to a calcareous clay which is not considered to be a continuous unit and does not act as an aquiclude.[15] Contours of



Source: Reference 1

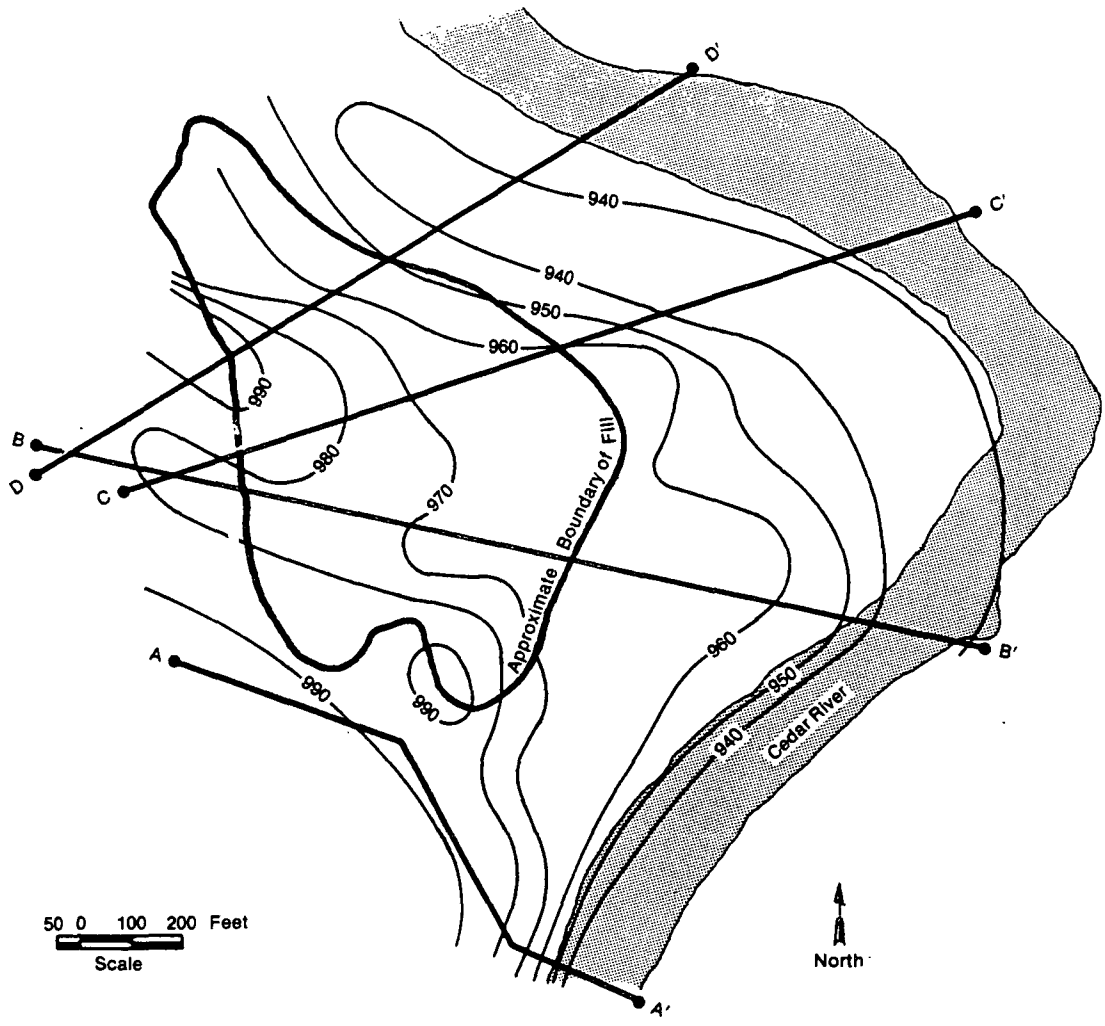
Figure 2. LaBounty Site Location Map, Charles City, Iowa, and Vicinity

the irregular upper surface of the upper bedrock (Coralville and Rapid members) are shown in Figure 3. The map in this figure was developed from borings data. The approximate boundaries of the landfill are also shown. The surface of the site is at an elevation of about 1000 feet, although this varies from one portion of the site to another. The bedrock contours suggest that the fill material lies above a bedrock bench that ranges in elevation from 970 to 990 feet. The bench is presumably cut into the Coralville member. The contours in Figure 3 suggest that the bedrock surface drops off steeply to the north and southeast and gently to the east.[4] Comparison of boring and seismic data suggest that two valleys exist in the upper surface of the bedrock, and that one valley passes beneath much of the chemical fill area (Figure 3).

The upper (Coralville) member of the Cedar Valley Formation is underlain by two other limestone and dolomitic limestone members separated by shale or shaley zones, as shown in Figure 4.

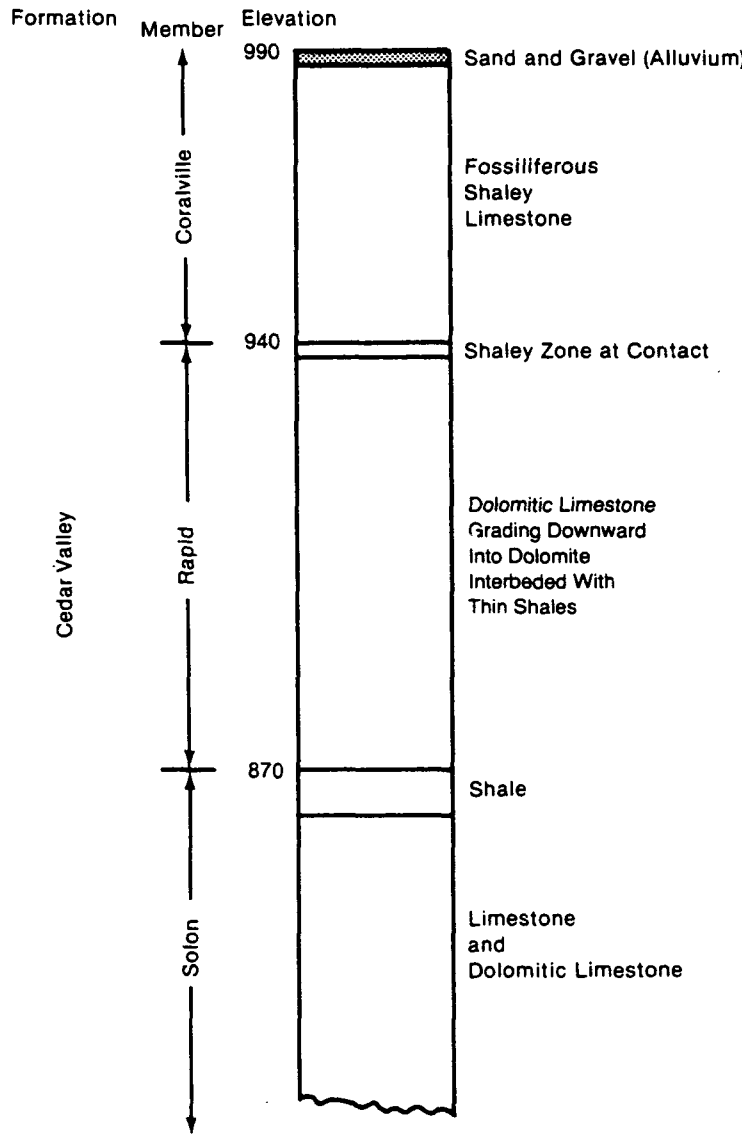
Hydrogeologic Characteristics

The Cedar Valley Formation includes an important aquifer system that supplies water to an area with a population of over 250,000 in northeast Iowa. The system involves upper and lower aquifers separated by a shale aquiclude. The shale layer was encountered at an elevation of about 870 feet (that is at a depth of about 120 feet below the ground surface) at Well No. 3 (Figure 4). The extent and thickness of the shale has not been determined.[15] The upper



Source: Adapted from Reference 15

Figure 3. Bedrock Topography at the LaBounty Site



Source: Adapted from Reference 4

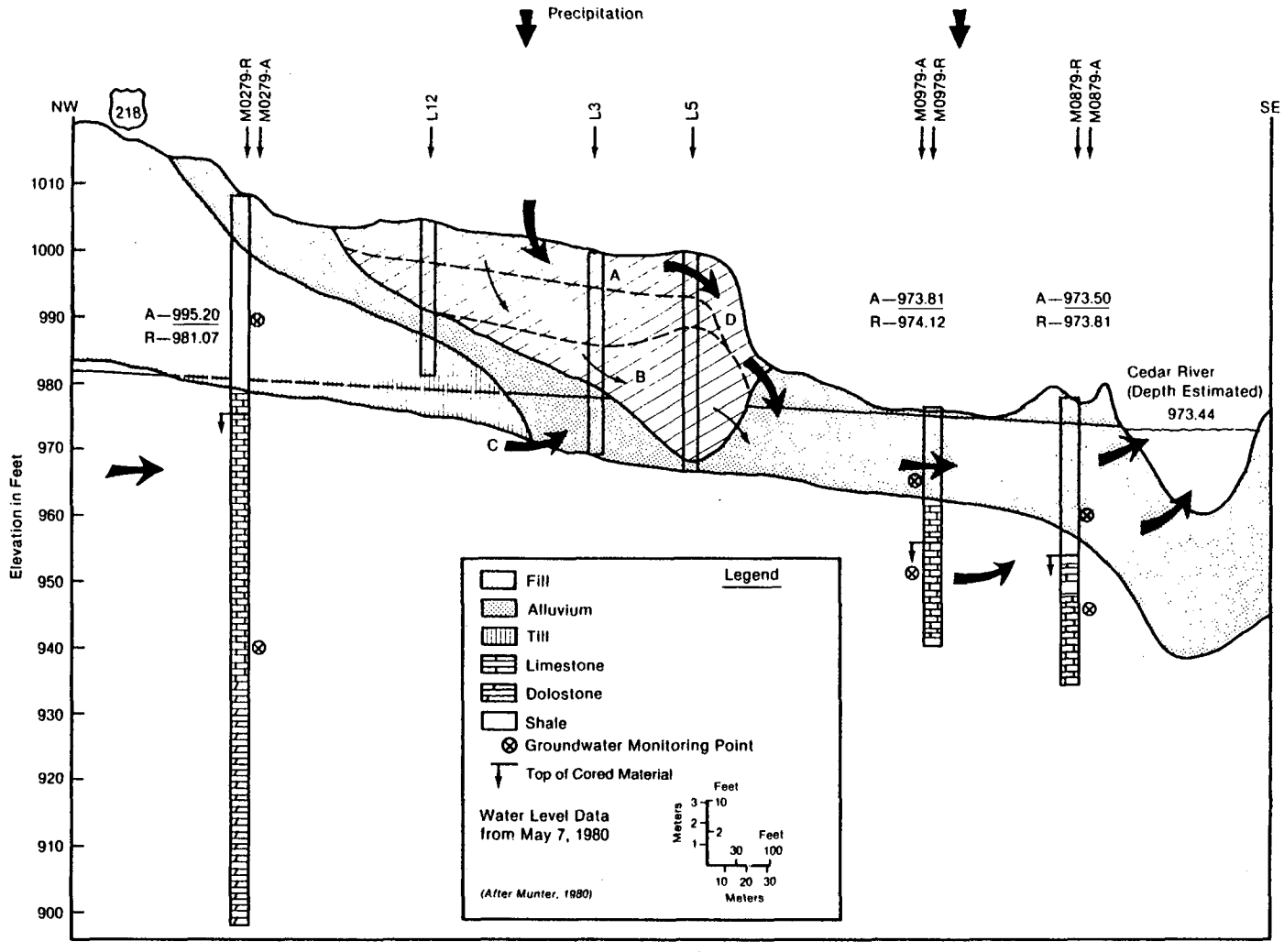
Figure 4. Generalized Geologic Section at the LaBounty Site

bedrock aquifer (Coralville and Rapid members) is hydraulically connected with the alluvium.

A generalized west-east cross-section diagram of the LaBounty site indicating probable flow patterns is shown in Figure 5 (corresponding to section B-B[1] in Figure 3. The Coralville member contacts the alluvium on the western side of the landfill. On the northern side, the Coralville member has been eroded and the Rapid member is in contact with the alluvium.[15] Groundwater is thought to discharge into the Cedar River in this area. Glacial till is encountered beneath the alluvium on the western side of the disposal area and extends under the disposal area in some locations (Figure 5). The hydraulic conductivity of the till is much lower (probably by several orders of magnitude) than the alluvium or the highly fractured upper bedrock, thus forming an impediment to groundwater movement.

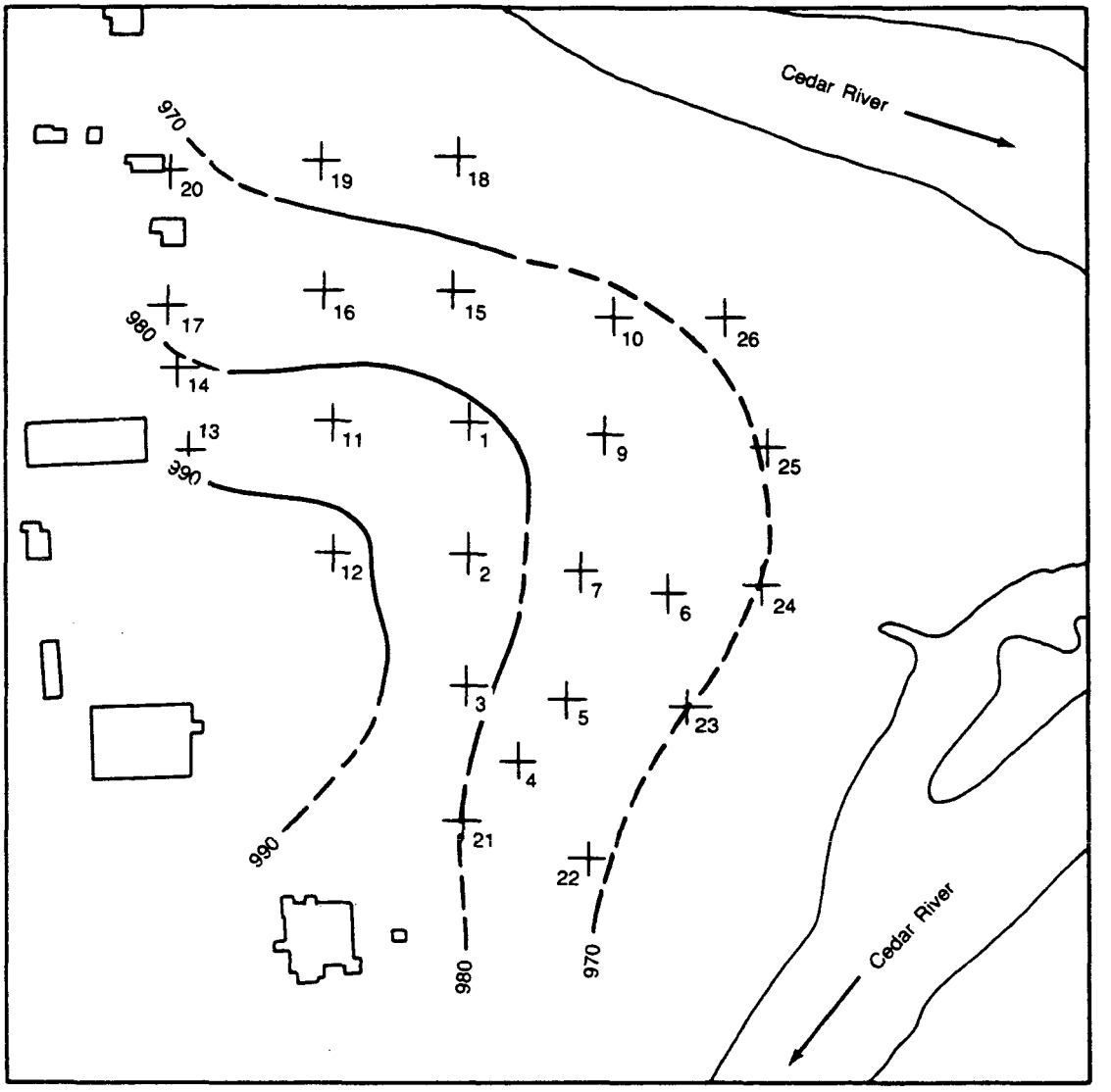
The lower aquifer (Solon Member) is artesian in this vicinity, exhibiting a hydraulic pressure of 12-14 feet greater than the upper aquifer (Coralville and Rapid members). This differential has been observed to vary with time and drought conditions.

Leachate moving laterally from the disposal site has contaminated the alluvial sediments and entered the alluvial groundwater and upper aquifer (Coralville and Rapid members) as well as the river. Alluvial groundwater elevations at the site are indicated in Figure 6. (Note: This figure is intended only to indicate the general patterns of groundwater elevations at the site. These



Source: Reference 11

Figure 5. Conceptual Model of Water Flow at the LaBounty Site Before Capping–1980



Note: Water Level Contours Based on Measurements at 1, 3, 12 and 16 During 6/22 to 7/1/77

Scale in Feet

0 125 250 500

Source: Reference 16

Figure 6. Groundwater Elevation Contours at LaBounty Site

groundwater contours are based on data from 1977, and do not correspond exactly with groundwater elevations shown in Figure 5, which are based on an observation in 1980.)

Waste Characteristics

Extensive studies have been made of chemical wastes placed in the LaBounty site. This subject has been investigated by analyzing the chemical manufacturer's production operations, performing rough materials balances, and sampling and analysis of both fill material and leachate from the disposal site (see Appendix A).

Information about the chemical characteristics of the wastes, as needed for investigating the feasibility of in situ stabilization, are derived primarily from data developed during the July 1980 measurement program (see Section 5). Additional information on chemical characteristics of the fill can be found in Reference 1.

Estimated quantities of some hazardous chemicals contained in wastes deposited at the LaBounty site are summarized in Table 3.

Soil Characteristics

All data in this report pertaining to soils at the LaBounty site, either in the fill material or underlying or surrounding the fill, are based on the July 1980 field investigation, and are reported with other results of this investigation in Section 5.

Location of Wells; Drilling and Core Sample Sites

Boring locations for the July 1980 field investigation were selected jointly by representatives of EPA's Municipal Environmental Research Laboratory and the National Enforcement Investigations Center on the basis of the following criteria:[8]

TABLE 3

QUANTITIES OF THE MORE PREVALENT HAZARDOUS MATERIALS
DEPOSITED AT LABOUNTY SITE
(August 1977)

Compound	Kg	lb
Asrenic	2,740,000	6,044,000
1,1,2-Trichloroethane	32,000	70,000
Nitrobenzene	130,000	280,000
Orthonitroaniline	680,000	1,500,000
Phenol	12,000	27,000

Source: Reference 8.

- Borings penetrating thick chemical fill
- Borings with high arsenic concentration
- Sites representing older, intermediate, and more recently deposited wastes (filling generally progressed from west to east.

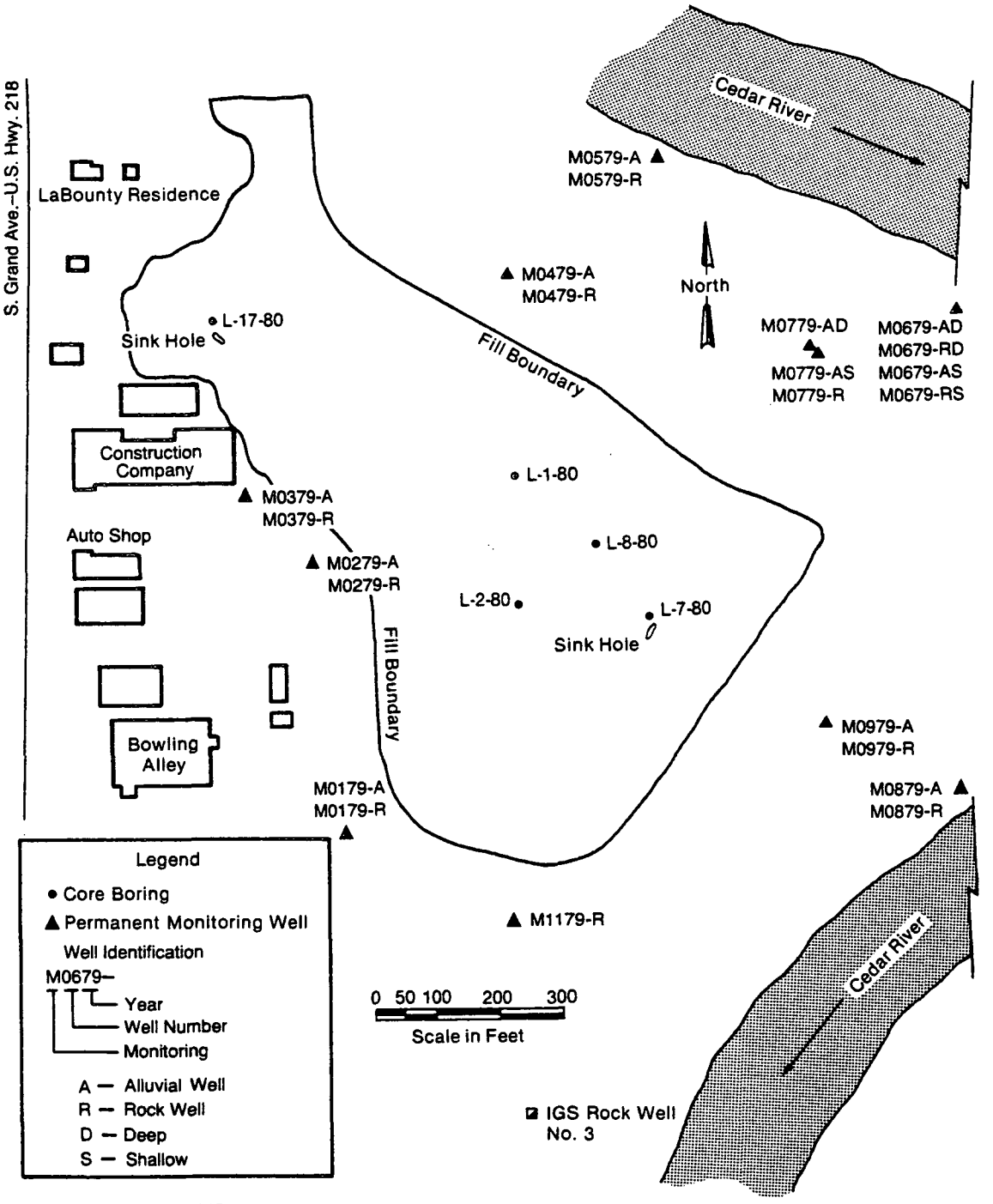
Results from the 1977 field investigations by Hickok and Associates for the Iowa Department of Environmental Quality (IDEQ) were taken into account in the selection of boring sites. The former Hickok sites L-1, L-2, L-7, L-8, and L-17 were selected as bore sites for the July 1980 work. These locations are shown in Figure 7, together with some of the permanent monitoring wells existing at the time of the July 1980 survey.

Results of the July 1980 Field Investigation at the LaBounty Site

The principal types of information derived from the MERL investigations in regard to the possible use of this site for demonstrating in situ stabilization methods are:

- physical and chemical characteristics of the fill materials and underlying alluvium (or upper surface of bedrock)
- chemical characteristics of leachate at various locations.

The investigations also acquired data on the chemical content of water in monitoring wells, the uptake of hazardous chemicals by vegetation, the head differential between the upper and lower aquifers, and gaseous or vapor-phase pollutants in the atmosphere. Field activities during the investigations of July 7-11, 1980, are described in Reference 8.



Source: Reference 8 and 15

Figure 7. Locations of Wells and Bore Sites, July 1980

Generalized Core Descriptions

Descriptions of cores from each boring site, as summarized from drillers' field logs, are summarized in Table 4. General descriptions of each of the major components of the cores--cover material, chemical fill, and underlying alluvial material--are given in Table 5.

Physical Properties of Core Materials

Continuous cores were collected where possible. In zones where core materials were not retained, split-spoon samples were collected at 5-foot intervals until bedrock was reached. Core samples for various depths at each site were analyzed for:

- permeability
- density
- moisture content
- porosity
- grain size classification

Results of these analyses are given in Tables 6 through 10.

Chemical Testing Data

Analyses for chemical constituents were performed on groundwater samples from wells and boreholes, and on leachates generated by washing core samples taken at various depths at each bore site.

Locations of wells and bore sites are shown in Figure 7. Bailer samples of groundwater were taken from each bore site except L-2, where no groundwater was encountered.

TABLE 4

GENERALIZED CORE DESCRIPTIONS[a,b]

Boring: L-1-80	Drilled: 7/8/80	No. Core Samples: 16
Description	Depth (ft)	Thickness (ft)
Cover soil	0-3	3
Chemical fill	3.0-22.5	19.5
Sand and gravel	22.5-28.0	5.5
Fractured limestone	28.0-28.3	0.3
Boring: L-2-80	Drilled: 7/7/80	No. Core Samples: 12
Description	Depth (ft)	Thickness (ft)
Cover soil	0-5	3.0
Chemical fill	5.0-18.5	13.5
Sand and gravel	18.5-22.4	4.0
Weathered rock	22.4-22.5	0.1
Boring: L-7-80	Drilled: 7/9/80	No. Core Samples: 16
Description	Depth (ft)	Thickness (ft)
Cover soil	0.4.5	4.5
Chemical fill	4.5-26.0	21.5
Fine to coarse sand	26.0-31.0	5.0
Fractured rock w/clay	31.0-34.5	3.5

TABLE 4
(concluded)

Boring: L-8-80	Drilled: 7/8/80	No. Core Samples: 16
Description	Depth (ft)	Thickness (ft)
Cover soil	0.5	5
Chemical fill	5-21	16
Silt to fine and medium sand	21-30	9
Fractured limestone with clay	30-34.5	4.5

Boring: L-17-80	Drilled: 7/9/80	No. Core Samples: 13
Description	Depth (ft)	Thickness (ft)
Cover soil	0.0.5	0.5
Chemical fill	0.5-13.0	13.0
Fine to medium sand	13.0-37.0	24.0
Fractured limestone with clay	37.0-39.0	2.0

[a]Summarized from the driller's field logs.
[b]Surface elevations for all borings were estimated to be 1,000 ft (±1 ft) from an April 1979 topographic map prepared by the chemical manufacturer.

Source: Reference 8.

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TABLE 5

GENERALIZED DESCRIPTION OF MAJOR COMPONENTS OF TYPICAL CORE[a]

Description	Depth (ft)
Cover Material - Yellowish gray to olive gray (5Y7/2 to 5Y3/2)[b] poorly sorted fine to medium silty sand, w/pebbles in upper portion, contained plant roots and debris, some plastic film fragments	0-5.3
Chemical Fill - Moderate yellow to olive brown (5Y7/6 to 5Y5/6), varying from uniform to extensive marbling, layered wet to saturated, fine grained sludge-like material. Roots to 6-foot depth from ground surface. Abundant plastic film fragments.	5.3-21.0
Underlying Alluvium - Interbedded light olive brown to moderate olive gray (2.5Y6/4 to 5Y4/2) sandy silt and yellowish gray (5Y7/2) well sorted medium sand. Moist to saturated. Plant fragments.	21.0-30.0

[a]Core from boring L-8-80.
[b]Determined by comparison with "Manual Soil Color Charts", by Munsell Color, Baltimore, Maryland (1975).

Source: Reference 8.

TABLE 6

PHYSICAL CHARACTERISTICS OF CORE BORE SITE L-1-80

Sample No.	Approximate Depth (ft)	Driller's Description	Grain Size Distribution Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Atterberg Limits LL	PL	PI	Moisture (%)	Dry Unit Weight (Pcf)	Permeability k_v (cm/sec)	Porosity (n)
3	5	Yellow moist chemical material	0	14	83	3	--	--	NP	113	38.3	7.74×10^{-6}	0.73
4	7	Yellow-black chemical material	0	4	93	3	--	--	NP	130	35.2	NR	0.76
9	15	Brown gravel, yellow chemical material, clay and wood	17	56	21	1	56	47	9	39	NT(1)	NT(1)	NT(1)
10	17	Yellow-black moist chemical material	0	7	88	5	57	49	8	100	40.8	6.08×10^{-5}	0.73
11	19	Yellow sticky moist chemical material	0	4	91	5	--	--	NP	139	NT(2)	NR	NT(2)
12	21	Same	7	17	14	8	34	15	19	96	86.9	7.63×10^{-7}	NT
15	27	Brown wet sand, gravel	4	95	1	--	NR	NR	NR	NR	NR	NR	NR
	28.1	Bedrock											
	28.3	End of Boring											

Remarks: NR = not recorded
NT = not testable
(1) wax contamination throughout sample
(2) extruded in field; sample disturbed
NP = nonplastic
-- = not reported

Sources: References 5, 6, and 9

TABLE 7

PHYSICAL CHARACTERISTICS OF CORE BORE SITE L-2-80

Sample No.	Approximate Depth (ft)	Driller's Description	Grain Size Distribution Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Atterberg Limits LL	PL	PI	Moisture (%)	Dry Unit Weight (Pcf)	Permeability k_v (cm/sec)	Porosity (n)
4	7	Brown gravely clay with yellow chemical material	1	50	42	7	47	36	11	95	46.2	NR	0.70
5	9	Moist yellow chemical material	0	7	89	4	55	50	5	149	31.8	3.6×10^{-5}	0.77
6	11	Moist yellow chemical material	0	10	83	7	--	--	NP	NR	NR	NR	NR
7	12	Very moist yellowish-brown chemical material	0	21	65	14	78	70	8	NR	NR	NR	NR
8	14	Very moist yellowish-brown chemical material	0	8	88	4	40	38	2	128	36.5	1.01×10^{-5}	0.76
10	18	Brown moist sand	4	95	1	--	--	--	NP	2	96.2	5.09×10^{-3}	0.41
	22.4	Weathered rock											
	22.5	End of boring											

Remarks: NR = not recorded
NT = not testable
(1) wax contamination throughout sample
(2) extruded in field; sample disturbed
NP = nonplastic
-- = not reported

Sources: References 5, 6, and 9

TABLE 8

PHYSICAL CHARACTERISTICS OF CORE BORE SITE L-7-80

Sample No.	Approximate Depth (ft)	Driller's Description	Grain Size Distribution Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Atterberg Limits LL	PL	PI	Moisture (%)	Dry Unit Weight (Pcf)	Permeability k_v (cm/sec)	Porosity (n)
4	6	Yellow-white fine chemical material	0	4	92	4	80	74	6	126	33.8	1.63×10^{-5}	0.80
5	8	Yellow-white fine chemical material	0	1	89	10	88	80	8	129	34.3	NR	0.78
7	11	Yellow-white fine chemical material	0	7	81	12	92	83	9	148	NT(1)	NR	NT(1)
8	13	Yellow-white fine	0	10	86	4			NP	120	37.9	3.81×10^{-5}	0.78
11	19	Olive and brown mixed chemical material	0	0	86	14	78	69	9	NR	NR	NR	NR
13	22	Olive and brown mixed chemical material	0	4	89	7	65	59	6	151	32.3	2.99×10^{-5}	0.78
14	24	Dark brown with yellow chemical material	0	19	68	13	99	72	27	NR	NR	NR	NR
15	26	Saturated fine-coarse sand, little gravel	0	5	90	5	58	46	11	145	33.6	1.73×10^{-5}	0.78
16	30	Saturated fine-coarse sand, little gravel; 6" fine sand layer, 30.0'-30.5'	0	91	4	—			NR	NR	NR	NR	NR
	34.5	Hardweathered rock											
	34.5	End of boring											

Remarks: NR = not recorded
NT = not testable
(1) wax contamination throughout sample
(2) extruded in field; sample disturbed
NP = nonplastic
-- = not reported

Sources: References 5, 6, and 9

TABLE 9

PHYSICAL CHARACTERISTICS OF CORE BORE SITE L-8-80

Sample No.	Approximate Depth (ft)	Driller's Description	Grain Size Distribution Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Atterberg Limits LL	PL	PI	Moisture (%)	Dry Unit Weight (Pcf)	Permeability k_v (cm/sec)	Porosity (n)
3	4	Yellow with black chemical fill	7	84	8	-	29	21	8	11	85.3	7.52×10^{-3}	0.47
4	6	Yellow with black chemical fill	0	2	85	13	56	51	85	NR	NR	NR	NR
5	8	Yellow with black chemical fill	0	10	80	10	49	46	3	126	33.0	NR	0.78
8	14	Yellow chemical fill	0	0	89	11	50	40	10	124	37.1	NR	0.75
9	16	Yellow chemical fill	0	8	83	9	61	51	10	NR	NR	NR	NR
11	20	Yellow chemical fill	0	5	90	5	51	44	7	153	28.2	2.34×10^{-5}	0.81
13	23	Dark brown fine sand, some clay, tr. metal	10	84	6	-	NR	NR	NR	NR	NR	NR	NR
14	25	Brown fine-coarse fill	0	65	26	9	41	20	21	10.2	94.5	1.60×10^{-6}	0.43
15	26	Brown fine-coarse fill	0	52	38	7	44	26	18	NR	NR	NR	NR
	34.5	Rock											
	34.5	End of boring											

Remarks: NR = not recorded
NT = not testable
(1) wax contamination throughout sample
(2) extruded in field; sample disturbed
NP = nonplastic
-- = not reported

Sources: References 5, 6, and 9

TABLE 10

PHYSICAL CHARACTERISTICS OF CORE BORE SITE L-17

Sample No.	Approximate Depth (ft)	Driller's Description	Grain Size Distribution Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Atterberg Limits LL	PL	PI	Moisture (%)	Dry Unit Weight (Pcf)	Permeability k_v (cm/sec)	Porosity (n)
2	3	Creamy white with rust colored marbling chemical material	0	2	91	7	74	70	4	NR	NR	NR	NR
3	5	Creamy white with rust colored marbling chemical material	0	2	89	9	80	79	1	126	31.9	7.06×10^{-5}	0.78
4	7	Creamy white with rust colored marbling chemical material	0	3	89	8	-	-	NP	137	33.5	NR	0.77
6	10	Creamy white, very moist chemical material	0	4	87	9	-	-	NP	NR	NR	NR	NR
7	12	Creamy white, very moist chemical material	0	9	87	4	77	72	5	129	35.8	1.15×10^{-3}	0.75
8	14	Brown moist sandy clay, tr. pebbles	0	10	87	3	46	60	6	128	36.8	5.96×10^{-4}	0.75
9	16	Tr. organics	0	54	39	6	37	20	17	18	94.7	1.8×10^{-6}	0.43
11	25	Brown fine sand	0	99	1	-	-	-	NR	NR	NR	NR	NR
13	35	Brown saturated fine-medium sand	0	98	1	-	-	-	NR	NR	NR	NR	NR
	39	Weathered rock											
	39	End of boring											

Remarks: NR = not recorded
NT = not testable
(1) wax contamination throughout sample
(2) extruded in field; sample disturbed
NP = nonplastic
-- = not reported

Sources: References 5, 6, and 9

A summary of the primary hazardous constituent content of well samples is given in Table 11. Similar information for bore-site samples (both bailer samples and lechates) is given in Table 12. More detailed results of the chemical analyses are presented in Appendix C.

Geophysical Interpretations Relevant to In Situ Stabilization

The following observations and interpretations are derived from examination of data from the June 1980 field investigation, except where otherwise referenced.

Bedrock Surface. The July 1980 borings support earlier findings that the upper bedrock surface is weathered in some locations and generally highly fractured. The following observations are based on Tables 6 through 11 and Table 12.

- At Bore Site L-1, weathered bedrock was encountered at 22.4 ft. Groundwater was found at approximately this same depth. The bedrock was overlain by about 2 feet of medium-to-coarse gravel.

- Almost the same conditions were found near the bedrock surface at Bore Site L-2 except that no groundwater was encountered.

- At Bore Site L-7, hard-weathered and fractured bedrock was found at 34 feet, with clay in the fractures. The surface of the rock was covered with a 6-inch layer of fine sand, all of which was saturated.

- At Bore Site L-8, rock was encountered at about 34 feet, covered by a 4-foot layer of fractured limestone layered with clay.

- At Bore Site L-17, weathered rock was found at 39 feet overlain by about 2 feet of fractured limestone with clay in fractures, which lay under about 3 feet of saturated sand.

TABLE 11

PRINCIPLE HAZARDOUS CONSTITUENTS IN LABOUNTY WELL SAMPLES

Sample Identification	mg/l of solution (ppm)			
	ONA	PNA	As	As/ONA
4A	0.56	ND	18.2	33
6AD	16.00	3.90	232	15
7AS	2.30	0.59	140	61
7AD	23.00	4.50	382	17
9A	65.00	18.00	336	5
9A (acid)	69.00	65.00	NA	--

Note: ONA = ortho-nitroaniline = 2-nitrobenzenamine
PNA = para-nitroaniline = 4-nitrobenzenamine
As = arsenic
NA = not analyzed
ND = not detected
As/ONA = ratio of As to ONA
ONA and PNA determined by gas chromatography
As determined on HNO_3-digested sample by ICAP

Source: Reference 4.

TABLE 12

PRINCIPAL HAZARDOUS CONSTITUENTS IN BOREHOLE GROUNDWATER SAMPLES (BAILER) AND LEACHATE PREPARED FROM CORE SAMPLES

Sample Identification	mg/ℓ of Solution (ppm)											
	ONA			PNA			As			As/ONA		
	1st	2nd	Liq	1st	2nd	Liq	1st	2nd	Liq	1st	2nd	Liq
Bore Site L-1												
3 ft.	7.9	1.9	--	0.075	ND	--	2.5	1.8	--	0.3	0.9	--
14.5 ft.	2.4	4.6	--	ND	ND	--	101	141	--			
17 ft.	0.40	0.52	--	ND	ND	--	2.6	8.4	--			
Bailer (23 ft.)	--	--	130	--	--	4.4	--	--	374	--	--	3
Bore Site L-2*												
21 ft.	3.6	0.015	--	0.24	ND	--	14.2	1.4	--	4	93	--
22.5 ft.	0.16	0.021	--	ND	ND	--	2.3	4.0	--	14	190	--
Bore Site L-7												
1.5 ft.	26	27	--	0.26	0.32	--	7.2	14.2	--	0.3	0.5	--
16.5 ft.	1.8	0.32	--	ND	ND	--	68.4	48.4	--	38	142	--
18 ft.	1.9	0.24	--	ND	ND	--	35.6	24.8	--	19	103	--
18.5 ft.	2.0	0.24	--	ND	ND	--	41.2	35.9	--	21	150	--
21 ft.	3.1	ND	--	ND	ND	--	27.1	21.1	--	9	--	--
Bailer (14.5 ft.)	--	--	16	--	--	ND	--	--	635	--	--	40
Bore Site L-8												
3 ft.	2.6	1.1	--	ND	ND	--	2.0	3.4	--	0.8	3	--
17 ft.	4.0	0.30	--	1.5	0.37	--	40.4	8.1	--	10	27	--
31 ft.	ND	ND	--	ND	ND	--	0.9	1.4	--	--	--	--
Bailer (24.5 ft.)	--	--	14	--	--	3.3	--	--	284	--	--	20
Bore Site L-17												
9 ft.	ND	ND	--	ND	ND	--	5.6	4.2	--	--	--	--
9.5 ft.	0.18	ND	--	ND	ND	--	12.0	5.6	--	67	--	--
21 ft.	ND	ND	--	ND	ND	--	ND	ND	--	--	--	--
31 ft.	ND	ND	--	ND	ND	--	ND	ND		--	--	--
Bailer (29.5 ft.)	--	--	0.81	--	--	ND	--	--	64	--	--	79

NOTE: 1st = leachate generated by washing with D.I. H_2O for one minute, S:L = 1:20 (W/V)
2nd = leachate generated by 24 hour tumbling with D.I. H_2O, S:L = 1:20 (W/V)
To convert leachings from mg/ -solution to mg/Kg-solid, multiply by 20
Liq = liquid taken by means of the bailer - not filtered prior to analysis.
ONA = ortho-nitroaniline = 2-nitrobenzenamine
PNA = para-nitroaniline = 4-nitrobenzenamine
As = arsenic
NA = not analyzed
ND = not detected
As/ONA = ratio of As to ONA
ONA and PNA determined by gas chromatography
As determined on HNO_3-digested sample by ICAP

*No bailer sample could be taken; dry bore hole.

The fractured condition of the bedrock surface, together with the apparent variation in the physical characteristics of adjacent overlying materials, could strongly influence any decision to stabilize the disposal site by bottom sealing against bedrock. Very little orthonitranaline (ONA) or other organic compounds that might be expected to interfere with the setting of either cementitious or chemical grouts were detected in extracts from the deepest core samples at four of the five bore sites (site L-7 being the exception).

Location of Chemical Fill Relative to Groundwater. Data from the July 1980 borings confirm the findings of earlier investigations that portions of the chemical fill extend below the water table, as depicted in Figure 5. (The configuration of the liquid saturated portion of the fill is based on Sisk's interpretation of the July 1980 data.[11]) This condition implies that, unless the water table is substantially lowered by the construction of impermeable surface cover and upgradient groundwater barriers or by other methods, any effort to stabilize or solidify the material in situ would involve working below the level of the water table as well as in the unsaturated zone.

The description of fill materials in Tables 6 through 10 suggests that the chemical fill was generally saturated at the time of the survey (July 1980), although the deeper alluvial materials were not saturated. The permeability data of these tables indicate

that much of the fill material is less permeable than the underlying alluvium.

Groundwater Movement Through Fill Material; Production of Leachate. Before the impervious cap was placed over the disposal site in 1980, pollutant-bearing leachate could be generated by the generally downward movement of rainfall through the chemical wastes, or by the generally lateral flow of groundwater through the wastes. Since the installation of the cap, the groundwater that moves through the waste material probably consists only of flow from (1) precipitation on lands upgradient of the site and (2) discharge from the upper bedrock aquifer.* Its movement through the wastes is the result of the gravity gradient toward the river (generally northeast, east, and southeast).

A study of the relation between rainfall and groundwater levels in monitoring wells, based on data acquired during the period October 1979 to February 1981, indicates that groundwater levels are

*A third, but less likely possibility, is that groundwater occasionally enters the fill as the result of "bank recharge" from the river. This would occur when the level of the river is significantly higher than both the base of the fill and the alluvial groundwater. Such conditions may arise during periods of heavy rainfall in the Cedar River watershed upstream from the site. Such conditions occur only as a transitory and relatively infrequent state, and therefore, are not likely to have a signficant effect on the production of leachate. However, in less extreme situations, when the river stage is higher than alluvial groundwater levels (though not necessarily high enough to affect the fill), bank recharge from the river could temporarily affect the pollutant concentrations and shape of the plume. The long term effects of these conditions would be minor, since the river would remain the primary discharge point of the flow system[15].

strongly affected by rain falling on the area upgradient from the site (upgradient rainfall). From this it is inferred that the volume of groundwater movement through the fill is also increased by upgradient rainfall. The rate of groundwater movement could be expected to increase the amount of leachate produced. The relation between rainfall and the pollutant concentration in one well (M0879A--See Figure 5) points to the tentative conclusion that upgradient rainfall appears to be a primary driving force in the production of leachate at the LaBounty site.[11]

Permeability of Soils and Fill Materials. The permeability and porosity of the fill and adjacent contaminated soils and rock strongly influence their amenability to in situ stabilization by injection of neutralizing or solidifying agents. Extensive measurements of the permeability of core sample materials were made in conjuction with the July 1980 field measurements. Results are summarized in Table 7 through 10. Measured permeabilities in the chemical fill samples are relatively low (generally in the range of 10^{-5} to 10^{-7} cm/sec) although two samples are as high as 10^{-3} cm/sec.

Alluvium samples consisting mainly of sand, or containing pebbles, show permeabilities in the order of 10^{-3} to 10^{-4} cm/second. These results are consistent with results from previous studies,[15,16] which report permeabilities (hydraulic conductivities) of alluvial material to range from about 10^{-2} to 10^{-9} cm/sec, and note that clean sand shows values between 1 and 10^{-4} cm/sec.

Chemical Constituents of the Fill. The types of chemicals and their concentration and spatial distribution within the fill would have direct implications on any undertaking to solidify, neutralize, or immobilize the hazardous landfill constituents in situ. Examination of Table 11 and 12 reveals that arsenic was found at essentially all depths at all boreholes sampled. As noted earlier, ONA was not detected in most samples from depths near bedrock. However, ONA and other organic constituents were found at shallower depths (less than 18 feet) in all five boreholes and in all well-water samples. The concentration of these organics generally decreased with depth, although this pattern was not uniform at all bore sites.

Prognosis for In Situ Solidification/Stabilization at the LaBounty Site

All available data at the LaBounty site were reviewed to assess the amenability of the site for the in situ application of solidification/stabilization techniques of pollution control. Our conclusion is that this site does not exhibit any of the special circumstances or conditions under which the identified techniques are technically and economically feasible, and, therefore, none of these techniques is appropriate for in situ application at the site at this time. The reasons underlying this conclusion are summarized below.

It is acknowledged at the outset that an exceptionally complete data base for the LaBounty site is available both from the July 1980

field survey and the sequence of investigations that preceded it. Although some additional data would be desirable (such as the nature of chemical or biological processes that may be occurring within the fill), the conclusion of non-applicability is in no sense a result of lack of information about the site.

1. The permeability of the landfill (both the chemical wastes and the intermixed and underlying alluvial materials) varies greatly--by several orders of magnitude--from one location to another within the fill. This variability appears too great to permit adequate distribution and mixing of either:

   a. solidification agents injected or otherwise applied in situ, thus precluding adequate incorporation and retention of hazardous components of the waste; or

   b. reactive (non-solidifying) agents injected to neutralize any single chemical pollutant of the waste. The prospect for neutralizing the various combinations of pollutants found throughout large portions of the fill appears even less promising.

2. The diversity of chemical constituents of the fill, and the variability of their concentration from one location to another, militates against the use of chemical agents injected into the fill to immobilize or decompose the identified pollutants. Also, even if a solidifying agent could be adequately distributed within the fill to insure proper incorporation of hazardous constituents, the diverse mix of the chemicals in the fill is likely to contain some substances that would interfere with the setting up of lower-viscosity solidifying agents such as polymers.

3. The highly fractured upper surface of the bedrock would make it difficult to anchor any type of vertical barrier to form a seal that would prevent inflow of groundwater or outflow of leachate. Probable patterns of groundwater flow, together with the possibility of bank recharge from the river, require that the macro-isolation approach include an effective bottom seal as well as impermeable vertical barrier. The fractured bedrock surface would also complicate the already questionably-effective procedure of emplacing an impervious bottom seal against the bedrock.

4. The magnitude and configuration of the fill (in terms of its depth) appear to render the energy-intensive fusion/vitrification method economically infeasible, even if the method is proven technically effective in large-scale applications.

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APPENDIX A

EVENTS LEADING TO THE IDENTIFICATION OF THE LABOUNTY SITE AS A MAJOR POLLUTION SOURCE*

Background

An abandoned quarry located near the Cedar River within the city limits of Charles City, Iowa, was formerly used as a source of sand, gravel, and fill material. Subsequently it was used as a land disposal site for construction and demolition debris, sanitary wastes, and chemical sludges and other chemical wastes from an industrial manufacturer of veterinary feed additives, pharmaceuticals, other biologic preparations and intermediate organic chemicals. The quarry, located on land owned by Duane LaBounty and leased to the chemicals manufacturer, Salsbury Laboratories, is referred to as the LaBounty site. Chemical wastes were deposited at the site from 1953 through 1979.

Process wastewater from the Salsbury Laboratories has been treated at the current Charles City municipal wastewater treatment plant since 1965. Wastewaters from the manufacturing plant are pretreated by the manufacturer before being conveyed via the municipal sewer system to the municipal plant for final treatment at the municipal plant. The purpose of the pretreatment is to render the industrial wastewater (1) amenable to treatment by the processes in use at the municipal plant and (2) compatible with these

*Material in this Appendix is based principally on References 1, 2, 3, 4, 8, and 9.

processes. Sludges from the pretreatment operation were among the chemical wastes deposited in the abandoned quarry. Prior to 1964, sludges from the municipal treatment plant were deposited at a municipal dump site about one-half mile east and slightly downstream of the LaBounty site. Since 1974, municipal plant sludges have been deposited on private farm land.

In 1974, the U.S. Environmental Protection Agency's Regional Office in Kansas City became aware of concern, based on visual observations and preliminary measurement data, about the compatibility of the chemical plant wastewater with the biological treatment processes of the municipal plant. This concern lead initially to a study of the influent and effluent characteristics and removal efficiencies of the municipal treatment plant, and later to an extensive series of field investigations by EPA, the Iowa Department of Environmental Quality (IDEQ), the Iowa Geologic Survey, and the manufacturer. These investigations have extended over a period of years, and have included hydrogeologic studies as well as sampling and analysis of groundwater, river water and soils at several locations in Charles City, and river water at various downstream locations. Results have pointed to the conclusion that toxic materials, including arsenic compounds and aromatic organics found in the sludges and wastewater from the chemical plant, were entering the Cedar River and groundwater in sufficient quantities to cause serious concern about potential public health impacts.

The various field investigations undertook to determine the types of chemical pollutants in the Cedar River, the quantities and rates of pollutant release, the specific sources of pollutant release, and the pathways by which the pollutants travelled from source to the river, the groundwater, or the general environment. These investigations revealed that hazardous chemicals were entering the water from several locations, including the manufacturing plant site through runoff, leaking or broken sewer lines, effluent from the municipal wastewater treatment plant, and the abandoned quarry used as a land disposal site. Hazardous constituents released from these sources included a number of derivatives of benzene, analine, and phenol; orthonitroanaline is among the more prevalent. However, the pollutant of predominant concern is arsenic (and its compounds) because of its toxicity, its concentration in the local environment, and the vast quantities of this material in wastes from the manufacturing plant.

The field investigations and studies of waste production by the manufacturer indicated that the quarry disposal site received some 8.7 million cubic feet of "total waste" during the interval 1953-1977, of which about 0.9 million cubic feet (or 11 percent) was classified as "arsenical waste", and that, in 1977, the disposal site contained some six million pounds of arsenic. The investigations also indicated that leachate from this site, produced by rainfall or groundwater flow, contained arsenic in significant

concentrations. The arsenic-bearing leachate apparently flows with the groundwater and enters the Cedar River, which passes within about 500 feet of the disposal site. The investigations have caused EPA and State agencies to conclude that the waste disposal site is the major source of arsenic in the Cedar River.

As a result of information developed by the field studies and on the recommendation of EPA's Region VII and the IDEQ, the manufacturer discontinued the use of the LaBounty site for waste disposal in December 1977, and developed a plan for remedial measures.

The manufacturer has since undertaken to implement a revised plan that incorporates monitoring and interim remedial measures, based in part on his initial plan of May 1978 with modifications recommended by EPA and IDEQ. This plan involves a three-phased approach. The first consists of installing wells for monitoring groundwater quality and levels at the site. Installation was completed in 1979 and monitoring has been in progress since that time. The second phase consists of surface modifications designed to prevent infiltration of rainwater into the landfill and thereby reduce the amount of leachate produced. These modifications consist of installing a low-permeability clay cover over the filled area and re-routing of surface water runoff around the site (completed in 1980). The third phase may consist of additional measures

to be installed if continuing monitoring of the leachate indicates that the previous measures had not adequately reduced the release of pollutants.

Monitoring of leachate and evaluation of the second-phase abatement measures was in progress as this report is being prepared.

Concurrent with the period of concern and investigation of the LaBounty site, EPA's Municipal Environmental Research Laboratory (MERL) in Cincinnati has been researching in situ stabilization of chemical waste dumps. This work has included extensive field measurement programs, evaluation of methods for control and abatement of pollution from chemically contaminated landfills, and development of computer models for predicting the effectiveness of such abatement measures. It has also specifically addressed problems associated with arsenic-bearing wastes.

At the request of EPA Region VII, the LaBounty site was examined by MERL research personnel, and has been considered as a possible demonstration site for selected in situ stabilization techniques. An intensive data acquisition project was conducted in July 1980, by MERL and its contractors, in cooperation with personnel from EPA's Region VII and National Enforcement Investigations Center (NEIC). These studies, together with selected data and interpretations from other investigations that relate to the feasibility of in situ stabilization, are the primary sources of site data for the present report.

Other Information about Water Pollution in the Charles City Area

As general background for this report, a listing of some of the principal field investigations conducted in the Charles City area during 1973-1981 is presented in Table A-1. No claim is made for comprehensiveness of this listing; it is intended to provide only the most general overview of the scope and timing of the various surveys and studies as summarized in a few of the references used in the preparation of this report. To compile and summarize all of the data and findings from sources pertaining to water and soil pollution that might be associated with waste discharges from Salsbury Laboratories would be far beyond the scope of the present report. It should be noted that two of the documents used in developing this report provide valuable summaries of the results of numerous field studies conducted in the period 1973-1979. These are References 2 and 3, both of which were prepared by EPA's Region VII Surveillance and Analysis Division.

As additional general background, a chronological listing of events relating to Salsbury Laboratories' waste disposal operations is presented in Section A.

Chronological Summary of Events, Relating to Salsbury Laboratories' Solid Waste Disposal Operations*

"In an executive order issued by the Iowa Department of Environmental Quality (IDEQ) in December of 1977, Salsbury was directed to stop using the LaBounty site..." In response to this

*Material in this Section is quoted from Reference 3.

TABLE A-1

LISTING OF WATER QUALITY AND SOIL INVESTIGATIONS IN THE VICINITY OF CHARLES CITY

Approximate Time Frame	Sponsor*	Other Participants	Water Quality and Soil Sampling
1953-1966	Salsbury Laboratories	--	Placed 7 sandpoint wells (15-20 feet deep) between LaBounty fill area and the Cedar River.
1971-1976	Salsbury Laboratories[3]	Engineering Sciences, Inc.	Summarized available data on Salsbury process wastewater and combined industrial/domestic wastewater at the municipal treatment plant.
1972-1974	Salsbury Laboratories[3]	Engineering Research Institute Iowa State University, Ames Ref.	Sampled municipal treatment plant influent and effluent (DOD and nonfilterable solids).
August 1974	EPA Region VII Surveillance[3] and Analysis Division (SVAN)		Sampled influent and effluent at Charles City municipal wastewater treatment plant.
August 1975	EPA Region VII SVAN[3]	--	Sampled: - Cedar River water samples at 2 locations 2-to-3 inches upstream of LaBounty site; also 9 miles and 44 miles downstream - Salsbury Laboratories process water discharge - Municipal treatment plant influent and effluent - Municipal treatment plant raw sludge, digested sludge, and sludge supernatant.
1975	Iowa Ceologic Survey and Iowa Department of Environmental Quality[4]		- Replaced 3 bedrock wells (depths: 56 ft., 65 ft., and 335 ft) between LaBounty landfill and river. Logged cuttings data. Installed 2 sandpoints on smaller-diameter casings in the deeper well (to different depths) - Interpreted groundwater data from Salsburg Laboratories wells at LaBounty site
February 1976	EPA Region VII SVAN[3]	--	Sampled: - Municipal treatment plan influent and effluent
February 10-11, 1977	EPA Region VII SVAN[3]	--	Observed yellow discharges and other features of soil, ice, and river near LaBounty site. Obtained information for structuring later field investigations.
1977	Iowa Department of Environmental Quality[1,4]	E.A. Hickok and Associates	Sank 26 shallow borings (to depths of 6 to 40 feet) and surrounding soil at LaBounty site. Obtained core samples and groundwater samples. (Boreholes were filled upon completion of survey).
1976	--	E.A. Hickok and Associates	Sank 15 shallow borings at disposal site for municipal treatment plant sludge. (not LaBounty site).

*Superscripts in "Sponsor" columns denote reference sources.

TABLE A-1
(continued)

Approximate Time Frame	Sponsor*	Other Participants	Water Quality and Soil Sampling
Feb. 22-23, 1977	EPA Region VII SVAN[3]		Sampled: - Cedar River water at 4 locations in Charles City and locations several miles downstream - Water from ground seep, from abandoned sand pit, and from city well - Municipal treatment plant effluent and Salsbury Laboratories' cooling water discharge - Sediments from open face of LaBounty site and at ground seep
April 1977	EPA Region VII SVAN[3]		Sampled: - Cedar River sediments at 6 locations within a 20-mile reach extending upstream and downstream of Charles City - flush of fish collected at upstream and downstream locations
Aug.-Sept. 1977	EPA Region VII SVAN[3]	Iowa Department of Environmental Quality	Sampling program: - Cedar River water at (at least) 6 locations in or near Charles City; some near LaBounty site - Cedar River streambed sediments at several locations in or near Charles City - Influent, effluent & sludge at Salsbury wastewater pretreatment plant - Groundwater at seven municipal and private wells in or near Charles City and one municipal well at Waterloo (downstream) - Boil on riverbank - Groundseep discharge - Salsbury Laboratories cooling water - 9 shallow (6 inch) soil borings from Salsbury plant grounds - Air samples at LaBounty site and at waste treatment plants
Jan. 1978	Salsbury Laboratories	--	Sampled Cedar River at 6 locations near LaBounty site
June-Sept. 1978	Salsbury Laboratories[4]	Layne-Western Corporation	- Made seismic reflection readings at 40 stations at LaBounty site to determine bedrock depth, contours - Made thermonic survey involving temperature profiles in boreholes at 12 locations at LaBounty site, as basis for predicting permeability and pathways of water flow - Installed six test wells in LaBounty site or between landfill and Cedar River. Maintained logs of boring materials. Sampled groundwater in wells.

*Superscripts in "Sponsor" columns denote reference sources.

TABLE A-1
(concluded)

Approximate Time Frame	Sponsor*	Other Participants	Water Quality and Soil Sampling
June 1978	EPA National Enforcement Investigations Center (NEIC)[2]	EPA Region VII (SVAN)	- Emplaced sandpoint wells for continued groundwater monitoring at 4 locations between the LaBounty chemical fill and the Cedar River. - Install piezometers for monitoring groundwater elevation and measuring hydraulic pressure
Summer 1979	Salsbury Laboratories[4]	- EPA Region VII - EPA Consultant William Walker - Layne-Western Corp. - Soil Exploration Co.	- Emplaced nested wells at eleven locations in or surrounding the LaBounty site, each nest comprising one well finished in the alluvial material and one finished in bedrock (except at 3 locations where only the rock well would be installed, or where additional alluvial wells were installed). These have been used for routing monitoring by Salsbury Laboratories since October 1979.
July 1980	EPA Municipal Environmental Laboratory[8]	- EPA Region VII - NEIC - Army Corps of Engineers (CE) - IDEQ - Salsbury Laboratories - Central Illinois Drilling Co. - Battelle	- Borings ranging in depth from 22 to 44 feet at five locations on the chemical fill portion of the LaBounty site - Acquired 12 to 16 core samples at each location - Sampled groundwater at 4 locations - Sampled vegetation at the site - Backfilled all boreholes

*Superscripts in "Sponsor" columns denote reference sources.

order and a number of news releases by IDEQ and EPA, Salsbury reported their position in a full page statement in the Des Moines Register.* In this newspaper, they released a list of the chronological events relating to Salsbury solid waste disposal operations. For background information, this list of events has been reproduced in its entirety as follows:

"1953, July 10 - Salsbury notifies Iowa State Department of Health (ISDH) results of the test drilling in LaBounty site. Type of wastes to be deposited described."

"1953, August 7 - ISDH informs Salsbury it can start disposing of the wastes with city garbage at the LaBounty site. Salsbury's first disposal of material at site."

"1953, August 10 - Letter from Iowa Geological Survey (IGS) indicating use of the LaBounty site would be okay."

"1953, August 26 - Letter from ISDH approving use of the LaBounty site."

"1953, August 31 - Salsbury letter informs ISDH that recommended four sand point wells are installed."

"1953, November 13 - Salsbury notifies ISDH of results of well samples taken on 9/04/53, 10/02/53, and 10/22/53."

"1953 to 1972 - Salsbury reports results of well testing to ISDH."

"1963, May 15 - Salsbury notifies ISDH that amount of material being deposited is four times greater than in 1962."

1966, October 6 - The LaBounty site on the agenda for the Iowa Water Pollution Control Commission meeting. Salsbury present."

"1966, December 2 - Three additional test wells at the LaBounty site."

"1967, April 12 - Dr. E.R. Baumann, Iowa State University (ISU), was engaged by Salsbury Laboratories as its pollution control consultant."

*Issue of January 31, 1977.

"1968, January 16 - Salsbury and consultant report "Disposal of Solid Wastes from Salsbury Laboratories Production Operations" to ISDH and IGS."

"1970, July 20 - IGS recommends observation wells into the Cedar Valley limestone with a water analysis program be carried out over several seasons."

"1970, September 3 - Meeting of IGS and Salsbury recommends monitoring wells be put into limestone at LaBounty site."

"1972, January 13 - IGS communicates to Salsbury initial thoughts on criteria and sites for hazardous waste disposal."

"1972, May 9 - Letter from IGS to Salsbury on sites that have deep beds of Juniper Hill shale (blue clay)."

"1972, September 13 - IGS, Salsbury meeting. State proposed four wells into the Cedar Valley Aquifer at LaBounty site."

"1973, May 12 - IGS reports Electrical Resistivity results on proposed Rockford site."

"1973, May 29 - IGS reports drilling logs from test drilling on Rockford site looks good."

"1973, December 4 - First soil and bedrock investigation report at Rockford site by Soil Exploration Company."

"1974, February 24 - Salsbury purchases a 140.68 acre farm southwest of Rockford, Iowa, with intentions of this farm being developed as a hazardous waste disposal site for Salsbury's chemical wastes. This farm has the thick deposit of Juniper Hill clay thought to be desirable for this purpose."

"1974, June 18 - Salsbury notifies DEQ of waste materials destined for future hazardous landfill site."

"1974, September 11 - IGS visits Salsbury and LaBounty site. Indicated that IGS would drill 7 or 8 sets of wells into the Cedar Valley limestone."

"1974, September 25 - IGS proposal for groundwater monitoring program at LaBounty site. Recommended 7 drive point wells and 12 drilling wells."

"1974, December 20 - Meeting of DEQ, IGS, Salsbury on LaBounty site. Salsbury consultant cautions against drilling in the actual dump site."

"1975, July 9 - Signed agreement with DEQ granting from $4,000 toward their expenses for drilling 3 wells at LaBounty."

"1976, December 15 - Meeting with DEQ, IGS, INRC, ISHL, Salsbury to discuss findings of November 1976 report on LaBounty site by IGS and DEQ."

"1977, January 18 - Meeting with DEQ and Salsbury on subject of solid waste disposal and wastewater treatment."

"1977, February - EPA carries out investigation of Salsbury disposal site and river sampling."

"1977, February 21 - Salsbury responds to DEQ request for information from January 18, 1977, meeting."

"1977, February 25 - Salsbury meets with DEQ, EAP, IGS, INRC, and Engineering-Science (ES) on solid waste disposal."

"1977, March 17 - Salsbury receives first DEQ Executive Order."

"1977, April 13 - Salsbury responds positively to all provisions of March 17 Executive Order."

"1977, April 29 - Date of Amended Executive Order. Expanded on the same points as in the original Order."

"1977, May 20 - Salsbury responds positively to all provisions of amended Executive Order of April 29."

"1977, June 9 - Date of Amendment to DEQ Executive Order."

"1977, June 10 - INRC approves construction of dike at LaBounty site."

"1977, June 13 - Salsbury sends DEQ soil testing program for Rockford site."

"1977, June 24 - Salsbury responds positively to Executive Order as amended June 9, 1977."

"1977, June 28 - DEQ indicates that proposed Soil Testing Program at the Rockford site is adequate."

"1977, July 1 - DEQ approves construction of dike at LaBounty site."

"1977, July 29 - Copy of bid package for interim storage basin sent to DEQ."

"1977, October 20 - Letter from Salsbury transmits to DEQ report entitled, "Preliminary Engineering Report for Wastewater Treatment" authored by Engineering-Science (Salsbury consultant). Request prompt review."

"1977, November 8 - Meeting at DEQ. First agreement to a reasonable approach to solid waste characterization."

"1977, November 16 - Meeting at Salsbury with DEQ. Agreement on solid waste stream characterization. Draft of executive order presented for review."

"1977, December 9 - Salsbury receives phone call from DEQ advising Salsbury the contents of a new Executive Order to be issued December 14, 1977. This Order drastically different than drafts previously agreed upon."

"1977, December 12 - Phone conversation between Salsbury and DEQ. Salsbury not given chance to meet with DEQ before the issuance of Executive Order."

"1977, December 15 - Salsbury receives Executive Order, ceases all disposal operations at LaBounty site and stops all chemical production."

"1977, December 16 - DEQ approves use of the interim storage basin which is lined with two clay and one polyethylene liners."

"1978, January 3 - Salsbury resumes limited chemical production."

"1978, January 4 - DEQ withdraws approval to use the interim storage basin because of failure to the top clay liner."

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15. SUPPLEMENTARY NOTES

Project Officer: Donald E. Sanning (513)684-7871

16. ABSTRACT

This report discusses the feasibility of solidifying or stabilizing hazardous industrial wastes that are already in place at a landfill. Solidification methods considered include (1) incorporating the waste into solids, (2) fusing the waste with soil, and (3) isolating the waste by enclosing it in impermeable inert envelopes or smaller capsules. None of the solidification methods appears generally applicable to large landfills containing mixed industrial wastes, although two methods appear promising for some specific applications. The more promising methods were examined for possible application at the 8.5 acre LaBounty site at Charles City, Iowa. None of the solidification/stabilization methods appears suitable for in situ application at this site because of large variations in the permeability of the fill material and the diverse chemical composition of the wastes. This report was submitted in fulfillment of Contract No. 68-02-3665 by the Mitre Corporation under sponsorship of the USEPA. This report covers the period November 1981 to March 1982 and work was completed as of April 1982.

17. KEY WORDS AND DOCUMENT ANALYSIS

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