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Potential Clogging of Landfill Drainage Systems

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by

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Contract No. 68-01-5949

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16. ABSTRACT

The potential clogging of landfill drainage systems was investigated, with particular emphasis on hazardous waste sites. The study accomplished five basic tasks: (1) to provide general background on the subject of drain clogging, (2) to examine the potential for clogging in leachate collection systems, (3) to investigate some cemented materials found in a drain at a landfill in Boone County, Kentucky, and to determine possible causes, (4) to identify preventive or remedial techniques for drain clogging, and (5) to identify avenues of research and development that might minimize the likelihood or impact of clogging.

Study results indicate that clogging is likely to occur in a probabilistic manner during the active and post-closure operational lifetime of a hazardous waste landfill, but preventive and remedial techniques can be used to avoid or mitigate clogging. Preventative methods (including increased safety factors or redundancy in design, monitoring, periodic inspection, and maintenance) are far superior to remedial techniques. Repair or replacement is expensive and potentially dangerous in the hazardous environment at secure landfills. Present regulations for hazardous waste landfills provide no guidance on engineering, design, or operational practices to prevent clogging or remedy a malfunctioning system.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the nation's environment and its effect on 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; 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 preserve 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 provides a most vital communications link between the researcher and the user community.

This document examines the potential for clogging of leachate collection systems at both sanitary and hazardous waste landfills, and discusses appropriate preventive and remedial measures.

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ABSTRACT

The potential clogging of landfill drainage systems was investigated, with particular emphasis on hazardous waste sites. The study accomplished five basic tasks: (1) to provide general background on the subject of drain clogging, (2) to examine the potential for clogging in leachate collection systems, (3) to investigate some cemented materials found in a drain at a landfill in Boone County, Kentucky, and to determine possible causes, (4) to identify preventive or remedial techniques for drain clogging, and (5) to identify avenues of research and development that might minimize the likelihood or impact of clogging.

Study results indicate that clogging is likely to occur in a probabilistic manner during the active and post-closure operational lifetime of a hazardous waste landfill, but preventive and remedial techniques can be used to avoid or mitigate clogging. Preventive methods (including increased safety factors or redundancy in design, monitoring, periodic inspection, and maintenance) are far superior to remedial techniques. Repair or replacement is expensive and potentially dangerous in the hazardous environment at secure landfills. Present regulations for hazardous waste landfills provide no guidance on engineering, design, or operational practices to prevent clogging or remedy a malfunctioning system.

This report was submitted in fulfillment of Contract No. 68-01-5949 by Arthur D. Little, Inc. under the sponsorship of the U.S. Environmental Protection Agency. The report covers the period 10/1/82 to 12/31/82, and work was completed as of 12/31/82.

CONTENTS

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SECTION 1

INTRODUCTION

Clogging caused by a variety of mechanisms is common to drainage systems of all kinds--agricultural irrigation, sanitary landfills, septic system leach fields, etc. Concern is particularly great over the potential clogging of leachate collection systems in hazardous waste landfills. Not only are the consequences of failure much higher at a hazardous waste site, but excavation and replacement are no longer simple last resorts.

In response to this concern, this report investigates the potential clogging of landfill drainage systems with emphasis on hazardous waste sites in particular. The study was designed to accomplish the following tasks:

- To provide general background on the subject or drain clogging,
- To examine the potential for clogging in hazardous waste leachate collection systems,
- To investigate cementacious materials found in gravel around a drain at a U.S. Environmental Protection Agency (EPA) demonstration sanitary landfill in Boone County, Kentucky, and to determine possible causal mechanisms,
- To identify and describe potentially useful preventive or remedial techniques to avoid, minimize or eliminate drain clogging, and
- To identify fruitful avenues for research and development to minimize the likelihood or impact of clogging.

The study was initiated with a literature review, a survey of field experience, and a limited laboratory study of the materials recovered from the Boone County landfill. The literature review was greatly expedited by the availability of a recent draft report on drain clogging (EPA, 1982).

Conclusions of this investigation and recommendations for further study are presented in Section 2 and Section 3, respectively.

The information base is summarized in Section 4. Analysis of the information base was guided by a composite of two related generic approaches used in elucidating failures in complicated systems--fault tree analysis and failure mode and effects analysis. These techniques, which have been extensively used to estimate failure probabilities, were used only as an organizing tool. The results of this analysis and brief summaries of the principal clogging mechanisms appear in Section 5. Results of the laboratory studies are also presented in Section 5.

The general background on drainage system clogging is discussed in relation to leachate collection systems in Section 6. The potential for clogging is examined by comparing a number of conditions in hazardous waste drain systems with those at other types of drains, and by examining information collected from operators of both secure hazardous waste and sanitary municipal waste landfills.

Techniques for preventing or remedying clogged drainage systems are described and discussed briefly in Section 7. The discussion is designed to provide a general background, not detailed information for design and implementation purposes.

SECTION 2

CONCLUSIONS

The following conclusions are based on the information and analyses summarized in this report.

1. Based on past experience in agricultural drainage and landfill leachate collection systems, and on the mechanistic analysis present in this report, it is reasonable to expect clogging of leachate collection systems to occur in a probabilistic manner during the active and post-closure operational lifetime of sanitary and hazardous waste landfills.

2. Mechanisms that affect other types of systems are expected to contribute to clogging in leachate collection systems. This study was limited to an examination of clogging in drainage system per se--that is, the pipe, drain layers and outlet system. The regulatory definition of "clogging" as used here could also involve localized blockages within the waste mass that rests on the liner, creating leachate head greater than the permissible limit. This type of potential problem was not examined in depth.

3. Landfill operators exhibited a varying degree of concern over the clogging potential of drainage systems. Most appeared to view the potential problem as unimportant in both design and operational considerations and felt that conventional practices should be adequate to prevent or remedy clogging. Only one source noted that the prevention and mitigation of clogging received careful and special attention in their design and operational considerations.

4. Established preventive and remedial techniques to avoid or mitigate clogging can generally be used at hazardous waste sites. Acid flushing should be used with great care, particularly if cyanides are known to be present.

5. Preventive methods (including increased safety factors or redundancy in design, monitoring, periodic inspection and maintenance) are far superior to remedial techniques. Repair or replacement, often considered quite practical in other settings, is expensive and potentially dangerous in the hazardous environment at secure landfills.

6. The present regulations regarding hazardous waste landfills do not appear to treat clogging system design and head build up with the same thoroughness and level of detail as liner design or loss of integrity. The regulations give substantial discretion to regional administrators with regard to the drainage system. Neither the regulations nor other supporting documents provide guidance on engineering, design or operational practices to prevent clogging or remedy a malfunctioning system.

SECTION 3

RECOMMENDATIONS

A number of recommendations for further research on leachate collection systems can be made based on the results of this study. The recommendations listed below are given with the understanding that it is important to integrate technical solutions with practical experience and expectations. Technical solutions arising from laboratory-based research and development alone are not likely to be implemented if they are considered too expensive or too complicated to apply under existing or future conditions. Conducting technical research in conjunction with experience on operating leachate collection systems can help avoid this problem.

1. Specific design and construction guidelines should be developed for leachate collection systems similar, perhaps, to the EPA Technical Resource Documents which provide guidance for the design and construction of liner systems, for example. Such a guide could be used by Regional Administrators in approving facilities or by the Administrator in preparing regulation for leachate collection systems. Aspects of any of the following recommendations could also be included in this task.

2. Specific operational procedures should be developed for the prevention of clogging. An effective program of treatment and maintenance can control the factors necessary for clogging mechanisms to occur and thereby avoid the clogging problems. This task should include a cost analysis of alternative preventive approaches.

3. Monitoring methods to detect clogging or conditions that promote it should be developed to anticipate problems before they become too serious. Conventional techniques can be applied from related fields such as groundwater hydrology and new techniques can be developed to indicate when significant clogging processes are occurring.

4. A quantitative analysis should be made of the probability of occurrence of the various clogging mechanisms. Specific preventive and remedial approaches can then be evaluated in the context of hazardous waste landfills to determine their quantitative effects on clogging potential. This recommendation would involve both a paper study and a field investigation under typical hazardous waste landfill conditions.

5. Methods for preventing and correcting clogs in drain envelopes or filter layers should be developed. Currently, no satisfactory remedial methods exist short of excavation and replacement.

6. Experimental data on the performance of leachate collection systems (including detailed leachate flow and composition data) should be gathered at both sanitary and hazardous waste landfills on a continuing basis. Such a data base is vital in evaluating leachate collection system performance and in developing design and operational guides to ensure proper system functioning throughout its required lifetime.

SECTION 4

BACKGROUND

INTRODUCTION

In order to assess the potential for clogging of leachate collection systems, information was obtained in a number of areas. These include:

- RCRA Regulations;
- design of leachate collection systems;
- leachate characteristics;
- mechanisms of drain clogging; and
- relevant experience.

Literature from related fields, such as agricultural drainage and irrigation systems, provided most of the background because information and direct experience with leachate collection systems in general is sparse. Although, as will be discussed below, there are many differences in conditions between leachate drains and other kinds of drains, basic mechanisms leading to clogging are similar in all systems. In particular, a white paper prepared by GCA Corporation for EPA's Hazardous Waste Management Division of the Office of Solid Waste (EPA, 1982) was used as a starting point for the research in this report. Many of its conclusions are incorporated below. This section presents relevant background information according to the topics listed above, except for the mechanisms of drain clogging, which are presented in the next section.

EPA PERMITTING STANDARDS

Before promulgation of the new regulations for hazardous waste disposal facilities on 15 July 1982, the Permitting Standards (40 CFR 264) did not contain any specific standards for leachate collection systems. The most specific requirement with respect to clogging was that liquid in the system be kept free flowing to prevent backwater and excess pressure head in the collection system (264.221(e), 222(c)). Leachate systems are only briefly mentioned in a number of other sections.

The internal EPA draft of the new Part 264 regulations, reviewed by GCA in preparation of the white paper, sought to "correct the inadequacies of currently existing regulations for leachate systems" which lacked specific design and operating standards. This internal draft, however, only required drain pipe "of sufficient strength... to resist collapse or clogging..." and "a graded granular or synthetic fabric filter above the drainage layer to prevent clogging". GCA felt that these requirements were inadequate to "guarantee the proper functioning of a drainage system" (EPA, 1982). Therefore, they recommended that the regulations incorporate performance criteria, minimum design criteria, and inspection and maintenance requirements.

As promulgated, the new EPA regulations require single and double-lined waste piles and landfills (except for existing portions) to have (264.251 (a)(2), 264.301(a)(2)):

> A leachate collection and removal system immediately above the liner that is designed, constructed, maintained, and operated to collect and remove leachate from the landfill. The Regional Administrator will specify design and operation conditions in the permit to ensure that the leachate depth over the liner does not exceed 30 cm (one foot). The leachate collection and removal system must be:
>
> (i) Constructed of materials that are:
>
> (A) Chemically resistant to the waste managed in the landfill and the leachate expected to be generated; and
>
> (B) Of sufficient strength and thickness to prevent collapse under the pressures exerted by overlying wastes, waste cover materials, and by any equipment used at the landfill; and
>
> (ii) Designed and operated to function without clogging through the scheduled closure of the landfill.

The only other significant mention of leachate collection systems is under monitoring and inspection requirements for landfills and waste piles. Part 264.303(b)(4) requires that "while a landfill is in operation it must be inspected weekly and after storms to detect evidence of... the presence of leachate in and proper functioning of leachate collection and removal systems, where present". The same requirement is made for waste piles. There are no leachate collection or drainage system requirements for surface impoundments.

To assume safe and legal operations at hazardous waste landfills and wastepiles, therefore, leachate collection systems must maintain flow capacity over the expected life and closure of the facility. In addition, it is the responsibility of the Regional Administrator in permitting a facility to specify design and operation conditions to ensure that these requirements are met.

DESIGN OF LEACHATE COLLECTION SYSTEMS

Although the specific configuration and specifications of every leachate collection system are fitted to the facility, the basic design includes the following components:

- o drain pipe
- o drainage layer
- o filter layer and
- o collection sump

A typical drain cross-section is shown in Figure 1. Collection systems should be designed to handle the maximum expected leachate flow as well as to withstand expected physical loading. Important design parameters with respect to clogging are discussed in more detail below.

It is important to note that alternatives to these basic designs have been developed specifically for hazardous waste disposal facilities. For example, a layer of upright standard drums containing waste can be placed immediately about the liner to serve as a drain layer for leachate. Bulk waste may then be placed on top of the drum layer or additional layers of drums may be added. The leachate would flow along the liner to a central drainage sump (e.g., a 48 inch standpipe surrounded by gravel) where it would be pumped out. Such alternate systems were not considered in detail in this report. The clogging mechanisms in these and other designs, however, are expected to be similar to those for conventional leachate collection system configurations.

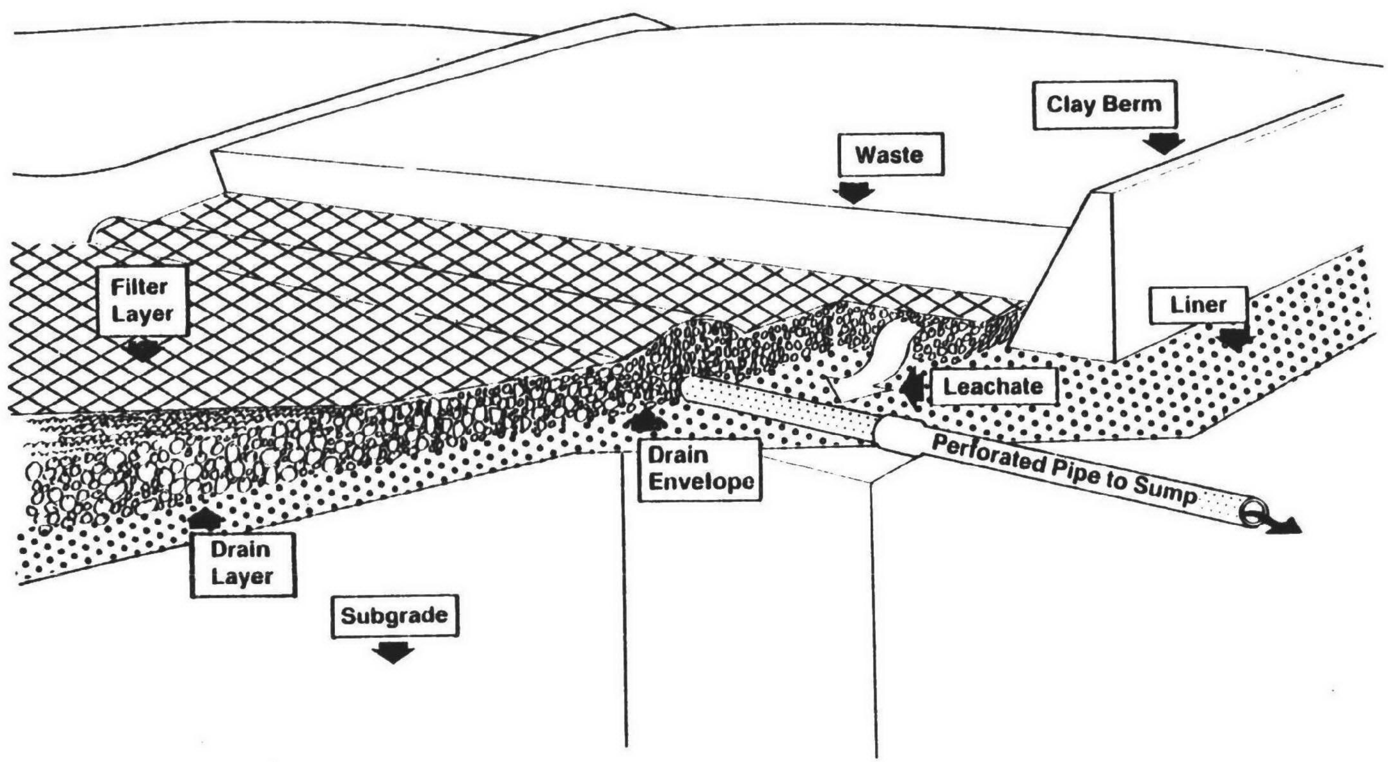
LEACHATE CHARACTERISTICS

Knowledge of the characteristics of leachate at sanitary and hazardous waste landfills is important in understanding the potential for clogging at these facilities. Many of the factors which contribute to clogging of leachate collection systems depend on these characteristics. In addition, comparing the important characteristics of sanitary and hazardous waste leachate gives insight into the relative difference in clogging potential at these facilities.

Information on leachate characteristics at sanitary landfills is plentiful. In particular, "Evaluation of Leachate Treatment, Volume I: Characterization of Leachate" (EPA, 1977) reports leachate characteristics from 18 different sources. Steiner, et al, 1971 also gives leachate concentration ranges, but for fewer pollutants. These two reports were used to characterize leachate from sanitary landfills.

Information on leachate characteristics at co-disposal and hazardous waste disposal facilities is reported in Ghassemi, et al, 1983. That report concluded that, based on 30 different leachates from 11 landfills,

FIGURE 1
SCHEMATIC OF A TYPICAL LEACHATE COLLECTION SYSTEM



inorganic constituents appearing in highest concentrations in the leachate are iron, calcium, magnesium, cadmium, and arsenic, and the organic constituents appearing in highest concentrations are acetic acid, methylene chloride, butyric acid, 1,1-dichloroethane, and trichloro-fluoromethane. The most frequently reported inorganic constituents are iron, copper, nickel, cadmium, chromium, zinc and manganese and the most frequently reported organic constituents are mono- and di-chlorobenzene, and methylene chloride. The constituent concentrations in the leachate from hazardous waste landfills studied fall within the reported ranges for municipal landfill leachate.

Statistical analysis of the data for sanitary leachate shows that the standard deviations exceed the mean in all but 7 cases. This finding indicates that concentrations of these parameters are highly variable. In addition, it should be noted that hazardous leachate can potentially contain a very high concentration of any chemical released in bulk form after being placed in the landfill. Such chemicals may inhibit or increase the potential for clogging.

RELEVANT EXPERIENCE

Most of the experience with drainage systems and drain clogging is in the area of agricultural drainage. In its EPA white paper, GCA presented an analysis of a study of 108 tile drains in Ohio. All of the drains over 40 years in age had required maintenance. A frequency analysis showed that an average service life of 11.7 years is expected before repairs are required. Most of the problems developed at drain junctions, and physical factors for drain failure tended to predominate. GCA concluded that better design could minimize drain failure, but that the analysis gave "a rather bleak outlook on the service life of draining systems." (EPA, 1982) Information from studies of other drainage systems is used elsewhere in the report to highlight specific failure mechanisms. Studies by other researchers support the conclusion that the clogging of agricultural drainage systems can be a serious problem.

Experience with leachate collection systems at hazardous and sanitary landfills is more limited. While modern agricultural drains have been in use for decades, leachate collection systems have generally been in use for less than five years and are only currently becoming widely utilized.

A survey of over 20 landfill operators, including some interviewed by GCA and some who operated more than one facility, discovered limited experience with clogged leachate collection systems. Six incidents of drain clogging were reported, including five at facilities which disposed of hazardous wastes. These six incidents are:

- o biological clogging of a drain envelope at a co-disposal site due to poor design;

- o clogging of a standpipe with solids at a hazardous waste disposal facility due to design or construction errors (no filter layer was installed);
- o siltation of a drain pipe at a hazardous waste facility;
- o leachate collection system rebuilt due to clogging at a hazardous waste landfill;
- o undefined drainage problems at a hazardous waste landfill; and
- o cementation of a drain envelope at a test sanitary landfill.

The number, and nature, of clogging incidents reported, however, may not be representative of the overall potential for system clogging. This is true for a number of reasons. First of all, companies are not comfortable with any type of leachate collection system failure and may be reluctant to volunteer information. Additionally, some personnel may not consider clogging to be as important as other problems such as liner failure or off-site contamination, so that all individuals in a company may not be aware of or concerned about clogging incidents. This was observed in one case where two individuals in the same company gave differing accounts of the company's experience with clogged collection systems. Second, many of the leachate collection systems discussed had been operational for only a few months or a few years. The oldest system was build in 1976. These systems, therefore, are too new to experience clogging problems which, in other types of systems, may be expected only after ten or twenty years of operation. Finally, many operators assumed that as long as leachate was being collected at a rate which seemed reasonable, the system was functioning properly. In some cases, leachate depths were not even monitored. As a result, some operators would not know if clogging, as defined in the RCRA regulations, had occurred and the incident would therefore go unreported.

Perhaps more significantly, conversations with landfill operators manifested an attitude that drain clogging is considered to be a minor problem. When asked whether or not they were concerned about potential clogging of their leachate collection systems, most operators indicated they expect no problems. This seemed to be due to an ignorance of potential clogging problems or confidence in their ability to unclog the system when necessary. In general, clogging problems were considered to be a minor nuisance and not a major threat. Only one company, which operates a number of hazardous waste landfills, considered clogging to be a major problem. They are designing their collection systems to facilitate prevention and correction of clogging problems. They are also one of the companies which has experienced clogged collection systems.

Some of the results of interviews with landfill operators are given in Table 1. This table includes companies which operate more than one landfill as well as individual facilities. Information is given on system design, clogging experience and attitude, and other relevant facts. Comments on the 30 cm head criterion in the present RCRA regulations are also included.

TABLE 1

INTERVIEW RESULTS

Name/Type Age	Waste Information	System Design	Clogging Experience	Clogging Attitude	Comments
Company A Hazardous, a few years	no limitations	-6" PVC pipe, 6-8" gravel -drums and gravel as drainage layer -automatic sump pump	none reported	no problems expected	use "intergradient" technique(waste below potentiometric surface) 30 cm criteria 'ridiculous,' "not determined by engineer"
Company B Hazardous, a few years	no limitations pH 5-8 2-20' heads locally possible	-6" PVC pipe, 12" gravel -cleanouts included -use manholes instead of risers ->1000' between cleanouts -pipe slotted on bottom only	biological clogging of drain envelope at co-disposal site; reason = poor design	serious problem design to prevent and remedy clogging crushing and sedimentation considered main causes	need for better filter design 30 cm criterion means 'no leachate' does not consider local mounding problems, effective head requires leachate collection if precipitation >25"/year
Company C Hazardous, a few years	no limitations pH 7-10.5 3.5' average head	-48" perforated standpipes surrounded by '57' stone -drums with swales as drainage layer -automatic sump pump	clogging of standpipe, reason = neglected to install filter layer siltation problem, jet cleared	no problems expected with new systems, concerned about scaling due to high pH	
Facility 1 Sanitary, one month	municipal	-4" PVC pipe,12' gravel, 0.5% slope -gravity drain to collection tank -liner with 1% slope to drains -manholes every 300'	none	take care in placing waste over drain "snake out" if problem	no knowledge of potential clogging mechanisms except crushing and biological
Facility 2 Hazardous, eight months	--	-6" PVC pipe,2' gravel, 4% slope -drains to 4' sump	none	no problems expected	no leachate, P = 5-7"/year
Facility 3 Hazardous, seven months	limited chemical wastes pH 6.5	-gravel drains to 1000 gallon sump, to treatment (filtration) to holding pond	none	no problems expected	sump pumped out weekly "nothing we have is leachable"
Facility 4 Co-Disposal, 1.5 years	metals pH pH 7.5-8	-8" perforated pipe, special material, 0.5% slope, pea stone gravel	none	no problems expected	"if pipe clogs, leachate will drain through gravel layer" monitor levels in sump, soon to monitor leachate levels on liner
Facility 5 Sanitary, a few years	organics	-6-8" perimeter drains forced drains to sewage system	none, but problems expected with pumps	no problems expected	previously accepted hazardous wastes liner of compacted soil

SECTION 5

MECHANISMS FOR CLOGGING

INTRODUCTION

Clogging mechanisms are occurrences or natural processes that inhibit the flow of leachate to or through the leachate collection system. A leachate collection system at a landfill is considered to be clogged if it cannot maintain the leachate depth over the liner at less than the 30 cm limit required in the RCRA Standards. The major types of clogging mechanisms in leachate collection systems are physical, chemical, biochemical and biological mechanisms.

Figure 2 presents a failure mode diagram for clogging of a leachate collection system based on these mechanisms. A failure mode diagram on a slightly different variation (a fault tree) represents the events and conditions that could cause an unusual event, such as drain clogging, to occur. This kind of analysis is often used where the causal events are unpredictable or random and are generally of low probability. It can be used, more generally, as a means to organize and display multiple causal paths leading to a single event and, if sufficient data are available, to estimate the probability of the event taking place. In this study, only the first application (organizing) was used; no estimates of clogging probabilities have been made. The diagram is set up so that the final event (i.e., a clogged drain) is at the top with factors which contribute to that event on subsequent levels. Each level moving down the page represents a higher degree of detail.

The main branches relate to the two major parts of a leachate collection system--the pipe and the envelope. The last factor in any branch of the diagram is called an end factor and indicates that no further breakdown is required. In addition, the letters beneath each end factor indicate the factor type. Factor types are specified to differentiate between the various categories of factors listed in the diagram's key.

The fault tree indicates parallel or alternative failure (clogging) mechanisms by connecting the pathways with an open circle (o) which represents an "or" node or function. This kind of node means that the next event or condition along the pathway toward clogging could occur when any one or more of the indicated events or conditions occurrs. A condition is a set of circumstances that is constant or persists for some time -- ambient temperatures, pH, pipe size, etc. Conditions include design, operation, waste/leachate and ambient condition factors. An event is an occurrence

Figure 2. Failure mode analysis of clogging mechanisms.

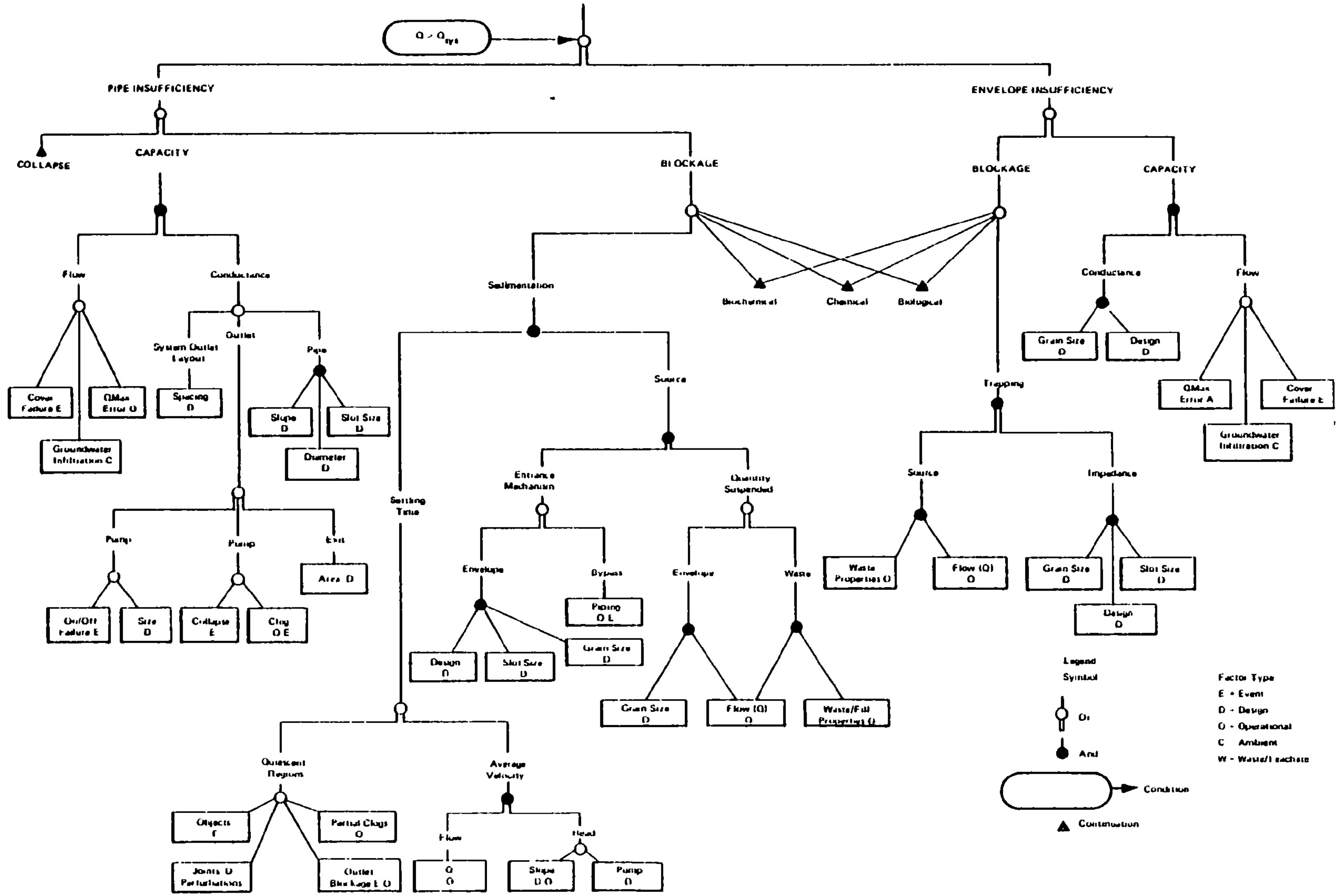
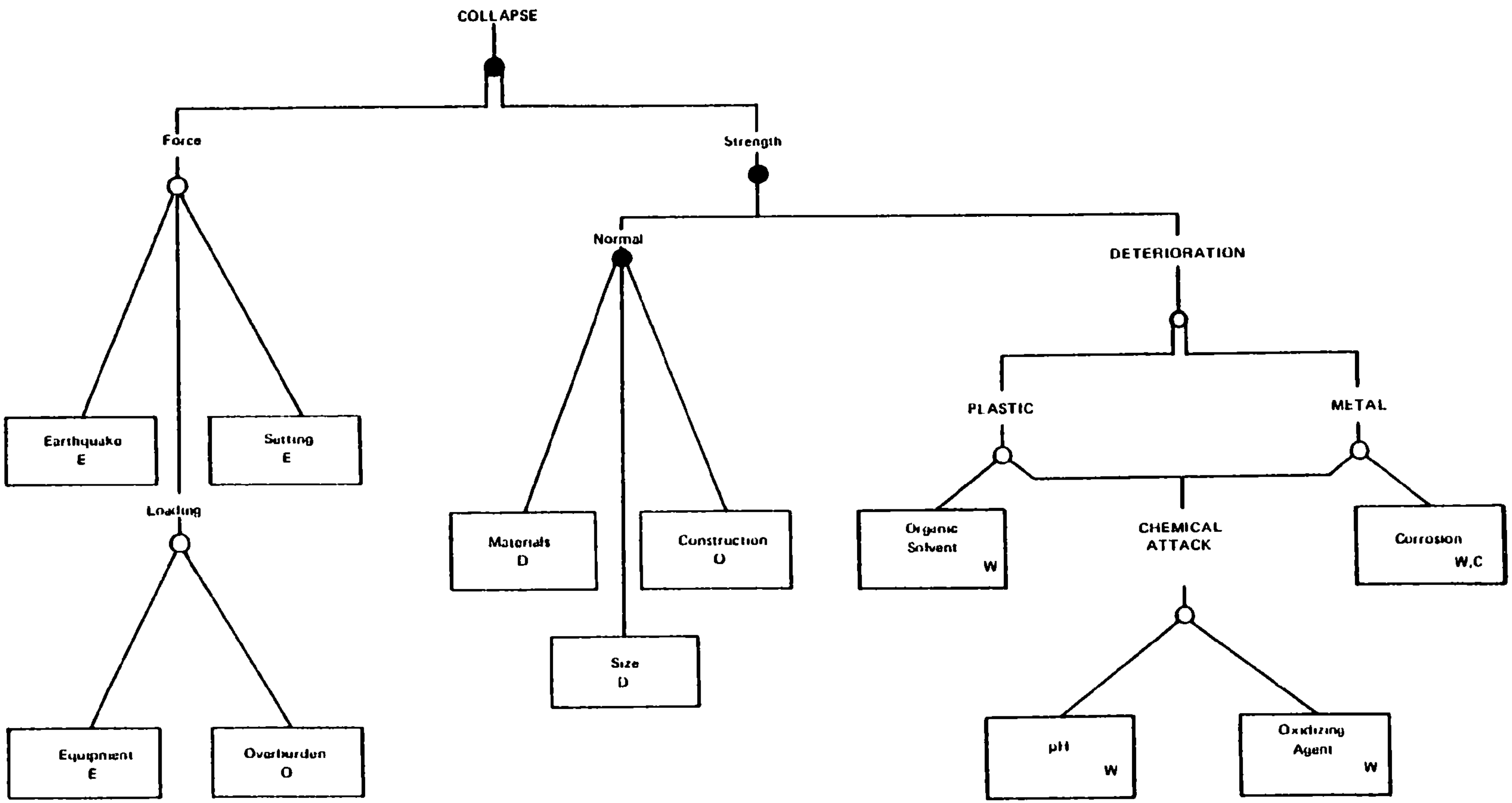


Figure 2. Failure mode analysis of clogging mechanisms (cont.).



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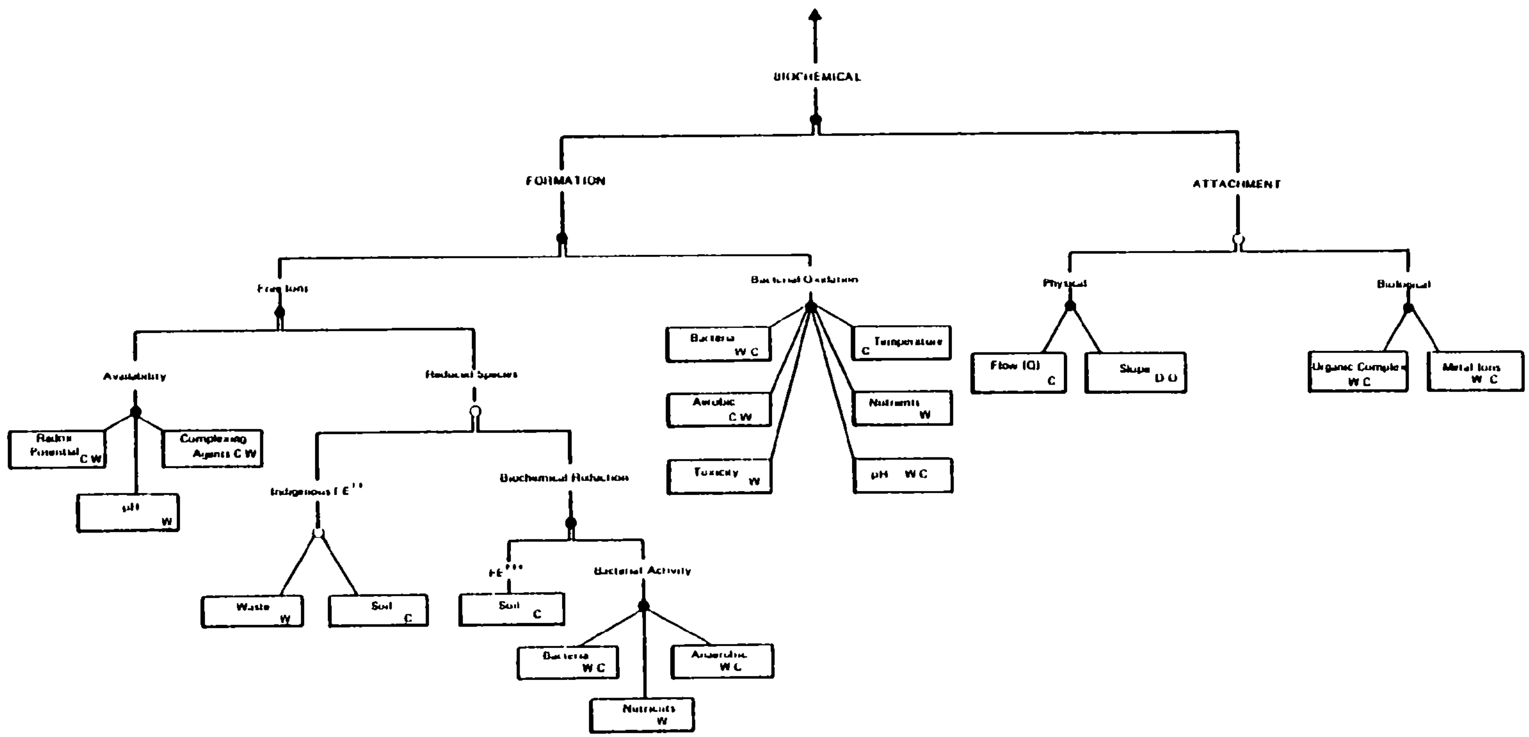

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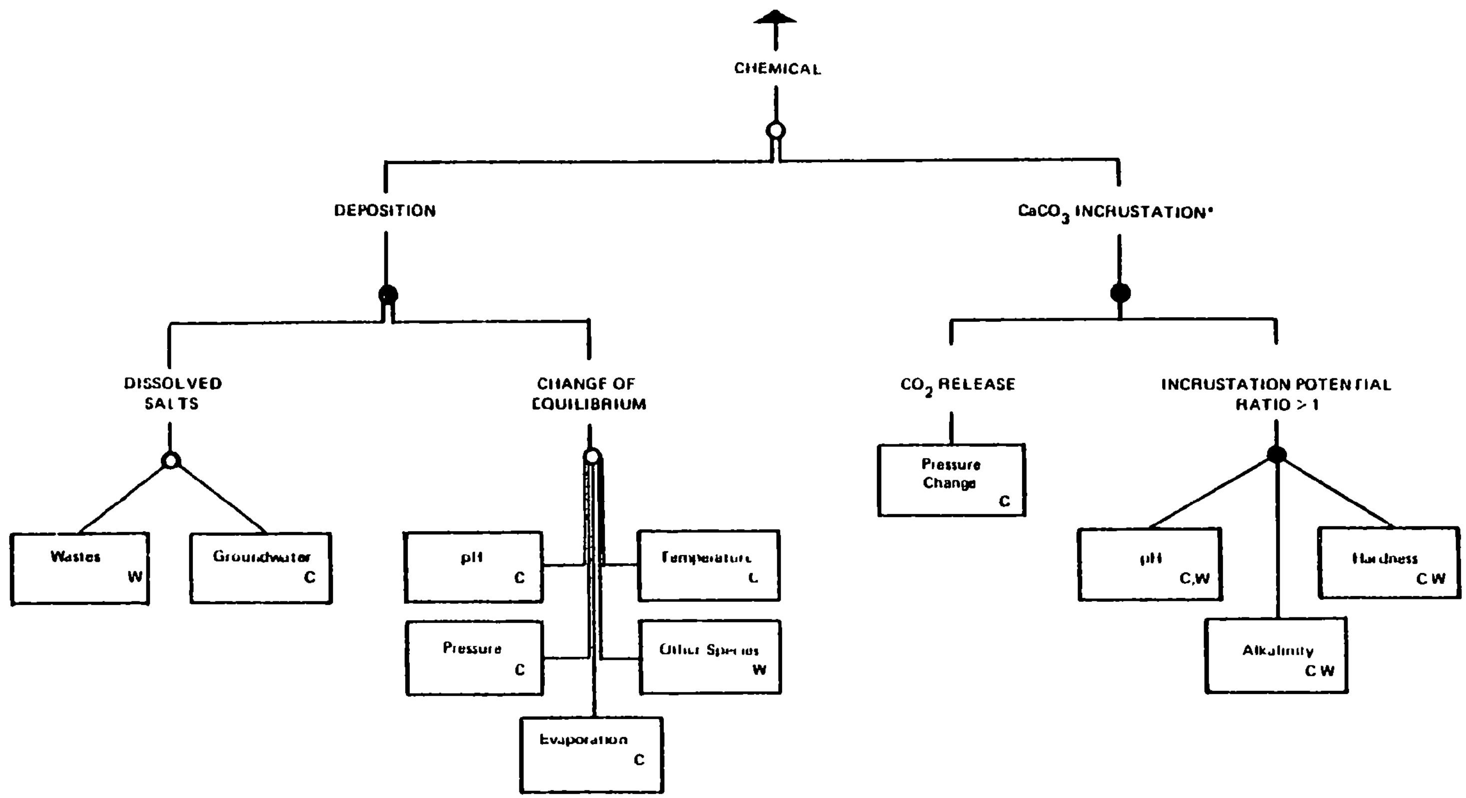
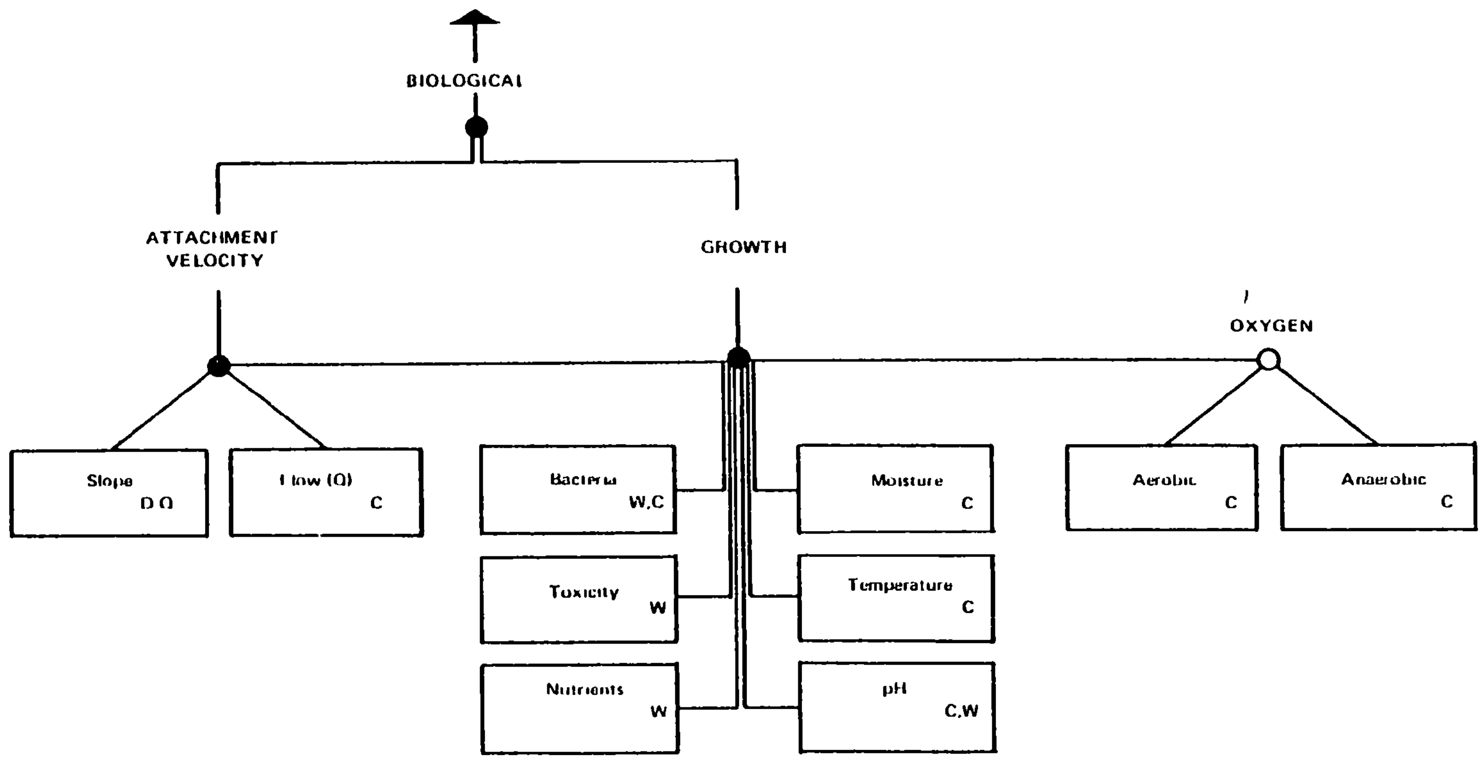


*$CaCO_3$ is a special case of deposition

Figure 2. Failure mode analysis of clogging mechanisms (cont.).



taking place unpredictably (e.g., an earthquake or a bulldozer being directed over a drain pipe) or as a result of a combination of factors along the fault tree.

Conditions or events that must occur together to cause advancement towards clogging are linked by a solid circle (•) which represents an "and" function. All of the events or conditions leading to an "and" node must occur in order for advancement toward the top.

The conditional factor at the very top of the diagram indicates that even though the system may have been inadequately designed or been deteriorated, clogging will not occur unless the leachate flow (Q) exceeds the actual system capacity (Q_{sys}).

Countless formulations and endless levels of detail are possible with a failure mode analysis. This particular diagram, however, is formulated to given enough detail to present the important factors involved for each of the clogging mechanisms. No attempt was made to make the diagram more detailed beyond this point. Additionally, this diagram is constructed based on the most common system design. Alternative designs would require different diagrams, although the basic clogging mechanisms would be the same.

Each of the four types of failure mechanisms is described in the following subsections. The last subsection in this chapter describes the results of an investigation of a potential clogging condition discovered during the disassembling of an EPA demonstration municipal waste sanitary landfill in Boone County, Kentucky.

PHYSICAL MECHANISMS

Physical mechanisms appear to be the most common and are the most well understood causes of drain failure. GCA concluded that "in general, physical factors tend to predominate in many drainage systems although it is important to recognize that any combination of factors might occur". (EPA, 1982) Physical failure of leachate collection systems can be due to:

- o inadequate capacity;
- o structural failure; or
- o sedimentation or filtration.

Each of these is represented in the failure mode diagram.

Inadequate pipe carrying capacity can be caused by underestimation of the maximum design flow, by problems in the outlet, by inadequate pipe spacing, diameter or slope, or by insufficient slot area. These factors are closely related and depend primarily on system design. Underestimation of maximum design flow can be the result of a design error, an event which causes the system to perform other than as expected (such as cover failure), or a condition which was inadequately accounted for (such as groundwater flow).

Outlet problems which cause inadequate capacity include design errors such as undersized pump or outlet diameter, and events such as outlet blockage. Outlet problems can also be due to operational procedures, as was the case with Boone County Test Cell #1 during the first six months of operation. The outlet of the upper drain was intentionally closed for periods of time causing leachate to back up in order to create sufficient head to force flow to the lower drain. Finally, inadequate pipe spacing, slope, or diameter can cause inadequate capacity since they are the principal factors which determine how much flow each pipe and the overall system can handle. They are interrelated, as indicated by the "and" junction, and are parameters of system design.

Inadequate flow capacity design in the envelope can also lead to clogging (the right-most branch in Figure 2). Use of a gravel mixed with fine-grained sand or too shallow a gravel layer could create sufficiently high flow resistance at peak flows to cause backup and clogging as defined herein.

Structural failure or collapse can be caused by mechanical crushing or displacement, and may be exacerbated by physical deterioration of the pipe material. Mechanical causes are due to operational and event factor types. Compaction of the waste and general loading during normal operations can cause crushing or displacement of the collection pipe. Settling of the waste and underlying soil, which is considered an event although it is influenced by design and operation, can also cause displacement. Physical deterioration can be caused by chemical attack due to pH extremes or oxidizing agents in the waste. Plastic pipes may also be susceptible to organic solvents and metal pipes to corrosion. These factors are primarily a function of the characteristics of the waste and leachate.

Sedimentation of or trapping of solids in the collection system can be caused by a number of design problems and events. Sedimentation in the pipe requires both a source of solids and a mechanism by which they can settle out. In a leachate collection system the sedimentary material appears in the leachate as suspended solids arising from the waste, daily cover, cap, envelope, or filter materials. Envelope material can enter the pipe as a result of incorrectly selected grain size distribution or pipe slot size design. Suspended solids can also enter if piping occurs in the envelope due to hydraulic failure or scouring.

Once solids have entered the pipe they can settle out if the flow is insufficient to keep them entrained. Low flow can be caused by a pipe slope which is too shallow and, also, by outlet problems. Quiescent regions can form behind hydraulic perturbations such as objects, or clogs, which inhibit flow around poorly designed or installed pipe joints and intersections.

CHEMICAL MECHANISMS

Chemical mechanisms for clogging involve the formation of insoluble precipitates which deposit on the surfaces inside of drainpipes, in openings (slots) and in the drain envelopes (gravel and geotextile filters). The most common form of chemical build-up is calcium carbonate. Manganese carbonate (rhodochrosite) and other insoluble forms (sulfides and silicates) have been found in clogged or partially incrusted drainage systems.

Chemical precipitates form under basic, neutral or slightly acidic (up to pH of about 8) conditions. One reaction leading to calcium carbonate incrustation is the formation of insoluble calcium carbonate ($CaCO_3$) from calcium bicarbonate ($Ca(HCO_3)_2$) solutions when pressure reduction allows carbon dioxide to escape (Baron, 1982). Another means is the depositing of calcium carbonate on surfaces when residual leachate caught in pipes or the drainage envelope evaporates during dry periods. This mechanism is similar to that which creates stalagmites and stalactites in caverns.

It is possible to describe the likelihood of forming calcium precipitates in terms of Incrustation Potential Ratio (IPR) (Baron, 1982) as:

$$IPR = \frac{(\text{Total Alkalinity})\ (\text{Hardness})}{10.3 \times 10^{(11 - pH)}}$$

where: Total alkalinity is expressed in ppm $CaCO_3$
Hardness is expressed as ppm $CaCO_3$

If the IPR is less than one, then no calcium carbonate precipitate can, in theory, be produced. If the IPR is greater than one, precipitates can, but not necessarily will, be formed.

Chemical reactions to form insoluble products are also part of the biochemical mechanisms, described in the next subsection. The precipitates produced in the absence of biological activity are generally quite different in form or structure from those accompanying biological activity, and may be less effective in leading to clogging. The presence of slimes or other forms of microbial biomass often enhance the adherent and clogging potential of the chemical precipitates.

BIOCHEMICAL MECHANISMS

Inorganic precipitates can also be formed in conjunction with biological systems in addition to the relatively simpler mechanisms discussed above. The principal products resulting from biochemical mechanisms are iron compounds, $Fe(OH)_3$ or FeS (although manganese compounds may also be involved), which deposit and build up on the pipe surfaces and in the envelope material. The deposits generally contain organic material as well in the form of adherent, sometimes filamentous slimes and organic complexes.

One of the most prevalent and also well understood biochemical mechanisms is depicted in Figure 2. In this mechanism, iron (or manganese) is initially present as ferric (Fe^{+++}) compounds in soils or wastes, in the case of a landfill, is reduced by anaerobic bacteria to the ferrous state. Ferrous compounds may also arise from inorganic reaction in the soil directly from materials deposited in a hazardous waste landfill.

The biochemical process depends on the availability of iron as dissolved (free) ions in the aqueous leachate which contacts soil, fill, and wastes containing bacteria. The availability of the ions is influenced by their tendency to become attached to soil particles (exchange), tied up in organic complexes, or to be reoxidized by inorganic mechanisms to the ferric state. Two physical chemical factors which influence availability are pH (low pH enhances the free ion concentration) and redox potential (the electrochemical potential that controls reduction or oxidation reactions) (Gotoh & Patrick, 1974).

Positive redox potentials lower the amounts of iron present as ferrous ions. Complexing agents such as tannins, humic acid (products of natural decay of vegetation) or certain classes of organic chemicals, such as phenols, that may be placed in landfills may tie up the ferrous ions so that they are not available for the next step in the process.

That next step is the oxidation of ferrous to ferric ions by bacterial action to produce insoluble ferric hydroxide ($Fe(OH)_3$). The $Fe(OH)_3$ precipitates along with and is mixed into a biological slime made up of the oxidizing bacterial colonies. This mixed type of precipitate (called ochre in much of the literature) is particularly adherent and can very rapidly block up interstices in a drain envelope, entrance slots, or even the inside of a pipe. The biological oxidation occurs under aerobic conditions, althougn some strains of bacteria can function with very little oxygen present.

This reaction scheme and the nature of the resultant products may be influenced by the presence of sulfate-reducing bacteria (Drew Chemical Company, 1978). Sulfate-reducing bacteria form hydrogen sulfide (contributing to the characteristic foul odor in anaerobic decay of organic matter). The sulfide ion will react with ferrous ions to produce an insoluble precipitate which, in conjunction with the organic biomass, can fill the interstices of the envelope and pipe slots (Ford, 1974).

All of the biochemical mechanisms produce the same results, blocked envelope, slots, or pipe, and, ultimately, a clogged drain system. The importance of understanding the specific operative mechanism at a particular site lies in the selection of preventive or remedial measures to avoid or mitigate clogging.

BIOLOGICAL MECHANISMS

Biological clogging is produced when organism growth fills the pipe or interstices of the drain envelope and interferes with normal flow of leachate (Ford, 1980). Figure 2 indicates that, for growth to occur, bacteria must be present in a supportive environment. Many forms of bacteria that can utilize hazardous organic chemicals for food are known (Kobayashi and Rittman, 1982), and will, under the general range of conditions, grow at the temperature, pH and oxygen content, found in landfills. Heavy metals, also often present at hazardous waste landfills, may be toxic or inhibitory to the clog-forming species.

ANALYSIS OF DEPOSITS FOUND AT BOONE COUNTY, KENTUCKY, LANDFILL

When Test Cell #1 of the Boone County Field Site was dismantled in September, 1980 after nine years of testing, a section of partially cemented gravel was discovered in the drain envelope extending from 6.5 to 13.5 feet from the collection sump (bulkhead). The discovery of the cemented section was significant because the Test Cell, along with four others, was constructed to provide a better understanding of the processes and related environmental effects that occur in sanitary landfills (Wigh, undated). It is therefore important to determine whether the causes of cementation are unique to the condition at the small-scale test landfill, or whether they are common to sanitary and hazardous waste disposal landfills in general.

The gravel sample available for analysis consisted of a small amount of loose, rounded pea-stone plus two or three large masses of similar stones firmly held at contact points between the stones by a thin layer of red-brown cement. The largest of these cemented aggregates was a flat, disc shaped mass approximately 12 cm across and 5 cm in thickness. It appeared to be graded or classified with large, individual stones of 1 to 2 cm diameter on one side, and smaller stones of 0.5 to 1.0 cm on the other. A photograph of the two larger masses of material is shown in Figure 3.

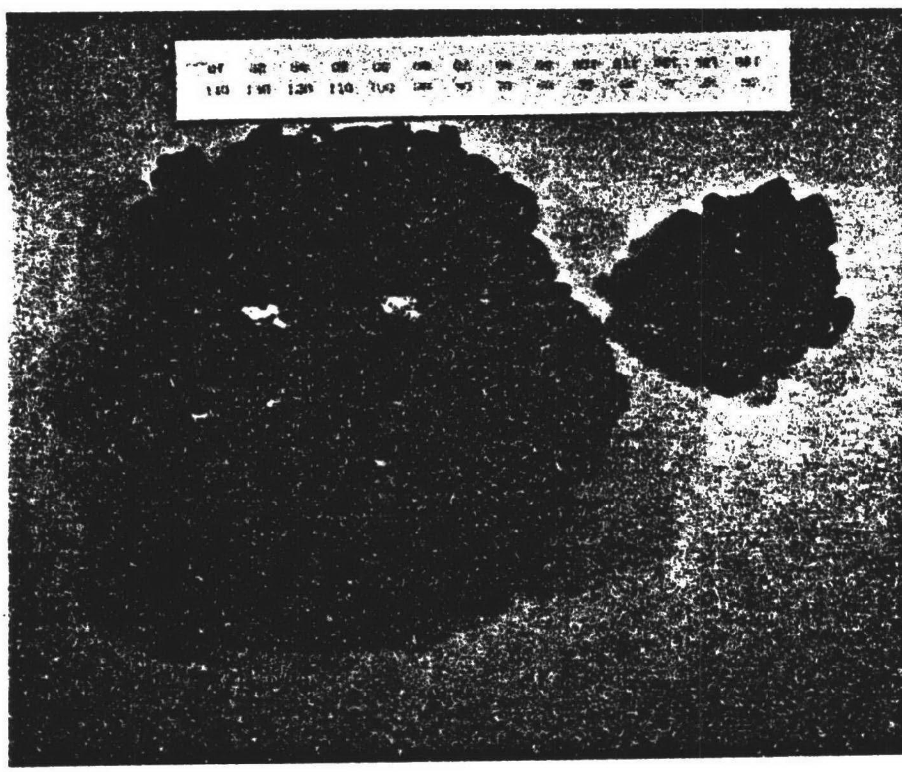
Two approaches were used in the initial analysis of the gravel sample. The first involved a physical analysis of the cement material itself, including scanning electron microscopy, optical microscopy, and X-ray diffraction and fluorescence analysis. The second involved a more general chemical analysis of the mass to determine the primary chemical constituents in the cemented sample.

The results of these microscopic studies lead to the preliminary conclusion that the cementing agent for the small stones is likely a co-precipitated mixture of calcium carbonate and an insoluble iron hydroxide. This combination, along with the silica, constitutes the principal components of the cement. However, aside from a few isolated crystals, calcium carbonate is not observed microscopically as a separate phase and is not present in the X-ray diffraction pattern. Since the calcium is present in a substantial quantity, we would expect to detect the crystalline form (either calcite or aragonite) by this technique, if it were present as pure calcium carbonate. This ambiguity suggests that the calcium and iron may well have co-precipitated in an amporphous form and, as such, are not "seen" by X-ray diffraction.

Chemical Analysis

In a preliminary test it was determined that dilute hydrochloric acid would not affect the gravel but would solubilize the material holding it together. To determine the composition of the cemented gravel material, a portion of the sample was treated with a known excess of acid and separated into acid-soluble and insoluble fractions. The soluble fraction was subjected to qualitative emission spectrographic analysis to identify the principal metal species which were then quantified by emission spectrometry. The insolubles were separated into size fractions and weighed.

FIGURE 3 - The two larger gravel sample masses.



A known weight (100 grams) of the cemented gravel was treated with a known amount of standardized hydrochloric acid and boiled for thirty minutes to effect complete dissolution of the cement material and to drive off the carbon dioxide formed. The insolubles were separated by decantation and filtration, dried, sieve-sized and weighed.

A portion of the filtered solution was analyzed for residual acidity by pH titration (to pH 5.0) using standardized sodium hydroxide solution, to measure the alkali content (acid consumption) of the dissolved material.

Physical Analysis

The microstructure of the cemented material as seen by the scanning electron microscope (SEM) is shown in Figure 4. Accompanying the SEM micrograph in Figure 4 is the spectrum of elements detected by the energy dispersive X-ray analysis system (EDS) attached to the SEM. EDS analysis of the cement material from various points on the sample indicated calcium and iron as the principal elements present. (Elements lighter than sodium are not detected). In addition, in the sample shown in Figure 4, a trace amount of manganese was detected.

A larger amount of the red cement was isolated for analysis of the crystalline content by X-ray fluorescence. X-ray diffraction indicated silica (quartz) as the only crystalline material present.

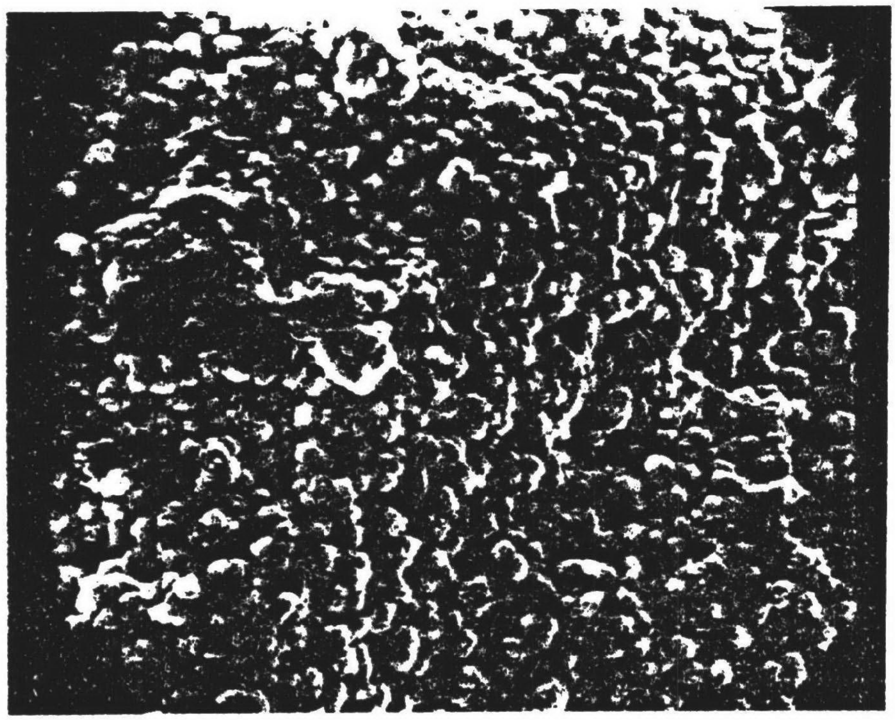
X-ray fluorescence, which detects the presence of elements heavier than aluminum in atomic number, indicated a relatively very strong signal for phosphorous, zinc, sulfur and silica, and a very weak signal for manganese and potassium.

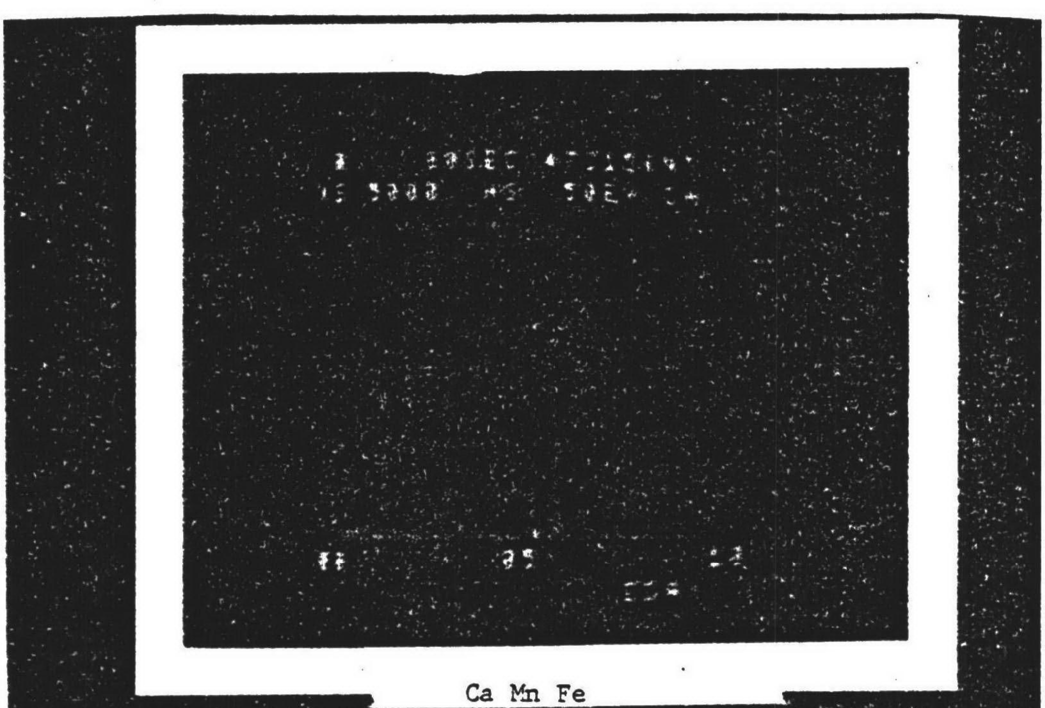
Using optical microscopy under the petrographic (polarizing) microscope, the reddish cement was observed to consist of three major constituents:

- silica;
- a colorless, apparently crystalline phase with calcium carbonate present; and
- an as yet unidentified phase consisting of an aggregated cluster of small red particles comingled with colorless crystalline particles of similar size range. The unidentified aggregates reacted vigorously with dilute acid, evolving large volumes of gas and leaving opaque red particles without the comingled crystalline phase.

The elemental composition of the major constituents in the cemented layer was determined by atomic emission spectroscopy. An emission spectrum was obtained using a Spectrospan III Direct Current Argon Plasma Optical Emission Spectrophotometer for qualitative analysis. This revealed Ca, Fe, Mg, and P as major constituents in solution, and Mn, Cr, Na, Ba, Si, Cu and Sr present

FIGURE 4 - Red cement microstructure with trace of manganese in EDS spectra.





at lower levels. The major constituents, along with Mn, were quantified on Spectrospan III Spectrometer using the method of standard additions for each element analyzed. The results of these analyses are shown in Table 2.

Preliminary Findings on the Composition

The "cement" is principally a calcium-iron-magnesium product containing significant proportions of carbonate (gas evolution) and phosphate. In addition, a relatively large proportion of fine silica appears to be dispersed in the cement.

The lack of significant X-ray diffraction patterns suggests that the cement is an amorphous material rather than composed of discrete crystalline phases. While little can be said yet about the clogging mechanism(s) at work here, carbonate incrustation is likely to have contributed. The role of iron is not clear--it may have been an active agent in precipitate formation, or may only be present as discrete oxide (red, Fe_2O_3?) particles which have been carried along.

These findings leave several questions unanswered. Additional investigation on chemical and physical characterization with emphasis on elucidating the role of the fine silica particles and the distribution and role of iron is needed to that end. Also, tests to determine the presence and distribution of organic materials would provide some evidence as to the possible role of biochemical mechanisms.

Location of the Clogging

Two questions were important in the analysis of the cemented pea gravel in Test Cell #1:

1. What is it? (addressed above)

2. Why did cementation occur only in a limited portion from 6.5 to 13 feet above the collection sump of the upper drain?

One explanation is that the conditions in the wastes above that section were different from those everywhere else in the landfill and caused the deposits only in a limited region. There are insufficient data, however, to evaluate this hypothesis. The discussion following suggests an alternative mechanism.

From a perusal of operating logs, it was discovered that in the first seven months of operation of Test Cell #1, special procedures were used in connection with the leachate drain system. During the first three months (from 6/11 to 8/27/71), the upper pipe was closed off in order to force leachate flow into the lower pipe. This procedure would cause leachate to back up in the pipe until all additional flow was routed to the lower drain. For the following four months (8/28 to 12/27/71) leachate was sampled and the collection system drained on roughly a weekly basis. Again, this operating pattern caused leachate to back up in the pipe.

TABLE 2

RESULTS OF CHEMICAL ANALYSES OF CEMENTED MATERIAL*

Size Distribution in insolubles

Size	Weight Found (g)
2.0 mm (#10 Sieve)	94.015 g
2.0 mm, 0.84 mm (through #10, on #20)	0.640 g
0.84 mm, 0.25 mm (through #20, on #60)	0.933 g
0.25 mm (through #60)	1.070 g

Elemental composition of dissolved material

Element	Weight Found (g)
Ca	0.851 g
Fe	0.551 g
Mg	0.103 g
Mn	0.020 g
P	0.240 g

Weight sample taken	=	100.488 g
Weight insolubles remaining	=	96.958 g
Apparent sample dissolved	=	3.530 g

The distance that leachate would back up in the upper pipe and drain envelope during each of these periods is approximated by:

$$x = k \quad v$$

where:

x = the horizontal distance of leachate back up (and roughly equal to the distance along the pipe due to the small slope of 1.875 percent);

k = a constant which is a function of pipe slope, wetted area and radius, and the porosity of the gravel; and

v = the volume of leachate collected from the upper pipe.

Table 3 gives v and x from 8/28/71 to 1/17/72, as well as other leachate characteristics. As can be seen, six of the first seven and the last four values of x are at or above the location of the cemented gravel (6.5 to 13.5 feet). The five intervening values are from an insignificant quantity of leachate. The three highest leachate quantities had an x value of about 32 feet, which is the length of the pipe.

This correlation suggests that the cementation may have occurred, or at least begun, during this time of unique operation. Further investigation, including a laboratory study, is necessary before more definitive conclusions can be made. It should be possible to simulate the conditions in the Test Cell and determine their effect on the gravel surrounding the upper pipe.

TABLE 3

HORIZONTAL DISTANCE OF LEACHATE BACKUP
(Relative to Cemented Area @ 6.5 to 13.5 ft)

Date	V (l)	X (ft)	pH	Fe*	Alk**	Hard**	Ca*	Mg*
8-28-71	125	above (32)	6.3	42	927	1320	444	63
9-6	20	12	-	-	-	-	-	-
9-13	38	above (17)	5.4	-	1630	2960	1010	132
9-20	22	13	5.4	190	1460	289	117	144
9-27	15	11	-	-	-	-	-	-
10-4	2	below	-	-	-	-	-	-
10-11	36	above (16)	5.5	-	1730	4080	223	133
10-18	0	0	-	-	-	-	-	-
10-25	0	0	-	-	-	-	-	-
11-4	.4	below	-	-	-	-	-	-
11-11	1	below	-	-	-	-	-	-
11-18	1	below	-	-	-	-	-	-
12-6	11	9	5.3	75	1130	1130	1170	152
12-13	125	above (32)	5.4	227	631	4310	1190	243
12-20	14	10	5.4	252	768	4120	1240	244
12-27	126	above (32)	5.6	262	1980	1980	1500	275
1-3-72	127	-	-	-	-	-	-	-
1-10	202	-	-	-	-	-	-	-
1-17	276	-	-	-	-	-	-	-
	Peak Concentrations:		7.07 high 5.10 low	616 (10/73)	8870 (3/73)	7500 (1/73)	2360 (10/73)	374 (11/72)

*mg/l
**mg/l $CaCO_3$

SECTION 6

POTENTIAL FOR CLOGGING AT HAZARDOUS WASTE LANDFILLS

The potential for clogging of leachate collection systems at hazardous waste landfills is of particular concern compared with sanitary landfills. Not only are clogged systems more problematic in that excavation and replacement is no longer a simple last resort, but the consequences of failure are much higher. This follows from technical factors, principally questions of safety resulting from the hazardous nature of the wastes and their leachates as well as institutional factors. The latter items include, for example, the importance of public acceptance of secure hazardous waste disposal sites. Problems with leachate collection systems could set off a public reaction similar to the reaction to reported problems with landfill liners. This is especially true since the collection system is an integral part of the overall system, including the liner, for protecting groundwater and the environment.

The literature clearly indicate that clogging is a serious problem in agricultural drainage systems. Direct assessment of clogging potential at hazardous waste or sanitary landfills, however, is difficult since there is little experience with modern leachate collection systems. It is therefore useful to compare the clogging potential in leachate collection systems at sanitary and hazardous waste landfills with agricultural drainage systems by using the set of clogging mechanisms identified in the Failure Mode Diagram (Figure 2) as a basis. The following discussion follows the major factor type shown in Figure 2, above.

DESIGN FACTORS

Design factors are particularly important to physical mechanism such as sedimentation or inadequate capacity. Design of agricultural drainage systems is similar to that of leachate collection systems in many respects. There are, however, more stringent requirements for leachate systems since aspects of the design are specified by regulation and approval by the appropriate agencies is required. In addition, large implicit costs of non-compliance with regulations should enhance quality control during construction of hazardous waste facilities. Design (and construction) error, while possible with all three systems, are therefore more likely to occur with agricultural drainage systems.

OPERATIONAL FACTORS

Operational factors are involved primarily with structural failure mechanisms. Compaction of waste and general equipment loading can cause pipe crushing or displacement. Compaction of waste (e.g., with a 20-ton compactor) occurs at both sanitary and hazardous landfills. General equipment loading occurs at all three systems, but heavier equipment is expected to be used at the landfill sites. Operational procedures which cause clogging appear, therefore, more likely to occur at hazardous waste and sanitary landfills.

WASTE/LEACHATE FACTORS

Waste/leachate factors are the most important in pipe deterioration, chemical, biochemical and biological clogging mechanisms. The composition of agricultural drainage is generally very different than landfill leachate except for a few parameters. Suspended solids, some common ions (e.g., Ca^{+++}), nutrients, and bacteria are not necessarily very different. The most important difference is that hazardous waste leachate contains various chemical constituents not expected in the others, and may have a lower pH. This means that mechanisms which require an environment which is not toxic to certain bacteria or favor a more basic pH range would be less likely to occur in hazardous waste landfills. Alternatively, mechanisms which require a lower pH or certain chemical constituents would be less likely to occur in sanitary landfills and agricultural drainage systems.

CONDITION AND EVENT FACTORS

Condition and event factors can be significant in all three types of systems and will depend in a large part on local conditions. Certain conditions, such as temperature, depend entirely on site-specific characteristics. Others, such as water inputs and groundwater flow, depend in part on design (e.g., cover, number of pipes) or operation (e.g., irrigation) or location. Clogging due to conditions and events is expected to be the same, on the average, for all three system types.

RELATIVE POTENTIAL FOR CLOGGING

Combining the effects of the factors it is possible to estimate the relative potential for clogging of leachate collection systems for each of the mechanisms. This is presented in Table 4. A "*" in the table indicates that clogging is possible, while a "+" or "-" indicates that clogging is more or less likely, respectively, relative to the "*". A "-" does not mean that clogging is not possible, nor does a "+" mean that clogging will occur. Table 4 gives the <u>relative</u> potential for clogging of agricultural drains and leachate collection systems at sanitary and hazardous waste landfills based on the major potential clogging mechanisms.

As can be seen in Table 4, crushing problems appear to be more likely to occur at both hazardous waste and sanitary landfills, whereas chemical, biochemical, and biological clogging appear less likely to occur in hazardous waste systems. This difference is primarily due to the lower pH range and

TABLE 4

RELATIVE POTENTIAL FOR CLOGGING OF LEACHATE COLLECTION SYSTEMS

Mechanism	Agricultural Drains	Sanitary Landfills	Hazardous Waste Landfills	Significant Differences
Physical				
Crushing	*	+	+	Compaction, greater equipment loading
Sedimentation	*	-	-	Less careful design and construction possible
Deterioration	*	*	+	Chemicals, solvents, low pH not expected
Chemical ($CaCO_3$)	*	*	-	Lower pH
Biochemical (Ochre, Fe)	*	*	-	Toxicity to indigenous bacteria, lower pH
Biological	*	*	-	Toxicity to indigenous bacteria, lower pH

- = less likely

+ = more likely

the potential toxicity of chemical constituents to indigenous bacteria. It should be noted that various toxic chemicals can be nutrients to certain bacterial strains, and hazardous leachate can have a high pH. Sedimentation and pipe deterioration are also potential problems in hazardous waste systems.

SECTION 7

PREVENTION AND REMEDIES

Problems with clogging of drainage systems can be addressed by means of preventive or remedial measures. Preventive measures are intended to eliminate or render highly improbable one or more of the pathway links shown earlier in Figure 2. Such measures would interrupt the sequence of causal steps necessary for a particular clogging mechanism to occur and would thereby avoid (prevent) the clogging problem. Prevention of drain clogging can be accomplished in a number of areas, including:

- o design and construction;
- o operation and maintenance;
- o waste disposal; and
- o treatment.

Remedial measures are intended to eliminate the clogging problem once the major (ultimate) event in Figure 2 (i.e., a clogged drain) has occurred. Remedial measures for clogged drain systems include:

- o excavation and replacement;
- o physical methods; and
- o chemical methods.

In terms of these definitions, preventive measures would include undoing or fixing conditions that exist before clogging as the final event (e.g., cleaning out partially clogged pipes). Examples of preventive and remedial measures are presented in Tables 5 and 6, and are discussed briefly below.

PREVENTION

Design and Construction

Proper design and construction is the most basic preventive measure. A study of agricultural drain systems found that more than 50% of drain failures were due to improper design and construction (in EPA, 1982). For leachate collection systems, design mistakes will need to be carefully avoided. It is also important that the system be constructed as designed.

TABLE 5

PREVENTIVE MEASURES FOR DRAIN CLOGGING

Category	Measure	Factors Affected	Mechanisms Affected	Comments
Design and Construction	pipe diameter 6"	pipe size, estimated flow	capacity	facilitate remedial measures, maintenance
	pipe in protective cradle, soil cover	crushing	structural	use high strength pipe
	sealed joint construction	displacement, slot size	structural, sedimentation	use slotted or perforated pipe
	corps grain size distribution criteria	filter material	sedimentation	options include graded, 2 or more layers geotextile, 4" minimum depth
	submerged outlet	anaerobic conditions	chemical, biochemical	may facilitate anaerobic mechanisms
	slope 2 percent	flow rate	capacity, sedimentation biochemical, biological	depends also on quantity of flow
	exercise special care in design and construction	all design	capacity, sedimentation structural	
	design for prevention	all	all	manholes, cleanouts, large pipe, etc.
Operation and Maintenance	care during placement	crushing, displacement	structural	most important for first lift of waste
	compaction operation in vicinity of drain			
	regular monitoring and inspection of system	all	all	identify factors, early stages of clogging for preventative cleaning
	cleaning	all	all	removes potential clogging in early stages, use flushing, low pressure jets
Waste Disposal	minimize nutrients	bacteria	biochemical, biological	organics, N and P compounds, other chemicals
	dispose biocides, toxics	bacteria	biochemical, biological	acids, bases, heavy metal wastes
	maintain low pH	bacteria	chemical, biochemical biological	contributes to deterioration
	avoid solvents, oxidizing agents	chemical attack	deterioration	
Treatment	biocides	bacteria	biochemical, biological	add directly to collection system
	acid	all	all	kills bacteria, removes early stages

TABLE 6

REMEDIAL MEASURES FOR CLOGGED DRAINS

Category	Measure	Effectiveness	Comments
Excavation and Replacement	same	complete remedy	most expensive option; difficult at hazardous waste sites
Physical Methods	-mechanical	limited for inactive deposits, not effective for slots, but good in combination with other methods	Roto-rooter, pigs, sewer balls, snakes, buckets
	-low pressure jets	effective for ochre, FeS, limited for mature deposits	70 - 140 psi at nozzle
	-high pressure jets	same as low pressure but can cause damage to drain envelope and better for mature deposits	440 - 1300 psi at nozzle
	-flushing (sub-irrigation	less than jets	
Chemical Methods	-SO_2 gas	effective for ochre, Mn in 2 cases, ineffective in one case for ochre	rate of use = 1 lb/7.5 gal water dangerous to personnel and environment, cost is 7 percent of replacement
	-Sulfamic Acid	effective for ochre	strength required depends on organic matter and age of ochre Na_2CO_3 used to neutralize treated drain

There is already at least one case where errors in design and construction have led to system clogging at a hazardous waste facility. In this case, the builder neglected to install a filter layer around the collection sump (although it is unclear whether this was actually a design or a construction error.) In addition, it is important that the system be designed specifically to prevent or minimize the potential for clogging. This includes proper sizing of components (e.g., pump size, pipe diameter and slope), material selection for strength and compatibility with wastes and leachate, and special features included especially to prevent or remedy clogging (e.g., cleanouts, graded or layered filter, submerged outlet).

Operation and Maintenance

Operation and maintenance is also of considerable importance in preventing clogging. Operational considerations include taking special care during placement and compaction of waste and during other operations when in vicinity of the drain. Placement of the first lift of waste is of particular concern since the filter layer is exposed and the cover over the drain is at its shallowest point. Maintenance considerations include monitoring and inspection of the collection system and regular preventive cleaning. Many of the remedial techniques for unclogging drains are more effective when used as preventive measures. Mature deposits of ochre, for example, can be difficult, if not impossible, to remove, while young deposits are more easily flushed out. This implies that careful system monitoring is also important since the early stages of clogging are more readily dealt with than the later stages when the ramifications of clogging may be more evident.

Control of Waste Disposal

Control of waste disposal at the facility can also be used as a preventive measure. Minimizing nutrient-rich waste (e.g., containing organics, nitrogen, phosphorus) and adding biocides or materials toxic to bacteria (such as heavy metals) can decrease bacteria growth and control biochemical and biological precipitation. Maintaining a low pH can also minimize bacteria activity as well as reduce calcium carbonate precipitation. Addition of solvents, oxidizing agents and caustic or corrosive chemicals should also be minimized since they can contribute to the deterioration of material used in the collection system. Maintaining a low pH may also contribute to deterioration.

Direct Treatment

Finally, direct treatment of the collection system can be used to prevent clogging. This involves the periodic application of biocides to kill bacteria or acid to dissolve deposits in their early stages of development. Treatment can be used in conjunction with pipe cleaning and other preventive measures to inhibit clogging mechanisms in the pipe and remove accumulations before clogging becomes a problem. Cleaning and treatment of the area surrounding the pipe is more difficult so that other preventive measures will need to be more heavily relied upon.

REMEDIES

Excavation and Replacement

Excavation and replacement is the most difficult and expensive remedial measure for clogged leachate collection systems. It involves actually digging up the clogged pipe or envelope material and installing new drain components. This is an expensive, but straightforward, procedure at sanitary landfills, but at hazardous waste facilities becomes more problematic since hazardous wastes may be exhumed. It should therefore be considered a last resort alternative to be used when all other options are ineffective. For example, for mature ochre deposits or a clogged envelope, excavation and replacement may be the only effective alternative.

Physical Methods

Physical methods for unclogging pipes include mechanical devices and hydraulic cleaning. Mechanical devices can be long, flexible tools, inserted in the pipe such as snakes or roto-rooters, or objects, such as pigs (bullet-shaped) and sewer balls, propelled through the pipe. These devices all serve to dislodge the material in the pipe which is restricting leachate flow. They may not, however, be effective for mature deposits or for material in slots or drain openings. They are also useful in combination with other techniques, for example in preparation for hydraulic flushing or acid treatment. Hydraulic cleaning uses high or low pressure jets or simple flushing to dislodge and remove deposited material. High pressure jets (440-1300 psi at the nozzle) are the most powerful hydraulic method, but may damage the drain envelope. Low-pressure jets (70-140 psi at the nozzle) are less powerful and are therefore safer for the drain envelope. Both types have been effective in removing ochre, FeS, and sediment deposits in pipes. No experience was noted for simple flushing. Presumably, the more pressure behind the water the more stubborn a deposit which can be dislodged.

Chemical Methods

Chemical methods utilize acid to dissolve clogs in drain pipes. The methods presented were developed to remove ochre and manganese deposits from agricultural drains. Acids also may function as a biocide to kill bacteria. The acid strength required to lower the pH to dissolve deposits and prevent further accumulations depends on the nature of organic matter present and on the age of the clogging material. Acid treatment is inexpensive compared to replacement (roughly 10%) but can also be dangerous to personnel. Fumigation with SO_2 gas, which dissolves in the leachate, has had varied success in reducing ochre and manganese deposits. Use of a dry, pelletized form of sulfuric acid has been effective for ochre deposits. This form has the advantage of being safer for personnel in handling than concentrated acid. Sodium carbonate can be used to neutralize acid-treated drainlines if necessary. As with physical remedial methods, chemical methods apply primarily to drain pipes and would be less effective for treating clogged envelopes.

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