INVESTIGATION AND REMEDIATION TECHNIQUES FOR CONTAMINATED WASTE SITES IN BRITISH COLUMBIA

by
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INTRODUCTION

Contaminated waste sites differ significantly in their genesis, ranging from random in situ soil and groundwater contamination at industrial and chemical spill sites to systematic waste deposition at municipal landfill sites and contaminated fill sites. All of these types of waste sites occur in British Columbia. The historical lack of planning, environmental controls and good engineering practices in the design of waste containment facilities have, and will continue to, result in the need to investigate and remediate a variety of contaminated waste sites in the province.

The genesis of a contaminated waste site has a significant impact on the distribution of waste material within the site and the contamination potential. Thus the genesis of the site will influence the selection of the most effective investigative techniques to employ to define the waste distribution as well as the most appropriate remediation techniques. The nature of waste sites, and their investigation and remediation implications will be discussed below. Finally, a case study will be briefly discussed.

MUNICIPAL/INDUSTRIAL LANDFILL SITES

Municipal and industrial landfills may contain a broad spectrum of waste materials, but typically comprise a relatively predictable waste stream, with well-documented proportions of various waste materials comprising the fill. The waste is generally quite porous, of low density and relatively high water content. Environmental hazards associated with these sites are not typically associated with the waste material itself, but with the production and off-site migration of leachate from the landfill facility. Historically, these sites have been constructed unlined, and often sited in abandoned borrow areas and gravel pits, with moderately permeable to permeable soils overlying water table aquifers, resulting in significant potential for groundwater contamination.

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The waste distribution within such landfill sites is generally quite homogeneous, with a predictable site geometry, due to the planned nature of these facilities. The leachate generated varies over the lifespan of the facility, due to evolution of the waste environment from aerobic to anaerobic waste decomposition. Leachate is typically characterized by elevated organics, salts and heavy metals, as well as BOD and COD (Freeze & Cherry, 1979).

CONTAMINATED FILL SITES

Contaminated fill sites are generally not as structurally defined as landfill sites, in terms of waste distribution. These fill sites in many cases represent relatively recent deposits, having often resulted from recent amendments to environmental legislation, which, for example, significantly constrains the potential for ocean dumping.

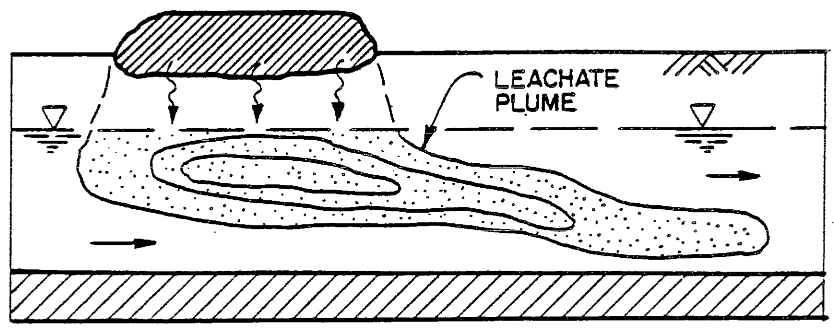
Unlike conventional landfill waste, this material is largely composed of mineral soils and construction debris, through which the contaminants are disseminated. Waste distributions are often irregular, due to the random nature of the source material and methods of placement. Environmental concerns with contaminated fill sites are usually associated with the waste material itself. At sites where the fill material is placed above grade, groundwater contamination may not be a significant issue, due to the limited mobility of many hydrocarbon and heavy metal constituents in the unsaturated regime. Groundwater flow through saturated contaminated fill is also unpredictable, due to the lack of continuous soil horizons, buried channels, and other features which normally influence groundwater flow patterns. Where the waste material resides completely within the unsaturated zone, leachate plumes will not normally develop for a significant period of time, if at all.

CONTAMINATED INDUSTRIAL SITES

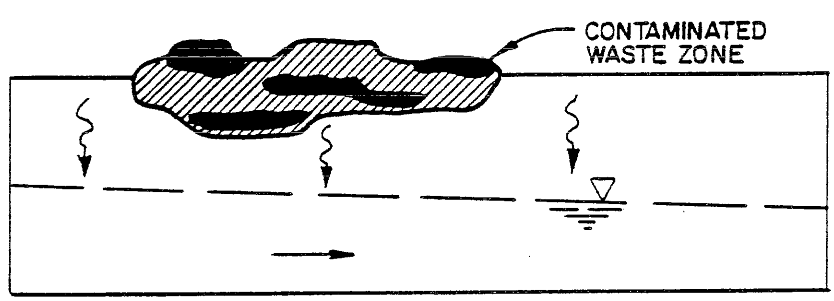
Contaminated industrial sites differ significantly from conventional landfills and contaminated fill sites in that the waste materials are normally a composite of soils contaminated in situ by discharge of industrial waste products to the subsurface, and on-site landfilling of solid waste material. In many cases, site contamination has occurred over a long duration, with a series of waste inputs to the site as newer industries are established. These sites typically contain the greatest variety of contaminants, due to the generally diverse nature of the input sources, including minor periodic chemical spills, leaking underground tanks, on-site burial of solid waste by-products, seepage from liquid holding ponds, and smoke stack emissions. In some cases, where contaminants have interacted, new contaminated end-products have resulted, creating a very irregular and relatively complex waste distribution. As most of these sites are located in or near transportation centres, which are typically sited in coastal environments, the contaminants are usually located in the saturated regime, or in close proximity to the water table.

Due to the age of such sites, leachate plumes are also typically well developed, in situations where the leachate generation potential exists. As a result, these sites are normally characterized by both contaminated soil and groundwater, and are generally the most complex sites to instrument, characterize and ultimately, remediate. Schematics of all three types of contaminated waste site are presented in Figure 1.

LANDFILL SITE



CONTAMINATED FILL SITE



CONTAMINATED INDUSTRIAL SITE

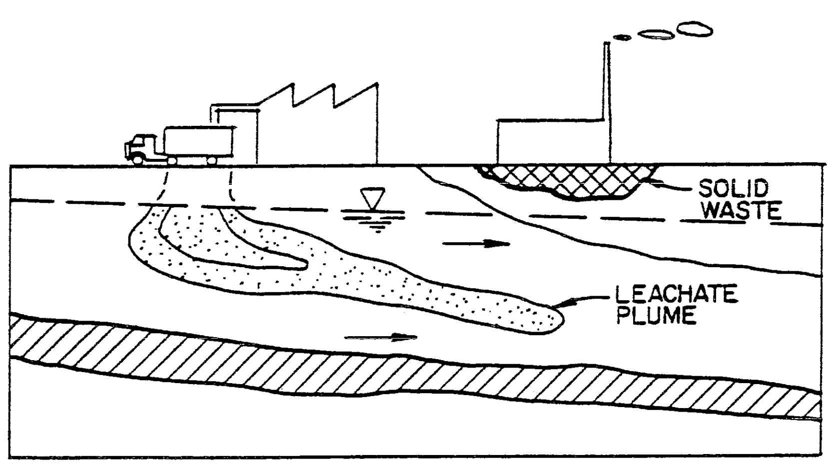


FIG. 1: SCHEMATICS OF CONTAMINATED WASTE SITES

INVESTIGATIVE TECHNIQUES

OVERVIEW

Investigative techniques for most contaminated waste site investigations should include both information review and field investigation programs. In most cases, undertaking a thorough review of relevant site data prior to designing and implementing a field program results in a more targeted, solution-oriented and cost-effective investigation. Relevant information often includes land use maps, insurance records, chemical inventory records, industrial product lists, plant operations manuals, site blueprints, discussions with site personnel and consultants' reports. When compiled in the form of a working plan, this information can then be used to develop a coherent field investigation program.

Where the nature and/or scope of the site contamination remains ill-defined from the results of the literature survey, a qualitative field survey may be considered to provide better definition of the scope of site contamination before committing to a comprehensive site investigation. Such techniques include surface geophysical surveys, such as electromagnetic and resistivity scans, soil gas monitoring and radar surveys.

Following initial definition of site contamination by review of historical information and/or a qualitative site assessment, a quantitative site assessment is required to define the nature and extent of site contamination. The scope of such investigations and approaches used will depend on the complexity of the site, the nature of the contaminants, and the proposed end use of the site. Some of the key points to consider before undertaking the design of a field investigation program include:

- anticipated contaminants,
- anticipated groundwater flow patterns,
- sampling philosophy (soil and groundwater),
- modelling requirements, and
- regulatory requirements.

LANDFILLS

Typically, there are considerable uncertainties associated with the position of the leachate plume during initial stages of the investigation. As the cost of monitoring well networks is generally significant, it is often useful to conduct an initial reconnaissance-level geophysical survey to provide a qualitative assessment of the approximate distribution of groundwater contaminants. This may be accomplished by means of an electromagnetic or resistivity survey, as leachate waters typically have significantly higher electrical conductance values than natural groundwater. However, in situations where a particular contaminant is of interest, or of particular concern, other methods may be more appropriate. For instance, induced polarization (IP) surveys have been effective in delineating cyanide distributions in groundwater. A positive correlation was found to exist between high cyanide concentrations and high relative polarities in recent studies conducted in Czechoslovakia.

A better and more quantitative definition of contaminant plumes is obtained in most cases by the installation of a groundwater monitoring network, consisting of either conventional standpipe piezometers, or multi-level samplers, or both. In a phased study, conventional standpipe monitoring wells may be installed to obtain a gross definition of the plume, including plume boundaries and approximate position of the centre of mass, followed by installation of multi-level samplers to refine the contaminant distribution.

While a simple concept in principle, the heterogeneities associated with most natural granular deposits results in the preferential migration of leachate within lenticular, higher permeability channels within the saturated deposits. Remediation of the entire contaminant mass is thus generally not possible or economically feasible (Crawford and Smith, 1985). Remediation of such leachate plumes is thus best accomplished by early detection of the plume at locations in proximity to the landfill facility. As the technical and economic infeasibility of fully delineating contaminant plumes is widely accepted, geostatistical models have been developed to provide probabilistic models of contaminant distributions, with associated levels of uncertainty. This approach has the advantage of reducing the required number of site monitoring locations in most instances.

CONTAMINATED FILL SITES

Contaminated fill sites, which typically represent a solid waste contaminant problem, often require a different approach. Where hydrocarbons and/or phenols represent the primary contaminants of concern, soil gas monitoring can be an effective reconnaissance-level indicator of their presence. Recent experience has indicated, however, that good correlations between soil gas ion counts and actual hydrocarbon/phenol concentrations are not always observed, and thus, as is the case with geophysical surveys, the information is more qualitative than quantitative. However, as a preliminary scanning tool, this method can be quite cost effective in delineating the overall scope of site contamination.

Following soil gas monitoring, test drilling can be employed to provide soil contaminant distributions. Typically, however, the distribution of contaminants is very irregular, and thus only approximate distributions of contaminated waste occurrences and volumes can be derived.

For large sites, with significant volumes of contaminated soils required to be excavated, three-dimensional computer modelling can be employed to simulate the distribution of waste bodies by geostatistical methods, optimize the waste excavation process, and assign costs to various extraction scenarios.

INDUSTRIAL SITES

Contaminated industrial sites are normally characterized by variable geologic environments, and typically located in major urban centres. Investigation and remediation of industrial sites is becoming a significant issue as redevelopment of older industrial land proceeds under urban renewal.

As industrial sites often comprise both solid waste and groundwater contamination more comprehensive investigative techniques are generally required. These include reviews of historical records, surface geophysical surveys, soil gas monitoring, test drilling and soil sampling, groundwater monitoring and sampling, and solid waste modelling studies, as discussed above. Typically, such investigations are conducted in a phased approach, with each phase building on the knowledge of the preceding ones. The objective is a methodical, comprehensive, cost-effective evaluation. Table I provides a summary of contaminated site characteristics and investigation and remediation techniques.

REMEDIATION OPTIONS

Options chosen for remediating contaminated waste sites will depend on:

- nature of site contamination,
- geologic setting,
- level of contamination,
- cost effectiveness, and
- environmental jurisdiction (i.e., provincial versus federal)

NATURE OF SITE CONTAMINATION

Remediation of contaminated groundwater typically involves the containment and/or extraction/treatment/disposal of leachate water. Containment systems may be either active or passive, such as interceptor wells and slurry trench walls, respectively. In some instances, these systems can be combined to provide higher rates of leachate recovery.

The most commonly-used groundwater remediation method is 'pump-and-treat', followed by either reinjection of the treated wastewater or pumping to waste after achieving the required water quality standard. Treatment systems for hydrocarbon extraction/destruction include air stripping, ultraviolet radiation, resin exchange and bio-remediation, with the process selected depending on the nature of the application.

Remediation of contaminated solid waste is typically accomplished in British Columbia by excavation and disposal at a suitably permitted disposal facility. However, as discussed in a later section, other remedial options are being considered, as a result of economic and technologic change.

GEOLOGIC SETTING

The geologic setting influences both the mobility of the contaminants and the ease with which the contaminants can be extracted from the subsurface. In highly permeable sediments, contaminants are generally very mobile, due to adventive transport mechanisms. Contaminant mobility in low permeability silts and clays is generally much lower, as the dominant transport mechanism is molecular diffusion. Recovery of contaminated groundwater in both instances can be problematic. Leachate recovery in highly permeable sediments is hampered by mobile contaminants which can become quickly dispersed within the aquifer, requiring the timely installation of leachate recovery wells, to reverse the direction of the plume, and allow significant leachate recovery. Under such circumstances, the ratio of leachate volume to total volume of groundwater extracted is generally very low. Furthermore, as mixing occurs in the leachate recovery process, all extracted groundwater must normally be treated. Hence, such remediation programs can be very time-consuming and costly. Conversely, contaminant recovery in low permeability sediments is constrained by the low efficiency and/or infeasibility of recovery wells, except where these deposits are heavily fractured. Under both circumstances, in situ bio-remediation may be appropriate (Srinivasan and Mercer, 1988; Major et al, 1988).

LEVEL OF CONTAMINATION

The Pacific Place Standards define the existing environmental legislation in British Columbia with respect to contaminated soils and groundwater. These interim standards were developed for managing contaminated waste at the Pacific Place site, and will be superseded by more comprehensive legislation in future. They define four major contamination concentration thresholds, namely Level A, Level B, Level C and Special Waste. Waste contaminated at a level above Level A but below Level B is defined to be slightly contaminated, waste contaminated above Level B but below Level C is defined to be contaminated, and waste above Level C but below Special Waste levels is defined to be significantly contaminated. Special Waste is the highest designated level of contamination.

Under the existing standards, slightly contaminated waste does not require remediation. Contaminated waste does need to be remediated, but can be disposed of as industrial fill, or disposed at a landfill facility. Significantly contaminated waste must be disposed of at a permitted landfill site, or otherwise treated to reduce it to acceptable concentrations with respect to its designated end use.

Remediation of solid waste material up to Level C (significantly contaminated) will likely consist of excavation and disposal, as this generally represents the most straightforward, cost-effective solution. Other remediation technologies, such as incineration or bio-remediation, may be environmentally or economically justifiable for waste at the significantly contaminated level or above, including Special Waste, which otherwise must be disposed of at a Special Waste facility. At present, such a site does not exist in British Columbia.

COST EFFECTIVENESS

In order for a remediation scheme to be feasible, it must be cost-effective, or a more economical alternative will be employed in its place. While the 'excavation and disposal' option has been cost effective in the past, the dramatic escalation in dumping fees at secure and hazardous waste disposal sites, the enacting of more stringent environmental legislation, and the escalating liability attached to waste owners is making other remedial technologies more cost-competitive, particularly in the long term. Hence, on site treatment is increasingly being viewed as an economically-justifiable approach.

ENVIRONMENTAL JURISDICTION

At present, legislation governing environmental issues in British Columbia has been established at both the provincial and federal levels. At the provincial level, the Ministry of Environment is responsible for enacting and enforcing all environmental legislation, while the Canadian Environmental Protection Agency (CEPA) undertakes the same functions at the federal level.

TABLE 1

SUMMARY OF CONTAMINATED SITE CHARACTERISTICS AND INVESTIGATION/REMEDIATION TECHNIQUES

	LANDFILLS	CONTAMINATED FILL SITES	CONTAMINATED INDUSTRIAL SITES
Typical Contaminant Media	Groundwater	Soil	Soil and Groundwater
Waste Type	Organics Heavy Metals Salts	Hydrocarbons Heavy Metals	Organic Chemicals Hydrocarbons Heavy Metals Resin Acids Other
Typical Age of Facility (years)	1-40	1-10	1-100
Degree of Complexity	Low to High	Low to Medium	Medium to High
Typical Investigative Techniques	Surface Geophysics Test Drilling/ Sampling Groundwater Monitoring/ Sampling	Soil Gas Monitoring Test Drilling/ Sampling	Historical Records Review Surface Geophysics Soil Gas Monitoring Test Drilling/ Sampling Groundwater Monitoring/Sampling
Remediation Technologies	1. Pump and Treat 2. Containment and Leachate Recycling 3. Capping	1. Excavation and Disposal 2. Incineration 3. Bio-remediation 4. Capping	1. Pump and Treat 2. Excavation and Disposal 3. Incineration 4. Bio-remediation 5. Capping

In both instances, the legislation is still in the interim, formative stages, and the respective areas of jurisdiction are not currently well defined. Under these circumstances, care must be taken on the part of the consultant to ensure that the appropriate legislation is being referenced in the design of investigative and remedial programs.

CASE STUDY

A brief case study of an industrial landfill in British Columbia is presented below. As the study is still ongoing, and the information is still proprietary, specifics of the study cannot be provided. However, an understanding of the principal features of the investigation is not contingent on knowledge of these specifics.

An industrial landfill site was investigated as a result of concerns expressed over the potential for groundwater contamination of underlying aquifers by the British Columbia Ministry of Environment. This led to an exploratory groundwater investigation in 1988, consisting of 10 monitoring wells installed upgradient, downgradient and within the landfill facility. The monitoring well locations were chosen after reviewing existing site plans, historical records of waste disposal operations, and discussions with site personnel.

The water chemistry results indicated the presence of a leachate plume downgradient of the landfill, as anticipated. A more extensive groundwater monitoring well network was installed in 1989, with well locations based on the results of the existing network, to better define the leachate plume, and allow evaluation of the remedial effects of the landfill cover installed in 1989.

The site is characterized by an unlined industrial landfill facility (Figure 2) overlying a series of shallow, permeable sand and gravel aquifers, separated by thin silt beds (Figure 3). The upper aquifer is predominantly unsaturated, and of little significance to the study. Both the middle and lower aquifers, composed primarily of coarse sand to fine gravel, are saturated and confined. Permeability estimates for these aquifers range from 7×10^{-4} m/s to 5×10^{-5} m/s. As can be seen from the cross-section, flow in both aquifers is predominantly horizontal, towards tidewater, representing the base level for groundwater discharge. Upward gradients are observed in the lower aquifer near the point of discharge, with groundwater flow both into the middle aquifer as well as directly into the receiving waters.

Recharge to the site is abundant, with two major recharge events per year; the first one in late spring, due to snowmelt, and the second in late fall. The lifespan of the landfill is in excess of 20 years, and was capped and decommissioned in 1989. As a result, there has been significant potential for the generation of a leachate plume over the operating period of the facility. This appears to have occurred, with leachate migration into both the middle and lower aquifers, forming well-defined contaminant plumes. The distribution of total cyanide within the middle aquifer is illustrated on Figure 2.

The prime contaminants of concern in the landfill leachate are cyanide and fluoride. Both constituents are present at significantly elevated concentrations, with total cyanide concentrations ranging from <1 mg/L to 400 mg/L, and fluoride concentrations ranging from <1 mg/L to 11 900 mg/L.

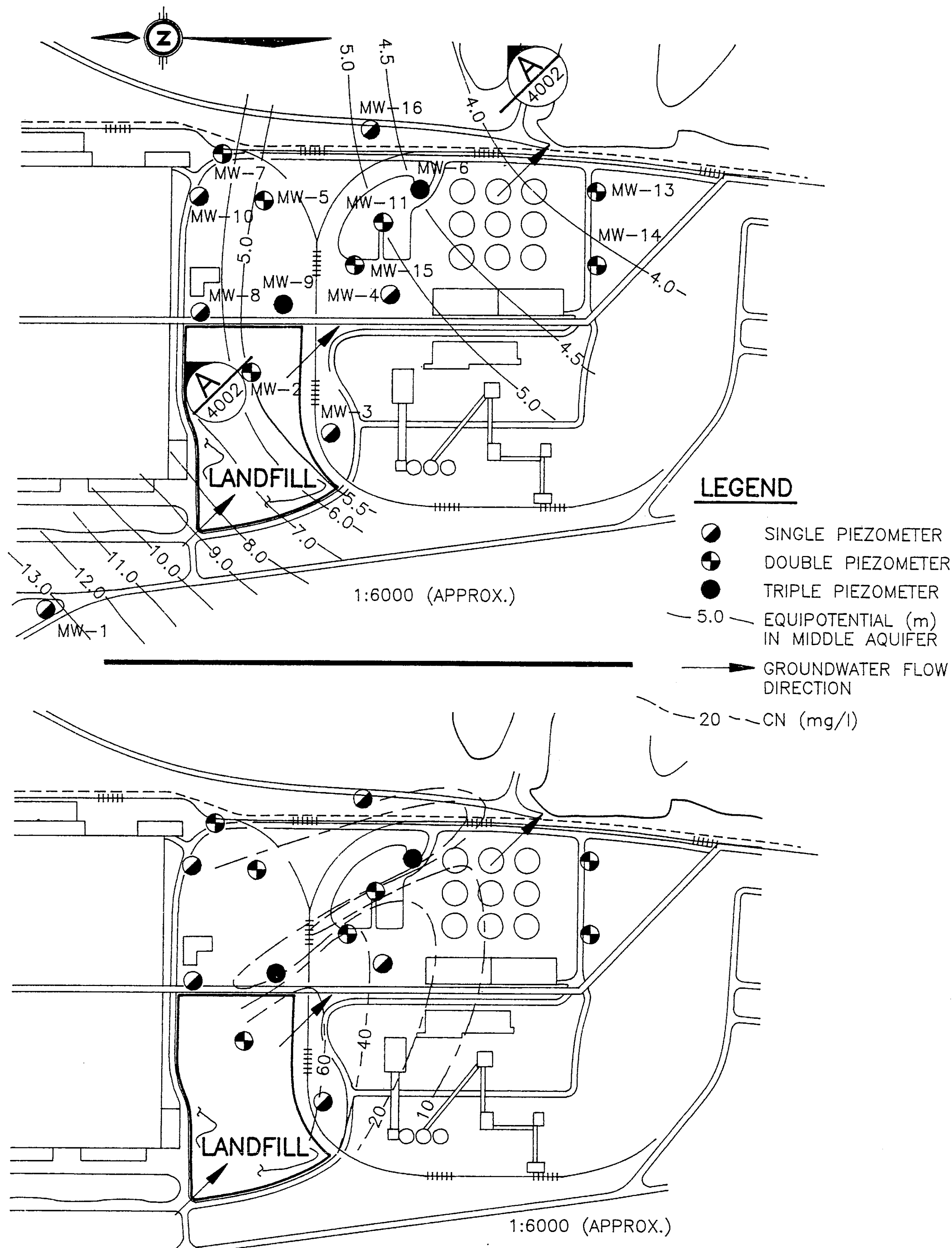


FIG.2. SITE PLANS SHOWING GROUNDWATER FLOW PATTERNS AND TOTAL CYANIDE DISTRIBUTION

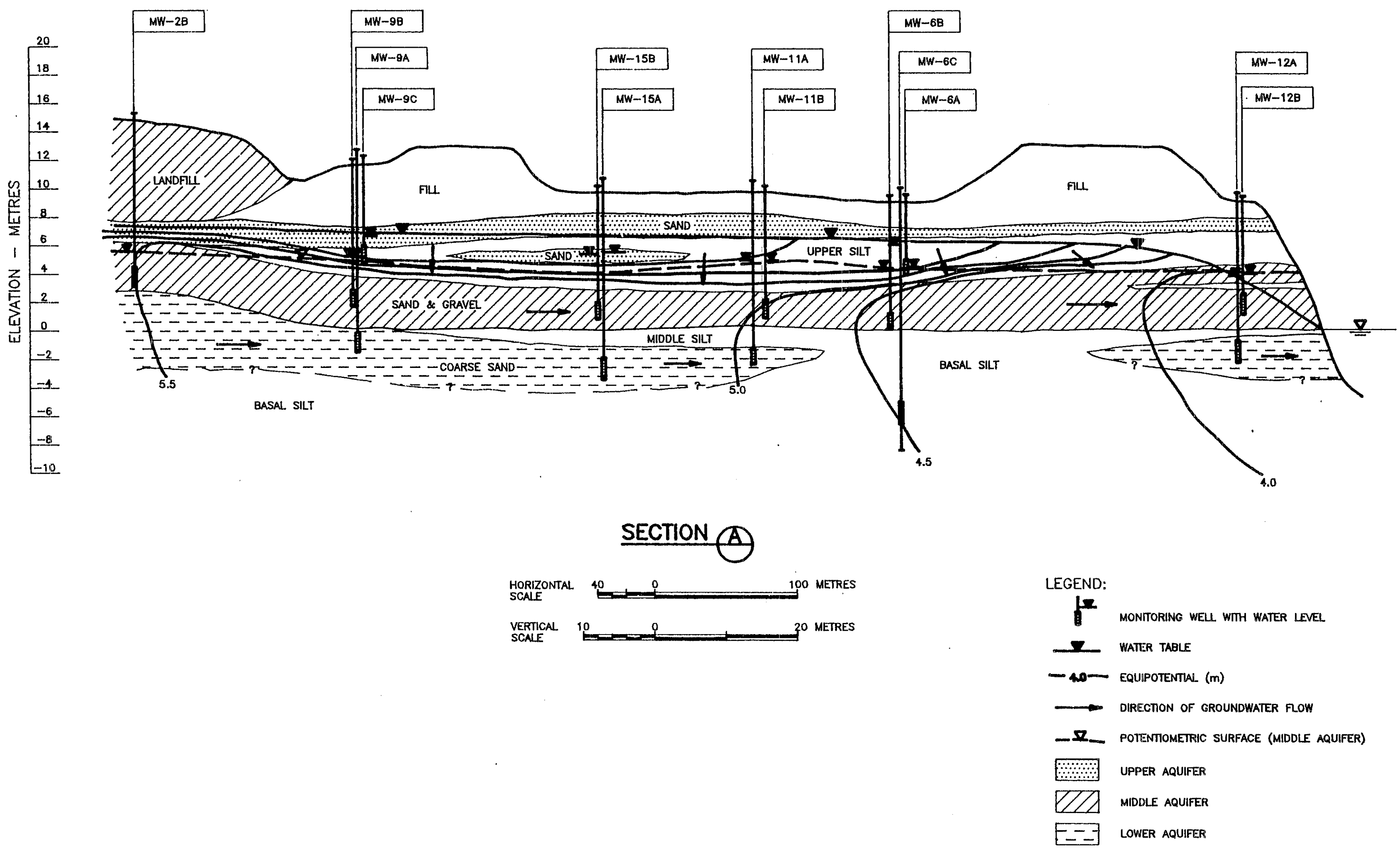


FIG 3: HYDROGEOLOGICAL SECTION ALONG PROFILE A-A.

The groundwater concentrations of both parameters vary significantly over an annual cycle, with the lowest concentrations of total cyanide in solution observed immediately following the spring and fall primary recharge events. In the case of cyanide, this phenomenon is attributed to the depression of groundwater pH by recharge from precipitation, with a typical pH range of 5.5 to 5.8. The ambient pH of the shallow groundwater, by comparison, ranges from a pH of 8 to 10. The solubility of cyanide decreases exponentially with decreasing pH. The observed relationship between cyanide concentrations versus pH values over an annual cycle is presented in Figure 4.

Similarly, fluoride solubility is also affected by aquifer recharge. It is anticipated that the generally high degree of fluoride mobility is due to formation of soluble salts, such as sodium fluoride. Sodium is present in significant concentrations in the landfill waste. It is expected that sodium ions are being released from exchange sites by competing ions, as a result of dissolution of additional solutes from the landfill by chemically aggressive, lower pH recharge water. The significant reduction in fluoride concentrations downgradient of the landfill can be partially attributed to dilution. In addition, it is probable that available fluoride is also being removed from solution by complexing with divalent cations such as calcium, magnesium and/or aluminum ions, which form relatively insoluble fluoride salts.

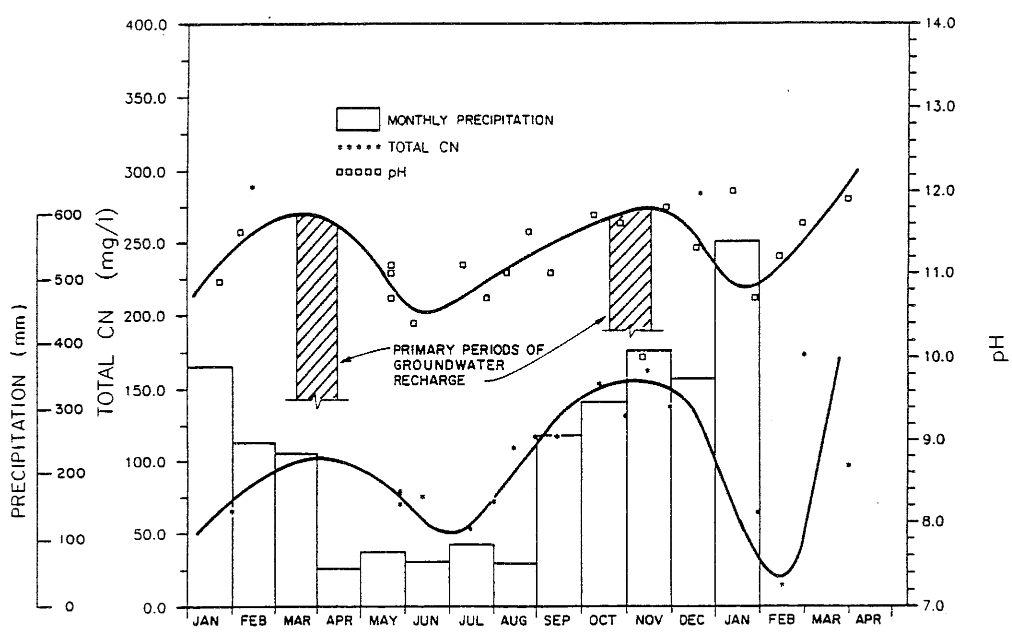


FIG. 4: pH VALUES vs TOTAL CYANIDE CONCENTRATIONS vs PRECIPITATION AND TIME

Remediation of cyanide waste in the subsurface has been achieved by a series of techniques (Kastman and Zimmerman, 1977). Cyanide can be chemically fixed in solid wastes. Liquid waste can be treated by means of alkaline chlorination, aeration/oxidation, and filtration through carbon media, with the potential for high removal efficiencies. However, reaction kinetics and treatment capacity constraints can limit the effectiveness of these remediation schemes.

As the landfill site has only been recently capped, however, the existing leachate plume represents transient conditions within the aquifer. As such, it is premature to consider other remediation measures, until it is clear whether or not they are required. Systems considered may include a passive carbon filter trench, which would strip the cyanide in solution as it percolated through the carbon media.

However, to the authors knowledge, no evidence has been obtained to date to indicate the landfill leachate discharging to the receiving waters is negatively impacting on the local environment. Furthermore, there are no groundwater users associated with the affected aquifers. As a result, further monitoring will be required before a final decision is made regarding the need for additional remediation measures.

CONCLUSIONS

The following conclusions are made with regard to undertaking investigations and remediation of contaminated sites.

1. The nature of site contamination is a function of the genesis of the waste site.

2. The investigative and remediation approaches undertaken are influenced by the nature and distribution of the contaminants.

3. The relative technical and economic feasibility of remediation options is evolving, as more innovative technologies are developed, and traditional disposal options become less economic.

4. Phased investigations, where feasible, generally provide a more thorough assessment of site contamination, and a more reasoned approach to assessing the need for and development of appropriate remediation measures.

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