R. Kuasa

RICHMOND LANDFILL
ASSESSMENT STUDY

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FOREWORD

The Richmond Landfill Assessment Study was initiated by the Federal Activities Pollution Abatement Group of the Environmental Protection Service at the request of the Fraser River Harbour Commission and as a result of concern expressed by both citizens and health authorities regarding the discharge of raw leachate to municipal ditches.

During preliminary planning the advantages of a team approach became evident. Such a team would utilize the available skills and resources within the Federal Government, contract outside expertise where needed, while simultaneously developing feedback communications with other regulatory personnel involved in related investigations.

The ad-hoc team was many facetted, nevertheless its joint findings will be of considerable value to all involved in resolving the site specific problems at Richmond Landfill, and the broader aspects of peat bog landfilling. The study findings will also be of value in understanding the role of peat bog landfilling in relation to solid waste disposal in the Greater Vancouver area.

The specific findings of this study refer to a site proposed for a future port development. Hence, it is presumed that the basic impetus of the site development will be that of structural integrity and not of the disposal of refuse.

The conclusions, therefore, reflect the concept that there is no requirement to handle Greater Vancouver waste other than possibly that contracturally committed (Richmond Municipality), and that the operation must be directed towards optimum structural engineering practice within given economic conditions, and yet meet the requirements of existing environmental constraints.

The report herein summarizes the work and findings to date. The Project Hydrogeologist is still finalizing his study, consequently the presented hydrogeological data is preliminary. However, it is anticipated that the generalized conclusions will not be affected by the updated hydrogeological data.

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Environmental specialists who contributed much to the study included: Mr.George Giles, P.Eng., Solid Waste Engineer, Pollution Control Branch, Ministry of the Environment, Victoria; Mr.Hans Mooij, P.Eng., Solid Waste Management Branch, Environmental Protection Service, Ottawa; and Mr.J.W. Atwater, P.Eng., Senior Program Engineer, Federal Activities Pollution Abatement Group, Environmental Protection Service, Vancouver.

The authors recognize the requirements for specialized expertise and team cooperation in a multi-facetted study such as is reported herein. The support received was of the highest order.

The authors also recognize the cooperation of the Fraser River Harbour Commission, and in particular, the efforts of Mr. Scott McLaren, Port Manager, in supplying historic information and background data.

ABSTRACT

Presented in this report is a hydrogeological and operational assessment of a major land reclammation project. The hydrogeological assessment takes into consideration the groundwater and surface water regimes affected by the refuse landfilling operation. The assessment involved the drilling of 45 holes and the installation of 42 piezometer/wells up to a depth of 60 feet. Extensive hydraulic measurements and chemical sampling of sub-surface and surface waters was carried out over a period of 16 months. The investigation showed that the landfilling operation is contaminating the surrounding surface waters, as well as a portion of the groundwater regime. The degree of contamination has been influenced by the operational methods. Additionally, the operational methods observed appear to have compromised the structural suitability of the fill. The principal conclusions of the study are that the present operation is environmentally unacceptable and that the continued use of refuse for fill may not be economically viable.

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(j) Ammonia (NH_3)
(k) Calcium
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1 CONCLUSIONS

1. The Richmond Landfill Site is a large peat bog land reclammation project which uses a large portion of the Greater Vancouver refuse as fill. Estimated annual tonnage has been placed at approximately 150,000 to 200,000 tons.

2. All refuse other than that discharged from compactors, private vehicles and tank trucks is discharged to the mattress fill.

3. The hydrogeological setting provides little or no protection of the adjacent surface waters from leachate contamination.

4. The largest proportion of the generated leachate is discharged to surface ditches and thence to the Fraser River directly or via municipal ditches.

5. Based on hydrogeologic and water quality data to date, there appears to be restriction of leachate migration to the lower (silty sands) aquifer over most of the present active site. However, interpretation of bore hole data in the western regions of the site indicate the existence of discontinuities in the sub-peat, clay unit.

6. In the northeast corner of the site there is geologic discontinuity where the peat bog is intersected by a former distributary channel. Where the leachate ditch intersects this channel, leachate migration occurs to the channel sands and to the deltaic silty-sands.

7. The excavation of the revised ditch system carried out in 1976 has allowed leachate to egress into groundwater.

8. Leachate discharges to municipal ditches and surrounding lands have resulted from inadequate design and construction of site ditching, as well as from operational procedures which interrupt the flow in the ditches and hinder their flow capabilities.

9. The contaminant loading of the toxic leachate discharge is greatly influenced by large inputs to the site water budget. Over and above precipitation, these inputs are dredgate and Fraser River water ingress during seasonal and tidal highs.

10. In view of the environmental policy of the federal government respecting federal activities and facilities, and federal and provincial environmental legislation, the leachate discharge from the Richmond Landfill Site to surface and ground waters is clearly unacceptable.

11. Pollution abatement and clean up measures required to bring the operation into compliance with federal government policies and legislation will require the design and institution of leachate containment, collection and treatment works. Containment will require hydraulic isolation of all waters having access to the fill materials. The presence of the geologic discontinuity in the northeast area of the site and indications of discontinuities in the sub-peat clay underlying the western portion of the site will necessitate a thorough geologic investigation in areas not covered by this study in order to assure an adequate containment design. Of immediate concern is the need to stop the sub-surface leachate egress occurring in the northeast corner of the site. Preliminary cost estimates of leachate treatment facilities required to render the leachate acceptable for disharge to the Fraser River has been placed at a minimum of eleven (11) million dollars (excluding containment and flow minimization costs).

12. Hazardous and toxic materials have been handled at the site. The site is inappropriately located and operated for disposal of such waste materials.

13. The laying of dust on the site roads could be accomplished by use of a water truck, thus preventing potential access to the site of a large proportion of hazardous and toxic waste materials.

14. Closer scrutiny and regulation of incoming waste materials in accordance with the detailed site specifications would have minimized the discharge of unsuitable materials.

15. The method of fill placement and compaction practiced does not achieve maximum fill density. Based on ultimate structural requirements, the method of filling appears inadequate.

16. The chemical and physical instability of the refuse fill will necessitate special consideration for structures and utility services design and construction.

17. Gas migration and collection works will be required for structures constructed on the refuse fill. Perimeter barriers may be required to prevent migration into neighbouring lands.

18. The continuation of the present fill operation or the extension of the present fill methodology into the adjacent site is clearly unacceptable due to production and discharge of leachate.

19. The landfill physiographic and hydrogeologic setting, together with the method of operation, preclude it from being designated a "sanitary landfill".

20. In consideration of the leachate containment collection and treatment costs, additional structural costs and gas control costs, continuation of filling with refuse on the present site or extension of filling with refuse on the adjacent site would not appear to be economically viable.

21. Cessation of refuse filling will not necessarily alleviate the requirement for leachate containment and treatment on the present site.

2 STUDY OBJECTIVES

The principal goal of this assessment study was to quantify and qualify the environmental impacts of the landfill operation on surrounding lands and waters. The following objectives were set down:

(a) determine the geologic setting of the site,

(b) determine the hydrologic variables as they affect the generation and migration of leachates to ground and surface waters,

(c) monitor the quality of ground and surface waters,

(d) evaluate the impact of the site operation on the integrity of the receiving environment as determined by the hydrogeological and water quality findings,

(e) provide recommendations for the elimination or minimization of environmental impacts through site operational modifications and management alternatives.

3 BACKGROUND

3.1 Generation of Leachates

3.1.1 General

The generation of pollutants termed leachates is one of the major environmental considerations associated with solid waste landfilling. Landfill leachate generation is directly influenced by the site specific hydrologic variable water inputs from precipitation, groundwater and other sources which are absorbed by the refuse.When the field capacity is exceeded, the refuse-contacted liquids begin discharging from the fill. Leachates, therefore, are liquids which have been in contact with the refuse and carry in suspension or solution some components of the refuse.

The leachate egress is of environmental concern in areas where the natural environment is not capable of providing attenuation or containment of the contaminants. This problem is evident in landfills where the refuse is below or near the free groundwater surface, and where there is a direct discharge of leachate to surface or ground waters. The environmental impact assessment of a landfill, therefore, requires a complete understanding of the hydrogeologic setting and leachate flow patterns.

3.1.2 At Richmond Landfill

The landfill site, located on a peat bog adjacent to the Fraser River, is influenced by many sources of water influx: precipitation of approximately 40 inches per year; tidal influence of the Fraser River; groundwater; and others. High volumes of leachates produced as a result of the large water inputs are intercepted by the surface ditch system. The Federal Activities Pollution Abatement Group of the Environmental Protection Service became involved at the request of the Fraser River Harbour Commission due to resident and municipal health department concerns with the "black" leachate discharging to the local municipal ditch network. As the landfill operation is located on federal land it has not been placed under the scrutiny of the Provincial Pollution Control Branch. This status is unique in that Richmond Landfill has not been required, to date, to meet any provincial environmental regulatory operational or effluent guidelines.

3.2 Richmond Landfill Site

3.2.1 Geographic Location and Operational Control

The Richmond Landfill Site (Figure 1) is located in the municipality of Richmond on the main arm of the Fraser River. The site comprises a total of 655 acres of federally owned land under the control of the Fraser River Harbour Commission (F.R.H.C.). The land is a development site for a future industrial park and deep sea port facility. The active landfilling area of 310 acres was acquired in 1971 by the F.R.H.C. through a land exchange principally involving Acme Peat and the Corporation of the Township of Richmond. Richmond had previously operated a municipal dump operation in various parts of the site since 1960. In 1975 the F.R.H.C. acquired the control of an additional 345-acre parcel of land adjacent to and west of the original 310-acre parcel. The acquisition was again accomplished by means of a land exchange in which other F.R.H.C. controlled federal lands were exchanged for the new parcel. The landfill operation has been carried out by a private company, Richmond Landfill Ltd.,as agents of F.R.H.C., since the land acquisition in 1971. To date filling has been carried out only on the original 310-acre site.

In addition to the 655 acres of F.R.H.C. controlled federal land, an adjacent 400-acre parcel of land was purchased by Richmond Landfill Ltd. in 1975. The company has recently initiated landfilling on this area. The total potential landfilling area as shown in Figure 2 is approximately 1055 acres. This assessment study has been primarily involved with the active 310-acre site. However, it is intended that the findings in this report will form the basis for directing development of the more recent 345-acre F.R.H.C. federal land acquisition. Any landfilling on the adjacent Richmond Landfill Ltd. freehold land, will come under the jurisdiction of the Provincial Pollution Control Branch.

3.2.2 Site History

Beginning in 1960, the Corporation of Richmond's program of land filling on the site may be chronologically recorded as follows: filling commenced at No.7 Road and continued east along the river until 1968 when the fill had reached No.8 Road; 1968 through to 1971, refuse was dumped east of No.8 Road and north of the river, covering an area extending back approximately 1200 feet from the river, see Figure 3. In 1971, F.R.H.C. acquired the original parcel of land and contracted with Richmond Landfill Ltd. for the orderly and progressive filling of the 310-acre site. The filling was to conform to specifications prepared by Public Works Canada and the schedules agreed to with the Corporation of Richmond (Appendix A). Previously site development and feasibility studies had been carried out by Phillips, Barratt, Hillier and Jones in 1968 [37].

The land acquired by F.R.H.C. was in six sections: parcels F and A which had been the area of dumping to that date and section 13 were acquired from the Corporation of Richmond; two properties owned by the Canadian Northern Pacific Railway; and an approximate 60-acre parcel of freehold land owned by Acme Peat Products Ltd. These six parcels brought the total potential land fillable area to 310 acres (See Figure 3). The land was considered to have potential only for landfilling, since the 1968 feasibility report indicated that construction of a port facility would be uneconomical if delayed by completion of the peat stripping process at the site.

The original purchase agreement between F.R.H.C. and the Corporation of Richmond required that F.R.H.C. dispose of Richmond municipal refuse for a period of 15 years. As a result, many areas were covered by municipal refuse, emanating both from Richmond and other Greater Vancouver areas. The site development plan drawn up by Public Works Canada in 1973 (Figure 3) indicates that between 1968 and 1973 domestic refuse was discharged to most of parcels F and A. The site plan (Figure 3) indicates that development after 1973 should restrict the domestic refuse to section 13 presumably to minimize settling problems to a specific area which could then be utilized for outside storage. However, other than the general placement demarcations of fill materials, there does not appear to be a development plan specifying building locations and expected structural requirements.

In 1975 the adjoining 345-acre westerly parcel of Fraser River Peat Moss Ltd. (formerly Acme Peat) land was acquired through a land exchange arrangement. This land has had part of its peat resource utilized, and to-date no landfilling has taken place.

3.2.3. Physiography of Surrounding Area

The Lower Mainland settlements of British Columbia are clustered along British Columbia's major river, the Fraser River. The Fraser River (watershed 90,000 square miles) has an average flow of 96,300 cfs (minimum ≈28,000 cfs, maximum >500,000 cfs)and carries 20×10^6 tons/year of sediments. The lower 19 miles of this river are estuary, which is defined as "a semi-enclosed body of water which has a free access to the open ocean and within which sea water is measurably diluted with fresh water derived from land drainage".[24]

The delta was formed by the fanning out of river sediments from the upland of New Westminster about 10,000 years ago. At that time the last of the Pleistocene ice had disappeared from the Fraser Canyon and local post-glacial rebound was essentially complete. The delta has encroached into the Strait of Georgia at an estimated rate of 450×10^6 feet^3/year and has built deposits of 300 to 700 feet thick over the Pleistocene sediments.

Large areas of the deltaic deposits are now buried under thick vegetative cover, generally termed peat bog. The Richmond Landfill Site is located in the southeast corner of the Greater Lulu Island Peat Bog - one of the delta's major bogs. This peat bog is elliptical has axes of 7 miles by 3.5 miles, and trends east-west. The satellite photograph (Figure 4) shows the geographic location of the Richmond Landfill Site in relation to the Fraser River Estuary and its contiguous waters.

3.2.4. Climatology of Surrounding Area

The climate of the Fraser River Estuary is generally described as a modified maritime type.[24] The portion of the delta which includes the Richmond Landfill Site, receives about 40 inches of precipitation annually, very little of which falls during summer. Mean temperatures for July and January are about 62°F (16°C) and 36°F (2°C), respectively.

4 SOLID WASTE DISPOSAL - MATERIALS AND METHODS

4.1 General Classification of Refuse Materials

Table 1 outlines the general classification of refuse materials and possible sources, and indicates specific constituents as observed at the Richmond Landfill Site.

4.2 Site Operation and Disposal Area Designations

Landfilling, which has progressed at the rate of approximately 50 acres per year, is guided by specifications laid down by Public Works Canada. Basically, the operation involves the construction of a mattress* base which is overlayed by the commercial and residential compactor transported refuse. Intermediate cover is sand and/or wood chips. Final cover is sand and/or other soil materials such as ditch cuttings and dredge spoils.

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* Mattress: this refers to the first major lift, layer or stratum of refuse overlying the peat surface. Components of this waste are not restricted to any special class of materials. See Section 4.2.1.1. for a list of common major constituent materials.

All vehicles entering the site are delegated to one of the following areas:

(a) Mattress fill area,
(b) Commercial and residential compactor transported refuse area,
(c) Private vehicle area,
(d) Waste tire area,
(e) Liquid waste area,
(f) International waste area,
(g) Cover material area.

Locations for the above disposal areas have varied considerably with time. Figure 5 shows the approximate disposal locations and generalized material designations as cited by Public Works Canada. Figure 6 shows the refuse locations as determined by this study in 1976.

4.2.1 Mattress Fill Area

4.2.1.1 Refuse Discharge Characteristics

The mattress fill area is the largest and most active on the site. The area is used by all vehicles except private haulers, compactor trucks and tank trucks. Materials commonly found in this area are:

- wood, wood chips, hog fuel
- demolition wastes including concrete, large timbers, masonry and various metals (reinforcing steel)
- paper waste - newspapers, corrugated cartons, magazines, books, etc., paper mulches, trimmings from packaging industries
- plastic materials - plastic containers containing some liquid (ammonia, chlorine, paint thinner), discards from plastic bag and plastic container manufacturing industries, miscellaneous plastic goods
- industrial solid and liquid wastes - gyproc boards and raw materials, paint and associated products and containers, printing and photography materials and papers, scrap metal, garage and machine shop wastes (oily rags, etc.), acid battery rebuilding wastes, tar and bituminous type materials

- miscellaneous materials - baled cloth, furniture and appliances, clothing discards (shoes, etc.), car interiors and rubber parts, chemical containers with residues
- organic materials - fish processing wastes, spoiled vegetables, culls and fruit and vegetable packing by-products (cranberries, etc.)

Figure 7 shows a typical mattress fill area.

4.2.1.2 Fill Method and Lift Thickness

There are no cells as such in the mattress. Mattress thickness is about 4 to 7 feet and it is placed in one lift. Thickness is least along the north boundary. In some areas the mattress is covered directly with 2 to 4 feet of soil. However, in other areas there is only minimal cover of sand to a depth of 2 to 6 inches in the interim before commercial and residential or private hauler refuse is deposited.

4.2.1.3 Compaction of Fill

Normal procedure in this area provides either D-7 or D-9 crawler tractor spreading of refuse. Compaction is limited to that accomplished by the tractor as it pushes the incoming refuse loads out onto the bog and to a limited extent by vehicles travelling to the fill face. Due to the random nature of both the incoming materials and the disposal locations, it is extremely difficult to estimate the fill density at any given fill location. The face of the mattress fill is not compacted since operator error would often result in a mired Caterpillar tractor. Perimeter faces are covered with trucked municipal ditch cuttings or barged dredging spoils. Figure 8 shows the mattress fill boundary progression.

4.2.1.4 Solid Waste Volumes

The following area estimates have been made from the mattress fill area advancements shown in Figure 8.

May 28/74 - May 12/75	≃	38.6 acres/year
May 12/75 - April 22/76	≃	33.2 acres/year
April 22/76 - Oct. 21/76	≃	29.6 acres/6 months
		or
		59 acres/year

Based on these figures, the estimated coverage area ranges between 33 and 59 acres per year, with an average fill thickness of approximately 6 feet and ranging between 4 and 8 feet.

4.2.2 Commercial and Residential Compactor Transported Area

4.2.2.1 Refuse Discharge Characteristics

This area is constructed above the mattress:

- material is comprised primarily of residential (Richmond Municipality) and commercial refuse transported to the site in compactor trucks. Some "giant-haul" type bins are also discharged to this area. (Figure 9 shows the compactor refuse disposal area).
- The major components of this refuse are paper and plastic, but putrescible materials, i.e. food waste products from restaurants and supermarkets, make up a significant portion of some compactor loads.

4.2.2.2 Fill Method and Lift Thickness

Fill thickness in the commercial and residential refuse area is estimated to vary from 8 to 14 feet and it is placed in one lift. Cells are irregular and often "worm-like". Cover material is a thin layer (< 1 foot) of silty sand. Roads are often hog-fuel or sawdust. Municipal ditch cuttings or dredging spoils may also be placed on this area up to a depth of 2 to 3 feet.

4.2.2.3 Compaction of Fill

Compaction of the single lift (8 to 14 feet) fill is attempted by a steel wheel compactor (Caterpillar 816). After pushing fresh refuse over the fill crest, passes are made parallel to crest of face. Until a cell is completed or radically re-directed, there is no compaction or covering of the working face.

4.2.2.4 Solid Waste Volumes

Table 2 lists the estimated volumes of compactor transported commercial and residential refuse for the year 1976 as submitted by the F.R.H.C. There are other miscellaneous compactor vehicles; for example, Interflow Systems which contribute a minor but unknown volume to this area.

It should be noted that the Richmond Landfill Site has no weigh scales; and as compaction and densities vary, no attempt has been made to convert volumes to weight.

4.2.3 Private Vehicle Area

4.2.3.1 Refuse Discharge Characteristics

This area is above the mattress fill and is comprised of anything that the householder or small business might conceivably discard. Material is generally high in metal and wood content. The contents and volumes are highly variable and depend upon season and weather.

4.2.3.2 Fill Method and Lift Thickness

Fill depth is approximately 6 to 10 feet. Cells are made at irregular intervals, usually in "fan-like" shapes. Intermediate cover material in this area is often hog-fuel to facilitate easy access for conventional type vehicles.

4.2.3.3 Compaction of Fill

The steel wheel compactor is used to push refuse over the fill crest and to compact the fill. Passes for compaction of the face are provided at intervals when the face is covered with uncompacted soils from dredged spoils or municipal ditch cuttings. The bulky nature of the refuse in this area makes it a difficult area to obtain compaction.

Note: A schematic drawing of the Richmond Landfill Site filling procedure is depicted in Figure 10.

4.2.4 Waste Tire Area

Only containers or loads composed entirely of rubber tires are sent to this area, therefore, a major portion of the tires in mixed loads that enter the site are buried in the normal manner elsewhere on site.

4.2.5 Liquid Waste Area

Tank trucks entering the site usually discharge their loads to the roads (as shown in Figure 11) or into large steel tanks on site. However, there are instances of direct discharge of liquid waste to the fill. These wastes are generally oil base liquids or toxic industrial wastes that are old, "off-spec", or contaminated. It is not known how many tank trucks have

entered the site, nor are their contents known. Section 9, Hazardous and Toxic Wastes, deals with the subject more fully.

The liquid wastes brought to and discharged to the Richmond Landfill Site by tank trucks are generally waste oils, contaminated industrial chemicals or waste industrial sludges. The only liquid waste allowed under the site specifications is waste oils, required for the laying of dust on the site roads. However, it is known that there are other industrial based liquids which have been discharged to the site. An example of such a discharge is given in Figure 11 which shows a tank truck discharging a phenolic-resin based glue washwater. Richmond Landfill Ltd. has indicated that about 60,000 gallons (approximately 25 tank trucks) are discharged annually onto the site. Other discharges of liquid wastes occur from time to time in the mattress fill area where industrial, processing or warehousing wastes are deposited. These sources often discard damaged containers or "off-spec" liquids such as paints, cleaning solutions, inks, disinfectants, etc.

4.2.6 International Waste Area

Bins containing refuse designated international are discharged to a disposal site segregated from the main refuse areas (see Figure 6). The manner of handling and disposal of international waste is controlled by Agriculture Canada under the Animal Contagious Diseases Act (A.C.D.C.). The disposal method involves discharge with immediate cover, followed by rinsing of the container. The amount of international waste handled at the Richmond Landfill Site varies each month, but is in the order of 1 load per month from the harbour area. A study carried out by B.H.Levelton and Associates on Solid Waste Management at the Vancouver International Airport [32] reported that airport solid waste, including some international waste, is disposed of at the Richmond Landfill Site. As this material is mixed and compactor hauled, it is discharged to the compactor disposal area and not to the international waste area. As a result of recent amendments to the federal legislation replacing the A.C.D.C., landfilling of international wastes will no longer be permitted as incineration will be mandatory.

4.2.7 Cover Material Area

4.2.7.1 Materials Used

There are four kinds of cover material used:

- sand dredged from the Fraser River by Public Works Canada
- soils from ditch cutting and excavations
- dredging spoils not suitable for ocean dumping or for which insufficient time was available to obtain an Ocean Dumping permit
- wood chips and hog-fuel.

All four are used for both mattress fill and compactor transported refuse fill cover material. However, wood chips are used primarily for construction of all weather roads to the fill face. Aside from the dredged sand stockpile, only the wood chips (hog-fuel) is stored for later relocation. Dredging spoils are brought to the site by barge and offloaded by trucks.

4.2.7.2 Material Sources

- Public Works Canada Dredge. Public Works Canada dredging spoils from the Fraser River are regularly (6 months to 1 year intervals) discharged to the site for use as cover material. In February and March, 1976, 344,000 cubic yards of silty sands and gravels were stockpiled. Figure 12 shows the dredging spoil deposition on site. Figure 6 shows the 1976 stockpile area.

- Barge Ramp Dredge Spoils. Another source of cover material is dredge spoils brought to the site via the barge ramp constructed in 1975. The barge ramp originally only received a minor volume of dredge spoils which were not expedited through the newly enacted Federal Ocean Dumping Act permit process. However, recently the dredge spoils discharge via the barge ramp has increased significantly with the number of barges unloaded totalling 52 as of December 1, 1976. The approximate weight of each barge is in the order of 750 tons.

- Wood Chips and Hog-Fuel. These materials are used extensively on site especially for maintaining all weather roads and area travel surfaces around the various active fill areas. The majority of this material ultimately ends up in the mattress fill.

5 STUDY APPROACH

5.1 Introduction

As noted in Section 3.1, the environmental assessment of a landfill operation requires a thorough understanding of the hydrogeological setting which, in turn, allows the formulation of predictions of leachate generation and movement. An understanding of the hydrogeological setting together with groundwater and surface water chemistry monitoring, enables quantification of the environmental impact of the landfill operation.

In the case of the Richmond Landfill Site, the discharge of raw leachate via surface ditches to the Fraser River and municipal ditches was well known. However, the variables affecting ditch discharges, degree of contamination, as well as the potential contamination of underlying aquifers had neither been previously addressed nor questioned. Furthermore, although several other landfill sites are located in an apparently similar hydrogeologic setting (e.g. Burns Bog), no thorough hydrogeologic investigations had been carried out on these sites from which a conceptual model of the Richmond Landfill Site could have been developed. Consequently, a hydrogeologic study program was developed with the capable assistance and direction of Mr.Hugh Liebscher of the Hydrology Research Division of the Inland Waters Directorate, Department of Fisheries and the Environment.

The hydrogeological study program involved evaluation of past bore-hole geology, an on-site drilling program, and the installation of monitoring piezometers.

5.2 Previous Work

Three previous subsurface studies have been carried out at the landfill site to determine the underlying geology and to investigate loading and settlement rates, primarily for feasibility of the proposed port development. Surficial geological information was also obtained from: adjacent properties [37]; structural and exploratory test holes on the LaFarge Cement Co. property (south end of Nelson Road); and the proposed 1937 Fraser River Bridge crossing near the Massey Tunnel. Figures 13 to 17 show a location map and geologic fences for the original 310 acres of F.R.H.C. land and two adjoining parcels of freehold land to the east.

5.3 Drilling Program

The drilling program was carried out initially over a four month period between November 1975 and February 1976. This aspect of the study was carried out using a truck-mounted Boyles hydraulic rotary drilling rig (Figure 18) on loan from Transport Canada and under the direction of Mr.Wes Knight. A total of 642 feet were drilled and logged under this phase. Limited soils investigations were also conducted by hand auger in areas of the site not accessible by the drill rig.

Figure 19 shows the sites of the drilling carried out throughout 1975 and 1976 both with the drilling rig and by means of a hand auger. The drilling locations were determined from the evaluation of previous geologic studies carried out as referred to in Section 5.2. Generally, the drilling locations were laid out so as to intercept areas of presumed hydrogeologic significance, i.e. stratigraphic unit highs and lows. The drilling sites were, therefore, intended to intercept presumed leachate flow paths thought to be controlled by the undulating sub-peat clay unit.

5.4 Piezometer Installation

During exploratory drilling, piezometers were constructed and installed at 23 stations within the property and one outside its boundary (Figure 20). Previous geologic investigations and the borehole drilling program defined four basic stratigraphic units: refuse; peats; organic silty clay; and silty sands. The piezometers, constructed of a 2-foot, 2-inch diameter plastic screen attached to a 3-inch diameter plastic well case, were installed in the recognizable water yielding units: refuse; peats; and silty sands; both singly and in piezometer nests.

Piezometer construction and installation schematics are shown in Figures 21 and 22, respectively. The construction method and installation procedures are illustrated in Appendix B .

6 RESULTS OF HYDROGEOLOGICAL AND WATER QUALITY INVESTIGATIONS

6.1 Geology

To date 18 locations have been drilled and logged. Ten were to below the sub-clay horizon, the others were to various depths to or above the clay horizon. From the drill log data (Appendix C), cross-sections of

the refuse covered portions of the site have been developed, and are shown in Figures 23, 24 and 25. A three-dimensional geological fence diagram showing the stratigraphy and piezometer locations is shown in Figure 26.

The basic interpretation is as follows:

(a) Generalized geologic stratigraphy:
- refuse (termed a stratigraphic unit for purposes of this study),
- peat,
- clay,
- silty sands.

(b) The upper surface of the silty sands unit underlying the site is relatively flat lying at about 10 feet, (Sand Heads elevation). Thickness of this unit ranges 100 to 120 feet.

(c) The clay unit probably underlies most of present active site but there is a great variability in thickness. Range in thickness is from 3 to 24 feet.

(d) The peat unit underlays most of the site and its unconsolidated thickness would have varied inversely with the thickness of the clay, since the upper peat surface was originally flat or slightly domed-shaped. Thickness ranges from 0 (at northeastern boundary) to a maximum consolidated thickness of 16 feet at location 1-C. Peat thickness is also 16 feet at 3-A but in that area the peat is unconsolidated.

(e) Refuse thickness not including soil cover ranges from 6 to 20 feet. At 1-F and 1-G, only 1 foot of refuse was noted; however, it is believed to be only a local anomaly that resulted because of excavation required during a fire in that general area.

(f) From sub-surface soil investigations to the west of the present disposal site in the area of point 4-J, it appears there may be sand lenses in the clays. Previous work by Cook, Pickering and Doyle,[37] soil consultants, outlined earlier indicates the possibility of no clay in one bore

hole and silty sands underlying the peats in an adjacent bore hole, and the existence of some sand near the ground surface in the northeast corner of the site.

6.2 Hydrology (investigated by H.Liebscher, Project Hydrogeologist)

Static levels of the 21 piezometers were monitored on a weekly basis. This information has been supplemented with the aid of continuous recordings using four Stevens Type F continuous recorders (Figure 27), which have been moved to various piezometers throughout the site during the same total time interval. Fourteen falling head or slug tests were carried out to determine the permeabilities of geologic units including the refuse. Appendix D outlines slug test procedures and mathematical derivations.

6.2.1 Surface Flows

During the site investigation considerable variation in ditch flows occurred as a result of the following:

(a) blockage of ditches due to:
  (i) basal failure of peats because of refuse loading adjacent to ditches,
  (ii) dumping of refuse into ditch to such an extent that flow was blocked,
  (iii) filling of ditch to accommodate the surcharge of dredged sands from the Fraser River.

(b) connecting of ditches that previously had opposite hydraulic gradients

(c) excavation of new ditches into areas previously unserviced by ditches

(d) deposition by slurry method of 300,000 cubic yards of river sand, thus causing large hydraulic gradients in opposition to native site gradients

(e) change in the water budget of large portions of the site by filling with mattress fill, thus consolidating the peats and displacing large quantities of water.

In view of the above events the surface water flow regimes were found to be highly variable depending on site activities, and consequently cannot be easily generalized with time. Superimposed on these manmade variables are the natural flow variables which are:

(a) diurnal tidal fluctuations and seasonal stage of the Fraser River

(b) variations in precipitation with season and resultant surface flows.

Figure 28 illustrates surface ditch flow directions around the site for one day in the spring of 1976 and illustrates the complexity of site surface flows. During this study many attempts were made by the operators to alter surface flow patterns, but this has only added to the confusing nature of the surface flow regime. An example of the unorthodox ditch hydraulic design was evident when a leachate diversion ditch across the north of the site flowed in the opposite direction to what was intended. One of the more recent attempts to control surface flows was the re-excavation of the east, north and No.8 Road ditches and their common connection. It is understood that the culvert connection from the south end of the east ditch will be utilized in conjunction with a pumping system so that the site surface drainage will be discharged from this point directly to the Fraser River. At this time, however, the pumps have not been installed and the leachate in this ditch system traverses along the dyke road ditch to the municipal ditch system at the Nelson Road pumping station. Figure 29 illustrates the flow pattern in the re-excavated ditches.

6.2.2 Groundwater Regime Model

As a result of the water level monitoring, a model of water flow or response has been developed for each of the three stratigraphic units in which piezometers were installed.

(a) Unit 1 (Refuse). This permeable or leachate bearing unit is definable over the entire site at some time of the year. Piezometer 1-A has shown that refuse waters develop a diurnal tidal response during certain combinations of stage and tide in the Fraser River. Figure 30(b) shows a continuous hydrograph for Refuse piezometer 1-A during the week of May 11-18, 1976. It is not known how far back onto the site this phenomenon extends. Lack of definition of this problem is a result of several reasons:

(i) insufficient level in some refuse wells (1-D, 1-K, 3-C and 3-B) has precluded the use of Stevens recorders

which require a 3-inch diameter well section over the entire water level range; the lower 2 feet of the piezometer is 2-inches in diameter.

(ii) due to improper or non-functioning of one-way or flap valves on No.8 Road ditch, it is not known if the response in 1-A is the result of water backup into the ditch and thus out into refuse, or if 1-A is directly responsive to the stage-tide Fraser River level through the dyke, or a combination of both. Figures 31 and 32 illustrate these two inundating mechanisms. The flow pattern of Unit 1 (Refuse) waters is essentially horizontal due to the impermeable nature of the compressed peats. Flow patterns vary considerably throughout the year due to natural and site operational events. Monthly refuse unit piezometric surfaces and leachate flow directions for the period January to December 1976, are given in Appendix E. For example, piezometric and flow pattern direction plots shown in Figures 33 and 34 for the month of March and September, 1976, respectively, illustrate the following:

Figure 33 - the influence of the dredging operation on the refuse aquifer.

Figure 34 - flow patterns in the refuse after re-excavation at No.8 Road ditch. These flow patterns are thought to be representative of typical leachate migration patterns. Figure 34 and Figure 33 illustrate the potential for flow to adjacent lands.

Most Unit 1 (Refuse) waters discharge to the Fraser River via springs in the dyke, to the ditches at the peat/refuse contact or to the unconsolidated peats to the west. Typical permeability for Unit 1 (Refuse) as determined by slug test values are in the order of 10^{-2} cm/sec.

(b) Unit 2 (Peat). Where comparison of data between Unit 1 (Refuse) and Unit 2 (Peat) piezometers, such as (1-A and

1-B) and (1-K and 1-J) can be obtained, the piezometric levels in the peat are continuously above those in the refuse. Therefore, for the present, flow will be either vertical or both vertical and horizontal. It would appear, therefore, that little transfer of leachate waters other than by diffusion to the peats can occur, once refuse has been placed. Permeabilities in the peat when compressed by the refuse are in the order of 10^{-5} cm/sec. Uncompressed peat (e.g. at piezometer 3-A), has a permeability in the order of 10^{-3} cm/sec. Figure 30(a) shows a continuous hydrograph for peat piezometer 1-B for period March 22-29, 1976, and illustrates that the piezometric levels respond to barometric change. In general, piezometric levels in Unit 2 (Peat) are constant but will fluctuate with the loading on the upper surface at the peat as a result of change of fill depth, depth of leachate in Unit 1 (Refuse) and surface loads on the refuse surfaces.

(c) Unit 3 (Silty Sands). The lowest geologic strata in which piezometers were placed is the silty sands aquifer whose upper surface was normally found at about 10 feet (Sand Heads elevation) and underlying the clay horizon. Permeabilities are in the order of 10^{-3} cm/sec., and all piezometers in this aquifer have a tidal response which varies in amplitude and lag time with their distance from the Fraser River. Figure 30(c) shows an example of a continuous hydrograph for Piezometer 3-D. The separation of this strata from Unit 1 (Refuse) and 2 (Peat) by 3 to 24 feet of clay of low but undetermined permeability, gives confidence that flow of leachate to this strata is negligible. However, maintenance of this state is dependent on the sustained integrity of the clay and the verification that in no portion of the site is there an absence of this clay strata. Detailed subsurface investigations would be required to establish the extent and depth of this clay layer in order to assure the long-term integrity of the lower sand aquifer. Flow in this aquifer is presumed to

be westerly, but confirmation is required.

6.3 Water Sources and Quality

6.3.1 Surface Waters

6.3.1.1 Sources

The surface waters are a mixture of waters from many sources some of which vary in contribution rate with time of year, date or activity on site. The surface waters originate from:

(a) surrounding lands to the west of the site,
(b) surface flow off landfill surface due to precipitation,
(c) surface runoff during dredging spoil deposition,
(d) tank truck discharges that flowed directly to the ditches,
(e) water percolations through the refuse from above due to dredging or tank truck discharges,
(f) water liberations to the upper surface of the peat due to its consolidation and may have thus passed through the lower portion of refuse,
(g) water infiltrations through the Fraser River dyke and onto the site during:
    (1) high tide,
    (ii) high stages in the river.
(h) water liberations during compression of refuse or during its decomposition,
(i) water entering the site from the Fraser River via the No.8 Road ditch during higher river stages and/or tides,
(j) sprinkling of fill to prevent or extinguish fires.

Thus, flows and quality of surface waters have the potential to vary hourly, daily, weekly and seasonally in marked random nature around the site.

The most significant factors causing extreme variability of water quality are:

(a) effects from dredging operations;
    - from surface runoff of the dredgate
    - from springs caused by increased percolation through the refuse

- re-routing of surface water due to filling or failing of ditches as a result of surcharging of peats during mattress filling or dredged spoil deposition.

(b) river water entering the site through culverts in the dyke whose flap valves were not functioning adequately ,

(c) re-routing and/or stagnation of waters due to ditch cutting or filling,

(d) heterogeneity of refuse and resulting leachates.

6.3.1.2 Quality Data

Three types of water quality investigations were conducted on the surface waters:

(a) chemical analysis of waters,

(b) bacteriological counts of ditch waters and sediments,

(c) bioassay of waters flowing directly from the site to the Fraser River.

6.3.1.3 Chemical Analysis*

Tables 3, 4 and 5 show chemical parameter values at three points (see Figure 35) at which discharged surface flows from the site have occurred for significant periods of time. These sampling points represent the three basic types of surface ditch water discharges. Sample point 7 is a direct discharge to the Fraser River. Sample point 4 is a direct discharge to a municipal ditch. Sample point 5 is a discharge to a drainage ditch through private property. All surface water samples were grab samples.

6.3.1.4 Toxicity

Bioassay results for ditch water flowing to the Fraser River are tabulated as follows:

Date	96-hour LC_{50} (% concentration)	Comments
June 24/76	44	- Discontinuous variation of toxicity with leachate conc.
Sept.8/76	29.5	- Consistent relationship.

* All analyses carried out by Fisheries - EPS Lab, W.Van [31]

Parallel chemical analysis data for June 24, 1976, are provided on Table 3.

The 96-hour LC_{50} toxicity data obtained by Vigers et al[48] in 1975 at approximately the same location was used to determine the following toxicity levels:

Date	96-hour LC_{50} (% concentration)
Aug. 6/76	35
11/76	92
18/76	38
21/76	59
25/76	38
Sept. 3/76	36

A summary of the toxicity analysis data and parallel water quality obtained during the Vigers study is attached as Appendix F.

6.3.1.5 Bacteriological Analysis

A cursory bacteriological sampling program was carried out during late May and early June, 1976. The samples were analyzed for confirmed coliform, faecal coliform, confirmed faecal streptococci and standard plate count. Figure 36 shows sample points and tabulated results.

6.3.2 Unit 1 (Refuse) Waters.

6.3.2.1 Sources

Refuse waters are a result of water:

(a) percolation through refuse, precipitation, sprinkling for fire and dust control, tank truck discharges, and/or dredging operations ;

(b) liberation to the upper surface of the peats due to their consolidation ;

(c) liberation due to compression of saturated refuse and water liberated during decomposition of the refuse ;

(d) infiltration through the river dyke onto the site and ditch walls, passing into the lower portion of the refuse horizon.

The most significant site-related factors affecting leachate quality pertaining to this site, other than variations of the refuse

constituents are:

(a) quantity and detention time of percolation through the refuse,

(b) age of the refuse,

(c) nature of the underlying mattress.

6.3.2.2 Quality Data

Unit 1 (Refuse) wells* (Figure 37) are those believed to sample the water quality of the refuse horizon. These wells may, in fact, be located in the peat strata where there was thought to be insufficient depth of leachate (see Figure 38) , but due to the method of installation used, are directly connected to the refuse strata (by sand packing) for purposes of water sampling. These same wells may not necessarily be used in the evaluation of flow patterns about the site, and they may not give the permeability of the refuse due to their "bucket" type configuration. In addition, waters in "bucket" configuration wells may have been diluted with the cleaner peat water. The extent to which this happens depends on the level of water in the upper stratigraphic unit.

Wells that are for the present considered together for the purpose of qualifying the water quality of the refuse horizon are: 1-A, 1-D, 1-E, 1-G**,1-H**,1-K,2-B**,2-C, 3-B, 3-C, 3-G, 3-H

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* Wells: the terms piezometer and well refer to the same installation. "Well" is limited to the discussion of sampling for water quality, whereas "piezometer" is used in all other cases. All wells were bailed prior to initiation of sampling and again the day before a sample was obtained. Due to the large amount of water in many wells, a complete change in well water could not be achieved before the sampling day, however, all wells had more than three well-volumes removed prior to any sampling for water quality.

** Indicates wells in which wide variations in water quality are likely to occur as a result of loss or gain of the water level in the refuse horizon.

Water quality data for the above wells are given in Tables 6(a) to 6(q) inclusive under the following parameters: Chemical Oxygen Demand, Specific Conductance, Total Residue, pH, Hardness, Alkalinity, Organic and Inorganic Carbon, Sulphate, Ammonia, Chloride, Iron, Calcium, Magnesium, Sodium, Chromium, Nickel, Zinc.

6.3.3 Unit 2 (Peat) Waters

6.3.3.1 Sources

The peat waters on site consist of a mixture of waters originally in the peat prior to any filling, and waters that percolated out of Unit 1 (Refuse) into unconsolidated peat adjacent to the active filling area. This area was subsequently filled with refuse. In addition, there will be a limited amount of water liberated to the peats or their lower interface from the underlying clays which will consolidate upon surcharging. The high piezometric levels in the peat were considered to be the result of the residual pressures of consolidation of a low permeability medium and not that of a confined flowing aquifer under recharge.

6.3.3.2 Quality Data

Unit 2 (Peat) wells are those believed to sample the water quality within the consolidated or unconsolidated peat aquifer. The consolidated peat wells are those installed in the peat that have the quality of both low permeability and either marked attenuation of constituent concentrations and highly damped response to activities occurring on site (e.g. dredging operations), or have piezometric levels above the upper surface of the peat strata. The above criteria resulted in the rejection, at least for the present, of Wells 1-E, 2-B, 2-C and 1-G as being "peat wells", even though the well screens were installed in the peat and were backfilled with bentonite to isolate the well from the refuse horizon. Other wells which were installed in the peat horizon in "bucket" configuration, but were never intended to provide peat strata water quality data were: 1-H, 3-C, 3-H. The remaining wells located in the peat were 1-B, 2-A, 3-A and 1-J. Wells 1-B and 1-J were located in nests adjacent to piezometer/wells located in the refuse and silty sand aquifers;and they yielded good hydrological data in terms of head differentials and reasonable permeability values, as well as consistent water quality data.

The water quality data listed in Tables 7(a) to 7(q) inclusive show parameter values with time for each of the three Unit 2 (Peat) wells installed in consolidated peat (1-B, 1-J, 2-A), and for the two peat wells installed in the unconsolidated peat (3-A, 1-M). (See Figure 39 showing Unit 2 (Peat) well locations.)

Parameters analyzed were: Chemical Oxygen Demand, Specific Conductance, Total Residue, pH, Organic and Inorganic Carbon, Hardness, Alkalinity, Sulphate, Ammonia, Chloride, Iron, Calcium, Magnesium, Sodium, Chromium, Nickel, Zinc.

6.3.4 Unit 3 (Silty Sands) Waters

6.3.4.1 Sources

The water is hydraulically connected with and, therefore, is assumed to originate from the Fraser River, with a very minor contribution from the compression of clays consolidating as a result of refuse surcharge. Interpretation of existing data indicates that very little, if any,leachate has reached or is reaching this aquifer.

6.3.4.2 Quality Data

Unit 3 (Silty Sands) wells are located in a silty sand aquifer under the clay and peat horizons. The six wells installed to date, five on-site and a control well on private property near Nelson Road, (Figure 40) are believed, because of the high plasticity of the clay and the bentonite slurry backfill placed during installation, to be hydraulically sealed from the upper aquifers.

Samples were analyzed for Chemical Oxygen Demand, Specific Conductance, Total Residue, Alkalinity, Sulphate, Ammonia, pH, Organic and Inorganic Carbon, Hardness, Chloride, Iron, Calcium, Magnesium, Sodium, Chromium, Nickel, Zinc. Values are listed on Tables 8(a) to 8(q) inclusive.

7 DISCUSSION OF RESULTS

7.1 Surface Waters

7.1.1 General Assessment

Surface water quality at Richmond Landfill Site generally can be assessed as too contaminated for discharge to water courses if considered in relation to established regulatory effluent requirements (See Section 8). At present, most surface flows ultimately discharge to the Fraser River. However, the hydraulic variations occurring on site force some waters to transgress private lands where agricultural use is made of the ditches, or to the municipal ditch system where domestic animals or children may frequent. Under these circumstances effluent water quality is of public health concern, whereas discharges directly to the Fraser River would have effluent quality requirements far less stringent due to the dilution and assimilative capacity of the river. Nevertheless, toxicity of the leachate and the possible presence of unassimilatable inorganic and man-made organic constituents warrant significant long-term concern for the estuarine environment receiving the discharge. At present further investigation is being carried out to determine the extent of surface ditch flow loss to silty sand horizon near the surface in the northeast corner of the site.

The variation of water quality with time is a combination of changes in the hydraulic regimes around the site; for example, in differing volumes and directions of flow and in various water inputs which comprise the surface waters. The large influx of river water entering through the flap valves at No. 8 Road ditch or the results of depositing dredging spoils on site make representative sampling difficult. The redirection and/or rerouting of flow around the site during the sampling period rendered the values obtained at the various site locations non-correlatable with time. Therefore, it was decided to express the results obtained at only those points where the leachates had egressed for periods of time on the site.

It is clear, however, that regardless of the day-to-day variables affecting the quality of surface water, these waters are significantly contaminated and their discharge largely uncontrolled.

7.1.2 Toxicity

The 96-hour LC_{50} in the order of 30% to 50% is consistent with bioassay results on similar leachate discharges[4,48]. Attempts to correlate specific constituent concentrations with toxicity have not been successful to-date[4]. This could be interpreted as indicative of the synergistic or combined toxic effects of several contaminants. Much work on the subject has been carried out by Dr. R.D. Cameron, Department of Civil Engineering, University of British Columbia. His published work on this subject confirms the above generalizations.

Referring to this semi-log plot, a toxicity of 30% is predicted in a bioassay conducted at pH 7 with low strength leachate. The graph indicates that a decrease in pH would yield a significant increase in toxicity. Hence, the buffering capacity of the receiving water would be expected to greatly influence the actual toxicity.

The bioassay analyses were performed in unbuffered solutions whose pH rose from near neutrality to approximately 8.0(+), possibly as a result of CO_2 stripping caused by aeration of the sampled water during the test. The increased concentration of OH^- denotes a rise in pH, which forces the precipitation of constituents thereby reducing the level of acute toxicity. However, some precipitates may remain in colloidal form in solution and contribute to a non-acute level of toxicity. Conversely, an increase in pH would increase the concentration of un-ionized ammonia which would tend to increase toxicity. To determine the governing relationship in the acute toxicity problem, bioassays would have to be conducted at various buffered pH's. Previous studies[4] indicates that for leachates the toxicity tends to decrease exponentially as pH increases within the pH range of 5 to 6.5 Referring to Figure 41, the semi-log plot indicates a predicted toxicity of 30% in a bioassay conducted at pH 6.5 in a sample containing high-strength landfill leachates. The Richmond Landfill Site yielded similar toxicity levels, despite the fact that its leachate is considered to be of medium to low strength. Field work has established that more than three cubic feet per second (3 cfs) of this leachate may be flowing from the site under normal conditions. As most of this leachate flow will reach the Fraser River, the toxicity of the discharge

will be strongly influenced by the buffering capacity of the river's receiving water.

7.1.3 Bacteriology

The multiple tube fermentation technique, the preferred method for high turbidity leachate analysis[35], was used during bacteriological investigations. Bacteriological tests were of the indicator type, that is, the presence of these organisms provides an indication of the probable presence of pathogenic organisms. Researchers generally agree that the absence of faecal coliforms would not preclude the possibility of pathogens[35]. The bacteriological results from all sample points were positive. However, highest values were found in leachate flows to private lands (northeast corner of site), thereby confirming a possible concern of public health authorities. Positive bacteriological counts were also obtained in the Nelson Road ditch, upstream of the leachate discharge. These positive upstream results are probably due to drainage from areas upstream that are used for livestock feeding; therefore, the municipal ditch system would appear to be already contaminated, and the effect of additional contamination would be difficult to quantify.

7.2 Unit 1 (Refuse) Waters

7.2.1 General Assessment

Water quality in Unit 1 (Refuse) can be assessed generally as too contaminated for discharge to water courses or groundwater regimes. Due to this site's geologic setting, it is hypothesized that good isolation of the leachate is provided from lower aquifers although some areas of concern exist on the northeastern and western portions of the site. It is thought that most of the Unit 1 (Refuse) waters discharge to surface ditches or to the unconsolidated peats to the west and as such, are directly connected with surface hydrologic regimes.

7.2.2 Factors Affecting Leachate Quality

Leachate from refuse is dependent on many factors, a large proportion of which may be indeterminate during field studies as

opposed to a laboratory or "lysimeter" type study where constituent densities and water balance can be directly controlled.

The quality of the leachate itself is a direct result of the:

(a) type or constituents of the refuse ;

(b) construction of the refuse fill (density, material size lift construction, placement of mattress, etc.) ;

(c) length of time the refuse has been subjected to a set of more or less consistent environmental circumstances - this is usually simplified as the age of the refuse ;

(d) vertical thickness of the fill ;

(e) volume of water flowing through the refuse ;

(f) variability of flow ;

(g) chemical nature of the landfill recharge water.

A sample of leachate, however, varies in chemical nature as a result of the:

(a) sampling procedure used to obtain the sample ;

(b) degree of re-establishment of the original groundwater regime and quality, after the installation of the well ;

(c) level or horizon in the leachate column from which the sample was taken ;

(d) cone of contribution around the well from which the leachate was removed.

In addition to the above factors, laboratory analytical procedures also influence the water quality analysis [35]. The degree to which the factors affect the results obtained from a field testing program has been amply illustrated by Hughes et al [25] in following table in which the results of chemical analysis are shown for three wells placed around a 10-foot diameter circle, located at the same level, sampled on the same day and by the same method except that different amounts were removed from the well prior to sampling.

EXAMPLE OF VARYING SAMPLING RESULTS OBTAINED FROM THREE CLOSELY POSITIONED WELLS (after Hughes et al., 1971[25]).

Well	pH	Cl	Ca	Mg	Fe	Alkal. (As $CaCo_3$)	SO_4	Total Hardness
LW5C	7.2	2060	400	583	40	7300	108	3400
LW12B	6.0	2270	2420	972	750	11,000	1300	10,100
LW13	5.5	71	1080	413	590	4500	430	440

Definitive evaluation of leachate quality through correlation of functional parameters between locations on site appears invalid considering the heterogeneity of a refuse in a landfill. Surveys of this type are best suited to downstream or plume type studies in homogenous materials outside of the refuse site itself, or confined to research studies where there is environmental and refuse constituent control.

Although piezometer/wells at the Richmond Landfill Site were originally placed so that plume or flow paths might be detected, at present they are useful only as informative data representative of water quality within a shallow fill depth peat bog landfill. In time refuse aging and reduction of site operational factors may result in a general damping of the variation of the leachate constituent concentrations.

Evaluation of Unit 1 (Refuse) waters therefore will be limited in general to two types of assessments:

(a) site specific - each well with time,

(b) water quality variations attributable or correlatable with large on-site events (i.e. dredging spoil deposition).

Comparison of COD values of, say, 1-A or 1-D with 3-G and 3-H is assumed to represent the dieoff of COD values as the refuse ages. It might be expected that the levels of these newer wells will fall to those of 1-A in perhaps 5 to 10 years, assuming that similar hydrologic phenomena occur.

Large changes in parameter levels can be seen in Wells 1-A, 1-D, 2-B and 2-C during or after dredge spoil depositions on the area just to the west of 1-D and to the south of 1-E. It should be noted that all parameters did not alter to the same extent. For example, COD level increases are not proportionate with increases in specific conductance or total residue. This may be a function of the age of the refuse in this area and may not reflect what could occur if new refuse were flushed in the same manner.

It is expected that continued monitoring of the wells will ultimately show some stabilization of values for each well. This, of course, will not occur until such time as large-scale hydrologic events cease. The parameter values obtained in Unit 1 (Refuse) wells during the study period should be only looked upon as the best condition of these waters. Considerably worse conditions may exist at times as a result of surface loadings, the dumping of clean or contaminated water, or the flooding of the refuse during high stages in the Fraser River.

Notwithstanding the above comments, contours of some leachate constituent values (COD, TR and Cl) have been plotted for two sample days and are shown in Figures 42, 43 and 44. It should be recognized, however, that these plots are approximate and are subject to the considerable constraints discussed above.

7.3 Unit 2 (Peat) Waters

7.3.1 General Assessment

Evaluation of the water quality data for this work is tempered with the following assumptions:

(a) As the peat is loaded its permeability drops to $\approx 10^{-5}$ cm/sec., consequently, this unit could be considered as an aquatard. Lower permeabilities might be expected on its upper and lower surfaces.

(b) Some attenuation of constituents will be experienced if leachate flows through the peat [11].

(c) Peats were probably contaminated before they were covered as the leachate from the advancing refuse front

migrated out of the refuse and into the unconsolidated peats.

(d) Well 1-M is considered to provide background peat water quality data for the purposes of this report.

Data at 1-B and 1-J is considered most representative since in these locations the following basic requirements have been met:

(a) static level is above upper surface of the peat thus implying good installation of piezometer,

(b) permeability is significantly different from unconsolidated peats or refuse,

(c) water quality in nearby 1-A and 1-K refuse wells is markedly different.

7.3.2 Water Quality Evaluation

From the COD values it would seem that this parameter is related to permeability. Low concentrations in 1-B indicate that if contamination occurred, it was a relatively long time ago (as compared with 1-J), and the COD constituents were biodegradable as was 50% to 70% of the natural or background COD in the unconsolidated and uncontaminated virgin peats and no new contamination reached this well for some period of time. This would indicate that the piezometric head in 1-B is not the head of a confined flowing aquifer, but the head of consolidating medium of very low permeability.

1-J appears to be showing the same trend of decreasing COD values with time to below background and high piezometric levels, indicating once again that recharge from contaminated zones does not exist, or if ion diffusion is occurring at velocities higher than the upward velocities of the peat consolidation waters, then attenuation is occurring.

pH levels above background are probably the result of Ca and Mg oxides or hydroxides that are readily extracted from the concrete dry wall and plaster materials in the refuse mattress when dumped in the acid environment of the unconsolidated peats. The hydroxides in the leachate would, as the leachate seeped into the unconsolidated peats, raise the pH of the peat water.

Chloride concentrations in both 1-B and 1-J indicate (omitting the anomalous value for 1-B on March 30), that this conservative ion is being neither forced into this aquifer during dredging operations nor is the ion capable of ion mobility by diffusion into the peats against the vertical movement of consolidation waters. The other possibility is that dredging-related high chloride values have simply not reached the wells. This would be more applicable to 1-B.

It is also possible that concentration may decrease slightly with time as the consolidation waters from the clay flow into the peats. The water quality of the clay is, however, unknown.

Well 2-A, although meeting the requirements of low permeability, high piezometric levels and installation of the well far into the peat horizon, cannot for the present be considered to provide representative data of peat water quality. To date this well provides anomalous data compared to any other well on site, including refuse wells. High pH's and concentrations of SO_4 and Ca imply that the well may be contaminated with a substance such as gypsum or gyproc, a product disposed of in large quantities at the site. This substance may somehow have been carried down during placement of the well or possibly even deposited in the well. In any case, the water quality cannot for the present be interpreted in terms of the model or data obtained from other wells.

Well 3-A to the west of the refuse filled area and just north of the dyke shows a significant degree of contamination. This contamination appears to be continuous with time, although its decrease in the non-conservative parameters is greater than for conservative ones, indicating only that flow may decrease during the drier summer months. Data from the next wet season may show the other half of this postulated contaminate cyclic trend. The migration of contaminated water into and through the unconsolidated peat could pose problems in areas like 4-J where sand lenses are found at the base of the peat.

The increase in chloride concentrations at 3-A may indicate the arrival at 3-A of the leachate plume created by the flushing of the refuse to the east of 3-A, during the late winter dredging spoil deposition in 1976. Additional wells in a line radial to the landfill

perimeter in this area, might provide valuable information on the rate of migration and the degree of leachate constituent attenuation attainable in unconsolidated peat. Nested wells could indicate the degree to which leachate stratifies as it migrates through a medium.

7.4 Unit 3 (Silty Sands) Waters

7.4.1 General Assessment

The silty sands aquifer underlying the site does not to date show any significant degree of contamination as the result of leachate ingress; however, anomalies do exist for which no explanation is given except as outlined below. The continuity of the clay horizon above the sands and the maintenance of its impervious integrity is required to protect the water quality of the underlying silty sands due to the tendency of the peats to fail or tear when loaded without complete lateral support or containment. Since support or containment cannot be guaranteed; for example, if a ditch or hole is cut into the peat, it is, therefore, only the clay which provides any degree of leachate containment security. With the ultimate reduction of pore pressure in the peats and due to the downward hydraulic gradient between the refuse and the silty sands, there will ultimately be some discharge to the sands. However, the chemical retardation of the peats and clays should provide sufficient attenuation if flow is through at least several feet of the peats and clays. Prolonged exposure of the clay horizon to leachate may, however, alter its physical properties. Some investigation should be carried out to determine those effects.

The water quality of Unit 3 (Silty Sands) though not acceptable by drinking water standards, cannot be determined to be the direct result of leachate discharge to the aquifer. High iron concentrations found in water from Well 3-D could be the result of leachate entering the well through a casing crack, seeping along the well annulus or migrating through the clays. In this regard, it is noted that Well 3-C located in the refuse above 3-D also shows continuous high iron concentrations.

Unusually high initial values of COD in Wells 1-F, 1-I, 3-D and 3-F were probably the direct result of the drilling operations required to install the wells. The contaminant was probably hydraulic oil from the drill rig. Poor water quality in Well 1-F is postulated

to be the result of a crack in the well casing, probably at one of the joints where the p.v.c. ducting was glued. Cracking of these joints could be expected as a result of the high stresses in the casing during the well installation procedure and during fill settlement and displacement as a result of the high surface loading with dredged sand just to the east of 1-F. It is now tentative that 1-F will be destroyed by a method that is commensurate with the requirement of non-transmittal of leachate to the lower aquifer. This procedure will be an ultimate requirement for all Unit 3 wells at the end of the study.

Figures 45 and 46 depict a hypothetical, though plausible, sequence of events by which leachate from the site discharging to the Fraser River may find itself injected into the Silty Sands aquifer underlying the site.

7.5 Groundwater Regime Synopsis

(a) Due to the impermeable nature of the clays and consolidated peats, most leachate generated on-site:
- is collected in the ditches and is discharged principally to the Fraser River (Figure 28), but frequently to adjacent lands (Table 5) via ditches ;
- seeps through the pervious refuse dyke to the Fraser River (Figures 33 and 34, and Appendix E);
- migrates to the unconsolidated peats to the west (Figures 33 and 34, and Appendix E) as evidenced by preliminary data interpretation at Well 3-A Tables 7(a) to 7(g) ;
- is lost to Silty Sands horizon near ground surfaces in the northeast portion of the site as leachate contaminated water travels along the ditch.

(b) No significant flow of leachate through the consolidated peats underlying the refuse can occur due to their

impermeable nature. Therefore, no significant alteration of leachate quality can be expected due to attenuation by peat.

(c) To-date, no constituents of the Silty Sands aquifer water beneath the active site has been attributed to the ingress of leachates. Contamination in Well 1-F is thought at present to be the result of a cracked well casing. Hypothetical mechanisms for leachate migration into the Silty Sands aquifer have been postulated, but are as yet unsubstantiated, (see Figures 45 and 46).

8 ENVIRONMENTAL REGULATIONS

8.1 General Review

The environmental implications of a raw leachate discharge to surface waters is a problem which environmental policy makers have been attempting to come to grips with for some time. As a consequence, the application of environmental regulations as they apply to leachate discharges do not always appear to be consistent. This apparent regulatory inconsistency is a function of the complexity of such discharges and the parochial nature of the environmental management process. The dual environmental concern with respect to leachate is a case in point. On the one hand there are the readily evident and quantifiable constituents which can be readily assimilated (e.g. Oxygen Demand, Organic Solids) in a receiving environment having sufficient dilution capability, such that the number of organisms and diversity of species is not adversely affected. As the impact of such constituents on the environment is a function of the receiving water assimilative and dilution capability, the application of regulations dealing with these constituents tends to be site specific. On the other hand, there are the myriad of chemical constituents within the leachate that are non-assimilative which may undergo biological accumulation and magnification in the food chain. The effect of these materials is largely unknown. Thus regulations dealing with these types of wastes can be arbitrary and need not acknowledge dilution capability. At the Richmond Landfill Site we have the Fraser River as the receiving water. The dilution and assimilative capability beyond the initial dilution zone renders the effect of oxygen demand and readily assimilative organic solids negligible. However,

at the same time the non-assimilative chemicals through biological accumulation can pose a threat to the highly productive Fraser Estuary.

This discussion is intended to provide some insight into the hybrid or mosaic-like nature of the environmental management process and the important yet subtle distinction between the immediate short-term pollution control considerations and the long-term prudence required for environmental protection of the Fraser Estuary. The following sections outline the codes and governmental regulations applicable to this study.

8.2 Federal Controls

8.2.1 Federal Facility Codes of Good Practice

The Federal Government Cabinet decision of June 8, 1972, entitled "Control and Abatement of Pollution from Federal Activities Clean Up and Prevention", calls for the clean up of existing sources of pollution from Federal establishments and for the assessment of all new projects initiated by the Federal Government for potential adverse environmental effects. With this stated position, it is the intention of the Federal Government to "provide a consistent and exemplary environmental pollution control program" (9), and as a result codes of good practice outlining environmental guidelines have been prepared to cover areas of environmental concern. Guidelines developed to date which have implications for the Richmond Landfill are as follows:

(a) Code of Good Practice for Management of Hazardous and Toxic Wastes at Federal Establishments,

(b) Code of Good Practice on Dump Closing or Conversion to Sanitary Landfill at Federal Establishments,

(c) Guidelines for Effluent Quality and Wastewater Treatment at Federal Establishments.

8.2.1.1 Hazardous and Toxic Wastes

The "code of good practice" dealing with hazardous and toxic wastes outlines specific requirements for characterization of such wastes prior to any handling or disposal procedure. For landfilling of such materials, there are firm requirements as to the contaminant attenuation and/or the containment capabilities of the landfill site, as well as specific disposal procedures.

8.2.1.2 Sanitary Landfill

This "code of good practice" has among its objectives "the prevention of surface and ground water pollution" and, as such, outlines the following requirements:

(a) Leachate collection and treatment systems should be used when necessary to protect ground and surface waters. Collected leachate should receive adequate treatment before discharge to a receiving body.

(b) In no case should solid waste be allowed to contact ground water. The ground water (i.e. high-water mark of the 50-year design flood) and deposited solid waste should be at least 5 feet apart.

The salient requirement of this "code of good practice", as it pertains to the Richmond Landfill Site, states that where refuse has been placed in wetlands (i.e. marshland or where ground water or surface waters have been contaminated), the method of closure specifies removal of solid waste and separation by placement of an inert material mat that reaches above high-water level.

This "code of good practice" is included in its entirety in Appendix .

8.2.1.3 Effluent Quality Guidelines

The Guidelines for Effluent Quality and Wastewater Treatment at Federal establishments[23] are intended for application to land-based establishments under the direct authority of the Federal Government. The specific limits outlined apply primarily to domestic type effluent, however, the general considerations of effluent quality requirements are applicable to a large effluent discharge such as leachate to surface water. Such a general requirement is that "Effluent from Federal establishments should be treated before being discharged to receiving waters so that they are free from materials and heat in quantities and concentrations or combinations which are toxic or harmful to human, animal, waterfowl or aquatic life".

Following treatment, maximum effluent levels are cited as:

5-day BOD - 20 mg/l

Suspended solids - 25 mg/l

Faecal coliform (MF method) 400 per 100 ml

pH 6 to 9

Phenols - 20 μg/l

Oils and greases - 15 mg/l

8.2.2 Fisheries Act

The Fisheries Act 1970 is considered to be the most important federal statute exercising control over water pollution in Canada [26]. Section 33[2] prohibits the discharge of any deleterious substance into waters frequented by fish and reads as follows:

> "Subject to subsection (4), no person shall deposit or permit the deposit of a deleterious substance of any type in waters frequented by fish or in any place under any conditions where such deleterious substance or any other deleterious substance that results from the deposit of such deleterious substance may enter any such water".

8.3 Provincial Controls

The environmental regulatory agency of the British Columbia Provincial Government is the Pollution Control Branch. This provincial agency has legislative jurisdiction over matters related to discharges to land, water and air under the Pollution Control Act 1967, and its appurtenant guidelines and regulations.

Provincial pollution control requirements respecting landfills as outlined in the"Pollution Control Objectives (P.C.O.) for Municipal Type Waste Discharges",[38] were promulgated in September 1975. These objectives ,the pertinent parts of which are included in Appendix H, do not include specific contaminant level limits for landfill leachate discharges. There are, however, specific requirements for landfill operations which are intended to preclude their environmental impacts. Included as part of these landfill objectives is the requirement for maintenance of receiving water quality shown in Appendix H as Table 5.3. It would seem consistent with the intent of the P.C.O.'s to apply effluent quality

criteria to leachates where these leachates constitute a point source discharge. Level A-A objectives would be applied to new discharges. Table 5.2 in Appendix H lists the limits for parameters that may be of concern in specific discharges.

8.4 Municipal Controls

The B.C.Municipal Act 1960 gives municipal councils important powers to deal with water pollution [26]. Section 5.19(a) gives council power by by-law to:

> "Prohibit any substance from fouling, obstructing, impeding the flow of any stream, creek, waterway, watercourse ... whether or not the same are situate on private property, and may provide for the imposition of penalties for any contravention of such regulations".

In addition, Section 9 of the Provincial Health Act 1960, dealing with Sanitary Regulations, puts the responsibilities for such matters under the jurisdiction of municipalities. In regard to a landfill operation the primary concern of the municipal health department would be the prevention of vector breeding in the fill itself and with the possible health hazards related to a raw leachate discharge.

9 HAZARDOUS AND TOXIC WASTES

9.1 Introduction

A discussion of hazardous and toxic wastes as it pertains to the acceptability of wastes for landfilling requires some clarification, at least in terms of definition. The terms "hazardous" and "toxic", through usage, have been lumped together to such an extent that we rarely talk of a waste being hazardous or being toxic, but rather talk of a waste which falls into a group labelled "hazardous and toxic". Most definitions of hazardous wastes include toxic materials such as the National Solid Wastes Management Association's definition: "Hazardous waste means any waste or combination of wastes which because of its quantity, concentration, or chemical characteristics poses a substantial, present or potential, hazard to human or animal health or the environment because such wastes are bioconcentrative, highly flammable, extremely reactive, toxic, irritating, corrosive or infectious". Separating hazardous

from toxic, hazardous wastes can be defined as a waste that is a danger to human life without direct ingestion. Among materials that fall in this category are: radioactive materials, strong acids or bases, some gases (e.g.chlorine, hydrogen sulphide), pesticides and compounds such as PCB (polychlorinated biphenyls), which can enter the body through the skin. In addition, there is a great range of chemicals which themselves are not necessarily hazardous, but when mixed can generate a great deal of heat, or themselves when heated form gases which can pose a hazard, e.g. strong bases on aluminum scrap, ammonium nitrate (common fertilizer) and diesel oil, scrap magnesium and water, bleach mixed with ammonia base cleaners or borax, vinegar and calcium carbonate.

Toxic materials are generally considered as those materials which through ingestion cause physiological alteration to some degree in the ingesting organism. The degree or effect of toxicity is a much discussed subject. On the one hand, there is lethal or acute toxicity where the presence of the material causes the organism to die within a short period of time. On the other hand, there is sub-lethal or chronic toxicity in which the effects of ingested material is to slow the organism down, decrease its ability to breed, or to disrupt its food supplies. Thus sub-lethal toxicity destroys the organism's natural responses and life patterns just as effectively as acute toxicity. On these effects there is no agreement as to what are "significant" concentrations or what effect other natural occurring circumstances such as temperature changes can have.

Virtually every compound known to man including those needed to sustain life is toxic at some concentration. However, within the context of the term toxic, the wastes normally discussed are mostly short-chain and ringed hydrocarbons, heavy metals, chlorine compounds and ammonia. At a landfill site, the toxicity of leachate can come from two sources. The most obvious being the discharge of toxic materials on landfill sites and the resultant percolation through the fill and appearance in the leachate. The second and typical source of toxicity is the bio-chemical and chemical breakdown of what would be considered innocuous material. The breakdown products are typically heavy metals, ammonia, organic acids, hydrogen sulphide, plus a wide range of less harmful salts and organic products.

9.2 Richmond Landfill

At the Richmond Landfill Site, wastes which fall into the class of hazardous and toxic are periodically handled. Often the materials are at least acknowledged to be different and are disposed of at a spot other than the working face. However, these locations are not isolated and can conceivably be worked over. In other cases, these materials end up on the working face without the acknowledgement of the operators; for instance, pails of paint which have a chromate base, bottles of Sudsy (ammonia base) and Purex (chlorine base), which are household products.

In other cases, liquid waste discharges are directly to the roads. Figure 11 shows a 3000-gallon tank truck which is discharging phenolic-resin based glue washwater to a road and in this particular case, passes within about 25 feet of a ditch directly connected with the Fraser River. This, together with the site hydraulic connections between ground and surface water, indicates that disposal of hazardous and toxic wastes by means of tank truck can be tantamount to discharge to the surface waters.

One of the aspects that must be considered with the non-selective acceptance of commercial wastes, is the effect of advancing knowledge and increasing awareness of hazardous materials. It is understood that at the Richmond Landfill Site prior to the F.R.H.C. acquisition, and possibly at every other major landfill in the Lower Mainland, transformers were dumped. There is a possibility that the cooling oils within many of the transformers contain PCB's, now considered one of the most toxic materials known to man. The manufacturing of these compounds is being phased out, but only six years ago they were used extensively for high temperature electric and plastic operational problems. A grab sample collected in the No. 8 Road ditch in February 1976 (Table 3) was found to have a PCB concentration of 20 ppb. This measured level, although not necessarily indicative of a major problem, does point out that these materials exist in the landfill soil /water system and, as a consequence, are being discharged to the Fraser Estuary. The Table below lists PCB levels tabulated by the U.S. Environmental Protection Agency for several landfills in the U.S. By comparison, the measured level of 20 ppb is two to three orders of magnitude greater. It is not known whether the PCB level measured is a result of

leaking electrical equipment, or the discharge of the oil itself.

POLYCHLORINATED BIPHENYLS IN MUNICIPAL LANDFILLS (EPA 1976)

LOCATION	TYPE OF LANDFILL	SOURCE AND CONCENTRATION (parts per trillion)
Washington	general	15 - leachate
Nebraska	general	41 - leachate wells
	general	8 - surface (creek)
	general	11 - ground water
	sludge & manure	115 - leachate
New York	general & sludge	640 - leachate
	general & sludge	7 - groundwater
Arkansas	sludge	15 - leachate
	sludge	17 - surface
	sludge	8 - ground water
Richmond Landfill Site	general	2000 - surface (ditch)

Another example of the accessibility of hazardous wastes to any landfill and in this case the Richmond Landfill Site, occurred on September 9, 1976, when a DDT spill occurred on a vessel in Vancouver Harbour. This pesticide was cleaned up and then dumped in a commercial container which was taken to the Richmond Landfill Site. The presence of materials such as DDT and PCB points out that where a landfill is located in a highly developed area such as Vancouver, a high degree of prudence is required when handling commercial and industrial wastes. In that the future port development will conceivably require excavation into the placed fill, considerable pre-thought will be required as to potential hazards which may exist as a result of the hazardous and toxic material discharged to the fill.

In view of the foregoing comments and the established minimum requirements for handling hazardous and toxic wastes as outlined in Section 8.2.1 of this report, it is clear that these materials must not be discharged to the Richmond Landfill Site. Furthermore, careful screening of materials entering the site must be regularly carried out in order to preclude any inadvertent discharge of hazardous and toxic materials to the fill during the course of normal site operations.

10 GENERAL CONSIDERATIONS OF LANDFILL DESIGN

10.1 The Solid Waste Problem in Metropolitan Areas

Within a Canadian metropolitan area it is estimated that an average of three pounds of refuse per capita per day is generated. The municipal governments are obliged to remove and dispose of this waste. The most common method of disposal is by "sanitary" landfill. A sanitary landfill is described by the American Society of Civil Engineers as:

> "A method of disposing refuse on land without creating nuisances or hazards to public health or safety by utilizing the principles of engineering to confine the refuse to the smallest practical area, to reduce it to the smallest practical volume and to cover it with a layer of earth at the conclusion of each day's operation or more frequent intervals as may be necessary." (13)

This simplistic definition assumes a coupling of an idealized hydrogeological setting with a conscientiously managed operation, handling only "garbage". More often than not solid waste landfills are located in less than ideal settings, forced to operate within minimal budgets and yet, are required to handle the myriad of wastes that result from industrialized metropolitan areas. The consequences of such less than "sanitary" landfills are often environmental degradation. The pressures which force such inadequate landfill operations are a complex mixture of social, economic and political factors.

What is clear for this study, is that it is not necessary to address these complex interrelationships as the subject site is a land reclamation project requiring a high quality fill. The apparent economic benefits derived from the use of refuse for fill is outweighed by additional

costs required to bring the fill up to structural requirements, as well as the long-term costs of environmental mitigation.

10.2 Environmental and Structural Aspects of Landfill Design

10.2.1 Environmental

A state-of-the-art discussion of many of the environmental factors affecting a landfill design and investigation are outlined in a paper prepared by Mr.Hans Mooij included in this report as Appendix I. This paper is included so that the reader may become familiar with many of the general environmental problems and design considerations associated with landfills.

10.2.2 Structural

A complete discussion of the structural considerations of landfill design is presented in Appendix J of this report.

11 DISCUSSION AND SUMMARY

11.1 Overview

This 310-acre crown-owned, F.R.H.C. operated,refuse landfill is located on a peat bog in the Estuary of the Fraser River. The site is subjected to many water budget factors. These include 40 inches annual precipitation, tidal flushing of the lower portion of fill on at least part of the site, and massive flushings of portions of the fill from above due to slurry deposition of dredged sand. As a result, large volumes of leachate are generated and subsequently discharged to the Fraser River, municipal ditches and occasionally to adjacent private lands.

The site specifications (Appendix A)outline clearly that the goal of this project is construction of a "sanitary landfill" having the highest structural competance obtainable, as well as the non-creation of nuisance or pollution conditions. Section 1 of the Detailed Specifications reads as follows:

> "The construction of the landfill is to be considered as an engineering project with two specific aims:
>
> a) The construction of a sanitary landfill, carried out without creating nuisances or hazard to public health

or safety. The operation is to be carried out in accordance with the requirements of governing health and pollution authorities.

b) The construction of a landfill of the highest quality with regard to subsequent utilization of the land as an industrial building site. The object of the undertaking is to produce ground with highest and most stable bearing capacity possible considering the nature of the operation."

The following sections summarizing the study findings illustrate why the first goal (part (a)) is clearly not being achieved and why the achievement of the second goal is questionable.

11.2 Solid Wastes

Refuse comprised of the entire spectrum of commercial, industrial and demolition wastes generated by a large metropolitan centre is deposited directly on the surface of the peat to form a mattress. Above this mattress are placed quantities of municipal and commercial compactor transported refuse. The major source of refuse is commercial, emanating from the Greater Vancouver area and discharged by contract haulers (Smithrite, Totem, Haul-a-Way, IXL). This refuse together with Richmond municipal refuse, accounts for an estimated total annual volume of 350,000 cubic yards, or about 88,000 tons.* Based on a 3 lb/capita/day population equivalent, the refuse discharged to the Richmond Landfill Site by compactor vehicles alone, represents a population equivalent of 160,000. These figures, however, do not include the larger portion of commercial, industrial and demolition refuse discharged to the mattress fill (estimated to be in the order of at least 100,000 tons per year). In addition to the above generalized categories of refuse discharged, there is an unknown amount of liquid wastes discharged directly to the site, over and above the 60,000 gallons of waste oils reported as received in storage tanks. These liquid wastes which include waste oils, waste sludge and liquid processing wastes, are discharged to the roads or fill.

* Assuming a truck density of 500 lbs/yd^3 based on 2:1 compaction ratio of refuse having an uncompacted density of 250 lbs/yd^3.

It should be restated that this F.R.H.C. crown land reclamation site is not obligated to handle Greater Vancouver solid waste. Although presently there is a contractual agreement with the Corporation of Richmond to dispose of its municipally collected and citizen transported refuse, the far larger portion of refuse discharged to this site emanates from other sources.

The Detailed Site Specifications (Appendix A) with regard to acceptable materials, would appear to be contravened in the following areas:

1. Schedule D, Part 6, Agreement with Corporation of Richmond. "No putrescible materials from outside the Municipality shall be collected specifically for disposal at this site. Such putrescible materials as may be received from outside the Municipality shall in no event exceed five per cent by volume of the carrying capacity of the transporting vehicle." As a large portion of the volume of refuse entering the site is transported by commercial compactor vehicles (e.g. Smithrite), collecting refuse from outside of the Municipality of Richmond, it is apparent that there is no control exercised over this specification.

2. Section (3) Part (a). "Materials which will not be allowed in the refuse fill include the following:
   Industrial process wastes including:
   volatile matter
   lime (except debris from building demolition)
   packing house wastes
   oil (except that oil may be used for laying of dust on roads and on the fill providing it is sprayed on with proper equipment. Bulk oil must not be dumped into the fill. Oil must be received and kept in storage tanks at site for subsequent spraying on the fill.)"

Both industrial process waste and oil have been discharged to the site. As is seen in Figure 11 application of liquid waste to the roads is not "sprayed with proper equipment", but is generally applied to the centre portion of the road through the discharge valve of the tank truck.

11.3 Hydrogeology

The hydrogeological setting of the Richmond Landfill Site is at variance with the accepted requirements of a "sanitary landfill", specifically with respect to level of the water table. The site, a deltaic setting, is underlain by at least three hydrostratigraphic units: sands and silty sands; above which is usually found a clay layer of large variations in thickness; and above this undulating surface of clays, a peat bog which has flourished in recent millenia and has developed to a maximum unconsolidated thickness of approximately 20 feet.

The hydrology of the peat bog itself is relatively simple. In general, the water table is near the bog surface. During the wet season or flood stage of the river, the bog water table will rise to the surface or above in accordance with the nearby river level. This can mean several feet of inundation. At Richmond Landfill, as the peat is covered, it compresses or consolidates under the weight of the refuse. The water table does not, however, drop with the peats. It can actually mound up in the refuse horizon, thus inundating at least the lower portion of the fill. River water at higher stages and tidal fluctuations seeps into the site through the porous refuse dyke and further inundates the refuse. As peats consolidate their permeability drops markedly from about 10^{-3} cm/sec to 10^{-5} cm/sec. The upper surface of the peat horizon thus tends to form an impervious layer under the refuse along which waters flow. Thus, the water from precipitation that has percolated through the refuse and waters that have seeped into the site through the pervious refuse dyke, all flow through the lower layer of refuse in the form of leachate. This leachate is ubiquitous in the lower portion of the Richmond Landfill.

An additional hydrological variable that results in massive flows through large sections of the site is the deposition of Fraser River dredging spoils on site by a slurry method. It is estimated that the minimum addition to the water budget of the site would be half the volume of the deposited solids (sands). In early 1976 this estimation method indicated a minimum of 25×10^6 gals. increase in the landfill water budget. Volumes could, however, be considerably larger depending on assumptions used.

11.3.1 Hydrogeological Update

As previously mentioned, a change in stratigraphic geology sequence exists in the northeast corner of this site. In this area a former Fraser River distributary channel (approximately 1 mile wide) intersects the peat bog. Typical stratigraphy of the channel is 3 to 5 feet of clay underlain by medium to coarse sands, see Figure 47. The redirection and excavation of leachate collection ditches during the summer of 1976 (see Figure 29), resulted in a ditch cut intersecting the sand horizon of the distributary channel. Concern regarding ex-filtration of leachate to this zone was documented in February and March 1977 when ditch flow measurements (Figure 48) indicated a significant loss of leachate in this area. Subsequent to this finding, a bore hole and piezometer installation program was carried out. Preliminary findings would imply the existence of a leachate plume in the underlying aquifer extending northerly from the ditch. The 1977 drilling program with piezometer locations is shown as Figure 49.

11.4 Environmental

Environmental protection is the maintenance of the integrity of ecological systems in air, water and on land. In the case of landfills, efforts are generally directed towards the protection of surface and sub-surface waters. This requires that landfill leachate be contained, collected and treated, or naturally attenuated prior to its appearance in the receiving environment.

At the Richmond Landfill Site both surface and sub-surface water qualities and integrities must be addressed. Sub-surface waters at the site appear to be afforded general protection through containment and/or attenuation of leachate over most of the present 310 acre site. However, recent findings, as outlined in Section 11.3.1 , have indicated that containment capabilities are not continuous throughout the site. Furthermore, there appears to be a significant loss of leachate to a sub-surface sand unit at the northeast corner of the site. This leachate in the form of a plume is expected to migrate through the hydrostratigraphic sand unit underlying neighbouring properties. As it is known that leachate migration through sub-surface soils can extend for thousands of feet

from landfills over a period of many years, the implications of this suspected sub-surface discharge must be considered as serious. Use of this aquifer for purposes of stock watering, crop irrigation or domestic supply may ultimately be precluded. The regulatory and legal implications of this scenario require prudent consideration.

Study of surface waters to date has indicated inadequate attenuation prior to discharge. Due to large water inputs, natural containment of the resultant leachate is not physically possible. At present, site hydraulic design is such that discharges of raw leachate to municipal ditches occurs. In the past the leachate ditch system has allowed direct discharges to private lands. The recent redirection by excavation of a perimeter ditch has, for the present, stopped surface discharges to surrounding lands; however, municipal ditches discharging to the Nelson Road pumping station are still highly contaminated with leachate.

The federal government environmental policy respecting crown lands as outlined in the June 8, 1972, Cabinet decision states the intention of the federal government to "provide a consistent and exemplary environmental pollution control program... thus providing leadership in the nation-wide effort to protect and enhance the quality of our environment".[9] Along these lines, codes of good practice and quidelines have been developed. It is clear from the information in this report that the Richmond Landfill Site does not comply with either the "Code of Good Practice on Dump Closing or Conversion to Sanitary Landfill", or the "Guidelines for Effluent Quality and Wastewater Treatment at Federal Establishments".

In terms of the B.C. provincial government guidelines respecting effluent discharges, this leachate discharge exceeds the requirements laid down in the objectives for municipal type discharges.

In terms of Federal Government legislation, the discharge of a toxic leachate to the Fraser River clearly contravenes the Fisheries Act (1970) section 33 (2), which prohibits the discharge of any deleterious substance into waters frequented by fish.

Beyond these specific non-compliances of Federal and Provincial guidelines and legislation respecting the discharge of leachate to the Fraser River, there are both short-term and long-term environmental con-

siderations which must be addressed. The short-term factors would include the possibility of human or livestock contact with the leachate either in the river or ditches.

The long-term concern involves two factors: long-term accumulation of metals and persistent organics in the Fraser River Estuary, and migration of leachates into underlying aquifers.

The possible long-term accumulation of metals and persistent organics in the river sediments followed by biological accumulation and magnification in the food chain, is a matter which should not be overlooked. It has been stated that "toxic wastes pose the greatest long range pollution threat to the ecological system of the Lower Fraser"[15]. Although quantification of the long-term effects of a leachate discharge containing a myriad of metals and organics may be difficult to predict, suffice it to say that on a worldwide basis, sufficient evidence exists as to the long-term adverse and somewhat insidious consequences of toxic discharges to a highly productive estuarine environment.

Further concern exists with the possible long-term effects of the recently determined migration of leachate to the sub-surface ground waters in the northeast corner of the site. The mechanisms of dilution, dispersion and attenuation will occur as a contaminant plume migrates through sub-surface soils. The adequacies of these mechanisms cannot, however,be taken for granted. Many case histories exist where aquifers have been contaminated for years following the completion of a landfilling operation. The health and legal implications of such an occurence, therefore, cannot be understated. Figure 50 shows the well locations and the water chemistry data.

Certainly it would seem reasonable to postulate that strict compliance to environmental guidelines and regulations as established by both the Federal and Provincial governments would be a large step in the right direction towards mitigating or at least minimizing the long-and-short-term consequences of a leachate discharge.

In view of the previous discussion, the admission of hazardous and toxic wastes to this site is a totally unacceptable practice because of the hydrologic setting of the site and the absence of attenuation prior to surface discharges to the Fraser River; and secondly, because no expertise or management procedures are available on-site to deal with these complex types of wastes. The potential hazards of such wastes are

discussed in Section 9 of this report. Regarding the apparent requirement in the specifications for the laying of dust on roads, this would be better carried out by the use of water.

The concern with the refuse constituents must not, however, end with hazardous and toxic wastes. The decomposition products in the leachate do, in fact, result from the myriad of constituents found in refuse emanating from a highly developed metropolitan area. The fact that the "mattress" fill also contains this myriad of waste as a result of the present compactor/refuse lift - other waste/mattress fill,designation method, point as clearly to problem sources throughout the entire depth of the fill. As well, woodwaste cannot necessarily be assumed to be without problems, certainly from an organic and oxygen demanding consideration. Leachates associated solely with decomposing wood have the characteristic black foamy appearance and the water soluable extractives of primary concern are phenols, sugars, alcohols and resin acids.[17] It has been suggested that the limiting factor in wood waste decomposition is the availability of nutrients and, therefore, the present mattress construction maximizes the release of leachate constituents.

11.4.1 Leachate Containment

An immediate need at the Richmond Landfill Site is the containment of all leachate to the site. The present method of pumping leachate from the landfill site to the Fraser River with the municipal pump at the foot of Nelson Road is unacceptable. Preliminary interpretation for the 1977 drilling program along the northern boundary revealed that the unconsolidated peats in the area beyond the perimeter ditch system show contamination with leachate. Control of leachate migration can be maintained by establishing a negative hydraulic gradient whereby site ditch water levels will be lower than those of adjoining properties and municipal ditches. This could be accomplished by establishment of a central pumping facility located at the south end of No.8 Road ditch. In addition, the existing ditch system requires redesigning to limit ditch flows through the northeast corner in order to minimize leachate loss to the pervious sands. At present approximately 2 cfs of leachate is flowing east from the intersection of No. 8 Road and north ditch to the northeast corner. Pumping facilities at the south end of No.8 Road ditch

with proper grades of ditches would divert much of this flow. Connection of the south end of the east ditch with the No.8 Road ditch will carry the leachate generated in the north east and east sectors of the site.

11.4.2 Leachate Treatment

In view of the non-compliance with federal and provincial guidelines and regulations, and contravention of the Federal Fisheries Act, leachate treatment must be provided prior to discharge to the Fraser River. Given the high water inputs to the site (dredging, precipitation, dyke seepage, ditch inundation, peat consolidation), any consideration of treatment would first require minimization of the leachate volume. Means by which this could be accomplished would involve: cover material grading and sealing; cessation of dredge sands deposition over refuse; and construction of an impermeable dyke. Present flows in the order of 2 to 4 cfs (approx. 1 to 2 MGD) could be substantially reduced possibly by as much as fifty percent. Based on this reduced leachate flow volume, preliminary cost estimates for treatment systems which are thought to be capable of meeting required regulatory effluent standards have been carried out. The costs were found to be highly dependent on three variables: volume; contaminant concentration; and number of years treatment works would be required. Based on the assumption that only a fixed percentage of the refuse is leachable and is independent of the above variables, conservative present worth capital and operating cost estimates have been placed at a minimum of 11 million dollars (excluding flow minimization costs, additional foundation costs and land costs).(Appendix K).

11.4.3 Vectors

Although not discussed in detail in this report, the health vectors require consideration at this site to ensure that no vector problems will occur upon closure. Because of the open face procedure of filling and the high lift thickness low-density fill, undoubtedly there is some degree of rodent infestation. The major vector problem at present, however, appears to be the thousands of seagulls which frequent the site. Food wastes in the form of chicken and other bones can be found distributed on the ground for relatively long distances from the active site. It is known that a litter problem attributable

to seagull-transported refuse is experienced at the Dow Chemical wharf on Tilbury Island just across the river and upstream from the site. Figure 51 shows the open face fill method used at Richmond Landfill and the availability of food it provides for seagulls. Large numbers of crows and starlings also frequent the site.

11.4.4 Monitoring Program

The water quality monitoring conducted as part of this study was a necessary endeavour in order to establish precise definition of the environmental problem to be solved. Continuation of this extensive monitoring program by the Environmental Protection Service, Federal Activities Pollution Abatement Group, will not be possible in the future; therefore, a monitoring program should be initiated by the F.R.H.C. in consultation with the Environmental Protection Service at the earliest possible date. It is envisioned that the monitoring program would involve both surface and ground water sampling with special attention given to direct discharges to the Fraser River and sub-surface discharges along the northern portions of the site.

For parallel and comparative purposes, it is understood that the monitoring program carried out at the City of Vancouver Burns Bog landfill site involves the monthly monitoring of 22 surface and ground water sample stations for approximately 25 parameters per station.

11.5 Structural

As previously mentioned, the 655-acre F.R.H.C. controlled crown land is proposed for future development of a deep sea port facility and a complimentary industrial park. As such, the structural requirements of this site are of utmost importance. Accordingly, the landfilling of the initial 310-acre land parcel has an encumbent primary responsibility for the achievement of a high quality structural fill, as is the apparent goal of the site specifications. As such, the following comments would seem to be in order:

a) The present one lift method of placing cells 8 to 14 feet in depth cannot be expected to achieve the maximum attainable fill density that would be expected if compactive machinery were operated according to standard

engineering fill placement practice. Referring to Appendix J , Figure J-1,it is seen that the standard fill procedure is one in which routine compaction of 6 inches to 1 ft. lifts is practiced, thereby achieving a greater fill density. It should be noted that the standard practice referred to is imperative even where minimal ultimate surface bearing capacities are required, e.g. playground, light buildings. With respect to the site specifications Appendix A, Section 7, under Class 3 materials there is some ambiguity as to the methods in which compactive energies are to be applied to the fill materials in the development of cells.

b) In addition to the normal consolidation mechanisms such as pore pressure reduction and soil particle structural deformation, there is the additional mechanisms of volume reduction with the decomposition of the refuse itself. Use of piles for foundations in refuse materials will have to be designed for loss and possible reversal of skin friction in the refuse zone (loss of pile bearing capacity).

c) Corrosion within a landfill environment can become a significant constraint in the design of sub-surface foundations and underground utility corridors. This factor will have to be considered in any future development design and may add to the capital and future operating costs.

d) Liberation of methane gas occurs as a by-product of anaerobic decomposition. This phenomenon requires special venting in areas where buildings or sealed surfaces are placed over the refuse fill. The extent of the gas production rate (present and anticipated) at the Richmond Landfill Site is not known. Presently gas venting is accommodated through the porous cover. Building construction on the present

site will require special ventilation works and/or construction of a porous sub-grade with an impermeable line and a gas detection system. If pilings are required for foundations, the gas protection of buildings would likely be done by positive ventilation of the building or false basement. Gas detection monitoring systems would be necessary with all buildings using this system.

e) The method of cell construction and variations in lift thickness and compactive energies applied may result in channels having high permeability to horizontal and vertical gas migration. If such channels are present, gases of decomposition can accumulate and discharge in concentrations sufficient to cause fire or explosion hazards. As underground horizontal migration of landfill gas can travel long distances, perimeter gas collection and venting works may be required to protect neighbouring lands and buildings.

f) Depending on the nature of the biological activity within the fill, underground fires caused by spontaneous combustion may be of concern. If aerobic conditions and organic wastes are present, biological activity could elevate the temperature. The presence of metals and industrial wastes could catalyse an exothermic chemical reaction sufficient to elevate temperatures to the combustion point.

g) During frequent site visits by study personnel, it was noticed that material size specifications were not always met. The oversize materials were usually timber (greater than 1 ft. diameter or 10 ft. long). However, it is not known what exemptions in terms of size specifications have been negotiated in this regard.

In addition to the above structural parameters of design in a landfill environment are the unique foundation considerations that the

site itself pose on the engineer regardless of the fill material. Peats and the associated organic clay base of the Lower Mainland peat bogs require special attention. No detailed reports on fill method, surcharging and initial foundation strengths for this site are known to exist. Some investigation[21] has been done to relate settlement versus time for a generalized depth of peat, but no procedural aspects for the maintenance of peat structural integrity were developed. Work done by others[10] for similar environments has yielded information that is generally applicable to the Richmond Landfill Site. In general, the motivation for filling with refuse is that a greater height of fill can be attained sooner using the low density loading. In the initial settlement or consolidation of the peats and organic clays, the very low initial strengths are substantially increased and subsequent surcharging can be carried out with less chance of failures, given that additional surcharges are not excessive and initial excess pore pressures are nearly dissipated.

The conclusion one gets from information elsewhere is that there is no benefit, structurally speaking, for filling a peat bog with refuse. The short-term benefits of having an operational fill height suitable only for very light structural purposes are outweighed if the long-term objective is the development of a high quality structural fill. The compounding problems as discussed earlier clearly indicate the complexities, and raise many questions as to the future problems at the present active 310-acre site and to the best procedural methods for filling the adjacent 345-acre site.

11.6 Further Work

The following further investigations are suggested as necessary in order to provide a clearer picture of the magnitude of the necessary environmental clean up program to bring this site up to the required environmental standards. As well, further scientific research endeavours by the Environmental Protection Service may be carried out in order to provide broader insight into overall environmental consequences of peat bog refuse landfilling.

11.6.1 Pollution Abatement Studies

11.6.1.1 Site Containment

This report has documented areas of immediate concern with respect to leachate discharges to both sub-surface and surface receiving environments. Evaluation of the possible leachate discharges to sub-surface aquifers will require a detailed geologic mapping to determine further areas of concern. With respect to the suspected leachate discharge in the northeast corner of the 310-acre site, further study is required to determine the extent of leachate migration which is a function of the total discharge and the soil attenuating capability prior to its egress to neighbouring lands. The extent of leachate migration to the unconsolidated peats to the east and west should also be quantified.

Following the determination of the sub-surface containment capabilities, design of adequate surface ditches could be addressed. This would include redirection of flows, re-grading of ditches and installation of suitably located and sized pumping facilities. The hydraulic isolation of surface flows from underlying pervious geologic units must be a governing design criterion in any surface design system. In this regard, the northeast corner is at present known to require particular attention. Sealing the present excavated ditch in this area would entail diversion of flows, cleaning of ditch,grouting of sand aquifer, and backfilling of the excavation with impervious material.

11.6.1.2 Leachate Treatment

This report having established the requirements for treatment of the toxic leachate discharges, has also addressed the level of treatment required (Appendix K). This treatment scenario as developed by Dr.R.D.Cameron was based on a state of the art review of leachate treatment. Prior to any treatment works design, bench and pilot scale design would have to be undertaken. Consideration of discharge to a municipal sewage treatment system could be evaluated. However, given the character of the leachate, pre-treatment would be required and, accordingly, appropriate works designed.

11.6.2 Scientific Studies

11.6.2.1 Hydrogeological Study

Continuance of this valuable aspect of the overall study is anticipated. This work, under the capable direction of Mr. Hugh Liebscher, Project Hydrogeologist, will hopefully provide broader interpretation of the local hydrogeological regime.

11.6.2.2 Peat Attenuation

Much research work has been conducted in recent years on the contaminant attenuation capabilities of peat[11]. As this aspect has not been specifically studied at the Richmond Landfill Site, further field work is warranted. It is proposed that this work be carried out along the north boundary of the property using the peat well installed during the recent 1977 drilling program in conjunction with other wells which will be located down-gradient. A further study area which may be used is on the west side of the active site in the vicinity of Well 3-A.

11.6.2.3 Impact of Leachate Discharges on Fraser River

In order to develop a better understanding of the resultant environmental impacts on the Fraser River, it is proposed that benthic and sediment sample analysis and further toxicity studies be conducted.

The benthic and sediment sample collection (samples collected in April 1977) will involve benthic Fraser River sediment sample analysis upstream and downstream of the Nelson Road pump station discharge, the No.8 Road ditch, and the barge ramp. These samples will be analysed for benthic macro-invertebrate species diversity, as well as chemical analysis for Total Organics, Chemical Oxygen Demand, Heavy Metals and Polychlorinated Biphenyls (PCB's). Sediment samples collected in the east ditch and the No.8 Road ditch will receive chemical analysis only.

Recent research has indicated the potential sub-lethal effects of toxicants on fish. To develop an understanding of the possible sub-lethal effects of toxic constituents in the Richmond Landfill leachate discharge, further bioassay tests will be carried out on samples collected in the site ditches and following mixing with the Fraser River. The salmonid species which are used in the LC_{50} determinations will be analysed for the "Corticosteriod" stress response. This technique has been suggested for use in evaluating effluents containing heavy metals.[14]

11.7 Summary Statement

This study involving a thorough evaluation of the hydrogeological setting, the site operation, and the resultant toxic leachate discharges to the Fraser River Estuary and surrounding lands, has clearly documented the environmental unacceptability of this landfill operation. The leachate discharges are clearly the result of utilizing refuse for fill. Although this study has not dealt in detail with the structural requirements for the future development, the use of refuse for a structural fill is considered questionable.

The entire quantification of the extent of the environmental problems and its encumbent abatement and clean up requires immediate attention, and is the imminent responsibility of the Fraser River Harbour Commission. As the findings of this study clearly illustrate and document the environmental consequences of the present operation, it is concluded that filling of the adjacent 345-acre site in the present manner would be unacceptable, as is a continuation of filling on the present site.

FIGURES

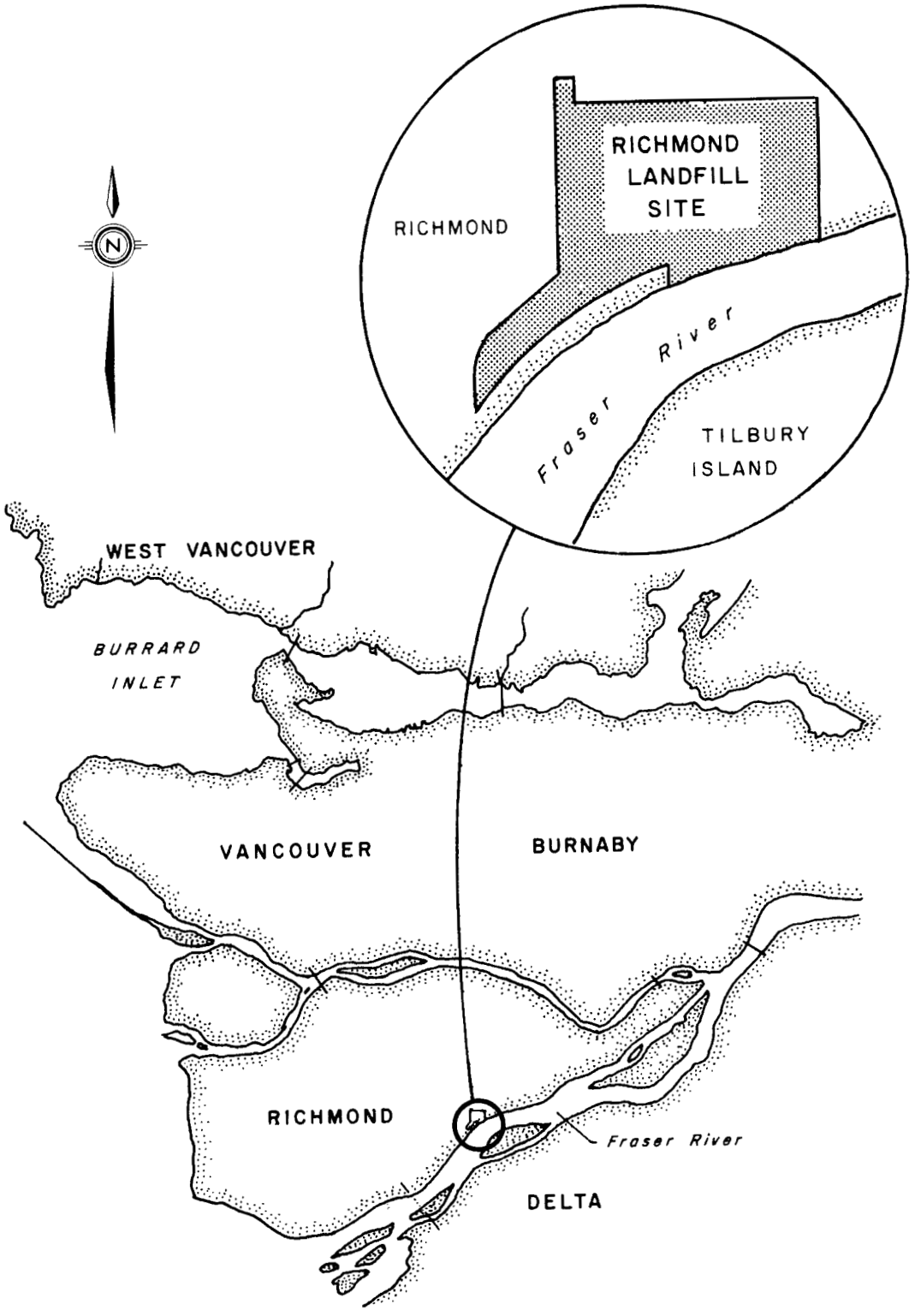

FIG. I RICHMOND LANDFILL LOCATION MAP

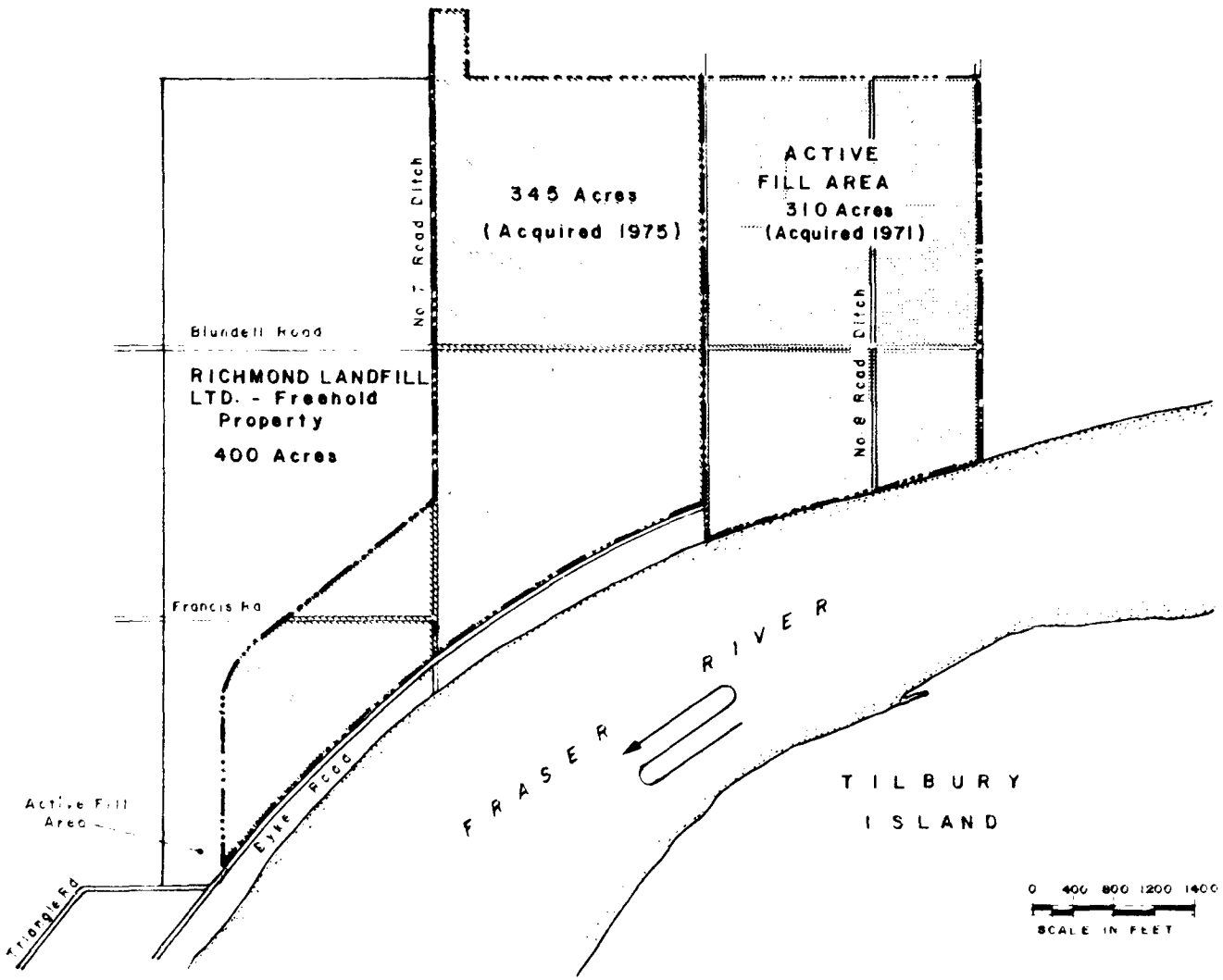

FIGURE 2 RICHMOND LANDFILL SITE MAP

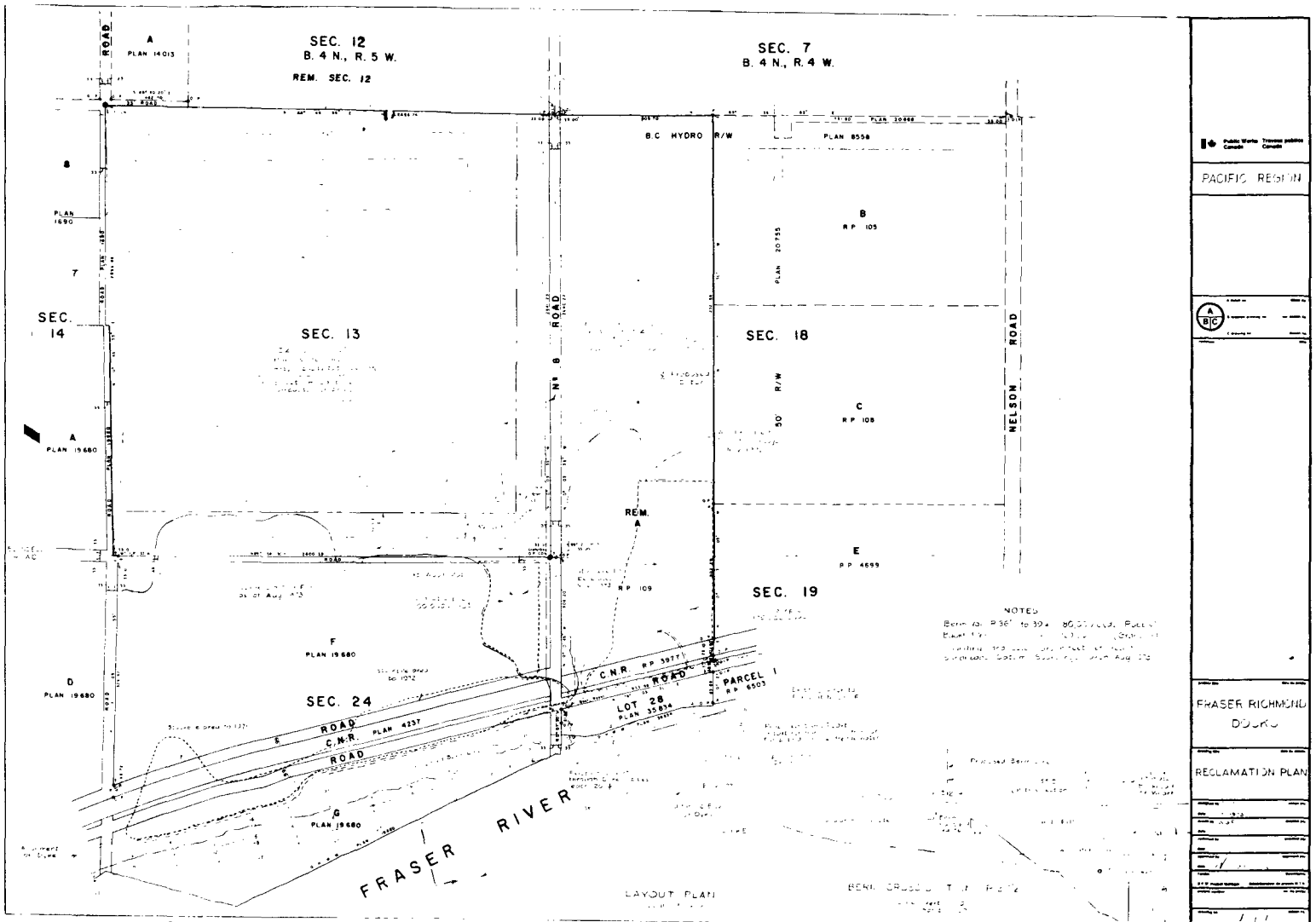

FIGURE 3 SITE DEVELOPMENT PLAN (Proposed by DPW, 1973)

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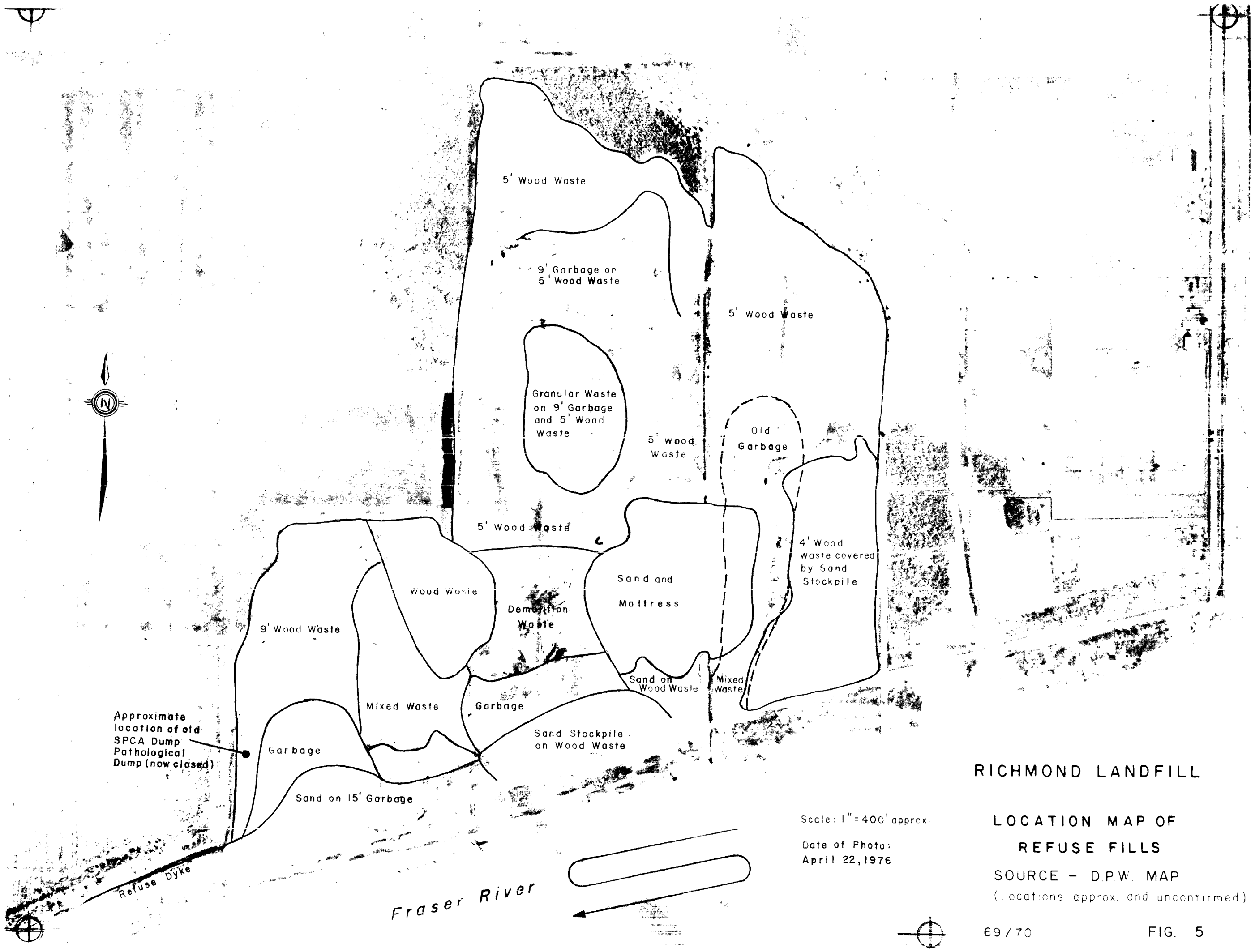
SATELLITE PHOTO OF THE FRASER RIVER ESTUARY AND CONTIGUOUS WATERS, JULY 30, 1972.

LITHOGRAPHED IN CANADA BY SMITH GRANT MANN



Scale: 1" = 400' approx.

Date of Photo: April 22, 1976

RICHMOND LANDFILL

LOCATION MAP OF REFUSE FILLS

SOURCE – D.P.W. MAP

(Locations approx. and unconfirmed)

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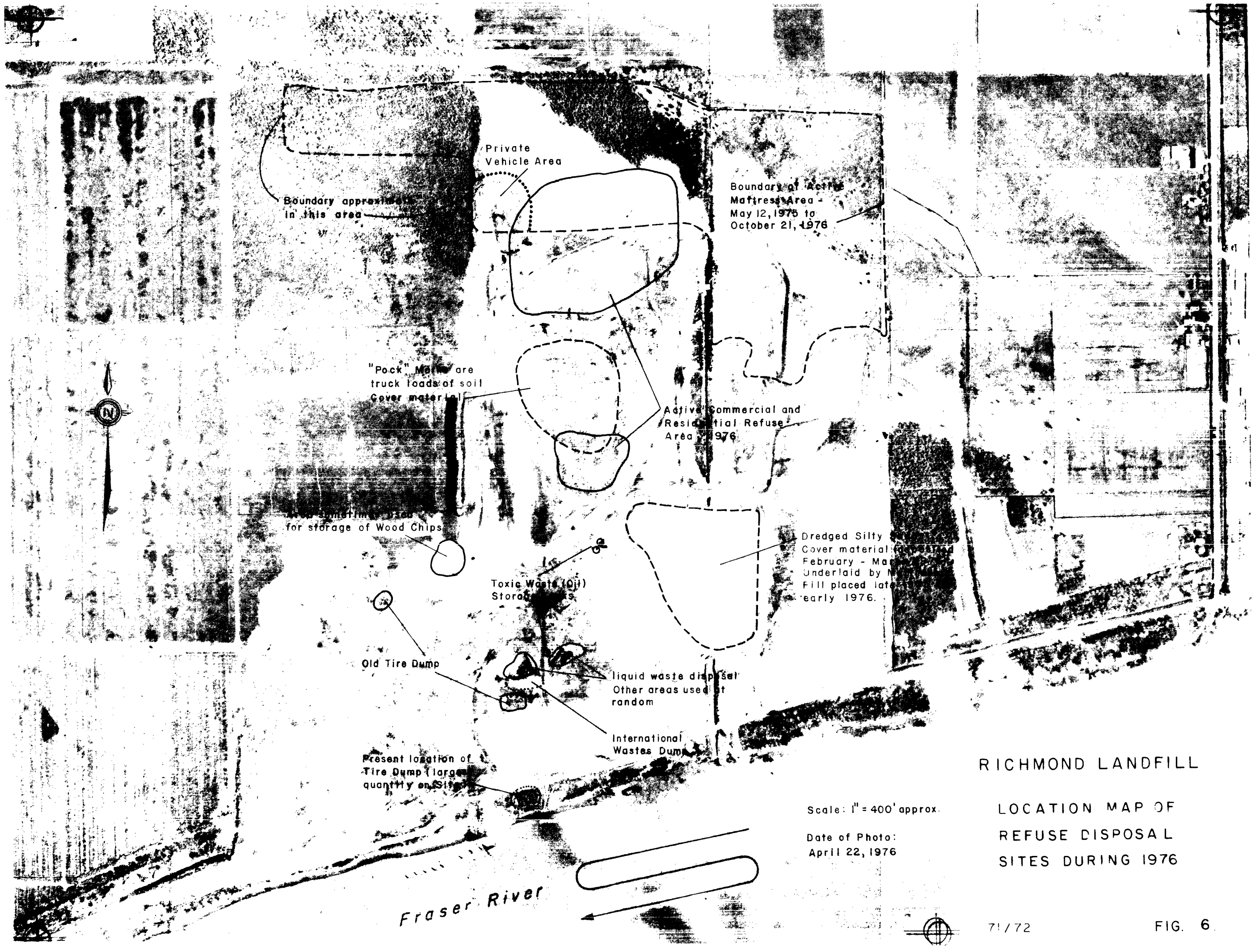
FIG. 5



RICHMOND LANDFILL

Scale: 1" = 400' approx.

Date of Photo:
April 22, 1976

LOCATION MAP OF
REFUSE DISPOSAL
SITES DURING 1976

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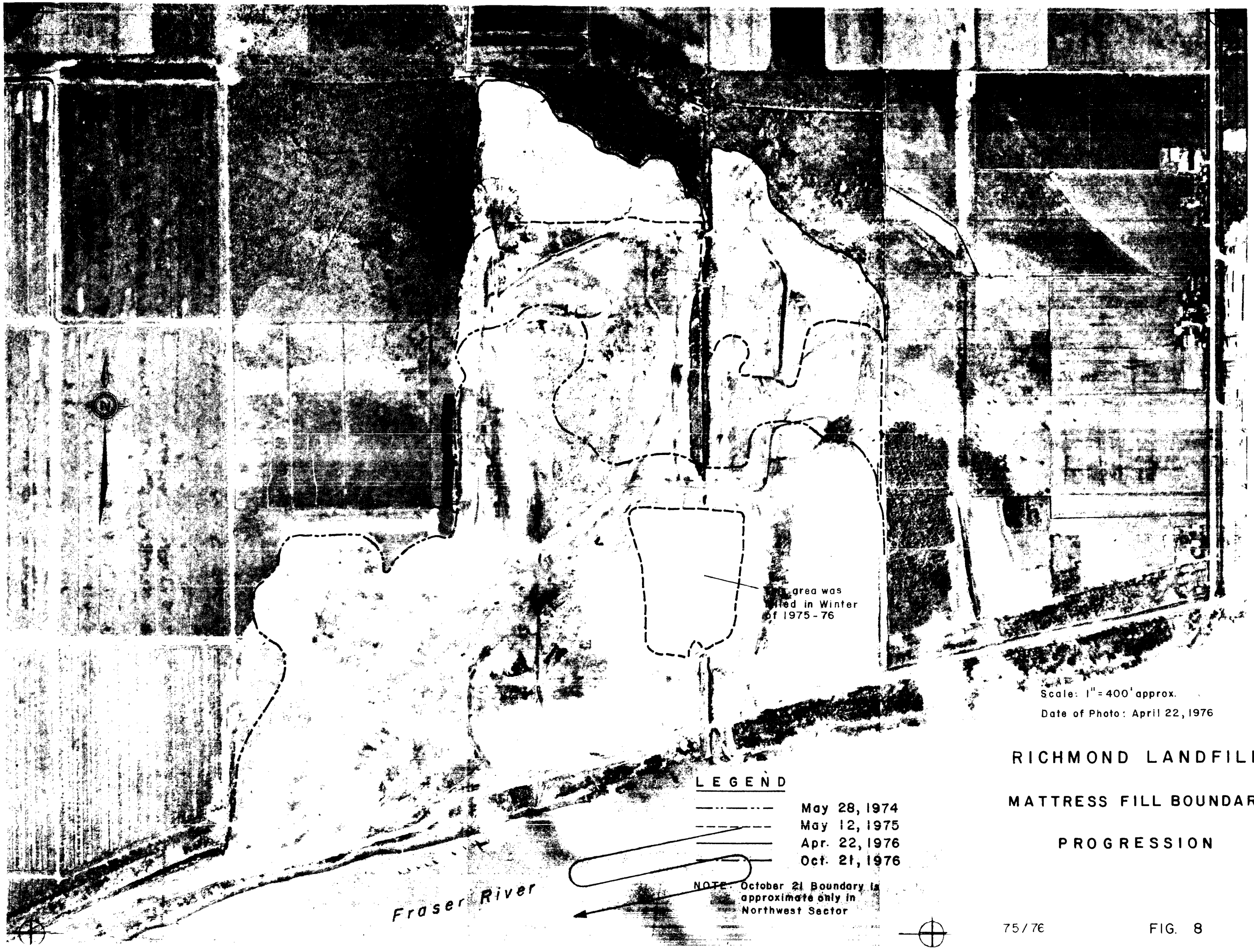
FIG. 6

FIGURE 7: TYPICAL MATTRESS FILL AREA



RICHMOND LANDFILL

MATTRESS FILL BOUNDARY

PROGRESSION

75/76

FIG. 8

FIGURE 9: COMPACTOR TRANSPORTED COMMERCIAL AND RESIDENTIAL WASTES AREA

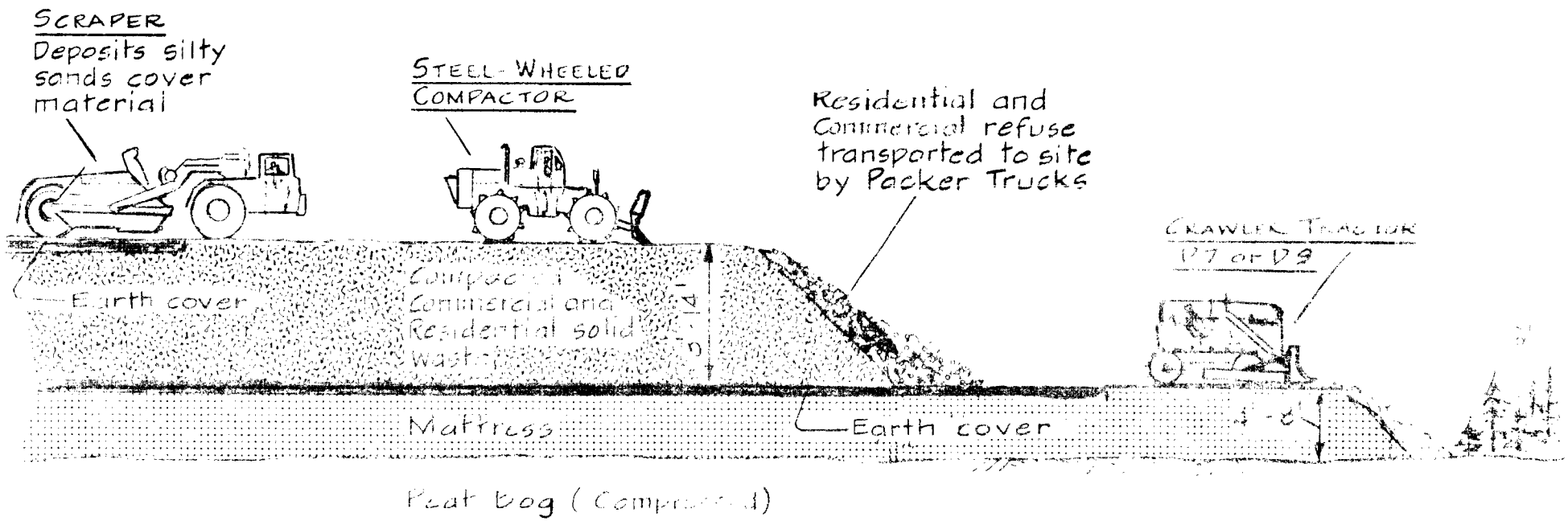


FIG. 10 SCHEMATIC OF TYPICAL FILL PROCEDURE AT RICHMOND LANDFILL

FIGURE 11: TANK TRUCK DISCHARGE

FIGURE 12: DREDGE SPOIL DEPOSITION

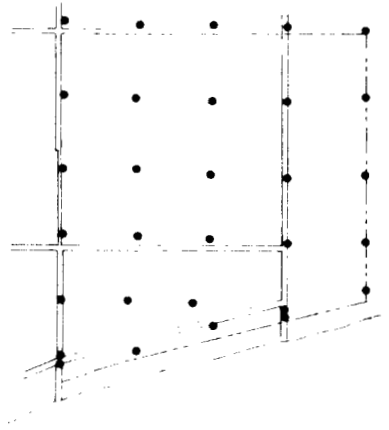


FIG. D.2 310 Acre Site

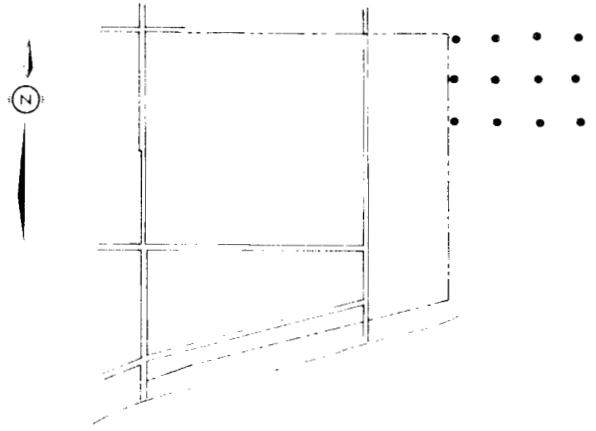


FIG. D.3 727 Nelson Rd.

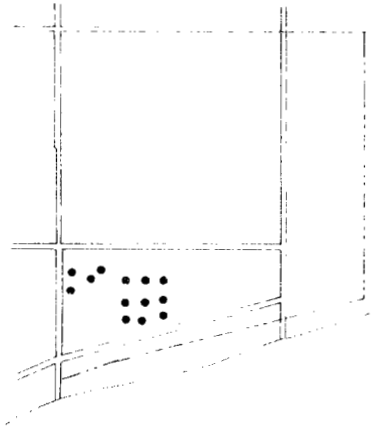


FIG. D.4 Southwest Corner

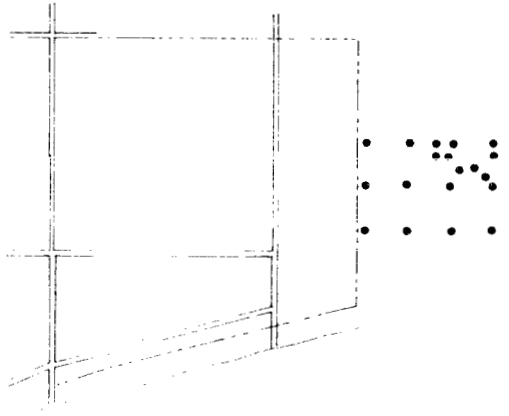


FIG. D.5 745 Nelson Rd.

FIGURE 13 LOCATION MAPS SHOWING AREAS OF PREVIOUS GEOLOGIC INVESTIGATIONS

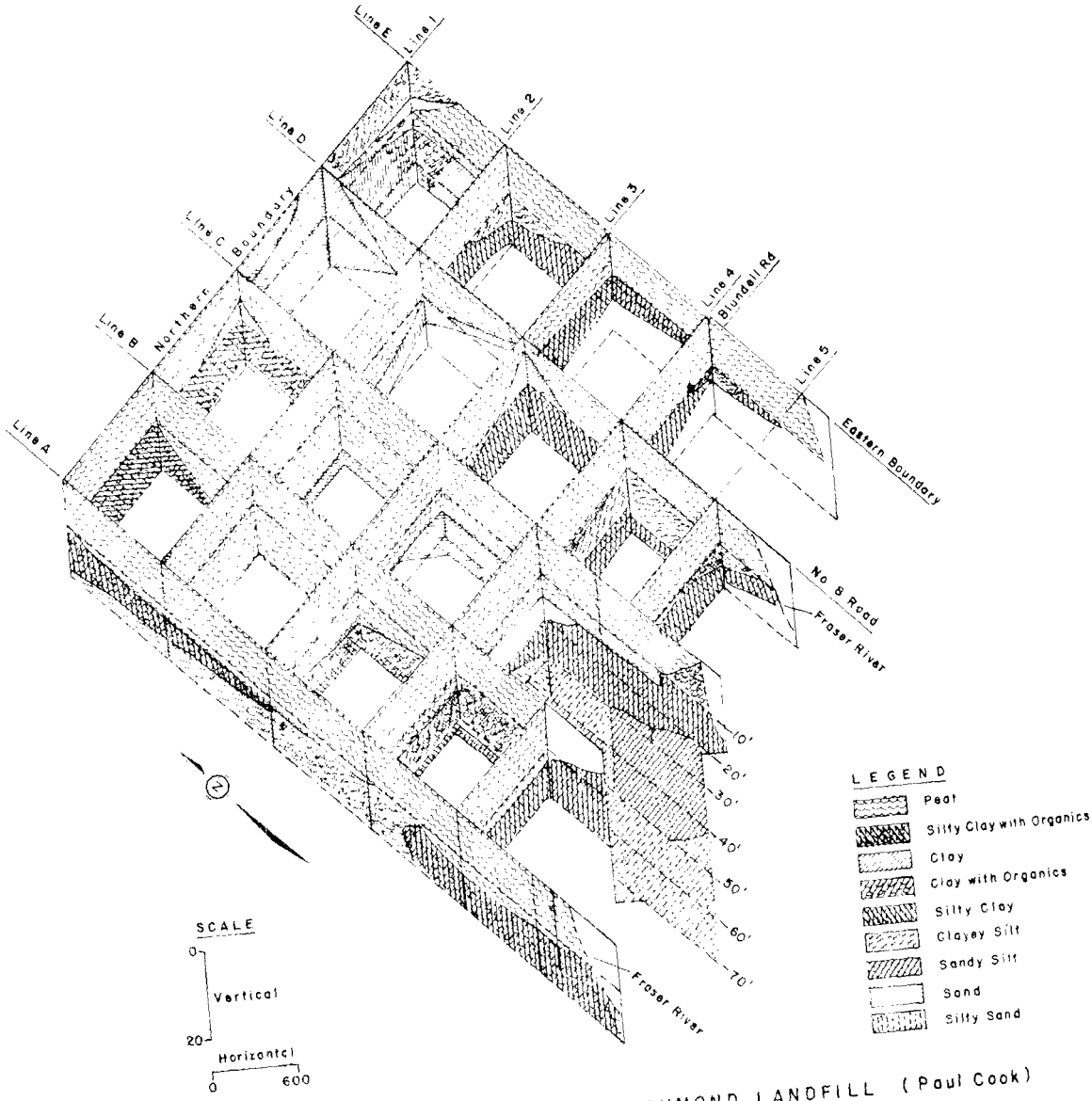


FIGURE 14 GEOLOGICAL FENCE DIAGRAM - RICHMOND LANDFILL (Paul Cook)

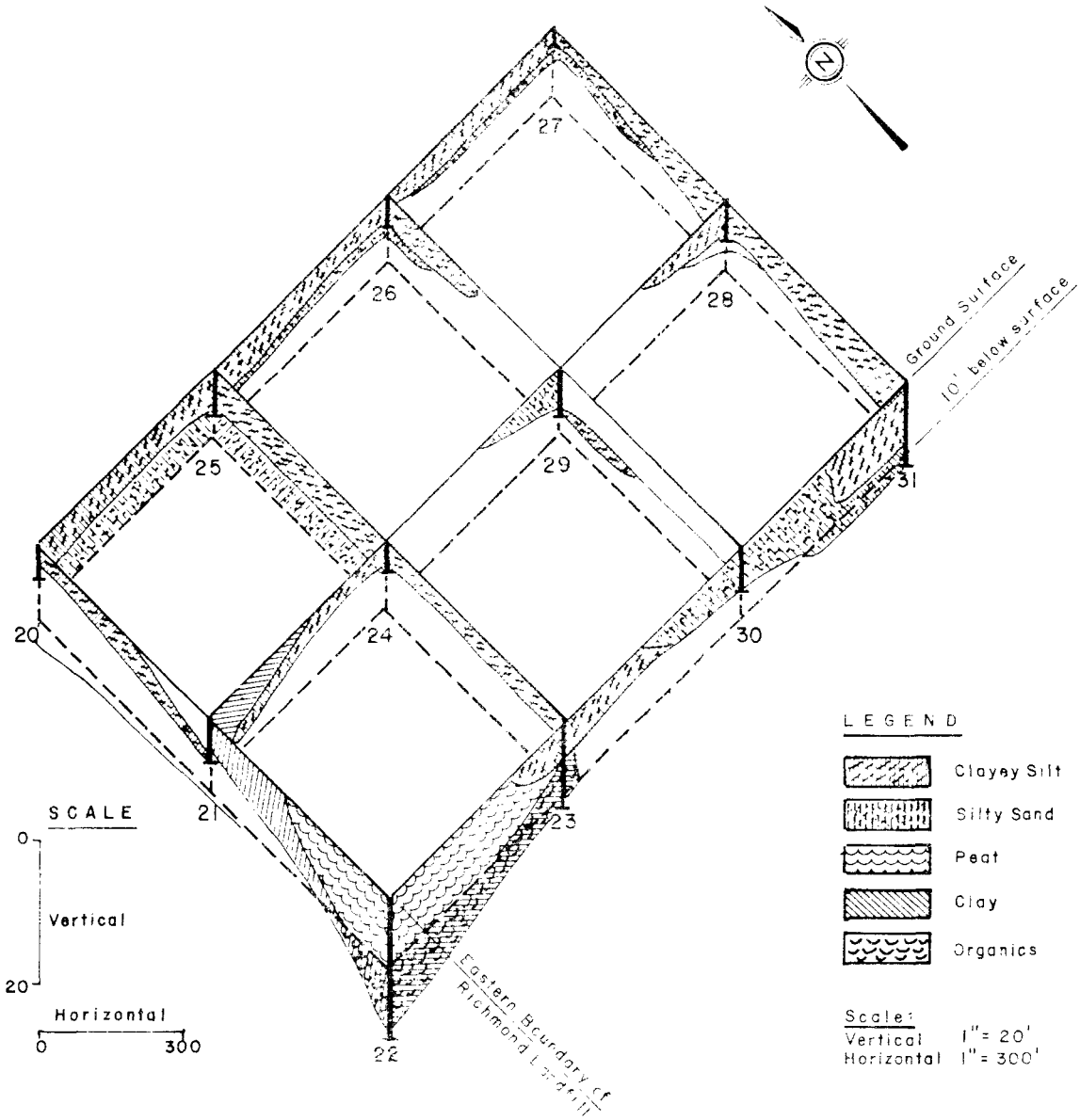


FIGURE 15 GEOLOGICAL FENCE DIAGRAM FOR 727 NELSON EAST OF RICHMOND LANDFILL SITE
(Cook Pickering and Doyle)

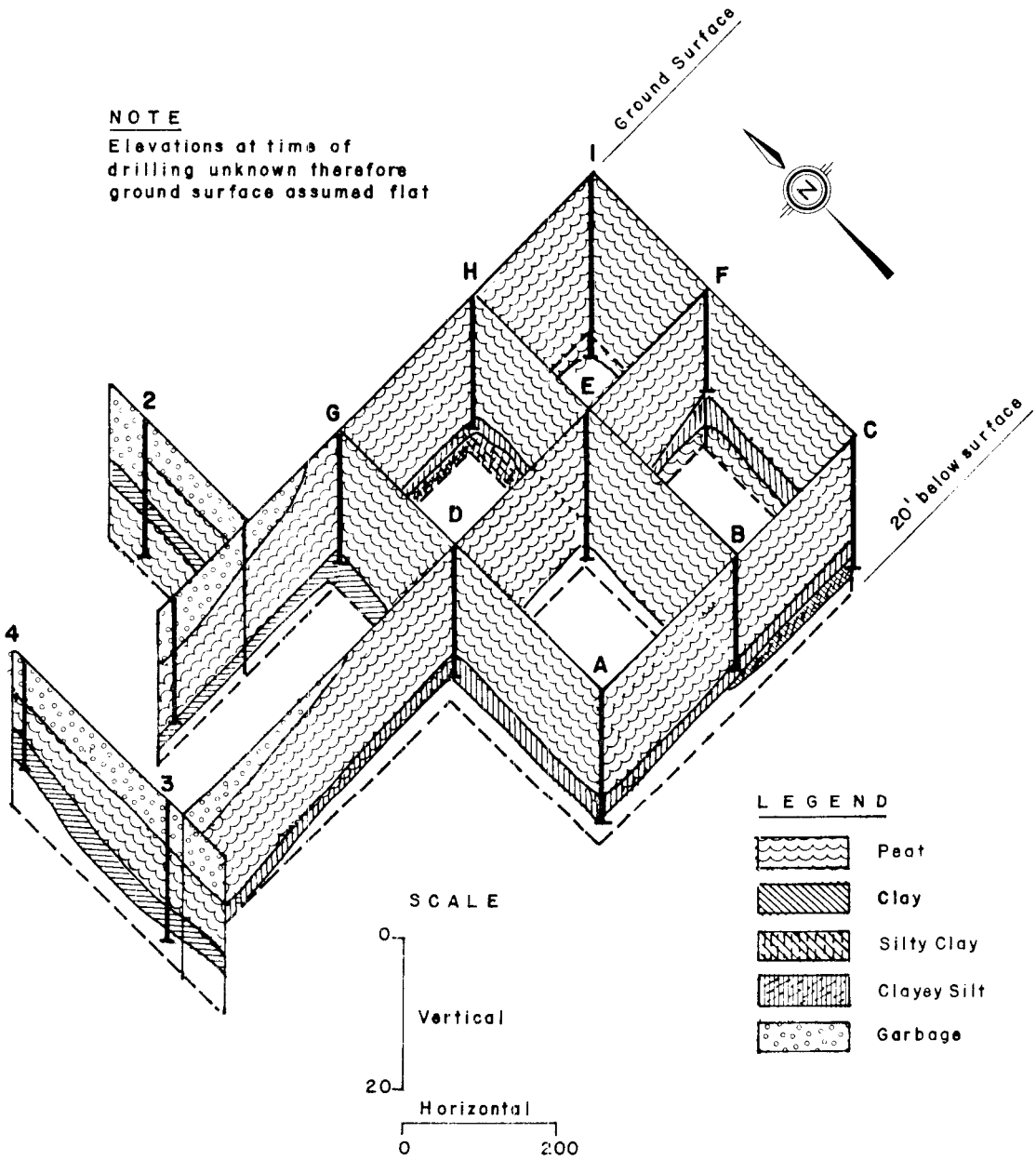


FIGURE 16 GEOLOGICAL FENCE DIAGRAM - (Southwest corner)
RICHMOND LANDFILL SITE (Paul Cook)

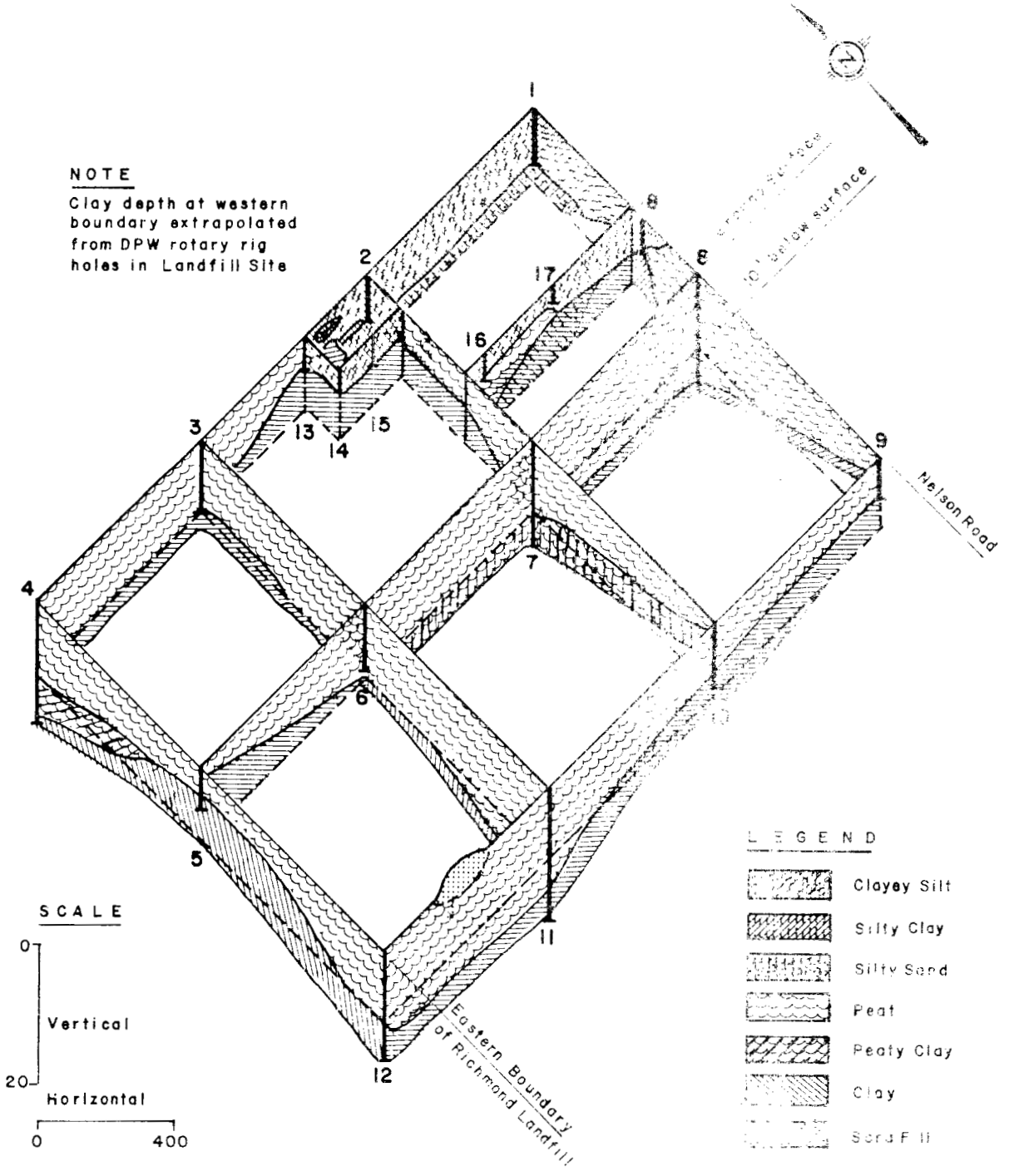


FIGURE 17 GEOLOGICAL FENCE DIAGRAM FOR 745 NELSON
EAST BOUNDARY OF RICHMOND LANDFILL SITE
(Cook Pickering and Doyle)

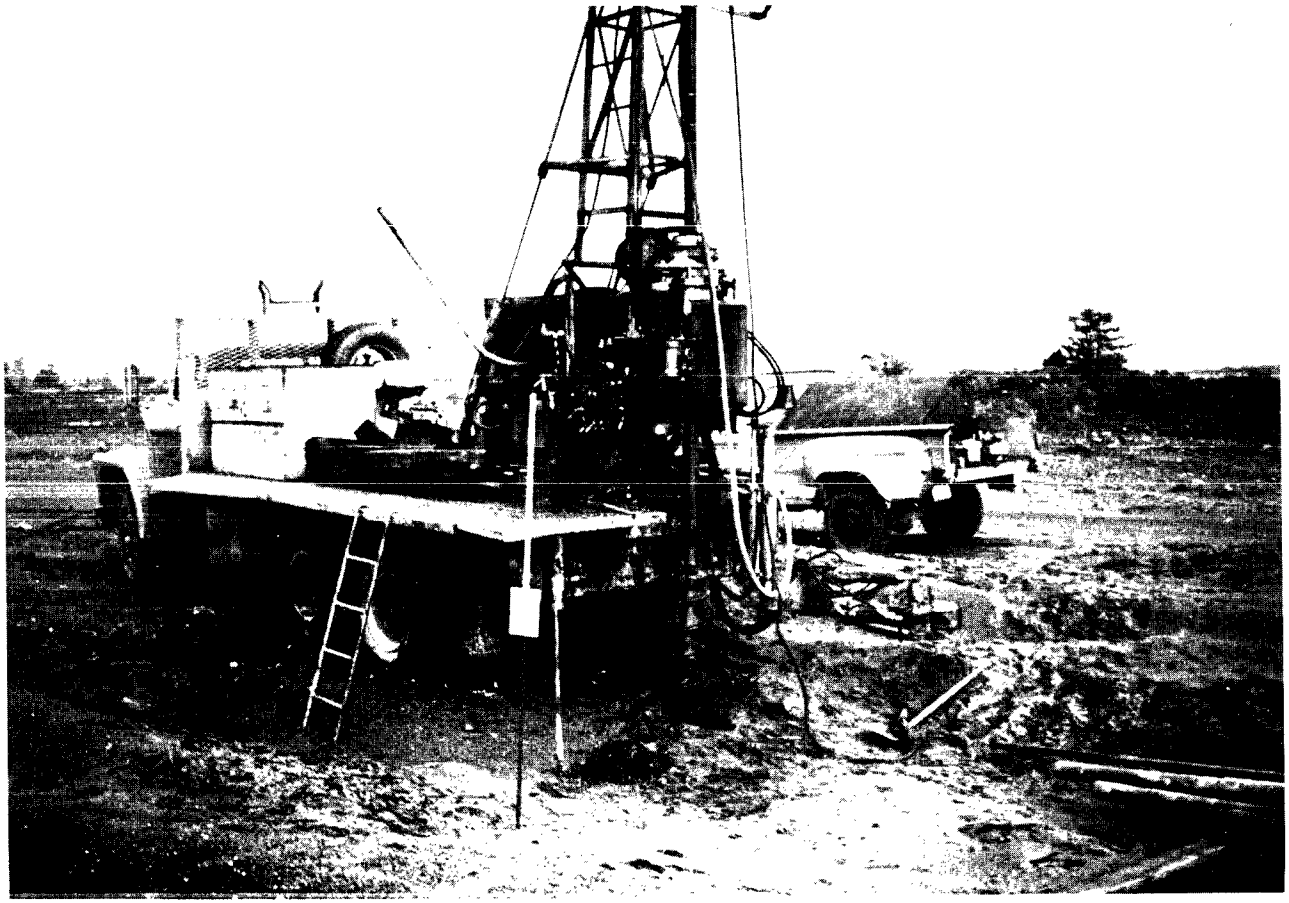
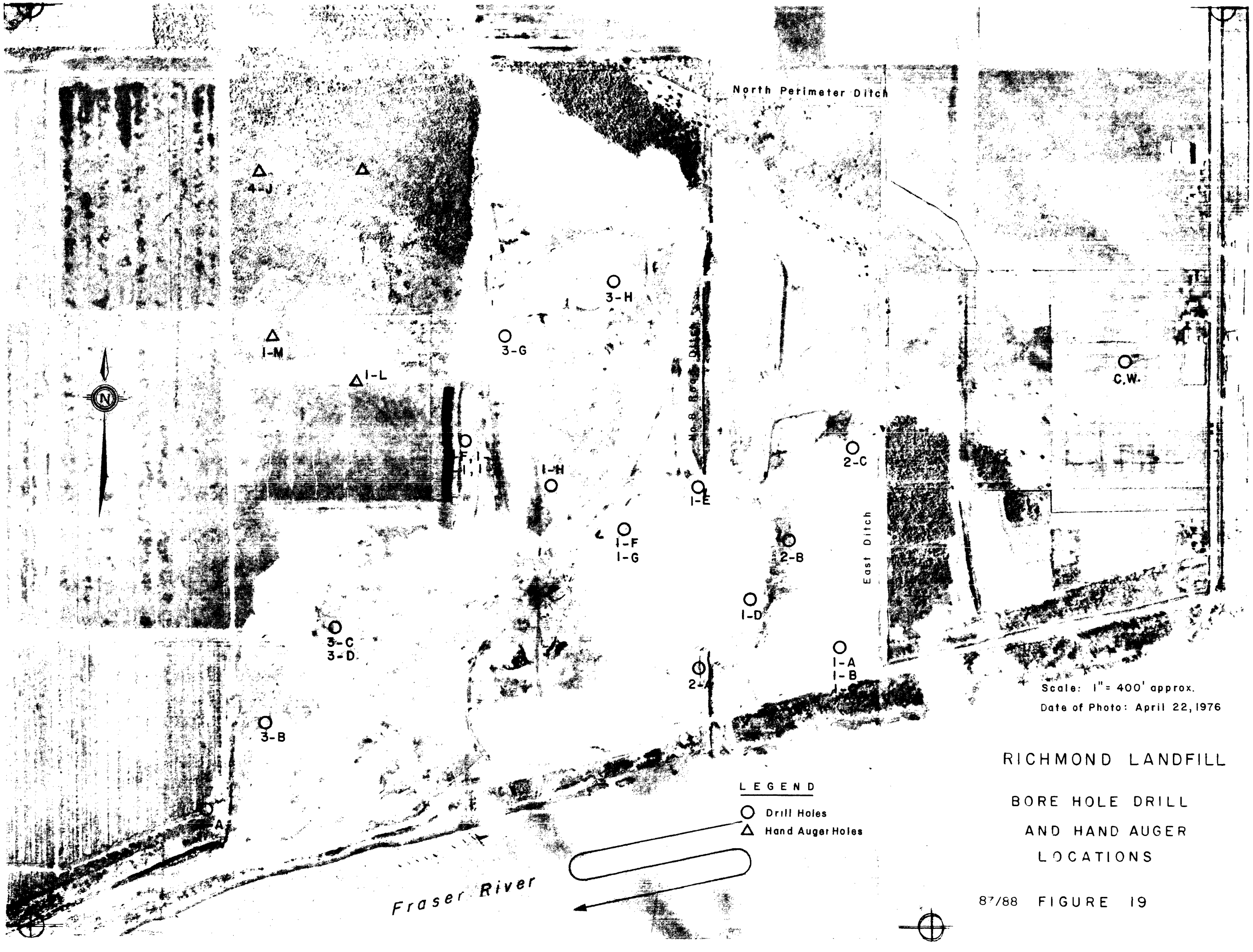


FIGURE 18: BOYLES ROTARY DRILL RIG



RICHMOND LANDFILL

BORE HOLE DRILL AND HAND AUGER LOCATIONS

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RICHMOND LANDFILL

PIEZOMETER LOCATIONS

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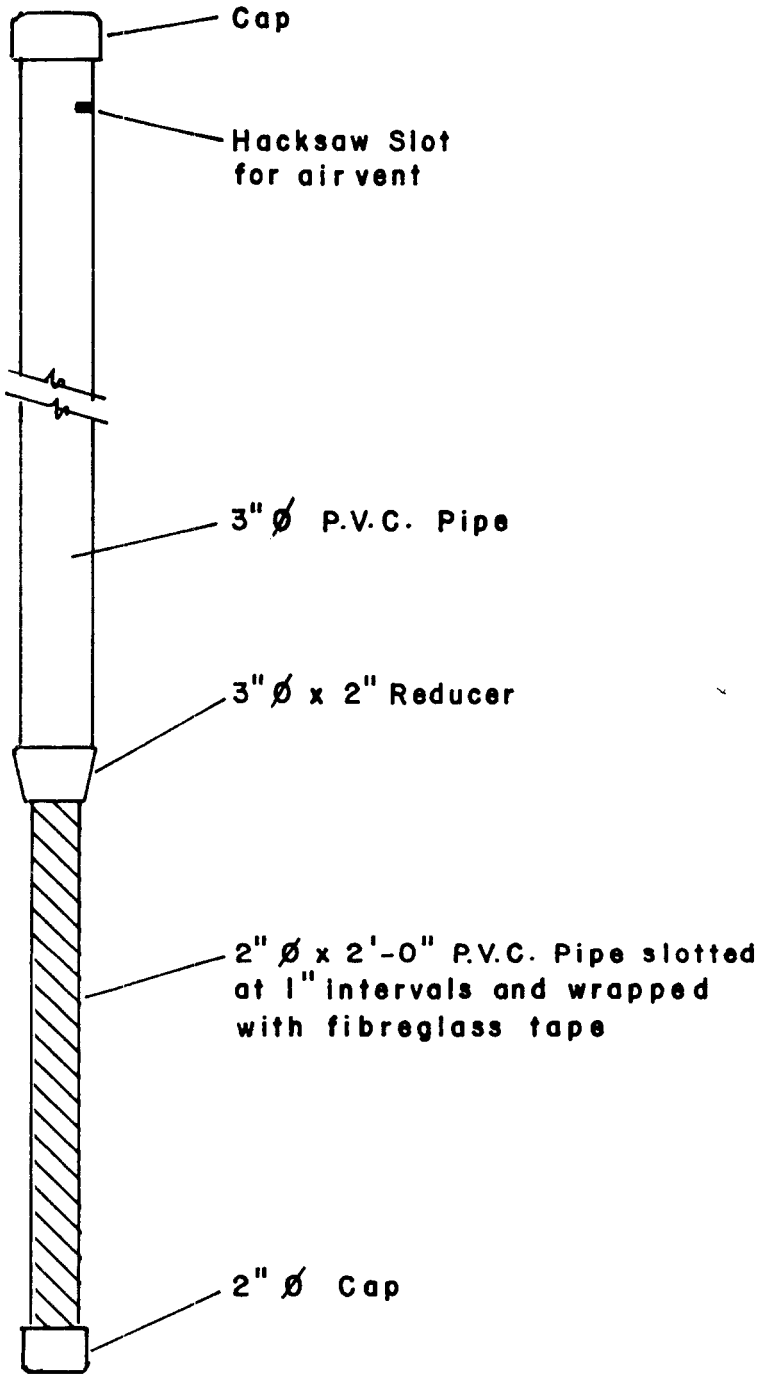
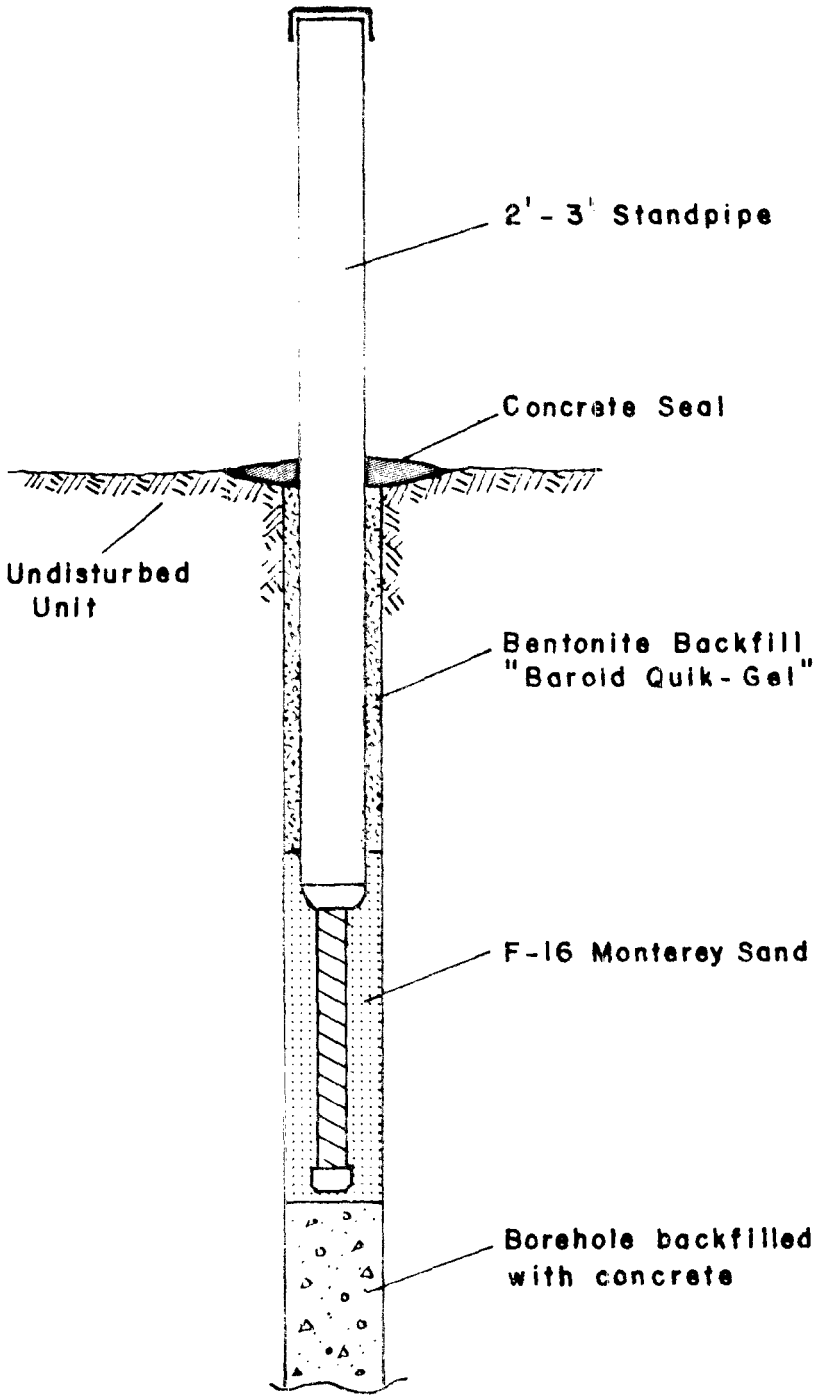
FIG. 20



PIEZOMETER CONSTRUCTION
FIGURE 21



PIEZOMETER INSTALLATION

FIGURE 22

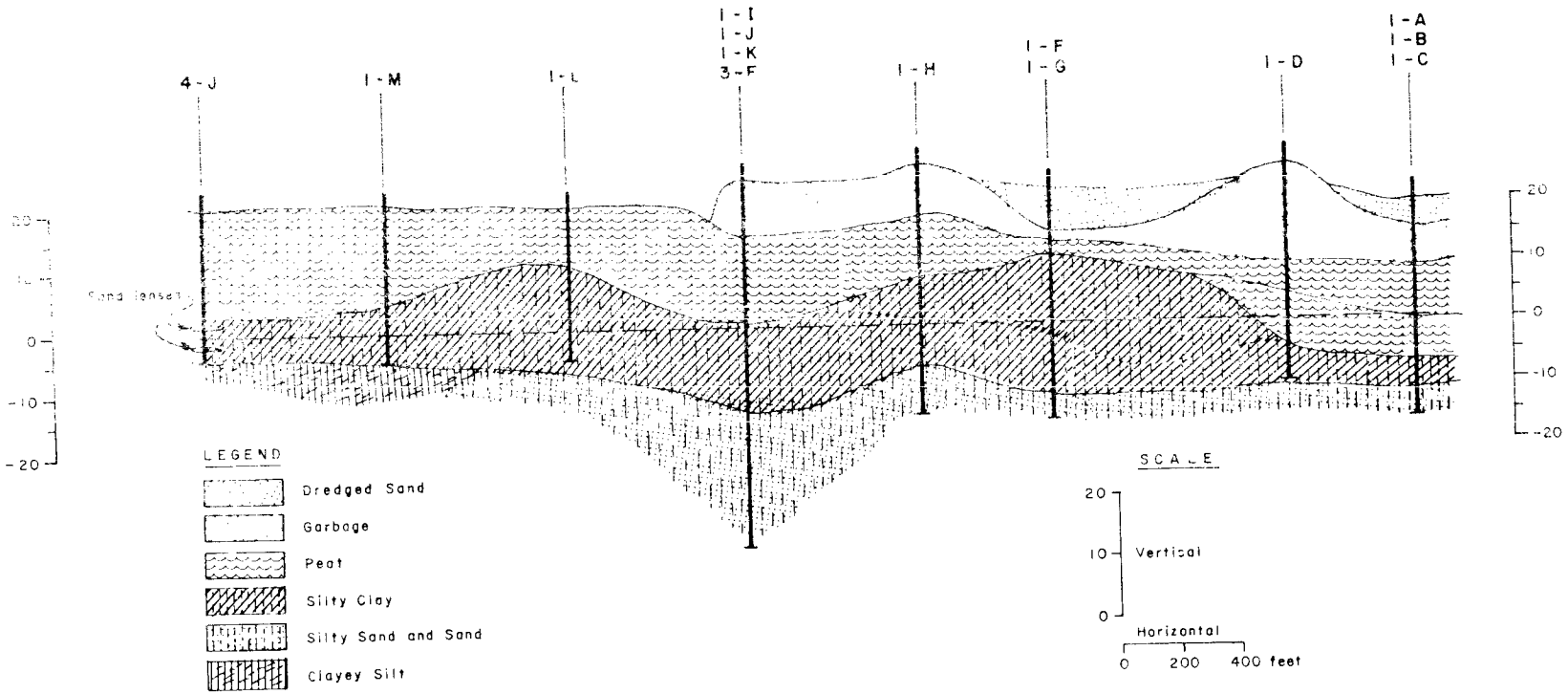


FIGURE 23 RICHMOND LANDFILL - GEOLOGICAL PROFILE - LINE 1

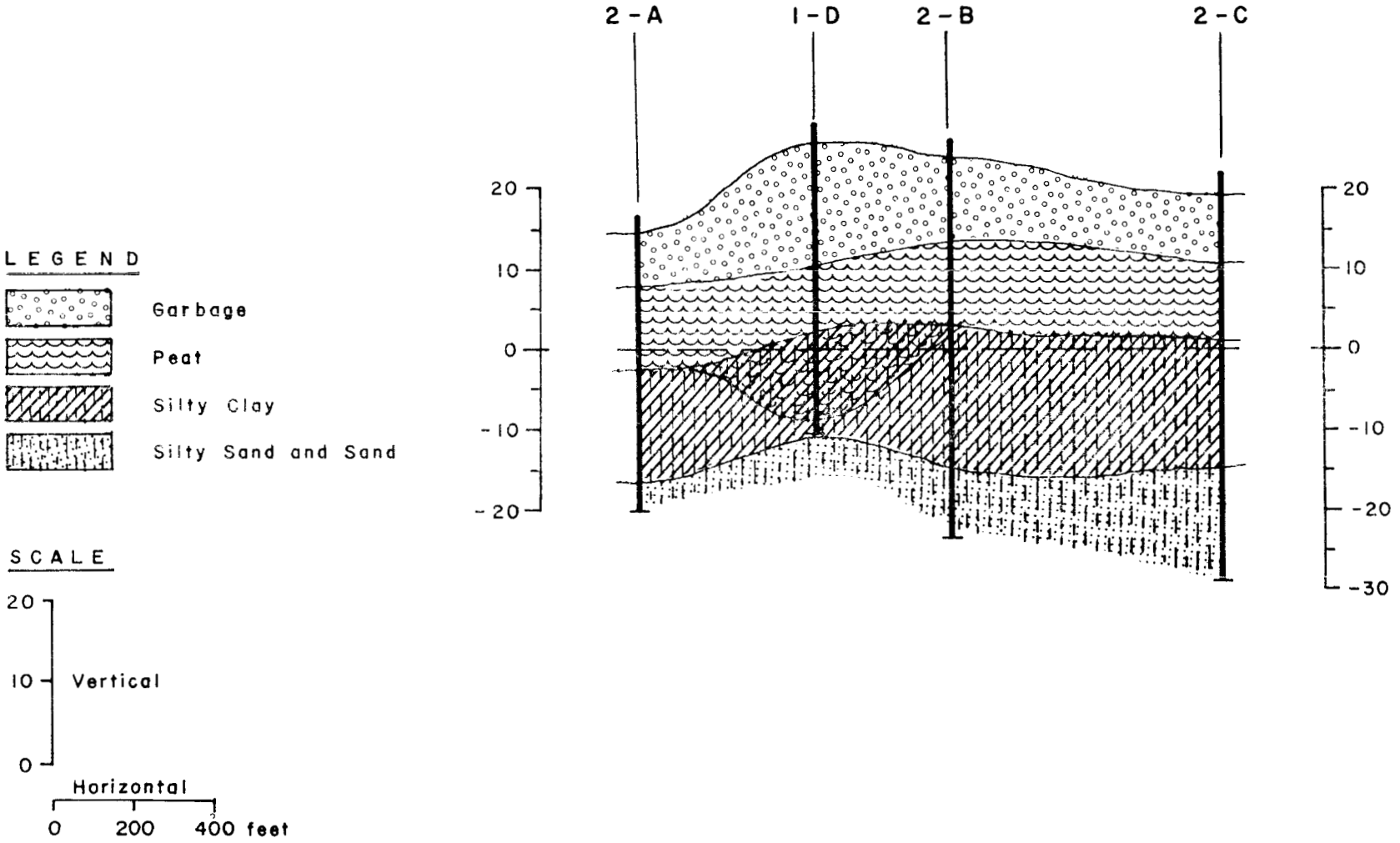


FIGURE 24 RICHMOND LANDFILL – GEOLOGICAL PROFILE – LINE 2

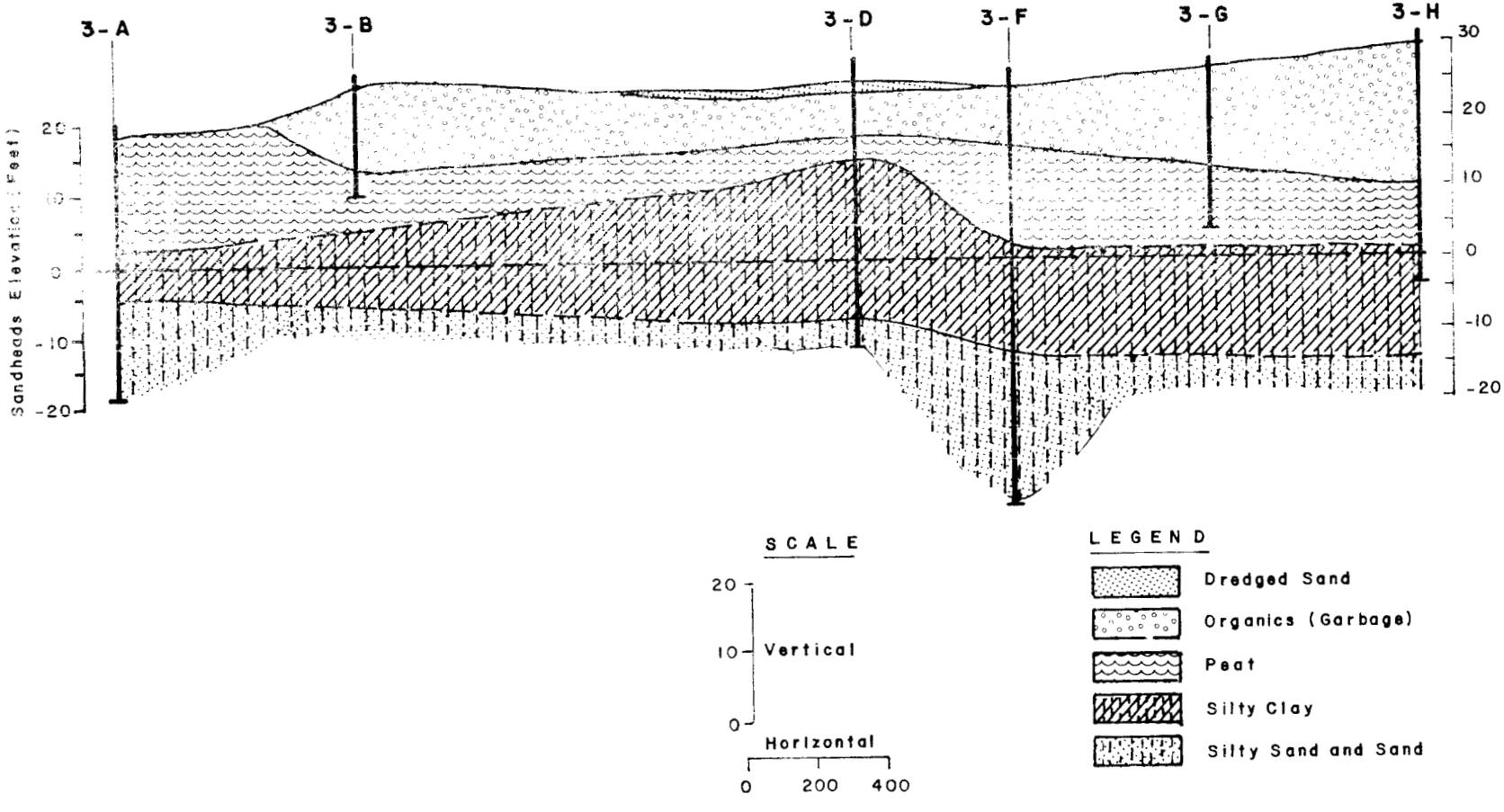


FIGURE 25 RICHMOND LANDFILL - GEOLOGICAL PROFILE - LINE 3

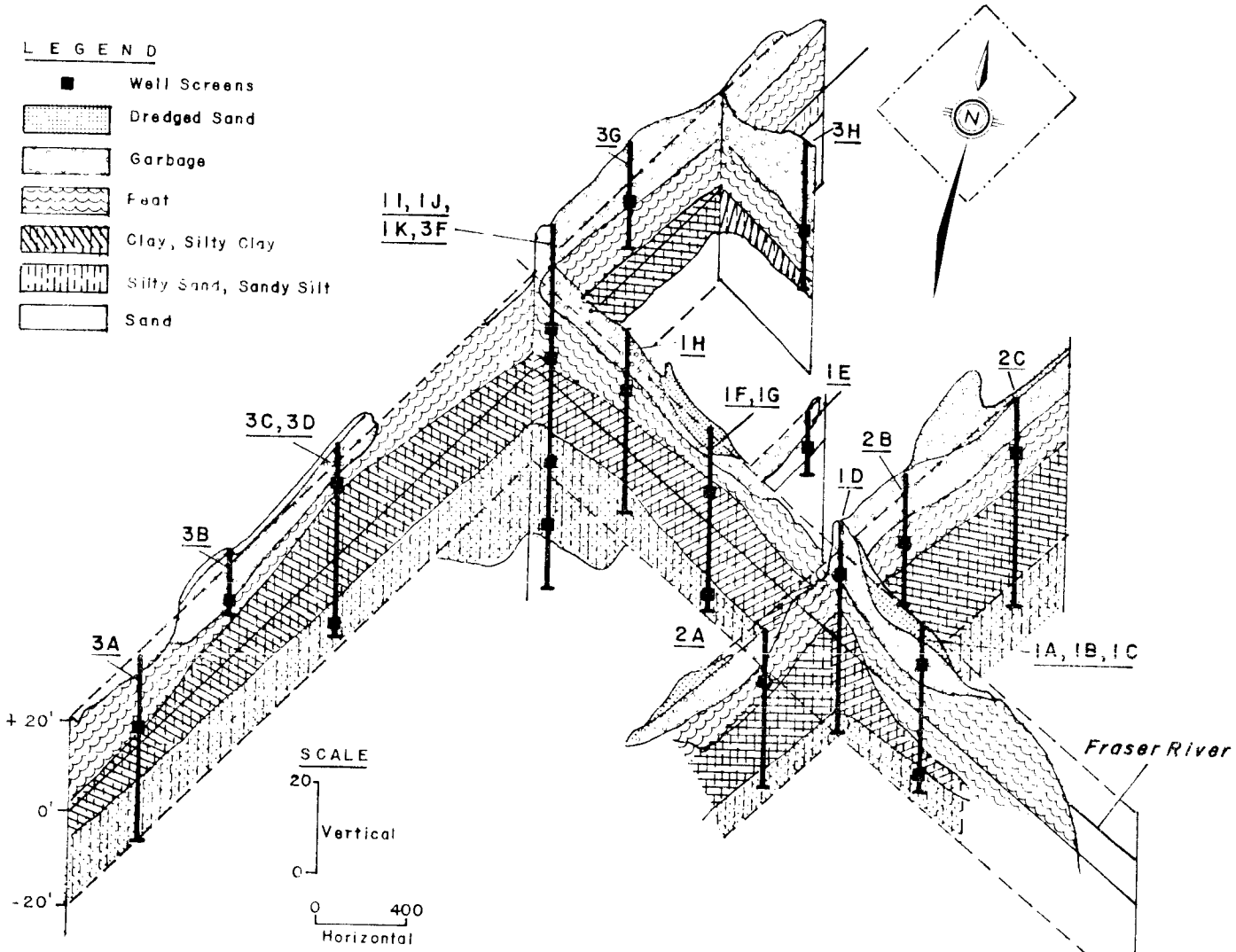


FIGURE 26 GEOLOGICAL FENCE - RICHMOND LANDFILL

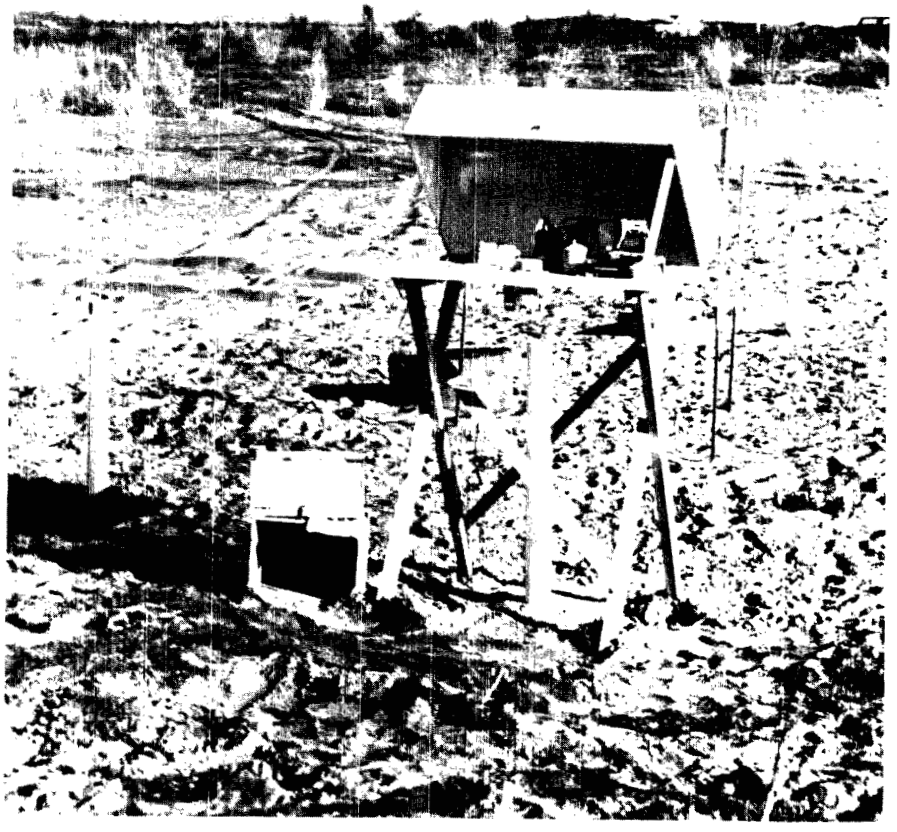
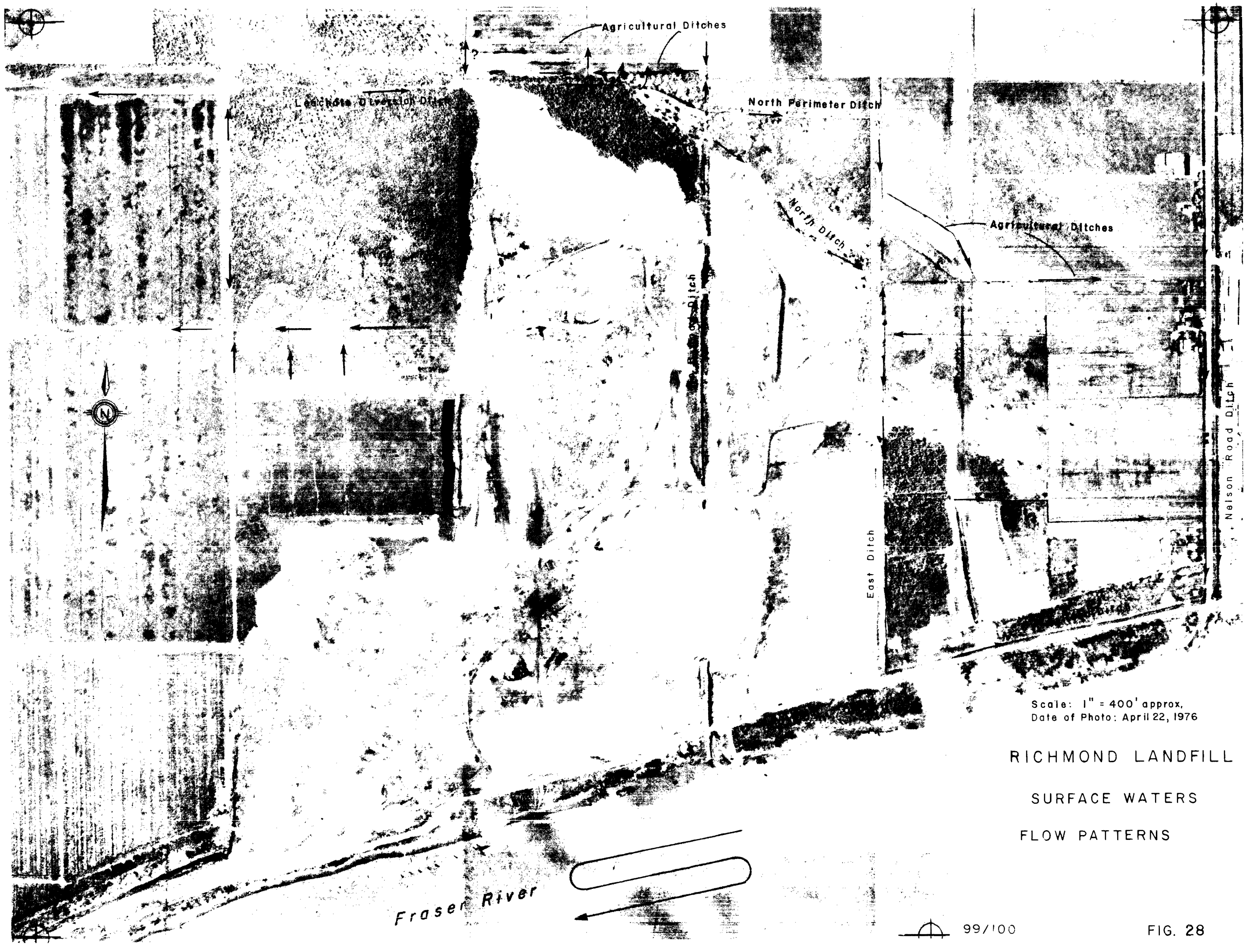


FIGURE 27: STEVENS RECORDER



RICHMOND LANDFILL

SURFACE WATERS

FLOW PATTERNS

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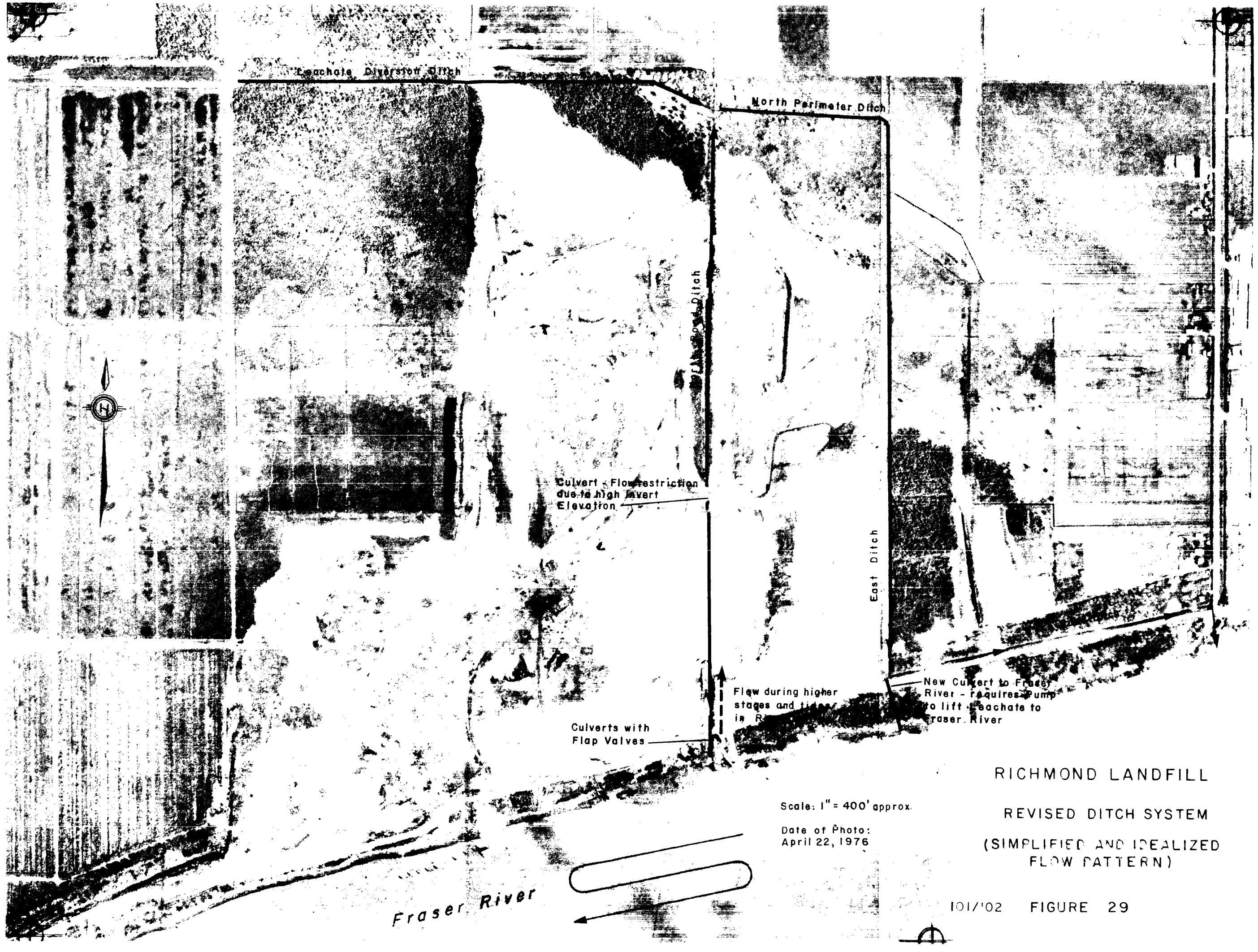
FIG. 28



RICHMOND LANDFILL

REVISED DITCH SYSTEM

(SIMPLIFIED AND IDEALIZED FLOW PATTERN)

101/'02 FIGURE 29

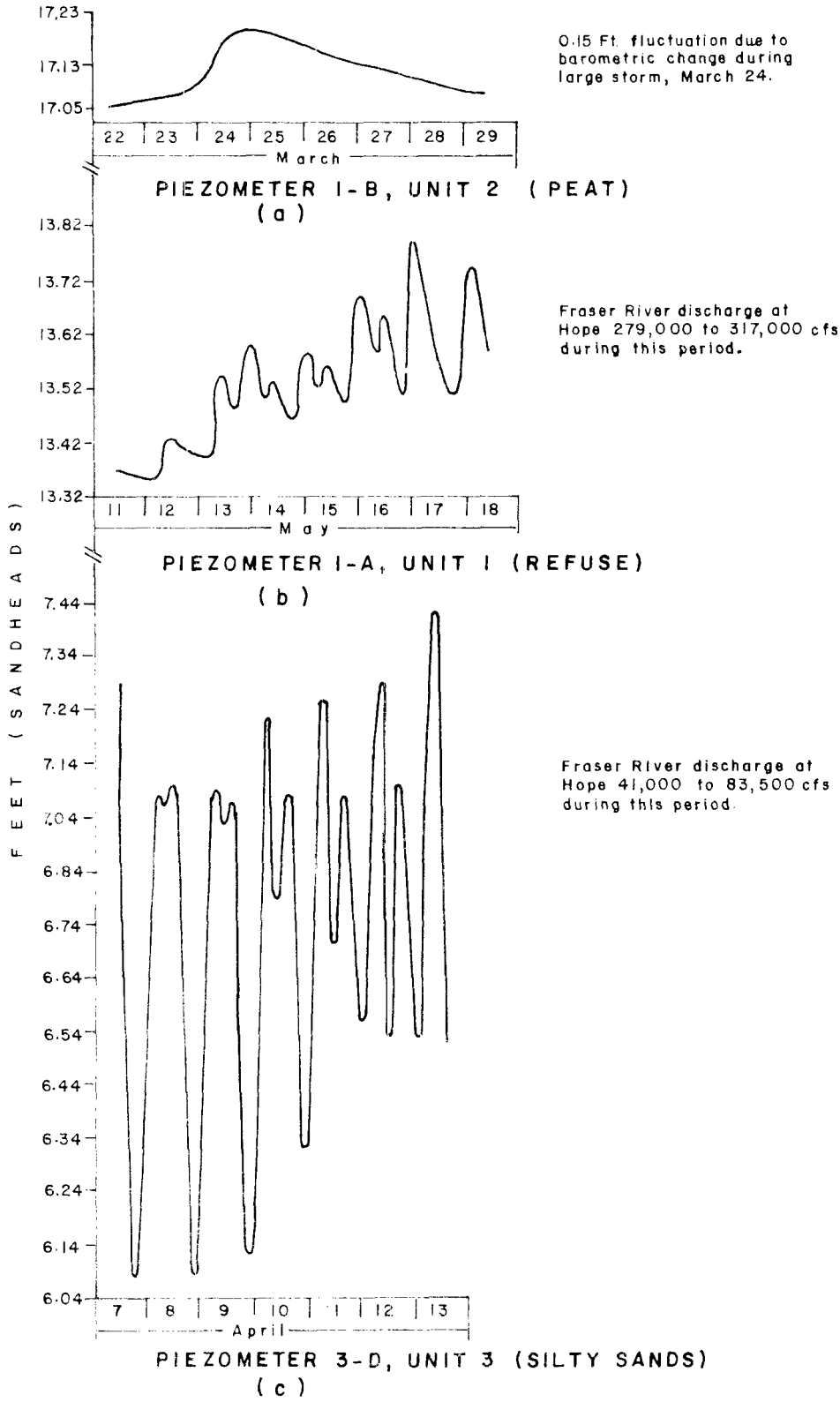
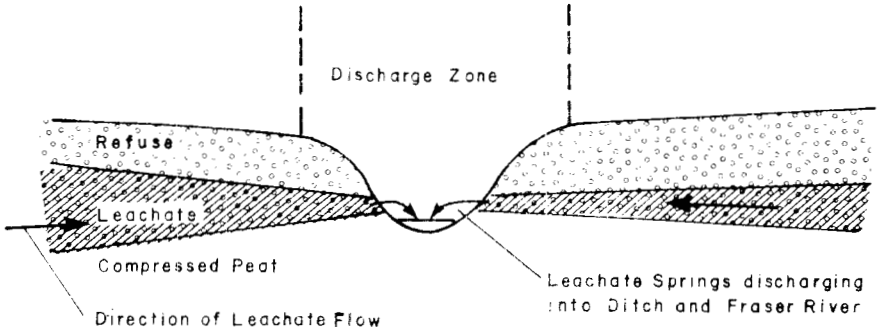
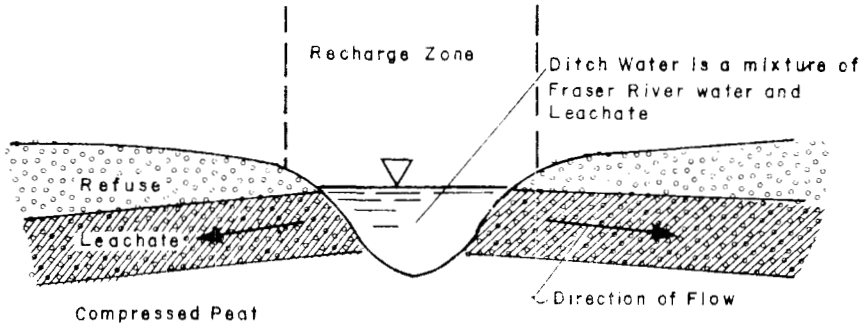


FIGURE 30 CONTINUOUS HYDROGRAPHS SHOWING VARIATIONS OF PIEZOMETRIC LEVELS



LOW TIDE

Low Tide Flow System at Fraser River Dyke and No. 8 Road Ditch ; Leachate discharging into ditch at 10.5 to 11.0 feet elevation (contact between Compressed Peat and Refuse along No. 8 Road ditch.



HIGH TIDE

High Tide Flow System at Fraser River Dyke and No. 8 Road Ditch becomes a Recharge Zone and as a result Leachate in Refuse near the ditch becomes diluted with Fraser River waters.

FIG. 31 RECHARGE OF REFUSE BY FRASER RIVER DURING HIGH TIDES (After Hugh Liebscher, Dec. 1976)

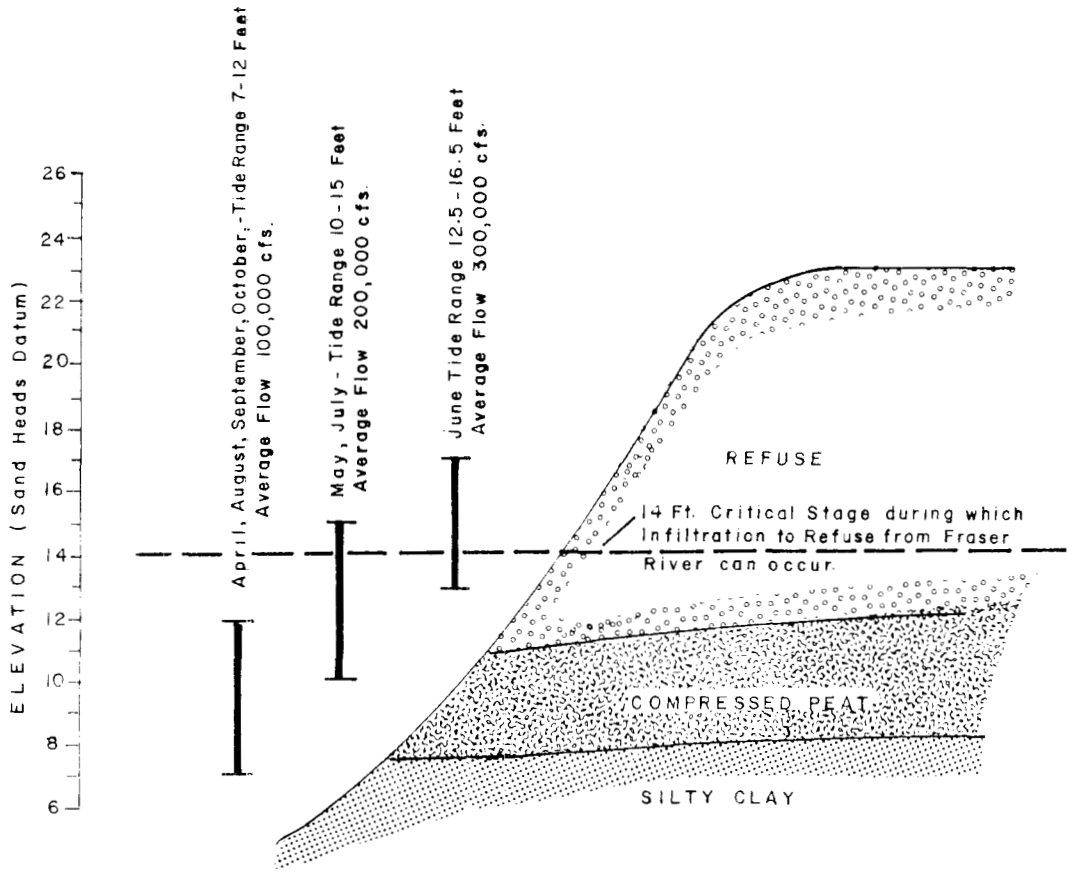


FIG. 32 EFFECTS OF FRASER RIVER TIDAL RANGE ON RECHARGE OF REFUSE. (After Hugh Liebscher, December 1976)

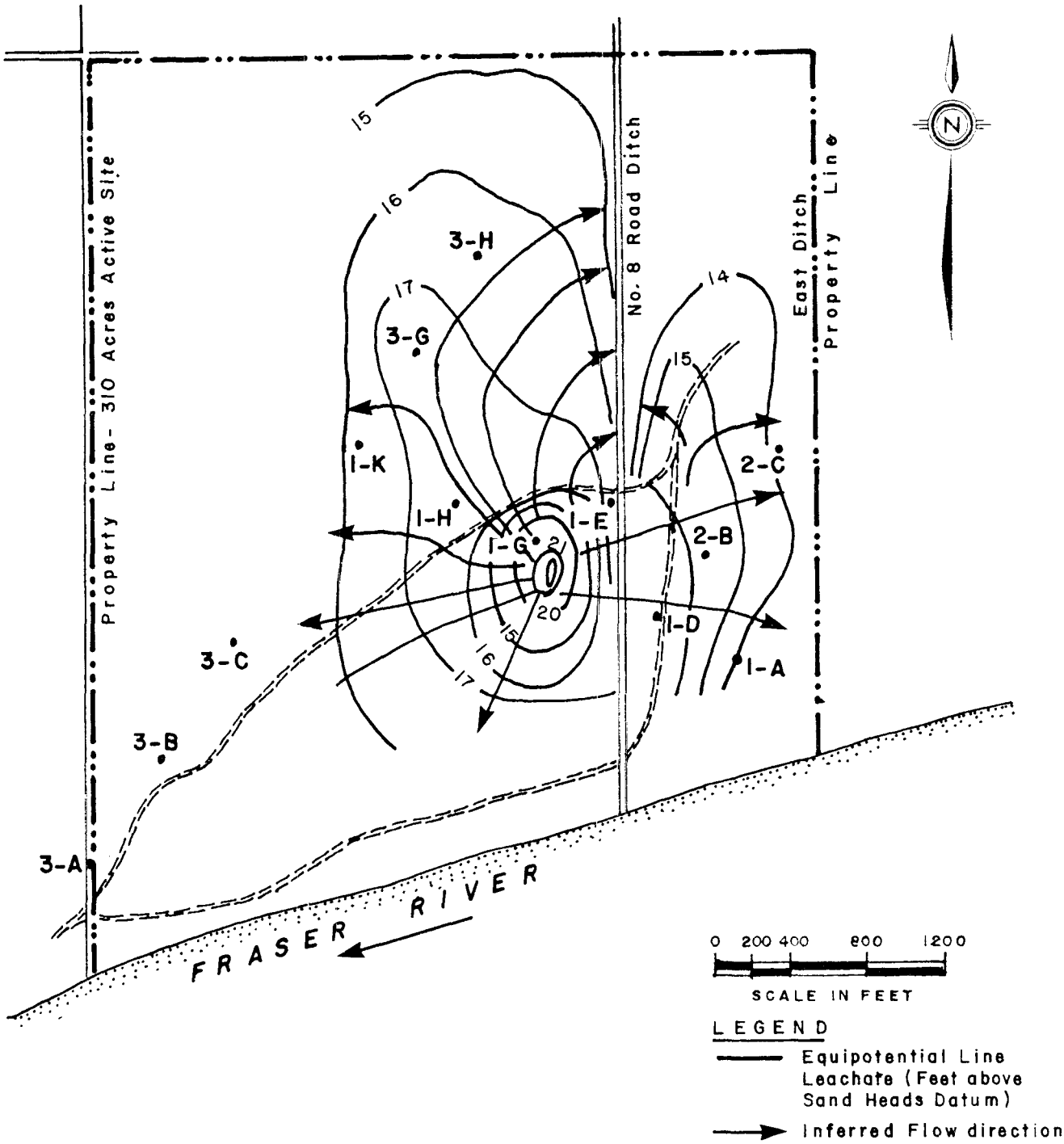


FIGURE 33 PIEZOMETRIC SURFACES AND LEACHATE FLOW PATTERNS - March 1976

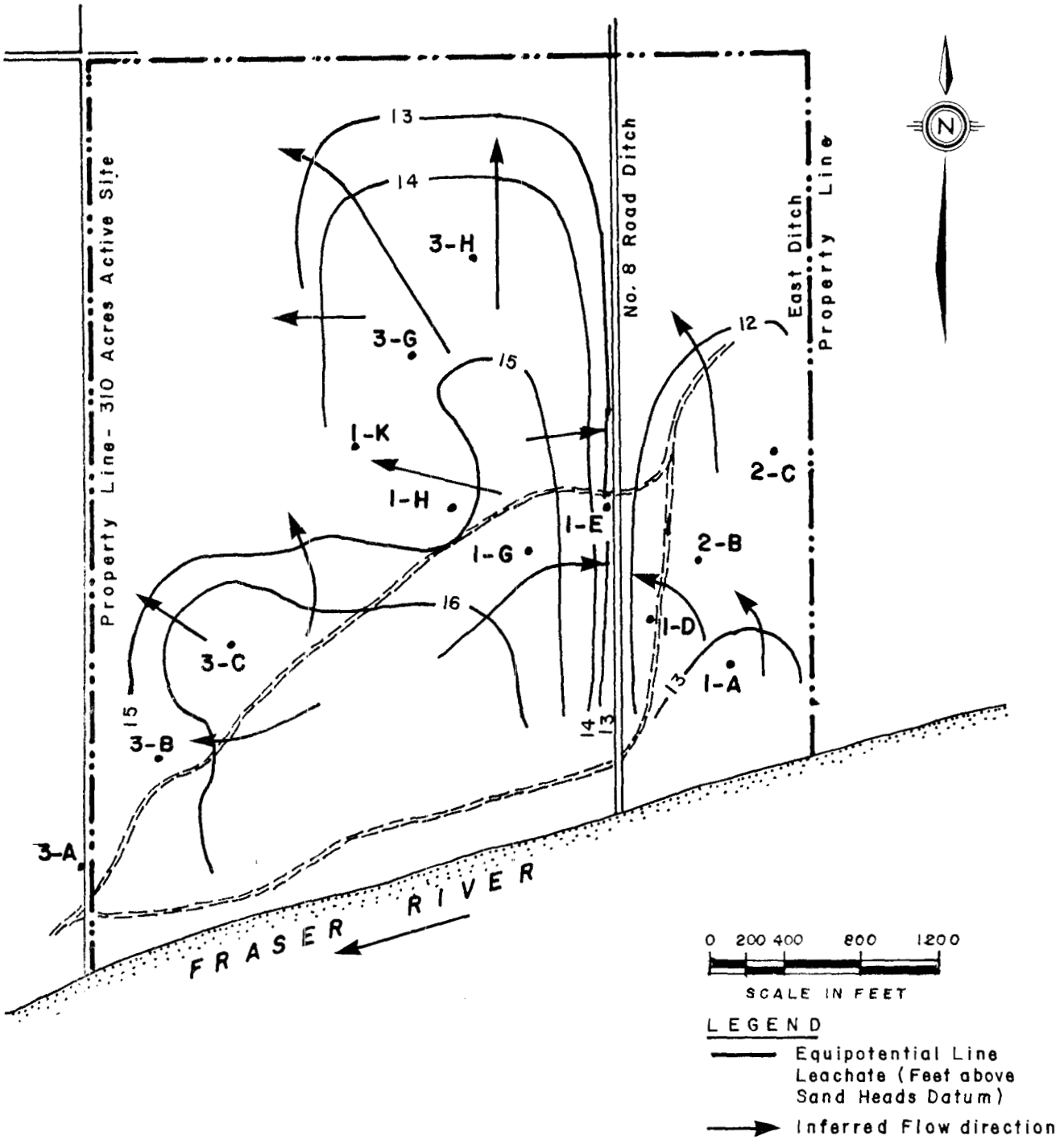


FIGURE 34 PIEZOMETRIC SURFACES AND LEACHATE FLOW PATTERNS - September 1976

RICHMOND LANDFILL

SAMPLING STATIONS
WITH GENERALIZED SURFACE
FLOW PATTERNS

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FIG. 35

Station	Test	May 31	June 1	June 3	June 4
A	S.P.	9.2×10^4	3.88×10^5	2.9×10^5	1.5×10^4 *
	C.C.	>16000	>16000	$>1.6 \times 10^5$	1.6×10^5
	F.C.	1300	1700	1700	800
	F.S.	>1600	>1600	>1600	>1600
B	S.P.	1.65×10^5	1.0×10^5	2.69×10^5	5×10^3 *
	C.C.	>16000	>16000	$>1.6 \times 10^5$	5.4×10^4
	F.C.	2400	2400	1.7×10^4	1.1×10^3
	F.S.	>1600	>1600	N.D.	>1600
C	S.P.	T.N.T.c.	6.45×10^3	T.N.T.c.	2.6×10^4 *
	C.C.	3200	>16000	1700	1.6×10^4
	F.C.	490	2400	130	1300
	F.S.	110	1600	240	>1600
D	S.P.	1.4×10^5	9.9×10^4	2.0×10^4 *	1.1×10^4 *
	C.C.	[illegible]	>16000	3.5×10^4	1.6×10^5
	F.C.	240	1700	1300	800
	F.S.	>1600	>1600	>1600	>1600
E	S.P.	[illegible]	320	295	405 *
	C.C.	350	[illegible]	110	[illegible]
	F.C.	[illegible]	2	2	20
	F.S.	[illegible]	[illegible]	[illegible]	13
F	S.P.	T.N.T.c.	1.3×10^4	1.34×10^4	3.85×10^4 *
	C.C.	[illegible]	[illegible]	[illegible]	>[illegible]
	F.C.	[illegible]	[illegible]	[illegible]	[illegible]
	F.S.	[illegible]	>1600	>1600	>1600
G	S.P.				[illegible]
	C.C.				[illegible]
	F.C.				[illegible]
	F.S.				>1600

LEGEND

S.P.	Standard Count (spc)/mℓ at 35°C
C.C.	Confirmed Coliform MPN/100 mℓ
F.C.	Fecal Coliform MPN/100 mℓ
F.S.	Fecal Streptococci confirmed MPN/100 mℓ
T.N.T.c.	Too numerous to count
N.D.	Not Done
*	Plates counted at 48 hours rather than 24 hours due to slow development of colonies
→	Flow Direction of Ditches

Scale 1" = 400' approx.

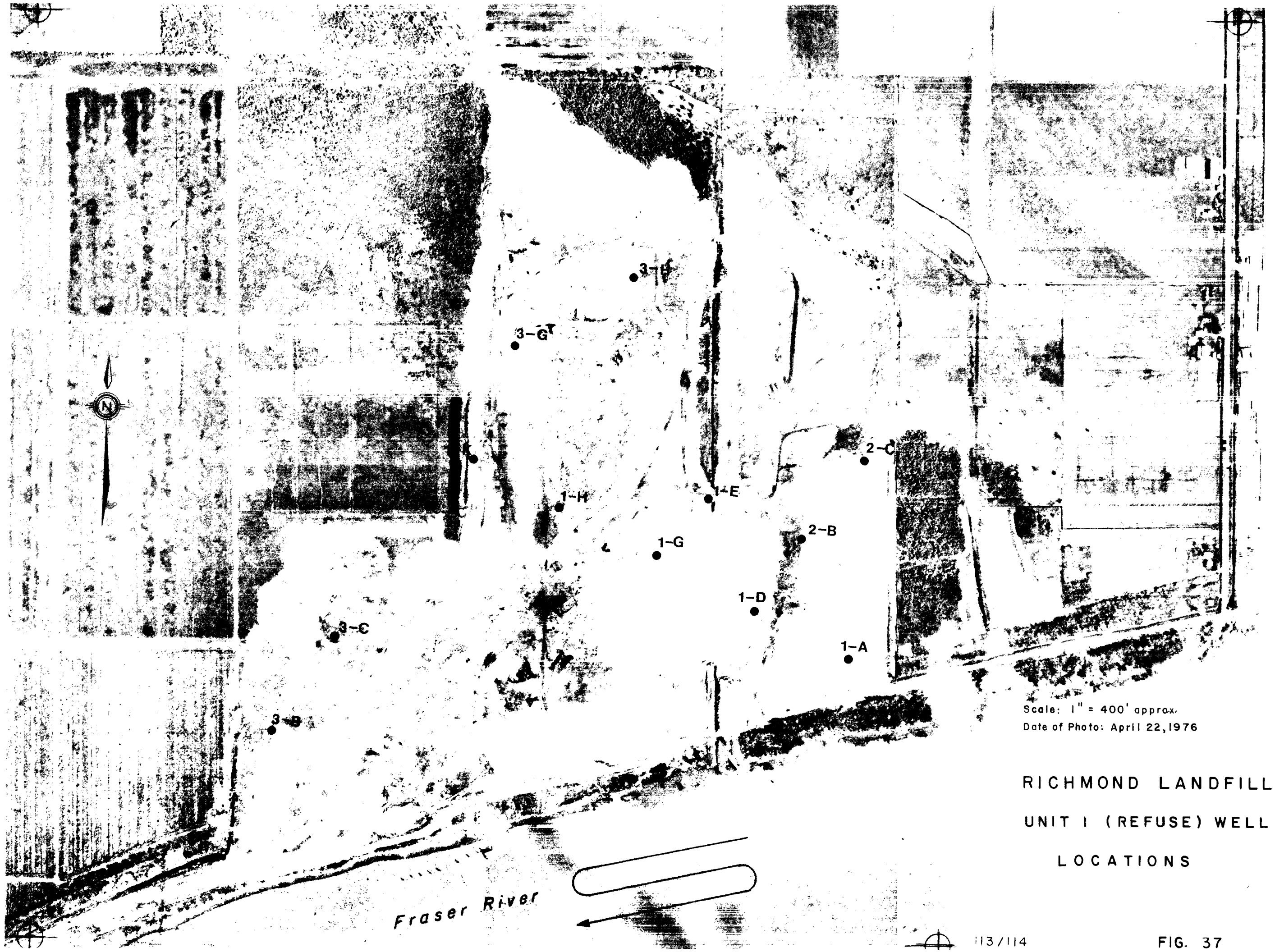
Date of Photo: April 22, 1976

RICHMOND LANDFILL

SAMPLE POINTS FOR LEACHATE BACTERIOLOGICAL STUDY

(May 31 to June 4, 1976)

FIGURE 36

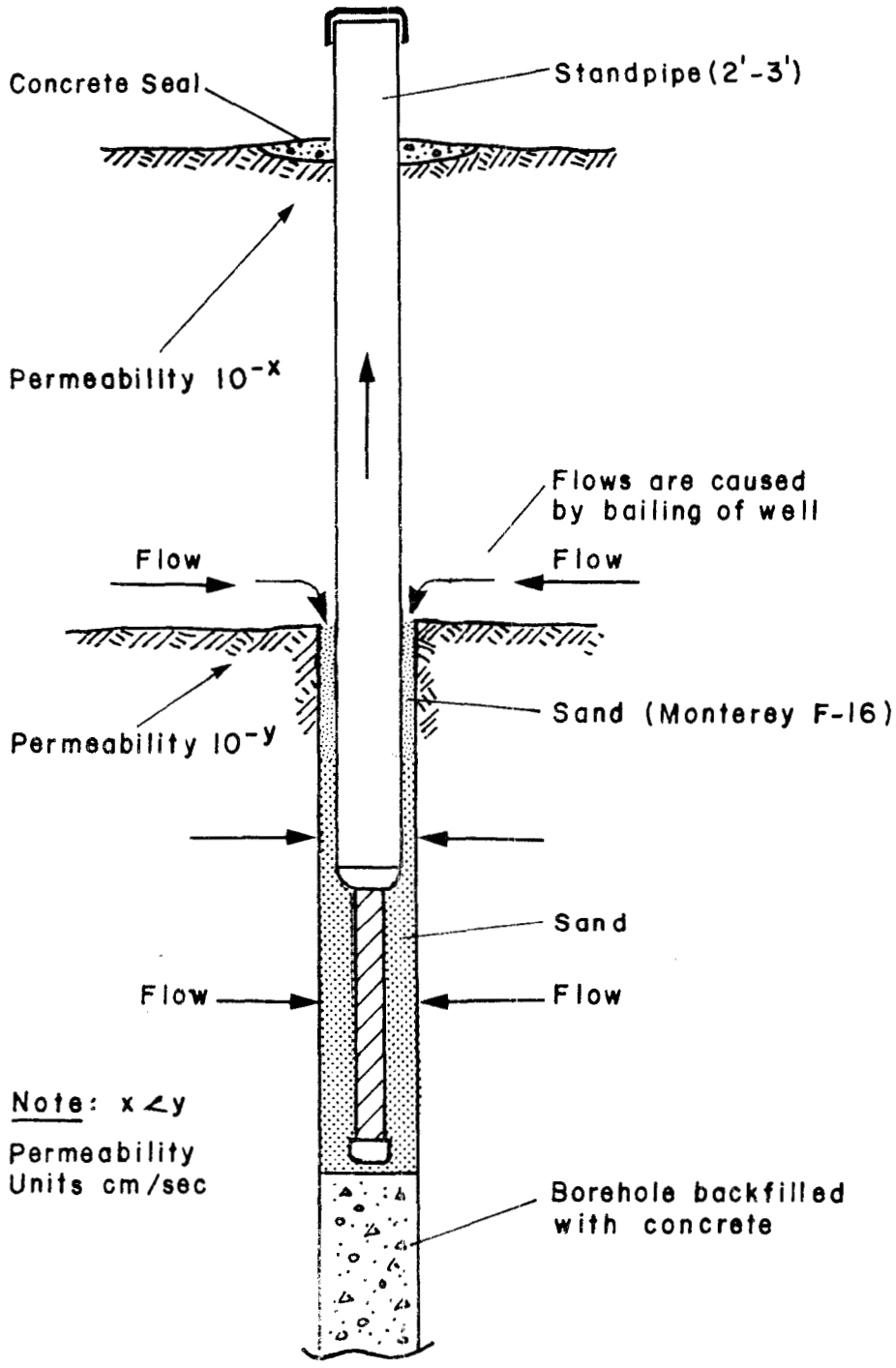


RICHMOND LANDFILL

UNIT I (REFUSE) WELL

LOCATIONS

FIG. 37



SCHEMATIC OF BUCKET-TYPE PIEZOMETER WELL INSTALLATION

FIGURE 38

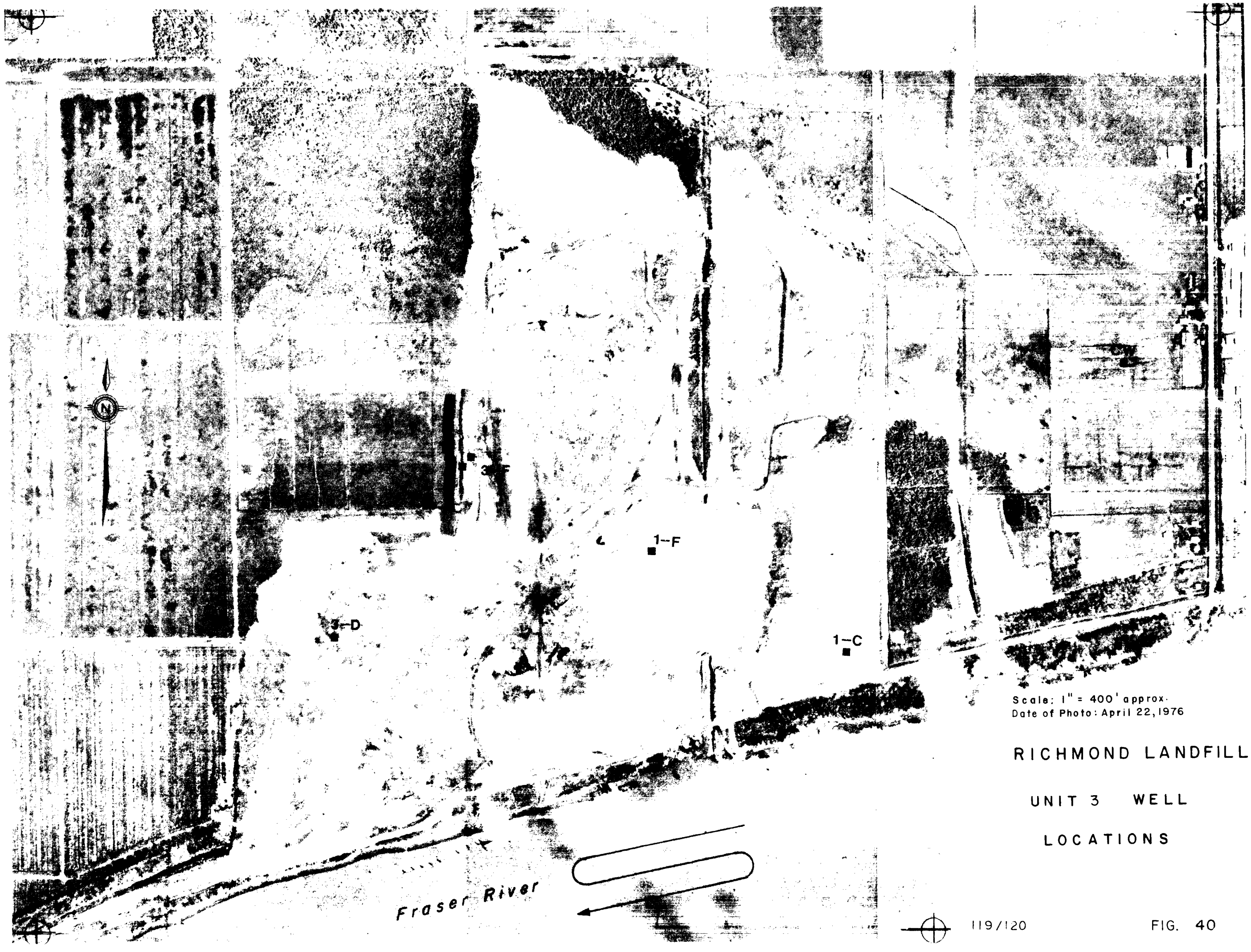
Scale: 1" = 400' approx.
Date of Photo: April 22, 1976

RICHMOND LANDFILL

UNIT 2 (PEAT) WELL

LOCATIONS

FIG. 39



Scale: 1" = 400' approx.
Date of Photo: April 22, 1976

RICHMOND LANDFILL

UNIT 3 WELL

LOCATIONS

FIG. 40

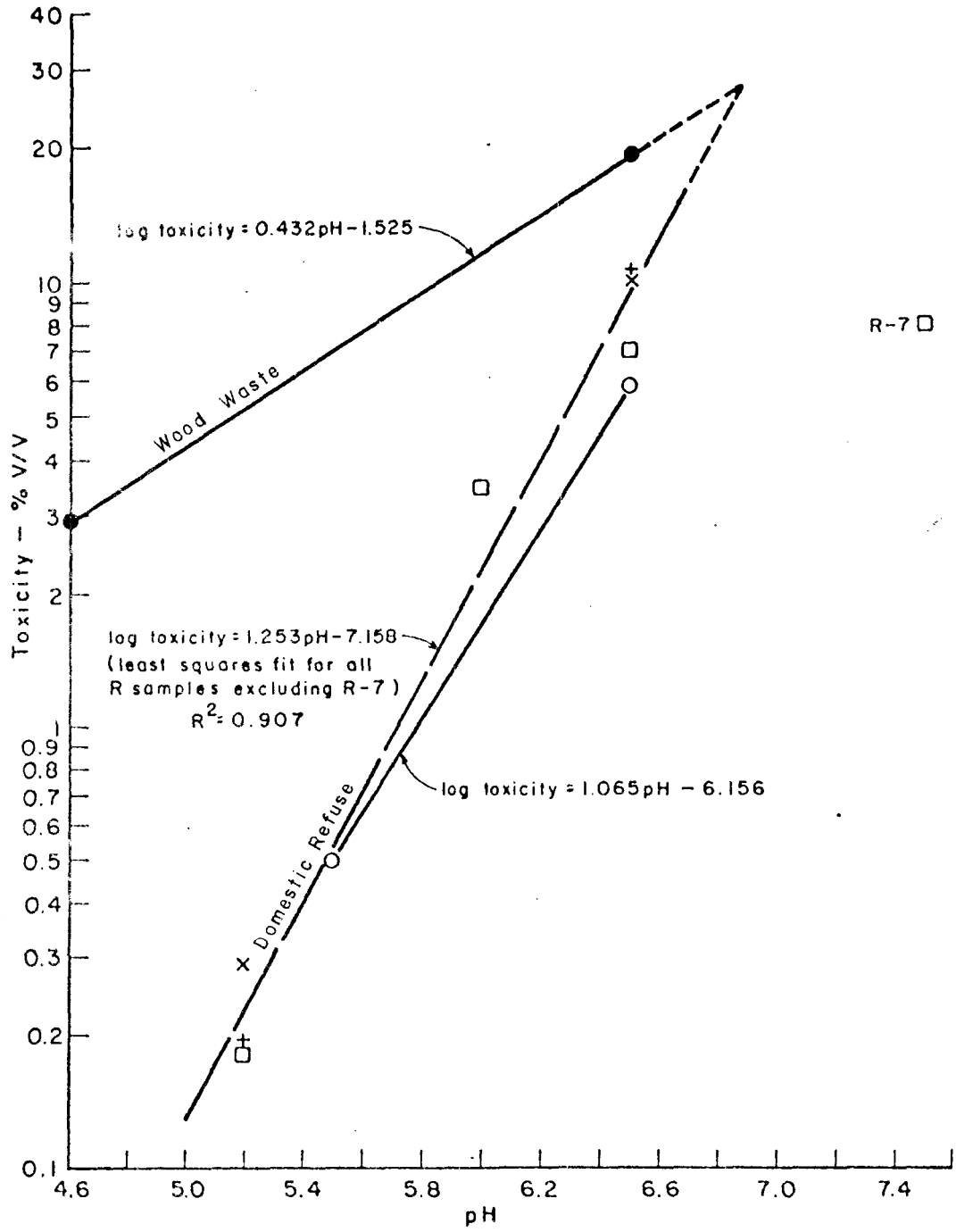


FIGURE 41 TOXICITY VERSUS pH AFTER CAMERON[4]

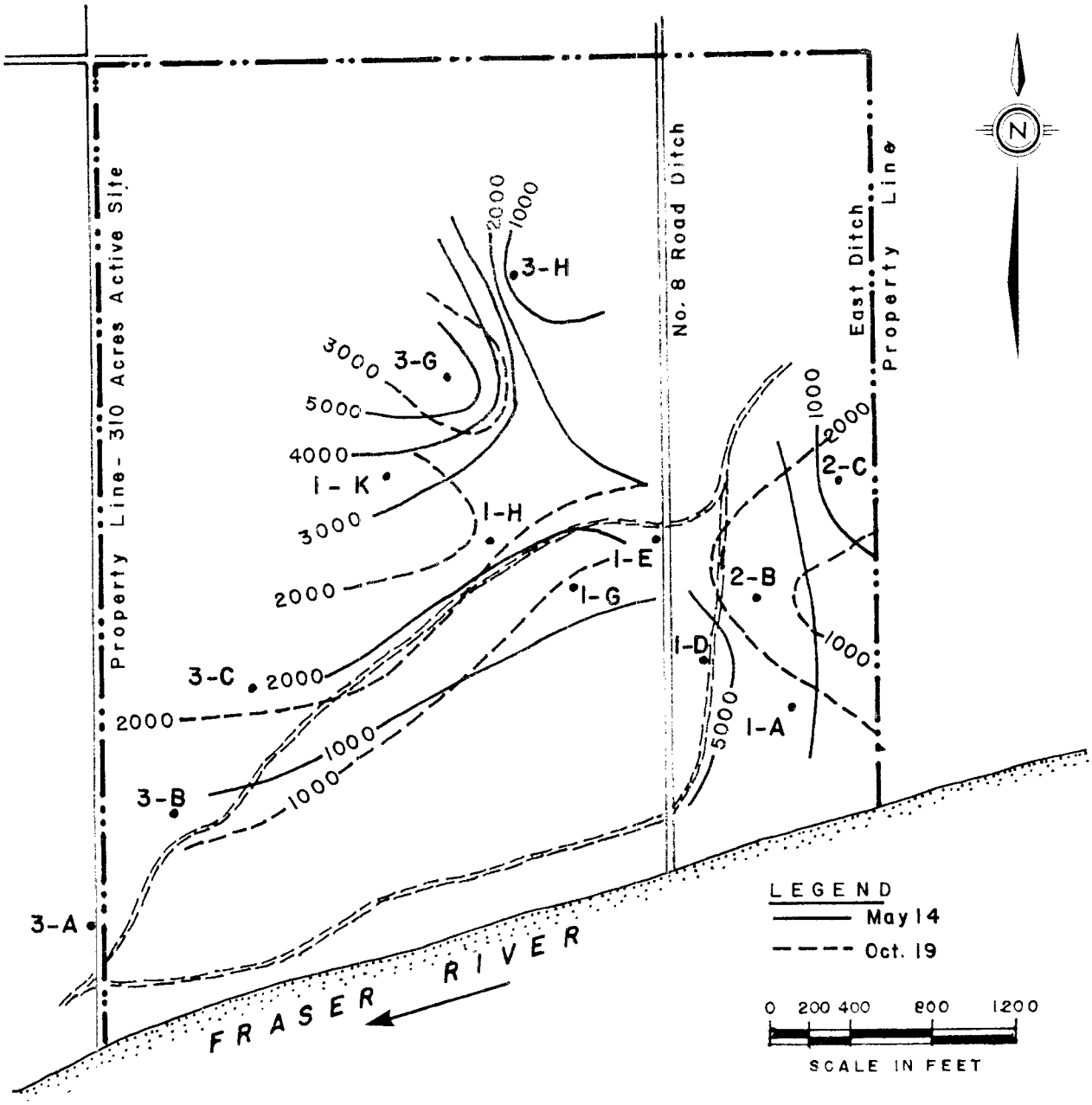


FIGURE 42 TOTAL RESIDUE CONTOURS

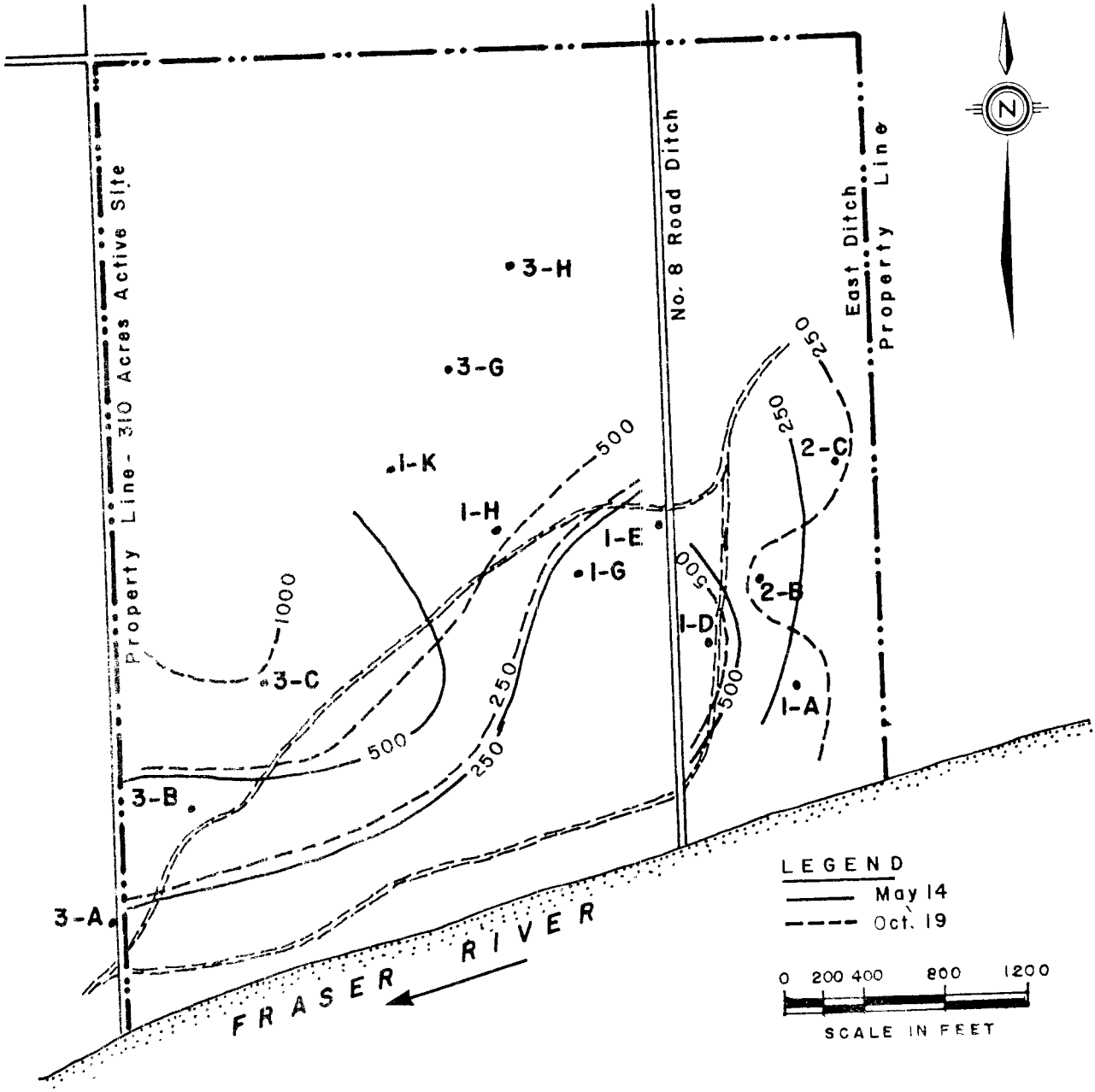


FIGURE 43 C.O.D. CONTOURS

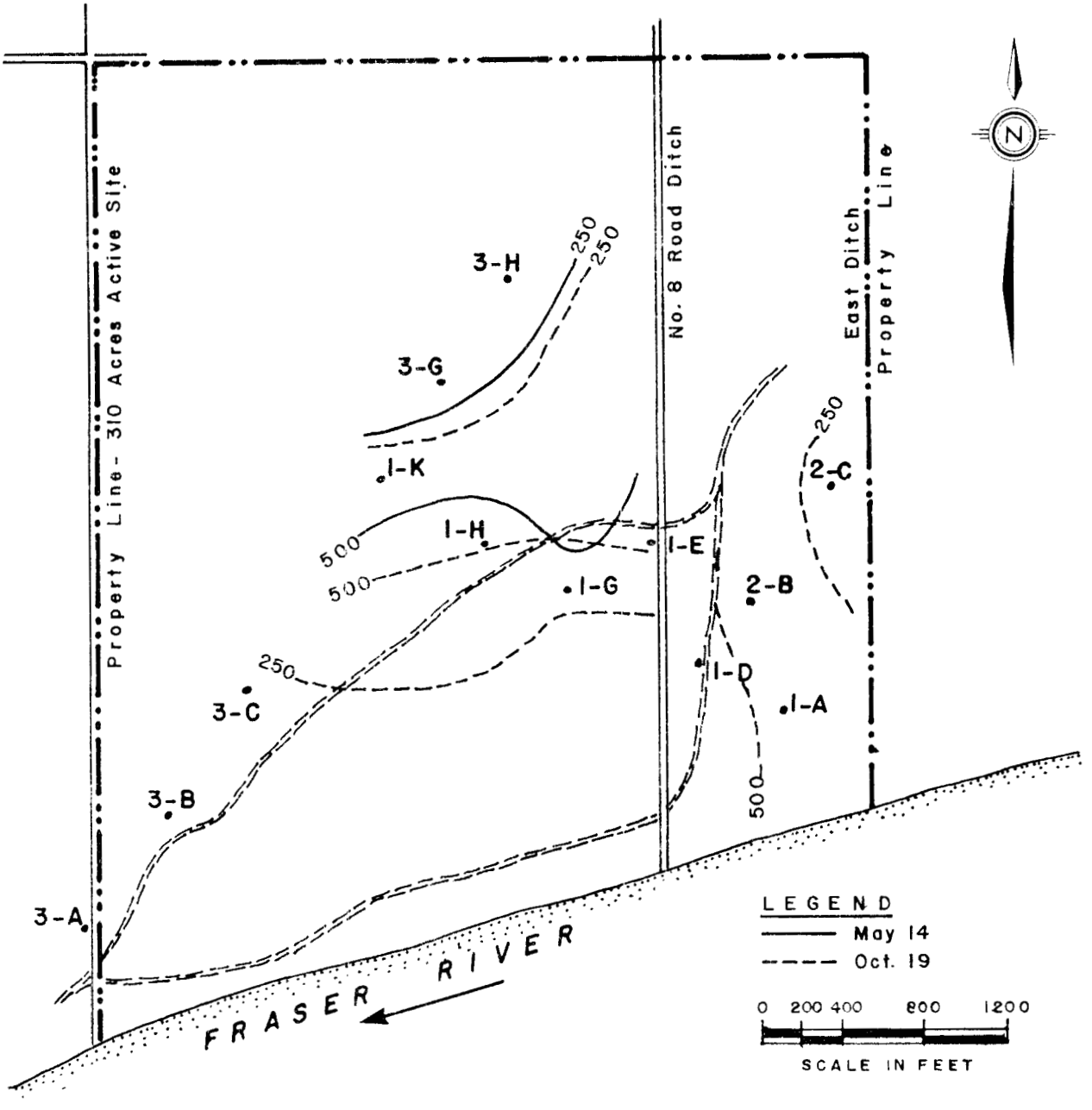


FIGURE 44 CHLORIDE CONTOURS

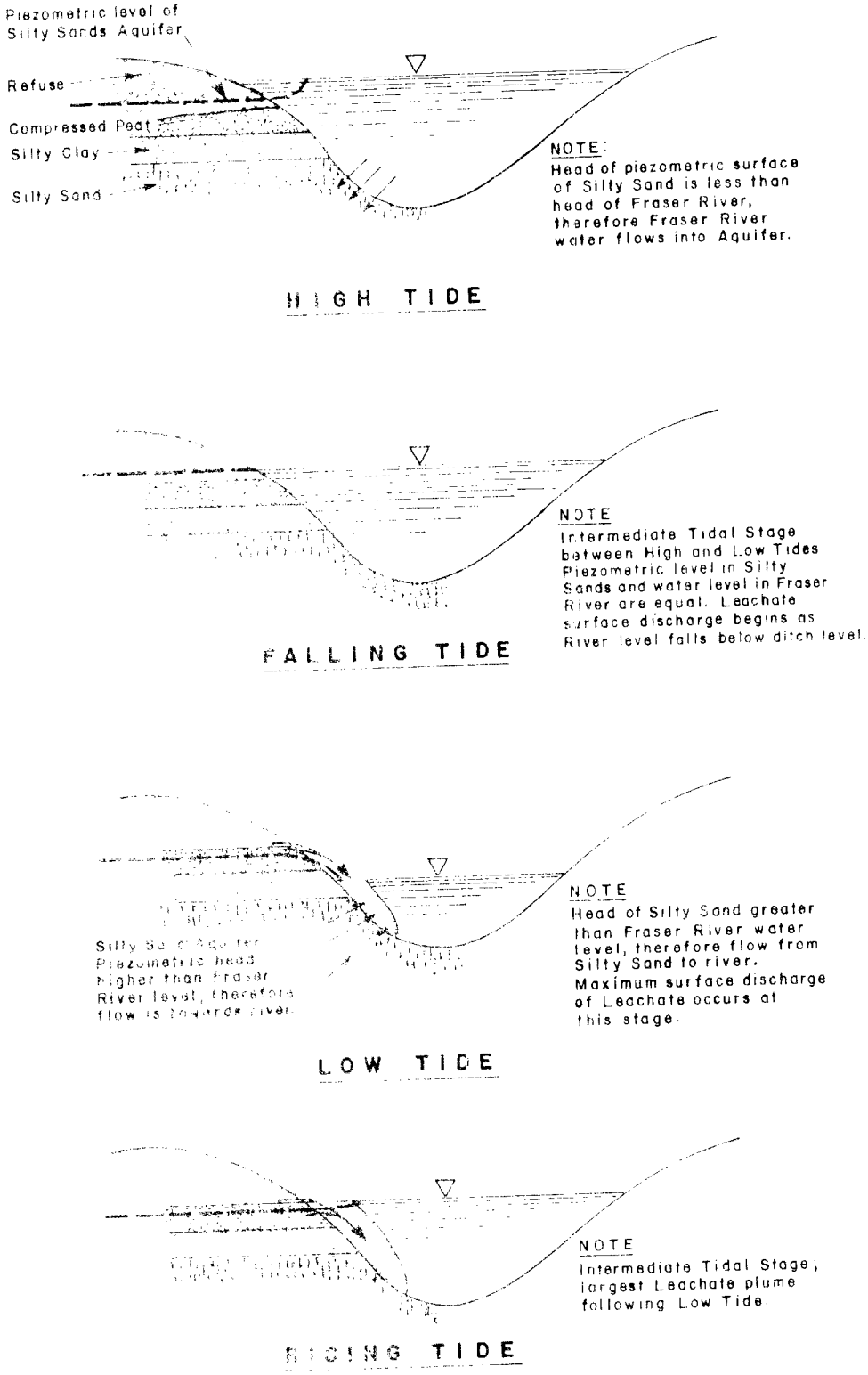


FIG. 45 DIURNAL VARIATION OF FRASER RIVER LEVEL AND SILTY SANDS AQUIFER PIEZOMETRIC SURFACE.

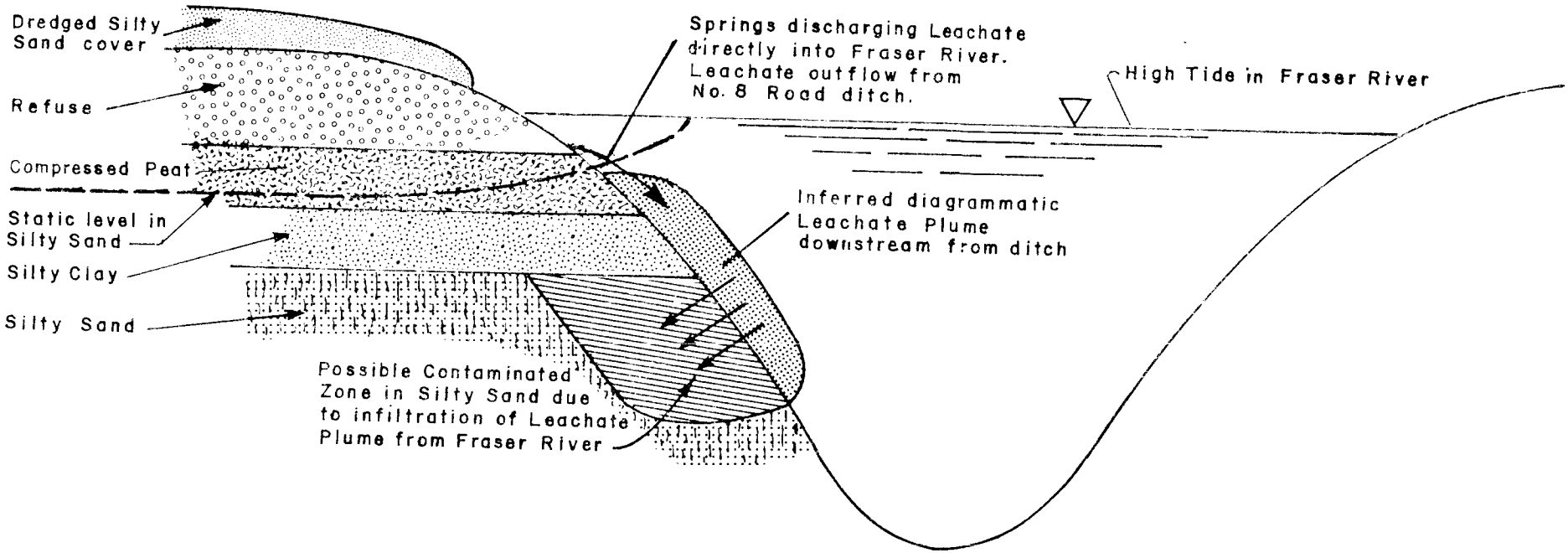


FIG. 46 SCHEMATIC DIAGRAM OF POSSIBLE LEACHATE MIGRATION INTO SILTY SAND AQUIFER

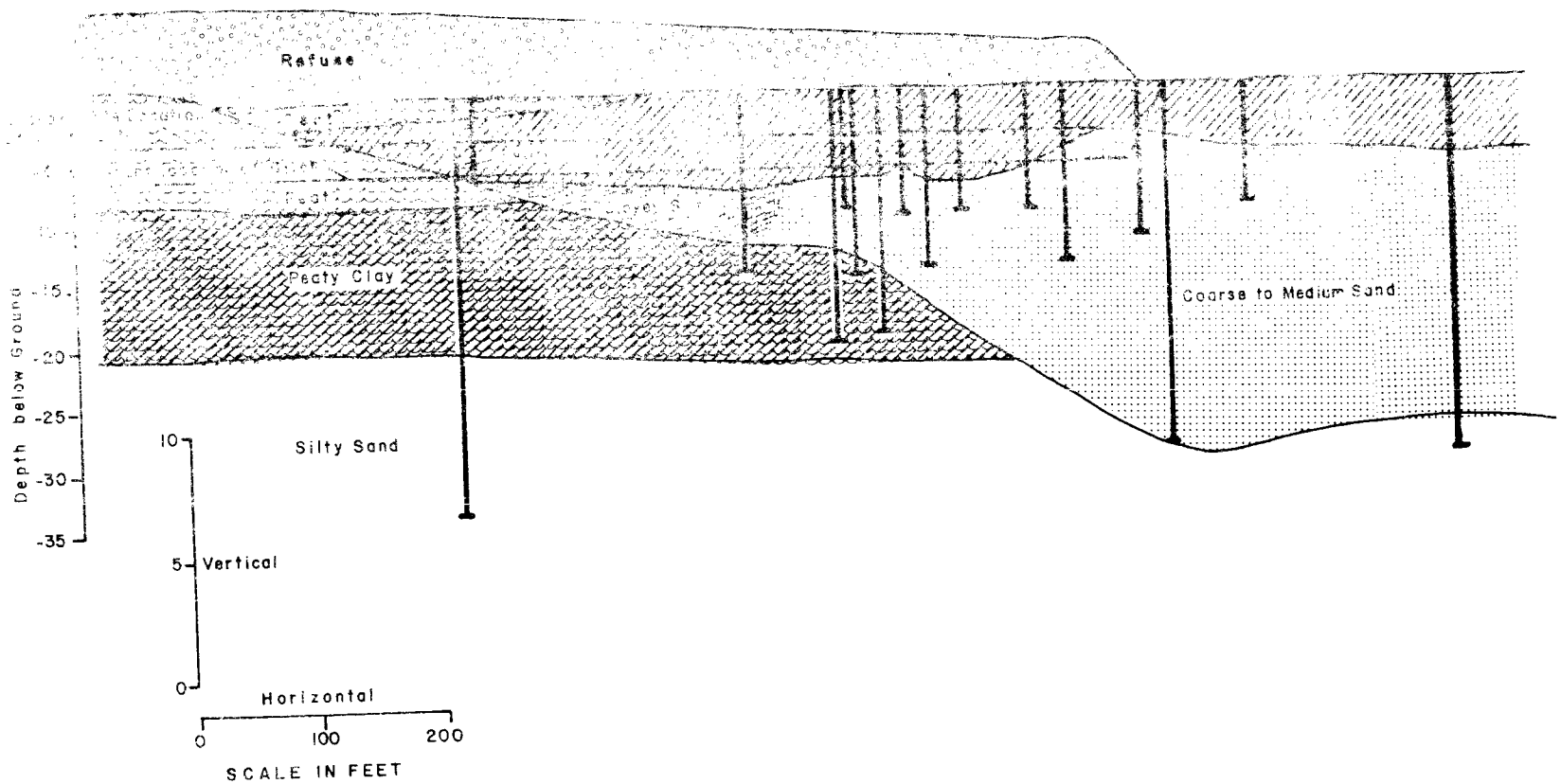
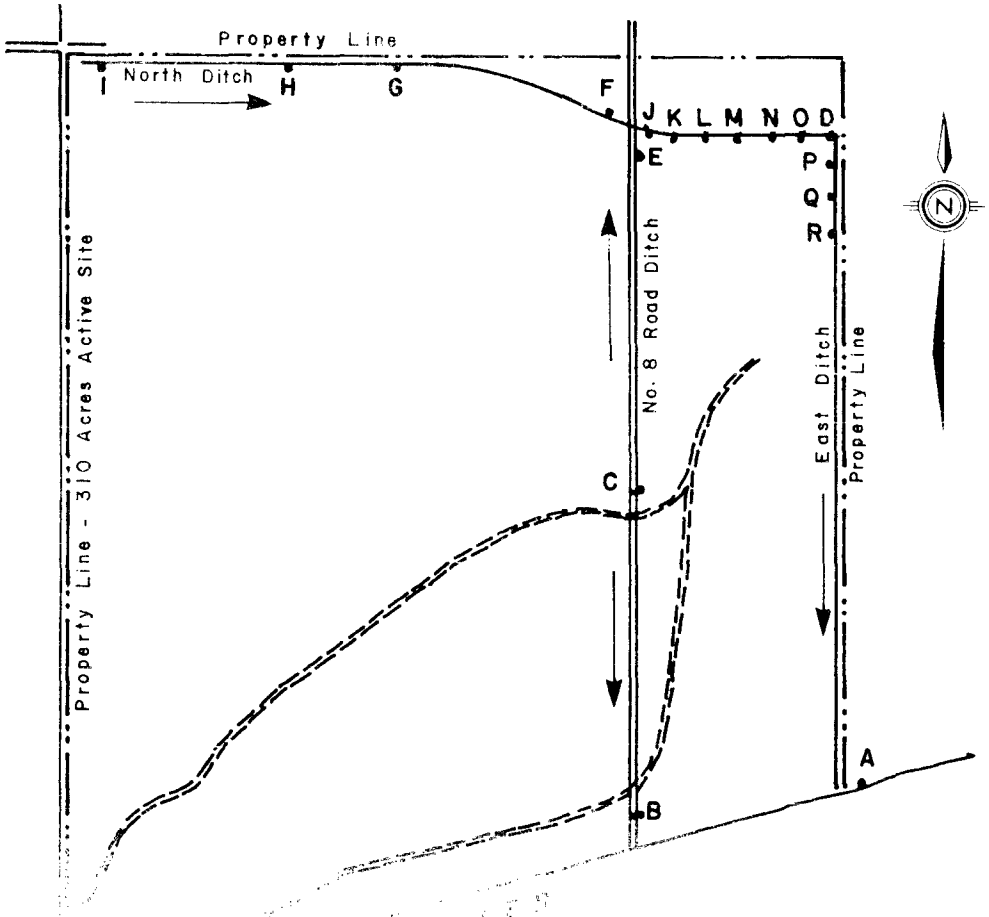


FIGURE 47 PROJECTED GEOLOGICAL CROSS SECTION - NORTHEAST CORNER RICHMOND LANDFILL AND ADJOINING PROPERTIES (After Hugh Liebscher, March 1977)



FLOW MEASUREMENTS cfs		
	Date 1977	
Station No.	Feb. 15	Mar. 9
A	1.6	–
B	0.6	–
C	0.07	–
D	1.2	2.1
E	1.2	1.3
F	0.54	1.7
G	0.45	–
H	0.19	–
I	0.0	–
J	–	4.0
K	–	2.8
L	–	2.1
M	–	2.3
N	–	1.3
O	–	1.5
P	–	2.3
Q	–	3.3
R	[illegible]	[illegible]

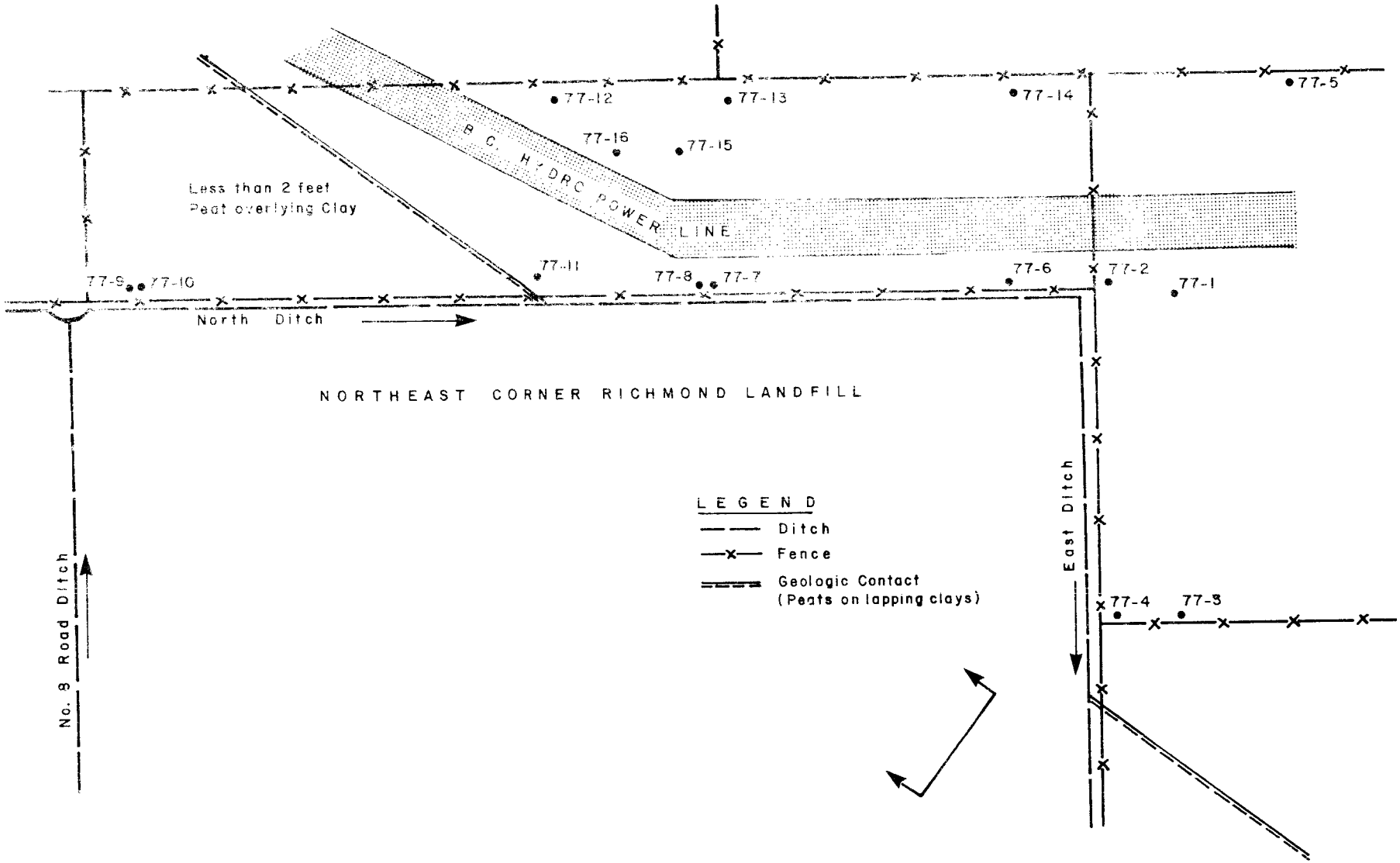


FIGURE 49 RICHMOND LANDFILL - 1977 DRILL SITE AND PIEZOMETER LOCATIONS
(After Hugh Liebscher, March 1977)

1977 DRILLING PROGRAM

Sample Number	Cl⁻	Specific Cond.	[illegible]	[illegible]	SO₄	Cl⁻	Mg	pH
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
77-2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
77-6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
77-8	[illegible]	[illegible]	[illegible]	[illegible]	15	[illegible]	[illegible]	[illegible]
77-7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
77-3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
77-9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
77-10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
77 [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
77-[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
77-12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
77-2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
77-5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
77-16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

RICHMOND LANDFILL

1977 DRILLING PROGRAM
PIEZOMETER / WELL LOCATIONS
WATER QUALITY DATA

13' / '32

FIGURE 50

FIGURE 51: UNCOMPACTED FILL FACE

TABLE 1: REFUSE MATERIALS BY KIND, COMPOSITION AND SOURCES

	KIND	COMPOSITION	NOTED R.L.	SOURCES
REFUSE	Garbage	Wastes from preparation, cooking, and serving of food; market wastes; wastes from handling, storage, and sale of produce	x	Households, restaurants, institutions, stores, markets
	Rubbish	Combustible: paper, cartons, boxes, barrels, wood, excelsior, tree branches, yard trimmings, wood furniture, bedding dunnage	x	
		Noncombustible: metals, tin cans, metal furniture, dirt, glass, crockery minerals	x	
	Ashes	Residue from fires from cooking, heating, on-site incineration	x	
	Street Refuse	Sweepings, dirt, leaves, catch basin dirt, contents of litter receptacles, ditch cleanings	x	Streets, sidewalks, alleys vacant lots
	Dead Animals	Cats, dogs, horses, cows	x *	
	Vehicles	Unwanted cars, trucks	x	
	Industrial Wastes	Food proc. wastes, cinders, lumber scraps, metal scraps, shavings	x	Factories
	Demolition Wastes	Lumber, pipes, brick, masonry, etc.	x	Sites for new bldgs., etc.
	Construc. Wastes	Scrap lumber, pipe, etc.	x	New construction, etc.
	Special Wastes	Explosives, patholog. wastes, radioactive wastes	x **	Homes, hotels, hospitals, etc.
	Sewage Treatment	Solids from screening, etc.; sludge	x ***	Treatment plants, septic tanks

* Former S.P.C.A. Dump

** Except Explosives and Radioactive Materials

*** Handled in past

R.L. Richmond Landfill Site

TABLE 2 COMPACTOR TRANSPORTED COMMERCIAL AND RESIDENTIAL WASTES

CARRIERS	ESTIMATED YDS/YR.	ESTIMATED TRUCK LOADS/YR.
Richmond Municipality	93,384 *	5,188
Smithrite Compactor only	138,600 **	4,620
IXL	1,970 **	399
Totem	93,990 **	3,133
Haul-A-Way	12,930 **	431

TOTAL ESTIMATED ANNUAL VOLUME = 351,800 yds^3

* Estimated 18 yd^3 compactor truck volume

** Estimated 30 yd^3 compactor truck volume

TABLE 3
VALUES OF CHEMICAL PARAMETERS OF SURFACE
WATERS AT SAMPLING STATION NO.7

Date	Feb.4	Mar.31	May 6	June 8	June 24	July 27
COD		300	240	190	290	110
T.R.		4000	2280	1500	2000	750
F.R.		-	2240	1400	1900	-
TOC-Inorganic		-	305	250	290	114
-Organic		-	115	60	65	40
pH		7.0	7.4	6.6	7.0	6.9
Spec.Conductance		6400	3800	2350	170	-
Alkalinity		550	920	690-740	800	337
NH_3		14	23	16-29	16	7.5
$NO_2 + NO_3$		-	0.01	0.02	0.13	-
F-		-	0.14	0.15	0.14	-
Cl-		1700	730	200-340	500	190
S_1O_2		-	11	12	9.4	-
SO_4		8.9	56	35-44	43	24.7
PO_4		-	-	0.25	0.16	-
Mn		-	4.4	2.5	2.1	1.5
Mg		150	70	40-49	60	20
Fe		37	47	47	36	18
Na		980	430	240	400	120
K		-	50	≈30	-	12
Cr		0.03	<0.02	-	<0.02	<0.02
Ni		<0.05	<0.05	<0.01	<0.05	<0.05
Zn		0.21	0.14	0.11	0.24	0.11
Pb		<0.02	<0.02	<0.02	0.04	-
B		-	1.43	-	-	-
Ca		210	220	180	180	86
Cd		-	-	-	-	<0.1
PCB	20 ppb	-	-	-	N.D.	-

All values in mg/l except for pH values and Spec.Conductance (μmhos/cm)

N.D. - Not detectable.

TABLE 4
VALUES OF CHEMICAL PARAMETERS OF SURFACE WATERS AT SAMPLING STATION NO. 4

Date	Feb.18	March 31	May 6	July 28
COD	190	320	240	120
T.R.	1700	4800	3650	2100
F.R.	1608	-	3530	-
TOC - inorganic	208	-	240	-
- organic	118	-	30	-
pH	7.4	7.3	7.5	7.1
Specific Conductance	2500	7500	6100	3600
Acidity	72	-	-	-
Alkalinity	-	660	830	731
NH	11	8	9	7.3
NO_2+NO_3	0.032	-	0.02	-
F-	-	-	0.22	-
Cl-	380	2200	1500	770
S_1O_2	120	-	8.8	-
SO_4	-	7.6	36	21.8
PO_4	0.5	-	-	-
Mn	-	-	3	2.9
Mg	45	140	120	61
Fe	2.4	31	30	42
Na	-	1200	900	500
K	-	-	45	29
Cr	-	0.02	<0.02	<0.02
Ni	-	<0.05	<0.05	<0.05
Zn	-	0.30	0.08	0.08
Pb	-	0.02	<0.02	-
Ca	170	230	200	130
Cd	-	-	-	<0.01

All values in mg/l except for pH values and Spec.Conductance (μmhos/cm)

TABLE 5
VALUES OF CHEMICAL PARAMETERS OF SURFACE
WATERS AT SAMPLING STATION NO. 5

Date	March 31	May 6	July 27
COD	480	1900	340
T.R.	3400	4050	4600
F.R.	-	4050	-
TOC - inorganic	-	320	-
- organic	-	300	-
pH	7.5	7.3	7.3
Specific Conductance	5400	590	7150
Acidity	-	-	-
Alkalinity	1200	1200	1280
NH_3	38	13	19
NO_2+NO_3	-	0.03	-
SO_4	12	49	80
PO_4	-	-	-
S_1O_2	-	16	-
F-	-	0.17	-
Cl-	1200	1300	1600
Mn	-	2.8	2.0
Mg	85	110	120
Ca	340	410	370
Fe	4.7	1.8	2.2
Na	700	740	900
K	-	63	63
Cr	0.04	0.02	<0.02
Zn	0.48	0.82	0.56
Pb	0.02	<0.02	-
B	-	2.59	-
Ni	<0.05	<0.05	<0.05
Cd	-		<0.01

All values in mg/l except for pH values and Spec.Conductance (μmhos/cm)

TABLE 6 (a) and (b)
WATER QUALITY DATA RELATED TO TWELVE
WELLS LOCATED TO SAMPLE UNIT 1 (REFUSE) WATERS
(Feb.1 to Oct.19, 1976)

(a) Chemical Oxygen Demand (mg/l)

DATE	SAMPLE WELLS 1-A	1-D	1-E	1-G	1-H	1-K	2-B	2-C	3-B	3-C	3-G	3-H
Feb.2	230	600	290	140	520	-	160	140	-	-	-	-
Feb.5	160	470	220	260	450	-	190	130	-	-	-	-
Mar.1	220	370	190	140	340	310	230	110	150	1800	1900	2800
Mar.26	270	910	210	150	360	340	190	100	120	1400	1700	2500
May 14	250	640	210	130	340	430	-	100	150	1140	11000	750
Oct.19	300	-	160	82	610	340	93	250	170	940	1100	-

(b) Specific Conductance (micromhos/cm)

DATE	SAMPLE WELLS 1-A	1-D	1-E	1-G	1-H	1-K	2-B	2-C	3-B	3-C	3-G	3-H
Feb.2	1480	2380	1950	3030	2630	-	900	2080	-	-	-	-
Feb.5	1430	2250	1950	3030	2630	-	890	1600	-	-	-	-
Mar.1	1510	3080	2080	2880	2280	2130	3080	1050	1280	2080	2750	2230
Mar.26	7600	6500	3500	2850	3450	2210	4150	6730	1180	2100	3170	1090
May 14	3480	10100	3530	2250	3680	-	-	600	1190	990	4650	560
Oct.19	3270	-	2580	1130	3350	2200	1760	865	1600	1900	4100	-

TABLE 6(c) and (d)
SAMPLE UNIT 1 (REFUSE) WATERS

(c) Total Residue (T.R.) and Non-Filterable Residue (N.F.R.)(mg/l)

DATE	SAMPLE WELLS 1-A	1-D	1-E	1-G	1-H	1-K	2-B	2-C	3-B	3-C	3-G	3-H
Feb.2	1100	1900	1300	1900	2200	-	620	1800				
Feb.5	990	1900	1790	1830	2010	-	600	1820				
Mar.1	1300	1900	1300	1800	2600	1700	2500	630	890	3000	2700	1800
Mar.26	4900	4500	2200	1800	2400	2000	2600	890	850	2600	3000	1000
May 14	2310	6080	2170	1480	2560	-	-	500	880	-	5200	630
Oct.19	2200	-	1500	720	2300	1400	1000	1400	1100	2400	3400	-

(d) pH

DATE	SAMPLE WELLS 1-A	1-D	1-E	1-G	1-H	1-K	2-B	2-C	3-B	3-C	3-G	3-H
Feb.5	6.8	11.6	6.3	6.4	6.8	-	6.2	7.3	-	-	-	-
Mar.1	6.8	8.3	6.5	6.4	6.9	7.1	6.5	7.2	6.5	7.2	6.9	5.3
Mar.26	6.7	8.5	6.3	6.3	6.8	7.1	6.3	6.9	7.1	6.4	6.8	5.5
May 14	6.9	7.4	6.5	6.5	7.0	-	-	7.6	6.7	7.3	6.7	6.2
Oct.19	7.8	-	6.7	6.7	7.6	7.7	7.9	7.1	6.5	6.8	7.1	-

TABLE 6 (e) and (f)
SAMPLE UNIT 1 (REFUSE) WATERS

(e) Organic and Inorganic Carbon (mg/1)

DATE	INORG./ ORG.	SAMPLE WELLS 1-A	1-D	1-E	1-G	1-H	1-K	2-B	2-C	3-B	3-C	3-G	3-H
Feb.2	Org.	40	202	98	84	190	-	62	52	-	-	-	-
	Inorg.	280	8	142	196	380	-	94	124	-	-	-	-
Feb.5	Org.	20	210	44	18	175	-	48	48	-	-	-	-
	Inorg.	290	14	152	210	395	-	108	104	-	-	-	-
Mar.1	Org.	55	138	57	148	130	116	51	34	60	495	598	885
	Inorg.	270	82	137	72	340	204	150	88	300	359	232	72
Mar.26	Org.	-	-	-	-	-	105	-	-	250	440	640	490
	Inorg.	-	-	-	-	-	285	-	-	50	360	400	62
May 14	Org.	80	100	85	44	120	135	-	40	70	360	1600	235
	Inorg.	250	150	150	96	290	260	-	80	270	220	360	55
Oct.19	Org.	110	-	54	23	70	-	36	98	40	290	280	-
	Inorg.	-	-	-	-	-	-	-	-	-	-	-	-

(f) Alkalinity (as $CaCO_3$)(mg/1)

DATE	SAMPLE WELLS 1-A	1-D	1-E	1-G	1-H	1-K	2-B	2-C	3-B	3-C	3-G	3-H
Feb.2	-	-	-	-	-	-	-	-	-	-	-	-
Mar.1	680	505	235	340	960	790	230	280	720	950	1300	47
Mar.26	690	510	310	240	900	890	230	260	690	1000	1600	260
May 14	800	1500	280	160	910	-	-	230	640	14	2200	210
Oct.19	1200	-	160	-	808	720	200	760	680	790	1564	-

TABLE 6 (g) and (h)
SAMPLE UNIT 1 (REFUSE) WATERS

(g) Hardness (as $CaCO_3$)(mg/l)

DATE	SAMPLE WELLS 1-A	1-D	1-E	1-G	1-H	1-K	2-B	2-C	3-B	3-C	3-G	3-H
Feb.2	805	595	244	579	1162	-	330	965	-	-	-	-
Feb.5	704	905	881	436	1089	-	183	692	-	-	-	-
Mar.1	855	370	355	590	1070	1050	270	560	674	1566	1410	535
Mar.26	1390	2250	669	487	1040	1190	737	538	633	1428	1550	388
May 14	1070	1390	710	384	482	844	-	310	684	890	1480	280
Oct.19	1270	-	455	222	1260	-	383	1110	702	1630	1780	-

(h) Chloride (Cl)(mg/l)

DATE	SAMPLE WELLS 1-A	1-D	1-E	1-G	1-H	1-K	2-B	2-C	3-B	3-C	3-G	3-H
Feb.2	35	130	500	-	240	-	180	180	-	-	-	-
Feb.5	34	150	460	650	270	-	180	150	-	-	-	-
Mar.1	41	720	510	730	210	67	290	100	21	100	82	390
Mar.26	2100	1900	930	760	140	84	1200	160	23	120	140	90
May 14	570	3000	990	560	680	-	-	5	24	-	190	27
Oct.19	480	-	760	280	500	-	420	110	39	28	230	-

TABLE 6 (i) and (j)
SAMPLE UNIT 1 (REFUSE) WATERS

(i) Sulphate (mg/l)

DATE	SAMPLE WELLS 1-A	1-D	1-E	1-G	1-H	1-K	2-B	2-C	3-B	3-C	3-G	3-H
Feb.2	180	80	12	6	105	-	7	500	-	-	-	-
Feb.5	170	60	14	8	70	-	10	330	-	-	-	-
Mar.1	170	160	22	8	5	430	110	12	18	70	51	16
Mar.26	7.4	6.6	9.8	13	13	32	9.1	17	7.3	28	20	9.1
May 14	19	11	13	5	51	-	-	11	6	14	27	4
Oct.19	96	-	30	9.2	11	-	16	7.8	6.5	-	27	-

(j) Ammonia (NH_3), (NO_2 + NO_3) (mg/l)

DATE	SAMPLE WELLS 1-A	1-D	1-E	1-G	1-H	1-K	2-B	2-C	3-B	3-C	3-G	3-H
Feb.2	2.1	46	3.2	4.9	6.4	-	11	10	-	-	-	-
	(<0.1)	(<0.1)	(<0.1)	-	(<0.1)	-	-	(<0.1)	-	-	-	-
Feb.5	1.9	97	4.6	5.1	6.5	-	3.2	8.9	-	-	-	-
	(<0.1)	(<0.1)	(<0.1)	-	(<0.1)	-	-	(<0.1)	-	-	-	-
Mar.1	2.0	67	3.9	5.8	6.9	20	22	6.5	17	13	24	46
Mar.26	-	-	-	-	-	26	-	-	16	13	48	20
May 14	4.4	62	4.1	7.5	5.9	-	-	5.7	15	15	71	7.4
Oct.19	9.3	-	3.5	13	8.2	49	11	5.0	24	13	79	-

TABLE 6 (k) and (l)
SAMPLE UNIT 1 (REFUSE) WATERS

(k) Calcium (mg/l)

DATE	SAMPLE WELLS 1-A	1-D	1-E	1-G	1-H	1-K	2-B	2-C	3-B	3-C	3-G	3-H
Feb.2	240	230	48	120	350	-	51	330	-	-	-	-
Feb.5	210	310	30	60	310	-	30	220	-	-	-	-
Mar.1	300	86	70	110	300	360	140	160	180	240	470	130
Mar.26	300	770	150	84	280	410	130	150	170	200	450	88
May 14	300	280	160	-	33	270	-	88	170	120	44	53
Oct.19	420	-	45	30	360	-	71	330	240	260	420	-

(l) Magnesium (mg/l)

DATE	SAMPLE WELLS 1-A	1-D	1-E	1-G	1-H	1-K	2-B	2-C	3-B	3-C	3-G	3-H
Feb.2	44	3.3	22	52	44	-	10	28	-	-	-	-
Feb.5	40	26	22	45	43	-	9.6	18	-	-	-	-
Mar.1	18	36	34	49	43	25	85	15	15	95	56	25
Mar.26	150	67	58	44	59	27	72	16	14	73	66	19
May 14	74	150	62	-	65	29	-	6	15	43	120	13
Oct.19	51	-	37	16	54	-	32	17	17	81	130	-

TABLE 6 (m), (n) and (o)
SAMPLE UNIT 1 (REFUSE) WATERS

(m) Iron (Total)(Fe)(mg/l)

DATE	SAMPLE WELLS 1-A	1-D	1-E	1-G	1-H	1-K	2-B	2-C	3-B	3-C	3-G	3-H
Feb.2	14	2.8	19	28	38	-	34	47	-	-	-	-
Feb.5	9.0	13	23	57	77	-	38	38	-	-	-	-
Mar.1	18	3.2	25	62	80	27	96	56	90	320	306	60
Mar.26	14	30	31	54	54	27	65	54	84	350	87	50
May 14	93	40	32	53	74	28	-	36	110	230	490	52
Oct.19	6.2	-	36	45	78	-	41	120	18	360	120	-

(n) Zinc (Zn)(mg/l)

DATE	SAMPLE WELLS 1-A	1-D	1-E	1-G	1-H	1-K	2-B	2-C	3-B	3-C	3-G	3-H
Mar.26	0.11	0.12	0.08	0.1	0.19	0.63	0.05	0.10	0.12	0.20	0.19	0.97
May 14	0.13	0.05	0.09	0.07	0.23	0.60	-	0.05	0.12	0.41	0.58	0.58
Oct.19	0.27	-	0.08	0.09	0.17	-	0.06	0.63	0.10	0.12	0.11	-

(o) Nickel (Ni)(mg/l)

DATE	SAMPLE WELLS 1-A	1-D	1-E	1-G	1-H	1-K	2-B	2-C	3-B	3-C	3-G	3-H
Mar.26	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	<0.05	<0.05	<0.05	<0.05
May 14	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Oct.19	<0.05	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

TABLE 6 (p) and (q)
SAMPLE UNIT 1 (REFUSE) WATERS

(p) Sodium (Na)(mg/l)

DATE	SAMPLE WELLS 1-A	1-D	1-E	1-G	1-H	1-K	2-B	2-C	3-B	3-C	3-G	3-H
Mar.26	1100	1100	510	400	420	75	560	120	23	56	180	78
May 14	430	1450	480	270	390	88	-	22	23	7.7	230	27
Oct.19	260	-	310	12	250	-	190	41	28	49	260	-

(q) Chromium (Cr)(mg/l)

DATE	SAMPLE WELLS 1-A	1-D	1-E	1-G	1-H	1-K	2-B	2-C	3-B	3-C	3-G	3-H
Mar.26	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.03	0.04	0.05	0.05	0.03
May 14	<0.02	0.02	<0.02	<0.02	<0.02	0.04	-	<0.02	0.03	0.06	0.09	0.03
Oct.19	0.02	-	<0.02	<0.02	<0.02	-	<0.02	0.04	0.02	0.04	0.03	-

TABLE 7(a) and (b)
WATER QUALITY DATA RELATED TO EIVE WELLS
LOCATED TO SAMPLE UNIT 2 (PEAT) WATERS (FEB.1 TO OCT.19, 1976)

(a) Chemical Oxygen Demand (COD)(mg/1)

DATE	SAMPLE WELLS 1-B	1-J	1-M	2-A	3-A
Feb.2	68	-	-	43	-
Feb.5	81	-	-	73	-
Mar.1	62	180	-	-	300
Mar.26	48	170	-	86	300
May 14	62	150	150	74	270
Oct.19	78	110	-	54	220

(b) Specific Conductance (micromhos/cm)

DATE	SAMPLE WELLS 1-B	1-J	1-M	2-A	3-A
Feb.2	105	-	-	101	-
Feb.5	113	-	-	3180	-
Mar.1	107	185	-	-	410
Mar.26	100	160	-	1980	440
May 14	105	141	57	1730	445
Oct.19	113	120	-	430	390

TABLE 7(c) and (d)
SAMPLE UNIT 2 (PEAT) WATERS

(c) Total Residue (T.R.)(mg/l)

DATE	SAMPLE WELLS 1-B	1-J	1-M	2-A	3-A
Feb.2	160	-	-	960	-
Feb.5	210	-	-	780	-
Mar.1	130	210	-	8	530
Mar.26	110	210	-	590	530
May 14	130	190	130	530	500
Oct.19	150	180	-	240	500

(d) pH

DATE	SAMPLE WELLS 1-B	1-J	1-M	2-A	3-A
Feb.2	-	-	-	-	-
Feb.5	6.0	-	-	12.0	-
Mar.1	6.3	6.1	-	-	8.7
Mar.26	6.2	6.2	-	11.8	7.6
May 14	6.4	6.3	4.6	11.9	7.4
Oct.19	6.4	6.3	-	10.5	6.8

TABLE 7(e)
SAMPLE UNIT 2(PEAT) WATERS

(e) Organic and Inorganic Carbon (mg/l)

DATE	Org./ Inorg.	SAMPLE WELLS 1-B	1-J	1-M	2-A	3-A
Feb.2	Org.	25	-	-	18	-
	Inorg.	39	-	-	10	-
Feb.5	Org.	24	-	-	18	-
	Inorg.	40	-	-	8	-
Mar.1	Org.	24	48	-	-	88
	Inorg.	34	60	-	-	48
Mar.26	Org.	-	56	55	-	109
	Inorg.	-	62	28	-	63
May 14	Org.	28	55	-	24	112
	Inorg.	38	55	-	6	68
Oct.19	Org.	25	36	-	22	72
	Inorg.	-	-	-	-	-

TABLE 7 (f) and (g)
SAMPLE UNIT 2 (PEAT) WATERS

(f) Hardness (as $CaCO_3$)(mg/l)

DATE	SAMPLE WELLS 1-B	1-J	1-M	2-A	3-A
Feb.2	64	-	-	830	-
Feb.5	52	-	-	725	-
Mar.1	49	65	-	-	225
Mar.26	38	55	-	475	235
May 14	56	54	7.4	425	235
Oct.19	67	58	-	142	205

(g) Alkalinity (as $CaCO_3$)(mg/l)

DATE	SAMPLE WELLS 1-B	1-J	1-M	2-A	3-A
Feb.2	-	-	-	-	-
Feb.5	-	-	-	-	-
Mar.1	46	69	-	-	510
Mar.26	35	66	-	480	230
May 14	42	56	<1	450	220
Oct.19	-	-	-	-	-

TABLE 7(h) and (i)
SAMPLE UNIT 2 (PEAT) WATERS

(h) Sulphate (SO_4)(mg/l)

DATE	SAMPLE WELLS 1-B	1-J	1-M	2-A	3-A
Feb.2	5	-	-	90	-
Feb.5	14	-	-	210	-
Mar.1	7	37	-	-	72
Mar.26	4	12	-	48	23
May 14	8	15	18	87	14
Oct.19	2.5	9.1	-	18	18

(i) Ammonia (NH_3)(mg/l)

DATE	SAMPLE WELLS 1-B	1-J	1-M	2-A	3-A
Feb.2	1.2	-	-	5.8	-
Feb.5	1.6	-	-	6.8	-
Mar.1	1.8	4.3	-	-	1.0
Mar.26	-	2.9	-	-	0.98
May 14	2.2	3.0	2.3	4.3	2.4
Oct.19	5.9	3.6	-	4.3	3.5

TABLE 7 (j) and (k)
SAMPLE UNIT 2 (PEAT) WATERS

(j) Chloride (Cl)(mg/l)

DATE	SAMPLE WELLS 1-B	1-J	1-M	2-A	3-A
Feb.2	6.5	-	-	10	-
Feb.5	5.1	-	-	0.03	-
Mar.1	8.0	8	-	-	6
Mar.26	600	7.4	-	8.5	7.5
May 14	6	7.5	7.5	5	9.5
Oct.19	5.7	6.8	-	4.9	20

(k) Iron (Fe)(mg/l)

DATE	SAMPLE WELLS 1-B	1-J	1-M	2-A	3-A
Feb.2	18	-	-	0.19	-
Feb.5	9	-	-	0.15	-
Mar.1	18	12	-	-	1.0
Mar.26	9.7	13	0.85	1.9	-
May 14	16	13	0.80	0.15	6.3
Oct.19	20	13	-	0.28	7.2

TABLE 7 (l)(m)
SAMPLE UNIT 2 (PEAT) WATERS

(l) Calcium (mg/l)

DATE	1-B	1-J	SAMPLE WELLS 1-M	2-A	3-A
Feb.2	8.8	-	-	330	-
Feb.5	4.8	-	-	290	-
Mar.1	4.2	13	-	-	78
March 26	4.8	10	-	190	80
May 14	7.5	9.8	1.0	170	78
Oct.19	9	12	-	57	66

(m) Magnesium (mg/l)

DATE	1-B	1-J	SAMPLE WELLS 1-M	2-A	3-A
Feb.2	2.5	-	-	0.35	-
Feb.5	2.3	-	-	0.20	-
Mar.1	2.6	2.6	-	-	6.8
March 26	2.0	1.8	-	0.12	8
May 14	2.2	1.5	0.85	0.07	7.8
Oct.19	2	1.1	-	0.16	6.7

TABLE 7 (n) and (o)
SAMPLE UNIT 2 (PEAT) WATERS

(n) Sodium (Na)(mg/l)

DATE	SAMPLE WELLS 1-B	1-J	1-M	2-A	3-A
Mar.2	-	5.9	-	-	10
Mar.26	6.0	4.8	-	11	10
May 14	5.8	4.3	3.8	11	11
Oct.19	5.0	3.7	-	7.5	12

(o) Chromium (Cr)(mg/l)

DATE	SAMPLE WELLS 1-B	1-J	1-M	2-A	3-A
Mar.26	0.03	0.02	-	0.03	0.03
May 14	<0.02	0.02	0.02	<0.02	0.02
Oct.19	<0.02	<0.02	-	<0.02	<0.02

TABLE 7 (p) and (q)
SAMPLE UNIT 2 (PEAT) WATERS

(p) Nickel (Ni)(mg/l)

DATE	SAMPLE WELLS 1-B	1-J	1-M	2-A	3-A
Mar.26	<0.05	<0.05	-	<0.05	<0.05
May 14	<0.01	<0.01	<0.01	<0.01	<0.01
Oct.19	<0.05	<0.05	-	<0.05	<0.05

(q) Zinc (Zn)(mg/l)

DATE	SAMPLE WELLS 1-B	1-J	1-M	2-A	3-A
Mar.26	0.13	0.15	-	0.03	0.04
May 14	0.17	0.08	0.06	0.03	0.05
Oct.19	0.09	0.05	-	0.02	0.04

TABLE 8(a) and (b)
WATER QUALITY DATA RELATED TO SIX WELLS
LOCATED TO SAMPLE UNIT 3 (SILTY SANDS) WATERS (FEB.2 TO OCT.19, 1976)

(a) Chemical Oxygen Demand (COD)(mg/l)

DATE	SAMPLE WELLS 1-C	1-F	1-I	3-D	3-F	C.W.*
Feb.2	34	100	-	-	-	-
Feb.5	53	86	-	-	460	-
Mar.1	40	210	510	140	43	-
Mar.26	40	67	39	86	35	-
May 14	51	51	47	74	160	47
Oct.19	51	51	59	87	47	-

(b) Specific Conductance (micromhos/cm)

DATE	SAMPLE WELLS 1-C	1-F	1-I	3-D	3-F	C.W.*
Feb.2	365	453	-	-	-	-
Feb.5	355	463	-	-	36.8	-
Mar.1	353	510	233	260	310	-
Mar.26	303	820	220	200	310	-
May 14	365	840	243	188	328	333
Oct.19	392	495	280	205	324	-

*C.W. = Control Well

TABLE 8(c) and (d)
SAMPLE UNIT 3 (SILTY SANDS) WATERS

(c) Total Residue (T.R.)(mg/l)

DATE	SAMPLE WELLS 1-C	1-F	1-I	3-D	3-F	C.W.*
Feb.2	350	380	-	-	-	-
Feb.5	160	350	-	-	-	-
Mar.1	-	-	220	250	260	-
Mar.26	200	520	220	270	220	-
May 14	310	600	200	210	270	340
Oct.19	290	340	280	290	310	-

(d) pH

DATE	SAMPLE WELLS 1-C	1-F	1-I	3-D	3-F	C.W.*
Feb.2	-	-	-	-	-	-
Feb.5	6.8	6.8	-	-	-	-
Mar.1	7.1	6.8	6.9	6.5	7.0	-
Mar.26	6.7	6.2	6.9	6.6	7.2	-
May 14	7.1	5.0	6.7	6.9	7.3	7.0
Oct.19	7.4	6.9	6.0	7.9	8.1	-

*C.W. = Control Well

TABLE 8(e)
SAMPLE UNIT 3 (SILTY SANDS) WATERS

(e) Organic and Inorganic Carbon (mg/l)

DATE	Org./ Inorg.	SAMPLE WELLS 1-C	1-F	1-I	3-D	3-F	C.W.*
Feb.2	Org.	18	31	-	-	-	-
	Inorg.	68	57	-	-	-	-
Feb.5	Org.	12	20	-	-	112	-
	Inorg.	66	62	-	-	6	-
Mar.1	Org.	11	21	17	34	16	-
	Inorg.	52	58	44	52	50	-
Mar.26	Org.	-	-	15	24	12	-
	Inorg.	-	-	48	50	54	-
May 14	Org.	22	24	21	22	18	23
	Inorg.	68	56	42	38	54	82
Oct.19	Org.	18	16	18	18	16	-
	Inorg.	-	-	-	-	-	-

*C.W. = Control Well

TABLE 8(f) and (g)
SAMPLE UNIT 3 (SILTY SANDS) WATERS

(f) Hardness (as Ca CO_3)(mg/l)

DATE	SAMPLE WELLS 1-C	1-F	1-I	3-D	3-F	C.W.*
Feb.2	150	143	-	-	-	-
Feb.5	121	116	-	-	8.9	-
Mar.1	140	170	122	147	165	-
Mar.26	99	130	105	106	134	-
May 14	156	142	96	108	140	168
Oct.19	176	82	142	135	178	-

(g) Alkalinity (as Ca CO_3)(mg/l)

DATE	SAMPLE WELLS 1-C	1-F	1-I	3-D	3-F	C.W.*
Feb.2	-	-	-	-	-	-
Feb.5	-	-	-	-	-	-
Mar.1	155	135	110	100	150	-
Mar.26	130	85	120	120	160	-
May 14	170	35	130	87	160	170
Oct.19	190	24	102	76	128	-

*C.W. = Control Well

TABLE 8 (h) and (i)
SAMPLE UNIT 3 (SILTY SANDS) WATERS

(h) Sulphate (SO_4)(mg/l)

DATE	SAMPLE WELLS 1-C	1-F	1-I	3-D	3-F	C.W.*
Feb.2	3	10	-	-	-	-
Feb.5	90	15	-	-	4	-
Mar.1	5	10	16	18	66	-
Mar.26	3.2	2.0	10	17	5.4	-
May 14	6	2	7	13	6	2
Oct.19	4.8	5.4	6.8	9	3.3	-

(i) Ammonia (NH_3)(mg/l)

DATE	SAMPLE WELLS 1-C	1-F	1-I	3-D	3-F	C.W.*
Feb.2	5.5	2.3	-	-	-	-
Feb.5	3.9	2.4	-	-	0.046	-
Mar.1	3.4	2.8	5.0	1.3	4.3	-
Mar.26	-	-	4.1	1.9	4.3	-
May 14	4.5	5.0	5.0	2.0	4.8	4.6
Oct.19	5.4	5.7	4.9	3.5	4.3	-

*C.W. - Control Well

TABLE 8(j) and (k)
SAMPLE UNIT 3 (SILTY SANDS) WATERS

(j) Chloride (Cl)(mg/l)

DATE	SAMPLE WELLS 1-C	1-F	1-I	3-D	3-F	C.W.*
Feb.2	18	47	-	-	-	-
Feb.5	16	55	-	-	5.0	-
Mar.1	17	77	11	11	7.0	-
Mar.26	110	180	3.9	7.8	6.8	-
May 14	10	230	3.5	7.5	180	7.5
Oct.19	8.6	110	4.3	8.0	6.0	-

(k) Iron (Total)(Fe)(mg/l)

DATE	SAMPLE WELLS 1-C	1-F	1-I	3-D	3-F	C.W.*
Feb.2	17	13	-	-	-	-
Feb.5	18	18	-	-	0.38	-
Mar.1	13	18	12	30	15	-
Mar.26	10	16	12	29	17	-
May 14	20	15	13	28	20	38
Oct.19	28	9.1	18	31	24	-

*C.W. = Control Well

TABLE 8(1) and (m)
SAMPLE UNIT 3 (SILTY SANDS) WATERS

(1) Calcium (mg/1)

DATE	SAMPLE WELLS 1-C	1-F	1-I	3-D	3-F	C.W.*
Feb.2	21	26	-	-	-	-
Feb.5	11	12	-	-	2.8	-
Mar.1	19	28	19	19	24	-
Mar.26	9.4	11	12	7.5	10	-
May 14	22	18	9.3	9.4	12	17
Oct.19	24	12	21	17	23	-

(m) Magnesium (mg/1)

DATE	SAMPLE WELLS 1-C	1-F	1-I	3-D	3-F	C.W.*
Feb.2	16	14	-	-	-	-
Feb.5	15	13	-	-	0.3	-
Mar.1	18	17	13	11	19	-
Mar.26	14	18	13	8.5	19	-
May 14	16	17	12	8.5	18	14
Oct.19	16	8.6	14	9.0	19	-

*C.W. = Control Well

TABLE 8(n) and (o)
SAMPLE UNIT 3 (SILTY SANDS) WATERS

(n) Sodium (Na)(mg/l)

DATE	SAMPLE WELLS 1-C	1-F	1-I	3-D	3-F	C.W.*
Feb.2	-	-	-	-	-	-
Feb.5	-	-	-	-	-	-
Mar.1	-	-	6.8	11	11	-
Mar.26	21	86	6.8	10	10	-
May 14	21	92	7.2	8.8	9.3	11
Oct.19	16	41	7.1	7.1	7.8	-

(o) Chromium (Cr)(mg/l)

DATE	SAMPLE WELLS 1-C	1-F	1-I	3-D	3-F	C.W.*
Feb.2	-	-	-	-	-	-
Feb.5	-	-	-	-	-	-
Mar.1	-	-	-	-	-	-
Mar.26	0.03	0.03	0.05	0.02	0.03	-
May 14	<0.02	<0.02	0.04	0.02	0.02	0.03
Oct.19	<0.02	<0.02	<0.02	<0.02	0.02	-

*C.W. = Control Well

TABLE 8(p) and (q)
SAMPLE UNIT 3 (SILTY SANDS) WATERS

(p) Nickel (Ni)(mg/l)

DATE	SAMPLE WELLS 1-C	1-F	1-I	3-D	3-F	C.W.*
Feb.2	-	-	-	-	-	-
Feb.5	-	-	-	-	-	-
Mar.1	-	-	-	-	-	-
Mar.26	<0.05	<0.05	<0.05	<0.05	<0.05	-
May 14	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Oct.19	<0.05	<0.05	<0.05	<0.05	<0.05	-

(q) Zinc (Zn)(mg/l)

DATE	SAMPLE WELLS 1-C	1-F	1-I	3-D	3-F	C.W.*
Feb.2	-	-	-	-	-	-
Feb.5	-	-	-	-	-	-
Mar.1	-	-	-	-	-	-
Mar.26	0.03	0.03	0.03	0.02	0.05	-
May 14	0.04	0.03	0.07	0.05	0.05	0.04
Oct.19	0.03	0.04	0.05	0.05	0.04	-

*C.W. = Control Well

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APPENDIX A

SITE SPECIFICATIONS

(with appended pertinent part of schedule
of the Agreement with the Township of the
Corporation of Richmond)

FRASER RIVER HARBOUR COMISSION

NEW WESTMINSTER, B.C.

CONSTRUCTION OF SANITARY LAND FILL

RICHMOND, B.C.

DETAILED SPECIFICATIONS

Ref. Plan No. 0153-34

These specifications have been extracted (and modified) from the "Invitation to Submit and Proposals for the Construction of Refuse Land Fill".

These specifications are prepared to cover the technical aspects of the construction of the sanitary fill in Richmond, and will become a section of a contract document covering a contract to be entered into by the Fraser River Harbour Commission and the Operator.

Where reference is made to "governing authorities", such authorities shall be those as designated by the Commission, in other sections of the contract document.

Matters such as the sources of fill material, and all matters of contractual arrangements, the identification of "governing authorities", hours of operation, arrangements with Richmond should be included in other sections of the contract document.

On-site control of the filling operation will be through a representative to be named by the Fraser River Harbour Commission prior to commencement of the work.

DETAILED SPECIFICATIONS

INDEX

1. General
2. Acceptable Materials
3. Unacceptable Materials
4. Separation of Materials
5. Surface Drainage
6. Service Corridor
7. Placement of Materials and Sand Cover
   - Class 1 Fill
   - Class 2 Fill
   - Class 3 Fill
8. Settlement Tests
9. Fencing
10. Inspection by the Commission and Others
11. Control of Wind-Borne Paper
12. Control of Odors
13. Control of Dust
14. Control of Rodents
15. Control of Fire
16. Salvage
17. Protection of Gas Main
18. Protection of Range Lights
19. Operation Management

DETAILED SPECIFICATIONS

1. General

The construction of the land fill is to be considered as an engineering project with two specific aims:

(a) The construction of a sanitary land fill, carried out without creating nuisances or hazard to public health or safety. The operation is to be carried out in accordance with the requirements of governing health and pollution authorities.

(b) The construction of a land fill of the highest possible quality with regard to subsequent utilization of the land as an industrial building site. The object of the undertaking is to produce ground with highest and most stable bearing capacity possible considering the nature of the operation.

In regard to paragraph (a) above it is anticipated that faithfully executed routines based on good practice will enable the operator to meet the health and nuisance requirements with a minimum of unanticipated problems. Periodic tests carried out by a recognized agency or laboratory may be required from time to time to prove the acceptability of leachates from the land fill materials.

In regard to paragraph (b) above, the construction of good building ground will require the utmost care and conscientious application by the operator. The entire area is underlain by peat of a depth up to 12 feet or more. In order for the final ground to be useful for building purposes, the peat must be compressed by the fill above, as much as possible.

The greatest compression in the peat will be obtained from the most densely compacted material above.

The highest possible compaction of the fill is therefore essential.

In order to determine the degree to which the peat is being compacted by the fill, elevation markers are to be installed as specified.

It cannot be accurately predicted how much the peat will compress, or to what exact extent the fill above will compress during compaction and during the decay process. Modifications of the planned sequence and height of filling may be necessary from time to time during the life of the operation and the operator may be required to adapt his operations, bearing in mind the extreme importance of producing a good building site.

Ultimate wharf deck elecations will be ± 20 ft. above sandheads datum with the land fill areas at ± 22 ft., to allow drainage contouring. Similarly, roadway elevations will be ± 22 ft. These final elevations combined with the underlying depth of peat and the time available for settlement will determine the amount of surcharging required.

Compaction of the fill is to be achieved by crawler tractor having at least the equivalent weight of a D6 Caterpiller directly on the fill, then by a sheepsfoot roller or equivalent on top of the sand cover.

The attached plan, C154-34, shows how the property is to be considered in various parcels for the purpose of planning the filling operation. Using this plan as a reference, the following sequence of work and materials utilization is contemplated. The actual program will be adjusted by the Engineer in the field to accomodate the characteristics of the material delivered, field conditions, the operator's procedure and available quantity of each class of material.

SEQUENCES

Start west end Area 1 and south end strip 2, Area 2
Complete Area 1, continue Area 2
Start south end No. 8 Road, continue Area 2
Complete No. 8 Road, continue Area 2
Complete Area 5, continue Area 2
Complete Blundell Road, complete Area 2
Complete Area 3, complete Area 6
Complete Area 4, complete area 7

The access road on the west boundary and the embankment for protection of the gas main will be fitted into the sequence as required in the field.

MATERIAL UTILIZATION

(See Clause 4 for material classification)

AREA 1 Class 2 mattress topped with Class 1 and/or hydraulic sand depending on availability of Class 1 material.

AREAS 2, 3, 4

Class 2 mattress topped with Class 3 material and sand dressing as specified. Should there be insufficient Class 2 material to provide a mattress in Areas 2,3, and 4, then Class 3 material only will be allowed, with the sand dressing as specified.

AREAS 5, 6, 7

Class 2 mattress topped with Class 1 and/or hydraulic sand depending on availability of Class 1 material.

ROADS Class 2 mattress topped with Class 1 material and dressed with sand as specified. Shoulder berms, i.e. widening of the underlying layer, will be formed as road filling progresses, to ensure against shear failure at the toe line. The mattress specified above will be minimum 3 ft. in thickness, after compaction.

The hydraulic sand filling noted above may be carried out by others, on a periodic basis, and the operator will adjust his program as may be found necessary at the time to allow for this.

120,000 YD^3 min. sand/yr. will be delivered to stockpile for placement by the operator. Additional sand required for covering the fill will be the operator's responsibility.

Lines and grades for layout purposes will be set in the field by the Commission's representative. However, it will be the operator's responsibility to set stakes as necessary for control of his day-to-day operation.

2. Acceptable Materials

Materials which will be allowed in the refuse fill, include the following;

(a) Materials obtained from the demolition of structures.

(b) Paper and paper producrs.

(c) Municipal refuse with the exception of materials listed below as being unacceptable.
On-site brush may be covered. Trees over 4 inches in diameter will be cut and placed to form a mattress.

3. Unacceptable Materials

Materials which will not be allowed in the refuse fill include the following:

(a) Industrial process wastes including:
Volatile matter
Lime (except debris from building demolition)
Packinghouse wastes
Oil, except that oil may be used for laying of dust on roads and on the fill providing it is sprayed on with proper equipment, Bulk oil must not be deumped into the fill.
Oil must be received and kept in storage tanks at the site for subsequent spraying on the fill.

(b) Construction rubble of masonry or concrete which has a maximum dimension of more than two feet. Such rubble must be broken into smaller pieces. Two considerations govern this requirement:

(i) The difficulty of driving piling in the future through such material.

(ii) The difficulty of filling voids between large pieces hence the difficulty in obtaining a dense, well-graded fill. Large voids may also harbour rats.
This requirement will be enforced in Areas 1,5,6 and 7. Should large dimension rubble be delivered to the site in quantity, the engineer will designate an area and method for its utilization as a fill material.

(c) Clay from excavations, except that clay may be accepted providing it is spread in layers not exceeding one foot in depth, depending on the type of clay.

(d) Trees or timbers with a through dimension greater than 12 in. or a length greater than 10' will not be allowed except in an area which may be designated by the engineer for such material.

(e) Dead animals.

4. Separation of Materials

Separation of materials as specified and placed in accordance with the attached plan will be the operator's responsibility. Any deviation in the basic terms of reference must be approved by the Commission.

Class 1

Masonary rubble, concrete rubble, stone rubble, soil from excavations and other dense material that will not decay.

Class 2

Waste lumber.

Class 3

Municipal refuse, paper, ashes, allowable putrescible material and other wastes which present a health hazard.

5. Surface Drainage

Each finished, covered layer of fill is to be sloped and graded so as to avoid the accumulation of surface water. If in the opinion of the Commission, excessive water will accumulate or has accumulated, then the Commission may direct low areas to be filled with sand.

6. Service Corridor

After completion of No. 8 Road, a service corridor will be constructed of sand along its full length. The corridor will be excavated to provide for placement of a minimum 3 ft. thickness of sand, 8 ft. in width. The service corridor will be constructed by others or by the operator on a cost-plus basis on instruction by the Commission. The ditch along the existing dyke will be filled with sand by others to provide for a service corridor to the east.

7. Placement of Materials and Sand Cover

Class 1 Fill

This class of material which is generally not-putrescible, non-combustible, and not subject to decay, is to be placed in the area designated. It is expected to be material containing large voids which must be filled with sand in order to produce a high density material. Except in Area 1 where sand will be placed hydraulically by others, Class 1 Fill is to be placed in four-foot layers, then compacted with a crawler tractor or other vehicle, then covered with a layer of sand which is compacted and worked into the voids with a sheepsfoot roller or equivalent.

Class 1 Fill may be covered as soon as a four-foot layer has been placed, however, at the operator's option, cover need not be placed more frequently than once per calendar month. It must be covered at least once per calendar month.

Alternate procedures for placement of Class 1 Fill will be entertained. For example, certain Class 1 Fill may be suitable for cover material in place of sand, for construction of service roads or other similar use.

Class 2 Fill

This class of material, which is lumber from demolition, or other waste lumber, is to be placed in the area designated. Two hazards exist in the handling of this material, namely fire, and the difficulty of altering the dumped material into a dense fill.

This class of fill is to be placed in layers, which when compacted are not thicker than six feet. After the loose material has been dumped it shall be broken up, crushed and compacted by a sufficient number of passes with a crawler tractor or other vehicle to produce a dense fill, and by not less than six passes of the tractor.

In order to prevent fire, this class of material is to be covered with a six inch layer of sand on the completion of each day's dumping, or at least once in ev ery 24 hour period if the dump is open continuously, except that this fire preventative measure shall not be required from November 1 until May 1 of each year.

Class 3 Fill

This class of material, which is generally municipal and commercial waste, comprises the sanitary fill. It is to be placed in the area designated.

The material is to be dumped, and spread in layers having a loose thickness not greater than eight feet, compacted with a crawler tractor, and covered daily, including the sloping face, with not less than one foot of sand. The possibility of using layers greater than 8' thick will be considered only after a procedure of compaction has been established and it can be demonstrated that a greater thickness can be compacted to equal density.

Once during each calendar month the fill and cover placed during the previous six months is to be compacted with at least six repeated passes of a sheepsfoot roller of approved design. On completion of the program of monthly rolling for six months, a final one foot of sand is to be placed.

Should more than one layer of filling be required to bring an area to grade, the final one foot of sand dressing will only be applicable to the last layer of filling.

It is expected that some of the one foot of sand placed during the daily covering, and some of the final one foot of sand cover will be lost through infiltration and compaction. The final depth of sand cover will be judged to be adequate only if the depth

to any of the sanitary fill is 2'0" or greater. If the depth to any part of the sanitary fill is less than 2'0" then additional sand is to be added.

8. Settlement Tests

In order to establish the extent of the settlement of the peat as it is loaded by the fill, settlement gauges are to be installed on a grid of 600 feet in both directions or as directed by the engineer. A settlement gauge shall consist of a 3/16" thick steel plate 3'0" x 3'0" to the centre of which is securely welded with gussets a 2 inch diameter pipe of sufficient length to project above the final fill. The Commission will use this guage to determine the elevation of the top of the peat. The length of the pipe shall be approximately 14 feet.

9. Fencing

The operator shall provide such fencing as may be required to maintain security from unauthorized entry to the operation. Gates are to be provided which will establish the same degree of security as the fence.

Scales, gate houses, and other buildings are to be constructed as required by the operator, except that washrooms are to be provided in accordance with existing regulations.

10. Inspection by the Commission and Others

The Commission or its representative shall have the right to enter the property at any time for the purpose of ensuring that the work is being carried out in accordance with the contract and its specifications. The Commission reserves the right to order operations to cease, and entry prohibited at any time, without notice, if in its opinion the requirements of the contract are not being met. The Commission reserves the right to maintain closure until the omission or act is corrected, or if this is not done forthwith, to correct the omission or act with its own forces,

and to change the operator with the costs.

Other governmental au-thorities having jurisdiction by means of by-laws or acts shall be provided entry as required by law.

11. Control of Wind-Borne Paper

Every effort is to be made to control blowing paper, and specifically, snow fences of suitable length (or similar devices) are to be available on the site and utilized as required.

12. Control of Odors

Most sanitary fills are faced with an odor problem, however, this situation can be minimized by good operation. Odors can be controlled by care in placing of daily sand cover, giving special attention to putrescible material, the replacing of sand cover which blows away or is otherwise lost, and general good housekeeping.

The operator is to take whatever action is necessary to ensure that odors are reduced to a minimum.

13. Control of Dust

The operator must be prepared to take preventative action should wind blown dust become a nuisance or hazard to adjacent property.

14. Control of Rodents

A properly operated and maintained refuse fill can be rodent free.

The most important factors responsible for rodent control are: thorough compaction of the refuse, good housekeeping, and daily covering of the surface and sloping face of the fill.

The operator is required to do everything necessary to control rodents, and may be ordered by the Commission to take additional action should this become a problem.

15. Control of Fire

The operator shall take special precautions to prevent fire, and shall provide at all times on the site, an adequate supply of water than can be delivered to a fire should one start.

Fires can be prevented from starting by taking special care to thoroughly water down any load which is suspected of containing smouldering material, and by the routine soaking of ashes, should this material be delivered in any regular quantity.

Should a fire start on the surface, these can usually be extinquished by soaking with water.

Should a fire start below the surface of the fill, the burning area must immediately be dug out, re-spread, and thoroughly extinguished.

Should a fire start which proves difficult to extinguish, the Commission may prohibit further dumping until the fire is eliminated.

16. Salvage

The Operator may engage in salvaging material with his own forces but may not subcontract the rights to others. Salvaged materials are to be stored in fenced compounds on fully completed fill areas, and may not be stores at random throughout the area.

17. Protection of Gas Main

A major natural gas line is located several hundred feet east of and generally parallel to the east boundary of the property. The Operator must take precautions that his work on the fill site does not in any way harm this line. To prevent lateral displacement of underlying material in the vicinity of the main, the Operator will place and compact an embankment of Class 2 mattress topped with Class 3 surcharge in order to induce consolidation prior to adjacent filling in Areas 1, 5, 6 and 7. The embankment will have a minimum crest width of 12 ft., with widening of the shoulders as necessary to prevent shear failure at the toe. Sand dressing as specified under Class 7 will be utilized.

18. Protection of Range Lights

The Operator shall do everything necessary to ensure the security of the navigation range lights located on the property, and shall report to the Commission immediately, should they be disturbed in any way. Repair costs will be borne by the operator.

19. Operation Management

The management of the refuse fill shall be the full responsibility of the operator.

The inspection which will be provided by the Commission does not relieve the Operator from providing its own inspection, and the Commission's inspector does not have the authority to relax or alter these specifications. Any changes in the contract must be recorded in writing by both parties.

Schedule D, Part 6, Agreement with Corporation of Richmond.

No putrescrible materials from outside the Municipality shall be collected specifically for disposal at this site. Such putrescrible materials as may be received from outside the Municipality shall in no event exceed five (5%) per cent by volume of the carrying capacity of the transporting vehicle.

APPENDIX B

PIEZOMETER CONSTRUCTION
AND
INSTALLATION PROCEDURES

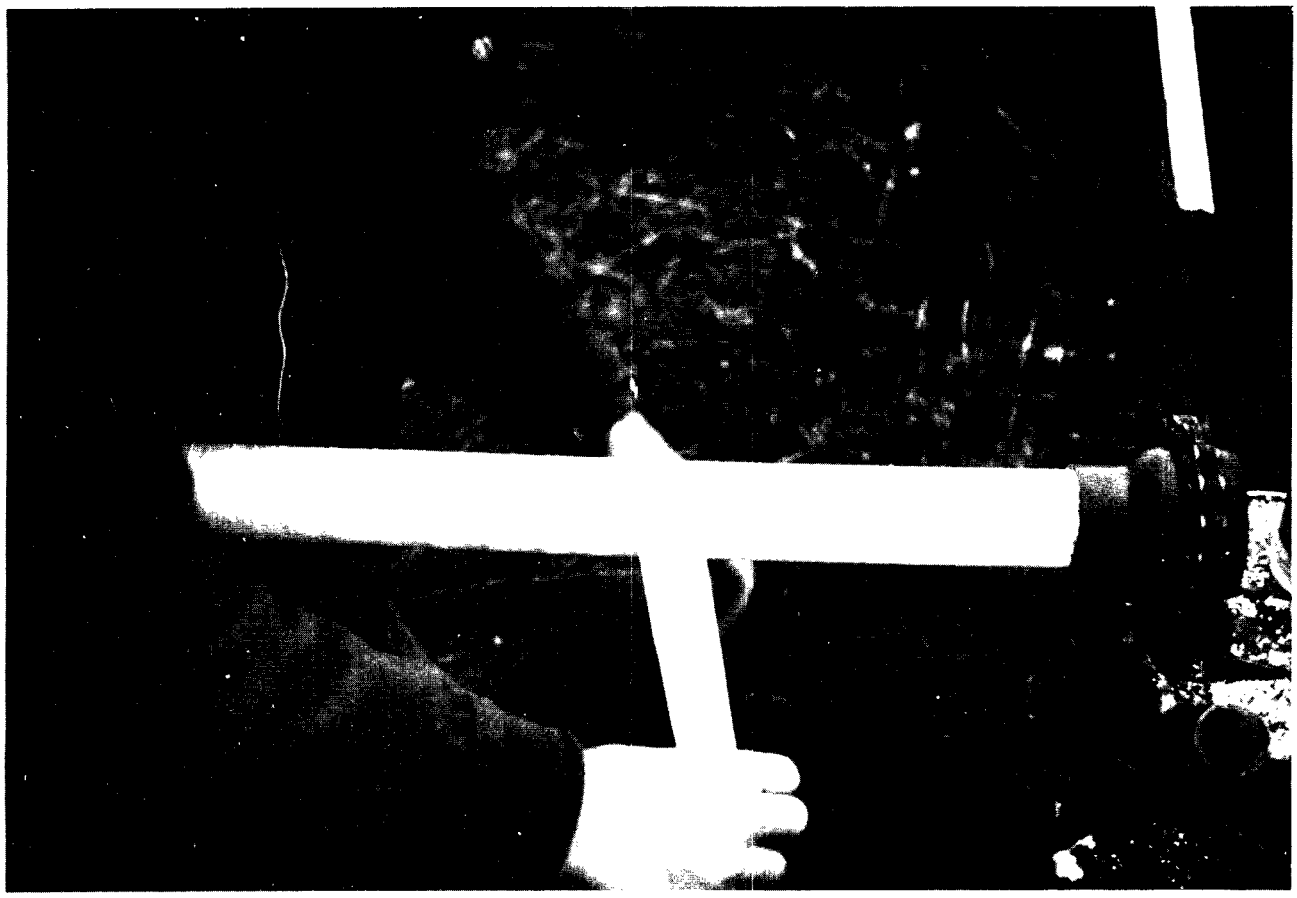


FIGURE B-1: WELL SCREEN CONSTRUCTION

- 2 ft. x 2 in. dia. PVC Pipe
- hacksaw slotted (36 slots - 180° apart)
- wrapped with fibreglass tape (glued)
- end cap and 3 in. x 2 in. reducer (glued)

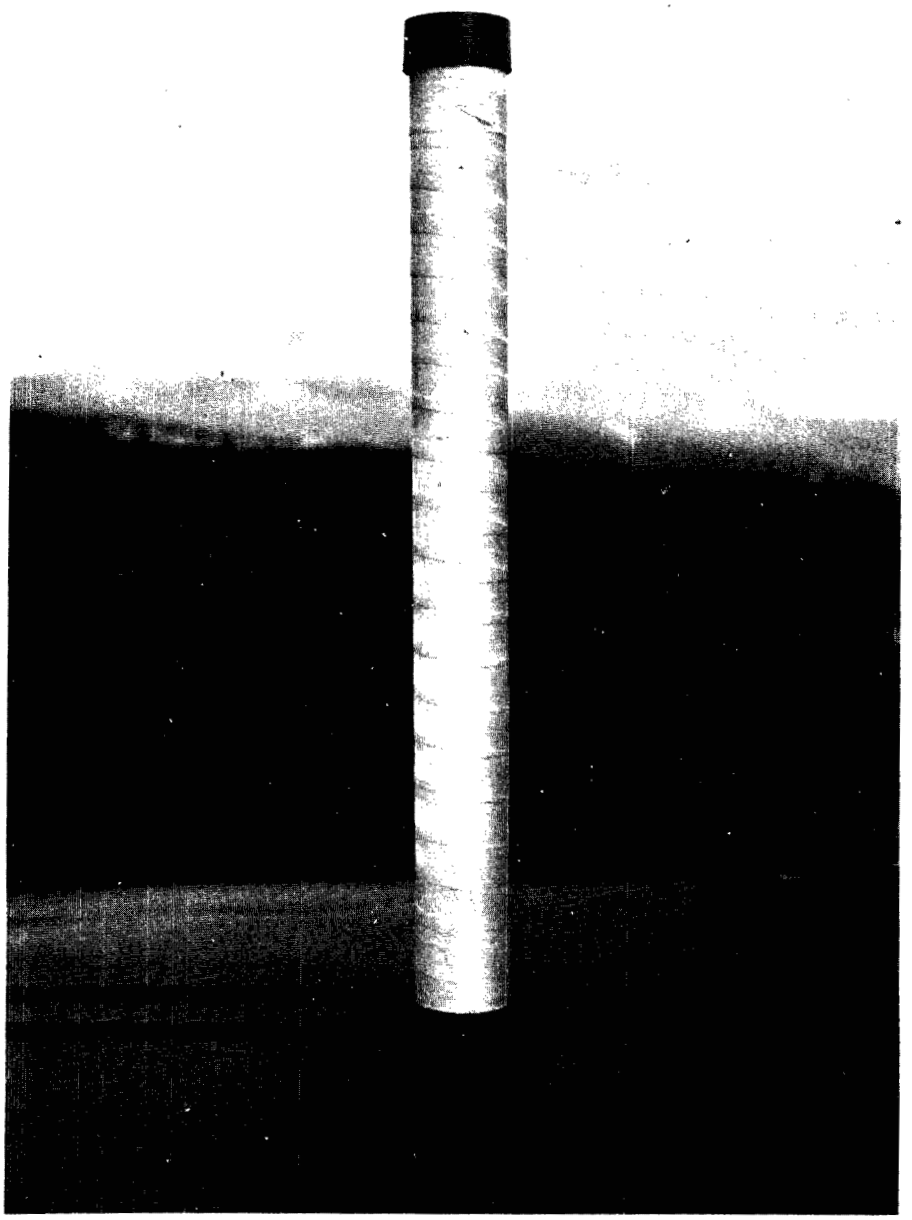


FIGURE B-2: COMPLETED WELL SCREEN

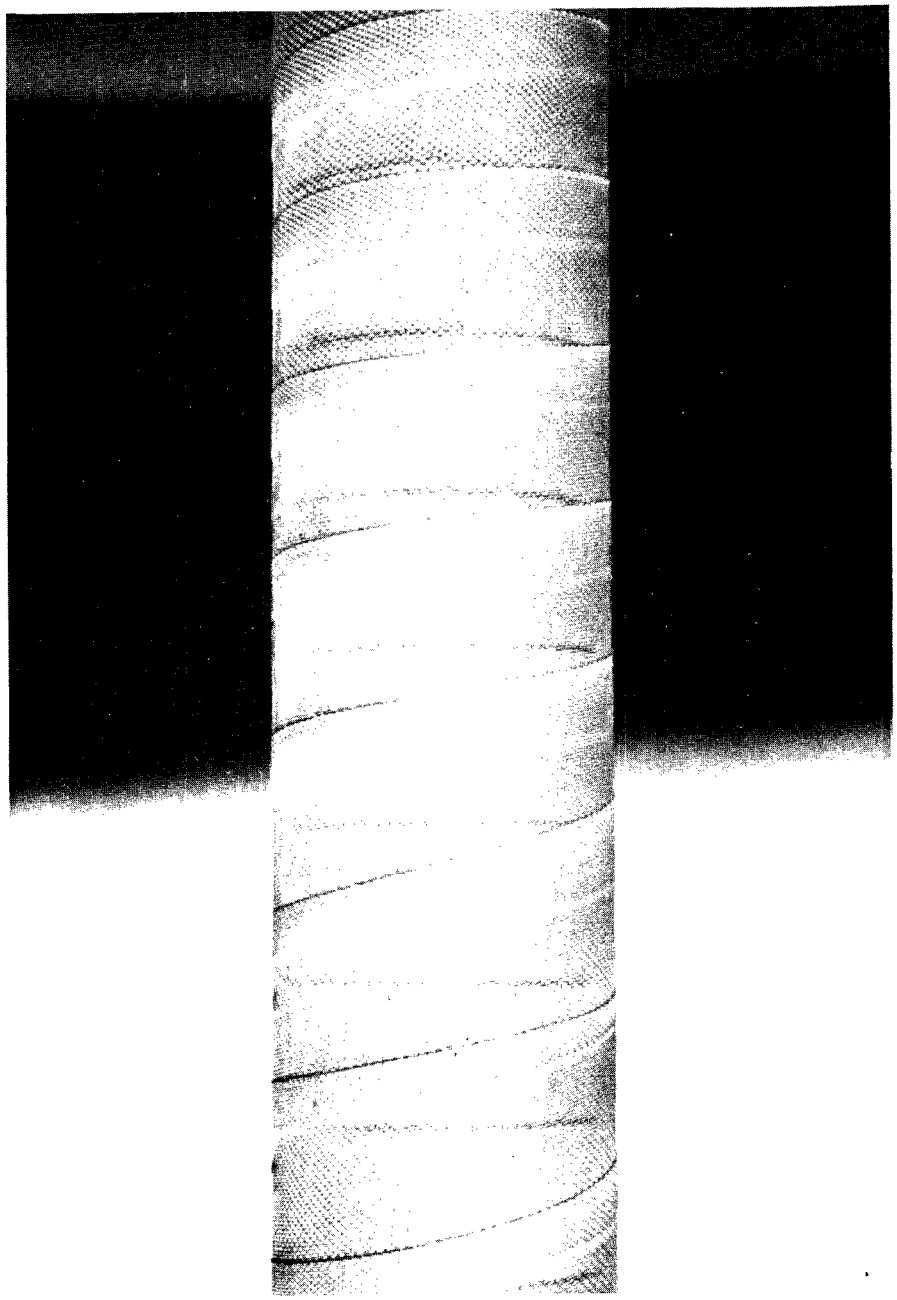


FIGURE B-3: WELL SCREEN SLOTS AND TAPE WRAPPING

FIGURE B-4: CLEANING WELL CASE

FIGURE B-5: WELL SCREEN ATTACHED TO CASING AND MEASURED

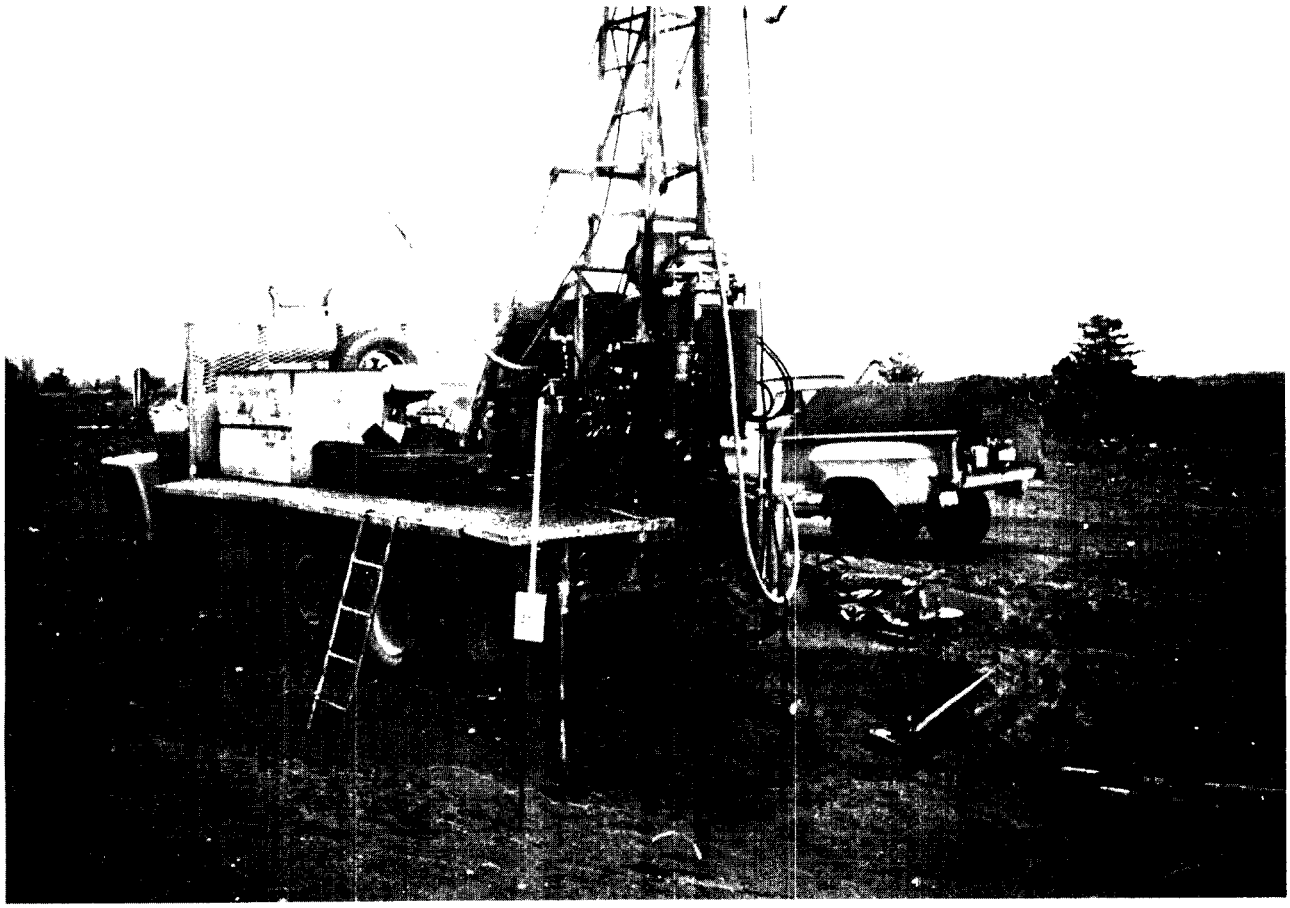


FIGURE B-6: DRILL RIG

FIGURE B-7: NOSE SAND PACK

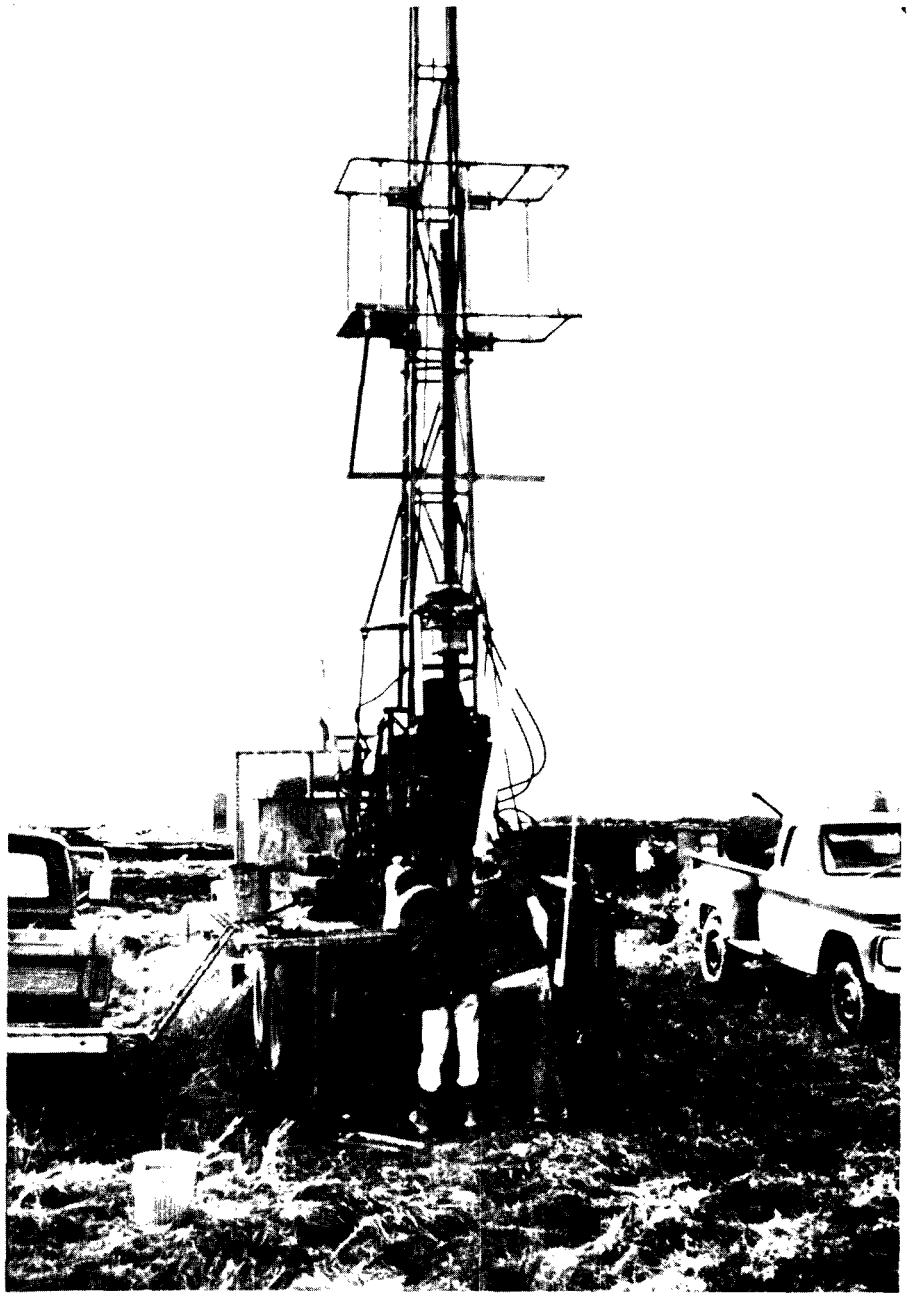


FIGURE B-8: WELL INSTALLATION IN DRILL CASING

FIGURE B-9: ADDITION OF WATER TO REDUCE BUOYANCY OF WELL

FIGURE B-10: F-16 MONTEREY SAND PACK AROUND WELL SCREEN

FIGURE B-11: PULL DRILLERS CASING

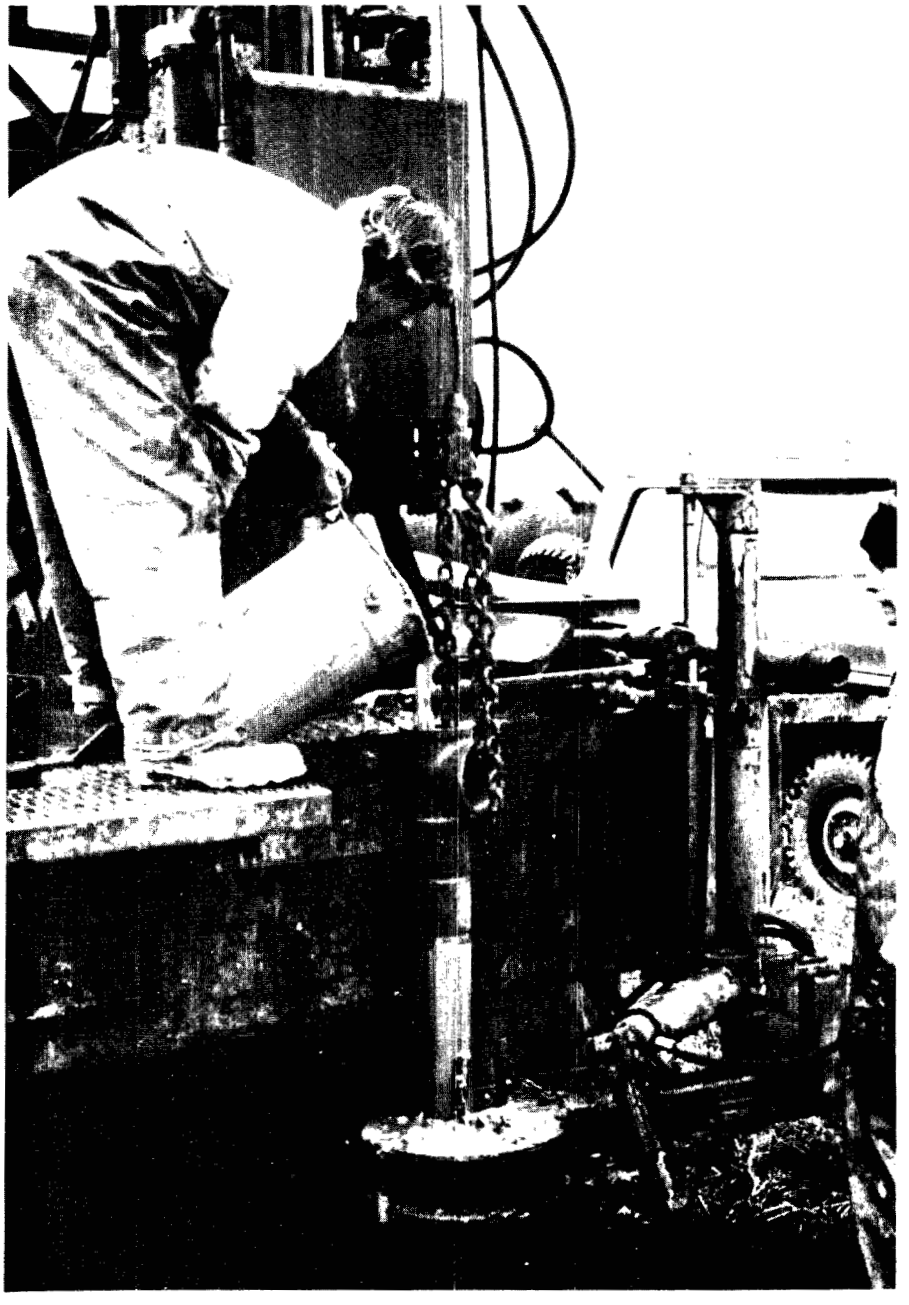


FIGURE B-12: BENTONITE SLURRY BACKFILL

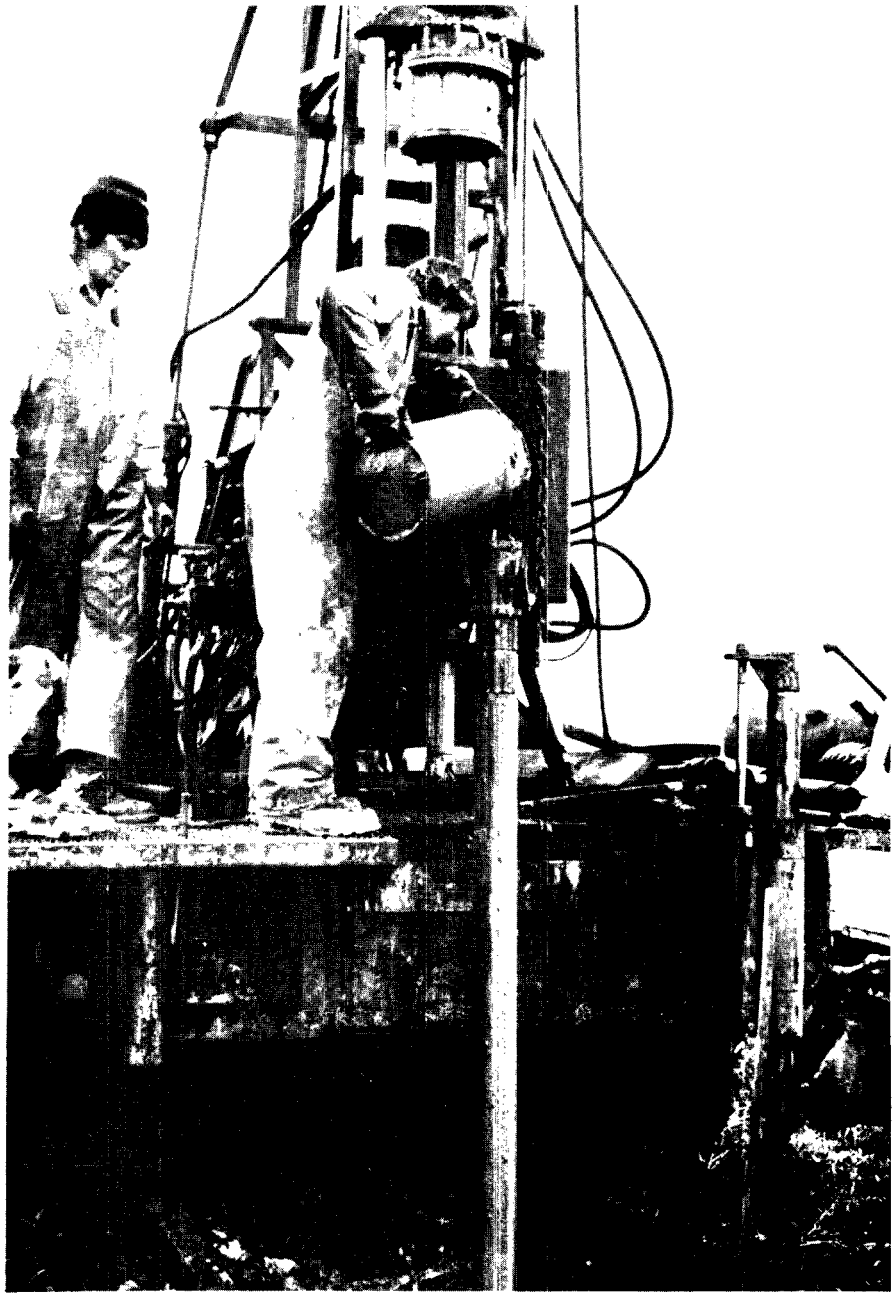


FIGURE B-13: CONTINUE BENTONITE BACKFILL AS DRILLERS CASING IS PULLED

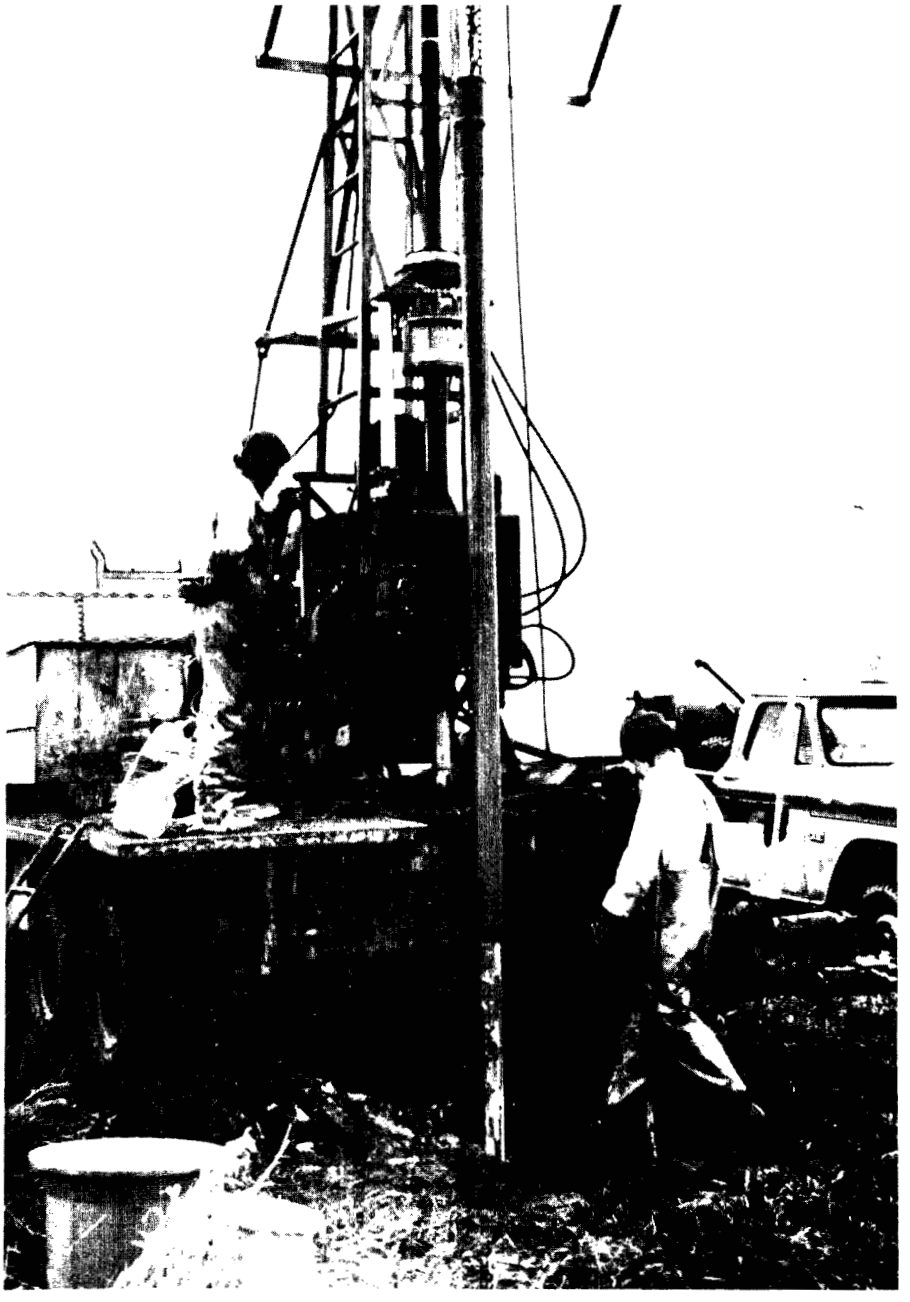
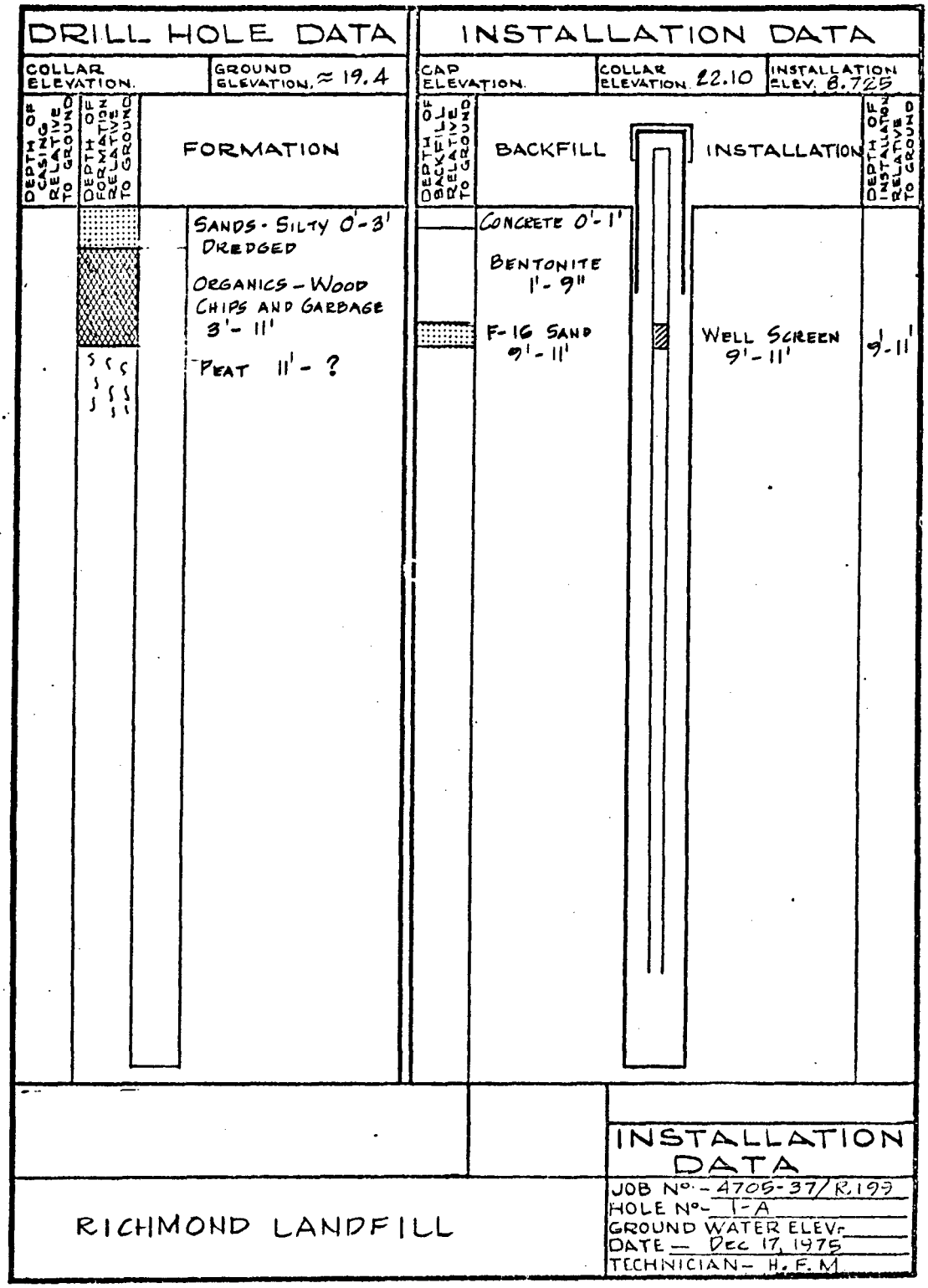


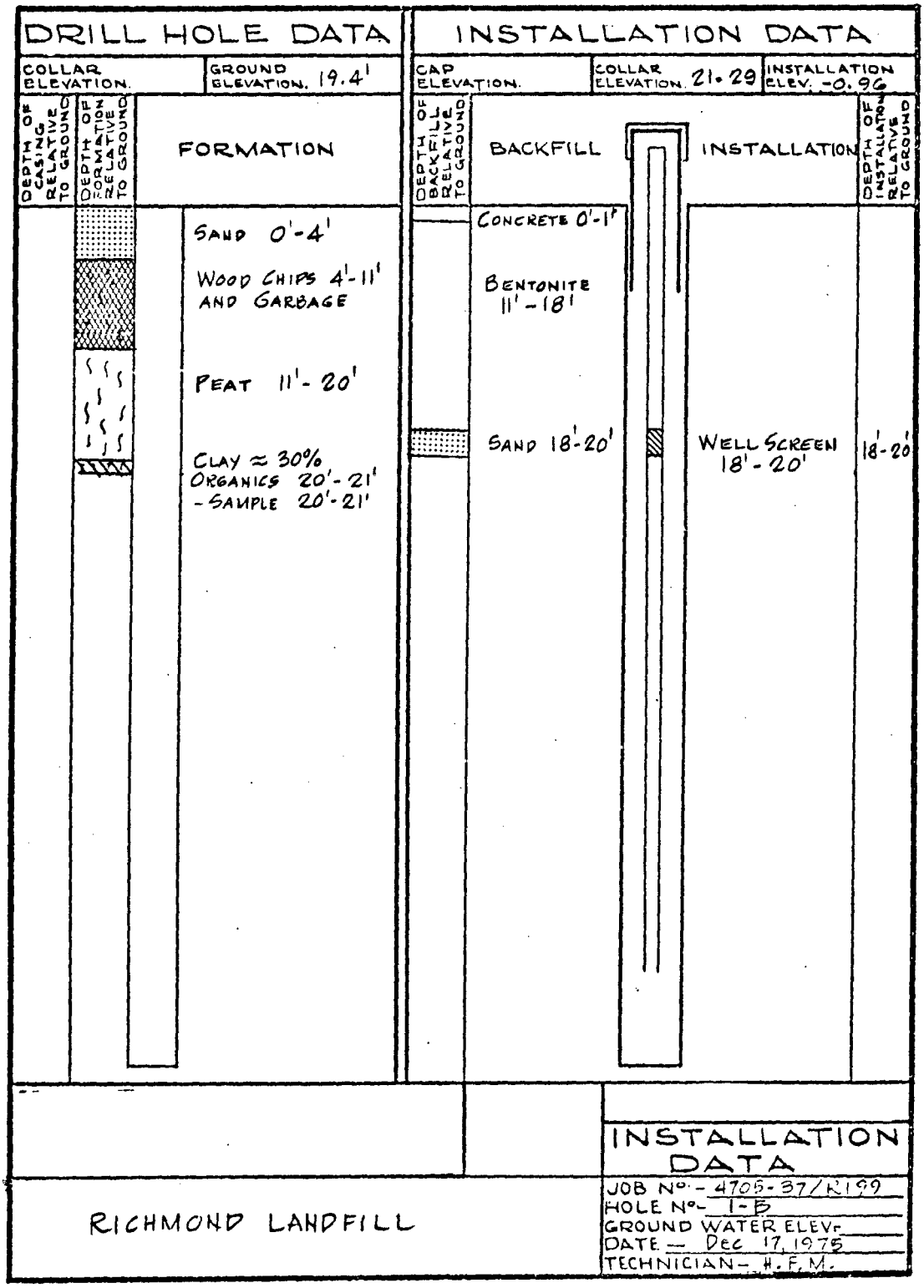
FIGURE B-14: COMPLETION OF DRILL CASING REMOVAL

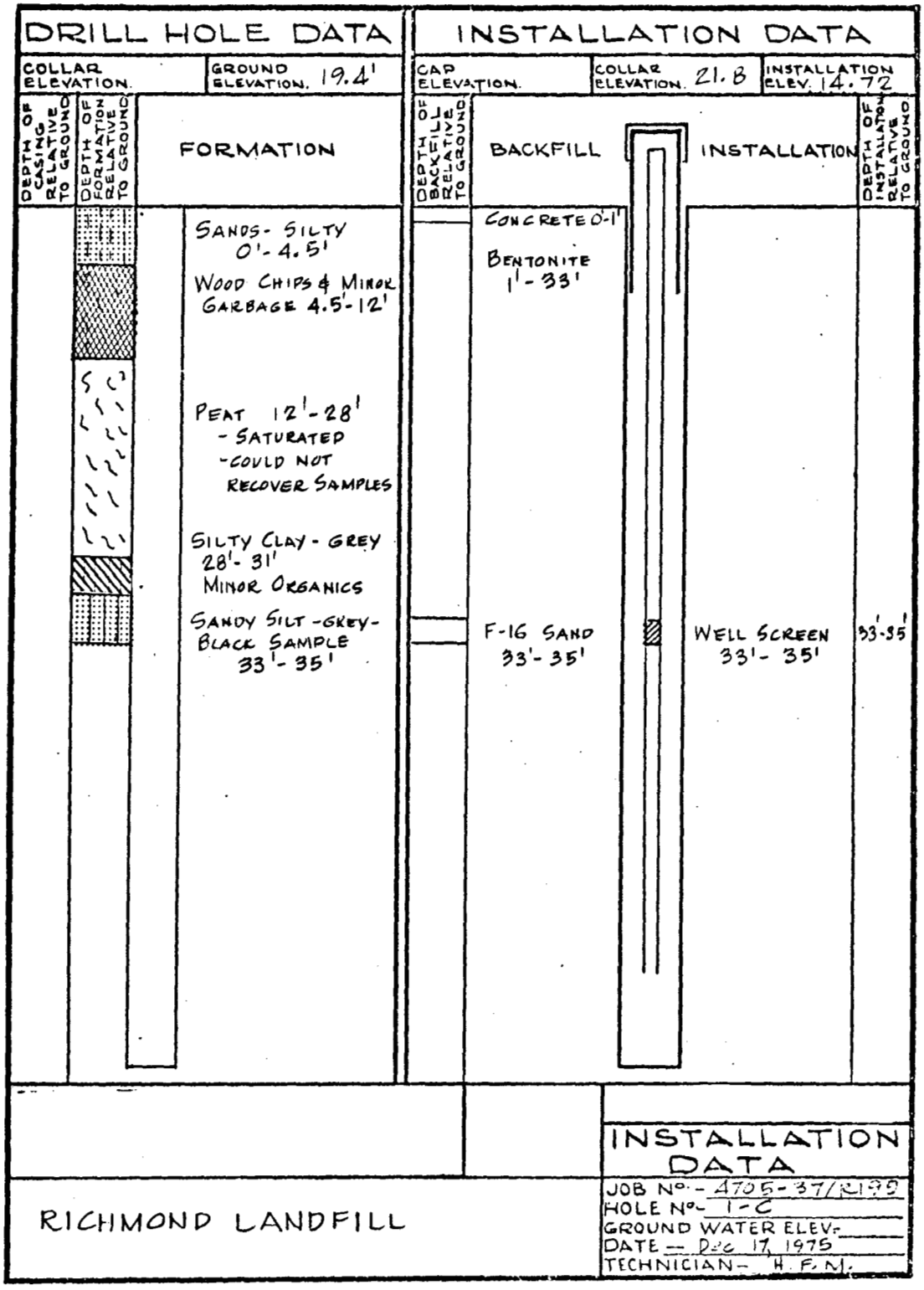
FIGURE B-15: COMPLETED WELL

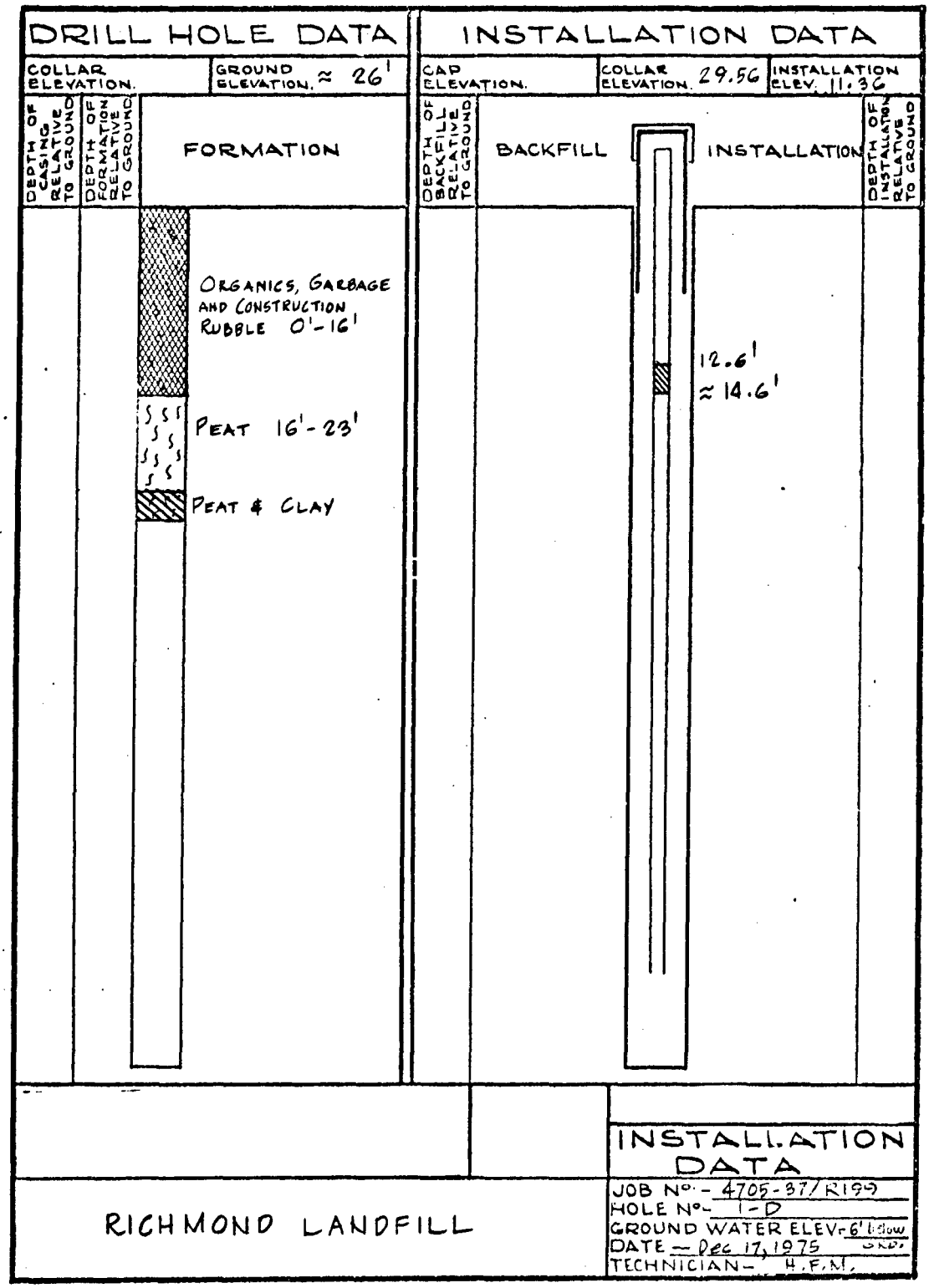
APPENDIX C

1975-76 DRILLING PROGRAM, BORE HOLE, AND HAND AUGER GEOLOGY LOG SHEETS, AND PIEZOMETER INSTALLATION ELEVATIONS


DRILL HOLE DATA
COLLAR ELEVATION.
GROUND ELEVATION. ≈ 19.4
DEPTH OF CASING RELATIVE TO GROUND
DEPTH OF FORMATION RELATIVE TO GROUND
FORMATION
SANDS - SILTY 0'-3' DREDGED
ORGANICS - WOOD CHIPS AND GARBAGE 3'- 11'
PEAT 11' - ?
INSTALLATION DATA
CAP ELEVATION.
COLLAR ELEVATION. 22.10
INSTALLATION ELEV. 8.725
DEPTH OF BACKFILL RELATIVE TO GROUND
BACKFILL
CONCRETE 0'-1'
BENTONITE 1'- 9"
F-16 SAND 9'- 11'
INSTALLATION
WELL SCREEN 9'- 11'
DEPTH OF INSTALLATION RELATIVE TO GROUND
9'-11'
INSTALLATION DATA
JOB No. - 4705-37/R.199
HOLE No. - T-A
GROUND WATER ELEV.
DATE - Dec 17, 1975
TECHNICIAN - H. F. M
RICHMOND LANDFILL


DRILL HOLE DATA
COLLAR ELEVATION.
GROUND ELEVATION. 19.4'
DEPTH OF CASING RELATIVE TO GROUND
DEPTH OF FORMATION RELATIVE TO GROUND
FORMATION
SAND 0'-4'
WOOD CHIPS 4'-11' AND GARBAGE
PEAT 11'-20'
CLAY ≈ 30%
ORGANICS 20'-21'
-SAMPLE 20'-21'
INSTALLATION DATA
CAP ELEVATION.
COLLAR ELEVATION. 21.29
INSTALLATION ELEV. -0.96
DEPTH OF BACKFILL RELATIVE TO GROUND
BACKFILL
INSTALLATION
DEPTH OF INSTALLATION RELATIVE TO GROUND
CONCRETE 0'-1'
BENTONITE 11'-18'
SAND 18'-20'
WELL SCREEN 18'-20'
18'-20'
INSTALLATION DATA
JOB No.- 4705-37/R199
HOLE No.- 1-B
GROUND WATER ELEV.
DATE — Dec 17, 1975
TECHNICIAN- H.F.M.
RICHMOND LANDFILL


DRILL HOLE DATA
COLLAR ELEVATION.
GROUND ELEVATION. 19.4'
DEPTH OF CASING RELATIVE TO GROUND
DEPTH OF FORMATION RELATIVE TO GROUND
FORMATION
SANDS- SILTY 0'-4.5'
WOOD CHIPS & MINOR GARBAGE 4.5'-12'
PEAT 12'-28' - SATURATED -COULD NOT RECOVER SAMPLES
SILTY CLAY - GREY 28'-31' MINOR ORGANICS
SANDY SILT -GREY-BLACK SAMPLE 33'-35'
INSTALLATION DATA
CAP ELEVATION.
COLLAR ELEVATION. 21.8
INSTALLATION ELEV. 14.72
DEPTH OF BACKFILL RELATIVE TO GROUND
BACKFILL
INSTALLATION
DEPTH OF INSTALLATION RELATIVE TO GROUND
CONCRETE 0'-1'
BENTONITE 1'-33'
F-16 SAND 33'-35'
WELL SCREEN 33'-35'
33'-35'
INSTALLATION DATA
JOB No.- 4705-37/R199
HOLE No.- 1-C
GROUND WATER ELEV.-
DATE -- Dec 17, 1975
TECHNICIAN- H. F. M.
RICHMOND LANDFILL


DRILL HOLE DATA
COLLAR ELEVATION.
GROUND ELEVATION. ≈ 26'
DEPTH OF CASING RELATIVE TO GROUND
DEPTH OF FORMATION RELATIVE TO GROUND
FORMATION
ORGANICS, GARBAGE AND CONSTRUCTION RUBBLE 0'-16'
PEAT 16'-23'
PEAT & CLAY
INSTALLATION DATA
CAP ELEVATION.
COLLAR ELEVATION. 29.56
INSTALLATION ELEV. 11.36
DEPTH OF BACKFILL RELATIVE TO GROUND
BACKFILL
INSTALLATION
DEPTH OF INSTALLATION RELATIVE TO GROUND
12.6'
≈ 14.6'
INSTALLATION DATA
JOB No. - 4705-37/R199
HOLE No. - 1-D
GROUND WATER ELEV. - 6' below GRD.
DATE - Dec 17, 1975
TECHNICIAN - H.F.M.
RICHMOND LANDFILL

DRILL HOLE DATA

COLLAR ELEVATION.

GROUND ELEVATION. 20.5'

DEPTH OF CASING RELATIVE TO GROUND	DEPTH OF FORMATION RELATIVE TO GROUND	FORMATION
		WOOD CHIPS 0'-7'
		PEAT 7'-10'

INSTALLATION DATA

CAP ELEVATION.

COLLAR ELEVATION. 24.96

INSTALLATION ELEV. 10.13

DEPTH OF BACKFILL RELATIVE TO GROUND	BACKFILL	INSTALLATION	DEPTH OF INSTALLATION RELATIVE TO GROUND
	0'-7' BENTONITE		
		SCREEN	7'-9'

RICHMOND LANDFILL

INSTALLATION DATA

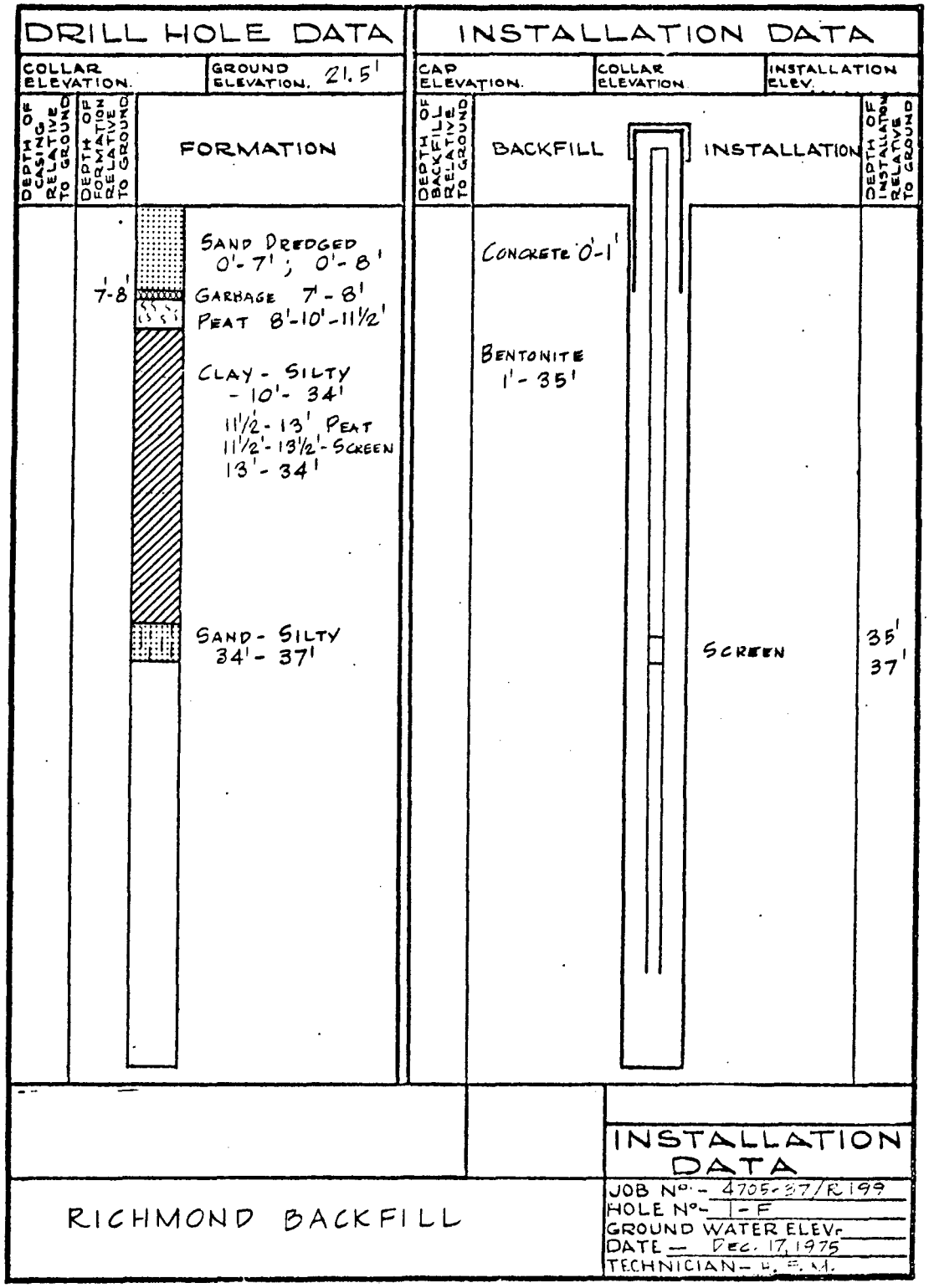
JOB No. - 4705-37/R199

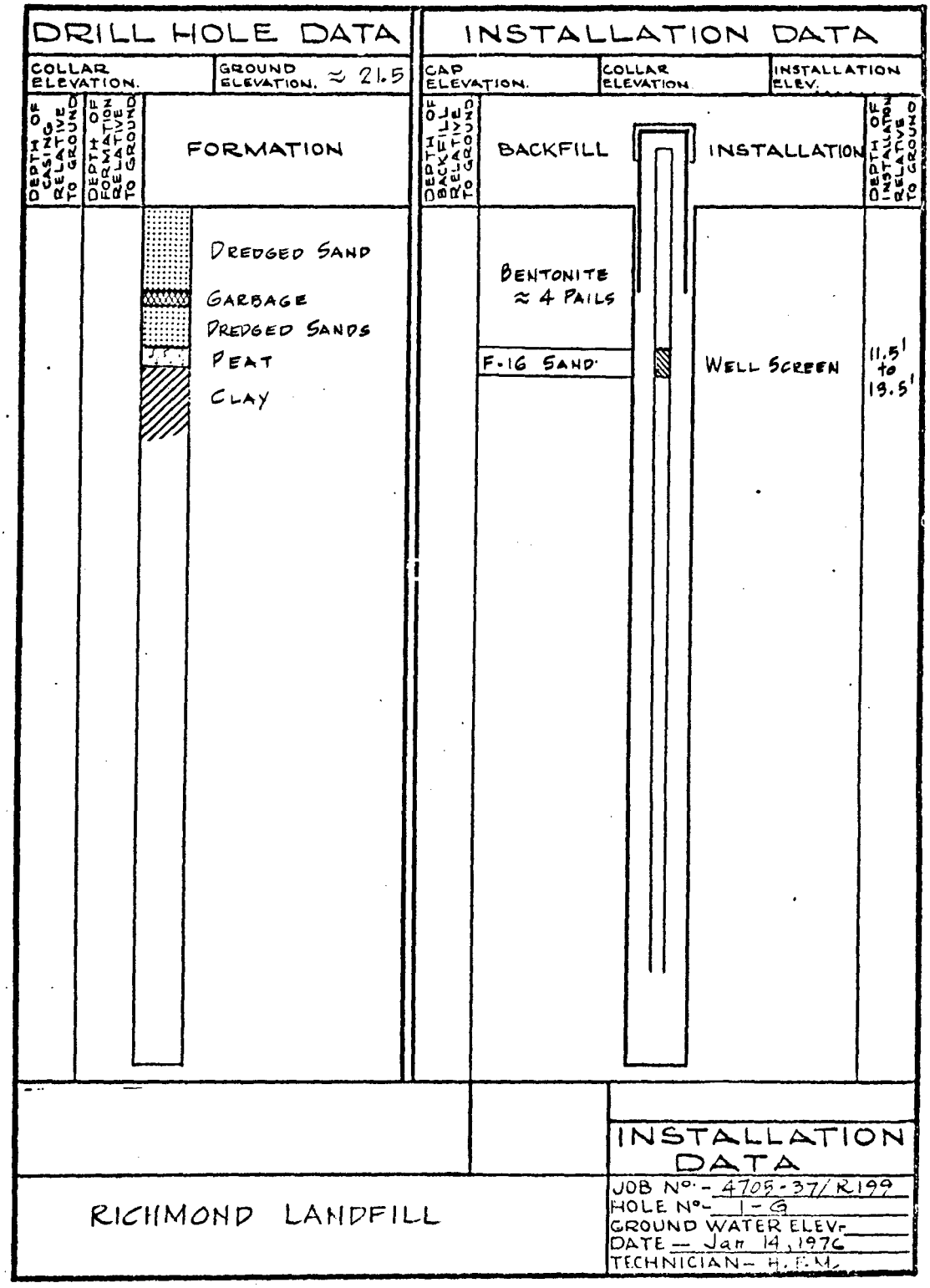
HOLE No. - I-E

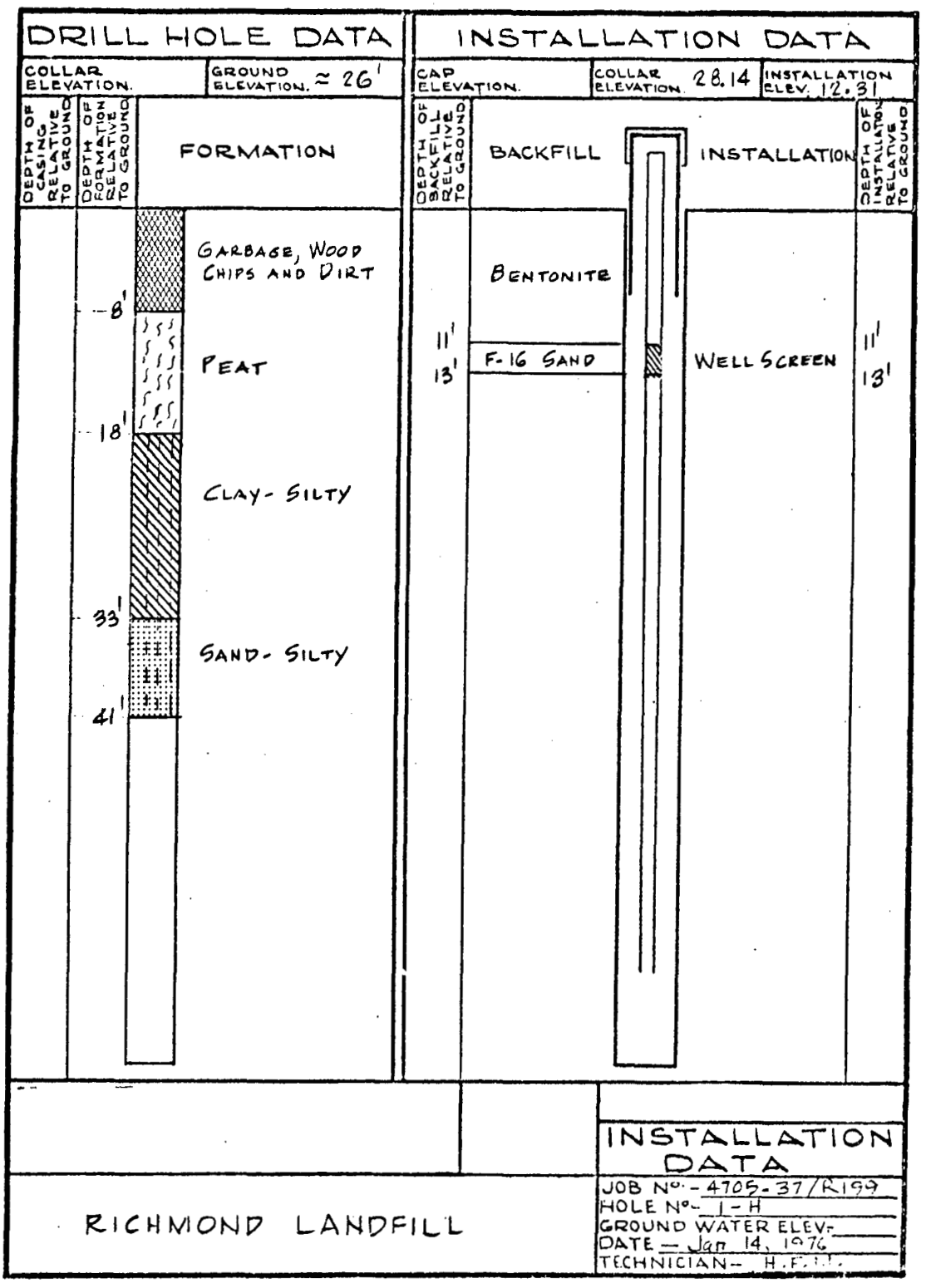
GROUND WATER ELEV.

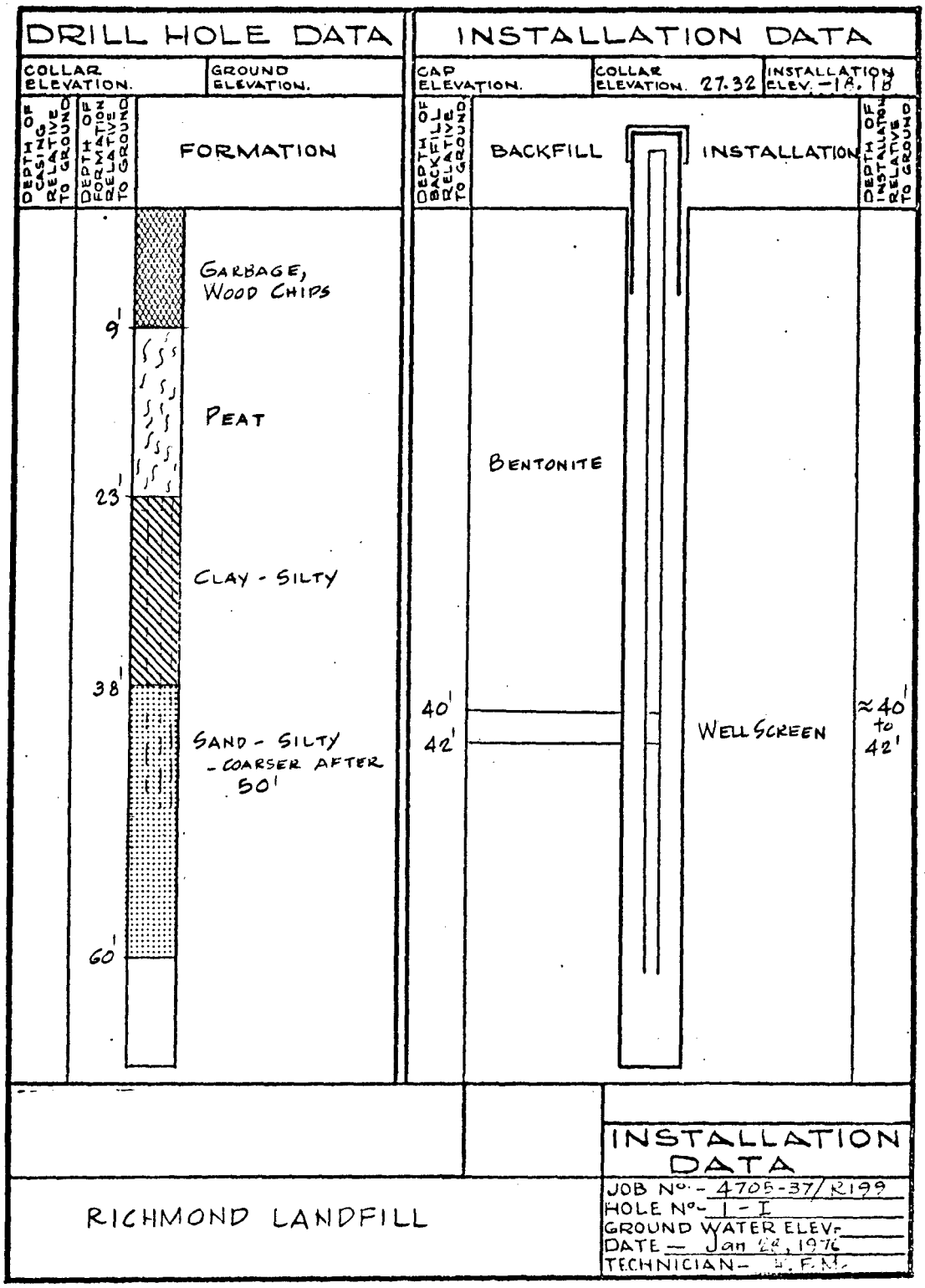
DATE — DEC. 17, 1975

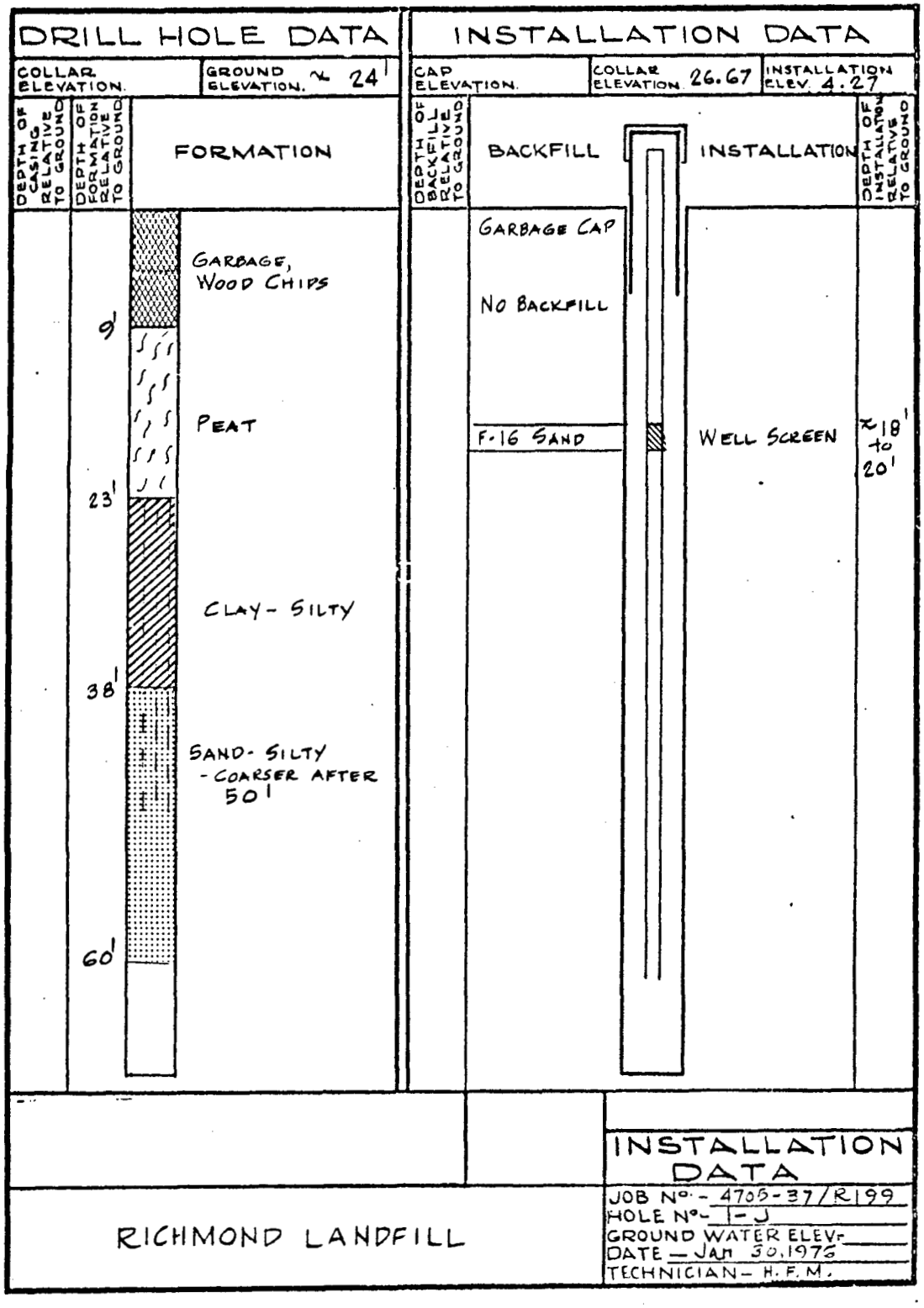
TECHNICIAN — H. F. M.

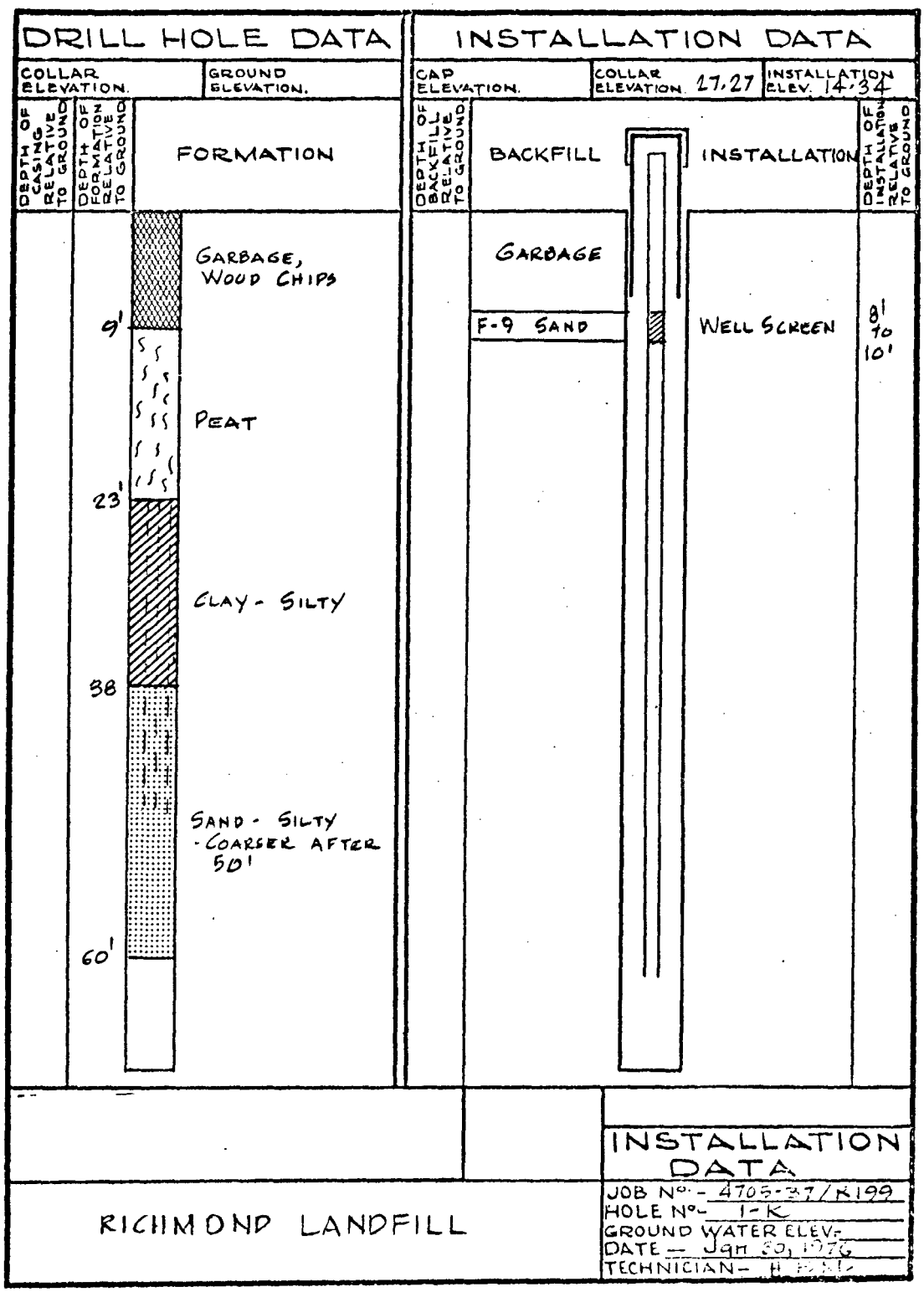

DRILL HOLE DATA
COLLAR ELEVATION.
GROUND ELEVATION. 21.5'
DEPTH OF CASING RELATIVE TO GROUND
DEPTH OF FORMATION RELATIVE TO GROUND
FORMATION
7'-8'
SAND DREDGED 0'-7'; 0'-8'
GARBAGE 7'-8'
PEAT 8'-10'-11½'
CLAY - SILTY - 10'-34'
11½'-13' PEAT
11½'-13½'-SCREEN
13'-34'
SAND - SILTY 34'-37'
INSTALLATION DATA
CAP ELEVATION.
COLLAR ELEVATION
INSTALLATION ELEV.
DEPTH OF BACKFILL RELATIVE TO GROUND
BACKFILL
INSTALLATION
DEPTH OF INSTALLATION RELATIVE TO GROUND
CONCRETE 0'-1'
BENTONITE 1'-35'
SCREEN
35'
37'
INSTALLATION DATA
JOB No. - 4705-37/R199
HOLE No. - 1-F
GROUND WATER ELEV.
DATE - DEC. 17, 1975
TECHNICIAN - H. E. M.
RICHMOND BACKFILL


DRILL HOLE DATA
COLLAR ELEVATION.
GROUND ELEVATION. ≈ 21.5
DEPTH OF CASING RELATIVE TO GROUND
DEPTH OF FORMATION RELATIVE TO GROUND
FORMATION
DREDGED SAND
GARBAGE
DREDGED SANDS
PEAT
CLAY
INSTALLATION DATA
CAP ELEVATION.
COLLAR ELEVATION
INSTALLATION ELEV.
DEPTH OF BACKFILL RELATIVE TO GROUND
BACKFILL
INSTALLATION
DEPTH OF INSTALLATION RELATIVE TO GROUND
BENTONITE ≈ 4 PAILS
F-16 SAND
WELL SCREEN
11.5' to 13.5'
INSTALLATION DATA
JOB No. - 4705-37/R199
HOLE No. - 1-G
GROUND WATER ELEV.
DATE - Jan 14, 1976
TECHNICIAN - H.E.M.
RICHMOND LANDFILL


DRILL HOLE DATA
COLLAR ELEVATION.
GROUND ELEVATION. ≈ 26'
DEPTH OF CASING RELATIVE TO GROUND
DEPTH OF FORMATION RELATIVE TO GROUND
FORMATION
8'
18'
33'
41'
GARBAGE, WOOD CHIPS AND DIRT
PEAT
CLAY- SILTY
SAND- SILTY
INSTALLATION DATA
CAP ELEVATION.
COLLAR ELEVATION. 28.14
INSTALLATION ELEV. 12.31
DEPTH OF BACKFILL RELATIVE TO GROUND
BACKFILL
INSTALLATION
DEPTH OF INSTALLATION RELATIVE TO GROUND
BENTONITE
11'
13'
F-16 SAND
WELL SCREEN
11'
13'
INSTALLATION DATA
JOB No.- 4705-37/R199
HOLE No.- 1-H
GROUND WATER ELEV.-
DATE - Jan 14, 1976
TECHNICIAN- H.F.
RICHMOND LANDFILL


DRILL HOLE DATA
COLLAR ELEVATION.
GROUND ELEVATION.
DEPTH OF CASING RELATIVE TO GROUND
DEPTH OF FORMATION RELATIVE TO GROUND
FORMATION
GARBAGE, WOOD CHIPS
9'
PEAT
23'
CLAY - SILTY
38'
SAND - SILTY - COARSER AFTER 50'
60'
INSTALLATION DATA
CAP ELEVATION.
COLLAR ELEVATION. 27.32
INSTALLATION ELEV. -18.18
DEPTH OF BACKFILL RELATIVE TO GROUND
BACKFILL
INSTALLATION
DEPTH OF INSTALLATION RELATIVE TO GROUND
BENTONITE
40'
42'
WELL SCREEN
≈40' to 42'
INSTALLATION DATA
JOB No. - 4705-37/R199
HOLE No. - I - I
GROUND WATER ELEV.
DATE - Jan 28, 1976
TECHNICIAN - W. F. M.
RICHMOND LANDFILL


DRILL HOLE DATA
COLLAR ELEVATION.
GROUND ELEVATION. ~ 24'
DEPTH OF CASING RELATIVE TO GROUND
DEPTH OF FORMATION RELATIVE TO GROUND
FORMATION
GARBAGE, WOOD CHIPS
9'
PEAT
23'
CLAY - SILTY
38'
SAND - SILTY - COARSER AFTER 50'
60'
INSTALLATION DATA
CAP ELEVATION.
COLLAR ELEVATION 26.67
INSTALLATION ELEV. 4.27
DEPTH OF BACKFILL RELATIVE TO GROUND
BACKFILL
INSTALLATION
DEPTH OF INSTALLATION RELATIVE TO GROUND
GARBAGE CAP
NO BACKFILL
F-16 SAND
WELL SCREEN
~18' to 20'
INSTALLATION DATA
JOB No. - 4705-37/R199
HOLE No. - I-J
GROUND WATER ELEV.
DATE - JAN 30, 1975
TECHNICIAN - H.F.M.
RICHMOND LANDFILL


DRILL HOLE DATA
COLLAR ELEVATION.
GROUND ELEVATION.
DEPTH OF CASING RELATIVE TO GROUND
DEPTH OF FORMATION RELATIVE TO GROUND
FORMATION
GARBAGE, WOOD CHIPS
9'
PEAT
23'
CLAY - SILTY
38
SAND - SILTY - COARSER AFTER 50'
60'
INSTALLATION DATA
CAP ELEVATION.
COLLAR ELEVATION. 27.27
INSTALLATION ELEV. 14.34
DEPTH OF BACKFILL RELATIVE TO GROUND
BACKFILL
INSTALLATION
DEPTH OF INSTALLATION RELATIVE TO GROUND
GARBAGE
F-9 SAND
WELL SCREEN
8' TO 10'
INSTALLATION DATA
RICHMOND LANDFILL
JOB No. - 4705-37/R199
HOLE No. - 1-K
GROUND WATER ELEV.
DATE - Jan 30, 1976
TECHNICIAN -

DRILL HOLE DATA				INSTALLATION DATA			
COLLAR ELEVATION		GROUND ELEVATION ≈ 20.5		CAP ELEVATION	COLLAR ELEVATION	INSTALLATION ELEV.	
DEPTH OF CASING RELATIVE TO GROUND	DEPTH OF FORMATION RELATIVE TO GROUND	FORMATION		DEPTH OF BACKFILL RELATIVE TO GROUND	BACKFILL	INSTALLATION	DEPTH OF INSTALLATION RELATIVE TO GROUND
			PEAT				
	2.9M		CLAY - VERY LIGHT - SOFT - GREY, VERY PLASTIC				
			SILTY CLAY - 7.5M COULDN'T GO ANY DEEPER				
			SAMPLES AT: 2.75' - 3.25' 4' - 4.5' 5.5' - 6' 7' - 7.6'				

HAND AUGERED HOLE

RICHMOND LANDFILL

INSTALLATION DATA

JOB No. - 4705-37/R199
HOLE No. - 1-L
GROUND WATER ELEV. -
DATE - Nov 11, 1976
TECHNICIAN - H.F.V.

DRILL HOLE DATA

COLLAR ELEVATION. | GROUND ELEVATION. ≈ 20

DEPTH OF CASING RELATIVE TO GROUND	DEPTH OF FORMATION RELATIVE TO GROUND	FORMATION
		PEAT
		FIBROUSY-MEDIUM BROWN
	~5.3 M.	CLAY-ORGANX VERY SOFT
		PIECE OF WOOD AT 6 METRES
		SILTY CLAY AT 7.5 METRES
		8.5-9 M. - CLAY SOFT GREY
	9.75 M	CLAYEZ SILT
		SAMPLES AT: 4-4.5 M. 5.5-6. M. 4.75-5.25 M. 7.-7.5 M. 8.5-9 M.

INSTALLATION DATA

CAP ELEVATION. | COLLAR ELEVATION. | INSTALLATION ELEV.

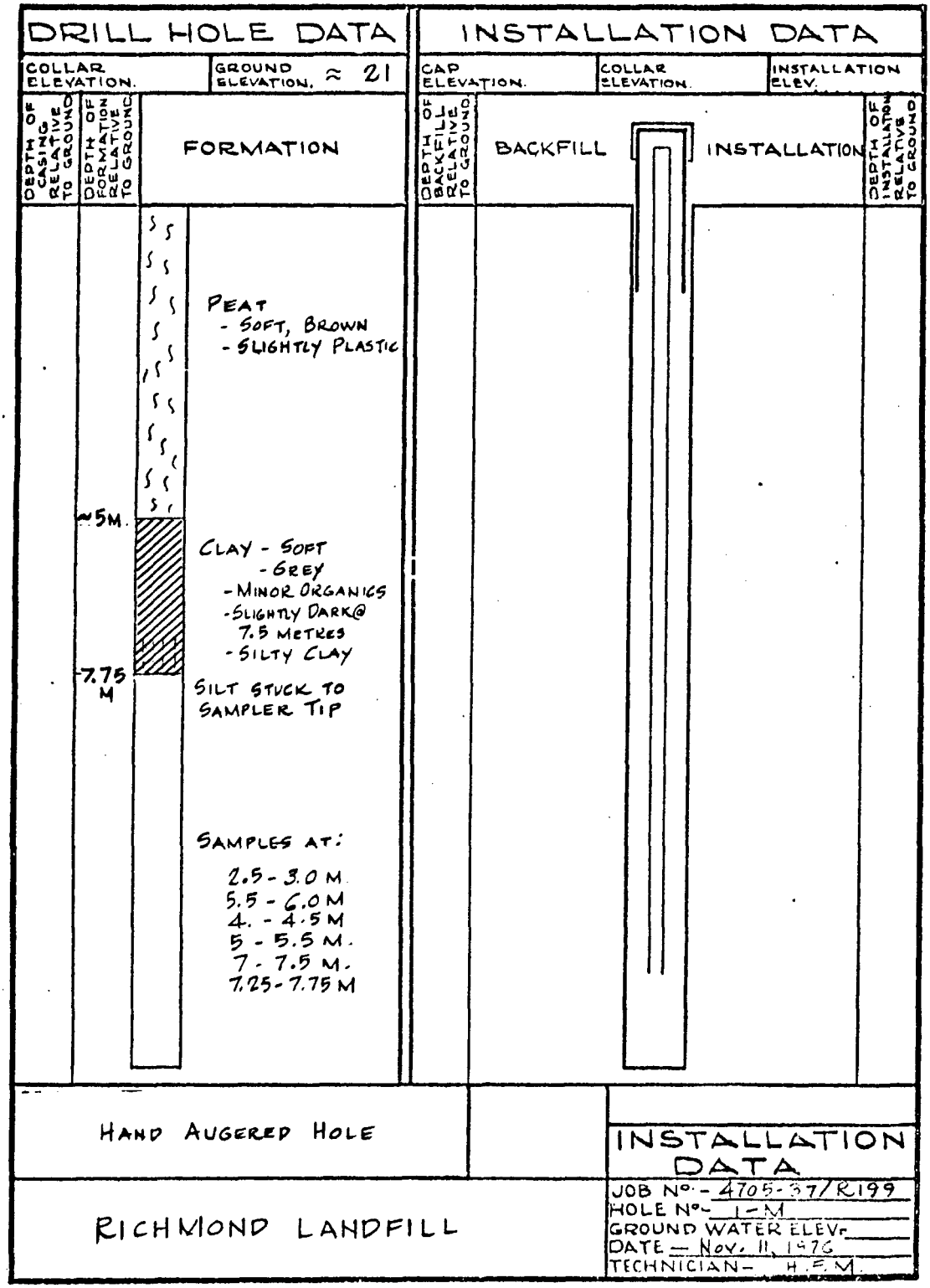
DEPTH OF BACKFILL RELATIVE TO GROUND	BACKFILL	INSTALLATION	DEPTH OF INSTALLATION RELATIVE TO GROUND

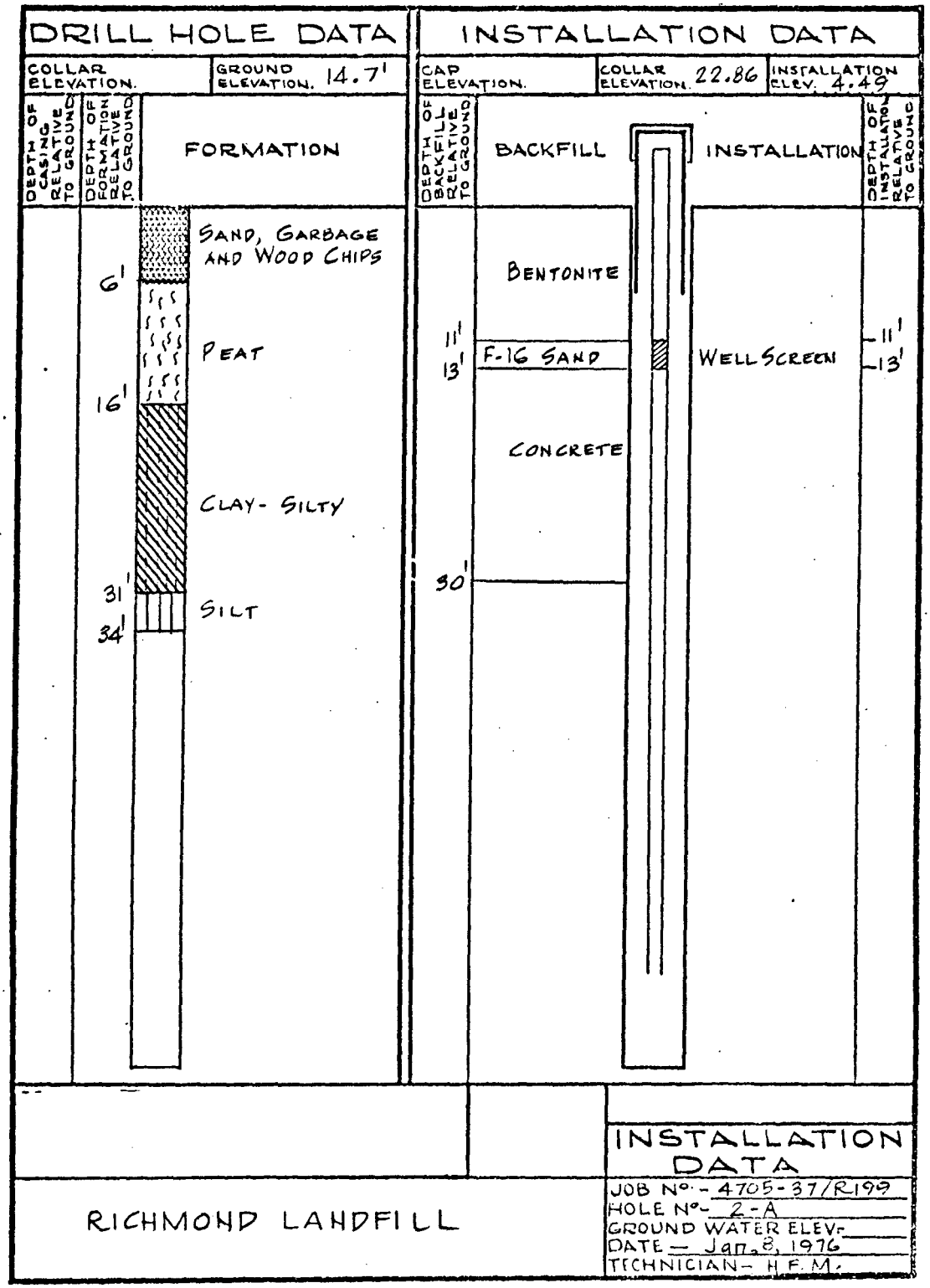
HAND AUGERED HOLE
LOCATION: IN BERN AT END OF CUT LINE PERPENDICULAR TO 1-M

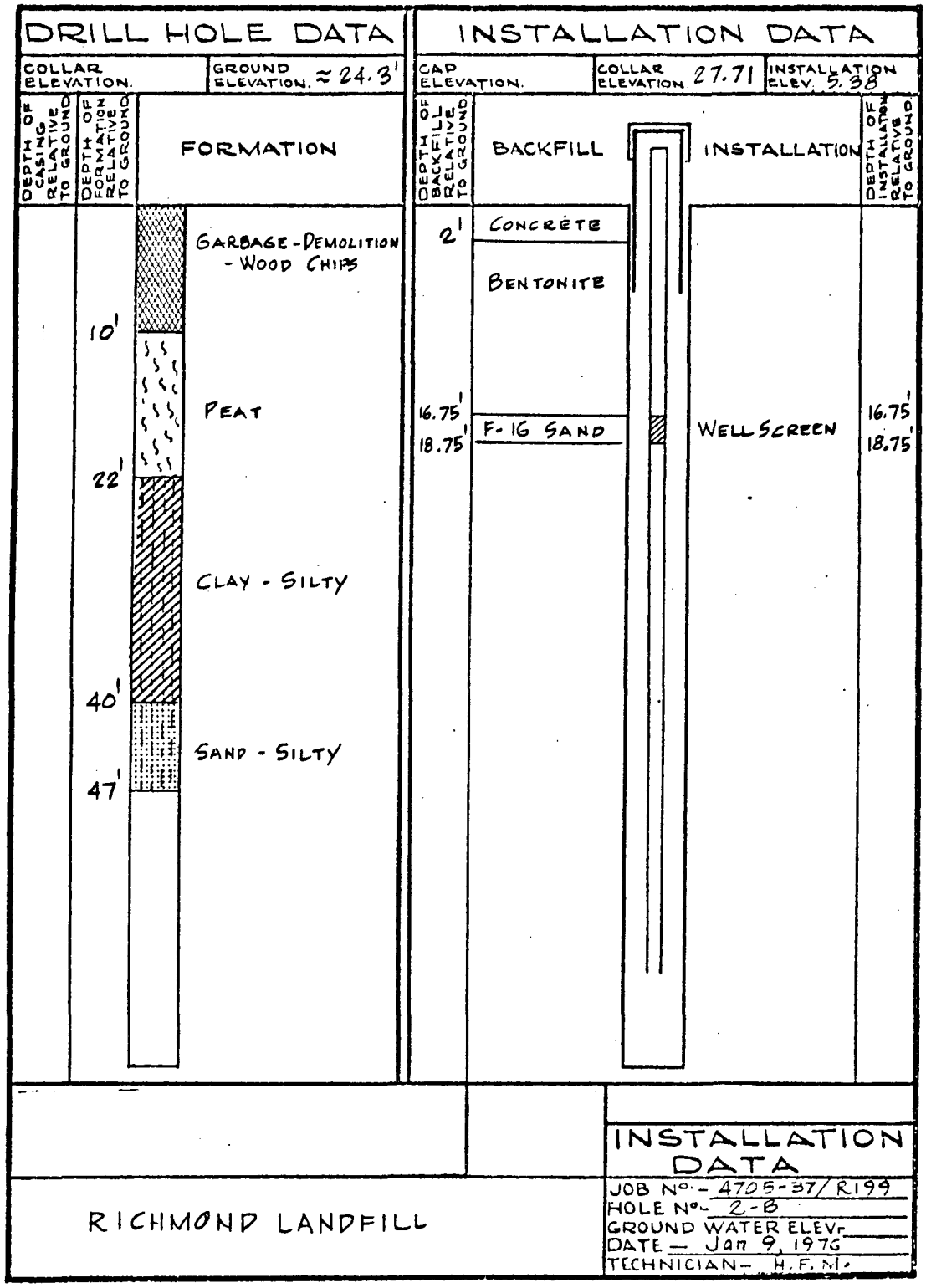
RICHMOND LANDFILL

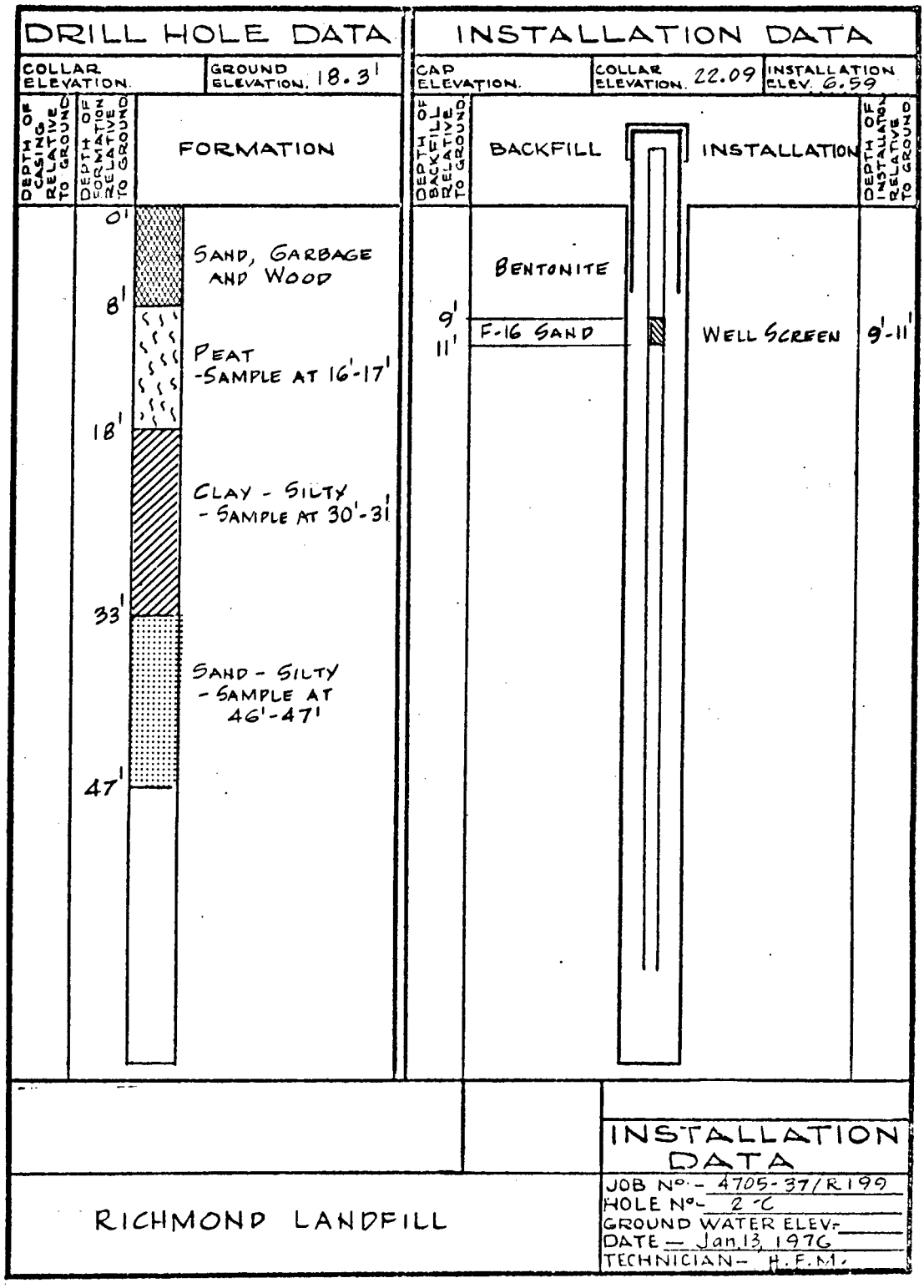
INSTALLATION DATA

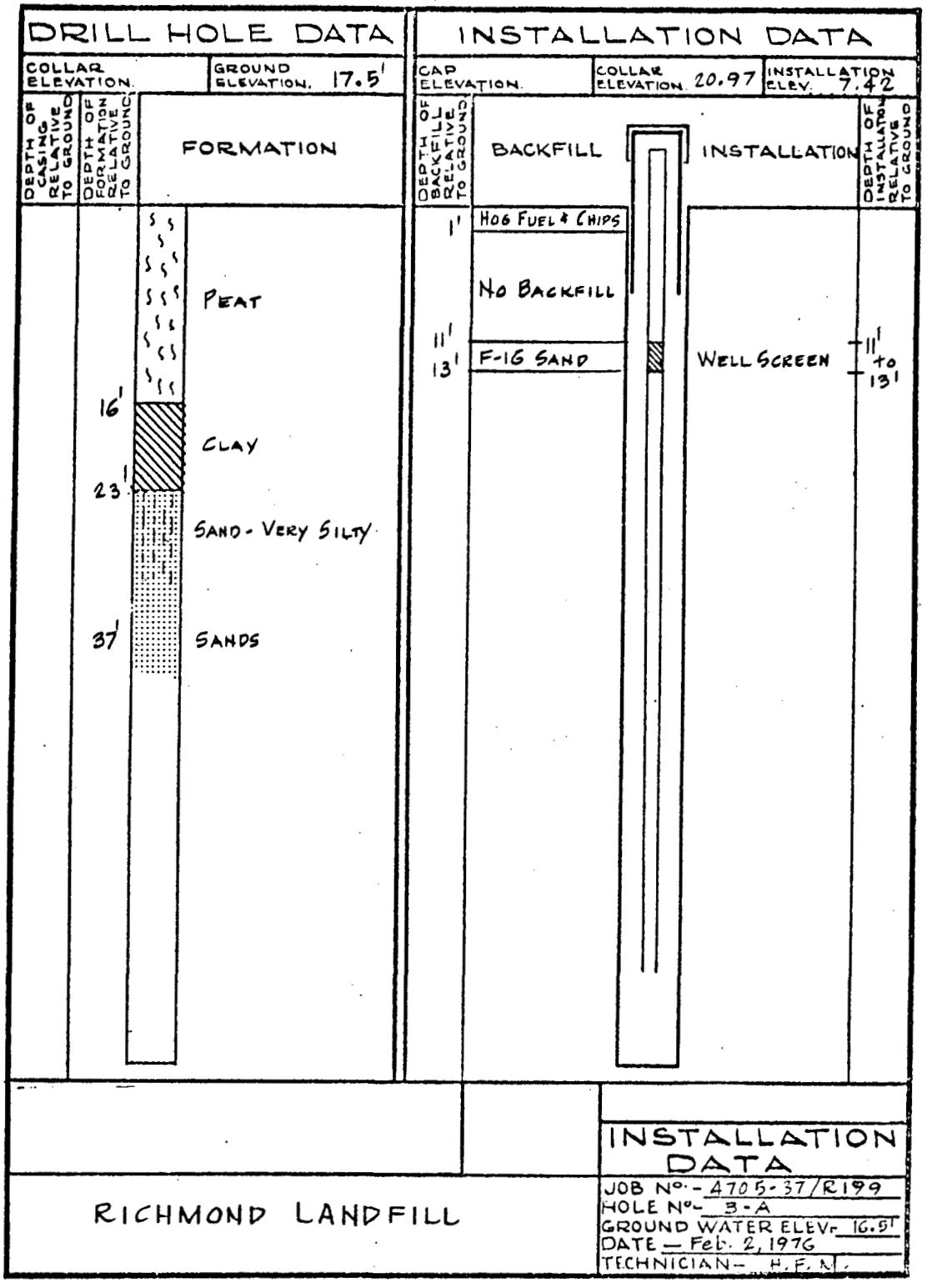
JOB No.- 4705-37/R1[illegible]
HOLE No.- 1-M NORTH EAST-200 YDS
GROUND WATER ELEV.-
DATE — Nov 11, 1976
TECHNICIAN- H.F.M.

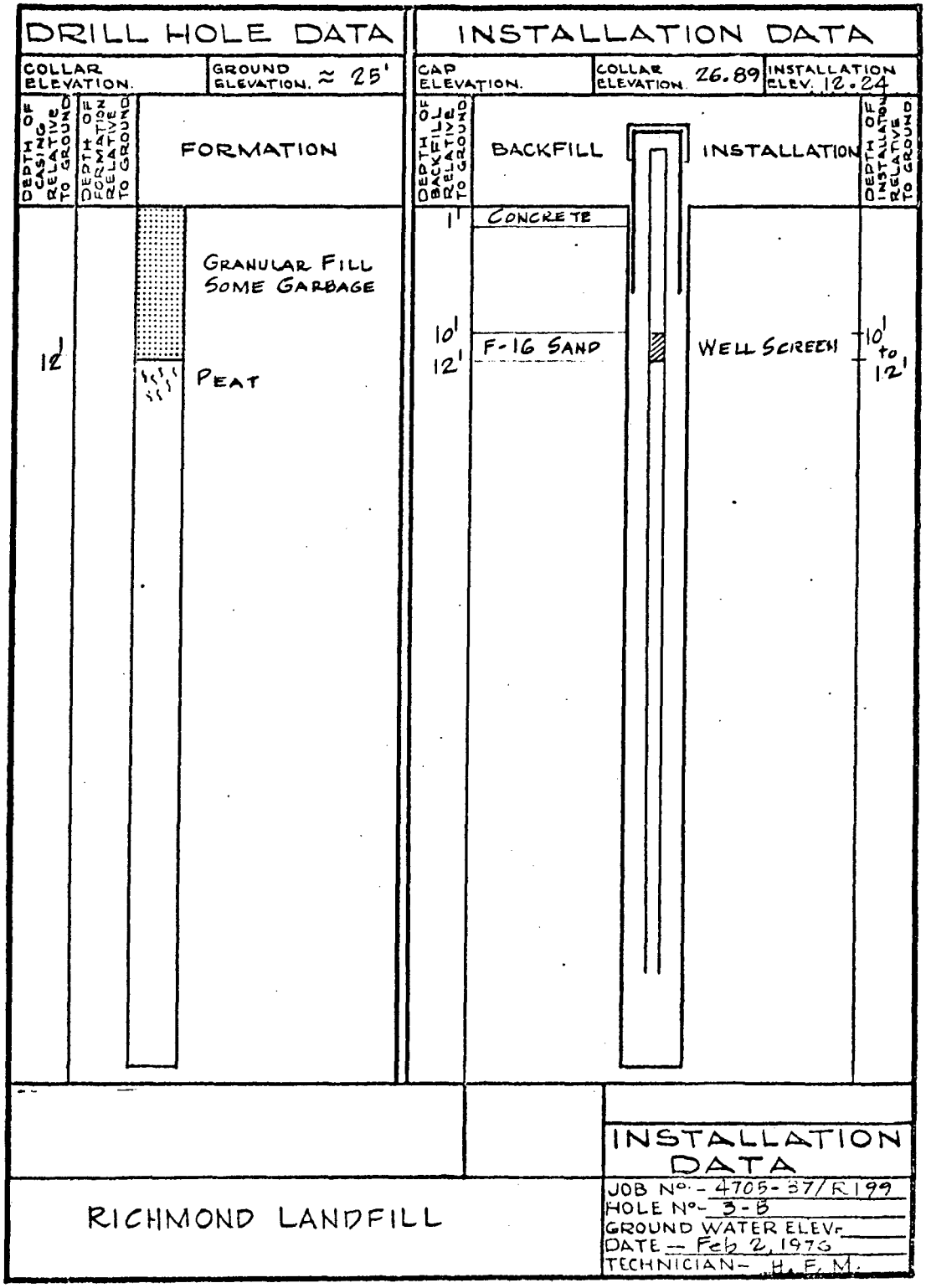

DRILL HOLE DATA
INSTALLATION DATA
COLLAR ELEVATION.
GROUND ELEVATION. ≈ 21
CAP ELEVATION.
COLLAR ELEVATION.
INSTALLATION ELEV.
DEPTH OF CASING RELATIVE TO GROUND
DEPTH OF FORMATION RELATIVE TO GROUND
FORMATION
DEPTH OF BACKFILL RELATIVE TO GROUND
BACKFILL
INSTALLATION
DEPTH OF INSTALLATION RELATIVE TO GROUND
PEAT
- SOFT, BROWN
- SLIGHTLY PLASTIC
~5M.
CLAY - SOFT
- GREY
- MINOR ORGANICS
- SLIGHTLY DARK @ 7.5 METRES
- SILTY CLAY
7.75 M
SILT STUCK TO SAMPLER TIP
SAMPLES AT:
2.5 - 3.0 M
5.5 - 6.0 M
4. - 4.5 M
5 - 5.5 M.
7 - 7.5 M.
7.25 - 7.75 M
HAND AUGERED HOLE
INSTALLATION DATA
JOB No. - 4705-37/R199
HOLE No. - 1-M
GROUND WATER ELEV.
DATE - Nov. 11, 1976
TECHNICIAN - H.E.M.
RICHMOND LANDFILL

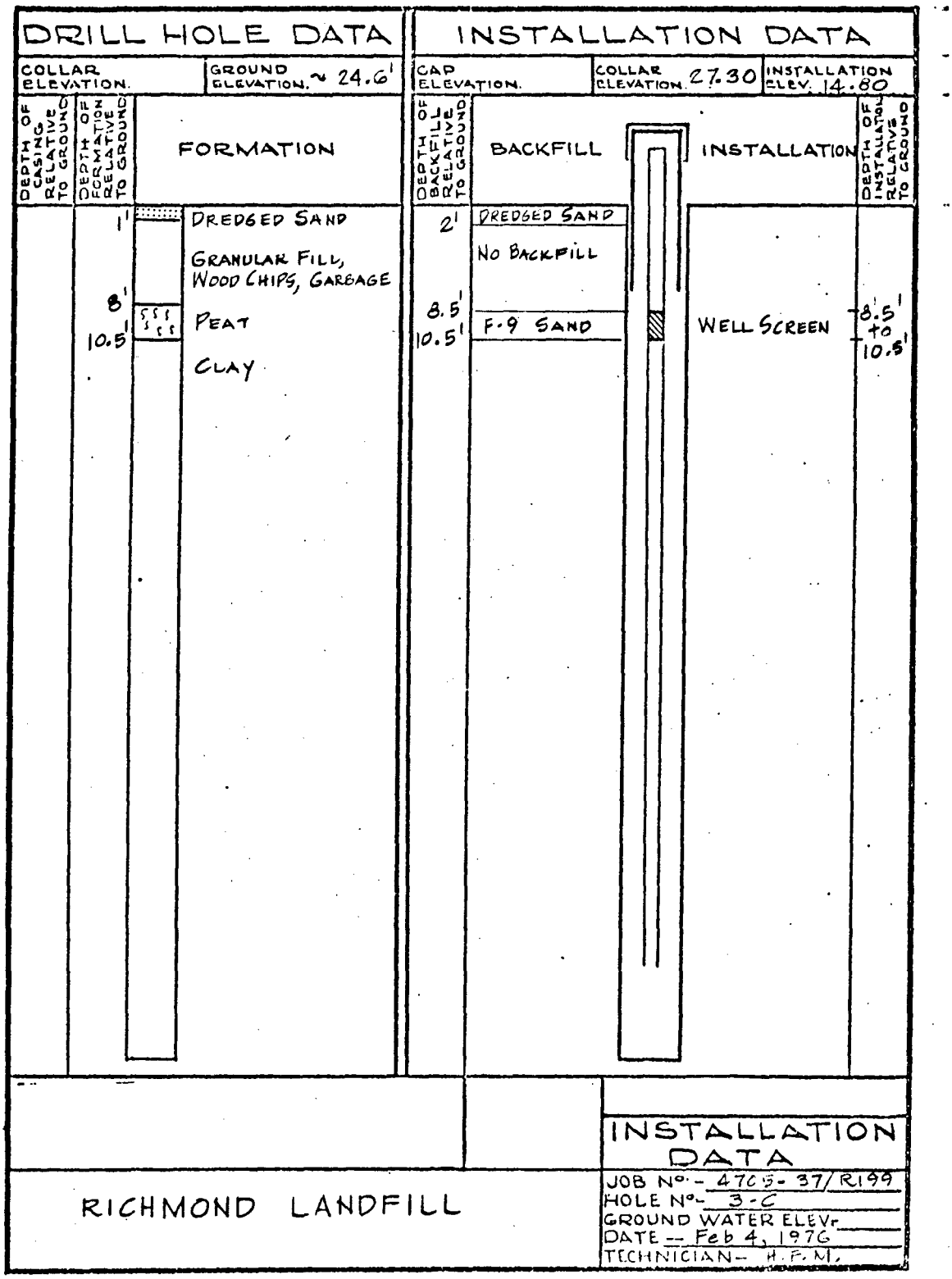

DRILL HOLE DATA
COLLAR ELEVATION.
GROUND ELEVATION. 14.7'
DEPTH OF CASING RELATIVE TO GROUND
DEPTH OF FORMATION RELATIVE TO GROUND
FORMATION
SAND, GARBAGE AND WOOD CHIPS
6'
PEAT
16'
CLAY- SILTY
31'
SILT
34'
INSTALLATION DATA
CAP ELEVATION.
COLLAR ELEVATION. 22.86
INSTALLATION ELEV. 4.49
DEPTH OF BACKFILL RELATIVE TO GROUND
BACKFILL
INSTALLATION
DEPTH OF INSTALLATION RELATIVE TO GROUND
BENTONITE
11'
F-16 SAND
13'
WELL SCREEN
11'
13'
CONCRETE
30'
INSTALLATION DATA
JOB No. - 4705-37/R199
HOLE No. - 2-A
GROUND WATER ELEV.
DATE - Jan. 8, 1976
TECHNICIAN - H.E.M.
RICHMOND LANDFILL

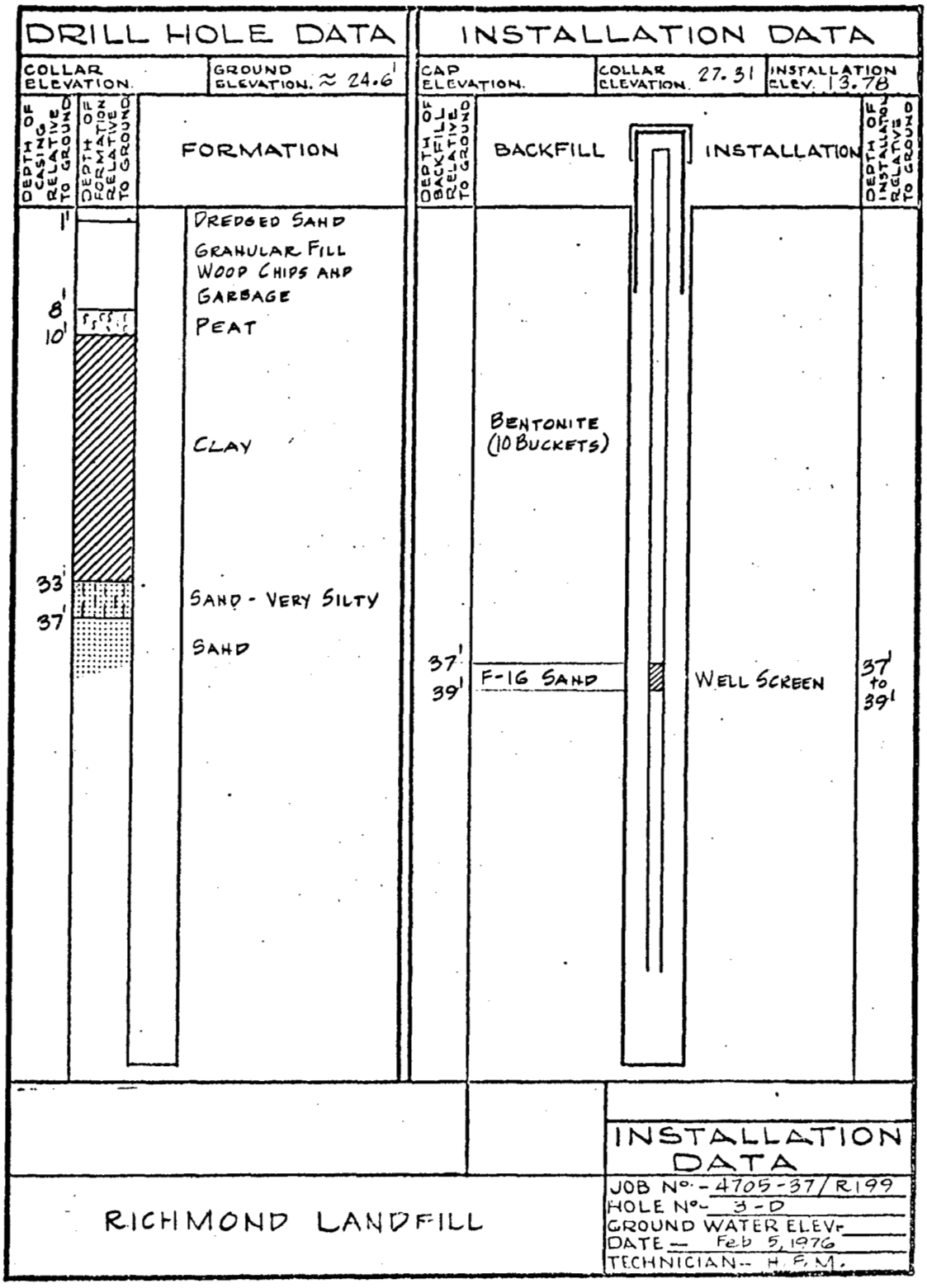

DRILL HOLE DATA
COLLAR ELEVATION.
GROUND ELEVATION. ≈ 24.3'
DEPTH OF CASING RELATIVE TO GROUND
DEPTH OF FORMATION RELATIVE TO GROUND
FORMATION
GARBAGE - DEMOLITION - WOOD CHIPS
10'
PEAT
22'
CLAY - SILTY
40'
SAND - SILTY
47'
INSTALLATION DATA
CAP ELEVATION.
COLLAR ELEVATION. 27.71
INSTALLATION ELEV. 5.38
DEPTH OF BACKFILL RELATIVE TO GROUND
BACKFILL
INSTALLATION
DEPTH OF INSTALLATION RELATIVE TO GROUND
2'
CONCRETE
BENTONITE
16.75'
18.75'
F-16 SAND
WELL SCREEN
16.75'
18.75'
RICHMOND LANDFILL
INSTALLATION DATA
JOB No. - 4705-37/R199
HOLE No. - 2-B
GROUND WATER ELEV.
DATE — Jan 9, 1976
TECHNICIAN - H.F.M.

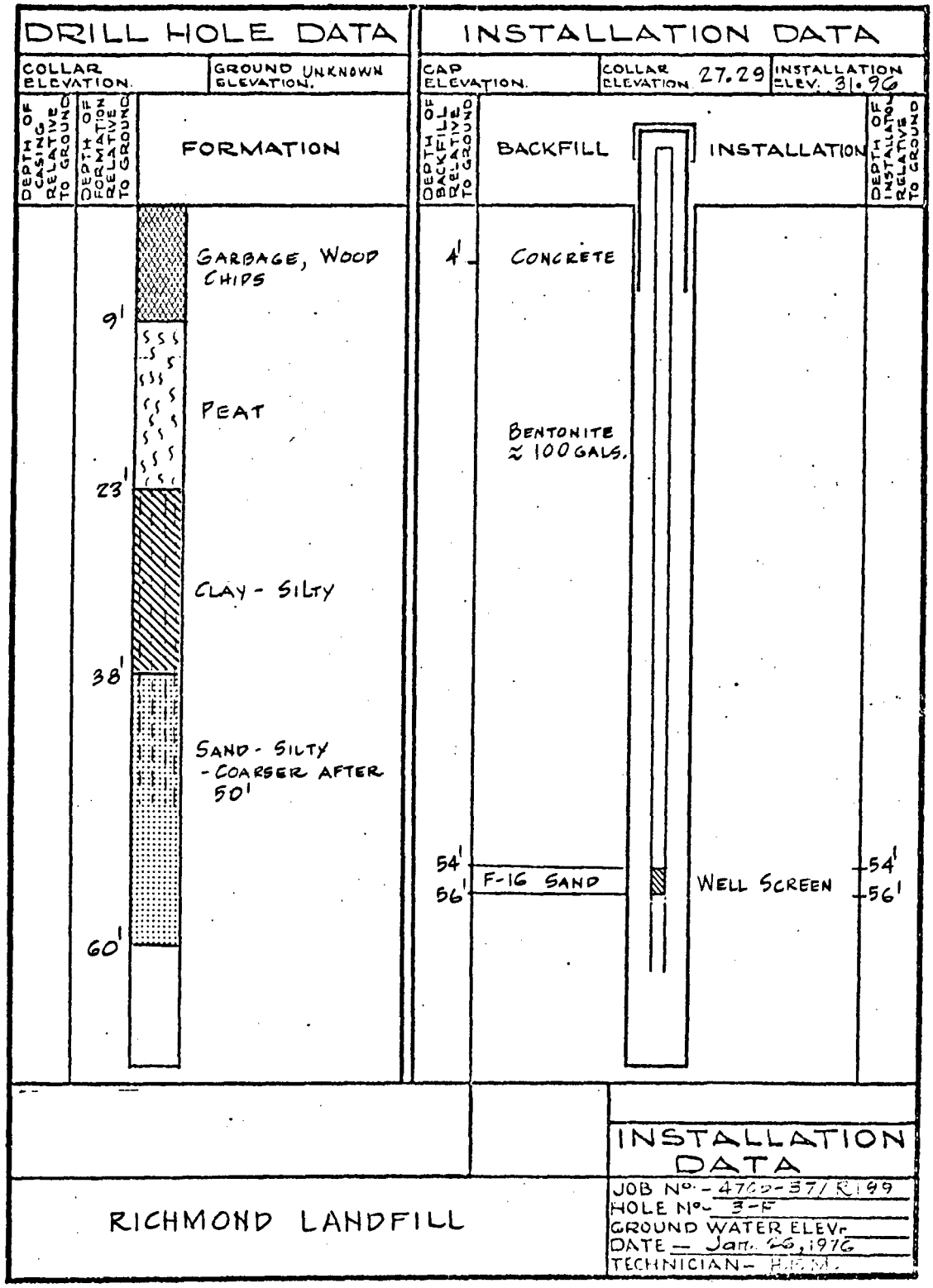

DRILL HOLE DATA
COLLAR ELEVATION.
GROUND ELEVATION. 18.3'
DEPTH OF CASING RELATIVE TO GROUND
DEPTH OF FORMATION RELATIVE TO GROUND
FORMATION
0'
SAND, GARBAGE AND WOOD
8'
PEAT -SAMPLE AT 16'-17'
18'
CLAY - SILTY - SAMPLE AT 30'-31'
33'
SAND - SILTY - SAMPLE AT 46'-47'
47'
INSTALLATION DATA
CAP ELEVATION.
COLLAR ELEVATION. 22.09
INSTALLATION ELEV. 6.59
DEPTH OF BACKFILL RELATIVE TO GROUND
BACKFILL
INSTALLATION
DEPTH OF INSTALLATION RELATIVE TO GROUND
BENTONITE
9'
F-16 SAND
11'
WELL SCREEN
9'-11'
INSTALLATION DATA
JOB No. - 4705-37/R199
HOLE No. - 2-C
GROUND WATER ELEV. -
DATE - Jan. 13, 1976
TECHNICIAN - H.F.M.
RICHMOND LANDFILL

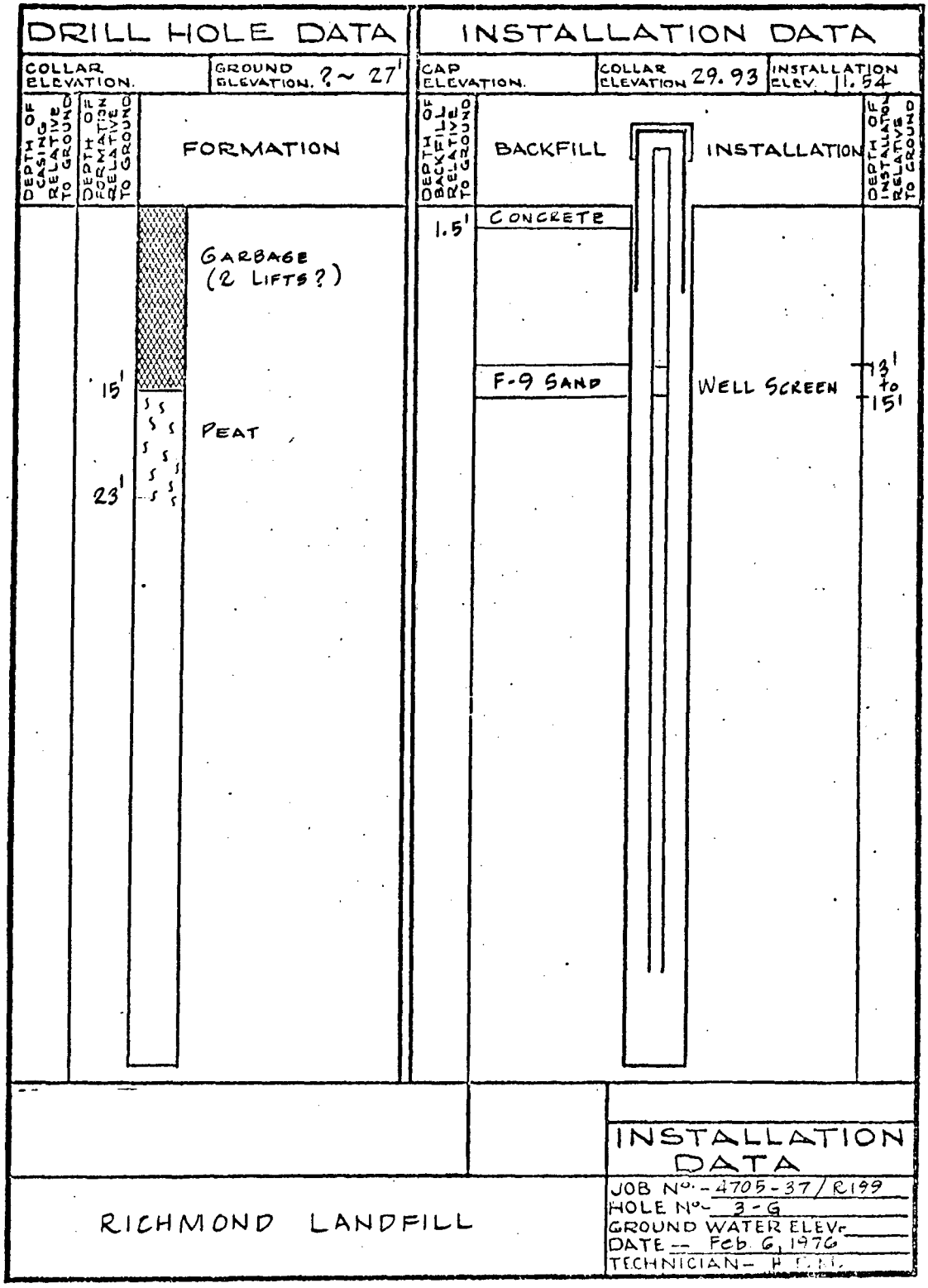

DRILL HOLE DATA
COLLAR ELEVATION.
GROUND ELEVATION. 17.5'
DEPTH OF CASING RELATIVE TO GROUND
DEPTH OF FORMATION RELATIVE TO GROUND
FORMATION
PEAT
16'
CLAY
23'
SAND - VERY SILTY
37'
SANDS
INSTALLATION DATA
CAP ELEVATION.
COLLAR ELEVATION. 20.97
INSTALLATION ELEV. 7.42
DEPTH OF BACKFILL RELATIVE TO GROUND
BACKFILL
INSTALLATION
DEPTH OF INSTALLATION RELATIVE TO GROUND
1'
HOG FUEL & CHIPS
NO BACKFILL
11'
13'
F-16 SAND
WELL SCREEN
11' to 13'
INSTALLATION DATA
RICHMOND LANDFILL
JOB No. - 4705-37/R199
HOLE No. - 3-A
GROUND WATER ELEV. 16.5'
DATE — Feb. 2, 1976
TECHNICIAN — H.F.M.

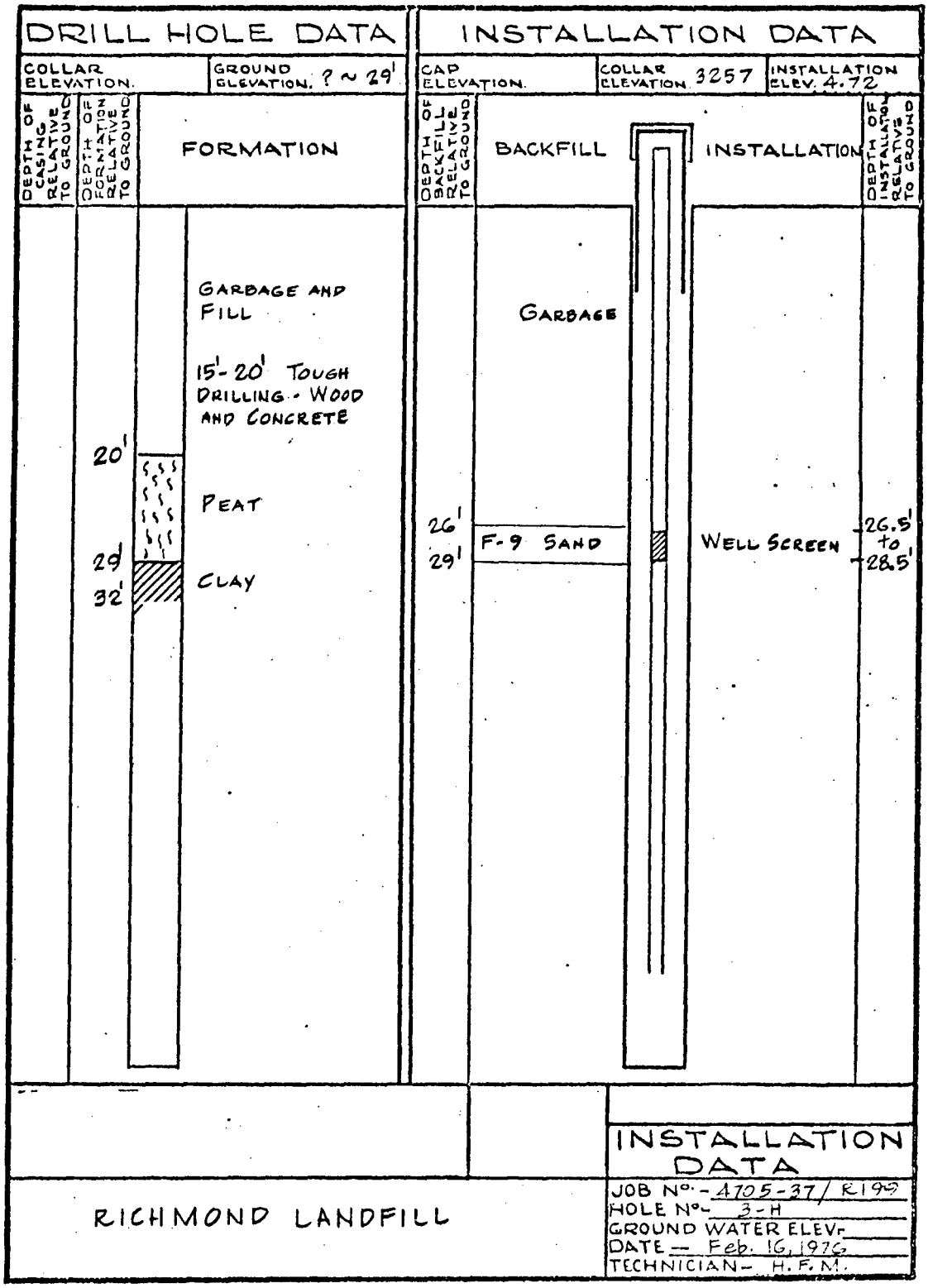

DRILL HOLE DATA
COLLAR ELEVATION.
GROUND ELEVATION. ≈ 25'
DEPTH OF CASING RELATIVE TO GROUND
DEPTH OF FORMATION RELATIVE TO GROUND
FORMATION
12'
GRANULAR FILL SOME GARBAGE
PEAT
INSTALLATION DATA
CAP ELEVATION.
COLLAR ELEVATION. 26.89
INSTALLATION ELEV. 12.24
DEPTH OF BACKFILL RELATIVE TO GROUND
BACKFILL
INSTALLATION
DEPTH OF INSTALLATION RELATIVE TO GROUND
1'
CONCRETE
10'
12'
F-16 SAND
WELL SCREEN
10' to 12'
INSTALLATION DATA
RICHMOND LANDFILL
JOB No.- 4705-37/R199
HOLE No.- 3-B
GROUND WATER ELEV.
DATE -- Feb 2, 1976
TECHNICIAN- H. F. M.

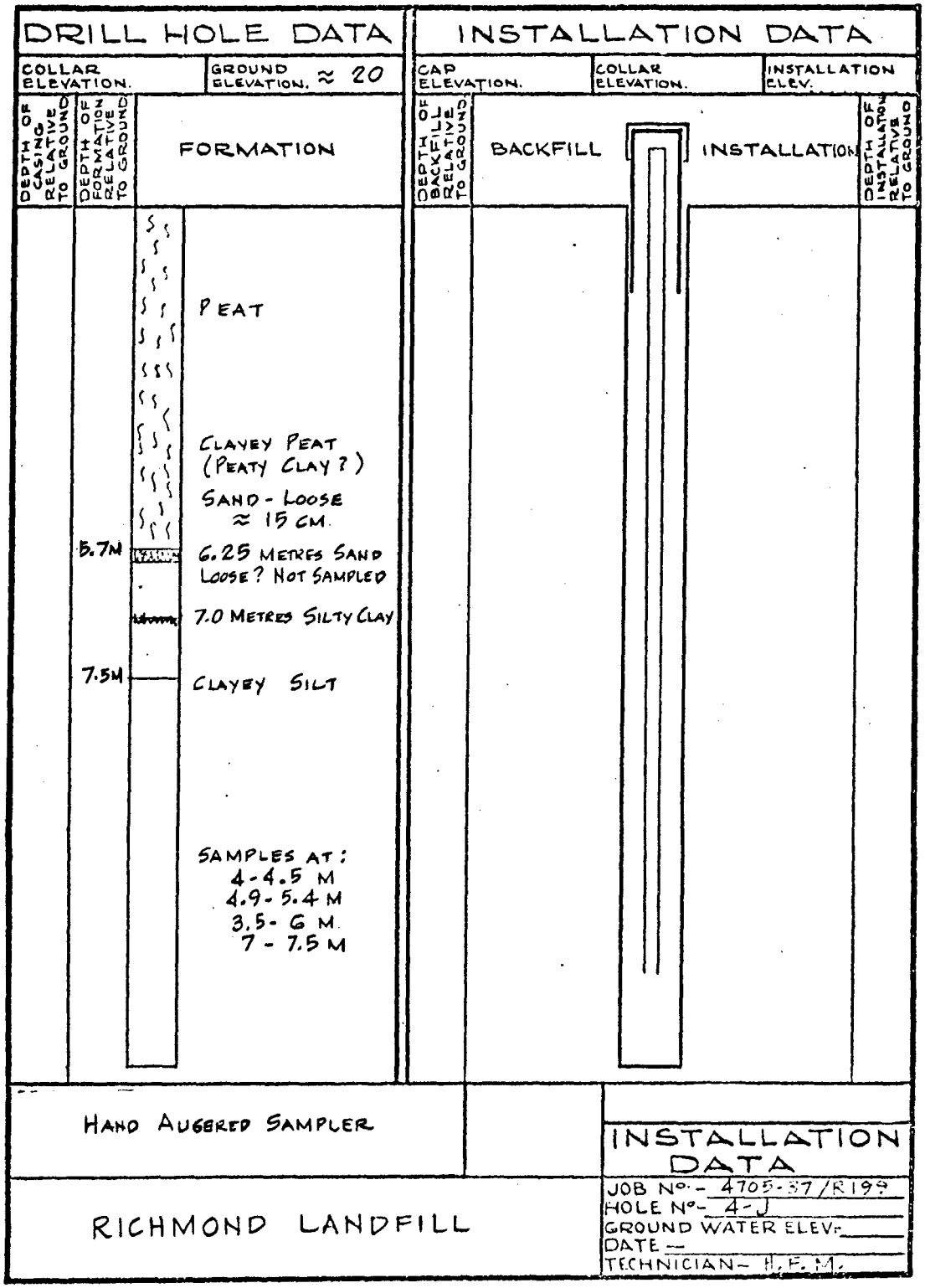

DRILL HOLE DATA
INSTALLATION DATA
COLLAR ELEVATION.
GROUND ELEVATION. ~ 24.6'
CAP ELEVATION.
COLLAR ELEVATION. 27.30
INSTALLATION ELEV. 14.80
DEPTH OF CASING RELATIVE TO GROUND
DEPTH OF FORMATION RELATIVE TO GROUND
FORMATION
DEPTH OF BACKFILL RELATIVE TO GROUND
BACKFILL
INSTALLATION
DEPTH OF INSTALLATION RELATIVE TO GROUND
1'
DREDGED SAND
GRANULAR FILL, WOOD CHIPS, GARBAGE
8'
PEAT
10.5'
CLAY
2'
DREDGED SAND
NO BACKFILL
8.5'
F-9 SAND
10.5'
WELL SCREEN
8.5' to 10.5'
INSTALLATION DATA
RICHMOND LANDFILL
JOB No. - 4705-37/R199
HOLE No. - 3-C
GROUND WATER ELEV.
DATE -- Feb 4, 1976
TECHNICIAN - H.F.M.

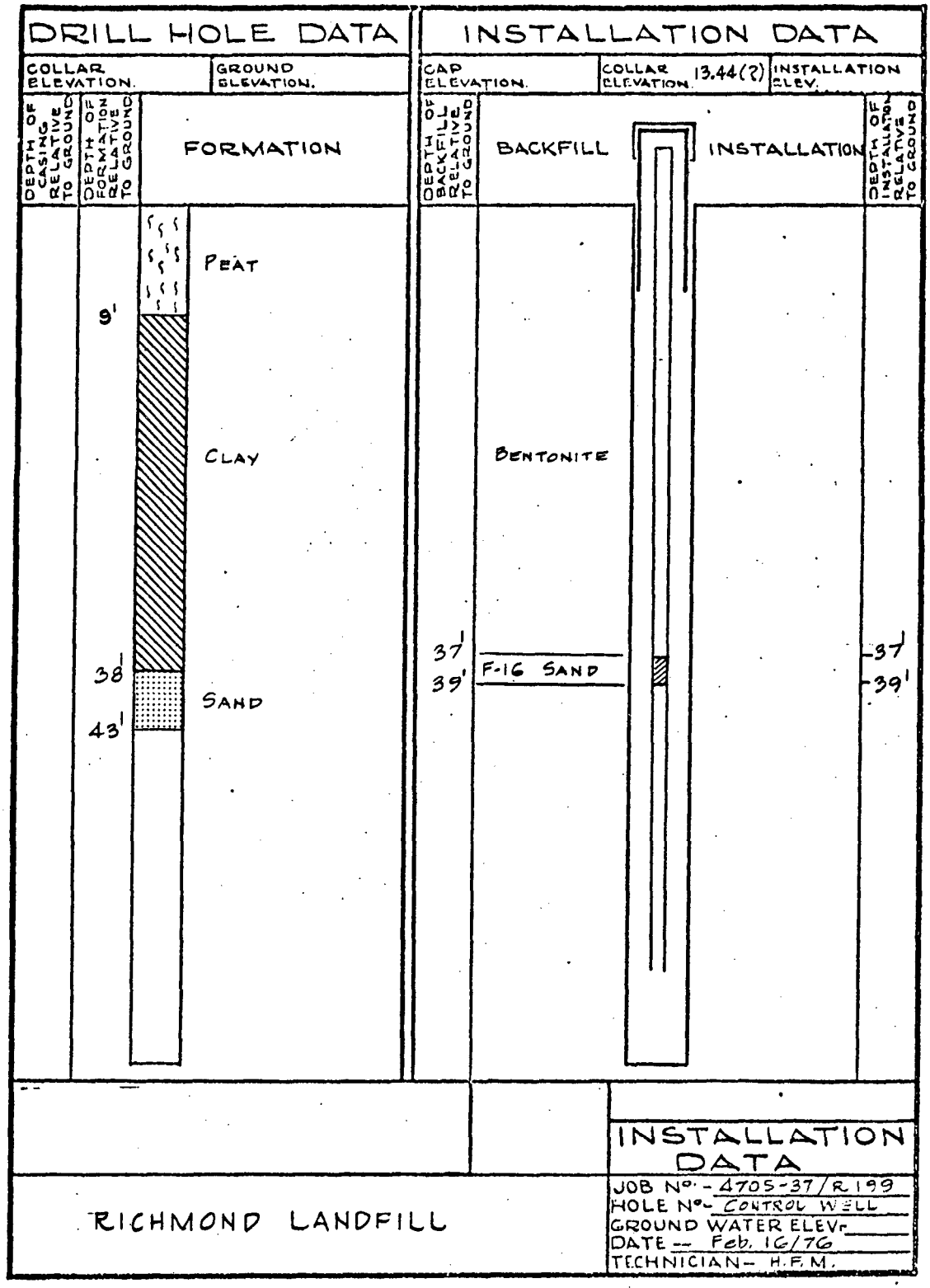

DRILL HOLE DATA
COLLAR ELEVATION.
GROUND ELEVATION. ≈ 24.6'
DEPTH OF CASING RELATIVE TO GROUND
DEPTH OF FORMATION RELATIVE TO GROUND
FORMATION
1'
DREDGED SAND
GRANULAR FILL
WOOD CHIPS AND
GARBAGE
8'
10'
PEAT
CLAY
33'
37'
SAND - VERY SILTY
SAND
INSTALLATION DATA
CAP ELEVATION.
COLLAR ELEVATION. 27.31
INSTALLATION ELEV. 13.78
DEPTH OF BACKFILL RELATIVE TO GROUND
BACKFILL
INSTALLATION
DEPTH OF INSTALLATION RELATIVE TO GROUND
BENTONITE (10 BUCKETS)
37'
39'
F-16 SAND
WELL SCREEN
37' to 39'
INSTALLATION DATA
JOB No. - 4705-37/R199
HOLE No. - 3-D
GROUND WATER ELEV.
DATE - Feb 5, 1976
TECHNICIAN - H. F. M.
RICHMOND LANDFILL


DRILL HOLE DATA
COLLAR ELEVATION.
GROUND UNKNOWN ELEVATION.
DEPTH OF CASING RELATIVE TO GROUND
DEPTH OF FORMATION RELATIVE TO GROUND
FORMATION
9'
23'
38'
60'
GARBAGE, WOOD CHIPS
PEAT
CLAY - SILTY
SAND - SILTY - COARSER AFTER 50'
INSTALLATION DATA
CAP ELEVATION.
COLLAR ELEVATION 27.29
INSTALLATION ELEV. 31.96
DEPTH OF BACKFILL RELATIVE TO GROUND
BACKFILL
INSTALLATION
DEPTH OF INSTALLATION RELATIVE TO GROUND
4'
CONCRETE
BENTONITE ≈ 100 GALS.
54'
56'
F-16 SAND
WELL SCREEN
INSTALLATION DATA
RICHMOND LANDFILL
JOB No. - 4700-37/R199
HOLE No. 3-F
GROUND WATER ELEV.
DATE - Jan. 26, 1976
TECHNICIAN - H.E.M.


DRILL HOLE DATA
INSTALLATION DATA
COLLAR ELEVATION.
GROUND ELEVATION. ?~ 27'
CAP ELEVATION.
COLLAR ELEVATION 29.93
INSTALLATION ELEV. 11.54
DEPTH OF CASING RELATIVE TO GROUND
DEPTH OF FORMATION RELATIVE TO GROUND
FORMATION
DEPTH OF BACKFILL RELATIVE TO GROUND
BACKFILL
INSTALLATION
DEPTH OF INSTALLATION RELATIVE TO GROUND
GARBAGE (2 LIFTS?)
15'
PEAT
23'
1.5'
CONCRETE
F-9 SAND
WELL SCREEN
13' to 15'
INSTALLATION DATA
RICHMOND LANDFILL
JOB No. - 4705-37/R199
HOLE No. - 3-G
GROUND WATER ELEV.
DATE -- Feb. 6, 1976
TECHNICIAN -


DRILL HOLE DATA
COLLAR ELEVATION.
GROUND ELEVATION. ? ~ 29'
DEPTH OF CASING RELATIVE TO GROUND
DEPTH OF FORMATION RELATIVE TO GROUND
FORMATION
GARBAGE AND FILL
15'-20' TOUGH DRILLING - WOOD AND CONCRETE
20'
PEAT
29'
32'
CLAY
INSTALLATION DATA
CAP ELEVATION.
COLLAR ELEVATION 3257
INSTALLATION ELEV. 4.72
DEPTH OF BACKFILL RELATIVE TO GROUND
BACKFILL
INSTALLATION
DEPTH OF INSTALLATION RELATIVE TO GROUND
GARBAGE
26'
29'
F-9 SAND
WELL SCREEN
26.5' to 28.5'
INSTALLATION DATA
JOB No. - 4705-37/R199
HOLE No. - 3-H
GROUND WATER ELEV.
DATE - Feb. 16, 1976
TECHNICIAN - H. F. M.
RICHMOND LANDFILL


DRILL HOLE DATA
INSTALLATION DATA
COLLAR ELEVATION.
GROUND ELEVATION. ≈ 20
CAP ELEVATION.
COLLAR ELEVATION.
INSTALLATION ELEV.
DEPTH OF CASING RELATIVE TO GROUND
DEPTH OF FORMATION RELATIVE TO GROUND
FORMATION
DEPTH OF BACKFILL RELATIVE TO GROUND
BACKFILL
INSTALLATION
DEPTH OF INSTALLATION RELATIVE TO GROUND
PEAT
CLAYEY PEAT (PEATY CLAY?)
SAND - LOOSE ≈ 15 CM.
5.7M
6.25 METRES SAND LOOSE? NOT SAMPLED
7.0 METRES SILTY CLAY
7.5M
CLAYEY SILT
SAMPLES AT:
4-4.5 M
4.9-5.4 M
3.5-6 M
7-7.5 M
HAND AUGERED SAMPLER
INSTALLATION DATA
RICHMOND LANDFILL
JOB No.- 4705-87/R199
HOLE No.- 4-J
GROUND WATER ELEV.-
DATE -
TECHNICIAN- H.F.M.


DRILL HOLE DATA
INSTALLATION DATA
COLLAR ELEVATION.
GROUND ELEVATION.
CAP ELEVATION.
COLLAR ELEVATION. 13.44(?)
INSTALLATION ELEV.
DEPTH OF CASING RELATIVE TO GROUND
DEPTH OF FORMATION RELATIVE TO GROUND
FORMATION
DEPTH OF BACKFILL RELATIVE TO GROUND
BACKFILL
INSTALLATION
DEPTH OF INSTALLATION RELATIVE TO GROUND
PEAT
9'
CLAY
38'
43'
SAND
BENTONITE
37'
39'
F-16 SAND
INSTALLATION DATA
RICHMOND LANDFILL
JOB No. - 4705-37/R199
HOLE No. - CONTROL WELL
GROUND WATER ELEV.
DATE -- Feb. 16/76
TECHNICIAN - H.F.M.

APPENDIX D

SLUG TESTS, PROCEDURES
AND
MATHEMATICAL DERIVATIONS

VOL. 3, NO. 1 WATER RESOURCES RESEARCH FIRST QUARTER 1967

Response of a Finite-Diameter Well to an Instantaneous Charge of Water[1]

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Abstract. A solution is presented for the change in water level in a well of finite diameter after a known volume of water is suddenly injected or withdrawn. A set of type curves computed from this solution permits a determination of the transmissibility of the aquifer. (Key words: Aquifer tests; groundwater; hydraulics; permeability)

INTRODUCTION

Ferris and Knowles [1954] introduced a method for determining the transmissibility of an aquifer from observations of the water level in a well after a known volume of water is suddenly injected into the well. (See also *Ferris et al.* [1962]). They reasoned that for practical purposes the well may be approximated by an instantaneous line source in the infinite region, for which the residual head differences due to the injection are described by

$$h = (V/4\pi Tt)e^{-r^2S/4Tt} \qquad (1)$$

where

- h = change in head at distance r and time t due to the injection;
- r = distance from the line source or center of well;
- t = time since instantaneous injection;
- V = volume of water injected;
- T = transmissibility of aquifer;
- S = coefficient of storage of aquifer.

They reasoned further that the head H in the injected well would be described closely by (1) when r is set equal to the effective radius r_e [*Jacob*, 1947, p. 1049] of the screen or open hole. Then, since r_e is small, the exponential approaches unity quickly, so that the equation approaches $H = V/4\pi Tt$, which can be written

$$T = V(1/t)/4\pi H \qquad (2)$$

To the extent that the equation is valid for a well of finite diameter, a determination of the transmissibility can be obtained from the slope of a plot of head H versus the reciprocal of time $(1/t)$.

Since the volume of water injected into the well is $\pi r_c^2 H_0$, where r_c is the radius of the casing in the interval over which the water level fluctuates and H_0 is the initial head increase in the well, equation 1 can be written

$$h/H_0 = (r_c^2/4Tt)e^{-r^2S/4Tt} \qquad (3)$$

and equation 2 can be written

$$H/H_0 = r_c^2/4Tt \qquad (4)$$

Recently *Bredehoeft et al.* [1966] demonstrated by means of an electrical analog model of a well-aquifer system that equation 3 gives a satisfactory approximation of the head in an injected well only after the time t is large enough for the ratio H/H_0 to be very small (see Figure 1). The observed discrepancy appears to arise from the assumption that the injected well can be approximated by a line source. We present here an exact solution for the head in and around a well of finite diameter after the well is instantaneously charged with a known volume of water.

ANALYSIS

Consider a nonflowing well cased to the top of a homogeneous isotropic artesian aquifer of uniform thickness, and screened (or open) throughout the thickness of the aquifer (Figure 2). Suppose that the well is instantaneously charged with a volume V of water. (We will consider

[1] Publication authorized by the Director, U. S. Geological Survey.

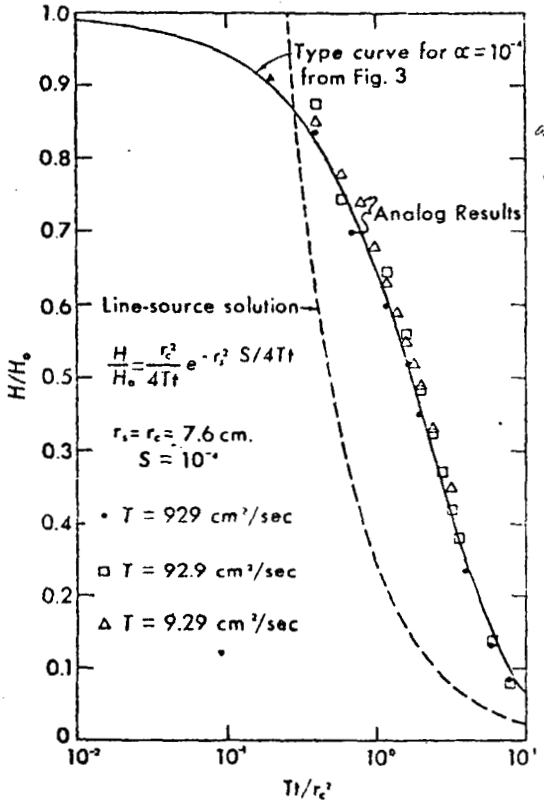

Fig. 1. Comparison of analog results with curve representing line-source solution.

an injection as a positive charge and a withdrawal as a negative one.) The water level in the well instantaneously moves to the height $H_0 = V/\pi r_c^2$ above or below its initial level and immediately begins to return to its initial level according to some function of time $H(t)$. Meanwhile the head in the surrounding aquifer varies according to $h(r, t)$. Our objective is to find a solution for $h(r, t)$ and $H(t)$. The inertia of the column of water in the well will be neglected. (See, in this connection, *Bredehoeft et al.* [1966]). Since the solution to be obtained can be superposed on any initial condition, we can simplify the problem without loss of generality by assuming that the head is initially uniform and constant.

The problem is described mathematically by

$$\partial^2 h/\partial r^2 + 1/r(\partial h/\partial r) = S/T(\partial h/\partial t) \qquad (r > r_s) \qquad (5)$$

Boundary Condition

$$h(r_s + 0, t) = H(t) \qquad (t > 0) \qquad (5a)$$

$$h(\infty, t) = 0 \qquad (t > 0) \qquad (5b)$$

$$2\pi r_s T[\partial h(r_s + 0, t)]/\partial r = \pi r_c^2(\partial H(t)/\partial t) \qquad (t > 0) \qquad (5c)$$

rate of flow to = rate of decrease casing

at t = 0 $H_0 = H_0$

$$h(r, 0) = 0 \qquad (r > r_s) \qquad (5d)$$

$$H(0) = H_0 = V/\pi r_c^2 \qquad (5e)$$

Equation 5 is the differential equation governing nonsteady radial flow of confined groundwater. (See, for example, *Jacob*, 1950, p. 333.) Boundary condition 5*a* states that after the first instant the head in the aquifer at the face of the well is equal to that in the well. Boundary condition 5*b* states that as r approaches infinity the change in head approaches zero. Equation 5*c* expresses the fact that the rate of flow of water into (or out of) the aquifer is equal to the rate of decrease (or increase) in volume of water within the well. The conditions 5*d* and 5*e* state that initially the change in head is zero everywhere outside the well and equal to H_0 inside the well.

By applying the Laplace transform with respect to time the problem is reduced to

$$\partial^2\bar{h}/\partial r^2 + 1/r\,(\partial\bar{h}/\partial r) = (S/T)\,(p\bar{h}) \qquad (6)$$

$$\bar{h}(\infty, p) = 0 \qquad (6a)$$

$$[\partial\bar{h}(r_s + 0, p)]/\partial r = (r_c^2/2r_sT)[p\bar{h}(r_s + 0, p) - H_0] \qquad (6b)$$

for which the solution is

$$\bar{h}(r, p) = \frac{r_s S H_0 K_0(rq)}{Tq[r_s q K_0(r_s q) + 2\alpha K_0(r_s q)]} \qquad (7)$$

where $q = (pS/T)^{\frac{1}{2}}$, and $\alpha = r_s^2 S/r_c^2$.
The solution $h(r, t)$ is the inverse transform, which is available from the analogous problem in heat flow [*Carslaw and Jaeger*, 1959, p. 342]

$$h = \frac{2H_0}{\pi}\int_0^\infty e^{-\beta u^2/\alpha}\{J_0(ur/r_s) \cdot [uY_0(u) - 2\alpha Y_1(u)] - Y_0(ur/r_s) \cdot [uJ_0(u) - 2\alpha J_1(u)]\}\frac{du}{\Delta(u)} \qquad (8)$$

where $\beta = Tt/r_c^2$ and

$$\Delta(u) = [uJ_0(u) - 2\alpha J_1(u)]^2 + [uY_0(u) - 2\alpha Y_1(u)]^2$$

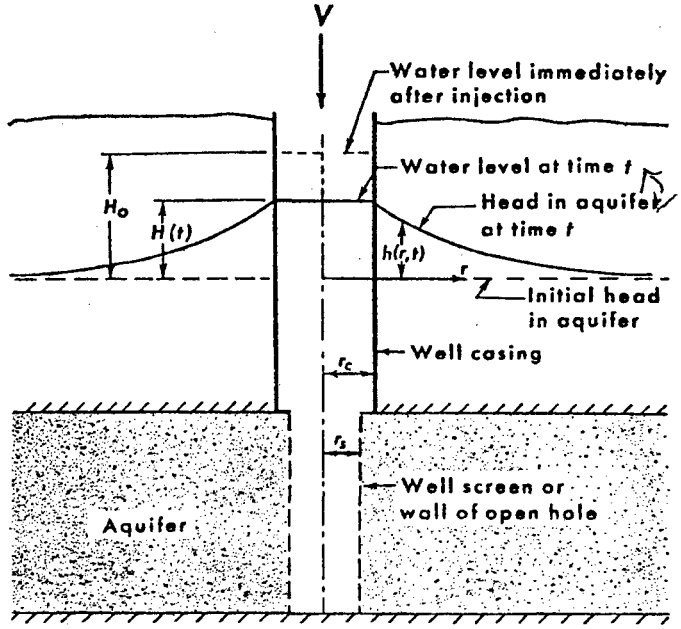

Fig. 2. Idealized representation of a well into which a volume V of water is suddenly injected.

The head $H(t)$ inside the well, obtained by substituting $r = r_s$ in equation 8, is

$$H = (8H_0\alpha/\pi^2) \int_0^\infty e^{-\beta u^2/\alpha}\, du/(u\,\Delta(u)) \quad (9)$$

Values of H/H_0 computed by numerically integrating equation 9 are given in Table 1. Values computed from the line-source solutions, equations 3 and 4, are given in Table 2. In Figure 3 the values from Table 1 are represented as a family of five curves of H/H_0 versus the dimensionless time parameter $\beta = Tt/r_s^2$, one curve for each of five values of the parameter $\alpha = r_s^2S/r_c^2$. Also represented, by a dashed curve, are the values computed from equation 4.

It is apparent from Tables 1 and 2 and from Figure 3 that the line-source solutions 3 and 4 proposed by *Ferris and Knowles* [1954] give a close approximation of the finite-source solution 9 only for large values of the time parameter Tt/r_s^2. The approximation seems to be acceptable for Tt/r_s^2 greater than 100 (or, equivalently, for H/H_0 less than about 0.0025). (In the test at Speedway City, Indiana, used by Ferris and Knowles to exemplify their method, H/H_0 ranged from 0.01 to 0.001, and the value of transmissibility determined from these data agreed fairly well with one obtained by another method.)

A family of type curves plotted on semilogarithmic paper, as in Figure 3, permits a determination of the transmissibility. The method is similar to the Theis graphical method [*Wenzel*, 1942]. A test on a well near Dawsonville, Georgia, will be used to demonstrate the method. This well is cased to 24 m with 15.2-cm (6-inch) casing and drilled as a 15.2-cm open hole to a depth of 122 m. Figure 4 is a reproduction of a chart showing the hydrograph of the well after the sudden withdrawal of a long weighted float from the well. The weight of the float was 10.16 kilograms, and hence by the principle of Archimedes it had displaced a volume of 0.01016 m^3 of water when floating in the well. Its withdrawal was therefore equivalent to a negative charge of $V = 0.01016$ m^3. From the relation $H_0 = V/\pi r_c^2$ the initial head change is found to be $H_0 = 0.560$ m.

The hydrograph in Figure 4 was recorded electrically from a pressure transducer, which was suspended below the water surface in the well. Table 3 lists data from this chart. To determine the aquifer constants the data are

TABLE 1. Values of H/H_0 for a Well of Finite Diameter (computed from equation 9)

Tt/r_c^2	H/H_0				
	$\alpha = 10^{-1}$	$\alpha = 10^{-2}$	$\alpha = 10^{-3}$	$\alpha = 10^{-4}$	$\alpha = 10^{-5}$
1.00×10^{-3}	0.9771	0.9920	0.9969	0.9985	0.9992
2.15×10^{-3}	0.9658	0.9876	0.9949	0.9974	0.9985
4.64×10^{-3}	0.9490	0.9807	0.9914	0.9954	0.9970
1.00×10^{-2}	0.9238	0.9693	0.9853	0.9915	0.9942
2.15×10^{-2}	0.8860	0.9505	0.9744	0.9841	0.9888
4.64×10^{-2}	0.8293	0.9187	0.9545	0.9701	0.9781
1.00×10^{-1}	0.7460	0.8655	0.9183	0.9434	0.9572
2.15×10^{-1}	0.6289	0.7782	0.8538	0.8935	0.9167
4.64×10^{-1}	0.4782	0.6436	0.7436	0.8031	0.8410
1.00×10^{0}	0.3117	0.4598	0.5729	0.6520	0.7080
2.15×10^{0}	0.1665	0.2597	0.3543	0.4364	0.5038
4.64×10^{0}	0.07415	0.1086	0.1554	0.2082	0.2620
7.00×10^{0}	0.04625	0.06204	0.08519	0.1161	0.1521
1.00×10^{1}	0.03065	0.03780	0.04821	0.06355	0.08378
1.40×10^{1}	0.02092	0.02414	0.02844	0.03492	0.04426
2.15×10^{1}	0.01297	0.01414	0.01545	0.01723	0.01999
3.00×10^{1}	0.009070	0.009615	0.01016	0.01083	0.01169
4.64×10^{1}	0.005711	0.005919	0.006111	0.006319	0.006554
7.00×10^{1}	0.003722	0.003809	0.003884	0.003962	0.004046
1.00×10^{2}	0.002577	0.002618	0.002653	0.002688	0.002725
2.15×10^{2}	0.001179	0.001187	0.001194	0.001201	0.001208

plotted on semilogarithmic paper of the same scale as that of the type curves in Figure 3, and this plot is superposed on the type curves. With the arithmetic axes coincident, the data plot is translated horizontally to a position where the data best fit the type curves, as

TABLE 2. Values of H/H_0 for Line-source Approximation of a Well

Tt/r_c^2	H/H_0 from equation 3					H/H_0 from eq. 4
	$\alpha = 10^{-1}$	$\alpha = 10^{-2}$	$\alpha = 10^{-3}$	$\alpha = 10^{-4}$	$\alpha = 10^{-5}$	
1.00×10^{-3}	0.000000	20.52	194.7	243.8	249.4	250.0
2.15×10^{-3}	0.001035	36.35	103.5	115.0	116.2	116.3
4.64×10^{-3}	0.2463	31.44	51.05	53.59	53.85	53.88
1.00×10^{-2}	2.052	19.47	24.38	24.94	24.99	25.00
2.15×10^{-2}	3.635	10.35	11.50	11.62	11.63	11.63
4.64×10^{-2}	3.144	5.105	5.359	5.385	5.388	5.388
1.00×10^{-1}	1.947	2.438	2.494	2.499	2.500	2.500
2.15×10^{-1}	1.035	1.150	1.162	1.163		1.163
4.64×10^{-1}	0.5105	0.5359	0.5385	0.5388		0.5388
1.00×10^{0}	0.2438	0.2494	0.2499	0.2500		0.2500
2.15×10^{0}	0.1150	0.1162	0.1163			0.1163
4.64×10^{0}	0.05359	0.05385	0.05388			0.05388
7.00×10^{0}	0.03558	0.03570	0.03571			0.03571
1.00×10^{1}	0.02494	0.02499	0.02500			0.02500
1.40×10^{1}	0.01783	0.01786				0.01786
2.15×10^{1}	0.01162	0.01163				0.01163
3.00×10^{1}	0.008326	0.008333				0.008333
4.64×10^{1}	0.005385	0.005388				0.005388
7.00×10^{1}	0.003570	0.003571				0.003571
1.00×10^{2}	0.002499	0.002500				0.002500
2.15×10^{2}	0.001163					0.001163

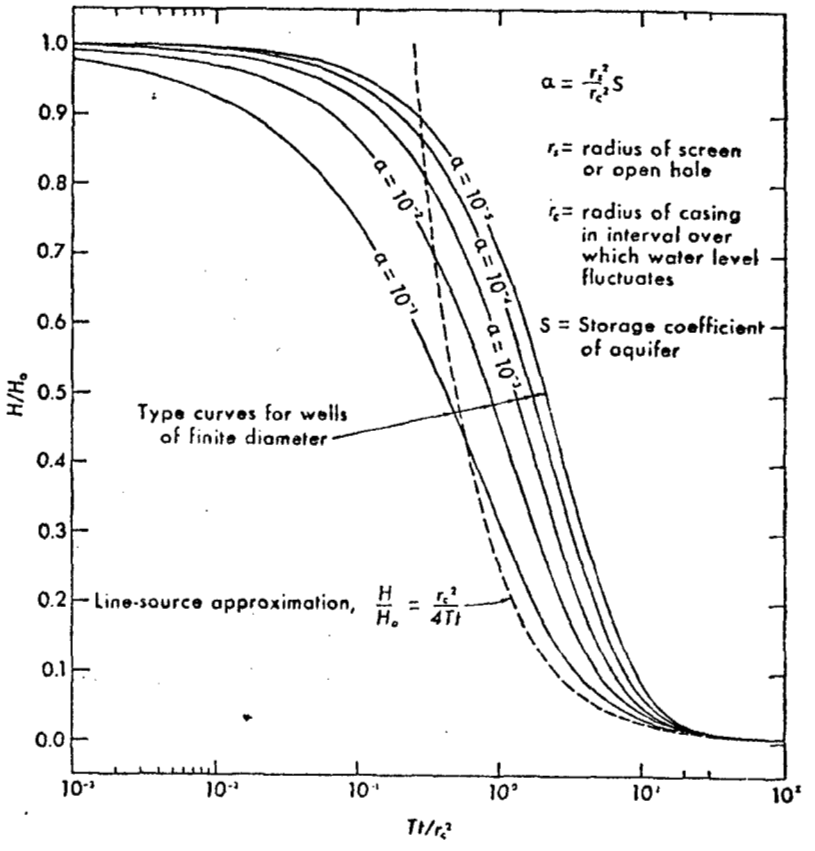

Fig. 3. Type curves for instantaneous charge in well of finite diameter.

shown in Figure 5. In this position the time $t = 11$ sec on the data coordinates is found to overlie the value $Tt/r_c^2 = 1.0$ on the type-curve coordinates. Hence the transmissibility is computed to be

$$T = \frac{1.0 r_c^2}{t} = \frac{(1.0)(7.6)^2}{(11)} = 5.3 \text{ cm}^2/\text{sec}$$

In principle the coefficient of storage can be determined by interpolating from its values for the curves that lie on either side of the data plot in the matched position. Thus, in the example just described, the coefficient of storage would be $S = 10^{-3}$, since for this well $r_o = r_s$, so that $\alpha = S$, and the points fall on the curve for $\alpha = 10^{-3}$. However, because the matching of data plot to the type curves depends upon the shapes of the type curves, which differ only slightly when α differs by an order of magnitude, a determination of S by this method has questionable reliability.

The determination of T is not so sensitive to the choice of the curves to be matched. Whereas the determined value of S will change by an

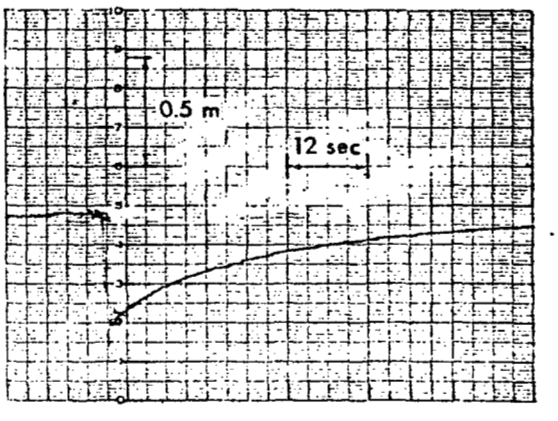

Fig. 4. Hydrograph of well at Dawsonville, Georgia, showing response of water level to the sudden withdrawal of a weighted float.

TABLE 3. Rise of Water Level in Dawsonville Well after Instantaneous Withdrawal of Weighted Float

t (sec)	$1/t$	Head (m)	H (m)	H/H_0
−1		0.896		
0		0.336	0.560	1.000
3	0.333	0.439	0.457	0.816
6	0.167	0.504	0.392	0.700
9	0.111	0.551	0.345	0.616
12	0.0833	0.588	0.308	0.550
15	0.0667	0.616	0.280	0.500
18	0.0556	0.644	0.252	0.450
21	0.0476	0.672	0.224	0.400
24	0.0417	0.691	0.205	0.366
27	0.0370	0.709	0.187	0.334
30	0.0333	0.728	0.168	0.300
33	0.0303	0.747	0.149	0.266
36	0.0278	0.756	0.140	0.250
39	0.0256	0.765	0.131	0.234
42	0.0238	0.784	0.112	0.200
45	0.0222	0.788	0.108	0.193
48	0.0208	0.803	0.093	0.166
51	0.0196	0.807	0.089	0.159
54	0.0185	0.814	0.082	0.146
57	0.0175	0.821	0.075	0.134
60	0.0167	0.825	0.071	0.127
63	0.0159	0.831	0.065	0.116

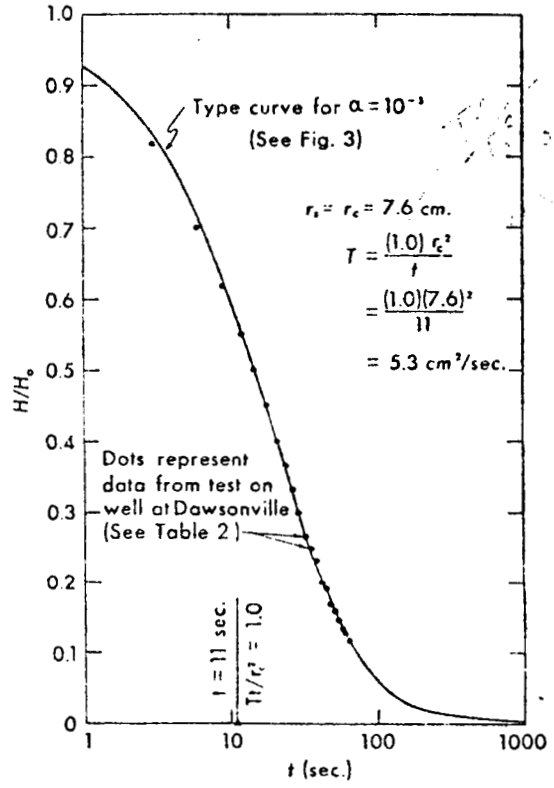

Fig. 5. Plot of data from test at Dawsonville, Georgia, superposed on type curve.

order of magnitude when the data plot is moved from one type curve to another, that of T will change much less. From a knowledge of the geologic conditions and other considerations one can ordinarily estimate S within an order of magnitude and thereby eliminate some of the doubt as to what value of α is to be used for matching the data plot.

Figure 6 shows the data from the test on the Dawsonville well plotted according to the Ferris-Knowles method. The points do not fall along a straight line as postulated in this method but, instead, fall along the trace of the type curve for $\alpha = 10^{-3}$, which has been transferred from Figure 5. Also shown is a straight line through the origin whose slope, when used according to the Ferris-Knowles method, will yield the transmissibility of 5.3 cm²/sec obtained by matching the data to the type curves.

CONCLUSION

The judgment of an experienced hydrologist is needed to decide the significance, if any, of a determination of T by the method of instantaneous charge. As *Ferris et al.* [1962] properly warned

> the duration of a 'slug' test is very short, hence the estimated transmissibility determined from the test will be representative only of the water-bearing material close to the well. Serious errors will be introduced unless the . . . well is fully developed and completely penetrates the aquifer.

Few wells completely penetrate an aquifer, but it is nevertheless possible under some circumstances for a hydrologist to derive useful information from a test on a partially penetrating well. Since the vertical permeabilities of most stratified aquifers are only small fractions of the horizontal permeabilities, the induced flow within the small radius of the cone that develops during the short period of observation is likely to be essentially 2-dimensional. Therefore, the determined value of T would represent approximately the transmissibility of that part

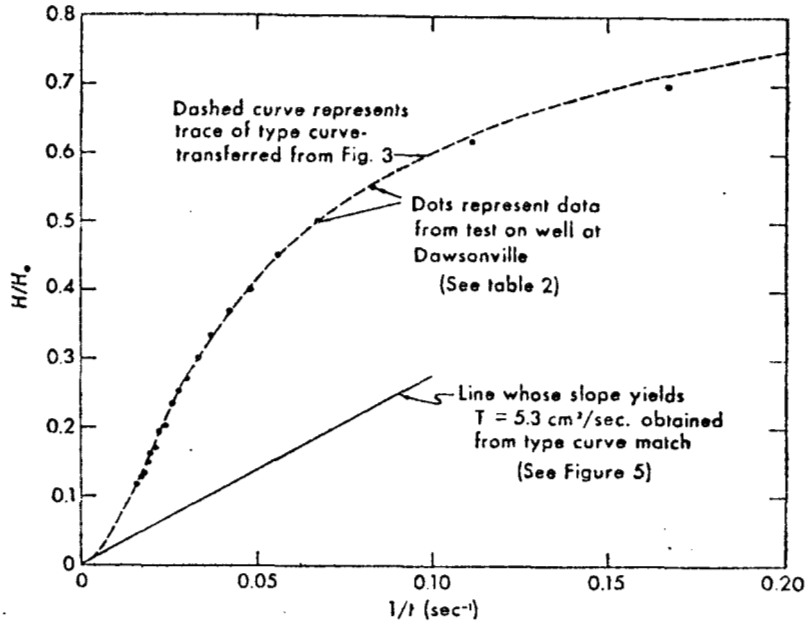

Fig. 6. Data from test on well of Dawsonville, Georgia, plotted according to the Ferris-Knowles method.

of the aquifer in which the well is screened or open, provided that the aquifer is reasonably homogeneous and isotropic in planes parallel to the bedding and provided that the effective radius r_e can be estimated closely.

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On the Analysis of 'Slug Test' Data

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Methods of analyzing 'slug test' data are reviewed, and additional type curves for the analysis of test data from formations with very low storage coefficients are presented.

The 'slug test' as a method of estimating the transmissivity of an aquifer was introduced by *Ferris and Knowles* [1954] (see also *Ferris et al.* [1962]). As is well known, the test consists of causing an instantaneous change in the water level of a well either by suddenly introducing or removing a known volume of water or by any other possible means and observing the recovery of the water level in the well with time. The method proposed by *Ferris and Knowles* [1954] for analyzing the test data is based on a solution that assumes a well of infinitesimal diameter (mathematical line source) and that can be expressed as

$$H/H_0 = r_c^2/4Tt \qquad (1)$$

where

- H_0, instantaneous head change in the well;
- H, head in the well at time $t > 0$;
- r_c, radius of the well casing in the interval over which the head change takes place;
- T, transmissivity of the aquifer;
- t, time since the instantaneous head change.

The transmissivity is determined from the slope of an arithmetic plot of H or of H/H_0 against $1/t$. Later we [*Cooper et al.*, 1967] presented a solution for a well of finite diameter and showed that the line source approximation of Ferris and Knowles is valid only for the relatively large times $t > 100\ r_c^2/T$, or, equivalently, when $H/H_0 < 0.0025$ (see the dashed line in Figure 1).

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Our solution, which is applicable for all times t, has the form

$$H/H_0 = F(\beta, \alpha) \qquad (2)$$

where

- $\beta = Tt/r_c^2$;
- $\alpha = r_e^2 S/r_c^2$;
- r_e, effective radius of the well;
- S, storage coefficient of the aquifer;
- $F(\beta, \alpha)$, a function whose tables and graphs were presented for five orders of α, 10^{-1}–10^{-5}, and for $10^{-3} < \beta < 2.15 \times 10^3$ (for larger values of β the function is closely approximated by equation 1).

On the basis of this solution a type curve method for analyzing test data was proposed.

As both *Ferris et al.* [1962] and *Cooper et al.* [1967] recognize, transmissivities determined from the analysis of slug test data are 'representative only of the water-bearing material close to the well.' The test provides, however, an economical means of determining 'point' transmissivities. In some types of groundwater investigations a large number of such point transmissivities are often of greater use than a single value of the transmissivity obtained from a long-term pumping test at the same cost. The test has also been used as an indicator of the effectiveness of well development (W. A. Meneley, oral communication, 1972). In a properly developed well the slug test transmissivity should be higher than the long-term pumping test transmissivity. In the oil industry the type curve method has been adapted to

TABLE 1. Values of H/H_0 for a Well of Finite Diameter

Tt/r_c^2	$\alpha = 10^{-6}$	$\alpha = 10^{-7}$	$\alpha = 10^{-8}$	$\alpha = 10^{-9}$	$\alpha = 10^{-10}$
0.001	0.9994	0.9996	0.9996	0.9997	0.9997
0.002	0.9989	0.9992	0.9993	0.9994	0.9995
0.004	0.9980	0.9985	0.9987	0.9989	0.9991
0.006	0.9972	0.9978	0.9982	0.9984	0.9986
0.008	0.9964	0.9971	0.9976	0.9980	0.9982
0.01	0.9956	0.9965	0.9971	0.9975	0.9978
0.02	0.9919	0.9934	0.9944	0.9952	0.9958
0.04	0.9848	0.9875	0.9894	0.9908	0.9919
0.06	0.9782	0.9819	0.9846	0.9866	0.9881
0.08	0.9718	0.9765	0.9799	0.9824	0.9844
0.1	0.9655	0.9712	0.9753	0.9784	0.9807
0.2	0.9361	0.9459	0.9532	0.9587	0.9631
0.4	0.8828	0.8995	0.9122	0.9220	0.9298
0.6	0.8345	0.8569	0.8741	0.8875	0.8984
0.8	0.7901	0.8173	0.8383	0.8550	0.8686
1.0	0.7489	0.7801	0.8045	0.8240	0.8401
2.0	0.5800	0.6235	0.6591	0.6889	0.7139
3.0	0.4554	0.5033	0.5442	0.5792	0.6096
4.0	0.3613	0.4093	0.4517	0.4891	0.5222
5.0	0.2893	0.3351	0.3768	0.4146	0.4487
6.0	0.2337	0.2759	0.3157	0.3525	0.3865
7.0	0.1903	0.2285	0.2655	0.3007	0.3337
8.0	0.1562	0.1903	0.2243	0.2573	0.2888
9.0	0.1292	0.1594	0.1902	0.2208	0.2505
10.0	0.1078	0.1343	0.1620	0.1900	0.2178
20.0	0.02720	0.03343	0.04129	0.05071	0.06149
30.0	0.01286	0.01448	0.01667	0.01956	0.02320
40.0	0.008337	0.008898	0.009637	0.01062	0.01190
50.0	0.006209	0.006470	0.006789	0.007192	0.007709
60.0	0.004961	0.005111	0.005283	0.005487	0.005735
80.0	0.003547	0.003617	0.003691	0.003773	0.003863
100.0	0.002763	0.002803	0.002845	0.002890	0.002938
200.0	0.001313	0.001322	0.001330	0.001339	0.001348

analyze drill-stem tests [*Kohlhaas*, 1972], most of which 'do not have production to the surface, either because of low formation productivity or because of the limited duration of the flow period.'

In recent years the increased interest in determining the hydrologic properties of low transmissivity formations, mostly in relation with deep-well waste disposal studies, has also increased the popularity of the slug test. The yield of test wells in tight formations is often too low to permit a pumping test of even relatively short duration, and the slug test becomes one of the few available field test methods. Some of these tight formations because of their low compressibility and low porosity, sometimes as low as 0.1%, have also a very small storage coefficient. Under these conditions the value of the parameter α appearing in (2) is smaller than 10^{-6}, and the test data cannot be matched to the available type curves. These conditions were observed in data from tests conducted on oil shales at the Piceance Basin, Colorado, by J. D. Bredehoeft and R. G. Wolff of the U.S. Geological Survey and were also reported to us by several investigators conducting tests on similar formations elsewhere.

Therefore we are presenting here an extension to the previously available values of $F(\beta, \alpha)$, i.e., of H/H_0, for another five orders of α, 10^{-6}–10^{-10} (Table 1). These values are plotted together with the previously available type curves in Figure 1. As can be noted in the figure, for these small values of α the curves have a very similar shape, run close to each other, and are almost parallel for most of their length. This fact indicates that, when the storage coefficient is so small, the recovery of the water level in the test well becomes very insensitive, even to order of magnitude changes in the storage coefficient. In *Cooper et al.* [1967] we stated that 'a deter-

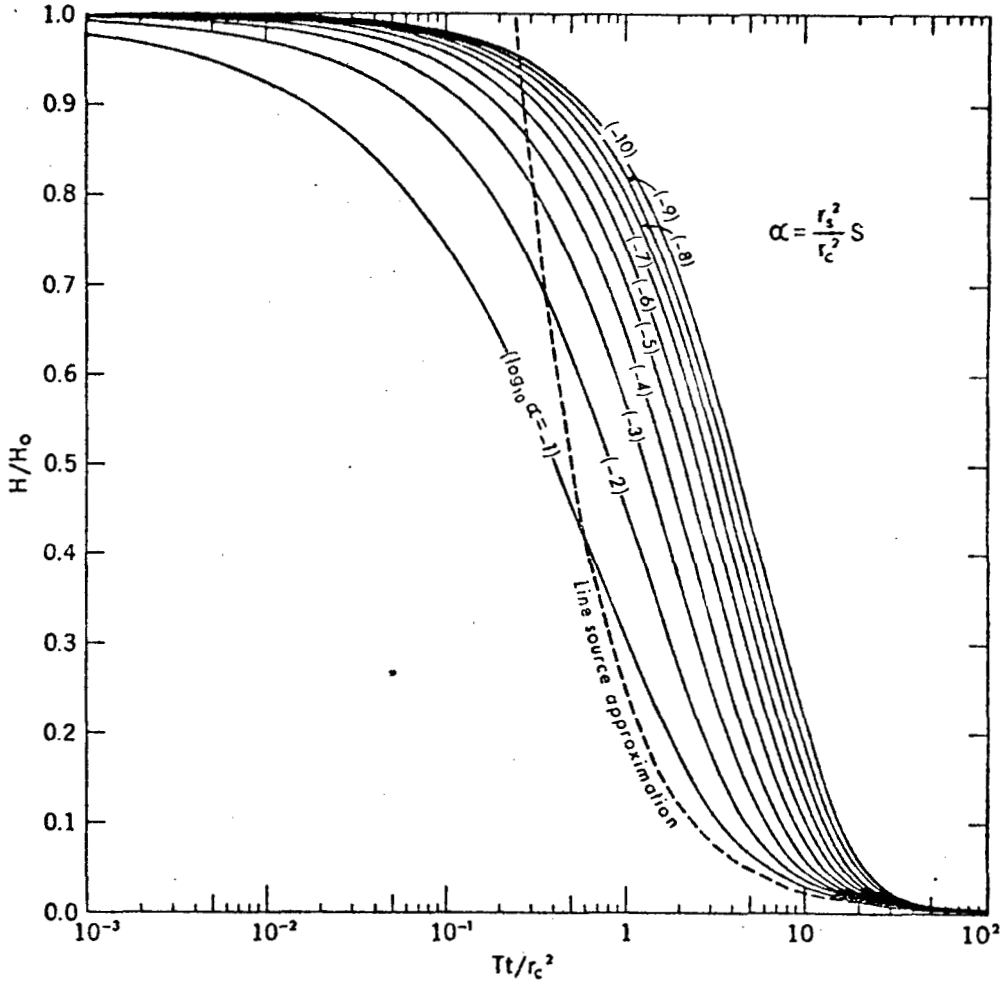

Fig. 1. Type curves for instantaneous change in a well of finite diameter.

mination of S by this method has questionable reliability[7]; reliability becomes even more questionable when α is smaller than 10^{-5}. Of course, the similarity of the type curves in this range of α also affects the determinations of transmissivity. Even the most carefully and accurately collected test data could easily be matched with more than one of the type curves. The best one could expect is to be within one or two orders of magnitude of the actual α. An analysis in the range $\alpha < 10^{-5}$ indicates that, if the value of α for the chosen type curve is within two orders of magnitude of its actual value, the error in the determined T would be less than about 30%. This possible error should be kept in mind when one is making use of transmissivities determined by this method.

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Microtime Measurements of Ground-Water Level Fluctuations

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Abstract

Water-level measurements made during the early seconds and minutes of aquifer tests may often be used to determine the hydraulic properties of an aquifer and to locate hydrogeologic boundaries. This paper describes a method, using a modified stylus carriage and pen and a stop watch, of recording microtime water-level measurements in a well equipped with a recording gage. Ordinary and microtime records of water-level fluctuations are simultaneously obtained. Microtime water-level measurements often aid in appraising the effects of slow gravity drainage under water-table conditions and anisotropic and heterogeneous conditions.

Introduction

During aquifer tests it is often important that data concerning the first few minutes of the drawdown or recovery of water levels in observation wells be collected whenever possible. The nonequilibrium formula (Theis, 1935) was developed from the assumptions that the aquifer tested is infinite in areal extent and that it is both homogeneous and isotropic. These conditions are not generally found in nature. More often aquifers are limited in areal extent by hydrogeologic boundaries which influence water levels in wells often during the early portions of drawdown or recovery tests. Sand and gravel deposits of glacial origin are often anisotropic and frequently contain intercalated lenses of clay or till. Under anisotropic conditions, the early portions of aquifer tests often deviate from the type curve for the nonequilibrium formula.

Under artesian conditions, the cone of depression spreads to relatively great distances from the pumped well in the first few minutes of a test. Boundary effects may cause time-drawdown and time-recovery curves to deviate from the nonequilibrium type curve a short time after pumping starts or stops. Only those portions of time-drawdown or time-recovery curves that represent the effect of the pumped well can be used to calculate values of the coefficients of transmissibility and storage. Thus, it is often difficult to analyze aquifer test data unless there are sufficient measurements of water-level fluctuations during the early portion of the test.

Because of the relatively small vertical permeability of many unconsolidated deposits, there is a time-lag between the lowering of the water table and the appearance of that part of the water which is derived from storage within a water-table aquifer. Rapid measurements taken during the early portion of aquifer tests may aid in analyzing these effects of slow gravity drainage.

When pumping under anisotropic conditions, it is probable that hydraulic interconnection throughout the aquifer will result in continuing adjustment of flow between regions of different permeability. The cone of depression should trend toward a steady-state condition that will reflect the average or over-all transmissibility of the aquifer. Under anisotropic conditions, the early portion of aquifer test data may deviate from the nonequilibrium type curve until growth of the cone of depression becomes stabilized in response to the over-all transmissibility of the aquifer. These deviations reflect the adjustment of flow between regions of different permeability and should be investigated.

Method of Making Microtime Water-Level Measurements

The writer has developed an inexpensive and relatively simple method for making microtime water-level measurements in a well equipped with a recording gage. Water-level measurements can be made at any desired interval of time. In addition, the hydrograph of water level usually made by a recording gage equipped with daily time-scale gears is also obtained.

A stylus carriage and pen for a Stevens type F recorder were purchased from the Leopold and Stevens Co., Inc. The part of the stylus carriage to which the time-scale cable is normally attached was removed so that it would not interfere with normal operation of the recorder. Prior to the start of the aquifer test, the conventional stylus carriage is set on the left side of the chart so that sufficient chart space is available to record the rapid measurements. Then, the micro-measurement stylus carriage is placed about ½ inch to the right of the conventional stylus carriage and is approximately centered between adjacent 15 minute time-scale graph lines on the F-2 chart. At selected intervals of time, the micro-measurement stylus carriage is manually moved across each time-scale graph line to the center of the next time-scale division. The space between the time-scale graph lines is used only to rest the pen before and after the micro-measurements. Thus, water levels at various periods of time are recorded as the stylus is moved across each time-scale line. If the stylus reaches the right side of the chart before the rapid measurements are completed, it

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Discussion open until June 1, 1963.

is moved to a new position near the left side of the chart and again is centered between two time-scale graph lines and the process is repeated. The regular clock driven stylus and pen continues to record the drawdown or recovery so that fast and slow records of the water-level fluctuations in the observation well are simultaneously obtained. These two records can be compared and checked against each other.

The following time schedule for micro-measurements is used by the writer:

> 5 seconds for the first 2 minutes; 10 seconds for the following 3 minutes; 30 seconds for the following 5 minutes; 1 minute for the following 10 minutes; 2 minutes for the following 20 minutes; 5 minutes for the following 30 minutes; and 10 minutes for the following 30 minutes.

Micro-measurements ordinarily are discontinued 100 minutes after the start of the aquifer test because by that time the hydrograph produced by the regular pen is adequate. The writer realizes that using the above time schedule gives data in more detail than can be plotted. However, float trouble often results in several poor water-level measurements. If more data is collected than is generally warranted, unsatisfactory measurements can be omitted in the analysis of the test.

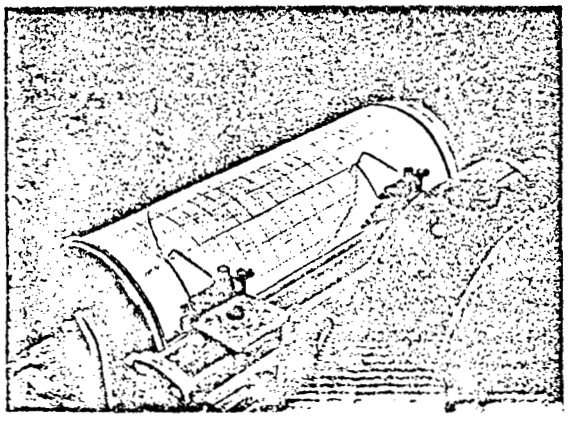

Fig. 1. Recording gage equipped with micro-measurement stylus carriage.

Figure 1 shows a recording gage equipped with a micro-measurement stylus carriage, and a chart showing the microtime water-level measurements made by the writer during an aquifer test. Best results are usually obtained if a stopwatch is held above the center of the chart as the observer moves the pen carriage with his other hand. The writer has found that water works personnel, often present at the aquifer test site, can be trained to operate the micro-measurement stylus carriage. In practice, prior to the start of the aquifer test, stopwatches are issued to those personnel who will take microtime water-level measurements or who will operate the pump. All stopwatches are started simultaneously. The aquifer test is then started after a predetermined lapse of time so that the actions of all personnel will be synchronized.

Data on the drawdown or recovery in at least three observation wells are required for identification of a hydrogeologic boundary. If available, the three observation wells should be equipped with micro-measurement stylus carriages. It is sometimes impossible to adjust the discharge to the predetermined pumping rate instantaneously. In addition the discharge decreases as the water level falls in the pumped well. Thus, recovery should be observed because these data have an advantage over drawdown data in that they are not affected by erratic pumping rates.

Although measurements of small microtime water-level fluctuations are sometimes useless for calculation purposes because of erratic initial pumping rates or the discharge of water in the pump column into the aquifer immediately after the pump is shut off, they do help in visualizing the growth and lateral extent of the cone of depression and they also often aid in analyzing the aquifer test data. The method devised by the author also can be used to study water-level fluctuations caused by trains or other loads passing over an artesian aquifer near an observation well. The water level rises above, falls below and then recovers to the regional trend in response to the loading.

Reference

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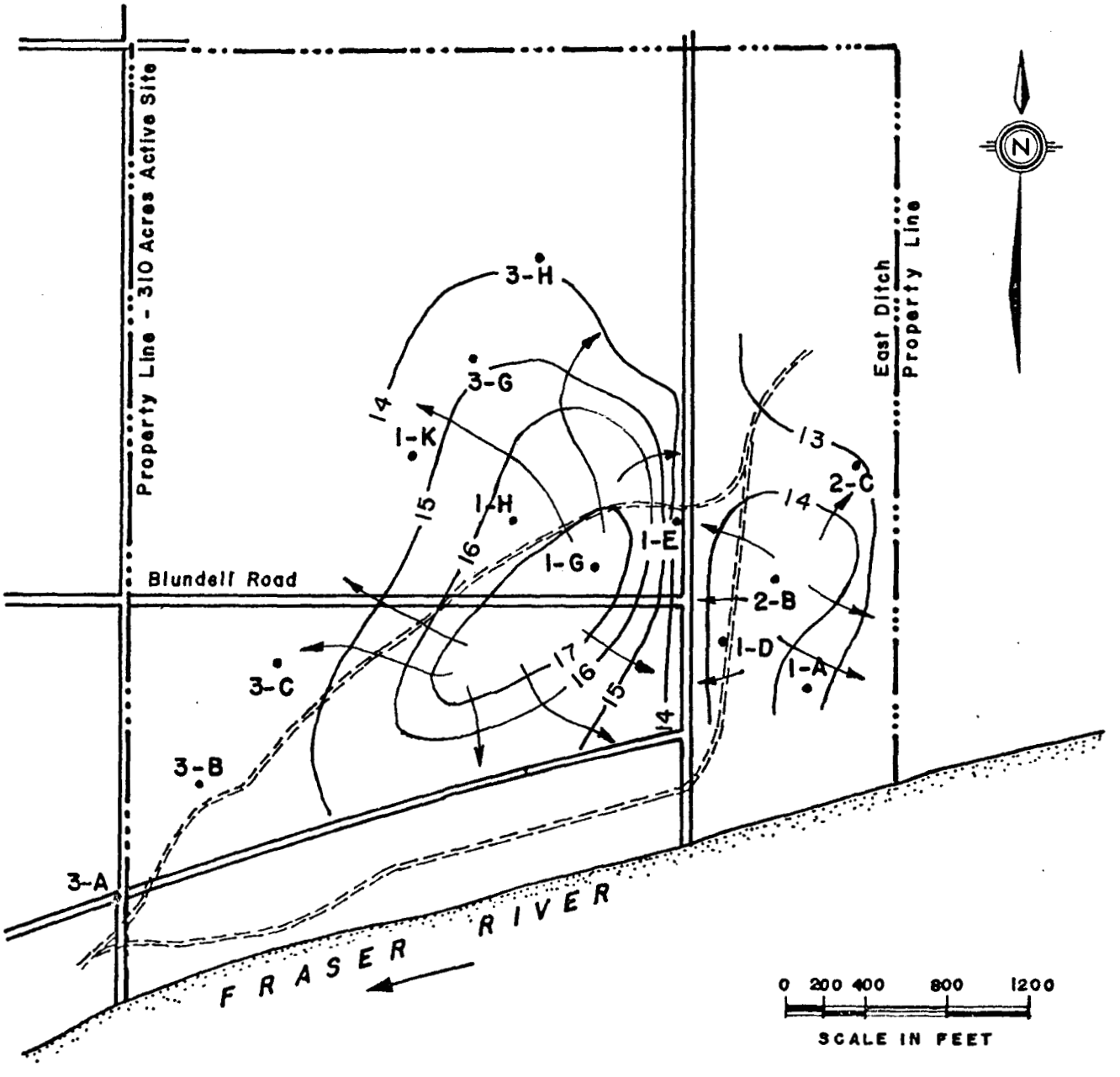
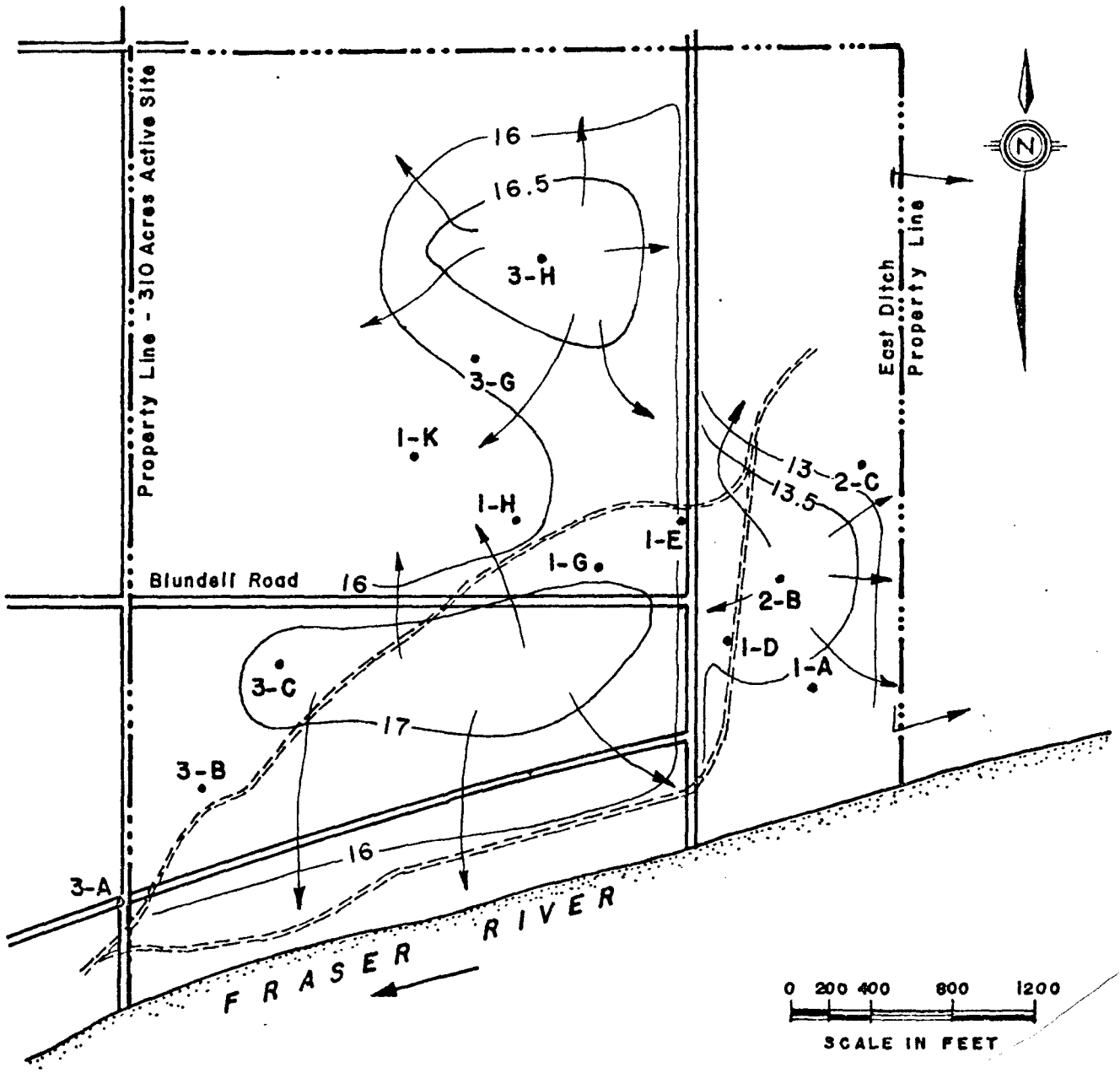
APPENDIX E

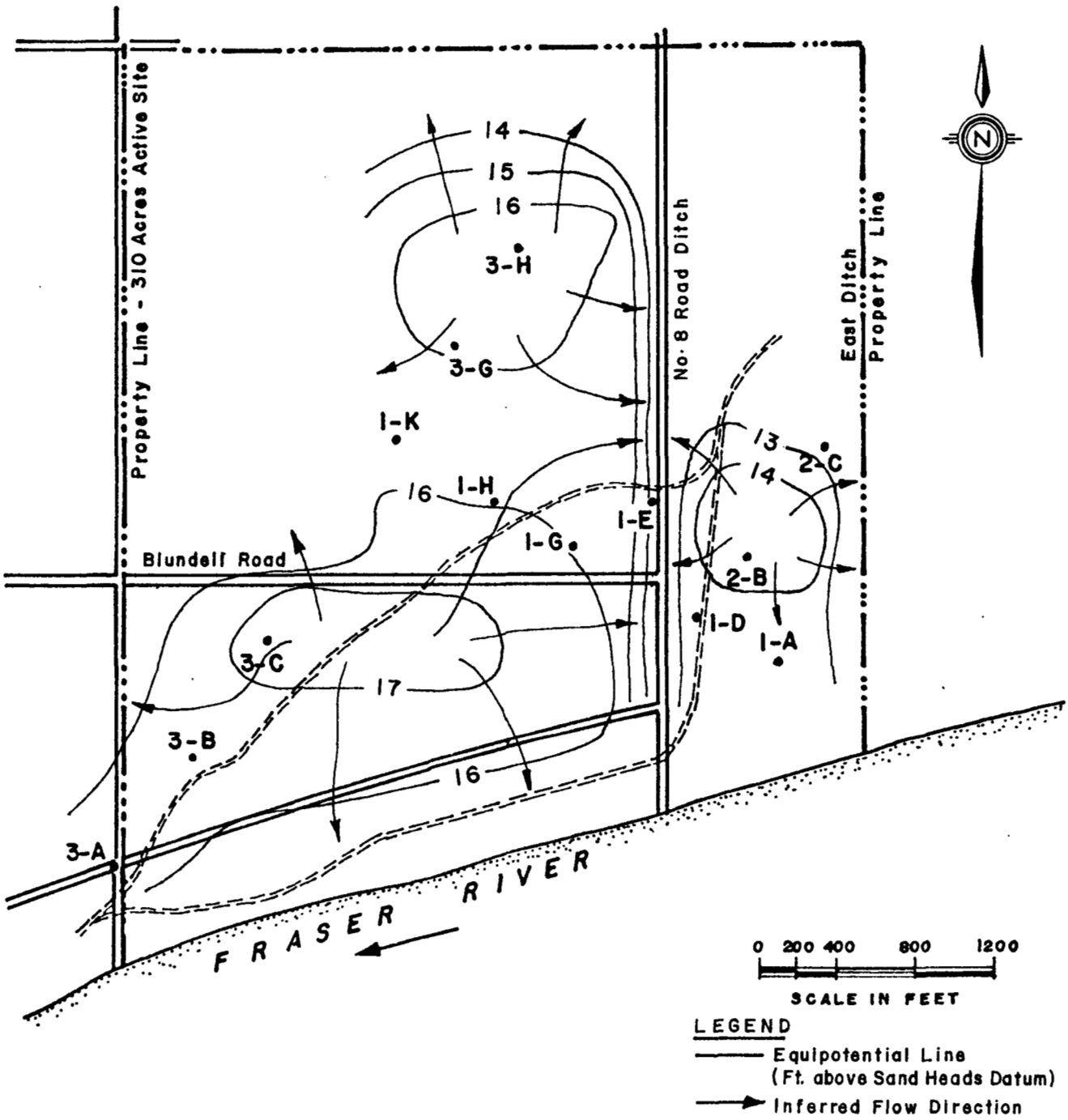
GROUNDWATER FLOW PATTERNS



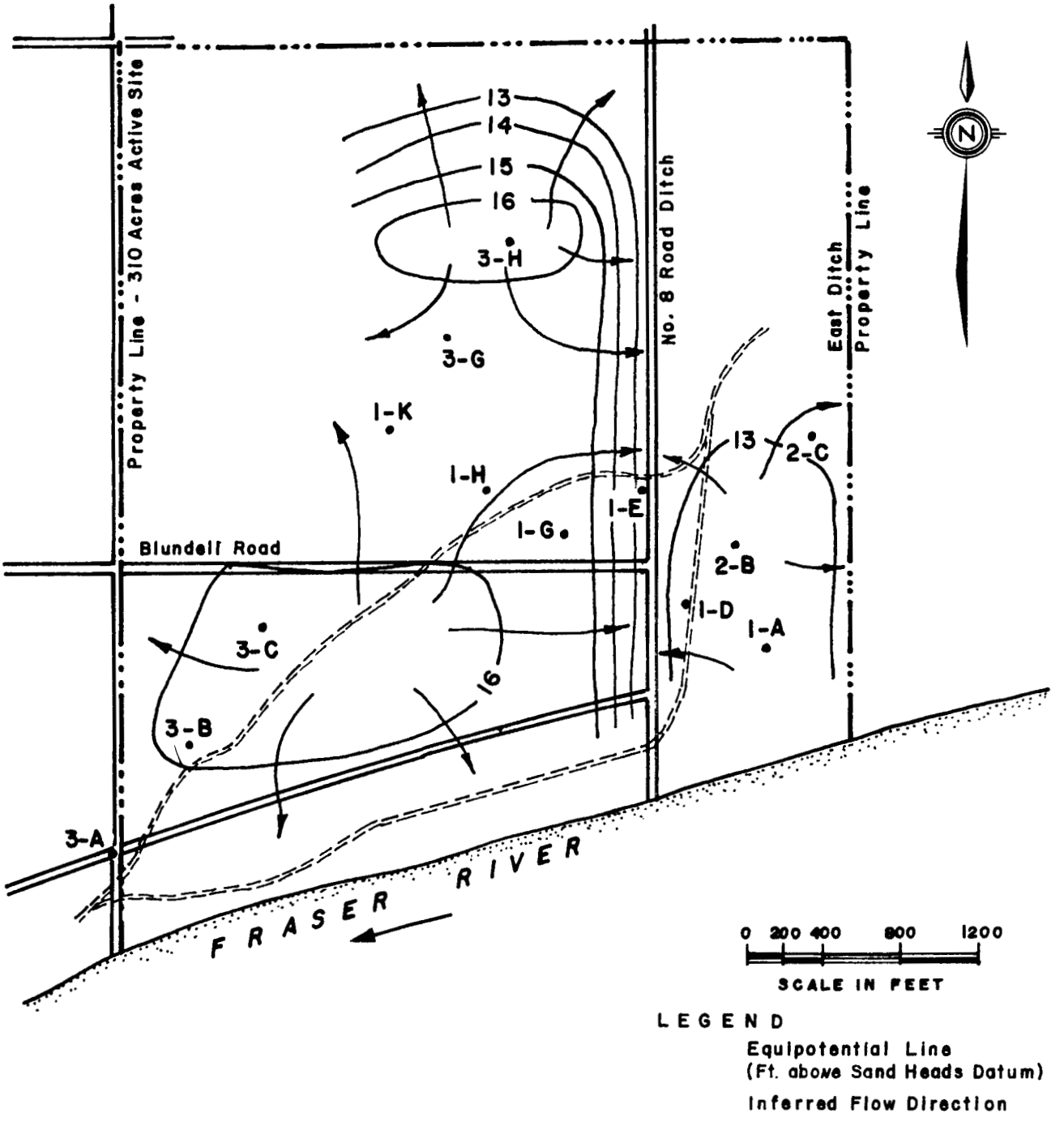
PIEZOMETRIC SURFACE AND LEACHATE
FLOW DIRECTIONS - January, 1976
Figure E - 1



PIEZOMETRIC SURFACE AND LEACHATE
FLOW DIRECTIONS - April 11, 1976
Figure E-2

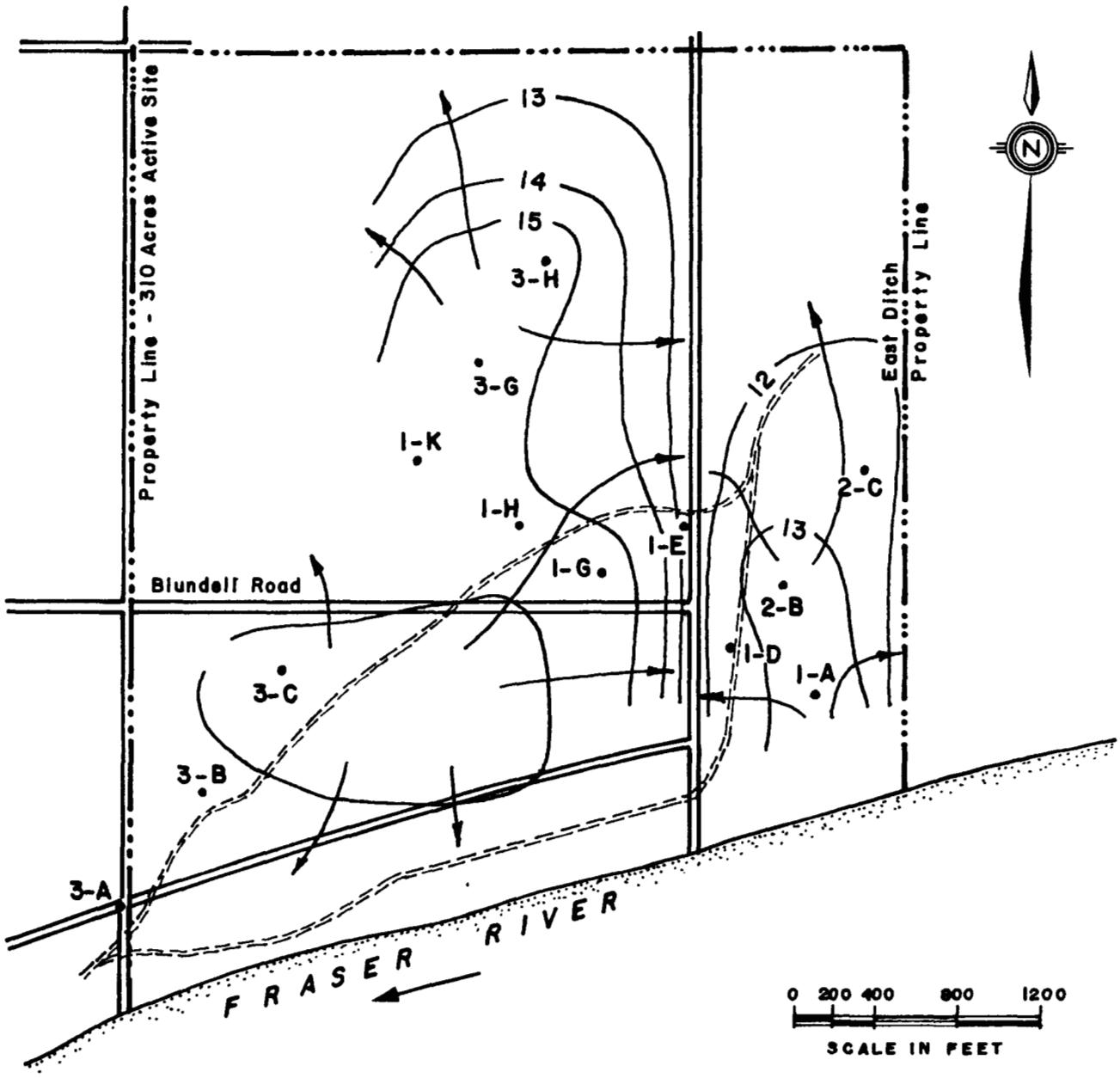


PIEZOMETRIC SURFACE AND LEACHATE
FLOW DIRECTIONS - May 11, 1976
Figure E - 3



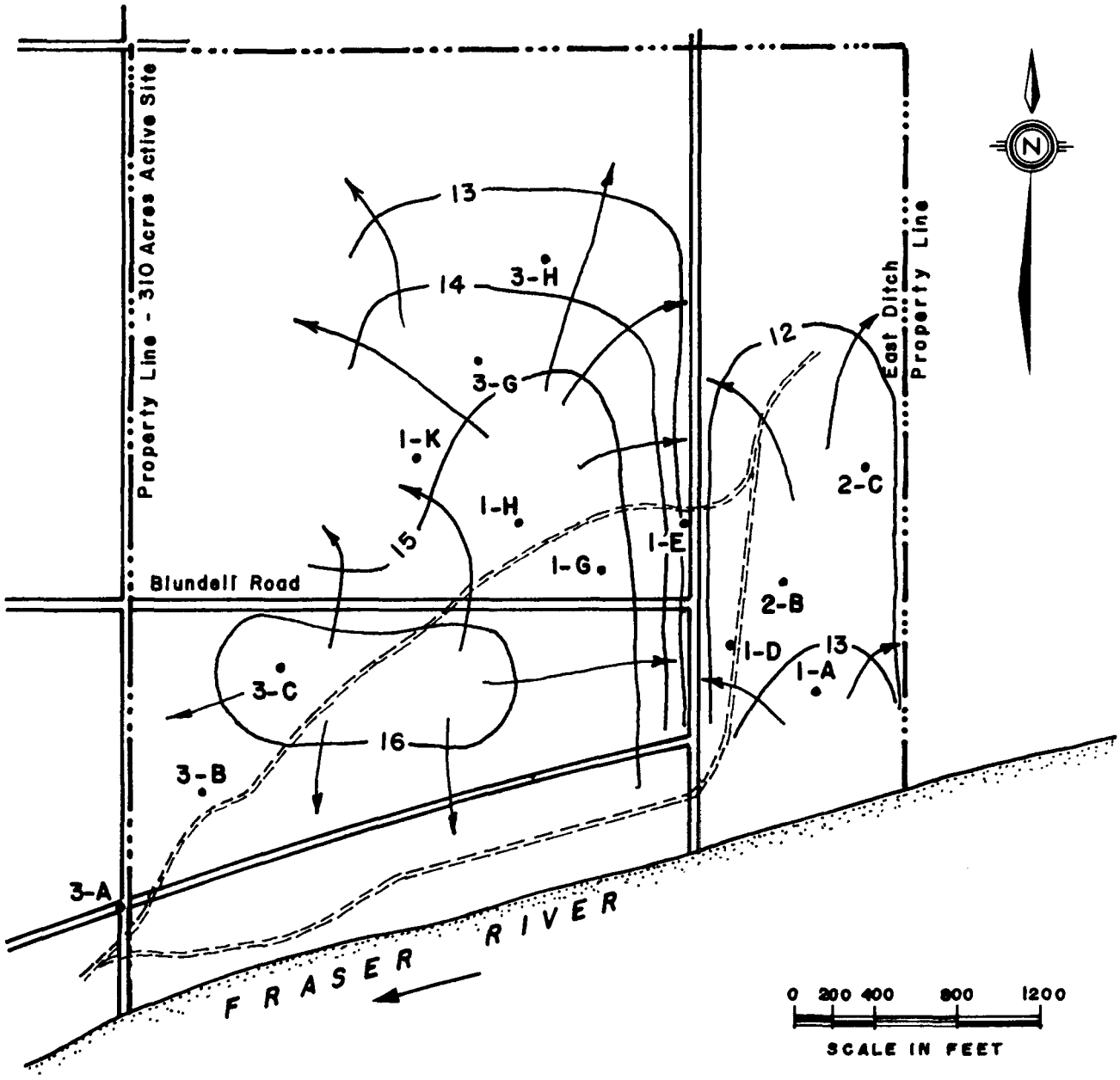
PIEZOMETRIC SURFACE AND LEACHATE FLOW DIRECTIONS - June 8, 1976

Figure E-4

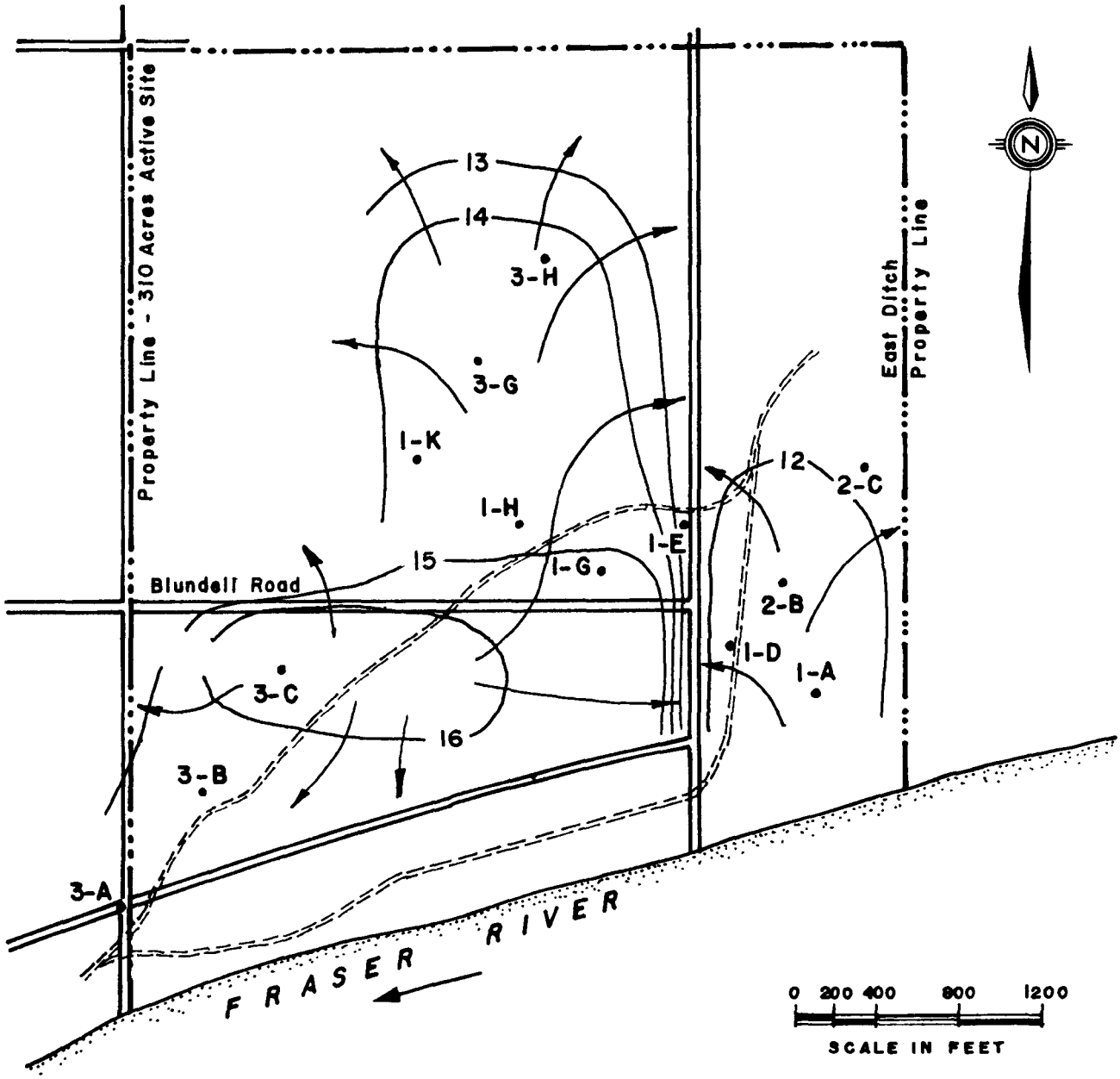


PIEZOMETRIC SURFACE AND LEACHATE FLOW DIRECTIONS - July 6, 1976

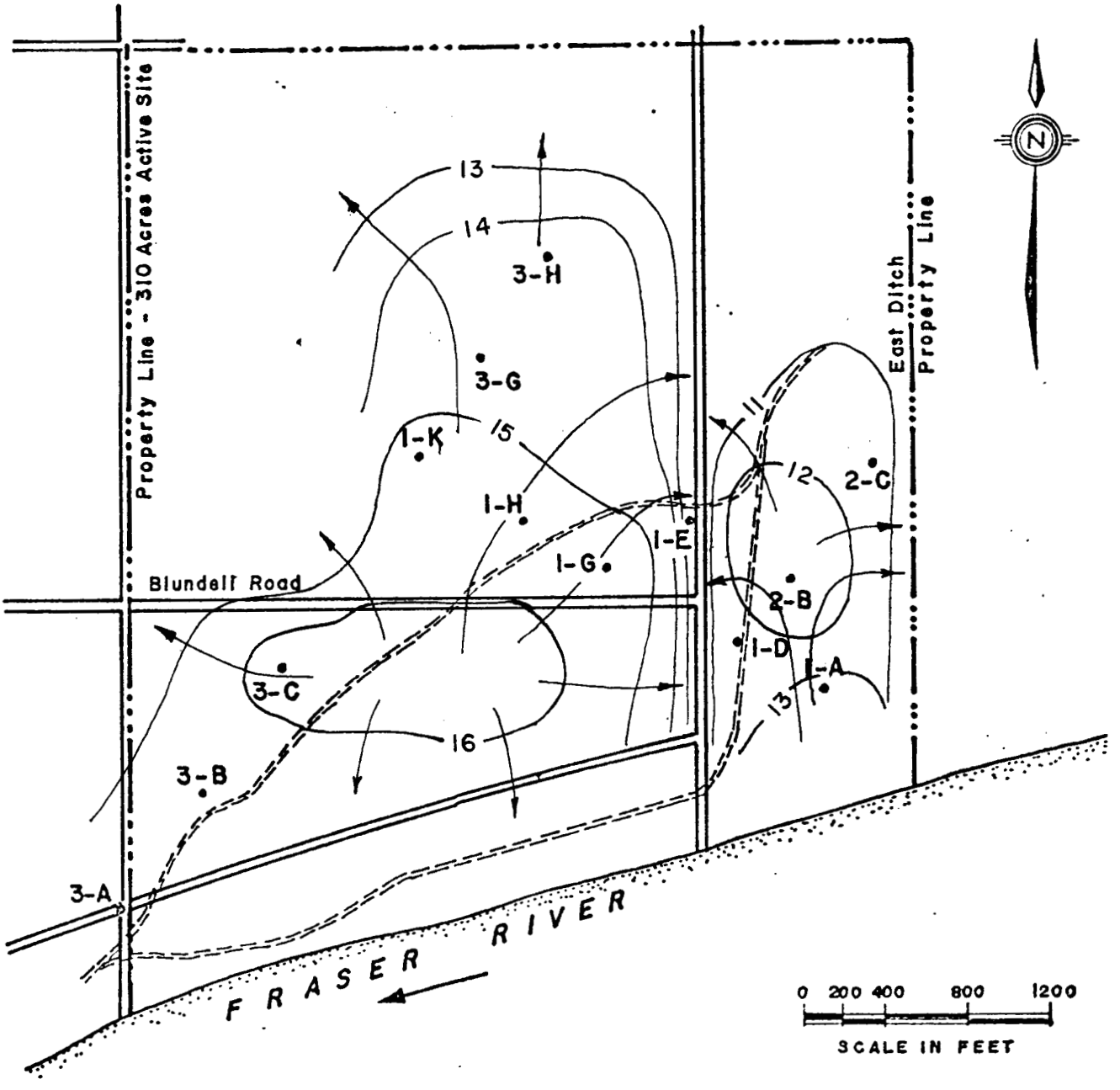
Figure E - 5



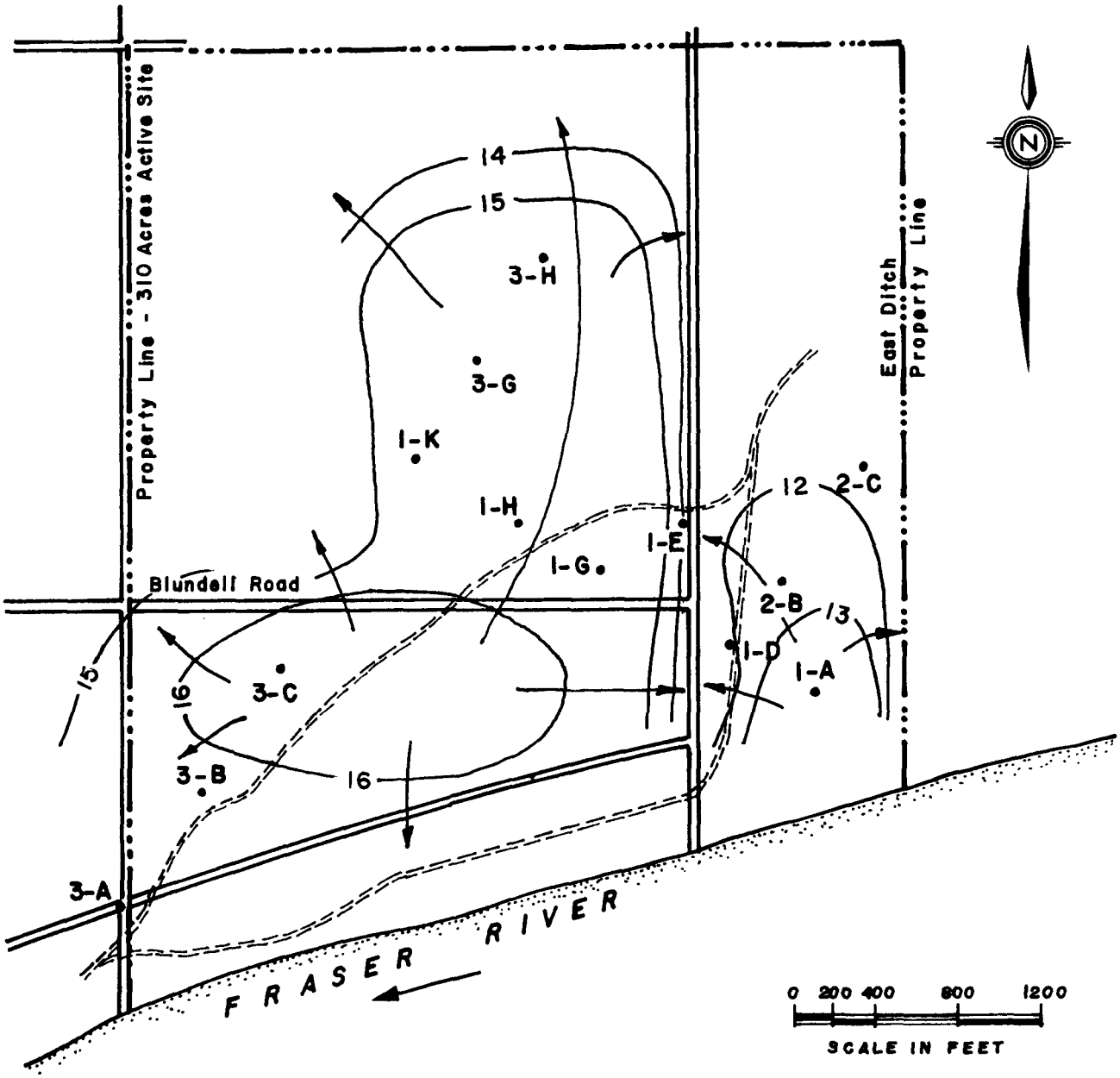
PIEZOMETRIC SURFACE AND LEACHATE
FLOW DIRECTIONS — August 10, 1976
Figure E-6



PIEZOMETRIC SURFACE AND LEACHATE FLOW DIRECTIONS - October 5, 1976
Figure E-7



PIEZOMETRIC SURFACE AND LEACHATE
FLOW DIRECTIONS - Nov. 16, 1976
Figure E - 8



PIEZOMETRIC SURFACE AND LEACHATE
FLOW DIRECTIONS - December 7, 1976
Figure E - 9

APPENDIX F

PREVIOUS BIOASSAY AND WATER QUALITY DATA (VIGERS ET AL)

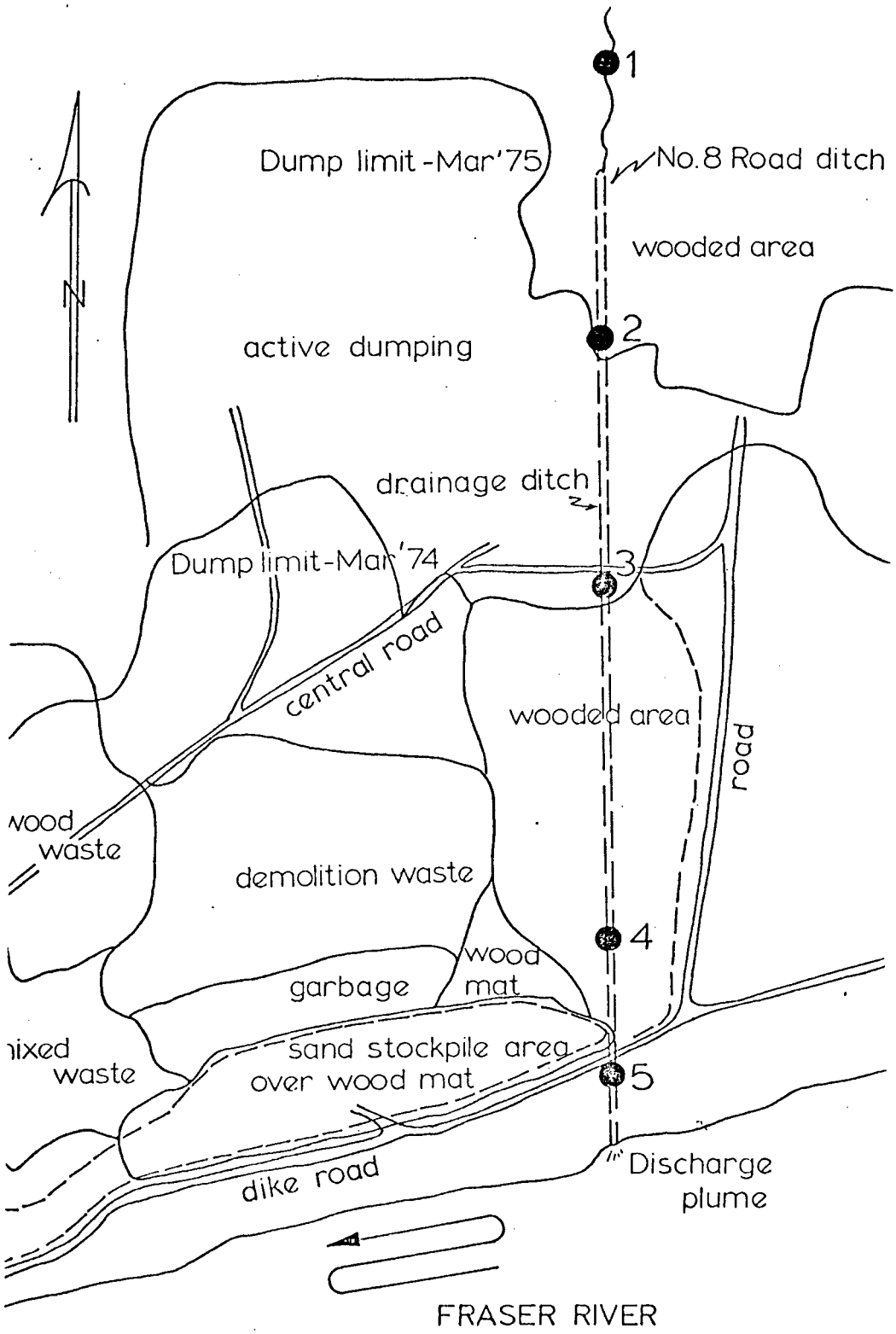


Figure 1. Location of Richmond landfill site.
Scale: 1 inch = 300 feet

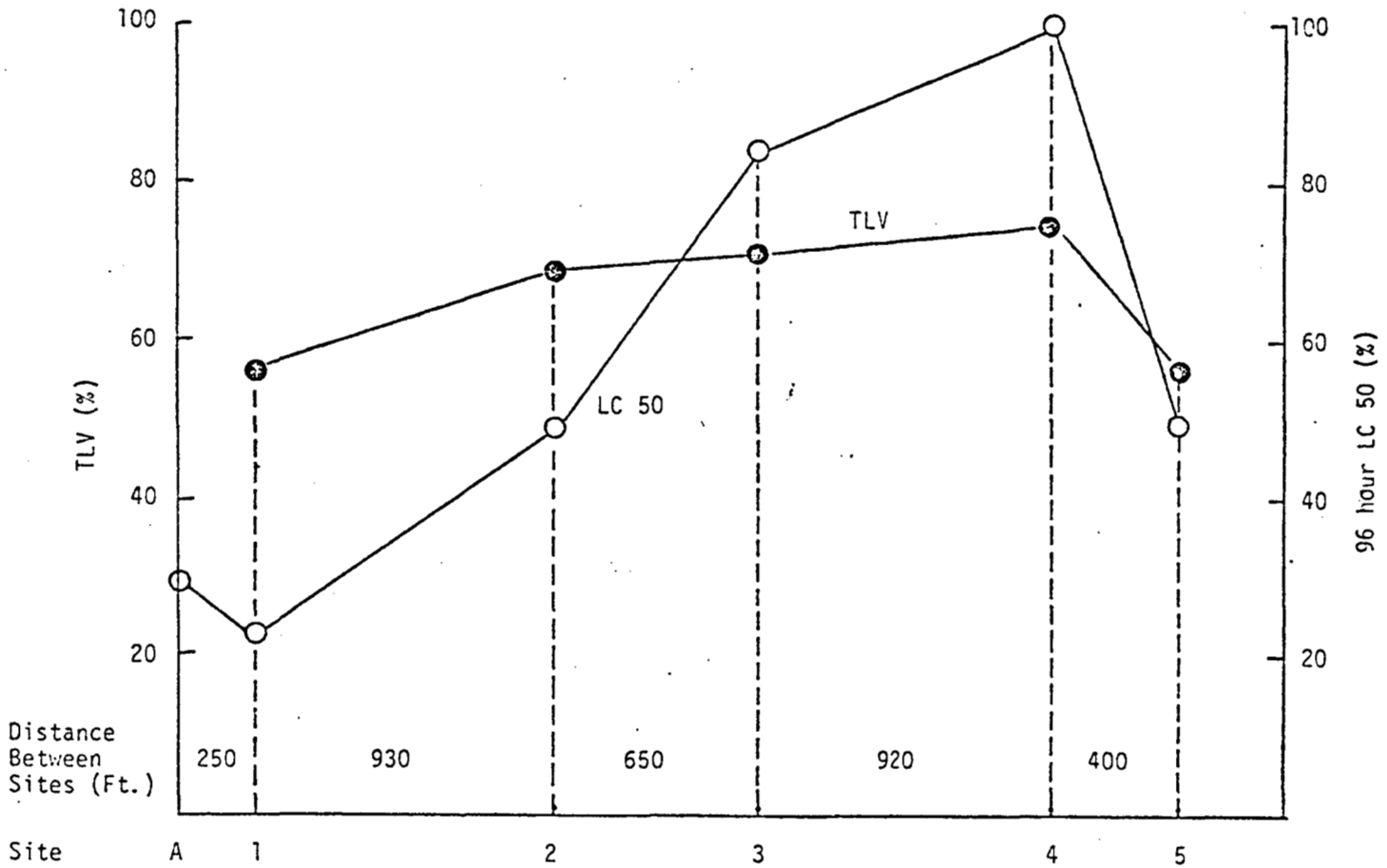


Figure 4. Attenuation of Leachate Toxicity as Determined by 96 hour LC 50 and Threshold Limit Values.

TABLE 4. RESULTS OF CHEMICAL ANALYSIS OF RICHMOND LANDFILL LEACHATE AT SITE #1 (SEPTEMBER 3, 1975)

Parameter	Site #1	Units
pH	7.1	-
B.O.D.	300	mg/l
C.O.D.	1100	mg/l
T.O.C.	320	mg/l
Ammonia	32	mg/l N

TABLE 3. SUMMARY COMPARISON OF TOXICITY DATA FOR RESIDUAL OXYGEN AND STATIC 96 HOUR LC 50 BIOASSAYS

Date	Site	96 Hr. LC 50 % Leachate est.	96 Hr. LC 50 % Leachate calc.	Go - No Go 96 Hr. Bioassays 100%	Go - No Go R.O.B. (Field) 100%	TLV % Leachate est.	TLV % Leachate calc.
Aug. 6/75	1	22	-	T	N*	32	>100
	2	25	-	T	T*	45	42
	3	33	29.5	T	T	55	52
	4	>100	-	N	T	58	57
	5	35	-	T	T	50	55
Aug. 11/75	1	28	-	T	N	30	31
	2	95	92	T	T	85	>100
	3	43	-	T	T	45	46
	4	>100	-	N	N	>100	>100
	5	92	90.8	T	T	79	83
Aug. 18/75	1	21	20.5	T	N	18	17
	2	35	-	T	T	55	71
	3	>100	-	N	N	65	70
	4	>100	-	N	N	38	40
	5	38	42.5	T	T	44	38
Aug. 21/75	1	25	-	T	N	>100	>100
	2	45	-	T	T	37	39
	3	>100	-	N	N	>100	>100
	4	>100	-	N	N	75	83
	5	59	59	T	T	65	53
Aug. 25/75	1	25	-	T	T	22	32
	2	40	-	T	T	49	57
	3	94	-	T	N	85	85
	4	71	-	T	T	68	69
	5	38	-	T	T	77	69
Sept.3/75	1	14	15	T	N	>100	>100
	2	49	-	T	T	>100	100
	3	>100	-	N	T	>100	>100
	4	>100	-	N	N	>100	>100
	5	36	-	T	T	42	41

*T - Toxic *N - Non-toxic

TABLE 5. MEAN AND RANGE OF RESULTS OF ON SITE MEASUREMENTS OF pH, DISSOLVED OXYGEN (D.O.) AND TEMPERATURE.

	pH		D.O.		Temp (^{o}C)	
Site #	Mean	Range*	Mean	Range*	Mean	Range*
1	7.3	6.5-7.8	0.77	0.6- 0.8	20.3	17.5-23.5
2	7.4	6.5-7.8	1.9	0.7- 3.8	17.4	14.5-21.0
3	7.4	6.6-8.2	4.8	1.6- 8.4	17.9	16.5-22.0
4	7.4	7.0-8.1	6.2	3.1-10.8	18.5	17.0-20.0
5	7.2	6.8-8.0	2.3	1.4-3.8	16.8	16.0-18.0

*n = 6

TABLE 7. RESULTS OF CHEMICAL ANALYSIS OF RICHMOND LANDFILL LEACHATE (AUGUST 6 1975)

Parameter	Site #1	Site #2	Site #3	Site #4	Site #5	Units
pH	7.6	7.1	7.6	7.6	6.9	
Alkalinity	1780	1400	975	875	800	mg/l $CaCO_3$
Total Phosphate	3.6	5.3	0.55	0.33	0.48	mg/l P
Sulfide	L0.01	0.2	L0.01	L0.01	0.01	mg/l $S^=$
Ammonia	48	36	22	10	21	mg/l N
Nitrite	L0.005	L0.005	L0.005	L0.005	L0.005	mg/l N
Nitrate	0.01	0.01	1.1	0.6	0.6	mg/l N
Sulfate	26	60	60	50	21	mg/l SO_4
Chloride	350	410	610	820	410	mg/l Cl^-
Conductivity	3800	3400	2900	3600	2500	umhos/cm
B.O.D.	345	123	20	18	13	mg/l
C.O.D.	1800	920	370	300	160	mg/l
Phenol	*	*	*	L0.015	L0.015	mg/l
Non filterable residue (NFR)	439	3620	9	67	114	mg/l
Filterable Residue**	2830	2440	2000	2360	1500	mg/l

* interference with analytical peak at 460 nm. However, Samples #1 and #2 both had high apparent phenols, based on color development with reagents.

** calculated, rather than measured directly.

TABLE 8. RESULTS OF ANALYSIS OF RICHMOND LANDFILL LEACHATES BY ATOMIC ABSORPTION (AUGUST 6 1975)

Parameter	Code*	Site #1	Site #2	Site #3	Site #4	Site #5	Units
Zn	D	1.8	150	0.02	0.04	L0.01	mg/l
	T	5.3	0.7	0.04	0.22	.09	"
Pb	D	0.04	0.04	L0.02	L0.02	L0.02	"
	T	0.13	0.06	L0.02	L0.02	L0.07	"
Cd	D	0.18	L0.01	L0.01	L0.01	L0.01	"
	T	L0.01	L0.01	L0.01	L0.01	L0.01	"
Ni	D	L0.05	0.17	L0.05	L0.05	L0.05	"
	T	L0.05	0.13	L0.05	L0.05	L0.05	"
Cu	D	0.03	0.06	L0.01	L0.01	L0.01	"
	T	0.07	0.06	0.02	0.01	L0.01	"
Cr	D	0.03	0.08	L0.03	L0.03	L0.03	"
	T	0.03	0.06	L0.03	.04	L0.03	"
Al	D	0.4	28	L0.1	0.6	L0.1	"
	T	1.1	24	0.5	0.4	0.2	"
Fe	D	5.6	56	1.3	7.0	17	"
	T	20	40	1.5	6.3	57	"
Hg		L0.15	L0.15	L0.15	L0.15	L0.15	ug/l
Ca	E	460	250	190	190	200	mg/l
Mg	E	65	87	60	61	51	"
Hardness (mg/l $CaCO_3$)		1400	980	720	730	710	"

*Code E - extractable, unfiltered, preserved by addition of 3 ml/l conc HNO_3 (10 ml/l conc HNO_3 for seawater)

Code D - dissolved, filtered by 0.45 micron membrane filter then preserved by addition of 5 ml/l conc HNO_3 (10 ml/l conc HNO_3 for seawater)

Code T - total unfiltered preserved by addition of 5 ml/l conc HNO_3 (10 ml/l conc HNO_3 for seawater) and acid digested

APPENDIX G

CODE OF GOOD PRACTICE ON DUMP CLOSING OR CONVERSION TO SANITARY LANDFILL AT FEDERAL ESTABLISHMENTS

CODE OF GOOD PRACTICE
ON
DUMP CLOSING OR CONVERSION
TO SANITARY LANDFILL
AT FEDERAL ESTABLISHMENTS

Environmental Protection Service
Environment Canada

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1 INTRODUCTION

1.1 Purpose of Code

This Code provides recommended practices for personnel who are engaged in the management of solid wastes at Federal establishments. In keeping with the Federal Government Cabinet Decision of June 8, 1972, entitled "Control and Abatement of Pollution from Federal Activities - Cleanup and Prevention", the Government wishes to provide a consistent and exemplary environmental pollution control program by reviewing, and where necessary, upgrading the design, operation, and maintenance of Federal installations, thus offering leadership in the nation-wide effort to protect and enhance the quality of our environment.

Use of this Code is intended to promote a consistent approach towards the cleanup and prevention of water, air and land pollution and ensure that the best practicable control technology is used.

Its purpose is to assist Federal agencies in developing waste management programs, and plans and specifications for the construction and operation of Federal facilities.

In addition to this Code, the following guidelines and codes of good practice have been prepared to cover other associated areas of environmental concern:

1. Code of Good Practice for Management of Hazardous and Toxic Wastes at Federal Establishments;
2. Guidelines for Effluent Quality and Wastewater Treatment at Federal Establishments;
3. Code of Good Practice for Handling Solid Wastes at Federal Establishments;
4. Guidelines Applicable to Incinerators at Federal Establishments;
5. Interim Guidelines Applicable to Boilers at Federal Establishments.

1.2 Application of Code

This Code shall apply to Federal facilities under the jurisdiction of the Federal Government as per Schedules A, B and C appended (Appendix 1). This Code will be revised and amended from time to time to reflect new developments in technology and/or changing circumstances.

The practice of closing dumps or converting them to sanitary landfill operations at Federal facilities should be in compliance with this Code and with applicable municipal, provincial and Federal regulations or requirements. The highest standard should always be followed.

Regional offices of the Environmental Protection Service (E.P.S.) will provide a list of these regulations on request. Addresses of Regional and District Offices of E.P.S. are appended (Appendix 2). Design groups of Federal Departments who are involved in the planning and design of solid waste disposal facilities should consult with E.P.S. of the Federal Department of the Environment to ensure that contract drawings and specifications are compatible with this Code.

1.3 User's Guide

The terminology used throughout this Code of recommended practices is consistent with that of the general practice of solid waste management, and will be familiar to personnel in Federal facilities involved in waste handling. New or modified terminology is used sparingly, and is concisely defined in the Glossary.

Guidelines and recommended practices for the following dump closing activities are included: extinguishing fires, rodent control, control of surface and ground water pollution, control of gas movement, covering the dump, cover material, and ultimate use of the land.

1.3.1 Disposal of Solid Waste on Land. Disposal of solid waste on land, as discussed in Section 2, describes the objectives of closing open dumps, the general requirements for a waste disposal site and a guide to evaluating disposal sites to check if they qualify as sanitary landfills.

1.3.2 Dump Closure or Conversion. Section 3 discusses the plan, sequence of activities and the time table of events in the closing of dumps. Specific techniques on how to extinguish fires, control rodents, prevent pollution, control gas movement and cover the dump are provided. Information on the ultimate use of the closed dump and the inspection of the site is also presented.

1.3.3 References. The user is referred to the numbered references in each section for further information in the various areas covered by this Code.

2 DISPOSAL OF SOLID WASTE ON LAND

2.1 General

The purpose of this section is to familiarize personnel with the important environmental design aspects of efficient waste disposal sites. A guide for the evaluation of disposal sites is included to assist the user in determining if a given site qualifies as a sanitary landfill.

Disposal of solid wastes by sanitary landfill is presently the only acceptable disposal method and when properly conducted on well chosen and well designed sites, it provides both an economic and environmentally sound means of disposal.

In any solid waste management program, some form of disposal on land irrespective of the processing or treatment method utilized is required, if not for all solid waste generated then at least to handle residue and special wastes, and to provide a back-up system for mechanized disposal techniques, such as incinerators, which are subject to mechanical and labour problems[1].

2.2 Objectives

The objectives of closing open dumps are[2][3]

1. The prevention of vector breeding or sustenance and the removal of a wildlife attractant.

2. The control of air pollution by dust, smoke, and odour.
3. The control of fire hazards.
4. The prevention of surface and ground water pollution.
5. The effective control of all other nuisance factors so that the site is aesthetically acceptable.
6. The recovery, when feasible and practical, of the land for a variety of purposes.

2.3 General Requirements

In order to be environmentally acceptable, a closed dump should meet the following requirements:

1. Proper fencing should be installed and access to the site should be prohibited at least until conversion or renovation is completed.
2. A uniform layer of suitable cover material compacted to a minimum depth of 0.6 metres (2 feet) should be placed over the entire surface of the refuse;
3. Refuse should not be allowed to be deposited in locations where contact occurs between refuse and the ground water table;
4. The entire site, including the fill surface, should be graded and/or provided with proper drainage facilities to minimize run-off into and onto the fill, and prevent collection of standing water. The final surface of the fill should be graded to a slope in the range of one percent to three percent, but no surface slope should be so steep as to cause erosion of the cover.
5. If decomposition gases are likely to present a problem, their movement should be controlled with proper venting facilities to prevent accumulation in structures or soil, explosions, and damage to vegetation. In small operations natural venting will likely be quite adequate.
6. The completed fill should be graded to serve the purpose for which the fill is ultimately planned, within the restriction of (4) above. The surface drainage should be consistent with the surrounding area. The finished construction should not in any way cause interference with proper drainage on adjacent lands nor should the finished fill concentrate run-off waters into adjacent areas. Seeding of finished portions with appropriate grasses to promote stabilization of the cover should be performed.
7. Necessary information signs should be posted near the site describing the dump closing program and the location of alternate operating sites.

2.4 A Guide to Evaluating Waste Disposal Sites

2.4.1 Evaluating Practices. The disposal sites will require evaluations to determine if they qualify as sanitary landfills and to measure the level of acceptability of the operations taking place at the disposal sites.

The form and checklist given here represent suggested types of information that should be collected and evaluated[4]. They are not intended to replace good judgement, but only to aid in its application to the evaluation of the disposal sites.

2.4.2 ***Evaluation Method.*** This evaluation method comprises 10 requirements, all of which should be satisfied if the site is to qualify as a sanitary landfill.

If the operation is a sanitary landfill a broad evaluation of other features of sanitary landfill design and construction should be made using the information contained in the "Code of Good Practice on Sanitary Landfilling of Solid Wastes at Federal Establishments".

2.4.3 ***Sanitary Landfill Requirements.*** The requirements that a disposal site should meet in order to qualify as a sanitary landfill are presented below and consist of a statement of what is needed to qualify, the reasoning for the statement, and the criteria that should be met. A suggested check list is included to aid in the evaluation (Table 2-1), summarizing these requirements.

Requirement 1: Open Burning Prohibited. No solid waste should be burned at the sanitary landfill.

Basis: Open burning of solid waste creates odours, air pollution, fire and safety hazards. It also adversely affects public acceptance of the operation and proper location of future sanitary landfill sites. Local laws that allow or require the open burning of such materials as diseased elm trees and condemned dry foods are outmoded. Such materials can either be incorporated within the sanitary landfill or disposed of in such a manner as to prevent health hazards or nuisances. Open burning for any reason converts the operation to that of the open dump.

Requirement 2: Access Limited. Access to a sanitary landfill should be limited to those times when an attendant is on duty and/or only to those authorized to dispose of solid waste.

Basis: If public access is permitted when no attendant is on duty, scavenging, burning, and indiscriminate dumping commonly occur. Men and equipment must then be diverted from other operations to restore sanitary conditions at the disposal site. Furthermore by selectively authorizing use of the disposal site traffic is reduced and operational hazards are minimized.

Requirement 3: Spreading and Compacting. Solid waste should be spread in uniform layers.

Basis: Successful operation and maximum utilization of a sanitary landfill depend on adequate compaction of the solid waste. In addition, settlement will be excessive and uneven if this is not done. Settlement permits invasion by insects and rodents and severely limits the usefulness of the finished area.

Compaction is best initiated by spreading the solid waste evenly in shallow layers, the thickness of the layers depending on the equipment available for compacting. A 0.6 metre (2 foot) layer will usually provide the most economical compaction operation. Better compaction is achieved if the working face is operated on a slope. Further compaction is provided by the repeated travel of heavy equipment (tractors, trucks) over the layers and, if necessary, by the use of equipment designed specifically for compaction.

Requirement 4: Daily or Periodic Cover. A uniform compacted layer of at least 0.15 metres (6 inches) of suitable earth cover (see Table 3-1) should be placed on all exposed solid waste by the end of each working day or at other practical frequency.

Basis: Daily or periodic covering is necessary to prevent insect and rodent infestation, blowing litter, fire hazards, an unsightly appearance, and to help control gas and water movement. Fly emergence generally is prevented by 6 inches of compacted soil. Covering also divides the fill into "cells" that may help to limit any underground fires that might occur. The cover material should be easily workable and compactible and should be free of large objects. It should not contain organic matter in quantities or distribution likely to encourage harborage and breeding of vectors.

Requirement 5: Final Cover. A uniform layer of earth cover compacted to a minimum depth of 0.6 metres (2 feet) should be placed over the entire covered surface of each portion of the final lift. This should be done not later than one week following the completion of a section of the fill area.

Basis: A minimum final cover of 0.6 metres (2 feet) of compacted suitable earth cover will prevent emergence of insects from the compacted solid waste, minimize the escape of odours, prevent rodents from burrowing, assist in the control of gas and water movement, support plant growth, and provide an aesthetically acceptable finished site. This cover also provides an adequate bearing surface for vehicles and is of sufficient thickness for cover integrity in the event of settlement or erosion. Workability and compaction characteristics should at least equal those provided for daily cover (see Table 3-1).

Requirement 6: Environmental Protection. The location and the operation must have the approval of the appropriate governmental agency.

Basis: Location, nature of the waste deposited, and substandard operational procedures may lead to pollution of surface waters or underground aquifers. Unless proper standards of location and operation are followed offensive and dangerous concentrations of gases may adversely affect the surroundings. A routine site evaluation will not normally reveal this sort of information. The exception may occur when obvious signs of leachate contamination of surface waters is apparent. The evaluator should generally examine the site looking for potential problem areas such as nearby surface watercourses, signs of high water tables, vegetation condition in streams and around the periphery of the fill area (abnormalities in growth, colour, etc).

This may result in a need for further detailed evaluation (hydrogeological study) depending on the size of the site and extent of the problem or, it may be necessary to provide site modifications or change operating procedures to control adverse environmental effects.

Requirement 7: Blowing Litter Controlled. Blowing litter should be controlled by fencing placed near the working area or by the use of earth banks or natural barriers. The entire site should be policed at least daily and litter clean-up operations performed as required to prevent unsightly conditions. Unloading shall be performed so as to minimize the scattering of the solid waste.

Basis: The purpose of the sanitary landfill is to dispose of solid waste in a nuisance-free manner. If papers and other light materials are scattered and the area is not policed, fire hazards, nuisances, and unsightliness result.

Requirement 8: Salvage **Prohibited**. Salvaging should not be permitted at the working face of the sanitary landfill.

Basis: Nothing can be tolerated that interferes with the prompt sanitary disposal of solid waste. Salvaging at the working face delays the filling operation and creates unsanitary conditions. The accumulation of salvaged materials also provides harborage for vectors and promotes an unsightliness that can be detrimental to public acceptance of the operation.

Requirement 9: Operational Considerations

Roads: Provisions should be made for all-weather access roads leading to the disposal site.

Equipment: Written provisions and guarantees should be made for the replacement of operating equipment when it is down for more than 24 hours.

Basis: Access roads that are not negotiable by collection vehicles cause unnecessary delays in the disposal operation.

The purpose of a sanitary landfill is the immediate disposal of solid waste, because this results in the elimination of nuisances and produces an aesthetically acceptable operation. A major breakdown (operating equipment out of service for more than 24 hours) reverts the sanitary landfill operation to an open dump. Sanitary landfills utilizing more than one piece of equipment are normally able to operate efficiently even if one piece of equipment has a major breakdown. The remaining pieces of equipment will usually have sufficient reserve capacity to allow the operation to continue. Smaller operations that involve only one piece of equipment require some type of prior written agreement that guarantees the equivalent of standby equipment within 24 hours after any major breakdown.

Requirement 10: Special Waste Handling. Toxic, pathogenic, corrosive, flammable, explosive, and other hazardous wastes should be handled in accordance with the requirements of the Code of Good Practice for Management of Hazardous and Toxic Wastes at Federal Establishments.

Basis: Materials such as oil sludges, chemical wastes, magnesium shavings, empty pesticide containers, and contaminated medical wastes can be a special hazard to employees and to the environment if their presence in the waste mixture is not known or if they are improperly handled.

TABLE 2-1
SANITARY LANDFILL EVALUATION CHECKLIST

Name of Facility: _____

Address: _____

Data By: _____ Date _____

	Requirements	No	Yes
1.	Open Burning Prohibited	_____	_____
2.	Access Limited	_____	_____
3.	Spreading and Compacting	_____	_____
4.	Daily Cover	_____	_____
5.	Final Cover	_____	_____
6.	Environmental Protection	_____	_____
7.	Litter Control	_____	_____
8.	Salvage Prohibited	_____	_____
9.	Operational Considerations	_____	_____
10.	Special Waste Handling	_____	_____

Remarks:

_____
_____
_____
_____

3. DUMP CLOSURE OR CONVERSION

3.1 Plan For Dump Closure

The closing of a dump is a planned procedure and not merely the act of abandonment.[2][3]

Important elements in a plan for closure or conversion include:

1. Preparing acceptable disposal facilities to replace those being closed;
2. Abating existing nuisances at the closed dump and preparing the site for its use with consideration given to compatibility of the renovated site with surrounding land.

3.2 Sequence of Operations

In closing a dump it is important to keep in mind not only what is to be done but also the sequence of activities and the timetable of events.

A typical sequence of operations that might be followed is:

1. Fence or otherwise restrict unauthorized access.
2. Place necessary informational signs and assign dump manager to the site during normal operating hours until the site closure is completed.
3. Provided the alternate disposal site is operational close dump to incoming refuse; if the new site is not yet operational establish a specific spot at the dump for sanitary landfill operation during closing
4. Extinguish fires (see Section 3.4)
5. Eliminate vectors (see Section 3.5)
6. Provide necessary drainage (see Section 3.6)
7. Establish grades (see Section 2.3)
8. Provide surface and ground water protection systems and gas movement control when necessary.
9. Clean up miscellaneous debris, compact and cover.
10. Seed the area or otherwise prepare it for final use.
11. Maintain the cleanliness of the site and monitor for settlement and cover material integrity.

3.3 Procedures

The dump closing and/or conversion procedure will necessarily depend a good deal on local circumstance. These include the particular problems of the dump itself, (rodents, fires, etc.), problems presented by the dump's location (water pollution, gas movement to neighbouring structures), and the area's intended ultimate use. If the dump is to be converted to a sanitary landfill operation, the sanitary landfill method employed may affect the dump conversion process.

3.4 Extinguishing Fires

Open burning at waste disposal sites near populated areas is both hazardous and obnoxious. Landfill fires may be difficult and expensive to extinguish.

A variety of fire fighting methods have been experimented with in the past.[5][6][7][8] Factors such as depth of fill, content of the fill, availability of water, space available and local availability of heavy equipment are known to affect the fire fighting procedure and operations.

The first step to take in fighting a deep seated fire is to isolate the burning fill area by trenching to bedrock or the bottom of the fill. In addition, the site should be examined for other hot spots which would be isolated as they are identified.

The second step is to douse. If immediate dousing is not likely to be effective, then the second step should be to encourage complete combustion and then douse.

Digging "firing" holes, trenching and windrowing are effective methods of aiding combustion of smouldering fill.

1. The "firing" hole method is described in Figure 3-1.
2. The excavation of trenches is usually more successful and less time consuming than digging a number of holes. Parallel trenches are dug to bedrock or the bottom of the fill, thereby allowing direct access to the bottom of the smouldering material. These trenches can be set ablaze and left to burn overnight, causing large amounts of material to be consumed. This method is shown in Figure 3-2.
3. The third method involves windrowing of smouldering debris by crawler tractors equipped with buckets and rakes. Windrowing does not rely on the availability of a hydraulic shovel, and produces results similar to the first two methods described above. Windrows are created by pushing material into long parallel piles as shown by the sequence in Figure 3-3.

The construction of windrows allows the wind to naturally ventilate the piles and also allows the material to be continuously stoked by the rake. Overturned and aerated windrows burn very effectively. The piles are usually able to retain heat as long as they are fed and aerated periodically.

Water which is applied to soak and to douse the fill material should be treated with wetting agents. Wetting liquids prepared specially for fire fighting should be used. These wetting agents increase the penetration action of water thus permitting more effective use of the available water. The user is referred to the Canadian Underwriter's Association and local fire protection equipment distributors for further information on the various types of wetting agents available on the market.

Precautions should be taken at all times during a fire extinguishing operation because of the numerous hazards that may arise, e.g. - dangers of working on top of smouldering debris subject to cave-ins, possible explosions from burning material during combustion.

3.5 Rodent Control

When closing a site or converting an open dump to a sanitary landfill type of operation, it will be necessary to carry out a rodent-baiting program[9]. The rodents must be exterminated so that they will not migrate to surrounding areas when their food supply is cut off at the refuse disposal site.

3.5.1 Time Schedule:

1. It will be necessary to close the site for a minimum of three days, even if it will continue in the future as a sanitary landfill.

    a) On the first day, the site must remain free of activity to allow the rodents to feed on previously deposited refuse and use up their existing food supply.

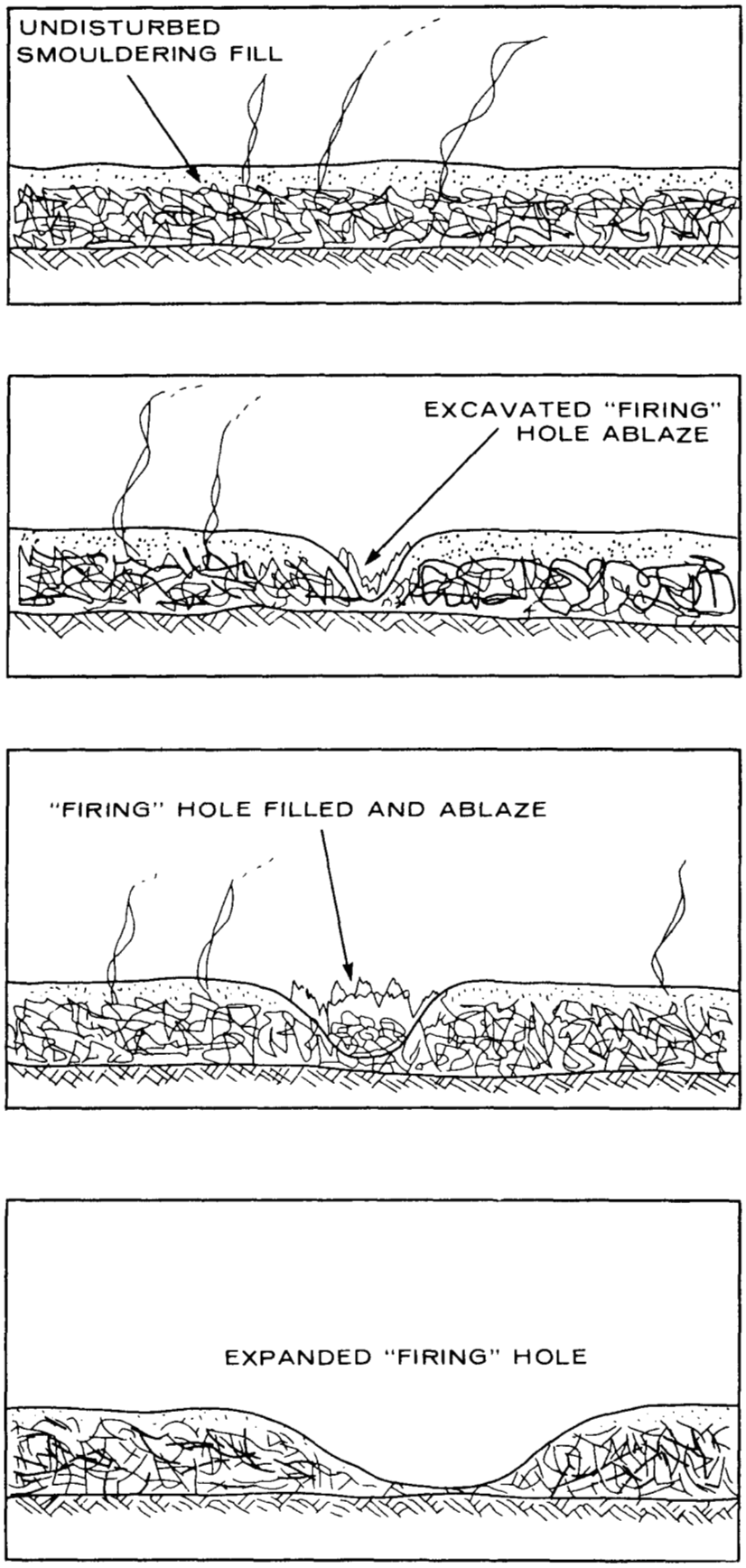
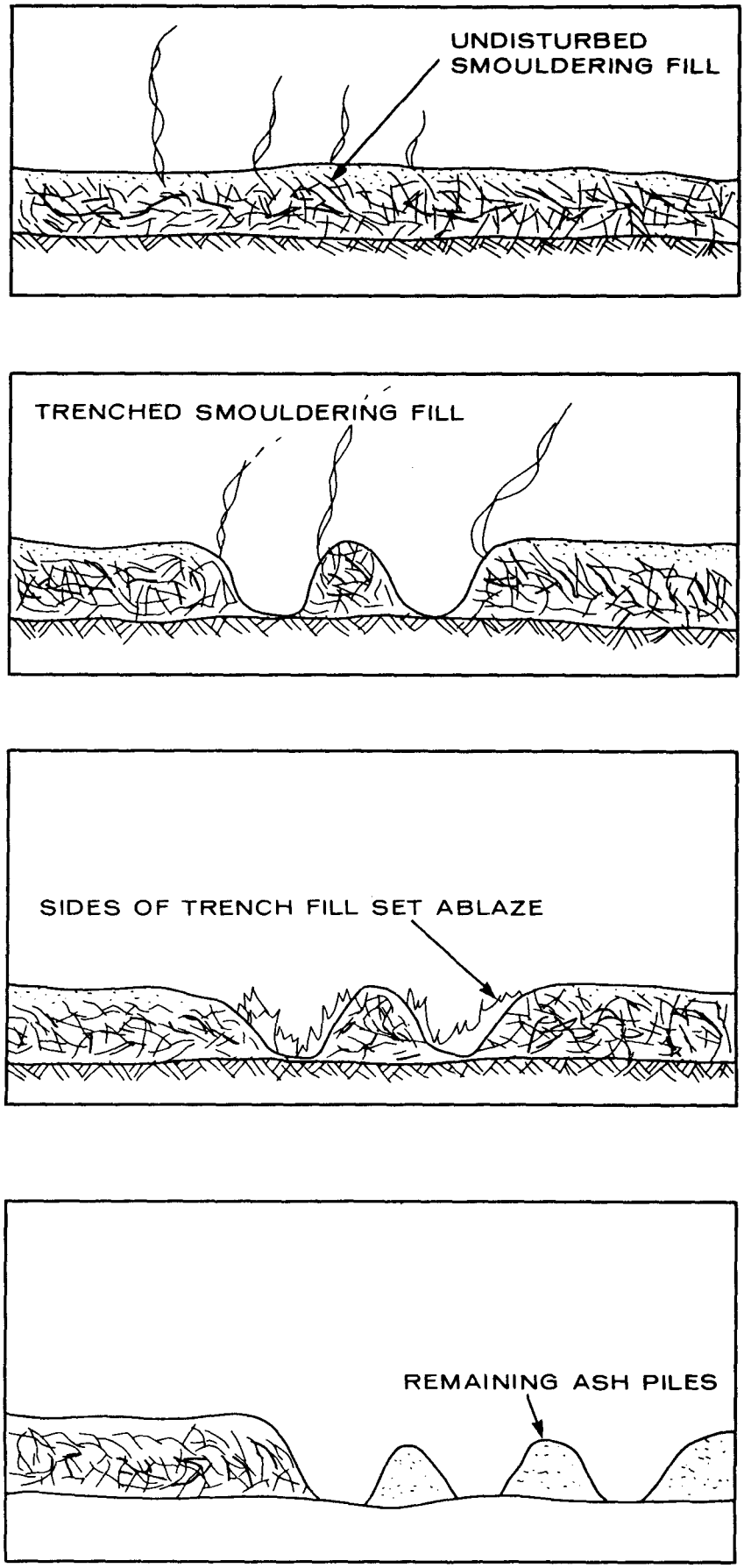
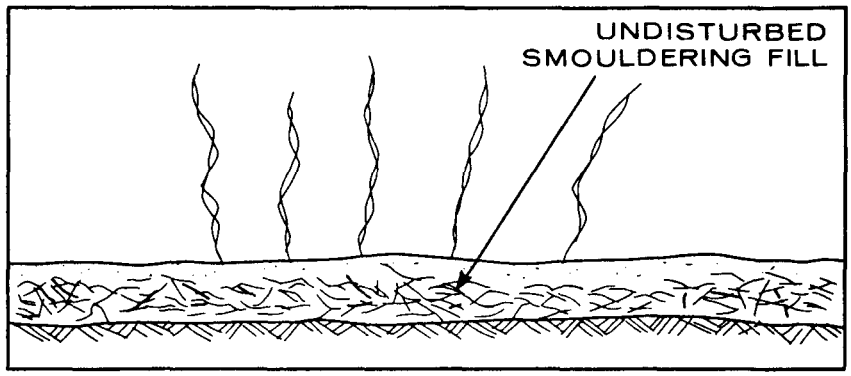
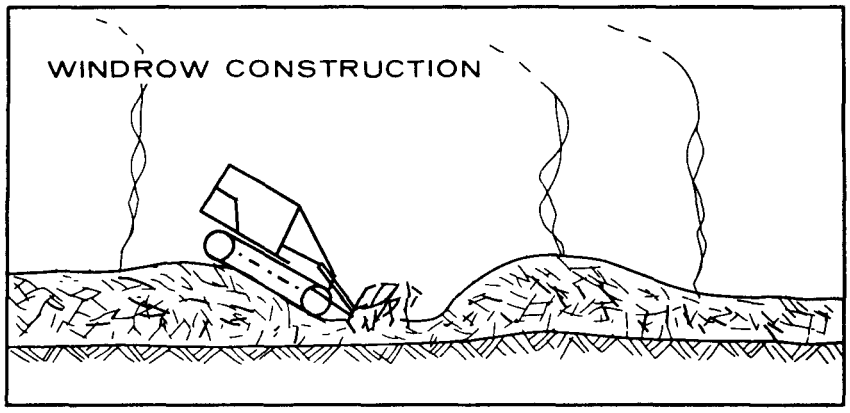


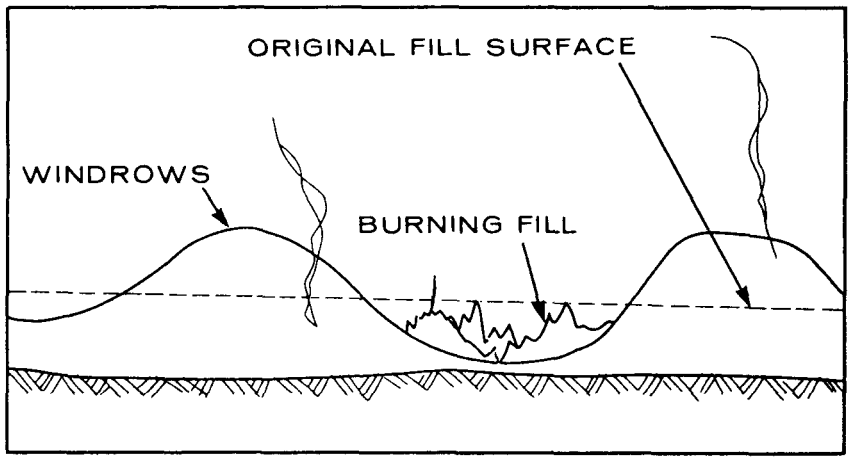
FIGURE 3-1 – OPERATION SEQUENCE – EXCAVATION OF "FIRING" HOLES



FIGURES 3-2 — OPERATION SEQUENCE — EXCAVATION OF TRENCHES







FIGURES 3-3 — OPERATION SEQUENCE — WINDROWING

b) On the second day, the bait is distributed in burrows and in sheltered areas.

c) On the third day, the rodents are allowed to feed on the bait. (If anticoagulant type rodent baits like warfarin are used, this time will have to be extended to at least 4 or 5 days).

2. The poison having done its work, dumping may be resumed and heavy equipment should be brought in immediately to initiate conversion to sanitary landfill and/or to spread, compact, cover and seal the area if the site is being closed. There should be no delay in completing this work.

3.5.2 ***The Bait.*** There is no such thing as an absolutely safe rodent poison. Freak accidents have occured even with red squill and anticoagulants. It is imperative, therefore, to use the safest possible pesticides, apply them safely, and guard the disposal site during the poisoning period. A list of suggested bait formulae is presented in Appendix 3.

3.5.3 ***Distributing the Bait.***

1. Only trained personnel should be allowed to conduct the operation since the improper use of poisons is dangerous. The work is best done by a pest control specialist or by a rodent control expert.

2. Regional offices of the E.P.S. will provide a list of pest control services on request.

3. Baiting should not be done on days when rain or snow is predicted during the next 24 hours.

3.6 Control of Surface and Ground Water Pollution

The dump closure or conversion process should minimize environmental hazards and should conform to applicable ground and surface water quality regulations.

Runoff should be diverted from the land disposal site by trenches and proper grading. If trenches or depressions are being filled, sumps and pumps may be used to keep them from flooding. Equipment size can be determined by analyzing storm and flood records.

Leachate collection and treatment systems should be used when necessary to protect ground and surface waters. Systems may consist of natural impermeable liners (e.g., clay) or synthetic liners (e.g., polyethylene membrane) which have a removal point for the accumulation and removal of contained fluid. Collected leachate should receive adequate treatment before discharge to a receiving body.

In no case should solid waste be allowed to contact ground water. The ground water (i.e. high water mark of the 50-year design flood) and deposited solid waste should be at least 1.52 metres (5 feet) apart.

3.7 Control of Gas Movement

When decomposition gases are generated in quantities sufficiently great to present a possible hazard, they should be controlled on-site. They should not be allowed to migrate laterally from the land disposal site. The control of gas movement should be done either by making use of the natural soil and hydrologic and geologic conditions of the site or controlling gas permeability.

The following techniques or methods for gas movement control have been used or are considered possible:

1. *Vents.* When vents are employed, they should consist of gravel vents or gravel-filled trenches.

2. *Barriers.* Barriers formed by compacted clay can be used to control the movement of gases. The clay will be installed as a liner in an excavation or be installed as a curtain wall to block underground gas flow. When the bottom and perimeter of the disposal site have been lined with impermeable material, the cover material should consist of permeable material in order to prevent buildup of dangerous concentrations of gases.

3. *Vent Pipes.* Vent pipes which are inserted through a relatively impermeable top cover can be employed. Collecting laterals placed in shallow gravel trenches within or on top of the waste will be connected to vertical risers. Vertical risers should not be located near buildings, but if this is unavoidable, they should discharge above the roof line.

The decomposition gases should be vented into the atmosphere directly through the cover material, cut-off trenches, or forced ventilation systems in such a way that they do not become concentrated in explosive quantities.

3.8 Covering the Dump

Methods of covering a dump will vary with existing conditions, but basically there are two methods of operation: trench and area. Other approaches are only modifications. The method selected will depend upon such factors as sub surface conditions, drainage and topography of the land.

3.8.1 Trench Method:

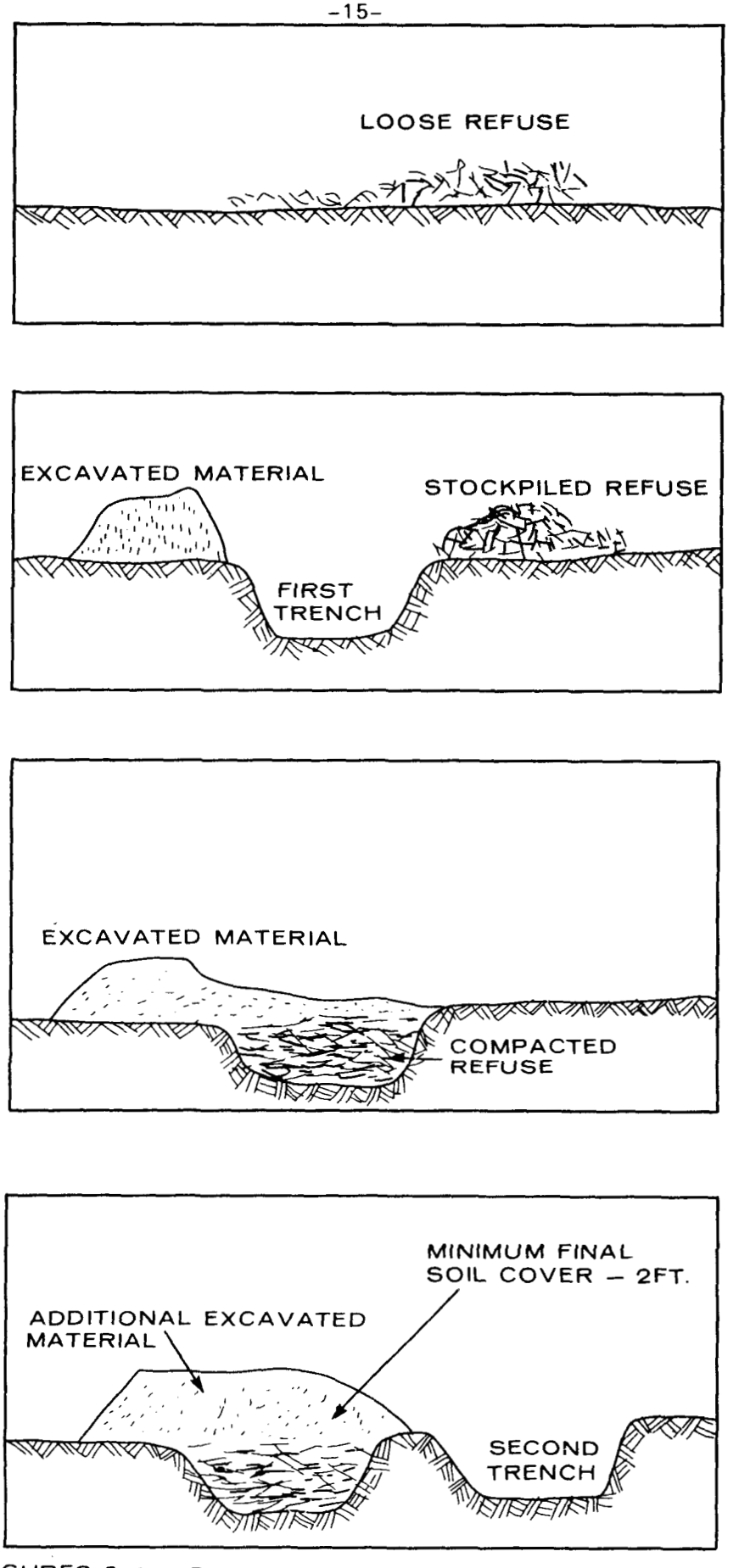
1. The trench method can be used where a high water table is not a problem.

2. In this method (Figure 3-4), the loose refuse is brought together and then spread and compacted, following the cell concept of sanitary landfill construction. The bottom of the trench should be kept above the level of high groundwater (minimum 1.52 metres (5 feet)).

3. The refuse is covered with soil and graded to prevent ponding of surface water.

3.8.2 Area Method:

1. The area method is used where high water tables may prohibit the excavation of trenches.



FIGURES 3-4 – DUMP CONVERSION – TRENCH METHOD

2. The loose refuse which generally is spread over a large area, is first stockpiled and then compacted against an earth berm using the cell concept for sanitary landfill construction (Figure 3-5).

3. Soil cover material may be hauled in from adjacent areas or obtained at the toe of the working face as shown in Figure 3-5.

4. The site should be graded periodically to avoid ponding of surface runoff.

3.8.3 Bank Method:

1. The bank method is a modification of the area method and merely takes advantage of the original sloping nature of the refuse (Figure 3-6).

2. When the refuse has been set to a 3:1 slope, it is compacted and covered, thus forming the berms for the adjacent cell.

3.8.4 Wetland Method:

1. This method is used where the dump is in a marshland or in an area where the groundwater or surface waters have been contaminated. The solid waste is first removed and then separated from the water by placement of a mat of inert material that reaches above high water level (Figure 3-7). Materials such as rocks, soil, broken concrete or demolition debris may be used for this purpose.

2. Another means of separation between the solid waste and the water can be achieved by diverting the flow of water or if necessary by lowering the ground water level.

3. When the refuse has been separated from the water by either one of the methods described above, it is compacted and covered with suitable cover method.

3.9 Cover Material

In all covering methods the surface of the refuse should be covered with at least 0.6 metres (2 feet) of compacted soil. The cover material should be selected according to its ability to perform the following functions:

1. Minimize vector breeding grounds,
2. Minimize surface and ground water pollution,
3. Minimize air pollution by smoke and odors,
4. Minimize fire hazard potential,
5. Minimize blowing paper and unsightly appearance of operations.

Not all soils perform these functions equally well (Table 3-1). While the soil is usually selected from the types available nearby, consideration needs to be given to its suitability before using it as cover material.

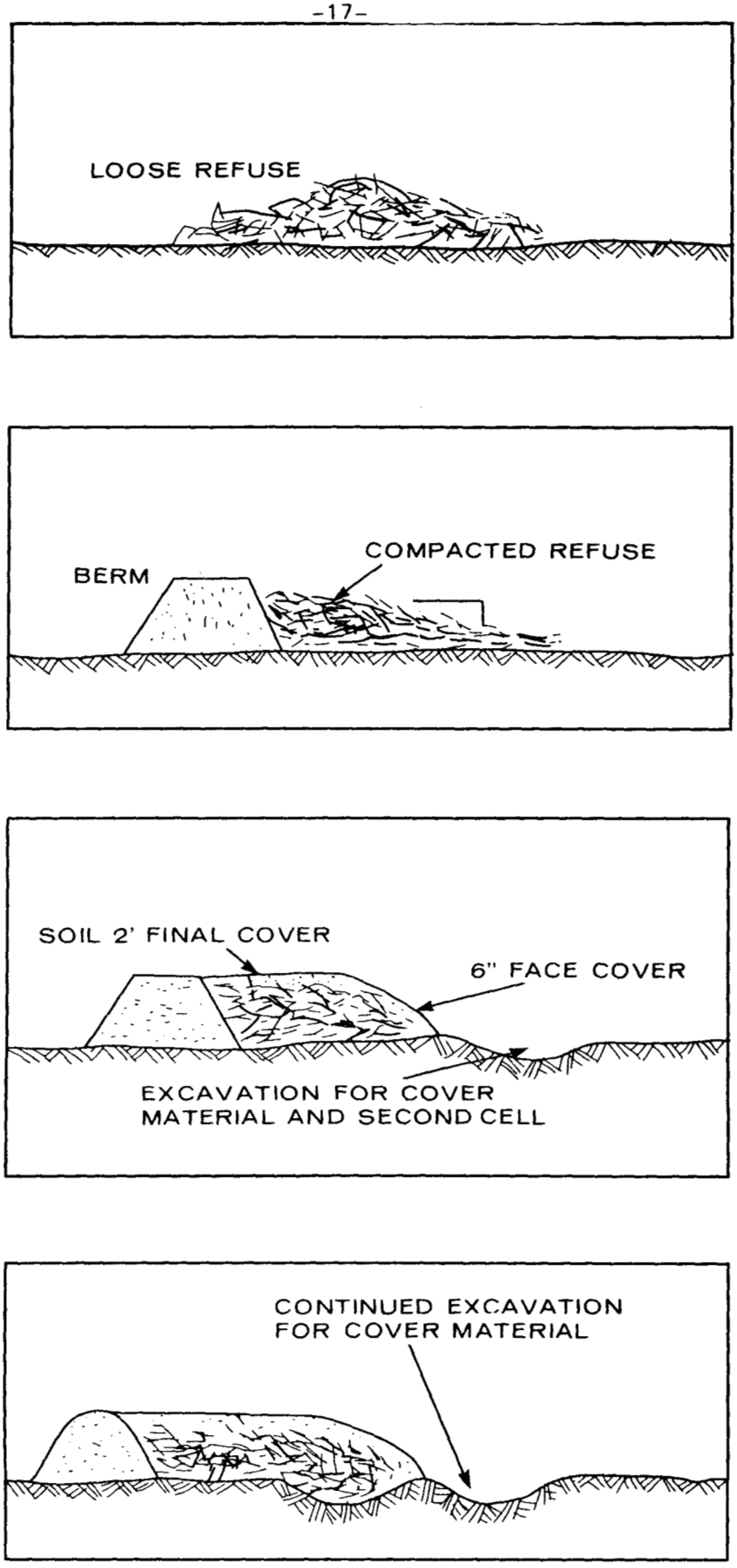


FIGURE 3-5 – DUMP CONVERSION – AREA METHOD

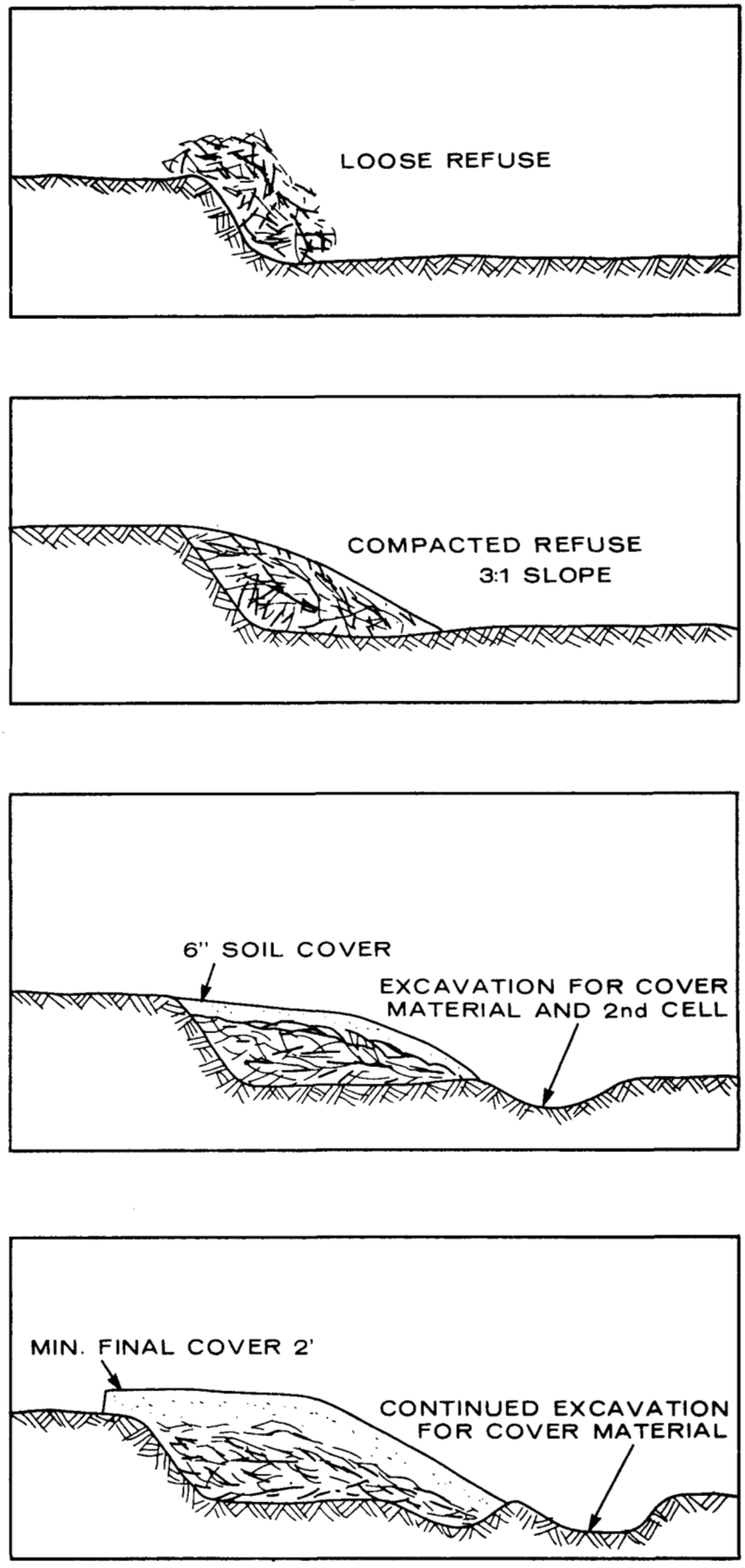


FIGURE 3-6 — DUMP CONVERSION — BANK METHOD

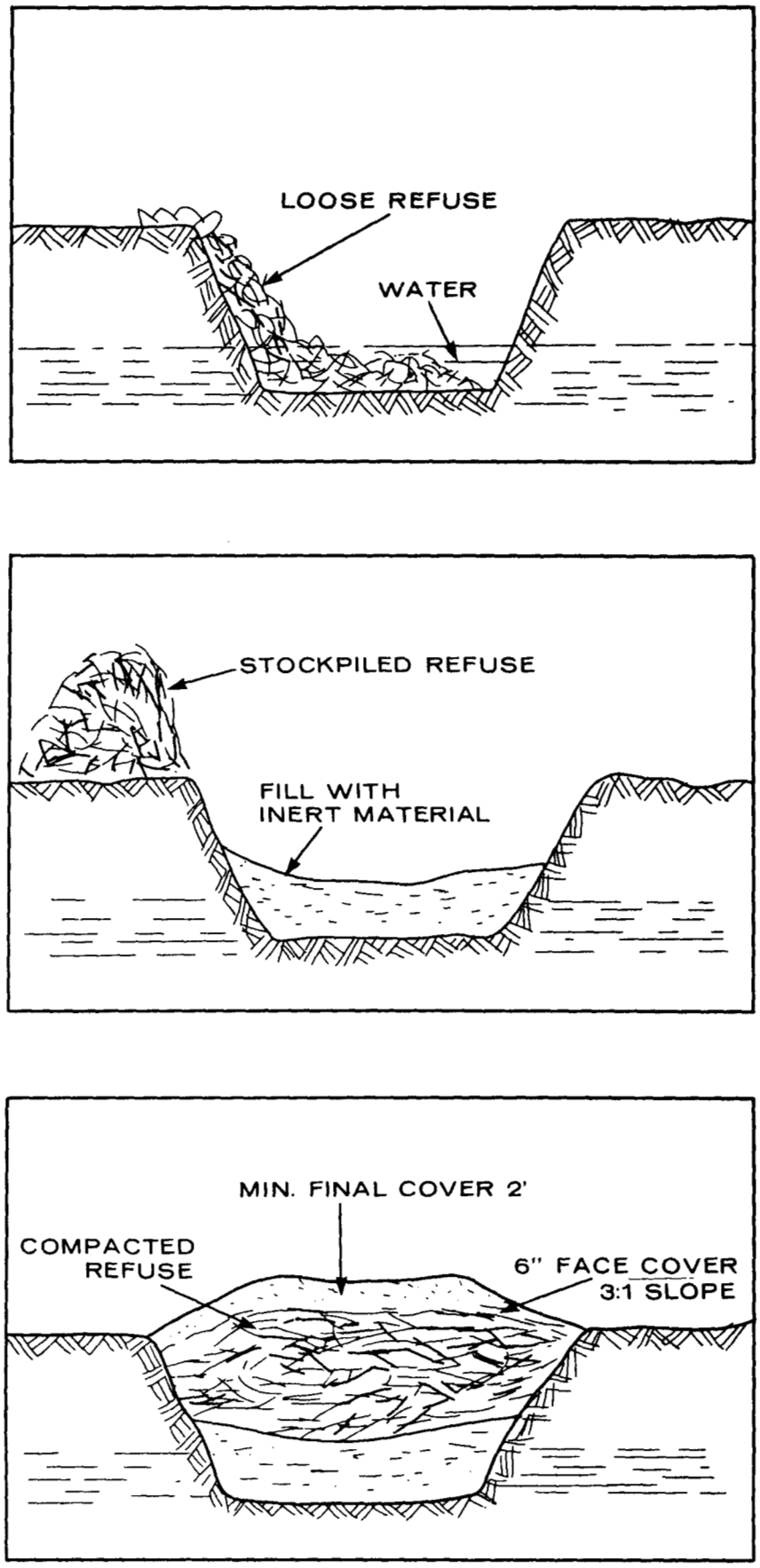


FIGURE 3-7 — DUMP CONVERSION — WET LANDS

TABLE 3-1

COVER MATERIAL SUITABILITY OF GENERAL SOIL TYPES

Function	General soil type					
	Clean gravel	Clayey-silty gravel	Clean sand	Clayey-silty sand	Silt	Clay
Prevent rodents from burrowing or tunneling	G	F-G	G	P	P	P
Keep flies from emerging	P	F	P	G	G	E*
Minimize moisture entering fill	P	F-G	P	G-E	G-E	E*
Minimize landfill gas venting through cover	P	F-G	P	G-E	G-E	E*
Provide pleasing appearance and control blowing paper	E	E	E	E	E	E
Support vegetation	P	G	P-F	E	G-E	F-G
Be permeable for venting decomposition gas+	E	P	G	P	P	P

E, excellent; G, good; F, fair; P, poor.

*Except when cracks extend through the entire cover.

+Only if well drained.

3.10 Ultimate Use of Closed Dump

There are many ways in which a closed dump can be used; it can, for example, be converted into a green area or be designed for recreational, agricultural, or light construction purposes. Each proposal should be evaluated from a technical and economic viewpoint. The use of the completed site should be planned before closing operations begin.

The main objective of solid waste management should be the safe and economic disposal of solid wastes, and the use of a completed site should not conflict with this objective.

The decomposing solid waste imparts characteristics to the fill that are peculiar to waste disposal sites. These characteristics require that the designer plan for gas and water controls, closing procedures, cover material specifications (as determined by the planned use), and the periodic maintenance needed at the completed site.

Design of gas and water controls should conform with the planned use of the completed site.

The completed site should be inspected by the governmental agency responsible for ensuring its proper operation.

Following final acceptance of the site, a detailed description, including a plan, should be recorded with the proper authority in the area where the site is located.

This description should include the type and general location of wastes, number and type of lifts, and details about the original terrain.

3.11 Site Inspection

Closed dumps should be visited periodically until such action is deemed not necessary by the Environmental Protection Service. Those dumps which have been converted to a sanitary landfill type of operation should also be inspected frequently to ensure that the operation maintains the sanitary landfill standard of operation. Inspections may be carried out by the regional Environmental Protection Service personnel, or by other responsible environmental protection agencies following Federal guidelines.

GLOSSARY

ANTICOAGULANTS: Materials which hinder clotting of blood.

CELL: Compacted solid wastes that are enclosed by natural soil or cover material in a waste disposal site.

COMPACTION: The process of achieving a denser state in a material by repeated applications of repeated loading on such material as achieved by passages of heavy equipment or by a series of heavy impacts.

HYDROGEOLOGICAL: That subject dealing with the ground water and subsurface geology of an area.

INCINERATION: A waste disposal process in which solid, liquid, and gaseous combustible wastes are converted through controlled combustion to a residue which contains no combustible matter and to gases which are released to the atmosphere.

PATHOGENIC: Causing or capable of causing disease.

RESIDUE: The solid materials remaining after completion of a chemical or physical process, such as incineration, evaporation or filtration.

SANITARY LANDFILL: A method of disposing of refuse on land without creating nuisances or hazards to public health or safety, by utilizing the principles of engineering to confine the refuse to the smallest practical volume, and to cover it with a layer of earth at the conclusion of each day's operation, or at such more frequent intervals as may be necessary.

SCAVENGING: The act of sorting through refuse in search of usable material, and the subsequent removal of that material from the disposal site. Uncontrolled removal of solid waste materials.

VECTORS (of disease): An animal or insect which transmits infectious disease from one person or animal to another.

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(2) Brunner, D.R., Hubbard, S.J., Keller, D.J., and Newton J.H. "Closing Open Dumps" Environmental Protection Agency, Solid Waste Management Office, Cincinnati, Ohio Report No. SW-61ts (1971).

(3) "Open Dump Closing - Alternative Procedures" Training Course Manual, U.S. Environmental Protection Agency, Solid Waste Management Office (1971).

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(5) "Millstream Landfill Fire Research Project" - Pollution Control Branch, British Columbia Water Resources Service, Department of Lands, Forests, and Water Resources, Victoria, B.C., March 1973.

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(7) Stateham, R.M. - "Detecting Hot Areas in Dumps with a Handheld, Infrared Scanner", Bureau of Mines, Coal Mine Health and Safety/Safety Program, Technical Progress Report #68, U.S. Department of the Interior, April, 1973.

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(9) U.S. Department of Health, Education and Welfare "Control of Domestic Rats and Mice" Public Health Service Publication No. 563, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. (1970).

APPENDIX H

EXCERPTS FROM SECTIONS 3 AND 5 OF B.C. GOVERNMENT POLLUTION CONTROL OBJECTIVES FOR MUNICIPAL TYPE DISCHARGES

3. SOLID WASTE LANDFILLS

3.1 Discharge Objectives

Subject to giving every consideration to good waste management practice, objectives for discharges of refuse to municipal landfills are presented as Landfill Location and Control Objectives. Tables 3-1 to 3-3 indicate the level of operation required for various sizes and types of municipal landfills. Objectives for the disposal of HAZARDOUS WASTES and SEMI-SOLID WASTES at landfills are discussed in Sections 3.6 and 3.7.

3.2 Upgrading Existing Landfills

3.2.1 Location and Operation

A number of landfills do not conform to the Location and Control Objectives.

Where non-conformance with these objectives is creating unacceptable pollution, hazard and/or nuisance, existing landfills will be upgraded, with the timing of upgrading and the control techniques to be APPROVED by the Director.

3.2.2 Leachate

A number of landfills are currently discharging leachates whose concentrations of pollutants exceed those considered acceptable.

Such existing landfills are therefore to be upgraded, so that receiving water quality (Table 5-3) is maintained. Where leachate from existing landfills degrades ground water suitable control techniques shall be REQUIRED. Where leachate from existing landfills surfaces outside the permittee's property and causes nuisance, hazard or pollution, suitable control techniques will be required.

3.3 Environmental Assessment Studies

Compliance with the Location and Control Objectives (given good operating practice) should normally prevent any unacceptable changes in the receiving environment and will generally obviate the need for an environmental assessment study.

Where environmental studies are required by the Director the responsibility for carrying out the studies shall rest with the discharger. The Director may, at his discretion, provide assistance in carrying out the study. The details of any study program and the organization carrying out the study are subject to the Director's APPROVAL.

3.4 Landfill Location and Control Objectives

The purpose of the following objectives is to ensure that landfills are located and operated in a manner which ensures control of pollution and eliminates nuisances and health hazards. It is recognized that variations in geography, geology and climate as well as the advent of new technology can make specific objectives too restrictive and it is to be noted that "guidelines" are to be published to which reference shall be made in addition to the following objectives. In part, site location is dependent on subsequent operation and accordingly "operating levels" are given in Tables 3-1 to 3-3. The ultimate use of the site when the landfill is complete is to be considered in selecting sites and modes of operation.

(a) The minimum recommended road distance between any operation of the B, C, D or E level is ten miles. Where a lesser distance is allowed, a Level A operation (Table 3-2) may be required. While the preceding distance is not intended to apply to INDUSTRIAL REFUSE disposal operations established on the industry's property for its sole use, the use of common facilities is encouraged.

(b) Refuse shall not be placed in FREE WATER.

(c) In general no refuse other than INERT REFUSE should be placed less than four feet above the normal highest ground water level measured at the FILL AREA. Where EXCESS MOISTURE exceeds one inch per foot of refuse depth, the above distance should be increased to eight feet.

(d) Sites shall be located wherever possible so as to minimize the production of leachates. Surface runoff waters shall be diverted so as not to enter the refuse fill area and no refuse other than inert refuse should be placed in an area where FLOODING is likely to occur such as a river FLOOD PLAIN.

(e) The suitability and availability of INTERMEDIATE AND FINAL COVER MATERIALS shall be considered in selecting sites.

(f) Appropriately designed fencing or screening of the area to be filled shall be installed to the Director's approval where it is reasonably established that hazards or nuisances may arise or have arisen due to blowing debris, animals in the area, SCAVENGING or any other factor. It is to be noted that the provisions of the Highways (Scenic Improvement) Act, 1968 may apply to landfills close to designated highways.

(g) All refuse disposal sites should have provision for the control of blowing debris as required. Such control may be achieved by trees, portable fences, earth cover, etc.

(h) All sites should have a firebreak between the fill area and the vegetation which the firebreak is intended to protect.

(i) In selecting sites it should be noted that burning of limited quantities of some materials may be permitted by the Director under certain conditions. These materials include demolition refuse, stumps, trees and similar items but exclude putrescible refuse and the like. When such regulated burning is permitted by the Director, the burning area shall be fenced and be a minimum distance of fifty feet away from the refuse fill area. Normally an attendant would then be required on site.

(j) Whenever refuse containing hazardous waste is landfilled, the site shall be fenced with a locked gate.

3.5 Monitoring

Where landfill leachate control or treatment is necessary or where pollution from leachates is suspected or anticipated, sampling and monitoring facilities may be required.

The discharger will be responsible for the monitoring of leachate entering receiving waters from leachate control or treatment facilities. However, receiving area monitoring will normally be implemented by the Director, and the discharger will be responsible for provision of any monitoring points which are required to be installed in order to proceed with receiving area monitoring.

Field sampling and analytical methods used are subject to the Director's approval and are normally to be based on those given in STANDARD METHODS and the LABORATORY MANUAL OF THE WATER RESOURCES SERVICE.

3.6 Disposal of Hazardous Wastes

3.6.1 General

Operators must recognize that disposal of hazardous wastes in landfills can, unless very carefully controlled,create highly hazardous conditions and also lead to the production of severely polluting leachates. Local conditions of precipitation, soil type and location of ground and receiving waters will each have a significant effect upon the magnitude of hazardous conditions and pollution problems. In the absence of other satisfactory means of disposing of such wastes, disposal of hazardous wastes

in landfills under closely controlled conditions is acceptable. The following represent *minimum* objectives which may, at the discretion of the Director, be revised depending upon the volume and/or character of hazardous wastes to be disposed. Generally only those hazardous wastes specified beforehand should be permitted.

3.6.2 Objectives for Disposal of Hazardous Wastes in Landfills

(a) When hazardous wastes are incorporated into a MUNICIPAL REFUSE landfill, the wastes shall be spread in thin layers to facilitate absorption into the fill. Such wastes shall be placed at as high an elevation as possible in the fill. The heights above ground water outlined in Section 3.4(c) shall be doubled. Those hazardous wastes which pose a direct hazard to landfill operators or persons using the fill area shall be covered immediately with at least six inches of cover material or two feet of compacted refuse.

(b) All municipal refuse landfills accepting hazardous wastes and to which the public has access, shall have an attendant present at the working face during unloading, compaction and covering of the hazardous waste until it is covered in a manner which will preclude any injury or hazard to the public. This attendant may be an equipment operator.

(c) A separate record of the quantity, type and discharge location of all hazardous wastes shall be maintained as required by the Director and submitted to the Director on request.

3.7 Disposal of Semi-Solid Wastes

(a) Semi-solid wastes shall be placed at as high an elevation as possible in the fill. They shall be placed in thin layers so as to facilitate absorption into the refuse.

(b) Semi-solid wastes shall normally be covered immediately after placement. This cover may be intermediate cover or may be two feet of compacted refuse.

(c) All municipal refuse landfills accepting semi-solid wastes to which the public has access shall have an attendant present at the working face during unloading, incorporation of the waste into the refuse and covering. The attendant shall remain at the working face until the semi-solid waste is covered in a manner which will preclude any hazard or offense to the public. This attendant may be an equipment operator.

(d) Non-DIGESTED organic SLUDGES, such as those arising from domestic sewage treatment plants or holding tanks shall not be placed on landfills. Septic tank pumpings will generally be considered to be sufficiently digested for landfill disposal.

3.8 Site Maintenance

The owner or operator of a landfill site shall maintain the completed fill site until such time as the fill has stabilized in order to prevent environmental pollution, health hazards, and nuisances from occurring after the fill has been completed. Placing of a final cover over a completed landfill does not relieve the owner or operator from the responsibility for proper maintenance. As outlined in Sub-section 3 of Section 5 of the Pollution Control Act, 1967, the Director may require an applicant for a permit to provide security to ensure compliance with the preceding maintenance requirement.

TABLE 3-1
Size Criteria for Solid Waste Landfill Operations (1)*

Size No. (1)(3)	Population (2)	Corresponding Weights and Volumes		
		Lbs. of Refuse per Calendar Day (2)	Uncompacted Volume in Trucks - Cubic Yards per Calendar Day (2)	Compacted Volume in Landfill - Cubic Yards per Calendar Day (2)
1	<500	<1,500	<6	<1.5
2	500-1,500	1,500-4,500	6-18	1.5-4.5
3	1,500-5,000	4,500-15,000	18-60	4.5-15
4	5,000-10,000	15,000-30,000	60-120	15-30
5	≥10,000	≥30,000	≥120	≥30

* Bracketed Numbers refer to Appendix to Table 3-1 which follows.

APPENDIX TO TABLE 3-1
Explanatory Notes

1. SOLID WASTE landfills shall conform to the level of operation outlined in Table 3-2. For the purpose of determining the required level of operation, the size number of the operation will normally be determined by the population being served (Table 3-1). Where it can be shown by an applicant that the weight or volume is less than the corresponding weight or volume for the population served, the size number shall be decreased accordingly. Conversely, where the weight or volume of refuse going to the landfill exceeds the corresponding weight or volume for the population served, the size number shall be increased accordingly.

   Increases or decreases in solid waste volume or weight caused by such factors as seasonal population changes will require a corresponding change in level of landfill operation if such increases or decreases are sufficient to change the size number of the operation. The changed level of operation shall be determined on the basis of calendar month averages.
2. Population, daily weights or daily volumes shall be taken as the average in any one month period.
3. At the discretion of the Director, where weights or volumes of putrescible refuse at any site exceed Size No. 4 quantities, provision shall be made for the venting of gases of decomposition in a manner which will pose no hazard to nearby structures or persons.

TABLE 3-2
Landfill Operating Levels*

Type of Refuse (1)	Size Number of Operation**				
	1	2	3	4	5
Municipal with or without non-hazardous industrial	E	D	C	B	A
INERT municipal with or without non-hazardous industrial	E	E	E	D	D
PROCESSED municipal with or without non-hazardous industrial	E	E	E	D	C
Industrial including hazardous waste	A	A	A	A	A
Industrial not including hazardous waste	E	E	E	D	D

* Bracketed Numbers refer to Appendix to Table 3-2 which follows.
** See Table 3-1.

APPENDIX TO TABLE 3-2
Explanatory Note

1. Special requirements for hazardous waste-disposal in landfills are outlined in Section 3.4 (j) and 3.6.

TABLE 3-3
Intermediate Cover for Landfills (1) (2)*

Level of Operation	Frequency of Intermediate Cover (3)
A	Daily
B	Three times per week when operating 6 or 7 days per week, or every second day of operation
C	Once per week
D	Once per 20 days of operation and at least once per month
E	Once per 40 days of operation and at least once every two months

* Bracketed Numbers refer to Appendix to Table 3-3 which follows.

APPENDIX TO TABLE 3-3
Explanatory Notes

1. All refuse shall be confined to the smallest practical area, reduced to the smallest practical volume, and completely covered with a minimum thickness of six inches of an intermediate layer of suitable cover material. Where "hog fuel" is used as an intermediate cover, the Director may require that special precautions be taken to avoid or control accidental fires. Such precautions may include additional soil cover or the provision of extra fire fighting equipment or any other measures deemed necessary by the Director.
2. A uniform compacted final layer of at least two feet of suitable cover material shall be placed over the entire surface of each completed portion of the landfill. This final cover shall be placed at the earliest possible date. Hog fuel is not acceptable as a final cover material.

   Intermediate or final cover shall be placed when the average depth of a compacted LIFT reaches a maximum of ten feet.

   The final surface of fills shall be graded whenever necessary so as to promote runoff of surface waters and prevent ponding. No surface slope shall be such as to cause erosion.

   Consideration shall be given to reducing surface water infiltration or promoting evaporation or transpiration by using vegetative covers or suitable soil cover.
3. FREEZING CONDITIONS

   (a) Where soil is liable to freeze to the extent that EXTRAORDINARY MEASURES will be required to excavate the soil, the operator should stockpile cover material in non-freezing weather for use whenever possible during the above mentioned frozen soil conditions and shall wherever possible keep the stockpile from freezing. The use of chemicals (for example, common salt or calcium chloride) is not considered desirable for this purpose.

   (b) While frozen soil conditions may prevent the placing of soil cover, the operator shall continue to confine and compact the refuse.

   (c) In areas where unexcavated or stockpiled soil is expected to be unworkable due to frozen soil conditions for extended periods, cover shall be placed as late as possible in the fall and as soon as the soil becomes workable in the spring.

4. REFUSE AND SLUDGE INCINERATION

4.1 Objectives for Incinerator Emissions

All municipal INCINERATORS and incinerators accepting municipal type waste shall conform to the incinerator emission objectives outlined in Table 4-1.

TABLE 5-1
Effluent Quality Objectives - Discharges to Receiving Waters (Including storm overflows)*

(Note Section 5.13 regarding use of this table for treatment plant design)

Portion of Effluent being Discharged		Receiving Waters						Parameter (Numerical values in mg/l)
		Streams, Rivers & Estuaries			Lakes	Marine (1)		
		Dilution (2)						
		≥20:1 <200:1 (3)	≥200:1 <2000:1	≥2000:1		Open	EMBAYED	
	Level	AVERAGE DWF ≥10,000 G.P.D.						
Effluent quality required for all flows up to 3 times AVG.DWF	AA	30 40 Yes Yes <0.05 1.5 (5)	45 60 Yes No 0.5-1.0 1.5 (5)	100 100 Yes No 0.5-3.0 -	30 40 Yes No (4) 0.5-1.0 1.5 (5)	130 130 Yes No 0.5-1.0 -	45 60 Yes No 0.5-1.0 1.5 (5)	BOD_5 SS DISINFECTION DECHLORINATION** Chlorine Residual** Total Phosphorus
	BB	45 60 Yes No 0.5-1.0	130 130 Yes No 0.5-1.0	130 130 Yes No 0.5-3.0	45 60 Yes No 0.5-1.0	130 130 No - -	130 130 Yes No 0.5-1.0	BOD_5 SS Disinfection Dechlorination** Chlorine Residual**
Requirements for all flows greater than the multiple of avg. DWF shown	AA	SCREENING 8	screening 6	screening 3	screening 8	none 3	screening 6	Treatment of overflow Multiple of avg. DWF
	BB	screening 6	none 3	none 3	screening 6	none 3	none 3	Treatment of overflow Multiple of avg. DWF
Effluent quality required for intermediate DWF multiples(6)	AA	45 60 Yes 0.1-1.0	130 130 No -	- - - -	45 60 Yes 0.1-1.0	- - - -	130 130 Yes 0.1-1.0	BOD_5 SS Disinfection Chlorine Residual**
	BB	130 130	- -	- -	130 130	- -	- -	BOD_5 SS
All flows		AVERAGE DWF <10,000 G.P.D.						
	AA	45 60 Yes (8) 0.2-0.5	130 130 Yes (9) 0.2-1.0	130(7) 130 Yes (9) 0.5-3.0	45 60 Yes (9) 0.2-1.0	typical septic tank effluent (10)	45 60 Yes 0.2-1.0	BOD_5 SS Disinfection Chlorine Residual**
	BB	45 60	typical septic tank effluent (10)	typical septic tank effluent (10)	45 60	typical septic tank effluent (10)	typical septic tank effluent (10)	BOD_5 SS

* Bracketed numbers refer to Appendix 1 to Table 5-1 which follows.
≥ means equal to or greater than.
< means less than.
** "Dechlorination" and "Chlorine Residual" designations apply where disinfection is by chlorination. Values shown are for total Chlorine Residual based on amperometric procedures.

APPENDIX 1 TO TABLE 5-1

Explanatory Notes

1. The effluent quality objectives for marine discharges for flows up to 3 times avg. DWF are based on outfall depth-distance combinations in Appendix 2 to Table 5-1. Alternatively, where outfalls are extended on the basis of maintaining receiving water quality as in Table 5-3, a lower effluent quality for flows up to 3 times avg. DWF may be accepted, but not less than comminution. Visual evidence of the discharge should normally not be noticeable. Approval for such an alternative will normally be given only where provision is made for space to house an appropriate treatment plant in the future. Where quality better than the tabulated values is provided and for any portion of flow exceeding 3 times avg. DWF, outfall lengths may be reduced.

2. Stated dilution ratios are based on the lowest week's stream flow anticipated during the discharge period in an average year and the highest estimated hourly effluent discharge rate (both flows expressed in the same units). For estuaries, the stream flow is to be based on the fresh water content.

3. If the receiving stream is used for recreation or domestic water extraction, discharge will be prohibited within this dilution range, unless there is no feasible alternate solution. Dilutions less than 20:1 will normally not be permitted, but where there is no alternative, discharge may be permissible with higher discharge standards required.

4. Dechlorination may be required if it is anticipated that a significant portion of any fish-bearing lake will be affected by the residual chlorine. Alternatively, it may be possible to reduce the chlorination requirements instead, if phosphorus removal facilities are included, and if they are found to be helpful in reducing coliform concentrations.

5. The total phosphorus requirement for effluents may be waived if it can be reasonably shown from a site-specific study that the receiving waters would not be subject to an undesirable degree of increased biological activity because of the nutrient input.

6. Where intermediate DWF multiples are passed through the treatment plant, the overall effluent quality objective shall be the flow-weighted average of the value shown and the value for the under 3 DWF portion of the flow. Chlorination and dechlorination shall be provided as required for the "up to 3 DWF" portion of the flow.

7. Where effluent volume is less than 1000 gpd and dilution is greater than 50,000:1 and no water extraction is practised in the vicinity, typical septic tank effluent quality may be permitted.

8. Dechlorination may be required if a significant fish resource exists.

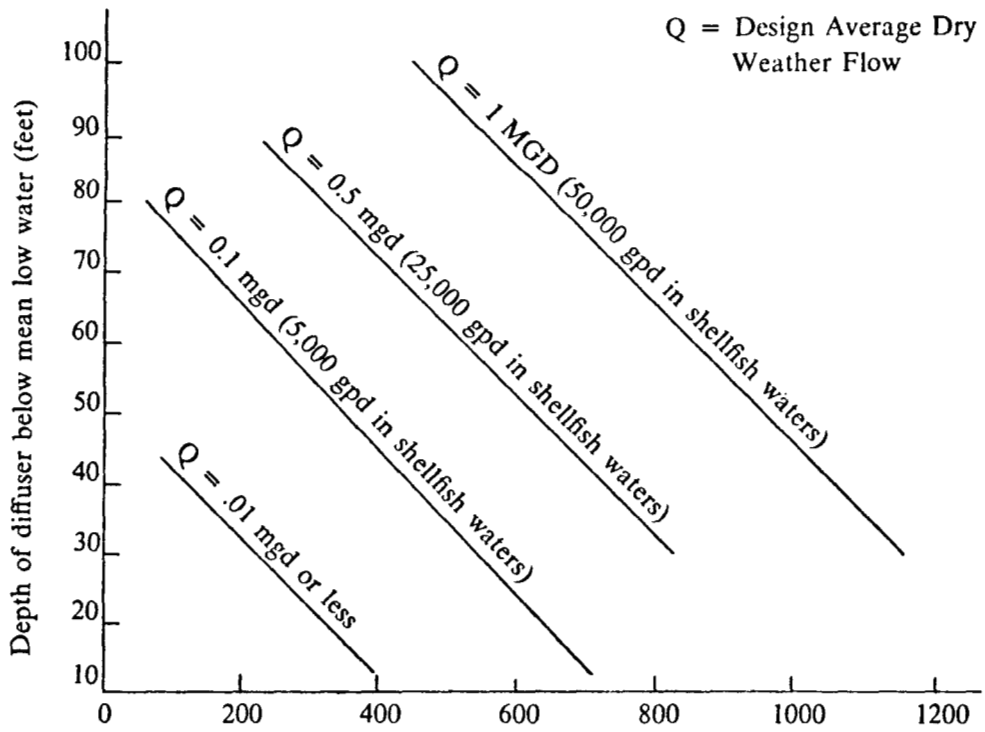
9. The chlorination requirement may be dropped where no domestic water extraction occurs in the vicinity.

10. Septic tanks must have a hydraulic capacity of at least two times the design average daily flow for the effluent to meet Level AA requirements. Lesser capacities may be permitted for Level BB.

APPENDIX 2 TO TABLE 5-1

OUTFALL DISTANCE - DEPTH COMBINATIONS FOR MARINE DISCHARGE

(Applicable to discharges up to 3 times avg. DWF in conjunction with effluent quality prescribed in Table 5-1)



NOTE: 1. For discharges in excess of 1 mgd (50,000 gpd in shellfish waters) see Section 5.4.3.
2. Interpolated lines may be used for intermediate flows.
3. Minimum outfall length in shellfish waters normally to be 400 feet.

TABLE 5-2
Limits for Effluent Parameters That may be of Concern In Specific Discharge(1)*

Parameter			Maximum Concentrations (2) mg/l (except pH and TL_m)	
			Level AA	Level BB
Methylene Blue Active Substances			5	-
Oil and Grease			15	30
pH			6.5 - 8.5	6.5 - 8.5
Phenol			0.2	0.4
TL_m (96 hr.)		(3)	100%	75%
Aluminum	(Total)		2.0	4.0
Arsenic	(Total)		0.05	0.25
Barium	(Dissolved)		1.0	1.0
Boron	(Dissolved)		5	5
Cadmium	(Dissolved)		0.005	0.01
Chromium	(Total)		0.1	0.3
Cobalt	(Dissolved)		0.1	0.5
Copper	(Dissolved)		0.2	0.5
Cyanide	(Total)		0.1	0.5
Fluoride	(Dissolved)		5.0	-
Iron	(Dissolved)		0.3	1.0
Lead	(Total)		0.05	0.1
Manganese	(Dissolved)		0.05	0.5
Mercury	(Total)		0.0006	0.002
Molybdenum	(Total)		0.2	0.5
Nickel	(Dissolved)		0.3	0.5
Nitrogen		(4)	-	-
Resin Acid Soaps			5	-
Selenium	(Total)		0.05	0.1
Silver	(Total)		0.1	1.0
Sulphate	(Dissolved)	(5)	50	250
Sulphide	(Dissolved)		0.5	1.0
Tin	(Total)		5	10
Zinc	(Total)		0.5	5.0

* Bracketed numbers refer to Appendix to Table 5-2 which follows.

APPENDIX TO TABLE 5-2
Explanatory Notes

1. The limits apply to discharges to all receiving waters and to ground unless otherwise noted. However, a limit will only be shown on a permit were investigations in accordance with Section 5.12 indicate this is needed.
2. Levels may be adjusted to take account of background levels in the water supply. Other parameters may be added at the discretion of the Director.
3. TL_m (96 hr.) samples to be prior to chlorination.
4. A limitation on nitrogen may be required where site-specific studies indicate nitrogen to be a controlling factor for eutrophication or where the nitrogen level of the effluent is considered to be abnormally high.
5. Applies to freshwater only.

TABLE 5-3
Receiving Water Quality Maintenance Objectives(1)*

Parameter	Objective
Dissolved Oxygen	Decrease not to exceed 10%
Residual Chlorine	Below detectable limits (amperometric method)
Nutrients	No detectable increase in site-specific productivity-limiting parameters (2) (5)
Coliforms—receiving waters —shellfish meat	(3) (3)
Toxicity	No increase above background (4)
Settleable Solids	Negligible increase
Floatable Solids and Scum	Negligible increase
Oil	None visible on water surface
Organisms	No change in productivity or development of nuisance conditions (5)
Heavy Metals	Negligible increase

* Bracketed numbers refer to Appendix to Table 5-3 which follows.

APPENDIX TO TABLE 5-3
Explanatory Notes

1. These objectives are for the maintenance of background receiving water quality, generally expressed in terms of the maximum allowable change for specified parameters. They are not applicable within the initial dilution zone as defined in this document. Other discharges may be taken into account in determining whether the allowable maximum change is to be less than any value given. Other parameters may be added by the Director.

2. Limiting parameters will normally be taken as phosphates and/or nitrogen forms.

3. In general, total coliform levels are not to exceed a median MPN of 1000/100 ml or a fecal coliform median MPN of 200/100 ml and in shellfish waters are not to exceed a fecal coliform median MPN of 14/100 ml and shellfish meats may not show a fecal coliform level greater than MPN of 230 per 100 gm. reference may be made to B.C. Health Branch "Recommended Water Quality Standards" and the "National Shellfish Sanitation Program Manual of Operation" published by the U.S. Department of Health, Education and Welfare.

4. As measured in a 96 hour TL_m static bioassay test.

5. Productivity refers to biological parameters which are not amenable to tabulation; however, the following nuisance conditions are typical of those to be considered:

   In freshwater lakes, presence of: 1) massive growths of planktonic bluegreen algae (Cyanophyceae) for more than several days duration; 2) massive growths of attached, filamentous diatoms (Bacillariophyceae) and/or rooted aquatic plants especially near the shoreline.

   In rivers and streams, presence of massive growths of attached green algae (Chlorophyceae), filamentous diatoms (Bacillariophyceae) and/or rooted aquatic plants, slime-forming bacteria (as *Sphaerotilus)*, sludge worms (Tubificidae) or chironomids (Chironomidae).

   At sea or in estuaries, presence of sludge beds with reduced species diversity and a restricted range of predominant organisms such as *Capitella capitata.*

APPENDIX I

MUNICIPAL LANDFILL LEACHATE GENERATION MIGRATION AND CONTROL

BY

HANS MOOIJ

MUNICIPAL LANDFILL LEACHATE GENERATION, MIGRATION AND CONTROL

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1. INTRODUCTION

An increasing emphasis is being placed on resource recovery, energy recovery, and source reduction aspects of solid waste management. Many communities and regional governments are focusing on their municipal refuse as a potential source of either secondary materials or energy. Feasibility studies today are evaluating the alternate systems for refuse reclamation and reuse in addition to the traditional processing and disposal methods. The "energy crisis" has generated an increased interest in resource recovery as a solution for the future. Great efforts and vast resources are being used to develop the technology associated with the objectives of energy and materials recovery.

In working towards these objectives, however, the landfill as a final disposal method should not be ignored. Common to all resource recovery systems proposed to date is the generation of residues in varying amounts which will continue to require disposal to land. Furthermore, resource recovery proposals being advanced are not applicable everywhere.

Until complete recycling is achieved, and this may never become a reality, a landfill will remain an integral part of any regionalized resource recovery or energy recovery system. Certainly for many industrial wastes, a landfill will always be a necessity for controlled disposal.

The major environmental concerns over landfills today relate to the impact of landfill leachate on receiving waters. Although other concerns exist, such as the lateral migration of methane from landfills near housing developments, they are not discussed in this paper.

The purpose of this presentation is to introduce the subject of landfill leachate, leachate migration and attenuation, and to outline means for controlling and treating leachate.

2. LEACHATE GENERATION

A landfill is situated within the terrestrial portion of the hydrologic cycle. As such, it will receive water inputs (Figure 1) mainly from precipitation, and also from ground water influx if the bottom

of the landfill intersects a water table. Surface drainage from the surrounding terrain may also be a source of water influx into the fill.

The landfill will generally absorb moisture until its moisture retention capacity, or field capacity, is reached and then discharges liquid as a leachate. Additional water losses result from surface run-off from the fill or from evaporation from the surface cover. A landfill disrupts the natural terrain and generally creates a localized increased water recharge to a ground water system.

As moisture infiltrates through a landfill cover soil and into the refuse, it dissolves soluble components of the refuse and also carries with it various hydrophilic colloidal and other suspended matter. The soluble components consist of: a variety of alkali earth and "heavy" metals which can go into solution either slowly as ions, depending on specific solubility products and specific rates of dissolution, or as organically complexed soluble compounds; a variety of soluble organic compounds such as intermediate or end products of refuse decomposition; and, a variety of other soluble constituents which may be present as part of the fill material. For example, a landfill may contain residual pesticides in spray cans, residual chemical solvents in drums, organic wastes in diapers, or industrial sludges of various kinds.

A considerable portion of municipal refuse landfill leachate strength may be attributable to the textiles, rubber, leather, wood, paper and cardboard present in municipal refuse[1].

Unfortunately not enough information exists today to define a relationship between fill composition and leachate component concentrations. Probably a reliable correlation will never be developed because of the varied complex and interacting variables affecting leachate generation and strength.

As the leaching water percolates through the landfill, the pH of the solution decreases because of an increased organic acid content and the reaction of CO_2, produced by biochemical reactions, with the leaching solution. Consequently, an increasing quantity of metals in various ionic forms are dissolved by the acidic medium and mobilized. In addition, an increasing variety of other materials and microoganisms are also being transported within the percolating liquid. The thicker the refuse, the more contaminated the leachate will be.

Leachate moves through the landfill the same as water moves through a column of soil. The field capacity of any imaginary horizon in the column must be exceeded before leachate moves downward any further. Therefore, leachate moves through the landfill as a result of an excess moisture driving force, and a characteristic wetting front is observed. Eventually breakthrough occurs after a specific number of pore volumes of water have been applied to the surface. These terms will be discussed later. The leachate then discharges from the bottom of the landfill into the receiving environment.

Simplified moisture routing methods have been developed to predict the quantity and temporal behavior of leachate discharges from landfills. These methods have been based on basic flow models, taking into account site climatology, fill moisture content, and all other factors affecting a landfill water mass balance.

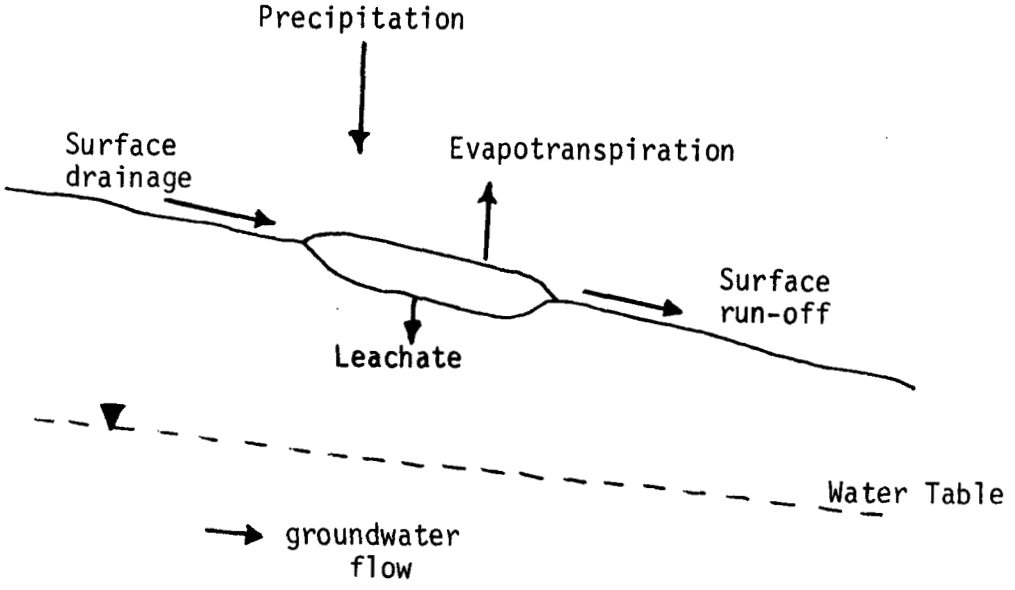


Figure 1 **Water Balance Around a Landfill**

Assuming that the time of first appearance of leachate is dependent only on percolation rate and fill depth, a generalized plot of appearance time can be drawn as in Figure 2. Furthermore, the relationship between annual percolation amounts and leachate quantities for various size landfills can also be plotted as shown in Figure 3. Details are found in the literature[2].

A more theoretical approach to the leaching of soluble solids based on column work, and applied to refuse in one instance, is also discussed in the literature[3]. This was an attempt to predict leachate concentrations using mathematical modelling of leaching processes.

The amount of leachate produced and its chemical characteristics vary seasonally with changes in the amount of moisture infiltrating the refuse[4]. Leachate discharge behavior typically parallels precipitation behavior, with wet periods producing greater leachate flows. During wet periods the leachate strength also increases quite significantly. During freezing periods no net infiltration occurs and only slight leachate discharges are observed. When spring thaw occurs, peak flows are recorded.

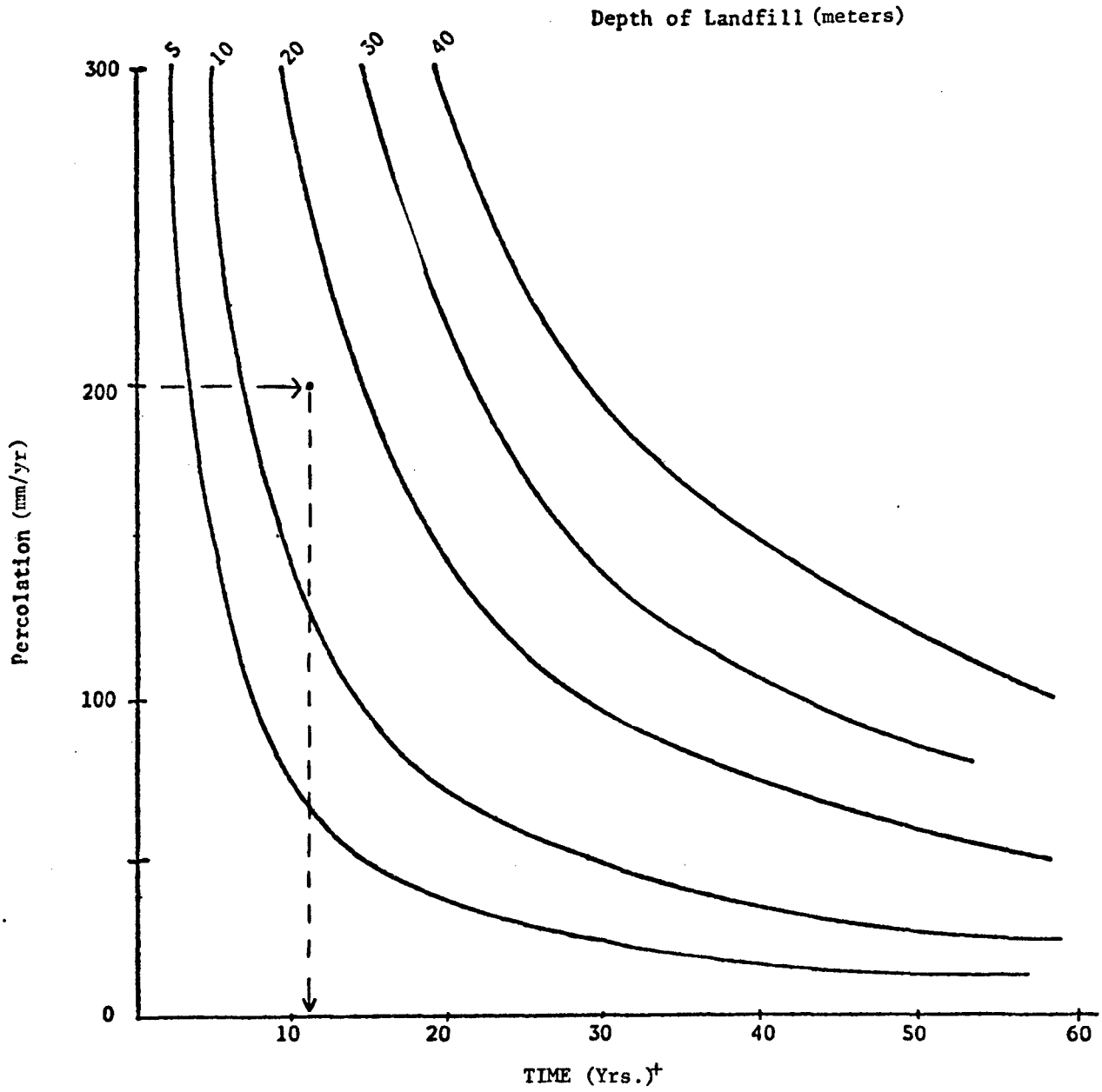
The rate of infiltration of moisture through cover soil into a landfill is dependent on soil type, soil compaction, soil cover slope, cover vegetation, and site climatic conditions. At Madison, Wisconsin, a net infiltration rate of approximately 20% of the precipitation through covered refuse with the cover sloped at about 3% was measured. In Illinois the infiltration rate was found to exceed one-half the annual rate of precipitation under sandy soil conditions. In Sonoma County, California, approximately 40% of rainfall leaves the landfill as run-off during periods of light rainfall. At higher rainfall intensities, a constant amount of approximately 0.55 inch appeared to be infiltrating a predominantly clay cover material with the remainder being run-off. A European study measured a leachate volume equal to 44% of the annual precipitation after fill saturation. In any case, infiltration rates generally cannot exceed the hydraulic conductivity or permeability of the cover soil, provided it is maintained as an effective cover. A tabulation of maximum hourly water transmission rates under saturated conditions is given in Table 1.

Field capacities of municipal refuse landfills have been calculated by numerous investigators based on lysimeter studies. Table 2 lists these findings.

Factors affecting field capacities include the state of decomposition of the refuse, the initial moisture content, the particle size of the refuse, the refuse composition, and the refuse density. These and other variables account for an expected variability in field capacity data, even though a correlation between moisture retention capacity and unit dry density apparently has been established for varying shredded refuse particle sizes (see Figure 4).

Relating all this information to the actual landfill situation, leachate generation rates can be reduced by a variety of methods including: effective application of cover material; proper grading and maintaining of cover soil; applying vegetation to the final cover; and, directing surface drainage around the landfill.

Whether site specific hydrogeology must necessarily minimize leachate generation in all cases, is questionable. Most regulatory agencies base their guidelines or regulations on the premise that a "dry" landfill is better than a "wet" landfill without exception. Recent findings may tend to contradict this basic premise.



*Based on a solid waste moisture absorption capacity of 150 mm/m.
+Time zero is defined as that time when the field capacity of the soil cover is first exceeded, producing the first amounts of percolation.

Figure 2 **Time of First Appearance**

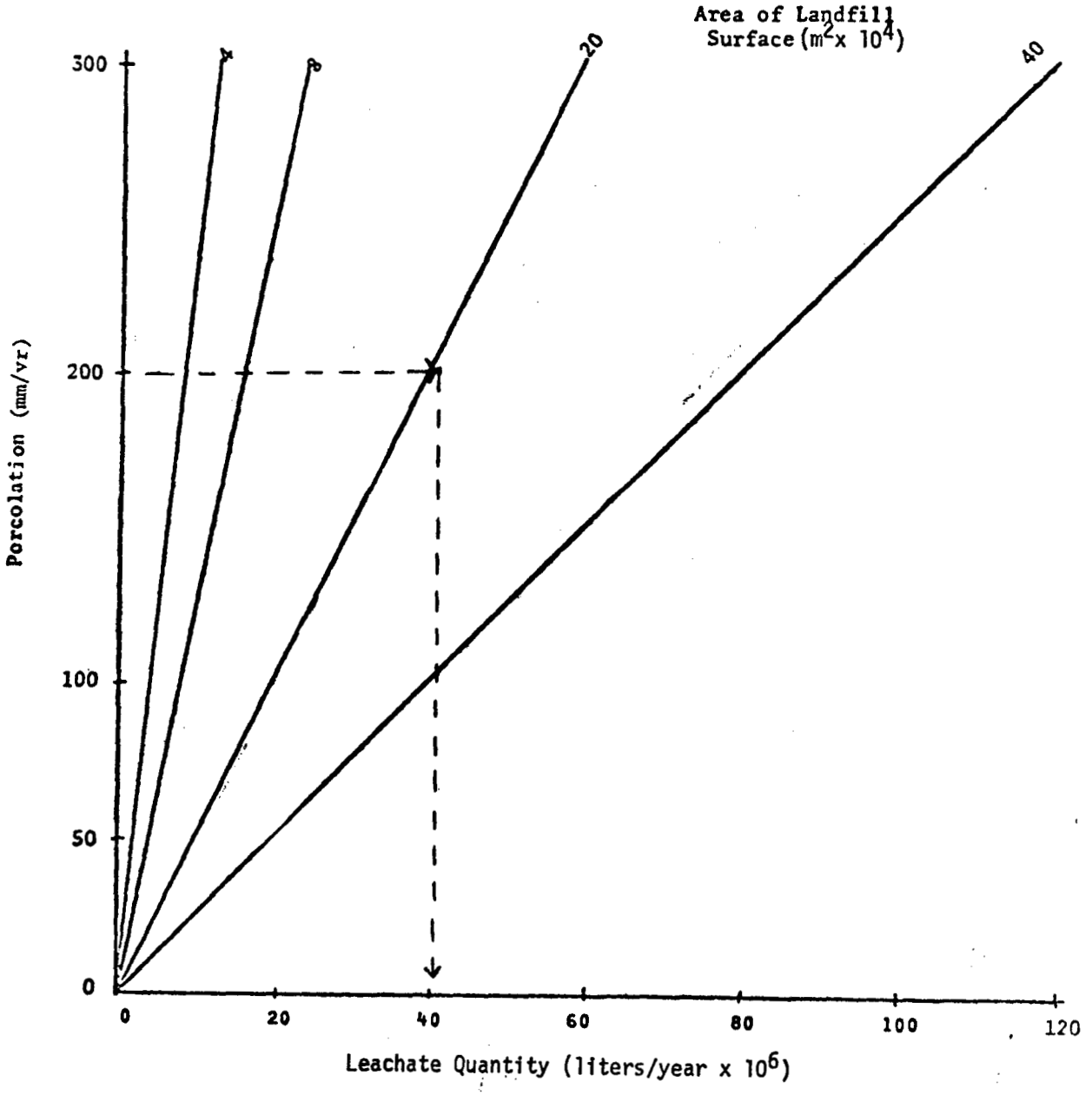


Figure 3 Annual Leachate Quantities After Time of First Appearance

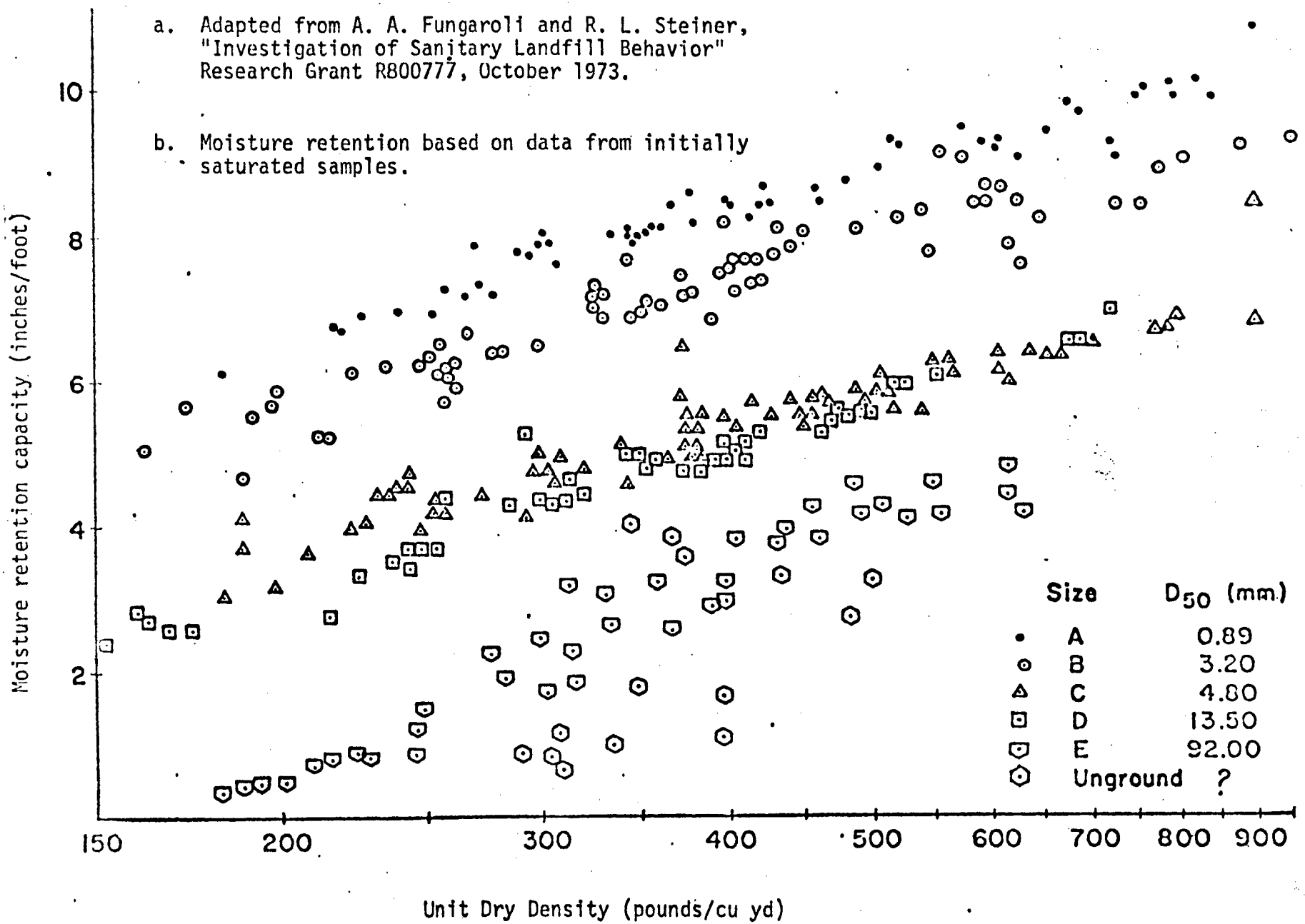


Figure 4 Moisture Retention Capacity of Solid Waste[5]

TABLE 1 MAXIMUM HOURLY WATER TRANSMISSION UNDER SATURATION[5]

Soil description	Hydraulic conductivity cm/sec	Hourly transmitted volume* Upper (gal/acre)	Lower (gal/acre)
Well-graded gravels or gravel-sand mixtures, little or no fines	$>10^{-2}$	$>3.85 \times 10^{5}$	
Poorly graded gravels or gravel-sand mixtures, little or no fines	$>10^{-2}$	$>3.85 \times 10^{5}$	
Silty gravels, gravel-sand-silt mixtures	10^{-3} to 10^{-6}	3.85×10^{4}	3.85×10^{1}
Clayey gravels, gravel-sand-clay mixtures	10^{-6} to 10^{-8}	3.85×10^{1}	3.85×10^{-1}
Well-graded sands or gravelly sands little or no fines	$>10^{-3}$	$>3.85 \times 10^{4}$	
Poorly graded sands or gravelly sands, little or no fines	$>10^{-3}$	$>3.85 \times 10^{4}$	
Silty sands, sand-silt mixtures	10^{-3} to 10^{-6}	3.85×10^{4}	3.85×10^{1}
Clayey sands, sand-clay mixtures	10^{-6} to 10^{-8}	3.85×10^{1}	3.85×10^{-1}
Inorganic silts and very fine sands rock flour, silty or clayey fine sands or clayey silts with slight plasticity	10^{-3} to 10^{-6}	3.85×10^{4}	3.85×10^{1}
Organic silts and organic silt-clays of low plasticity	10^{-4} to 10^{-6}	3.85×10^{3}	3.85×10^{1}
Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	10^{-4} to 10^{-6}	3.85×10^{3}	3.85×10^{1}
Inorganic clyas of high plasticity, fat clays	10^{-6} to 10^{-8}	3.85×10^{1}	3.85×10^{-1}
Organic clays of medium to high plasticity, organic silts	10^{-6} to 10^{-8}	3.85×10^{1}	3.85×10^{-1}
Inorganic clays of low to medium plasticity, gravelly clays, snady clays, silty calys, lean clays	10^{-6} to 10^{-8}	3.85×10^{1}	3.85×10^{-1}

TABLE 2 MOISTURE RETENTION OF SOLID WASTE*

Initial Moisture Content (% wet wt.)	Added Moisture Content (in/ft)	Solid Waste Density (lb/yd^3)	References
29.9	5.1[a,b,c]	661	(5)
25.1	3.1[a,b,c]	727	(5)
32.0	5.3[a,b,c]	705	(5)
27.6	2.4[a,b,c]	1000	(5)
62	1.2[a,b,c]	570	(4)
50	1.7[a,b,c]	530	(4)
	0.75 to 4.0	varies	(5)
	1.3 to 1.5		(5)
	2.5[a,b]		(5)
	1.5	647	(6)
	1.6	687	(6)

a. not corrected for evaporation and transporation losses
b. includes H_2O retained in soil cover
c. includes H_2O retained in sub-drain

* This Table taken partially from an unpublished U.S. EPA Report (5)

3. LEACHATE COMPOSITION

Data on leachate composition is available in numerous reports on landfill lysimeter studies, and from some actual field investigations. In reviewing field data, however, it should be noted that the data may in fact be reporting on leachate which has already been somewhat attenuated by subsurface soil.

It should also be noted that a variety of analytical methods have been used to generate this data. Variation in technique leads to quite a data scatter, making comparison difficult.

A review of the available information shows composition ranges for many parameters, as listed in Table 3. Cursory examination of Table 3 values will indicate that leachate has a high organic content, a high total solids content, a relatively low metals content except for iron, and that leachate is slightly acidic. Additional data suggests that the toxicity of leachate varies from 0.1% to 32% by volume as measured by 96 hr. TLm bioassays[7], with typical values probably being 7% by volume[1].

Leachate composition is affected by fill content, leaching rates, fill depth, and fill age. In time, all readily oxidizable organics are removed, the leachate pH increases, and the rate of dissolution of metals decreases. Figure 5 and Table 4 provide an indication of the change of leachate strength with time. Data from northwest Illinois studies indicate similar findings.

In terms of total pollutant loadings to the environment, the impact of leachates may surprisingly not be so detrimental. For example, compare loadings from a landfill and a biologically treated sewage treatment plant effluent. The data in Table 4 also shows that sewage treatment plant effluent concentrations are typically much lower than leachate concentrations. However, Table 5 indicates that contaminant loadings from a landfill are in fact much less because of the much lower flow rates.

It is also rather typical in lysimeter study results that contaminant concentrations peak quite rapidly after the first appearance, or breakthrough, of leachate and then decay. This extreme behavior would not be expected at a landfill, however, because refuse is being discharged and thereafter leached continuously as the operation progresses. The situation being simulated in lysimeter studies is typically that of continued leaching of a constant mass of already covered refuse after landfilling is complete.

4. LEACHATE MIGRATION

Leachate migration behavior is dictated by the hydrogeology at the landfill location. A landfill is typically situated some distance away from a surface watercourse in an uplands area with a low watertable rather than a flood plain area with a high water table. In this typical situation landfill leachate would affect either a local or regional groundwater flow system, depending upon its location.

In exceptional and extreme situations, a landfill will be constructed on or near bedrock, in which case leachate discharges at the "toe" of the landfill, or a landfill will be constructed in a high water table area or a natural groundwater discharge area such as a swamp or peat bog, in which case the

Figure 5 Relationship Between Age of Refuse and COD of Leachate[3]

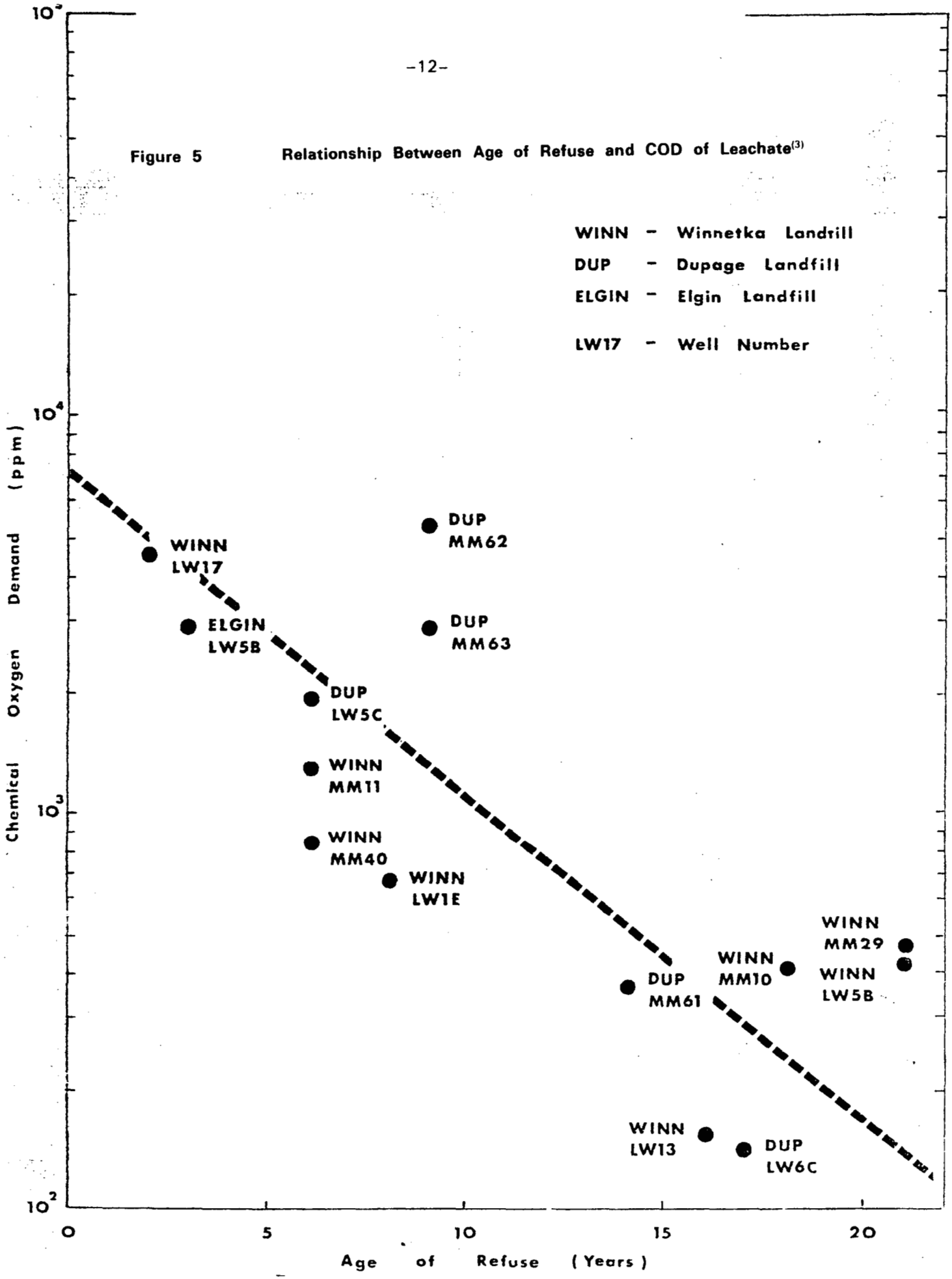


TABLE 3 LEACHATE COMPOSITION - LEACHATE SOURCE

Constituent	SHWRL[1]	U of Ill.[3]	Drexel[3]	Ga. Tech[4]	Ga. Tech Recirculate	Olin Ave Landfill[5]
COD	16,000 - 22,000	45,000 - 71,000	1,000 - 51,000	4,320 - 12,000	4,280 - 9,288	2,700 - 10,650
BOD_5	7,500 - 10,000			2,500 - 11,000	2,750 - 6,900	1,550 - 8,450
TOC	13,000	14,000 - 28,000		1,230 - 5,000	256 - 2,798	
pH	5.2 - 6.4	4.5 - 6.0	3.7 - 8.5	5.2 - 5.6	4.8 - 5.4	5.9 - 8.1
TS	10,000 - 14,000	34,000	0 - 42,000	2,442 - 12,500	1,627 - 6,918	4,028 - 7,790
TDS	10,000 - 14,000	15,600 - 23,000				
TSS	100 - 700	139	10 - 26,500	34 - 610	12 - 385	
Specific Conductance	6,000 - 9,000	9,400 - 16,800				
Alkalinity ($CaCO_3$)	800 - 4,000		0 - 9,700	558 - 2,280	302 - 1,370	1,800
Hardness ($CaCO_3$)	3,500 - 5,000		0 - 5,500	459 - 1,940	370 - 1,040	1,400
Total-P	25 - 35	20 - 100	0 - 130	1.8 - 26	0.65 - 22	12
Ortho-P	23 - 33	6.5				
NH_4-N	247.7	400 - 1,000	0 - 482	56 - 187	68 - 114	
NO_3+NO_2+N	0.2 - 0.8	0.5 - 10.0Δ				
Ca	900 - 1,700	2,300 - 4,000		125 - 750	60 - 435	80
Cl	600 - 800	1,500 - 2,500	4.7 - 2,340	98 - 385	91 - 248	400
Na	450 - 500	750 - 1,600	0 - 7,700	64 - 143	62 - 109	
K	295 - 310	860 - 2,300				
Sulfate	400 - 650	900 - 1,550	25 - 450	81 - 156	12 - 138	
Mn	75 - 125			3 - 10	4 - 65	20
Mg	160 - 250	530 - 1,100		16 - 75	17 - 63	
Fe	210 - 325	730 - 2,200	0 - 1,716	9 - 95	4 - 110	330
Zn	10 - 30	104	0 - 167	74	<0.05	5.5
Cu	0.5	0.5	0 - 9.9	0.48	<0.03	
Cd	0.4			17	<0.03	
Pb	1.6	1.25		1.16	<0.10	

Dupage[6] MM61	Dupage MM63	Dupage LW5B	Dupage LW6B	Winnetka[6] LW17	Winnetka LW13	Winnetka LW5B	Riverside[7] BIN #1
360	2,940	8,000	40	4,260	153	415	
125*	4,560*	14,080*	225*	6,400*	105*	250*	81-33,100
		6.3	7.0				5.6-7.6
1,104	5,910	6,794	1,198	2,306	584	994	
1,630	4,720	5,810	2,250	3,370	1,450	3,080	730-9,500
690+	2,250+	2,200+	540+	1,180+	710+	970+	650-8,120
0.5	0.17	1.2	8.9	2.6	1.3	2.75	0.2-29
0.14Δ	0.5Δ	0.7Δ	1.6Δ	0.5Δ	0.2Δ	0.43Δ	0.2-890
156	447	308	102	100	109	109	115-2,570
205	946	1,330	135	429	70	701	96-2,350
63	615	810	74	298	34	348	85-1,805
85	220	610	100	168	39	220	28-1,860
1	1	2	2	13.6	5	1	
0.24	0.09	0.06	0.06	1.14	0.2	0.1	
110	725	450	90	198	75	200	64-410
106	12	6.3	0.6	96	11	13.6	6.5-305
0.10	0.05	0.4	4.5	1.5	0.1	0.6	
<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
BDL	BDL	BDL	BDL	BDL	BDL	BDL	
1.0	1.0	0.5	1.0	1.0	1.0	0.5	

NOTE: All figures in Mg/l except Specific Conductance which is measured as mhos/cm.

* Based on 20 Day BOD

\+ Blackwell value calculated from Mg and Ca concentration

Δ Using only NO_3 analyses, NO_2 not determined

BDL = Below detectable limits, for Cd = <0.05 mg/l

TABLE 4 LEACHATE STRENGTH VERSUS AGE OF SITE[3]

Source	Average Site Age	Characteristic						
		BOD_5 (mg/l)	C1 (mg/l)	NH_2–N (mg/l)	Hardness as $CaCO_3$ (mg/l)	Phenols ppb	SO_4 (mg/l)	pH
Fergus–Elora+	1 year	13000	1000	180	3400	–	500	–
St. Agatha+ (leachate pond influent)	4 years	225	900	600	1400	200	10	7.3
Brantford+ (wells 66 & 67)	9 years	110	300	175	900	30	10	7.2
Waterloo+ (well 504)	30 years	2	96	10	772	4	–	7.5
Uncontaminated Groundwater (St. Agatha Well 8)	–	10	3	0	120	6	–	8.0
Final Effluent (Waterloo PCP)	–	20	248	–	316	–	190	–
Domestic Sewage Typical Data	–	200	250	25	300	–	200	7.5

+ Landfill locations

TABLE 5 CHEMICAL DISCHARGE TO THE ENVIRONMENT (LBS PER DAY)[3]

Characteristic	Waterloo PCP Final Effluent	Waterloo* Old Landfill (3)
BOD_5	1320	25
Sodium	10080	78
Calcium	4980	20
Magnesium	1560	27
Chloride	14880	90
Sulphate	11400	1
Total Kjeldahl-N	270	99
Total Iron	60	3.3
Phosphorus	108	.5
Chromium	-	.02
Nickel	-	.07
Lead	-	N.D.**
Cadmium	-	N.D.**
Zinc	-	.78

* Fergus-Elora site as per Table 4.
** N.D. - Not detected.

leachate will tend to migrate towards adjacent drainage ditches in accordance with the groundwater gradient.

In the subsurface, leachates migrate first vertically through the unsaturated zone, and after reaching the top of the saturated zone, i.e. the water table, in the same direction as groundwater.

Groundwater moves along a predetermined flow path from areas of high potential (recharge area or upland) to areas of lower potential (discharge area, as shown in Figure 6). At any point in the flow system, water has the tendency, or potential, to flow towards an area of discharge. Lines connecting points of equal groundwater potential are called potential lines and they are basically perpendicular to the flow path lines. In a recharge area, the groundwater potential is decreasing with depth and water moves downward away from the water table. In a discharge area, potential is increasing with depth and water moves upward toward the water table.

The pattern of groundwater flow from a recharge to a discharge area constitutes a dynamic flow system. It is composed of several super-imposed elements. The largest one is the regional flow system, in which the deeper portion of the groundwater flows from a regional recharge area to a regional discharge area, such as a major stream. Water level in the stream represents the lowest water table elevation of the system.

The shallow portion of groundwater flow consists of several local systems depending upon the configuration of the terrain. Possible pollution of groundwater from a landfill is essentially limited to shallow zones, unless the location is in the area of the regional recharge. Therefore, the determination of small, local flow systems is of prime interest in solid waste disposal planning. The higher the topographic relief, the greater is the importance of the local flow system since this tends to increase the depth and the intensity of the local flow system. If the local relief is negligible, a local flow system may not form at all. Once the groundwater flow system around the landfill is determined, it is possible to predict the movement of leachate with some degree of accuracy.

Leachate tends to travel in the direction of groundwater flow in well defined configurations called enclaves or plumes, characterized by a core of maximum concentrations[9].

Each contaminant within the leachate has a distinct plume configuration which is affected by the attenuating capabilities of the soil. Some contaminants are only attenuated by dispersion and diffusion, whereas others are subject to many attenuating mechanisms. Chloride, for example, is a conservative ion which tends to travel at the same rate as groundwater flow, whereas the phosphate ion is rapidly attenuated. Therefore the chloride plume would obviously have a different configuration than the phosphate plume, and similarly for other parameters. In some situations, migrating leachate might flow through an aquifer containing impermeable lenses. Contaminant plumes finger out under such conditions.

Contaminant plumes grow when the rate of waste addition exceeds the rate of attenuation, and shrink when the rate of attenuation exceeds the rate of waste addition. After waste discharging ceases, the plume configuration is affected by desorption processes and eventually the plume shrinks to an undetectable size. However, before contaminants are attenuated by the soil to background conditions,

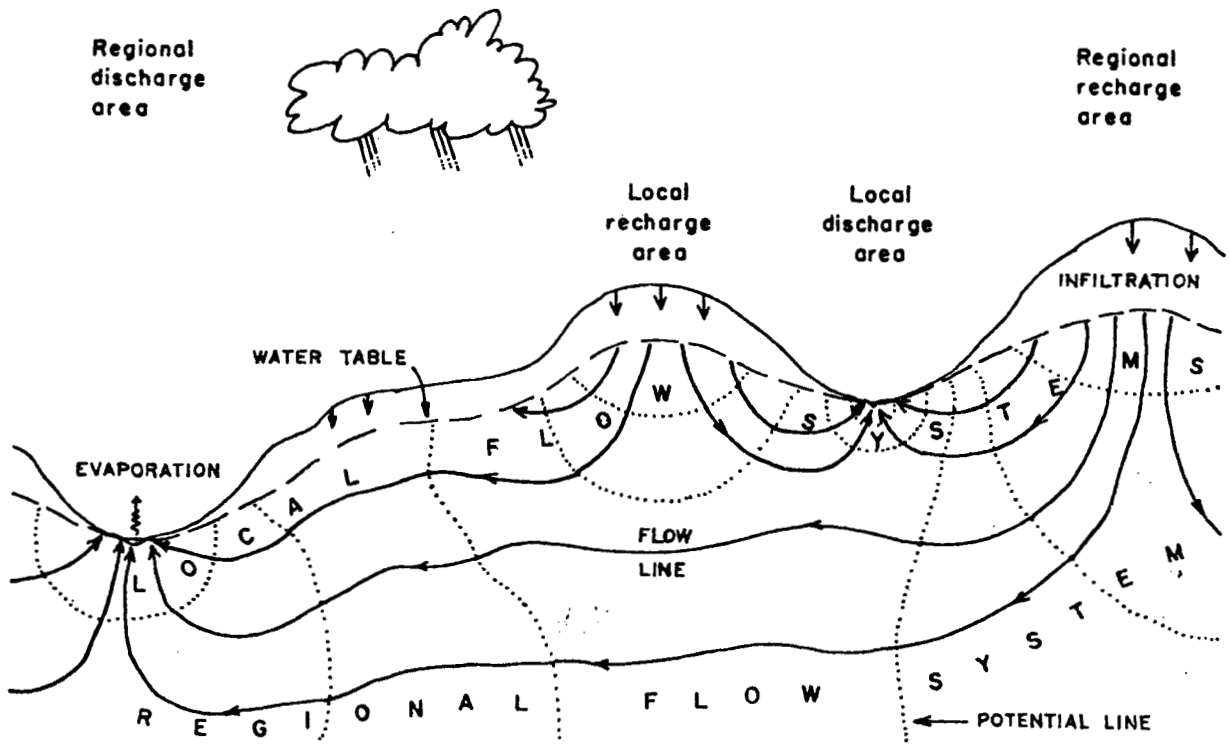


Figure 6 **Idealized Groundwater Flow System[8]**

the plumes are often truncated by groundwater discharge areas such as streams. Plume configuration is a function of the distance between the contamination source and a discharge zone, the gradient of the flow system, and the rate of attenuation. For this reason, upland areas may not be the best location for a landfill operation, since groundwater contamination will persist for longer periods of time, will spread over a greater area of the aquifer, and will probably affect lower useable aquifers.

On the other hand, landfills located relatively near a groundwater discharge zone will only affect upper aquifers, which are generally separated from a useable regional aquifer by impermeable aquicludes. Provided that the distance from the landfill to the discharge zone is adequate for the site soil conditions, the leachate contaminants may be sufficiently diluted or attenuated so as not to cause a pollution problem.

The axis of the plume is oriented parallel to the groundwater flow lines, providing that the density of the contaminated groundwater is nearly that of background water. In most instances, however, leachate probably has a specific gravity greater than that of uncontaminated groundwater and the leachate plume actually cuts across gradients as it follows groundwater flow. In one instance it was reported that the leachate migrated vertically through both the unsaturated and saturated zones to the bottom of the aquifer and then migrated laterally. Conversely, groundwater contaminated by hydrocarbons has a lower density than native groundwater and the enclave will form at or just above the water table. This is important with respect to designing a monitoring program.[10]

5. LEACHATE ATTENUATION

Until recently, the only information available to landfill operation planners relating to the attenuation of landfill leachate by soils was obtained from field sampling results reported in the literature. Groundwater samples taken downgradient of landfills apparently showed that in most cases attenuation was adequate to significantly reduce contaminant concentrations to acceptable levels over short distances. The information, however, was no assurance that samples were taken from within the contaminant plume, or that the core of the contaminant plume had migrated to the sampling location. Nor did it always relate to specific soil characteristics or site hydrogeology.

As examples of the type of empirical information available Table 6 indicates significant attenuation in silty sand, Table 7 indicates the same trends for a clay-till, Table 8 shows attenuation in a fine sand, and Table 9 shows how liquid industrial waste dumped onto land was significantly attenuated on migrating through till and sand.

Current research efforts in Canada, the U.S.A., and in Europe are being directed towards gaining a better understanding of actual attenuation mechanisms. The objective is to gain enough knowledge about the attenuation of leachate contaminants to be able to develop both predictive methodologies for estimating the impact of disposal sites at the outset and specific landfill guidelines.

In North America, major research efforts are being conducted at the University of Arizona, the University of Waterloo and the University of Illinois.

TABLE 6 LEACHATE ATTENUATION IN FINE SILTY SAND[3]

Chemical Characteristics	Sample Point		
	Leachate	200' South of Fill	700' South of Fill
Ammonia Nitrogen (N)	175	60	1.0
Organic Nitrogen (N)	125	25	10.0
Chloride (Cl)	350	350	20
Phosphorus (P)	6.0	.6	–
Phenols ppb	30	12	0
Hardness (as $CaCO_3$)	900	850	500
BOD_5	200	30	5
Calcium (Ca)	156	215	153
Magnesium (Mg)	122	77	25

Average Refuse Age – 9 years

TABLE 7 LEACHATE ATTENUATION IN CLAY-TILL[3]

Chemical Characteristics	Sample Point			
	Leachate	10' Beneath Refuse	100' East of Fill	Base Quality
Ammonia Nitrogen (N)	600	40	0.5	0.2
Organic Nitrogen (N)	300	60	1.0	0.4
Chloride (Cl)	900	250	20.0	4.0
Iron (Fe)	50	25	0.5	0.5
Phosphorus (P)	4.5	4.0	.05	.06
Phenols – ppb	200	150	8.0	8.0
Hardness (as $CaCO_3$)	1400	700	250	140
BOD_5	250	150	5	4
Calcium (Ca)	156	100	40	25
Magnesium (Mg)	249	120	37	19
Iron (Fe)	35	15	.8	.7
pH	7.2	7.2	7.6	7.7

Age of Site – 10 years

TABLE 8 LEACHATE ATTENUATION IN FINE SAND[3]

Chemical Characteristics	Sample Point			
	150′ South of Site	800′ South of Site	2000′ South of Site	Base Quality
Chloride (Cl)	252	132	10	5
Iron (Fe)	2.5	.2	.3	.2
Sodium (Na)	4.3	3.5	7.0	1.7
Potassium (K)	0.4	0.1	2.0	0.1
Hardness (as $CaCO_3$)	414	503	285	301
Alkalinity (as $CaCO_3$)	220	432	252	-
Zinc (Zn)	.08	0.38	.06	.17
Calcium (Ca)	100	147	91	87
Magnesium (Mg)	40	33	14	20
COD	131	83	-	-

Age of Site - 20 years

TABLE 9 LIQUID INDUSTRIAL WASTE ATTENUATION IN TILL UNDERLAIN BY SAND AQUIFER[3]

Chemical Characteristics	Sample Point: Movement Through Till from Lagoon "A" 15'	125'	Movement Through Sand Aquifer from Lagoon "B" 150'	600'	Base Quality
Hardness (as $CaCO_3$)	2840	640	23	340	228
Alkalinity (as $CaCO_3$)	684	467	306	220	229
Chloride (Cl)	72	46	28	19	2
pH	7.0	7.1	10.0	7.1	7.6
Phenols ppb	30	20	600	<6	2
Sulphate (SO_4)	2040	207	79	70	20
Iron (Fe Diss)	.15	.10	.30	<.02	.10
Chromium (Cr Tot)	<0.1	<0.1	<0.1	<0.1	0.0
Copper (Cu)	12.0	.88	.67	<.02	0.0

Age of Site – 15 years

The Arizona work is investigating trace element mobility through ten different soils under anaerobic conditions, and identifying factors affecting attenuation. The investigators are using soil columns and a 1000 gallon leachate generator, from which leachate is drawn off under high Co_2 pressure and applied to the columns. The elements of interest are As, Be, CN, Cr, Fe, Cu, Cd, Hg, Ni, Pb, Se, and V. In each case, the leachate is acidified and spiked with the element of interest. Leaching is continued until either breakthrough occurs, steady state is attained, or a continued absence of the metal is observed. Thereafter, columns are segmented and the element extracted. Per cent reductions are then related to various soil properties.

Their findings released to date indicate that the important attenuation factors are: soil particle size (i.e. clay content); free hydrous iron oxide content; soil pH value; and solution flux[11]. Particle size distribution (i.e. clay content) plays the dominant role in attenuation of the trace elements, as would be expected, with the partial exception of chromium where pH is also important. The negative effect of pH on Cr^{+6} migration was similarly noticed for Se. All other trace metals showed increased mobility with decreasing pH.

The factors found to be least important in attenuation are: sand; cation exchange capacity; and, soil organic matter, except for Hg. The presence of organic substances in the leachate appears to have enhanced Hg movement.

The most generally mobile elements are Cr, Hg, and Ni. The least mobile were Pb and Cu, whereas the mobility of the other metals varied with conditions.

Another interesting finding, which is currently being further explored at Arizona, is that lime and hydrous oxides of iron, applied as a landfill liner, appear to have a tremendous attenuating effect.

It should be noted that soil column results are usually plotted as breakthrough curves in terms of c/c_o versus either column discharge volume or pore volumes of leachate. A pore volume is usually defined as the ratio of the volume of effluent to the total water in the soil column. These type of plots can be used to define breakthrough (i.e. when $c/c_o = 1$) and to show the various effects of attenuation mechanisms. The chloride ion follows the idealized breakthrough curve, showing that Cl is not attenuated other than by dispersion. Breakthrough curves for other elements deviate somewhat, indicating that other mechanisms such as ion exchange, microbial degradation, filtration, precipitation and coprecipitation, absorption, complexation, or gaseous exchange are affecting the breakthrough behavior of the element.

The conservative ions such as Cl simply dilute because of hydrodynamic dispersion within the soil water or groundwater system. These ions are not attenuated by any other mechanism. Other ions, however, may be subject to a variety of mechanisms during their migration. For example, a species may initially be oxidized, and precipitated onto a soil particle. As the system quickly becomes anaerobic, solution pH decreases, the ion may become released and migrate. During its migration it may become complexed with an organic compound and sorbed onto the soil. Soil microbes will digest the organic portion and release the ion, which may then take part in an ion exchange reaction with another ion on a clay surface. It may stay there, occupying an exchange site on the surface of the clay particle or within

clay layers until a slug of desorbing water comes along, carrying with it ions that will replace it. This is an exaggeration of what might actually happen, however, it does provide an illustration of the migration-sorption cycle taking place.

The University of Waterloo has also undertaken some attenuation work. Their technique development work showed that column studies using remoulded as opposed to undisturbed soil samples provided almost identical breakthrough curves. The use of remoulded columns therefore seems to be justified for future work involving soils exhibiting intergranular flow. Additional work also proved that dispersed soil experiments may also be used to reproduce column performance. The dispersed soil technique involves reacting effluent with soil in an agitated batch reactor. This study technique is less time consuming than traditional column studies[12].

The University of Waterloo's attenuation work, using the batch dispersed soil reactors, identified possible attenuation mechanisms for various contaminants of an industrial waste in typical Ontario soils. Attenuation runs were followed by desorption runs[13]. It was evident that desorption was greatest for those contaminants which were attenuated mainly by dispersion or diffusion alone. However, it could be anticipated that desorption processors would be complete for all contaminants in time. The Waterloo work also showed that the zone of influence of the disposal operation is closely related to the waste loading. In this regard, their data suggest that a number of small waste disposal sites with a limited zone of influence are preferable to a large site with a large zone of influence. It can be postulated that the past practice of waste disposal in small sites may account for the limited environmental impact measured to-date.

The University of Illinois work was an investigation of the use of clay minerals to limit the pollution of waters by landfill leachate. Column leaching tests were conducted to simulate the slow, saturated, anaerobic flow of leachate from a landfill into a soil column. The mechanisms involved in attenuating contaminants, including microbial activity, were evaluated using municipal refuse leachate and three clay minerals[14]. Their findings indicate that montmorillonite attenuates contaminants nearly four times better than illite and five times better than kaolinite. These ratios were found to be nearly identical to the cation exchange capacity ratios for the three clays. Therefore, the conclusion from this work is that cation exchange capacity is probably the principal attenuating mechanism. Solution pH was also shown to be an important attenuation factor. Five cations, namely Cr, Cu, Pb, Cd, and Zn showed a marked increase in adsorption with increasing pH in the range from pH2 to about pH6. The metals Se and Cr^{+6} followed a reverse trend with respect to pH, as was the case in the Arizona work.

The differences in conclusions regarding the major attenuation mechanisms may be partially explained by the following: leachate application rates in Arizona were 7 1/2 times greater than in the Illinois work. Under the lower flow rates, cation exchange probably becomes a more important mechanism because the leachate contaminants have a greater opportunity to seek out additional exchange sites during the increased intergranular detention time. Also, the soil columns in the Illinois work were filled with nearly pure clay materials whereas the Arizona work used *in situ* soils. The Arizona studies used spiked leachate artificially generated, whereas the Illinois investigators used landfill leachate collected in

the field. It should also be noted that the Arizona soils were extracted from B horizons only. Landfill leachate generally discharges into C or lower horizons.

At this time it is thought that the Illinois results can be used to assess attenuation of municipal landfill leachate in clay soils, and the Arizona work, because of the greater solution flux applications accelerating contaminant migration, is thought to be a ''worst case'' study[15].

6. LEACHATE CONTROL

Regulatory agencies have become aware of the fact that any landfill, even a sanitary landfill, is capable of generating a leachate which can migrate with groundwater flow to points of groundwater discharge or extraction. Instances of leachate from improperly located and operated landfills contaminating wells and surface streams have been reported. Despite the fact that research seems to be indicating that the soil's attenuation capacity has been underestimated, regulatory agencies are demanding stricter leachate control facilities. Many new landfills are required to be equipped with liners, collection facilities and even treatment facilities. The expense of these additional appurtenances is significant, especially for large landfills.

The new concern for leachate control has added to landfill jargon. Landfills are now being referred to as either ''attenuation'' sites or ''containment'' sites. The distinction is that the latter is to be characterized by zero discharge of pollutants to the environment, whereas the former has a distinctive zone of influence.

The ''attenuation'' sites rely on natural leachate control mechanisms. At these sites leachate is attenuated by subsurface soils or diluted by surface water. A landfill site properly located to take advantage of the soil's attenuating capability will not require expensive control measures. It's impact on the receiving environment in terms of total loadings of most parameters will probably be much less than that of a sewage treatment plant, as previously noted, and the concentrations of contaminants reaching usable water should not deteriorate extracted water quality.

Many fine grained moderately to poorly permeable silt or clay rich soils offer excellent potential for natural control of landfill leachate. Favourable hydrogeologic environments where such soils occur can usually be found.

In any case, good site design and proper landfill operation can minimize the rate of leachate generation, which in turn will accelerate natural attenuation in the soil environment.

However, a site which has not been properly located for reasons of economics, politics, public reaction, or whatever, may require precautionary control measures to ensure that pollution or a health hazard does not result.

Leachate control measures may include landfill lining to facilitate leachate collection and to prevent leachate discharging to an underlying aquifer; groundwater gradient manipulation or interception to force leachate to flow to a convenient groundwater discharge point; leachate recirculation through the

landfill to control the volume of leachate being released to the receiving environment and to increase stabilization of the landfill; and, leachate treatment.

Where the soil conditions are unsuitable or the travel distance for leachate too short for natural control, waste may be deposited on essentially impermeable in-situ soil or bedrock where careful bottom grading directs leachate along the bottom of the fill to suitable collection facilities. Where natural soils may not provide an adequate lining and flow control means, a synthetic or an admixed liner material should be provided at the base of the landfill to intercept leachate and to ensure leachate flow to a collection point. From there, leachate can be removed for treatment. Indications are that a liner permeability less than 10^{-7} cm/sec is required to ensure at least 75% retention based on water infiltration studies, as per Figure 7[3].

At the present time, the integrity of landfill liners is under investigation. It has been generally accepted to date that clay liners and most plastic liners will not allow leachate leakage, even though the manufacturer's guarantees for membrane liners are not as long as the usually expected duration of leachate flows.

A current U.S. EPA solid waste management report discusses the various materials available as liners, as well as the methods of liner installation and liner protection[16].

The University of Illinois study has already shown that natural clay liners have a finite attenuation capacity and do breakdown, in terms of permeability increases, in the presence of leachate. A study currently in progress at Oakland, California, has also led to some interesting preliminary observations[13]. It appears that natural liners are subject to failure under acidic or basic conditions. Synthetic liners subject to similar conditions have either dissolved, hardened and become brittle, or swelled. This study is investigating six polymeric liner membranes and six admixed materials under exposure to landfill leachate and a variety of industrial waste sludges. It is anticipated that the results of this study will lead to a re-evaluation of the effectiveness of many landfill liners currently being installed at great expense at large regional landfills.

Cost figures for liners are given in the above mentioned EPA report[16]. It appears that bentonite (sodium montmorillinite) costs could be as low as $800 per acre, based on experience at an Ontario landfill. The next cheapest landfill sealant, other than soil admixtures, is polyethylene at approximately $7,000 per acre. The most expensive liner is hypalon at $19,400 per acre.

Another method of leachate control utilizes natural groundwater flow systems. In particular, upward groundwater movement to a point of discharge can be intercepted downstream of the disposal site by pumping or by installing an infiltration gallery between the landfill and the discharge area[3,18]. The leachate interceptor must be installed well below the normal water table to ensure that it will not be above that zone during dry periods. Leachate flows collected in this manner, because of groundwater dilution, can be significantly greater than the same situation where undiluted leachate is collected on the site.

Leachate recycling can be considered as both a leachate control and a leachate treatment method. It will be discussed in the next section.

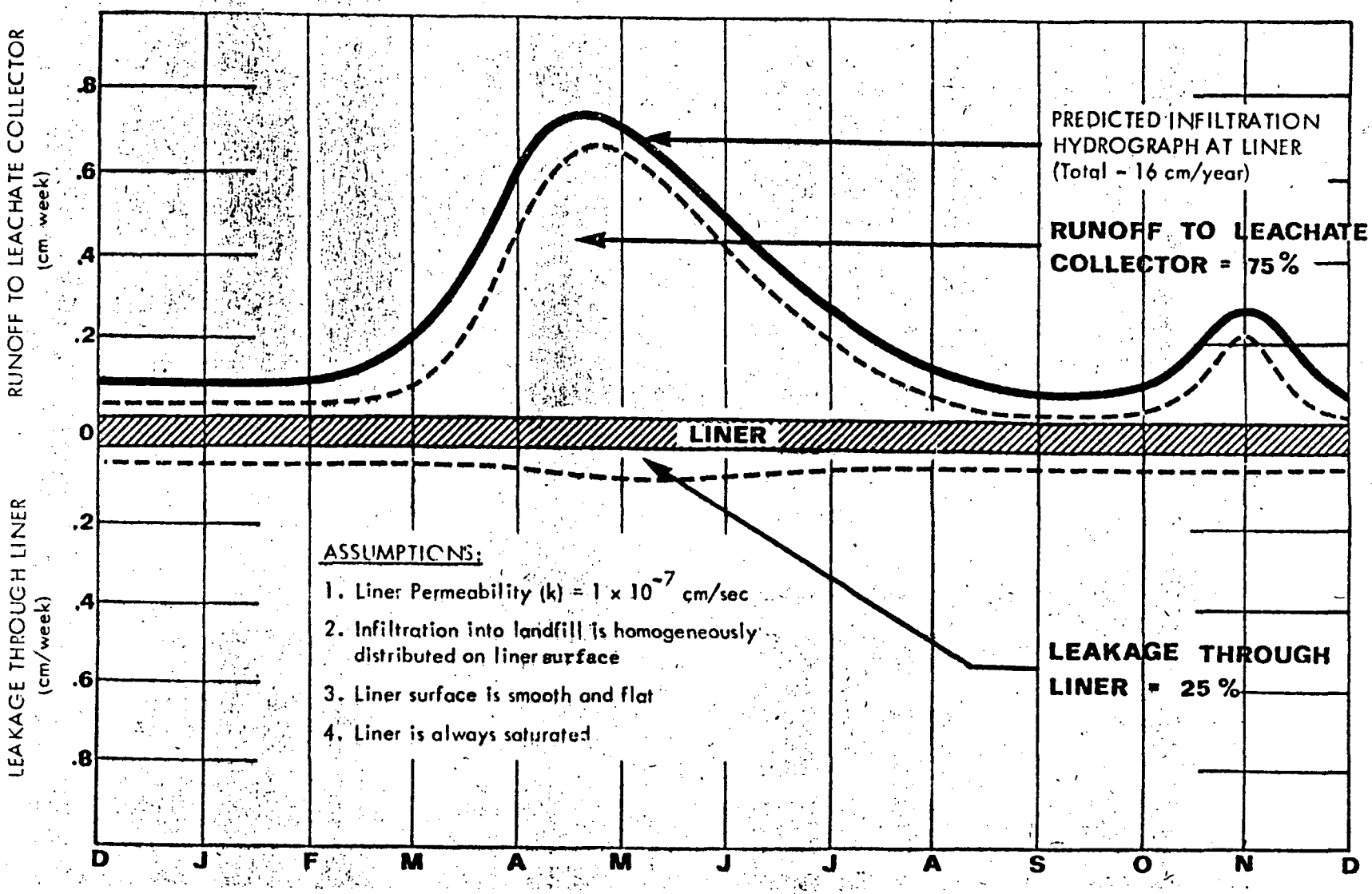


Figure 7 Bentonite Liner Performance

7. LEACHATE TREATMENT

Several investigators have studied the treatment of sanitary landfill leachate, and promising results were obtained with a number of treatment methods[5].

Biological treatment methods were most effective when treating leachate generated from a recent fill. Physical-chemical methods showed better results than biotreatment when treating leachate generated from an old fill. For example, in one study, COD values showed no decrease after an aeration period of 148 hrs. being leachate with a BOD/COD ratio of 0.036[19].

The removal of heavy metals was generally larger in aerobic systems than in anaerobic treatment units. While both resulted in large reductions of iron, the reduction of Ca and Mg was larger in the aerobic units. For example a University of Illinois study showed the following reductions under aerobic conditions[5].

Fe	99.95%
Zn	99.0%
Ca	99%
Na	98%
Mg	89%
K	9%

Another study using leachate obtained from an actual landfill showed similar results except that Mg reductions were only 23% as compared to 89%.

Other investigators showed that pH adjustment by lime, NaOH or Na_2CO_3 addition did not significantly affect treatment efficiency, although one study did show some improved treatment performance after nutrient additon and pH adjustment.

It was also found that aeration in combination with coagulation to enhance floc formation showed no benefits.

Physical-chemical treatment does not result in large reductions of organic matter in new leachate, but is effective in the removal of heavy metals, turbidity, and colour. Most promising results were obtained when the leachate was well stabilized and the percentage of fatty acids was small.

It is apparent from results obtained to date that biological treatment, either aerobic or anaerobic, followed by phys-chem treatment using filtration, for example, provides a suitable treatment system for landfill leachate. Typical costs of leachate treatment are shown in Figure 8, although the treatment operations considered in deriving the cost data are not mentioned[20].

Other feasible methods of landfill leachate treatment include spray irrigation of biologically treated leachate and leachate recycle through the landfill. For spray irrigation, pretreatment with lime has been suggested to remove solids and metals which would tend to enhance soil clogging, or which would produce undesireable metal oxide coatings on vegetation.

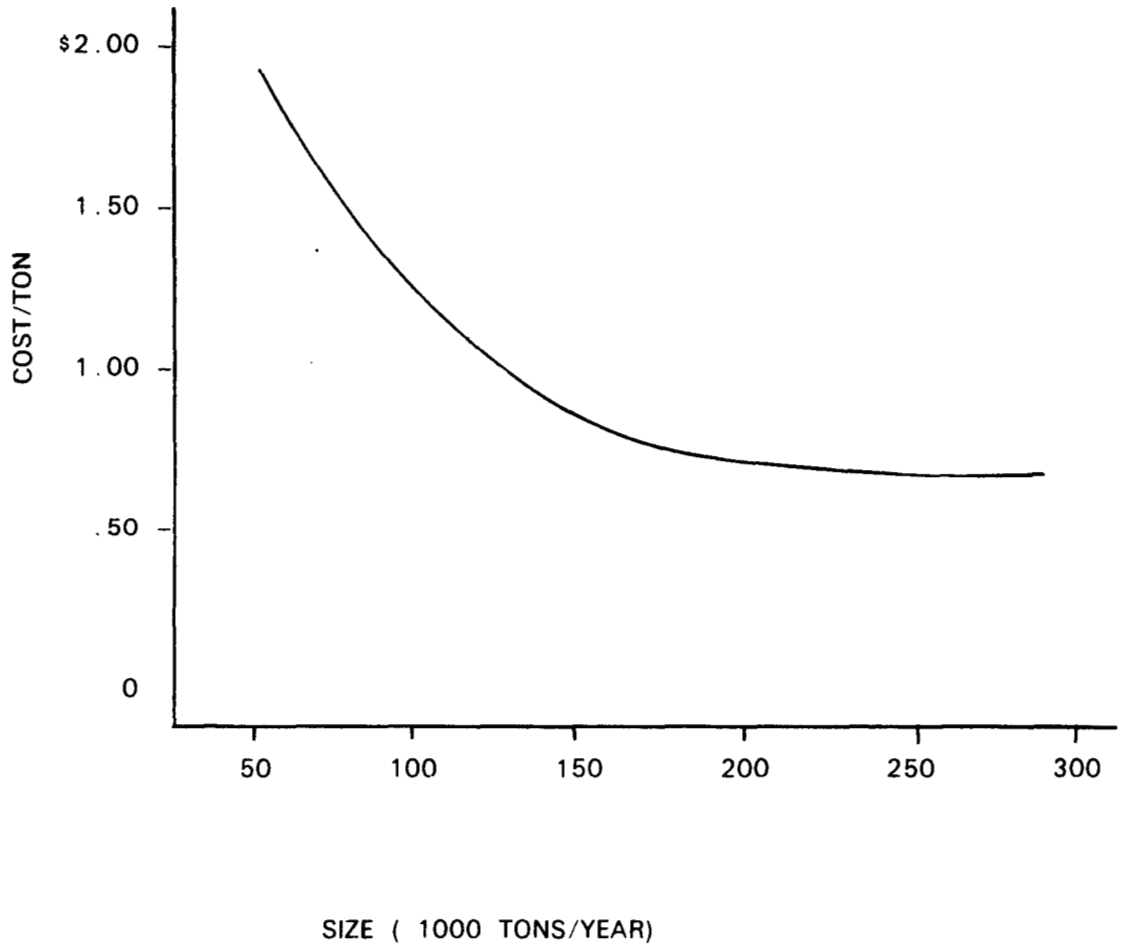


Figure 8 **Leachate Treatment Cost**[20]

Leachate recirculation has only been studied on a lab bench scale and on some test plots[5,21]. The recycling tends to reduce organics, although this hasn't been proven for large scale operations. It also tends to concentrate metals in the leachate. The feasibility of using recycling only as a treatment method in areas characterized by moisture surpluses is questionable and is being investigated by ourselves. Leachate recycling as a pretreatment process, however, may be feasible.

8. SUMMARY

There are numerous factors affecting the rate of generation and the characteristics of leachate from a landfill. Although much work has been done on investigating the phenomenon of landfill leaching, there is still no means of predicting leachate characteristics on the basis of fill constituents. Furthermore, the behavior of leachate discharging from a landfill and migrating through the soil has only recently become subject to investigation. Eventually, there may be means available for predicting contaminant migration patterns and the resulting environmental impact of leachate discharges from a landfill as part of the site selection planning or approval process. In the meantime, the concern over leachate control continues. It may be that the soil's attenuation capabilities, at a properly located and operated site, may be sufficient to avoid costly leachate control and treatment.

The subjects of leachate detection and monitoring of landfills have not been discussed as part of this presentation. These topics are the subject of a series of round-table discussions being held by our Branch in an effort to develop recommended procedures documents based on a concensus of expert opinion. We have reported on leachate analysis techniques, and we will be following up with reports on ground water and soil sampling methods, and on procedures for the design and implementation of landfill monitoring programs.

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APPENDIX J

DESIGN CONSIDERATIONS IN CONSTRUCTING A SANITARY LANDFILL

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AND

H.F.MC ALPINE

DESIGN CONSIDERATIONS IN CONSTRUCTING A SANITARY LANDFILL

"A sanitary landfill is as much an engineering project as is construction of a building." (41) *

This synopsis is a consensus amongst landfill designers where usually the ultimate use of a completed landfill site demands minimal loading requirements; e.g. playgrounds and golf courses.

Where the ultimate use will require construction of buildings and services, sound, well-planned design engineering is obviously mandatory.

Density

In-situ densities of solid waste in a landfill at depth may vary from 500 to 1500 lb/yd^3. Moderate densities at depth of 750 to 1000 lb/yd^3 may be developed if good practice and moderate compactive energies are applied. Densities are also, however, greatly dependent upon the state of decomposition of refuse at the time of measurement and the waste-to-cover volume ratio. Maximization of density per se is the object,only to the extent that settlement of a fill be minimized.

Maximization of fill densities for given available machinery and their compactive energy is a function of the fill material's constituent types and the placement method. Amplification of density by increasing the waste-to-cover volume ratio should also be considered. Figure J-1 illustrates an accepted compaction procedure for fill density maximization. Materials of bulky and/or inert nature are spread and compacted with crawler tractor of compactive effort equivalent to D-8. Sufficient cohesionless cover material should be added as required in order to attain fill density and void ratio adequate for structural specifications. Low density refuse can then be placed in lifts of compacted thickness <1 ft. until desired cell depth is achieved. This first cell will be shaped in the form of a truncated pyramid where its five surfaces have been adequately covered for vector control and packed to encourage migration of fines into the fill. Cells can now be made as shown in the referred figure by working the sloping face of the original pyramid. Care must always be given by the site engineer that lifts are placed and compacted adequately. Although no method of filling will eliminate settlement of a landfill due to biological and chemical alteration of the refuse, the absolute value of this settlement can be minimized.

Settlement

Refuse will settle as the result of waste decomposition, filtering of fines, surcharge loads and the weight of the fill itself, decomposition and surcharging being the most effective or significant. The decompositional rate is greatly dependent upon the amount of moisture in the fill, the presence of sufficient nutrients for rapid and prolonged high levels of microbial activity, and on whether the decompositional processes are aerobic or anaerobic. In general, for comparable fills the aerobic fill settles faster than the anaerobic, and the wet

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* References listed in report bibliography.

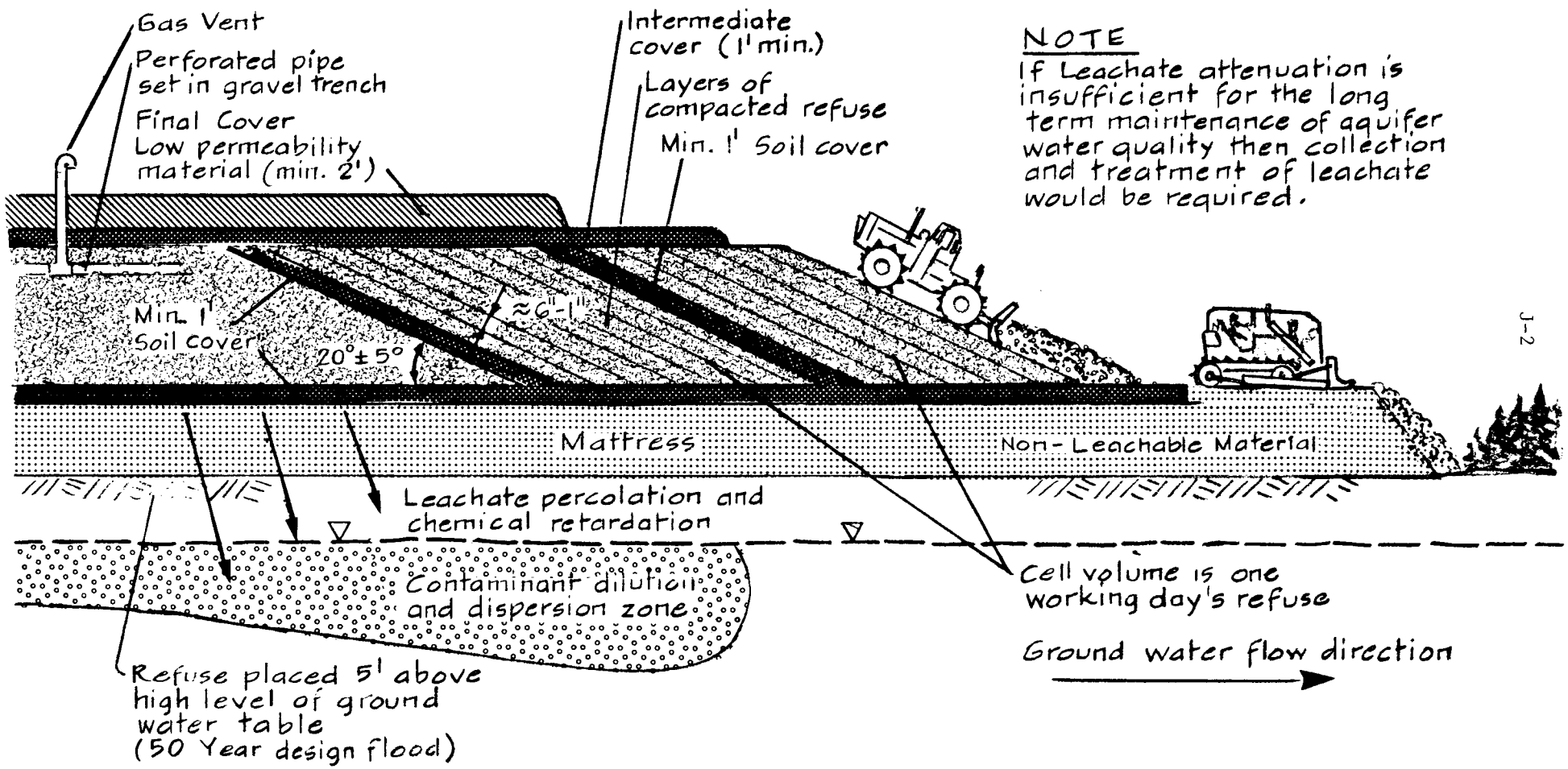

FIGURE J-1 MODEL LANDFILL

faster than the dry. Figure J-2 shows consolidation of similar refuse quantities under controlled moisture and water content. (42) In Seattle, which has about 30 inches of precipitation, a 20-ft. deep fill settled 4 ft. in the first year. However, a 75-ft. and 46-ft. fill settled only 2.3 and 1.3 ft., respectively, in 3 years in the drier climate of Los Angeles, where precipitation is about 15 inches.

Other factors in settlement are: the type of refuse and the waste-to-cover volume ratio. Total settlement can be in the order of 33%.

Settlement can cause cracks in cover material exposing the fill to rodents and flies, and may disrupt normal or planned gas venting routes. Depressions may develop where water collects and infiltrates the fill, increasing gas production and leachate volumes and possibly concentrations, and thus treatment costs if required. Settling of a landfill may disrupt underground utility services.

Bearing Capacity

Bearing capacity is the pound per square foot loading that can be supported by the surface in question. The ratio obtained, however, must be considered in relation to deformation of the surface as a result of this load.

Some investigators have stated that expected capacities are in the order of 500 to 800 lbs. per square foot. However, standard procedures for interpreting the results of solid waste bearing tests have not been fully developed and, as such, any values should be considered with extreme caution.

Most procedures for bearing capacity determination can only take into consideration the drained and undrained sheer strength. Solid waste has, in addition, the capability of varying its structure and composition through microbial decomposition and chemical dissolution. This makes results variable with time and location.

Gas

The decompositional activity within a refuse fill is dependent on several factors, such as permeability of earth cover, depth of fill, precipitation, degree of refuse compaction and refuse moisture content and putrescibility. Upon placement of the fill, rapid aerobic stabilization of the wastes begins; however, within a few weeks the atmospheric oxygen level within the fill drops to zero,and anaerobic decomposition begins with an associated marked drop in fill temperature. The microorganisms through many cycles of feeding and growth,breakdown the refuse through the action of their enzymes and putrescibles to gases and humus. The major gaseous end products of refuse decomposition are carbon dioxide (CO_2) and water for aerobic decomposition, and CO_2 and methane (CH_4), ammonia (NH_3), and hydrogen sulfide (H_2S) under anaerobic conditions.

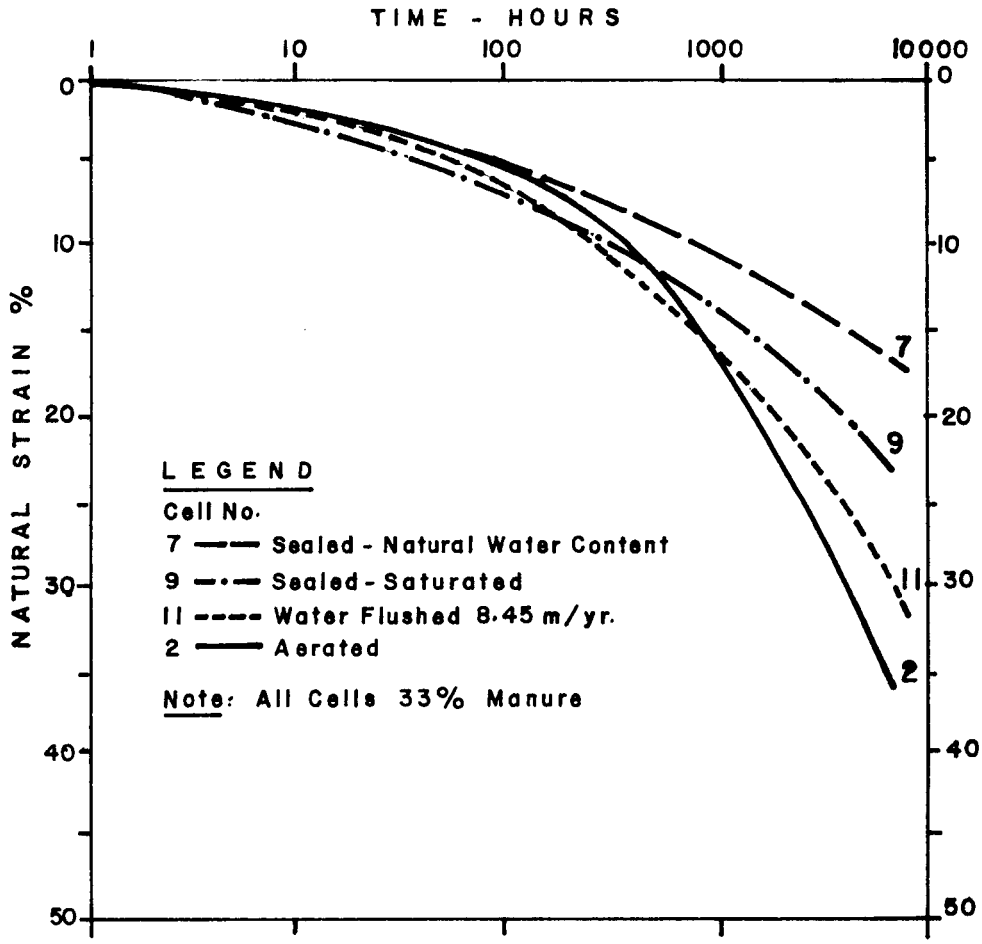

FIGURE J-2 SETTLEMENT OF A SOLID WASTE MIXTURE UNDER VARIOUS ENVIRONMENTAL CONDITIONS AFTER SANGRAY ET AL (42).

The length of time over which decomposition occurs depends greatly on such factors as refuse composition, depth of fill, local climatic conditions and, possibly, on artificial stimuli like sprinkling of fill with water or recycled leachate, and forced ventilation to maintain aerobic conditions in the fill.

Without the latter, artificial stimuli decomposition and the associated gas production will normally continue for more than twenty years. Glass, plastic, and aluminum refuse in a fill will remain relatively unaltered for twenty years as will paper in some instances. Steel, most woods, cloth, and other organic wastes will, however, be partially or totally decomposed after this time. The ratio and degree of decomposition is governed by nutrient concentrations and availability.

Methane (CH_4), carbon dioxide (CO_2) are the principal gases produced in a landfill, and various sources indicate that maximum production of CO_2 is achieved within six months to two years, but the CH_4 production will increase slowly over several years. Gas generation estimates under fully efficient biological conditions have been estimated to be as high as 4 ft.^{3}/lb refuse (12), however actual production is normally considered to be in the range of 25 to 75% of the fully efficient state. Generally, CH_4 production is higher in wet fills and CO_2 production is lower. Masking of the true CO_2 production can occur in wet fills, because CO_2 is highly soluble in water and, as such, is rapidly taken away in the ground water in the form of carbonates and bicarbonates. The CH_4 and other gases produced, tend to rise through the porous fill and escape through the cover material, or, if impermeable, migrate horizontally to vents, structures, or in many cases to neighbouring lands.

Alone, methane is not explosive, but when it accumulates at concentrations in air of 5 to 15% it is explosive and is flammable at other concentrations. Beneath a landfill which is densely compacted and sealed, there is an absence of oxygen so there should be no danger of the fill exploding. However, if methane migrates through soil and collects in voids or into structures containing air, explosive conditions can result.

A further concern is that gas migration through the sides or the top of the fill may adversely affect plant life. Recent studies have shown that below-ground and above-ground migration of gases has led to vegetation kills. Underground gas migration is thought to cause anaerobic conditions in the root zone resulting in plant death, while above-ground gas movement is thought to kill plants due to traces of toxic ethylene gas.

The concern for gas migration is well documented and accordingly, landfill designers must be concerned with gas prior to the onset of landfilling. Several gas migration control works have been installed at landfills. For horizontal migration control, permeable perimeter gas collection trenches are used. These may include impermeable barriers and gravity or induced exhaust ventilation. Generalized schematics of perimeter gas collection methods are shown in Figure J-3.

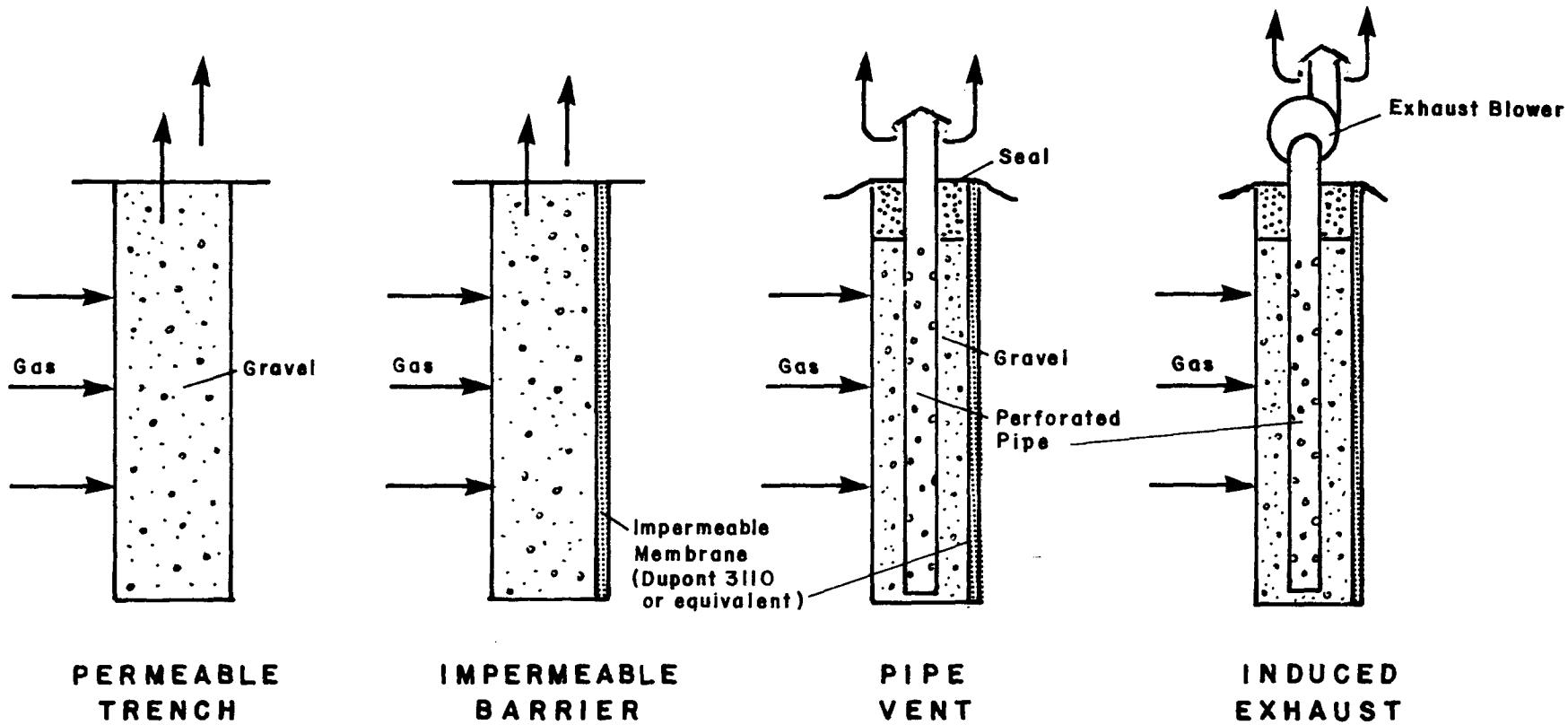

FIGURE J-3 GAS CONTROL SYSTEMS - SCHEMATIC

Gas protection works for buildings generally involve the installation of a porous subgrade which allows collection and venting of migrating gases. Figure J-4 illustrates such a system involving two lines of defence with a gas probe detection device placed between. This system is only suitable for slab on-grade constructin. Where buildings are placed directly on a refuse fill, considerable additional problems in maintaining the gas mat integrity, due to differential settlement, would have to be addressed. Further design complications will obviously be encountered when pilings are used, due to difficulty in sealing around the piles. In this case the incorporation of further lines of defence would be required. These might include construction of a membrane-sealed sub-structure with gas detection and positive ventilation.

With any construction at a landfill particular attention must be paid to possible gas leaks at construction joints and at locations of utility connections.

Corrosion

The environment within a decomposing landfill tends to be highly corrosive. Organic acids are produced from food, garden and paper wastes. Some weak acids are derived from ashes. Deposition of chemically active liquid wastes on the fill may further enhance corrosiveness of leachate. Severe pitting of unprotected and underground utilities, leachate drains, and building foundations may occur. Deterioration of concrete surfaces can occur, exposing reinforcing steel; failure of the footings or structure could ultimately occur.

Construction Considerations

The unique design factors of gas movement, corrosion, bearing capacity and settlement require a high degree of specialist foundation design and engineering to be carried out if any use is to be made of the completed landfill. Cost of design, construction and maintenance of all structures will normally be considerably higher than for similar structures located on well compacted earth fills or undisturbed soil.

One of the better plans for land use is the preplan method in which cell materials and fill placement method are coupled to the ultimate structural requirements. This often requires that islands of undisturbed soils be bypassed during excavation and landfilling. Alternatively some areas could be filled with rock and rubble and compacted to densities in line with structural design requirements. Stability of side slopes may be critical as refuse settles around these islands. Less adequate and certainly less aesthetic, is the possibility of excavating refuse and replacing it with structural fill. This method is expensive and could prove hazardous to workmen. The decomposing wastes emit a very putrid smell, and hydrogen sulphide, a toxic gas, may be present along with methane, an explosive gas. Problems of this nature increase with landfills of greater depth. Redeposition of excavated materials also poses a considerable problem.

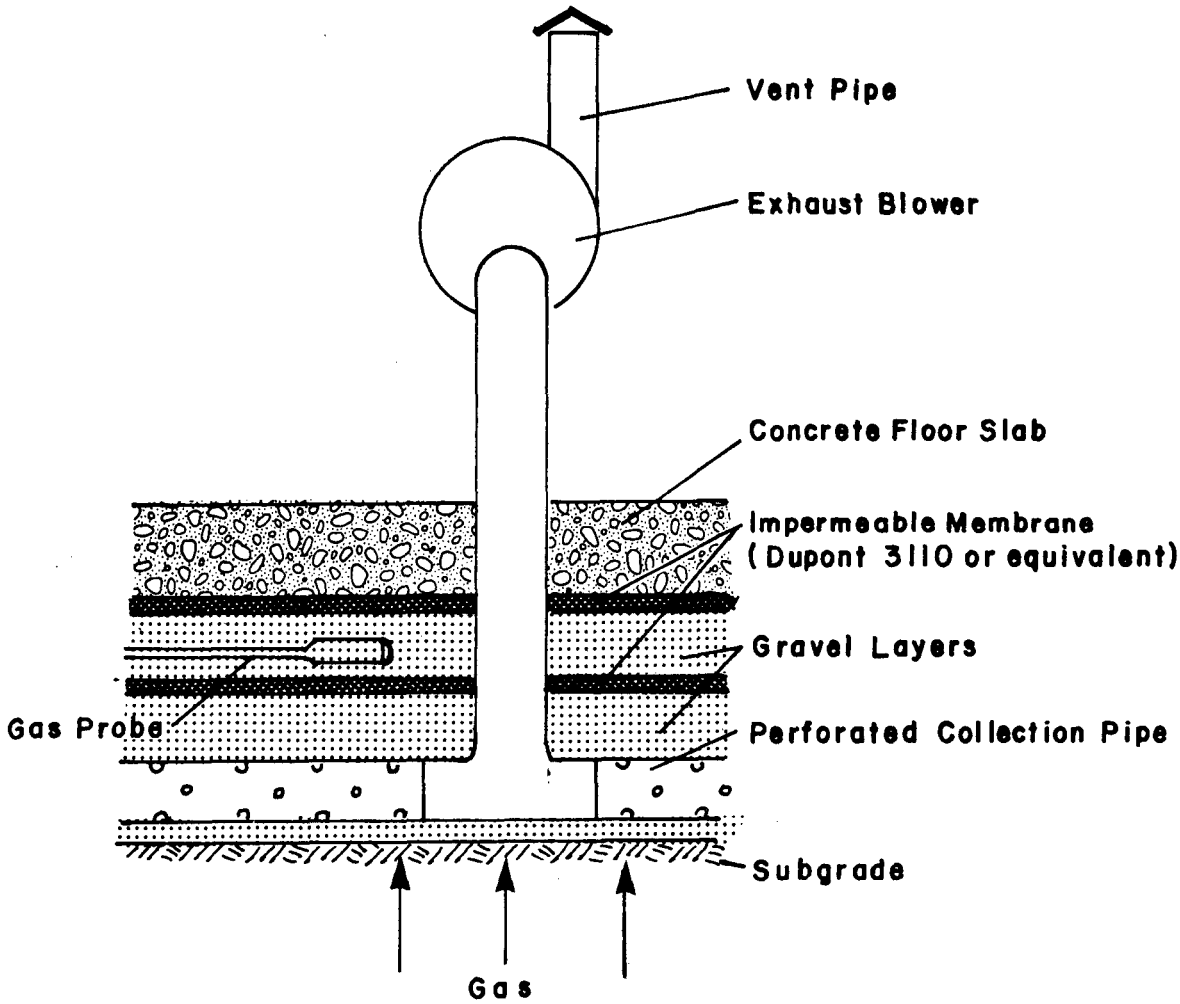

FIGURE J-4 GAS CONTROL SYSTEM (Slab on Grade)

Piles are often used to support structures above a completed landfill. Some piles should be battered to resist any lateral movement of the fill that may result as the fill settles or compresses under nearby surface loads. Pile driving costs may escalate if insufficient attention is paid to refuse material sizing during the fill placement, as piles cannot be easily driven through concrete slabs, large timbers, tangles of cables or reinforcing steel or large metal objects. The extent to which consolidating materials of a landfill can affect the bearing capacity of a pile has not, to-date, been well documented. Reversal of skin friction on the pile section within the refuse from positive to negative, is a design variable which cannot be overlooked. Piles in refuse also require corrosion protection.

All buildings on site must be designed to provide protection against gas and odor entrapment. It should be noted that even buildings constructed on the structural islands require gas protection.

In general, all light buildings that can be constructed on the landfill surface must be designed to withstand both uniform and differential settlement. Foundations should be reinforced to bridge gaps that occur because of differential settling of the fill. Continuous floor slabs reinforced as mats could be used. Doors, windows and partitions should be able to adapt to slight differential settlements. The infrastructure will be required to accommodate differential settlement, thus flexible and easily repairable materials should be used, regardless of the increased costs throughout the site. Breaks in water and sewerage services may also cause problems due to localized settlement. Building utility connections must be made gas proof if they enter structures below grade. In general, unless on-site relief is significant and no possibility of low points exist as a result of settlement, gravity type service systems should not be attempted.

Records

Complete records should be kept of weights, volumes, types of materials and areal and vertical distribution for the entire time of site operations. This comprehensive fill information will allow design engineers to best utilize the structural capability of the completed fill. It is considered desirable to have a competent engineer to supervise and direct all filling and placement procedures.

APPENDIX K

LEACHATE TREATMENT

PREPARED BY

R.D.CAMERON

Leachate Treatment - Richmond Landfill

Terms of Reference and Objectives

The terms of reference provided for effluent quality suitable for discharge were largely based upon Tables 5-1 and 5-2 of the Province of British Columbia "Pollution Control Objectives for Municipal Type Waste Discharges". As the dilution ratio provided by the Fraser River for the estimated flow of 1.5 Imgd (7×10^6 ℓ/day) is greater than 2000:1 the figure for BOD_5 in the effluent has been increased to 100 mg/l from 45 mg/l. The resulting design criteria are shown in Table I.

Five major items must be brought out here.

(1) The terms total and dissolved will not be used in subsequent discussion as all contaminants will be considered to be total measurements. This contention is supported by the figures provided for total and non-filterable residues which show essentially no suspended solids.

(2) Tables 5-1 and 5-2 in the Provincial Government Objectives do not apply to leachate discharge. Table 5-3 "Receiving Water Quality Maintenance Objectives" (Appendix A) are indicated in Section 3.2.2 as being the appropriate objectives. There are two reasons for using Tables 5-1 and 5-2. Firstly, in order to assess leachate treatment requirements, some numbers are necessary and these are not provided in Table 5-3. Secondly, it is understood that at least one landfill in British Columbia is being required by the Pollution Control Branch to meet the objectives in Tables 5-1 and 5-2.

(3) While again this section is not applicable to landfill leachates, Section 5.4.1 of the Objectives stipulates that an environmental assessment study will be required if discharge exceeds one million gallons per day. This point is only mentioned to create awareness that there is concern about the potential for environmental damage when discharges exceed 1 Mgd.

(4) The standards given in Table I are, according to Section 5.1 of the Municipal Objectives, not to be exceeded. Thus, the values shown for per cent reduction would have to be increased somewhat to provide for normal variation in effluent quality. With the inherent assumptions being made about the quality of leachate, this refinement is considered unnecessary.

(5) Section 5.8 and Appendix 2 to Table 5-1 of the Municipal Objectives appear to allow the use of an outfall (with consequent dilution) to meet the required objectives in Table 5-3.

Table I - Leachate Treatment Design Criteria

Parameter	Expected Range	Influent Design	B.C. Effluent Standards	% Reduction Required
COD mg/l	200-2000	1500		
*BOD_5 mg/l		750	100	87
Total Residue mg/l	1300-5000	4000		
Non filterable residue mg/l	0-200	200	60	70
Spec. cond. µS/cm.	2000-8000	7000		
pH	6-7.5	6-7.5	6.5-8.5	
Alkalinity mg/l as $CaCO_3$	500-2000	1700		
Hardness mg/l as $CaCO_3$	500-1500	1500		
Inorganic Carbon mg/l	150-500	400		
Organic Carbon mg/l	30-400	300		
NH_3-N mg/l N	5-70	45	Not abnormally high	
Cl mg/l	400-2000	2000		
SO_4 (Dissolved) mg/l	10-250	200	50	75
B (Dissolved) mg/l	1-5	5	5.0	0
Cr (Total) mg/l	<0.02-0.1	0.1	0.1	0
Fe (Dissolved) mg/l	2-60	50	0.3	99.4
Pb (Total) mg/l	<0.02-0.1	0.1	0.05	95
Mn (Dissolved) mg/l	1.0-5.0	5.0	0.05	99
Ni (Dissolved) mg/l	<0.05-0.1	0.1	0.3	0
Zn (Total) mg/l	0.02-1.5	1.25	0.5	60
PCB µg/l	nil-30	20		
96 hr TLm % $^V/_V$	18-60%	20%	Non toxic	80

* Estimate using $BOD_{5/COD} = 0.5$ and $\frac{TOC}{BOD_5} = 0.4$

Treatment Systems

(a) Primary Treatment (Sedimentation)

With very little suspended material sedimentation would have little effect on this leachate.

(b) Biological Treatment

(i) Aerobic

Several modifications are available here. Conventional oxidation ponds and facultative lagoons would be unacceptable as the high organic load would soon generate anaerobic conditions. Virtually all of the various modifications of the conventional activated sludge process would suffer failure. Boyle and Ham[1], Cook and Foree[2], and Uloth[3] have all found that a minimum of five days detention time is necessary to avoid failure. Other reports show that while failure at the conventional detention times of two to twelve hours did not occur, BOD removal was not significant. Of the aerobic biological systems, only the aerated lagoon has met with success and has been able to achieve significant BOD removal. One other possibility which has been attempted is feeding leachate to an existing biological treatment system. Boyle and Ham[1] found they could add up to 5% by volume of a high strength (COD = 20,000 mg/l) waste to an extended aeration system. While effluent quality was not deteriorated up to this percentage, poor settleability and high oxygen uptake rates were noted at additions exceeding 2%. The authors also expressed concern that conventional activated sludge plants would not accept these percentages of leachate addition.

Aerated lagoon treatability studies have been carried out by a variety of researchers. A full scale lagoon in England is effective in reducing BOD by about 94%. Laboratory studies show efficiency of COD removal ranging from 58 to 99 per cent at detention times ranging from 5 to 10 days. Only one study has indicated the fate of heavy metals in aerated lagoons. This study[3] showed effective reduction of Al, Cd, Cr and Ni to below acceptable levels at 20 and 30 day detention times. Acceptable levels of As, Cd, Pb and Mn could not be met and 45 days detention and 60 days detention were required to meet the Zn and Fe standards respectively. These results were achieved by settling the biological floc in a sedimentation basin after aeration. No significant toxicity to microorganisms has been reported after initial acclimation.

(ii) Anaerobic

Anaerobic lagoons would not likely achieve any significant BOD removal as virtually all organics are in the dissolved form so that no settling would occur.

Anaerobic digestion has been found to be successful for leachate treatment as quoted by Chian and De Walle[4]. COD removal efficiencies were reported to range from 92 to 99% at 7 to 15 day detention times. Poorman and Cameron[5] achieved 82 to 98½% BOD removal with 5 to 20 day detention times respectively and had no difficulty with toxicity after initial acclimation. The lowest effluent BOD in the latter studies was 188 mg/l which exceeds acceptable standards. While anaerobic digestion treatment facilities would normally only be used for a high strength leachate (>5000 mg/l) the latter studies showed effective metal removal in the settled effluent. The metals exceeding acceptable values were Fe, Mn, Pb and Zn.

Combined anaerobic-aerobic treatment has been found to require 1 to 7 days aeration following anaerobic digestion to achieve COD removals of 17 to 40%. Aeration following anaerobic digestion does not therefore appear practical.

(c) Chemical Treatment

A broad variety of chemicals have been used to treat leachates. Some of these are summarized in reports by Chian and de Walle[4] and Cameron[6]. The chemicals used include:

(i) Precipitants and Coagulants

Lime, ferric chloride, sodium hydroxide and alum have met with only nominal success in COD or BOD removal. As might be expected however, precipitation of iron, manganese, zinc and lead have been achieved albeit at fairly substantial chemical dosages. One of the most extensive studies as far as metal removal is concerned, reported by Cameron and Corbett[7], achieved adequate removal of Mn, Zn and Pb but insufficient removal of Fe at 2000 mg/l of $Ca(OH)_2$ followed by 200 mg/l of $FeCl_3$. Toxicity in this case was only modestly reduced.

(ii) Oxidants

Potassium permanganate, chlorine, sodium hypochlorite and ozone have been used. The reported results, again at high dosages, show 20 to 70% COD removal and 91 to 100% Fe removal. No other metal removal values were reported.

(iii) Polyelectrolytes

Only two references to the use of polyelectrolytes have been found. In each case little success was met in leachate treatment.

(d) Physical Treatment

(i) Adsorption

Activated carbon treatment of leachates has been reported to remove from 34 to 85% of influent COD at dosages ranging from 10,000 mg/l to 160,000 mg/l in both batch and column systems. Pohland[8] achieved COD removals ranging from 50 to 90% at dosages ranging from 500 mg/l to 10,000 mg/l respectively. This particular powdered activated carbon however, increased both specific conductance and total dissolved solids as leaching of carbon particles occurred. Up to 70% iron removal was achieved by Ho, Boyle and Ham[9].

No attempts have been found to treat raw leachate with either cation or anion exchange resins.

Peat has been reported as an effective leachate treatment material. Cameron and Corbett[7] found that British Columbia effluent objectives could be met using 159 Kg of dry peat per 1000 ℓ of low strength (COD = 650 mg/l) leachate. Manganese was found to be the limiting parameter. Some desorption of adsorbed contaminants occurred when the peat used for treatment was exposed to applications of tap water.

Nordstedt, et al[10] applied leachate to sandy pasture land. BOD and total solids removals were 70% and 57% respectively. While the crop to which the leachate was applied was more lush than a control crop, build up of CaO, MgO and P_2O_5 in the soil indicates that heavy metal accumulations may occur.

(ii) Reverse Osmosis

Chian and de Walle[4] report removals of 56 to 89% COD using a cellulose acetate membrane. The improvement in COD removal was accomplished by raising leachate pH from 5.5 to 8.0. Total dissolved solids removals as high as 99% were achieved but severe membrane fouling occurred. Although not reported in this study, reverse osmosis is known to be effective in metal removal.

(e) Combined Treatment

As illustrated by the preceding, no one system provides satisfactory treatment for all of the leachate parameters. This has led several researchers to examine the possibilities for combined treatment systems. The systems generally found to be the most successful are the biological aerobic or anaerobic systems followed by either carbon adsorption, ion exchange or reverse osmosis. A summary of the various researchers findings follows.

1. Chian and de Walle[4]. Anaerobic digestion or aerated lagoon treatment followed by either reverse osmosis or activated carbon.

2. Pohland[8]. Aerated lagoon treatment followed by carbon adsorption, cation exchange and anion exchange.

3. Cook and Foree[2]. Aerated lagoon treatment followed by carbon adsorption.

One manufacturer of package treatment systems, Met-Pro Water Treatment Corp. (Appendix B) advertises a leachate treatment system comprising

(1) Equalize and aerate

(2) Chemical addition - Flash mix 100 to 10,000 mg/1 $Ca(OH)_2$.

(3) Flocculation

(4) Sedimentation

(5) Activated carbon

(6) Pressure filtration - anthracite on graded sand at 50 psig.

(7) Break point chlorination

(8) pH adjustment

(9) Dechlorination

Reported Results - Landfill Leachate
Steps (1) through (6) only

Parameter	Influent	Effluent	% Removal
pH	7.8	8.8	
Alkalinity mg/1	1080	280	74
Sulfate mg/1	20	20	0
Specific conductivity	220	1300	490% Increase
BOD_5 mg/1	235	3.8	98
Total Iron "	7.1	1.09	85
Susp. solids "	140	40	71
Nitrite N "	2.0	2.0	0
Nitrate N "	4.6	1.6	65
Ammonia N "	43.5	4.3	90
Chloride	400	400	0

Correspondence with this company brought the reply that "... the effluent standards outlined in your letter could be met..." "... we do not manufacture systems capable of handling a leachate flow of 1.8 US mgd." The package systems advertised will apparently handle up to 250,000 US gpd. No costs were provided. One report from Pennsylvania where a package plant is treating 75,000 US gpd shows removal for BOD of 75% for iron of 99½% and for NH_3-N of 52%. The plant is reported to operate poorly under surge flows and that an equalization basin is desirable.

(f) Leachate Recycle

Experimental work by Pohland[8] and Cameron[11], shows that recycling of leachate back through the landfill enhances biological activity within the fill. The increased biological activity is effective in reducing the amount of organic material (BOD) which would normally be discharged from the fill through biological conversion of the organics to gases and water. Biological uptake, chemical precipitation and adsorption on the refuse are the mechanisms thought to be effective in reducing the masses of metals which are discharged from the fill. It is not known whether or not adsorbed or chemically precipitated metals within the fill will eventually be discharged once recycle stops. Ongoing research at the University of British Columbia will provide insight into this aspect. A major problem with leachate recycle is the hydraulic aspect. In high rainfall areas, leachate recycle could probably only be practised during the dry season. In the rainy season, the volume of leachate to be handled would become unmanageable after some period of time.

(g) Landfill Operation Modifications

Treatment of the landfill in some fashion to increase leachate pH and consequently to chemically precipitate metals has been practised. The techniques which have been tried in experimental studies include, (1) addition of limestone (2) addition of primary sewage sludge (3) addition of waste activated sludge and (4) addition of septic tank pumpings. Streng[12] indicates that he added limestone to municipal refuse but does not include any data in his report. Streng also added sewage sludge to the refuse in different proportions. He reports that increasing concentrations of sewage sludge increase the concentrations of organic material and metals in the leachate.

Stone[13] reports that addition of septic tank pumpings or sewage sludge is effective in reducing the quantity of BOD discharged in the leachate. Emcon Associates[14] report that addition of septic tank pumpings to refuse is not beneficial to leachate quality. Small scale test cells set up by Cameron[15] have provided preliminary evidence that the addition of septic tank pumpings is effective in significantly reducing concentrations of organics and metals under low (15" per year) rainfall conditions. Under higher (45" per year) rainfall conditions this effect was not as pronounced. This research is at an early stage so that a determination of the total masses of organics and metals which might be discharged from these test cells cannot yet be appraised. Previous work by Cameron[11] also indicated the beneficial effect on leachate of adding septic tank pumpings to municipal refuse.

While not the subject of a report nor of research, one operational modification is the utilization of demolition material as a base upon which to place refuse. Experience with the City of Vancouver's Burn's Bog landfill indicates that this procedure can aid in reducing leachate strength. Leachate from municipal refuse generally has a low pH. If demolition debris such as concrete, plaster and dry wall material is exposed to this acidic leachate, it is felt that Ca or Mg oxides or hydroxides are readily extracted and that a pH increase then occurs. This pH increase is probably beneficial in two respects. First, it can help to chemically precipitate many metals and second, it can provide a better pH environment for biological activity with consequent reduction in organic discharge. This theory is supported by the low BOD ($\simeq$ 120 mg/1) and high pH (7.1-7.5) values in leachate from the Burn's Bog landfill. A potential problem exists here however. If considerable quantities of gypsum ($CaSO_4$) are present, formation of odorous H_2S may occur. At least one lower mainland landfill has had odour problems attributed to this.

Another operational modification involves the minimization of leachate formation. This may be accomplished by reducing the rate of entrance of water into the refuse. While other procedures are possible, the following is an outline of the techniques which might be used at the Richmond Landfill. A bentonite slurry trench might be excavated along the dike between the fill and the river, between the fill and the ditches passing through or around the fill and between the fill and any other area where groundwater might enter the fill. The method involves excavating a trench to a depth sufficient

to cut off a water table connection between the fill and surrounding ground and surface waters. As the trench is excavated, a slurry of bentonite clay and water is pumped into the trench so that the excavation is carried out through the slurry. This has the effect of mixing the soil particles with the bentonite and thus provides a virtually impervious trench. It is possible however, that chemical reactions between the bentonite and the leachate could occur and that the permeability of the seal would increase with time. This may not be all bad however as attenuation of leachate contaminants could occur during passage through the bentonite. In order to prevent the ingress of precipitation the fill would have to be covered with an impermeable membrane. While earth membranes can be used, they are generally not initially impermeable and tend to become more permeable with time due to differential settlement and cracking. Synthetic liners such as PVC, Hypalon, Neoprene, CPE and butyl rubber have and are being used for this purpose. Permanent maintenance of these liners is, of course, necessary to maintain the integrity of such a liner. In addition, careful design of a gas collection and venting system would be necessary. Even if water infiltration into the fill might be completely prevented, the fill would have sufficient moisture to allow the continuation of anaerobic decomposition and consequent production of methane gas for many years. It should be noted here that carrying out any part of the program outlined could have a significant effect on reducing the quantity of leachate flow. The ramifications of this are discussed in subsequent sections.

Another operational modification, which, while of little benefit in the short term, would help to reduce the length of time required for leachate treatment, would be to (1) stop adding semi-solid wastes to the fill and/or (2) stop adding refuse to the fill. Some alternative disposal site would then have to be found which could be designed to minimize or treat leachate right from the start. The leachate from the existing fill would then begin to improve in qualtiy with no more refuse being added.

Feasibility of Treatment Methods - Summary

1. Sedimentation.

Not feasible as virtually no settleable materials.

2. Oxidation ponds, facultative lagoons.

Not feasible as high BOD would create anaerobic conditions and consequent odors.

3. Anaerobic lagoons.

With most organics in the dissolved form no sedimentation would occur. A large pond area would be required and odor problems would likely be severe.

4. Anaerobic filter.

Insufficient work has been done on this type of system to make a recommendation in its favor.

5. Conventional activated sludge.

Sufficient research has been done to indicate that this system would fail rapidly. Variation in hydraulic loading would require an equalization pond as well.

6. Extended aeration.

The commonly used detention time of 24 hours would lead to system failure.

7. Anaerobic digestion.

The sensitivity of this process to upset precludes its serious consideration. In addition, the leachate strength is too low, capital and operating costs are high, incomplete treatment would likely result and a large physical plant (plus foundations) would be required.

8. Adding leachate to an existing sewer system.

This would merely move the problem from one place on the Fraser River to another. While some chemical precipitation of metals might occur because of possible increased pH when mixed with sewage, no significant reduction in leachate strength would occur in the existing primary sewage treatment plants in the Lower Mainland.

9. Chemical Treatment.

Chemically treating raw leachate has been found to be unsuccessful and therefore cannot be considered. It is possible, but not likely, that some form of chemical treatment could be used as a polishing treatment following another type of treatment system. If manganese, for example, were found to exceed the required effluent concentration after biological treatment, then

pH adjustment with lime or sodium hydroxide might be used to chemically precipitate the manganese. The use of chemicals would have to be assessed on the basis of effluent quality from the first stage system and therefore can neither be predicted nor recommended at this time.

10. Land spreading.

The possibility of a significant metal accumulation in soils as well as the extensive land areas required plus the attendant odor problems preclude consideration of this method.

11. Peat adsorption.

A minimum of 15,000 m^3 of peat per day would be required. This is about twelve acre feet per day which is not considered practical. If the discharge rate of leachate were reduced 100 or 1000 times then peat treatment might become an attractive possibility.

12. Leachate recycle.

The winter rains would create hydraulic problems so that this method could not be recommended for winter time. It could however, be used during the summer. This could help to reduce the operating cost of whatever other treatment system is utilized as this system would not have to be operated during the summer. The reduction in leachate BOD due to recycle could also reduce the size of a biological treatment system. Another possibility would be to utilize peat as a cover material and recycle the leachate through the peat cover and the refuse. Leachate recycle, however, is not a likely possibility due to the land use plans for this site. It should be noted here that leachate recycle would likely have the advantage of more rapid stabilization of the refuse. This would then reduce the time over which significant gas production and rapid site settlement would occur.

13. Package Treatment Systems.

The package treatment system outlined on page 6 of this report cannot be recommended. Even if the leachate flow from the landfill were reduced to a value low enough to be handled by the package unit, it would be necessary to carry out pilot studies on the leachate itself to determine the efficiency of the system. Examination of the process steps and the findings of researchers treating leachate leads to the conclusion that requisite metal removals would not be achieved using this system.

14. Aerobic Lagoons.

For removal of organics from this leachate, an aerobic lagoon system is seen as the best option. With proper control of detention time the goal of 87% BOD removal is not unrealistic. With a properly designed sedimentation basin following aerobic treatment fairly significant removal of metals would also be found. The metal removal would not likely be sufficient to meet the standards established so that a polishing treatment would be required.

15. Activated Carbon (Polishing)

Most of the residual suspended and dissolved organics following aerobic treatment would be removed. Metal removal however would not likely be sufficient to meet the standards. PCB removal would also occur.

16. Reverse Osmosis or Ultra filtration (Polishing)

Reverse osmosis can achieve metal removals sufficient to meet standards. The major drawbacks to the process are membrane fouling from dissolved and suspended organics and the lack of research which has been carried out on other than a pilot scale basis. The problem with organics can be overcome by pretreating to remove most of the organics.

17. Ion exchange resins (Polishing)

Cation exchange will remove metals in order of decreasing valence. Pohland[8] found that an 80% reduction in total dissolved solids could be achieved at 25 gm/l and a one hour contact time. About the same removal was achieved at 10 gm/l using a mixed cation-anion exchange bed. At this treatment level calcium, nitrate and sulfate were reduced to essentially zero.

General Conclusions

To achieve the per cent reductions outlined in Table I a two or three stage treatment system is visualized. The first stage would comprise an aerated lagoon followed by or including a settling area. Based upon Uloth's[3] work the effluent from this system would probably contain sufficient quantities of metals (notably Fe, Mn, Pb, As, Cd and Zn) which would require further treatment.

The next step would likely have to be activated carbon adsorption. This stage is considered to be necessary to reduce the organics to the point where the subsequent treatment step would not be fouled by these organics. The effluent BOD following this step would likely be well below the most stringent B.C. standard of 20 mg/l. PCB's might also be reduced.

The last stage would be either ultrafiltration (reverse osmosis) or mixed cation-anion exchange. The final effluent from either of these systems would likely meet all of the requirements outlined in Table I.

Costs of Treatment

Very little information is available regarding leachate treatment costs. The following figures have been taken from a variety of literature sources (16, 17, 18, 19, 20, 21, 22) and generally apply to treatment of conventional wastes. The most confidence can be placed in the figures for aerated lagoons as several of the literature sources produced similar results. The figures for activated carbon are also thought to be reasonably reliable. The reverse osmosis costs come from a single source(16) and are based upon pilot studies for spiral wound systems. Tubular or hollow fine fiber systems may have different costs. The ion exchange costs are the least reliable as very little information was found for these systems. The information given, from two sources (16, 17), is based upon projected costs from pilot plant studies. The costs however are felt to be reasonably indicative for comparison purposes.

All costs have been brought to June 1974 (the latest readily available EPA-STP index date). Generally, capital costs have been amortized over 25 years at 8%. Power costs quoted were usually about two cents per Kwh. No attempt has been made to allow for extra foundation costs which will likely be encountered at the Richmond site. No land acquisition costs have been included.

Aerated Lagoon Costs*

	140,000 Igpd	500,000 Igpd	1,000,000 Igpd
Area req'd - acres	5	10	15
Total capital cost - $	64,000	121,000	185,000
Annual O & M cost - $	9,000	14,000	18,000
Total cost - ¢/1000 gal	31	14	10

* Including embankment protection (concrete), and settling.

Activated Carbon*

	140,000 Igpd	500,000 Igpd	1,000,000 Igpd
Total cost - ¢/1000 gal.	120	63	45

* Includes regeneration and make up carbon.

Reverse Osmosis*

	140,000 Igpd	500,000 Igpd	1,000,000 Igpd
Total cost ¢/1000 gal	72	63	59
Capital cost ¢/1000 gal			12

* Includes cleaning and membrane replacement.

Ion Exchange*

	140,000 Igpd	500,000 Igpd	1,000,000 Igpd
Total cost ¢/1000 gal.			66

* Includes regeneration and makeup. Costs for smaller plants could not be found.

For a complete system including aerated lagoons, activated carbon and reverse osmosis the cost figures are as follows.

	140,000 Igpd	500,000 Igpd	1,000,000 Igpd
Total cost ¢/1000 gal	223	140	114
Annual cost - $	114,000	255,000	416,000

These costs were derived from the literature and represent figures for the types of concentrations which are given in Table I. The cost figures for the reduced flow rates are therefore somewhat misleading. If it is assumed that, for a given mass of refuse, a fixed percentage of materials will be leached, then reducing the rate of flow will result in one of two things or (more likely) a combination of both. Either the concentrations will increase in the leachate in direct proportion to the reduction in flow, or, the length of time over which leachate will be produced will be increased. If the concentrations are increased then capital and operating costs will increase. If concentrations remain the same, then the treatment system will have to be operated over a longer period of time. If it is assumed for case number one that the concentrations increase in inverse proportion to the flow and that costs increase in direct proportion to the concentration and, if it is assumed for case number two that the length of time required for treatment is in inverse proportion to flow, a picture can be developed. First it is necessary to start at a common base which for this argument, is the cost for the 1 million gallon per day plant. Second, it is assumed that the scale

factor for smaller plants will still continue to hold. For example, for the 500,000 gpd plant for case number one the total cost would be

$$\frac{1000,000}{500,000} \times 140 = 280¢/1,000 \text{ gal.}$$

Third, the period required for treatment is 15 years for the 1 MIGD plant.

The following table extends this example.

		140,000 Igpd	500,000 Igpd	1,000,000 Igpd
Case One	Total cost ¢/1000 gal	1592	280	114
	Annual cost $	814,000	511,000	416,000
	Total cost (15 yr. @ 8%)	$22 million	$14 million	$11 million
Case Two	Total cost ¢/1000 gal	223	140	114
	Annual cost $	114,000	255,000	416,000
	Years required to treat	107	30	15
	Total cost @ 8%	$5,000 million	$29 million	$11 million

This argument is not valid for the biodegradable organic material in the landfill as essentially free treatment is provided within the landfill itself. Thus, for case two the total costs would be reduced somewhat for the low flows as it is difficult to visualize much in the way of organic material remaining after 30 or 107 years. This must be tempered by the realization that the cost of treating the organics represents only 8.8 to 13.9% of the total cost of the treatment system outlined. In case one it is unlikely that costs would be directly proportional to concentration. Even if the unit treatment costs were reduced in direct relation to the increased unit costs attributed to the scale factor, the total cost would be the same for each flow rate. Another factor, reported by Cameron[11] is that increasing flow through the landfill up to a point increases biological activity. Thus the total cost in case one for the greater flow rates might be somewhat lower because of the "free" treatment of organics in the fill.

The figures presented are definitely extremes. They do however serve to point out that considerable thought should be applied to the costs of attempting to reduce leachate flow rates and the value obtained by so doing.

It will be noted that ion exchange has not been included in the preceding system. This is because, (1) little information is available, (2) the costs appear to be higher than reverse osmosis costs and (3) the literature indicates more operational problems for ion exchange than for reverse osmosis.

If a treatment system such as the one outlined is to be considered it is recommended that laboratory scale experiments be set up first, using the leachate from the landfill to determine aeration and settling basin sizes and air requirements. Before any attempt is made to include the advanced treatment techniques, bench scale experiments should be set up to test the treatability of the effluent from the aeration basins using activated carbon and reverse osmosis. A very careful appraisal of the cost effectiveness of these systems should however, be undertaken. This is exemplified by considering the following table which is generated from Table I.

Table II
Solids Analysis

	Average of Range	mg/l	Spec. Conductance (Calculated) μS/cm
Alkalinity mg/l as $CaCO_3$	1250	1525 (HCO_3^-)	1090
Hardness mg/l as $CaCO_3$	1000	400 (Ca^{++})	840
Chloride mg/l	1200	1200	2568
$SO_4^=$ mg/l	130	130	200
Total		3255	4698
Average Values from Table I of Total Dissolved Solids		3050	
Specific Conductance			5000

It can be seen that virtually all of the dissolved constituents which would be removed by a reverse osmosis unit are those for which no standards have been set (except $SO_4^=$) and for which there is little environmental concern. The reverse osmosis unit therefore would be removing generally very low concentrations of the metals of concern at very significant cost especially when it is remembered that the purpose of the activated carbon unit is basically to improve the efficiency of the reverse osmosis system. It is possible that the aerated lagoon treatment alone would reduce most effluent metal concentrations to near acceptable levels which is all the more reason to very carefuly appraise and test any treatment system selected.

As previously discussed, isolation of part or all of the landfill from groundwater flow is possible. If a decision is made to use methods similar to those previously outlined, the services of a competent geohydrologist and soils engineer should be obtained. Evaluation of the possibility of chemical reactions between the leachate and bentonite type soils as well as attenuation of contaminants by such soils would have to be carried out probably in a manner similar to that described by Griffin et al.[23]

The use of a synthetic membrane to prevent surface water infiltration is not considered appropriate at the Richmond landfill because of the uses to which the landfill is to be put. Using a relatively impermeable clay, properly sloped, as a final cover could reduce surface infiltration significantly. This however, would have to be assessed considering ultimate land use, leachate treatment costs and gas control. No recommendation is therefore made in this regard.

One aspect which has not yet been discussed is that of sludge disposal. From any treatment system, sludge will be generated which will contain most of the undesirable characteristics of the wastewater treated, although in more concentrated and modified form. This material has to be put somewhere. If treatment is practised to prevent the contaminants from entering a receiving water, then it is not reasonable to place the sludge in that receiving water. (This argument is not valid for purely organic wastes where the object is to reduce oxygen demand and toxicity). The sludge therefore should be placed on the land. If it is placed back on the landfill in its relatively wet form then further leaching of contaminants would occur to some extent. While this leachate quality might be better than the original leachate quality because of attenuation in the landfill it is not possible to guarantee that it would meet the standards. The advantage of this method of recycle (placing sludge on the landfill) compared with direct leachate recycle, is that the increase in liquid flow rate would be substantially reduced but at considerable cost.

To reduce leaching and to further reduce the hydraulic load if sludge is reapplied to the landfill, dewatering using centrifugation or vacuum filtration might be considered. A rough estimate of the sludge characteristics before and after dewatering follows.

Assuming 1 Mgd flow and 75% of total residue goes to sludge, sludge will contain 30,000 lb/day solids.

If sludge total solids concentration is 5% then volume of sludge ≈ 60,000 gal/day of which about 57,000 gal/day is water.

If dewatering increases sludge total solids to 30% and solids capture efficiency is 80% then sludge volume ≈ 8,000 gal/day of which about 5,600 gal/day is water; virtually none of which will flow from the sludge by gravity drainage.

Dewatered sludge would therefore not be expected to significantly contribute to an increase in leachate volume if placed on the landfill. Non-dewatered sludge on the other hand would increase leachate volume through gravity drainage. If 50% of the water in the sludge were free to contribute to leachate flow then it would take about $\frac{1,000,000}{0.5 \times 57,000} = 35$ days for the flow of leachate to double. While these figures are only rough guesses, it is reasonable to expect that problems with hydraulic overload of the treatment plant would arise if non-dewatered sludge were placed back on the landfill. Costs for a centrifuge or vacuum filter to handle the solids volume of 60,000 gal/day would be about:

Capital - $275,000

O & M)
Chemicals & materials) $30,000 - $100,000/yr.

The chemical and operating cost figures can be misleading as chemical costs can vary dramatically depending upon the nature of the sludge. The figures used however, are felt to provide a representative (although not all encompassing) range.

A further step which might be considered is sludge incineration. This step is not considered necessary as further volume reduction and liquid removal from dewatered sludge solids is felt to be unwarranted under the previously outlined conditions. Should consideration be given to incineration however, the following are rough costs covering both multiple hearth and fluidized bed systems.

Capital - $400,000 - $850,000

Operating - $80,000 - $175,000/yr.

It should be pointed out here that an incineration unit located at the landfill could be used for burning some of the toxic and hazardous wastes which are apparently being brought to the landfill. This is especially true for PCB's as they would not be expected to be degraded significantly in the biological treatment systems. The Federal Register[24] indicates high temperature incineration as being the first choice for PCB disposal. Another consideration is that heat from the incinerator could be utilized to generate steam which could be used to re-activate the activated charcoal which might be part of a treatment system. A charge could also be levied for hazardous waste incineration. As with the other systems outlined for leachate treatment and disposal, a careful analysis would have to be performed to determine proper sizing and actual need for incineration facilities.

The preceding outline of treatment systems has emphasized the need for a careful analysis of what the purpose of treatment is and what goals are to be achieved. It is felt worthwhile to briefly outline some waste treatment perspectives to re-emphasize this point.

Recycling leachate back to the landfill whether before or after treatment will reduce BOD and possibly some PCB. Aerobic treatment will reduce BOD. BOD reduction would also occur if the wastes were discharged into the Fraser River.

Advanced waste treatment techniques serve to concentrate contaminants within sludges. Without the use of incineration (which would tend to form insoluble metal oxides), so-called sludge disposal techniques will likely place the sludge in a location where further contaminant leaching could occur. The magnitude of this leaching in terms of the per cent of material which might be permanently bound up in the sludge or in the landfill (using recycle) is not possible to predict at this time. If all of the contaminants were leached then the advanced waste treatment systems would have served no purpose as eventually the contaminants would be discharged to a receiving water. Placement of sludges in an encapsulated fill is felt to be merely postponing the problem.

While perhaps not considered by some as an environmentally satisfactory solution to the "problem", provision has been made in the current British Columbia Pollution Control Objectives to utilize a portion of the "assimilative capacity" of receiving waters. As outlined in the first page of this report, dilution into the Fraser River appears to be acceptable. Consideration could therefore be given to this method of "waste treatment". If this is done, the "assimilative capacity" of the receiving water must also be considered. For readily biodegradable organics, the "assimilative capacity" of a receiving water can be defined in terms of a reduction in dissolved oxygen concentration. For persistent organics (PCB and DDT, for example) and for inorganic toxicants,a definition of "assimilative capacity" is virtually impossible. These materials may become diluted and dispersed to undetectably low levels or they may become permanently adsorbed by suspended particles and eventually settle to the bottom. As the Japanese have learned however, whether dispersed or settled, these materials may well accumulate in the food chain and lead to human illness and death. In such cases, there is no "assimilative capacity". If consideration is given to a continuation or utilization of raw leachate discharge, the potential long term toxic effects must be given serious consideration.

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APPENDIX A

B.C. Receiving Water Quality Objectives

TABLE 5-3
Receiving Water Quality Maintenance Objectives(1)*

Parameter	Objective
Dissolved Oxygen	Decrease not to exceed 10%
Residual Chlorine	Below detectable limits (amperometric method)
Nutrients	No detectable increase in site-specific productivity-limiting parameters (2) (5)
Coliforms—receiving waters	(3)
—shellfish meat	(3)
Toxicity	No increase above background (4)
Settleable Solids	Negligible increase
Floatable Solids and Scum	Negligible increase
Oil	None visible on water surface
Organisms	No change in productivity or development of nuisance conditions (5)
Heavy Metals	Negligible increase

* Bracketed numbers refer to Appendix to Table 5-3 which follows.

APPENDIX TO TABLE 5-3
Explanatory Notes

1. These objectives are for the maintenance of background receiving water quality, generally expressed in terms of the maximum allowable change for specified parameters. They are not applicable within the initial dilution zone as defined in this document. Other discharges may be taken into account in determining whether the allowable maximum change is to be less than any value given. Other parameters may be added by the Director.

2. Limiting parameters will normally be taken as phosphates and/or nitrogen forms.

3. In general, total coliform levels are not to exceed a median MPN of 1000/100 ml or a fecal coliform median MPN of 200/100 ml and in shellfish waters are not to exceed a fecal coliform median MPN of 14/100 ml and shellfish meats may not show a fecal coliform level greater than MPN of 230 per 100 gm. reference may be made to B.C. Health Branch "Recommended Water Quality Standards" and the "National Shellfish Sanitation Program Manual of Operation" published by the U.S. Department of Health, Education and Welfare.

4. As measured in a 96 hour TL_m static bioassay test.

5. Productivity refers to biological parameters which are not amenable to tabulation; however, the following nuisance conditions are typical of those to be considered:

   In freshwater lakes, presence of: 1) massive growths of planktonic bluegreen algae (Cyanophyceae) for more than several days duration; 2) massive growths of attached, filamentous diatoms (Bacillariophyceae) and/or rooted aquatic plants especially near the shoreline.

   In rivers and streams, presence of massive growths of attached green algae (Chlorophyceae), filamentous diatoms (Bacillariophyceae) and/or rooted aquatic plants, slime-forming bacteria (as *Sphaerotilus*), sludge worms (Tubificidae) or chironomids (Chironomidae).

   At sea or in estuaries, presence of sludge beds with reduced species diversity and a restricted range of predominant organisms such as *Capitella capitata*.

APPENDIX B

Package Leachate Treatment System

news release

FROM: MET-PRO SYSTEMS DIVISION OF
MET-PRO WATER TREATMENT CORPORATION, LANSDALE, PA.

New self-contained, factory built wastes treatment plant successfully treats LEACHATE, the seepage from sanitary landfills, trash and garbage dumps, that is up to 100 times more polluted than raw sewage.

Met-Pro Systems Division of Met-Pro Water Treatment Corporation, Lansdale, Pennsylvania, announces the first successful and commercially available leachate treatment plant of its kind, the Series 12000 self-contained, factory built independent Physical-Chemical system.

Leachate is the very highly polluted seepage that results when surface waters percolate through the compacted layers of decomposing refuse/garbage and soil, making up a sanitary landfill. It is not unusual that the pollution concentration (BOD) of streams affected by leachate is ten to twenty times that of raw sewage, even far downstream from the point that the leachate entered the stream. Full strength leachate can have 100 times or more pollution than raw sewage. It is a major pollution factor, in both municipalities and industries.

The Met-Pro system includes chemical flocculation and settling, followed by adsorption in upflow fluidized beds of activated carbon and then filtration. The effluent will be chlorinated for disinfection and also to reduce the nitrogen concentration in the treated wastewater, which can be discharged to the receiving stream with no ill effects.

The skid mounted equipment package is furnished completely assembled, including all piping, wiring, controls, chemical feed equipment and finish painting.

A 105,000 gpd unit is being installed in Nockamixon Township, Bucks County, Pa. at the Hidden Valley Sanitary Landfill.

Contractor: Pollution Control Construction Co., Danboro, Pa.
Consulting Engineer: Paul X Blattler, Levittown, Pa.
Authorized and approved by the Bucks County Commissioners and the Pennsylvania Department of Environmental Resources
Facility scheduled to be in operation by mid-summer, 1973

For additional information contact:
MET-PRO SYSTEMS DIVISION
MET-PRO WATER TREATMENT CORPORATION
Fifth Street & Mitchell Avenue
Lansdale, Pa. 19446 (215) 368-1671

Photo of Series 12000 Leachate Treating System and copy of WWT-1 accompany this news release.