REMEDIAL INVESTIGATION

AND

FEASIBILITY STUDY

FOR THE

GORICK C & D LANDFILL

KIRKWOOD (T), BROOME (C), NEW YORK

VOLUME II FEASIBILITY STUDY

NYSDEC SITE NO. 7-04-019
WORK ASSIGNMENT NO. D002340-5

Prepared for:

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GORICK C&D LANDFILL FEASIBILITY STUDY (FS)

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8. IDENTIFICATION OF GENERAL RESPONSE ACTIONS

8.1 Purpose and Organization of Report

The purpose of this Feasibility Study (FS) is to identify and develop remedial alternatives which, based on the potential risks identified in the Remedial Investigation (RI), are protective of human health and the environment. These alternatives will then be evaluated, both with respect to federal Superfund criteria and with each other, prior to selection of a preferred alternative.

This report is organized as follows:

Section 8 provides a summary of information developed from the RI. This information is necessary to develop site-specific remedial action objectives and potentially applicable remedial alternatives. Remedial action objectives, as well as general response actions to satisfy these objectives, are presented in this section for each medium of interest.

Section 9 presents potentially applicable remedial technologies which are identified and screened. This screening eliminates those technologies and process options not technically feasible, and allows, where possible, for the selection of a single process representative of each technology. The discussions on the post-screening technology evaluations performed in support of the screened remedial alternatives are presented in this section. Feasible technologies are combined in this section into remedial alternatives for use in meeting the remedial action objectives for the site.

Section 10 presents a detailed analysis of the alternatives passing the initial screen, a comparative evaluation of these alternatives, and the selection of the best remedy for the site.

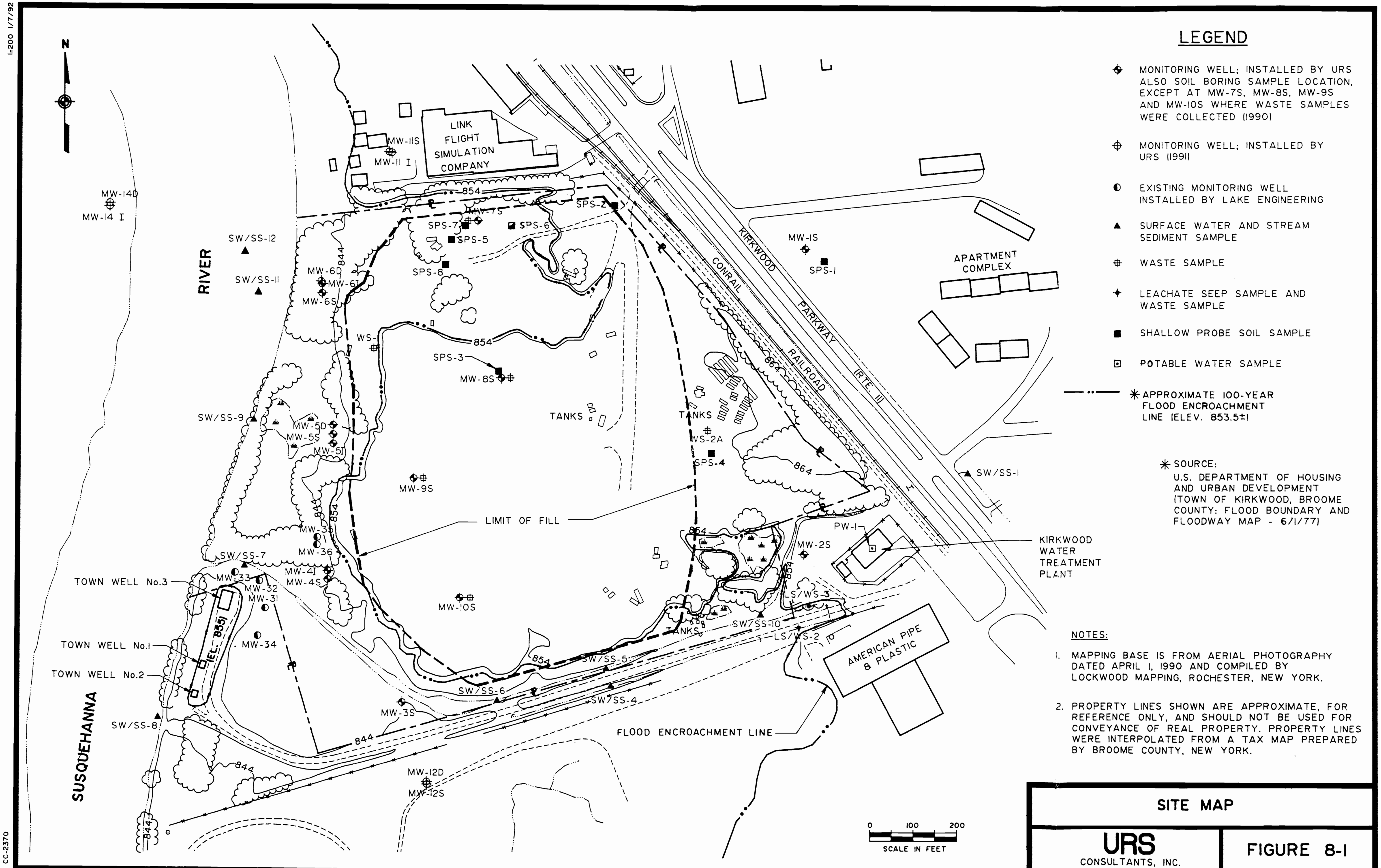
Section 11 describes a conceptual design for the selected remedial alternative and presents a preliminary cost estimate for remediation. Appendix S (in which groundwater modeling calculations are discussed) is an integral part of this FS.

8.2 Remedial Investigation Summary

Sections 1 through 7 of this report, found in Volume 1, present the results of the RI conducted at the Gorick C&D Landfill site. The purpose of the RI was to collect data and to characterize the site in sufficient detail as to allow an identification and evaluation of remedial alternatives in the Feasibility Study (FS). The site background and key findings of the RI, upon which the FS is based, are as follows:

- o The Gorick C&D Landfill (Figure 8-1) is an approximately 35-acre inactive landfill in the Town of Kirkwood, Broome County, New York. The site lies approximately 5 miles southeast of Binghamton, off Route 11, near Fivemile Point. Site stratigraphy consists of fill or floodplain deposits overlying a highly productive valley-fill aquifer (sands and gravels) which in turn overlies a thick till deposit. The fill is mostly construction and demolition debris. Quantities of a "foundry-sand-like" material, however, were found in various places. The sand and gravel aquifer has a hydraulic conductivity of 10^{-2} cm/sec and ranges in thickness from zero on the east side of the site to approximately 60 feet near the Susquehanna River. The till unit underlying the sand and gravel aquifer appears to prevent significant downward migration of groundwater.

- o The findings of the groundwater analysis have been presented in detail in the RI report. Significant groundwater contamination was encountered beneath the fill and


LEGEND
MONITORING WELL; INSTALLED BY URS ALSO SOIL BORING SAMPLE LOCATION, EXCEPT AT MW-7S, MW-8S, MW-9S AND MW-10S WHERE WASTE SAMPLES WERE COLLECTED (1990)
MONITORING WELL; INSTALLED BY URS (1991)
EXISTING MONITORING WELL INSTALLED BY LAKE ENGINEERING
SURFACE WATER AND STREAM SEDIMENT SAMPLE
WASTE SAMPLE
LEACHATE SEEP SAMPLE AND WASTE SAMPLE
SHALLOW PROBE SOIL SAMPLE
POTABLE WATER SAMPLE
* APPROXIMATE 100-YEAR FLOOD ENCROACHMENT LINE (ELEV. 853.5±)
* SOURCE:
U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT (TOWN OF KIRKWOOD, BROOME COUNTY: FLOOD BOUNDARY AND FLOODWAY MAP - 6/1/77)
NOTES:
1. MAPPING BASE IS FROM AERIAL PHOTOGRAPHY DATED APRIL 1, 1990 AND COMPILED BY LOCKWOOD MAPPING, ROCHESTER, NEW YORK.
2. PROPERTY LINES SHOWN ARE APPROXIMATE, FOR REFERENCE ONLY, AND SHOULD NOT BE USED FOR CONVEYANCE OF REAL PROPERTY. PROPERTY LINES WERE INTERPOLATED FROM A TAX MAP PREPARED BY BROOME COUNTY, NEW YORK.
N
SUSQUEHANNA RIVER
LINK FLIGHT SIMULATION COMPANY
KIRKWOOD PARKWAY (RTE. 11)
CONRAIL RAILROAD
APARTMENT COMPLEX
KIRKWOOD WATER TREATMENT PLANT
AMERICAN PIPE & PLASTIC
LIMIT OF FILL
FLOOD ENCROACHMENT LINE
TOWN WELL No.3
TOWN WELL No.1
TOWN WELL No.2
(EL. 855)
TANKS
MW-14D
MW-14 I
MW-11S
MW-11 I
MW-7S
MW-6D
MW-6I
MW-6S
MW-8S
MW-5D
MW-5S
MW-5I
MW-9S
MW-35
MW-36
MW-4I
MW-4S
MW-33
MW-32
MW-31
MW-34
MW-10S
MW-3S
MW-12D
MW-12S
MW-1S
MW-2S
PW-1
SPS-1
SPS-2
SPS-3
SPS-4
SPS-5
SPS-6
SPS-7
SPS-8
WS-1
WS-2A
SW/SS-1
SW/SS-4
SW/SS-5
SW/SS-6
SW/SS-7
SW/SS-8
SW/SS-9
SW/SS-10
SW/SS-11
SW/SS-12
LS/WS-2
LS/WS-3
844
854
864
0 100 200
SCALE IN FEET
SITE MAP
URS CONSULTANTS, INC.
FIGURE 8-1
1=200 1/7/92
CC-2370

downgradient of the landfill. The nature of this contamination has been given in detail in Section 7 of the RI report.

- Generalized groundwater flow in the area is from east of the site towards the Susquehanna River. Superposed on this flow is the cone of depression formed by the combined pumping of the Town of Kirkwood's well field and the constant 150 and 190 gpm withdrawal by a nearby industrial well (American Pipe and Plastic). These wells form a sink for most of the groundwater in the area. The source of much of this water is induced infiltration from the Susquehanna River.

- Due to pumping withdrawals by the Town of Kirkwood and the American Pipe and Plastic plant, the Susquehanna River does not receive groundwater flow from much of the site for much of the year. Instead, induced infiltration causes the river water to flow through the ground towards the site. The exception is the northwest portion of the site, from approximately MW-6S north, where the flow is from the site to the river for at least part of the year. However, because of the low gradients, groundwater inflows to the river are not thought to be large.

- The waste in the landfill is inadequately covered, and the surface soils are generally contaminated with polycyclic aromatic hydrocarbons (PAHs).

8.2.1 Media of Concern

Prior to the determination of remedial action objectives or general response actions, the media of concern at the site must be determined. Media of concern are those media which have been found during the RI to contain elevated levels of contaminants and therefore pose a threat to human health or the environment. Each of the media at the Gorick C&D Landfill site is discussed below.

8.2.1.1 Soil/Fill

No PCBs were found in soils at the site. VOCs were not detected in any waste samples, except those from MW-7S, and in two samples collected from test pits. However, the areal distribution of the VOCs detected in the groundwater samples indicates that the fill is the source of VOC contamination. Presuming the fill to be the source of groundwater contamination, contaminants are being flushed out of the fill probably both from above and from below. From above, precipitation is infiltrating the waste and flushing contaminants downward. From below, the periodic rise and fall of the water table (due largely to radical changes in river level) is flushing out contaminants in a sort of "tea bag" action. Flushing from below may even be the principal mechanism of groundwater contamination at this site.

Surficial soil is considered to pose a certain degree of risk, however small, to humans and the environment. Consideration will be given to methods of mitigating this risk, although the risk is considered to be small enough that such mitigation might be undertaken as a part of the landfill closure rather than as a part of any site remedial action.

8.2.1.2 Groundwater

Based upon the analytical data presented in Section 5 of the RI report, groundwater flowing through and beneath the site becomes contaminated. As a result of local soil characteristics, the contaminated groundwater is affecting the aquifer used for the Town of Kirkwood water supply. Groundwater from the northwest portion of the site also flows into the river for at least part of the year. The analytes found to exceed Standards, Criteria, and Guidance Values (SCGs) in groundwater are VOCs (primarily trichloroethylene and dichloroethylene) and metals (primarily iron and manganese).

Groundwater remediation efforts, therefore, should address all contamination that is attributable to the site and that affects the quality of the aquifer.

8.2.1.3 Surface Water

The RI showed contamination of surface water by VOCs and semivolatiles to be minor. Treatment of this medium will therefore not be considered further.

8.2.1.4 Sediments

Cleanup criteria for selected contaminants found in the sediments of the drainage stream and the Susquehanna River have been developed in accordance with NYSDEC Division of Fish and Wildlife Guidance. The criteria are based upon the degree to which a sediment will give up non-polar organic contaminants to its porewater and thereby impact the surface water. Levels of contaminants found in sediments are well below the cleanup criteria developed (Table 5-4 of the RI report). Sediment contamination therefore will not be considered further.

8.2.1.5 Air

No air sampling was conducted at the site, with the exception of real-time ambient air monitoring using a photoionization detector (PID). No readings above background levels were found for VOCs at any point on site. A soil gas survey of samples collected 2 to 5 feet below the ground surface also showed no significant concentrations of methane or other VOCs at the site. Since no evidence of airborne contamination has been found, remediation of this medium is not necessary.

8.2.2 Extent of Remediation Required

The extent of remediation for the one medium of concern, namely groundwater, is determined by the extent of contamination. The source of contamination of this medium is primarily the fill, where evidence of industrial waste similar to foundry sand and grease was seen during the excavation of test pits and trenches, conducted as part of the RI. The medium requiring remediation therefore consists of the groundwater that flows through and beneath the landfill. The extent to which the contaminant plume has migrated has not yet been determined.

8.3 Remedial Action Objectives

The effectiveness of remedial efforts depends upon focusing on both the media and the contaminants of concern. Remedial action objectives are based on site-specific conditions such as contaminant types and media of concern, exposure pathways, and applicable or relevant and appropriate federal, state, and local requirements (namely, SCGs). The major objectives of this FS will be the reduction of elevated concentrations of contaminants in the aquifer and the prevention of contaminated groundwater from entering the Susquehanna River. The contaminants of primary concern are VOCs, primarily trichloroethylene (TCE) and dichloroethylene (DCE).

The carcinogenic risk posed by human ingestion of untreated contaminated groundwater is considered significant. The contaminants that are almost entirely responsible for the high carcinogenic risk are TCE and 1,2-DCE. Therefore, the primary remedial action objectives for the Gorick C&D Landfill site are as follows:

- o Reduce TCE and DCE concentrations in the groundwater to acceptable levels (class GA standards).

- o Prevent migration of groundwater contaminated with TCE and DCE through the northwest corner of the site into the Susquehanna River and the aquifer beneath it.

Because of the potentially significant health effects of dermal contact with site soils, prevention of human contact with these soils is considered a secondary remedial action objective.

8.4 General Response Actions

General response actions are, like remedial action objectives, medium-specific. These general response actions are actually categorical approaches to remediation, into which fit various specific technologies and process options. The following general response actions have been identified for groundwater, the medium of concern at this site: no action; institutional action; containment; and collection and treatment.

Applicable remedial technologies and process options for the general response actions are identified and screened in Section 9.

General USEPA requirements demand that at least one alternative from each of the following categories be evaluated according to the document: "Guidance for Conducting RI/FS Under CERCLA," October 1988.

1) No-action alternative.

2) Treatment or disposal in an offsite facility.

3) An alternative that meets all New York State Standards Criteria, and Guidance Values (SCGs) and all health or environmental standards.

4) An alternative that exceeds all SCGs and all health or environmental standards.

5) An alternative that reduces the present and future threat from hazardous substances, but that does not necessarily achieve all SCGs.

8.5 New York State Standards, Criteria, and Guidance Values (SCGs)

New York State Standards, Criteria, and Guidance Values (SCGs) considered for the site are discussed in Section 5 of the RI. SCGs are divided into the following categories:

- o Chemical-Specific Requirements - Health or risk-based concentration limits or ranges in the various environmental media for specific chemicals. These limits may take the form of cleanup levels, discharge levels, and/or maximum intake levels, such as for a public water supply.

- o Action-Specific Requirements - Controls or restrictions on particular types of remedial activities, such as hazardous waste management or wastewater treatment.

- o Location-Specific Requirements - Restrictions on remedial activities that are based on the characteristics of a site or its immediate environment, such as restrictions on wetlands development.

8.5.1 Chemical-Specific Requirements

The standards identified for the protection of water quality are listed in Table 5-2 of the RI. New York State ambient groundwater standards for chemicals on the Target Compound List (TCL) have been taken from NYSDEC's "Water Quality Regulations for Surface Waters and Groundwaters" (6NYCRR Parts 700-705), September 1, 1991.

No chemical standards are applicable to soil or fill except for the tests to determine whether any fill must be characterized as hazardous waste. In New York State, either the EP Toxicity test or the Toxicity Characteristic Leaching Procedure (TCLP) may be employed to determine whether a given waste is hazardous. [TCLP has replaced EP Toxicity at the federal level (40 CFR Part 261) but NYSDEC has not yet promulgated this rule.] For purposes of actual disposal, as opposed to characterization, TCLP must be used in all states, including New York.

8.5.2 Action-Specific Requirements

Action-specific SCGs pertaining to remedial technologies at the Gorick C&D Landfill site define the regulatory framework within which the technologies may be developed and executed.

Federal regulations that must be considered in technology screening include CERCLA and its amendments under SARA, the Federal Clean Air Act and its amendments, the Clean Water Act and its amendments, and RCRA Subtitle C (40 CFR 264).

Another action-specific requirement includes discharge limitations applicable to groundwater treatment technologies. The New York State

Pollution Discharge Elimination System (NYSPDES) provides for permitted discharges based on ambient water quality standards for classified streams. Discharges to a Publicly Owned Treatment Works (POTW) must not include pollutants which: create a fire or explosion hazard; cause corrosive damage; obstruct flow; or increase the temperature of wastewater so as to cause interference with the treatment plant. Discharge must also comply with local POTW pretreatment programs (40CFR 403.5 and local POTW Regulations). Groundwater monitoring requirements are covered in 40 CFR 264 Subpart F. Containment options must comply with or at least be defined in reference to 6NYCRR Part 360.

8.5.3 <u>Location-Specific Requirements</u>

A portion of the site is located in a 100-year floodplain. Executive order 11988 of May 24, 1977, and amendments, require that, during federal remedial actions, alternatives be considered that avoid adverse effects to 100-year floodplains, or that minimize potential harm within the floodplain. Floodplain boundaries are shown in Figure 8-1. In any alternatives developed for this site, the effect of encroachment upon the floodplain must be considered and such alternatives must include actions to minimize this impact.

9. IDENTIFICATION/SCREENING OF TECHNOLOGY TYPES AND PROCESS OPTIONS

9.1 Identification of Remedial Technologies

The purpose of this section is to identify remedial technologies that are potentially suited for treating groundwater at the Gorick C&D Landfill site, based primarily on effectiveness, but also upon implementability and cost. Remedial technologies have been selected for each environmental medium and general response action, as presented in Table 9-1. Corresponding process options for each remedial technology are also presented.

Based on the general response actions developed for the site in Section 8.4, the following technologies/process options have been identified.

9.1.1 No Action (Existing Remedial Measures in Place)

"No action" is included as required by the National Contingency Plan. This "technology" represents the continuation of existing conditions at the site. Interim Remedial Measures (namely air stripping and monitoring of the water supply by NYSDEC and the Town of Kirkwood) are already in place at this site, and will remain in place. The No Action alternative will therefore be understood as being equivalent to No Further Action. This alternative would not address the source of the groundwater contamination at the site nor prevent the offsite migration of contaminated groundwater. However, it would include a continuation of the Interim Remedial Measures (IRMs) described below.

The key component of the IRM for the site was the installation of an air stripper to protect the town of Kirkwood water supply. This air stripper is dedicated to Town Well #3 and is capable of achieving 98.5

TABLE 9-1

TECHNOLOGY SCREENING SUMMARY

ENVIRONMENTAL MEDIA	REMEDIAL ACTION OBJECTIVES	GENERAL RESPONSE ACTIONS	REMEDIAL TECHNOLOGIES	PROCESS OPTIONS
Groundwater	Reduction of Contaminants in Groundwater and Prevention of their Migration to the River / Aquifer	No Further Action	No Further Action	No Further Action
		Institutional Action	Institutional Action	Deed Restrictions
				Long-term Monitoring
		Containment	Capping	6 NYCRR Part 360 Cap
				6 NYCRR Modified Part 360 Cap
			Vertical Barriers	Slurry Walls/Sheet Pile Walls
				Partial Slurry Walls/Sheet Pile Walls
		Collection and Treatment	Extraction	Extraction Wells
				Interceptor Trenches
			Onsite Treatment with Onsite Discharge	Specific Process Options, with Discharge to River
				Specific Process Options, with Recharging into Aquifer
			Offsite Treatment with Offsite Discharge	Specific Process Options, with Discharge to POTW
				Discharge Contracted to Commercial Facility
Surface Soils	Prevention of Human Contact	No Action	No Action	No Action
		Institutional Action	Deed Restrictions	6 NYCRR Part 360 Cap
		Containment	Capping	6 NYCRR Modified Part 360 Cap

TABLE31.WK1/DMc

percent removal of trichloroethylene (TCE) from raw water containing up to 100 ppb of TCE. The operating requirements of the air stripper are:

A. Water flow rate: 1,000 gpm

B. Average water temperature: 50^{o}F

C. Minimum water temperature: 40^{o}F

D. Minimum air temperature: -15^{o}F

9.1.2 <u>Institutional Action</u>

With institutional action, or non-remedial action by local government, the use of groundwater from this area might be severely restricted or prohibited by passage of appropriate local laws or enactment of codes. Deed restrictions might be imposed. Existing and possibly new monitoring wells might be used to track the migration of contaminated groundwater and to provide a long-term data base on the extent and nature of groundwater contamination. Institutional action in the form of site monitoring will be a part of any alternative selected.

9.1.3 <u>Containment</u>

Containment technologies for this site consist of capping and vertical barrier technologies.

9.1.3.1 <u>Capping</u>

Capping is a well developed and reliable technology for landfill closure. Wastes are covered so as to prevent their exposure at the surface. Percolation of surface water is minimized by the enhancement of runoff. Capping is a primary component of any containment alternative. At the Gorick Landfill site it would meet the following objectives:

- Reduction of infiltration through the fill area due to precipitation. The poorly covered and graded fill area presently allows contaminants to be leached from the waste into the groundwater.

- Reduction or elimination of contaminants in the surface water runoff from the fill area. The surface water runoff at present flows into the Susquehanna River either directly or through the drainage ditch south of the site.

- Elimination of direct human contact with contaminated surficial soil in the fill area. Potential health risks due to dermal contact and ingestion of contaminated soil/fill would be reduced or eliminated.

All capping options include grading, vegetative cover, and surface water drainage provisions. Typical landfill cap components include an impermeable horizontal barrier layer, drainage layer, and vegetated topsoil layer.

The major differences in cap design are in the types and thicknesses of the materials in each layer. Both soil and synthetic materials have been used as barrier layers in landfill caps. Typical soil materials include natural clay or a clay-bentonite mixture compacted to achieve a permeability of 1×10^{-7} cm/sec or less. Soil barrier layers offer the advantage of puncture resistance due to the thickness of the layer, and the ability to settle slightly while still maintaining integrity. The disadvantages of soil materials are that their availability is limited in some regions, they must be compacted in place under tightly controlled conditions, and extensive QA/QC testing is required to ensure compliance with the permeability specification.

Synthetic barrier layers (flexible membrane liners, or FMLs) may be composed of a variety of materials, including high-density polyethylene (HDPE), very low density polyethylene (VLDPE), polyvinyl chloride (PVC), chlorinated polyethylene, and chlorosulfonated polyethylene (CSPE or Hypalon). The materials range in thickness from 20 mils (0.020 inches) to 100 mils. Advantages of FMLs include their relative ease of installation, elimination of a soil layer within the cap, and their availability. The main disadvantages include their susceptibility to puncture or tear, and their limited applicability on sideslopes.

Cap construction at this site would be regulated by 6NYCRR Part 360. General components of the cap, as well as permissible variances from recommended cap design, are covered by this regulation.

Construction of a Part 360 or Modified Part 360 cap would be greatly complicated at this site by the need to construct a portion of the cap on the 100-year floodplain of the Susquehanna River. In addition to the difficulty of obtaining permits for such construction, the question of cap effectiveness arises, since, during a flood event, groundwater may be expected to rise beneath the cap, carrying off contaminants by "tea bag" action. In short, a cap at this site would do little to stop the contamination of groundwater by contaminated soil or fill. Despite these probable difficulties, because of its common use in the remediation of hazardous waste sites, the capping option will be carried through to later stages of analysis.

9.1.3.2 Subsurface Vertical Barriers

Commonly used technologies for subsurface vertical barriers are the cutoff steel sheetpile wall or slurry wall. Sheetpile and slurry wall vertical barriers are normally viable options for controlling movement of groundwater. A low-permeability, cutoff slurry wall is an effective way to keep contaminants from migrating off site. This is usually achieved by digging trenches and filling them with a clay-bentonite slurry to act as a barrier. A number of factors at the Gorick C&D Landfill make the slurry wall option impractical for this site. Among these are:

- The instability of the surficial sand and gravel unit;
- The depth to which excavation would have to be carried to key the wall into till;
- The necessity of constructing part of the subsurface barrier within a floodplain; and
- Excessive cost.

Costs would be relatively high because of the need to excavate a pilot trench in loose soil, and to backfill and compact it prior to slurry wall construction. Moreover, special guide wall construction may be necessary during slurry wall construction because of the poor quality of site soils.

As for sheetpile, driving through the sand and gravel to required depths beneath the site would be difficult, and sheet piling is, in fact, seldom used as a cutoff wall in a sandy and gravel aquifer. Among the usual problems associated with use of sheet piling in sandy soil (problems that would compromise sheet piling's effectiveness) are the following:

- Deflection of piles during driving.
- Interlocks loose enough to be driven, resulting in joints not being watertight once in place.
- Need to use relatively heavy and costly z-type piles for deep driving.

For these reasons, no further consideration will be given to vertical barriers of either kind.

9.1.4 Groundwater Extraction and Treatment

Extraction of contaminated groundwater from the aquifer is a remedial technology used in combination with treatment technologies to control/remove contaminants present in groundwater. Extraction of groundwater is generally accomplished by one of two methods. One method is to install collection wells at locations that will maximize groundwater withdrawal. Wells will be located so as to intercept contaminated groundwater between the fill and the river. A second common method for intercepting groundwater migrating from a site is a subsurface groundwater collection trench.

Once extracted, by whatever method, contaminated groundwater must be treated either on site or off site to meet the standards of the receiving body of water or treatment plant. [Treatment options will be for an unknown period. The exact duration will be determined by laboratory testing after the installation of the recommended alternative for the site.] Groundwater from the Gorick site might be reintroduced to the subsurface, discharged to a surface water body such as the Susquehanna River, or discharged to the local POTW. Each of these options entails different discharge limitations and may require complete, partial, or even no treatment of the groundwater. Depending upon the contaminants present, and the levels to which they must be removed, various treatment process options are available.

9.2 Screening of Remedial Technologies/Process Options

General response actions and applicable remedial technologies listed in Table 9-1 have been screened to eliminate those technologies that are not technically implementable at the site. A brief description of the technologies and process options that have survived initial screening is provided below. Technologies that have survived this screening will be incorporated into the development of remedial action alternatives. The evaluation of process options will be based primarily on effectiveness and implementability, with costs playing a minor role at this stage of the evaluation.

9.2.1 Containment

Due to the nature of past activities at the Gorick C&D Landfill site, the only containment option to be considered will be capping, and the only capping options are a Part 360 and a Modified Part 360 cap.

A New York State Part 360 cap consists of the following (from top to bottom):

- 6 inches of topsoil supporting erosion-preventing vegetation
- minimum 24-inch thick soil protection layer
- minimum 18-inch thick low-permeability layer (or synthetic barrier such as 40-mil thick HDPE)
- 12-inch gas-venting layer of sand or gravel

In order to reduce the cap thickness and to simplify construction, a Modified Part 360 cap might be considered. The gas venting layer in such a cap might consist of a synthetic fabric capable of performing the function of 12 inches of sand or gravel. For C&D landfills such as the Gorick site, however, where no gas problems are known or suspected, a gas venting layer will serve no purpose, and is therefore not required. The total thickness of this C&D landfill cap (when HDPE is used as the low-permeability layer) would be approximately 3 feet, including a 6-inch base material for the FML.

Variances to be sought would therefore include:

- o Absence of gas venting layer
- o Substitution of geonet for the gas venting layer.

With proper maintenance, the Part 360 cap, modified or not, would permanently and significantly decrease infiltration of water from the surface into the fill, thereby reducing leaching of contaminants from buried waste into groundwater. This type of cap would also provide long-lasting protection to human health and the environment against risks associated with contact with the contaminated soil and migration of hazardous substances. A Part 360 cap is an effective environmental control for landfills, and is thus considered a proven capping option.

On the other hand, there would be problems associated with such a cap at this site. For example, a considerable area of the landfill lies within the 100-year floodplain. A berm would therefore have to be constructed to prevent flood damage to the cap. To achieve this, per 6 NYCRR Part 360.14, a considerable amount of borrowed fill would be required. This will increase cost. No cap, moreover, would alter the "teabag" effect of rising and falling groundwater levels. Despite these drawbacks, however, because of the Part 360 cap's normal usefulness as a site remedial measure, this option will be carried forward for further evaluation.

9.2.2 Groundwater Extraction and Treatment

Groundwater withdrawal at the Gorick C&D Landfill site can be achieved by using withdrawal wells, subsurface collection trenches, or a combination of both. With this technology, contaminated groundwater can be extracted for onsite or offsite treatment and disposal.

9.2.2.1 Extraction

Wells

Wells can be installed in the unconsolidated sand and gravel deposits above the till. Hydrogeological evaluations might assist in the effort to identify optimal well locations. Because of its demonstrated effectiveness and wide acceptability, this technology will be evaluated further.

Interceptor Trenches

Groundwater interceptor trenches have been used instead of wells to extract groundwater in situations where groundwater is shallow or where the contaminated water lies in low-permeability soils. Use of this process option requires the presence of soils that can be excavated without the requirement of trench shoring. In view of the excessive depth of the aquifer (60-70 feet deep on the river side of the site), and because of the permeable soil conditions, extraction through the use of groundwater interceptor trenches is not considered to be as technically implementable as withdrawal wells and will not be considered further.

9.2.2.2 Onsite Treatment

Full treatment of extracted groundwater would be required if the groundwater discharged to the Susquehanna River had to meet Class A standards. The primary contaminants of concern in the groundwater are volatile organics. Many process options are available for the removal of organic contaminants, biological processes being among the most effective. Several of the contaminants present in the groundwater at the Gorick site are relatively unbiodegradable, however, and, under a full-treatment scenario, would require some other method of removal. Air stripping is one of the most common methods of removing volatile organic contaminants, and is therefore likely to be the treatment method of choice at this site.

Although volatile organics are the primary contaminants of concern, if Class A standards had to be met, metals removal would be required prior to disposal into the Susquehanna River. Metals such as iron, manganese, and magnesium exceed discharge limitations into the river, which is a Class A water body. This contamination has not migrated to the extent that the volatile organics have. Treatment of groundwater to remove these metals may be accomplished using a combination of precipitation/flocculation/sedimentation processes. However, these processes may not be capable of removing metals sufficiently to meet the discharge requirements. If such should be the case, an additional metals treatment step such as ultrafiltration or ion exchange may be required.

Thus the processes required for full treatment of groundwater prior to discharge to the river are expected to include air stripping and metals precipitation. Depending upon the effectiveness of these processes, and upon the effluent discharge requirements, additional polishing steps such as carbon adsorption or filtration may also be required.

Groundwater might also be treated on site without being discharged to the Susquehanna River, but rather being discharged back to the aquifer through the fill. In this case it is likely that treatment would not have to be as complete as if Class A standards had to be met, since discharged water would be subject to retreatment. Under this process option, a recharge pond--outside the boundary of the 100-year floodplain--would be constructed to receive discharged water that would then be allowed to percolate into the fill upgradient of the extraction wells. It would be re-extracted and re-treated. As in the river-discharge option, treatment would likely consist of air stripping but without the addition of a metals-removal step.

The above cycle of operation will continue until groundwater meets Class GA standards.

Since treatment capacity is known to be available in the Town of Kirkwood stripping facilities, it is at least theoretically possible that use could be made of these facilities for groundwater remediation. Contact with the Town, however, has shown this to be infeasible, since all pumping facilities, whether in actual use or not, are required by the Town to be available for its usage at any time.

9.2.2.3 Offsite Treatment

If contaminated groundwater were to be discharged to either a POTW or to a commercial facility for further treatment, full onsite treatment would not be required. Discharge to a commercial hazardous waste treatment facility would probably require no pretreatment of groundwater, but only storage and transport of pumped water.

Discharge of groundwater to a POTW would probably require that some pretreatment be performed, depending upon the treatment processes used at the wastewater treatment facility, and upon the effluent limitations established by the plant. Actual treatment processes and design of the pretreatment facility would have to be based on the POTW's permit conditions. The pretreatment process train would most likely be similar to that for full treatment, except that the levels of required removal might not be as stringent. Some processes may have to be added or modified, depending on the actual sewer discharge requirements.

Of the offsite treatment options, discharge to a POTW is the most preferable. However, during discussions with the local POTW (the Binghamton-Johnson City Sewage Treatment Plant) it was determined that the facility is already operating near capacity and would therefore not be able to accept groundwater from this site. In light of this, offsite treatment options will be considered no further.

9.3 Summary

The remedial technologies and corresponding process options selected for consideration in the development of alternatives are shown on Figure 9-1. Since soil contamination is considered only of secondary importance to groundwater contamination at this site, remediation of contaminated soil will be left for closure of the landfill, and will be given no further attention in this document.

9.4 Development of Alternatives

The remedial alternatives are the site-specific and media-specific remedial technologies and associated process options which, when combined and implemented, will achieve one or more remediation goals for the site. The formulation of remedial alternatives from the remedial technologies is based on the following criteria:

- o Alternatives may include a range of general response categories, including no action, institutional action, containment, and groundwater collection/treatment.

- o Alternatives must address the remedial action objectives identified for the site, and specifically for the various contaminated media.

Four remedial alternatives were developed as shown in Table 9-2. Three of these were driven by the specific technologies required for groundwater remediation. All four of the alternatives include monitoring of groundwater, and completion and continued operation of the IRMs.

FIGURE 9-1

REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS

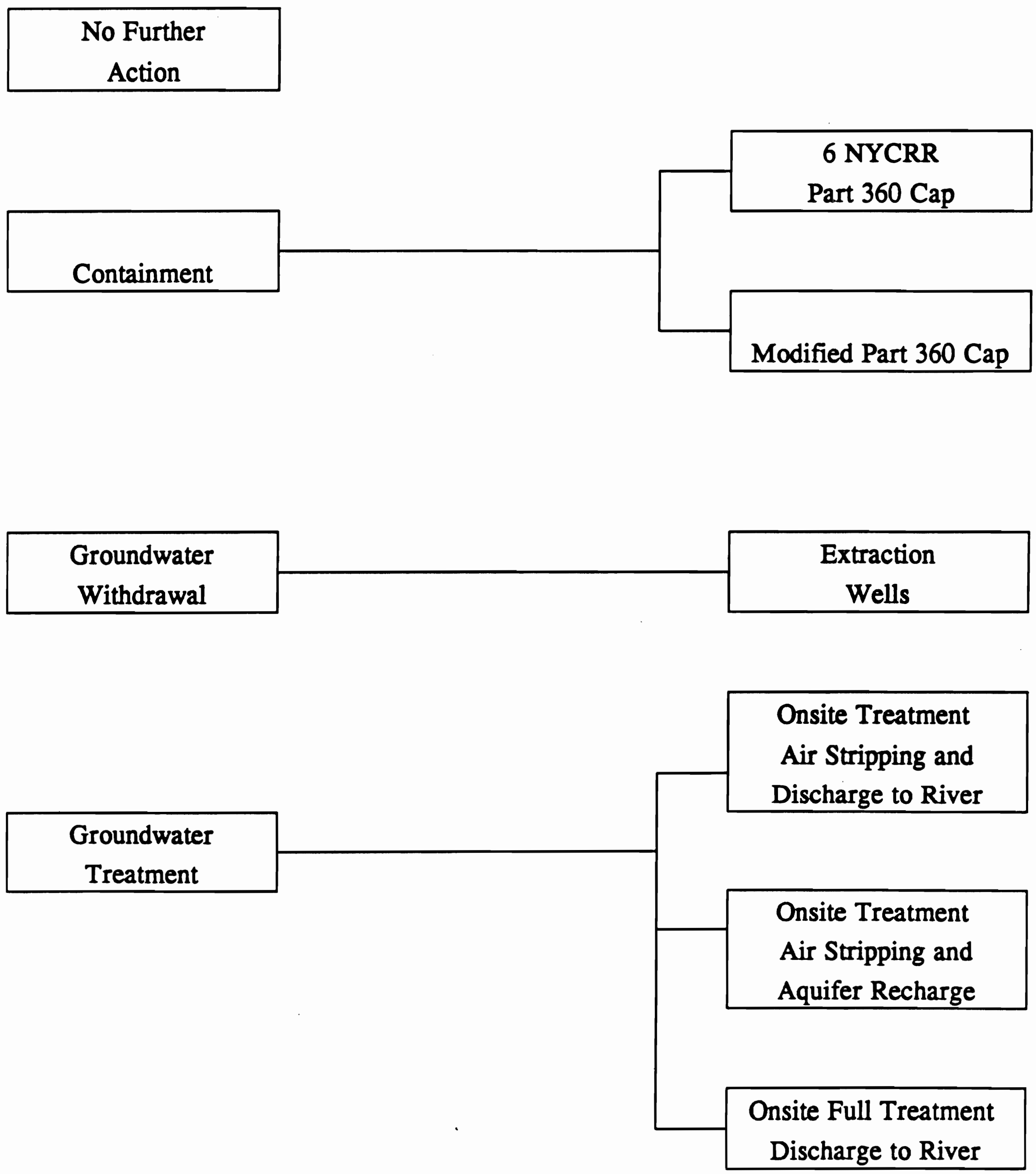


TABLE 9 - 2

DEVELOPMENT OF REMEDIAL ALTERNATIVES

	Alternative	Cap	Groundwater Collection and Treatment
1	No Furthher Action (IRMs in Place)	No	No
2	Groundwater Extraction Onsite Partial Treatment and Discharge to River	No	Yes
3	Groundwater Extraction Onsite Partial Treatment Recharging of Aquifer	No	Yes
4	Modified 6 NYCRR Part 360 Cap Full Onsite Treatment and Discharge to River	Yes	Yes

a) **Alternative 1** - No Further Action (Existing Remedial Measures in Place): This alternative provides a baseline against which other remedial action alternatives may be assessed. This alternative would not address the source of the groundwater contamination itself. The further spread of groundwater contamination would not be controlled. In this alternative, monitoring of groundwater and the current remedial activities being carried out by the Town of Kirkwood will be continued.

b) **Alternative 2** - This alternative will include installation of groundwater extraction wells and pumps along the northwest side of the landfill. These pumps will be placed and operated so as to intercept contaminated groundwater flowing from the landfill before it reaches the river or aquifer. Extracted water will be treated on site using Best Professional Judgment (BPJ), as detailed in NYSDEC's Division of Water Technical and Operational Guidance Series (1.3.4) Document, BPJ Methodologies, (April 1, 1987). It will then be discharged to the river.

c) **Alternative 3** - This alternative includes the same groundwater extraction and treatment features as Alternative 2. Instead of being discharged to the river, however, the treated groundwater will be reintroduced to the landfill, to "wash" contaminants from the fill and attack the problem at its source. Reintroduction will be achieved by the construction of low berms and percolation trenches, and subsequent flooding of the bermed area with treated groundwater for percolation into the fill and ultimately re-extraction and retreatment. The bermed area will be constructed outside the boundaries of the 100-year floodplain. At this time, it is assumed that treatment will be required for the volatile organics only.

Should PAHs and metals, however, be found at levels of concern at a future date, process units can be designed for removal of these contaminants as well.

d) **Alternative 4** - This alternative will include a 6NYCRR Modified Part 360 cap over the entire landfill area, and groundwater extraction and full treatment. Discharge will be to the river. The Modified Part 360 cap will significantly reduce infiltration of water through the waste/fill to the groundwater but will not significantly reduce the quantity of water to be treated. The groundwater collection wells will be placed downgradient of the site to intercept the contaminated groundwater flowing towards the Susquehanna River, into the aquifer, and towards the Town wells.

10. DETAILED EVALUATION OF ALTERNATIVES

10.1 General

In this section, the alternatives developed in the previous section will be subjected to a detailed evaluation in order to determine the most appropriate and cost-effective remedy for the site. The detailed evaluation of alternatives comprises three steps. In the first step a determination is made of an individual alternative's effectiveness in meeting the following requirements as stated in NYSDEC's Technical and Administrative Guidance Memorandum (TAGM) on Selection of Remedial Action at Inactive Hazardous Waste Sites, dated September 13, 1989:

- o Protection of human health and environment;
- o Attainment of Federal and New York State SCGs; and
- o Provision of treatment designed to significantly and permanently reduce toxicity and mobility of contaminated groundwater.

To make this determination, a weighted matrix scoring system in accordance with the NYSDEC TAGM is used to assign numerical values to each alternative's capacity to satisfy the requirements listed above.

In the second step, the costs associated with the implementation and operation of each alternative are estimated. The cost factor has been assigned a value, which is included in the TAGM scoring table.

In the third step, the alternatives are compared to one another using the results of the weighted-matrix scoring system and the cost estimate for each alternative. Following this comparative analysis, a remedial alternative is selected and recommended.

10.2 Weighted Matrix Scoring System

10.2.1 Procedure

The selection of a site remedy based upon a scoring system approach involves a quantitative evaluation of the alternatives against the criteria listed below, using weighting factors and a simple, numerical scoring system:

- Short-term impacts and effectiveness;
- Long-term effectiveness and permanence;
- Reduction of toxicity, mobility, or volume of hazardous waste;
- Implementability;
- Compliance with ARARs and SCGs;
- Overall protection of human health and the environment; and
- Cost

In the scoring system each alternative is numerically rated against the factors developed for each criterion. [The higher the number, the closer the match to the criterion.] The results of the weighted-matrix scoring analysis, presented in Table 10-1, are discussed in detail below.

10.2.2 Alternative 1 - No Further Action

A. Short-term Impacts and Effectiveness - Score: 10 out of 10

Since no construction beyond that associated with the IRMs (which is substantially complete) is required to implement this alternative, there are no associated risks to the community, environment, or workers. Implementation of this alternative would presume the continuation of the current treatment of the water supply wells for the Town of Kirkwood, and the potential

TABLE 10-1
WEIGHTED-MATRIX SCORING SYSTEM FOR REMEDIAL ALTERNATIVES

ALTERNATIVE 1: No Action (Present Situation)
ALTERNATIVE 2: Groundwater Treatment Extraction & Partial Treatment
ALTERNATIVE 3: Groundwater Extraction, Partial Treatment and Aquifer Recharge
ALTERNATIVE 4: 6 NYCRR Part 360 Cap (Modified) & Full Treatment

A. SHORT-TERM EFFECTIVENESS (Weight = 10)

FACTOR	BASIS FOR EVALUATION	WEIGHT	ALTERNATIVE			
			1	2	3	4
1. Protection of community during remedial actions	– Are there significant short-term risks to the community that must be addressed? (if no, go to factor 2)	Yes – 0 No – 4	4	4	0	0
	– Can the risk be easily controlled?	Yes – 1 No – 0	0	0	1	1
	– Does the mitigative effort to control risk impact the community lifestyle?	Yes – 0 No – 2	0	0	2	2
2. Environmental Impacts	– Are there significant short-term risks to the environment that must be addressed? (If no, go to factor 3)	Yes – 0 No – 4	4	4	0	0
	– Are the available mitigative measures reliable to minimize potential impacts?	Yes – 3 No – 0	0	0	3	3
3. Time to implement the remedy	– What is the required time to implement the remedy?	<2 yr – 1 >2 yr – 0	1	0	0	0
	– Required duration of the mitigative effort to control short-term risk.	<2 yr – 1 >2 yr – 0	1	1	1	1
SUBTOTAL (MAXIMUM = 10)			10	9	7	7

TABLE 10-1
WEIGHTED-MATRIX SCORING SYSTEM FOR REMEDIAL ALTERNATIVES

B. LONG-TERM EFFECTIVENESS AND PERMANENCE (Weight = 15)

FACTOR	BASIS FOR EVALUATION	WEIGHT	ALTERNATIVE			
			1	2	3	4
1. Permanence of the remedial alternative	– Will the remedy be classified as permanent in accordance with Section 2.1(a),(b) or (c) of the NYSDEC TAGM for the "Selection of Remedial Actions at Inactive Hazardous Waste Sites", Sept. 13, 1989? (if yes, go to factor 3)	Yes – 5 No – 0	0	0	0	0
2. Lifetime of remedial actions	– Expected lifetime or duration of effectiveness of the remedy	25–30 yr – 4 20–25 yr – 3 15–20 yr – 2 <15 yr – 0	0	4	4	4
3. Quantity and nature of waste or residual left at the site after remediation	i. Quantity of untreated hazardous waste left at the site	None – 3 <25% – 2 25–50% – 1 >50% – 0	0	0	1	0
	ii. Is there any treated residual left at the site? (if no, go to factor 4)	Yes – 0 No – 2	2	2	2	2
	iii. Is the treated residual toxic?	Yes – 0 No – 1	–	–	–	–
	iv. Is the treated residual mobile?	Yes – 0 No – 1	–	–	–	–
4. Adequacy and reliability of controls	i. Operation and maintenance required for a period of:	<5 yr – 1 >5 yr – 0	0	0	0	0
	ii. Are environmental controls required as a part of the remedy to handle potential problems? (if no, go to "iv")	Yes – 0 No – 2	0	0	0	0
	iii. Degree of confidence that controls can adequately handle potential problems	Moderate to very confident – 1 Somewhat to not confident – 0	1	1	1	1
	iv. Relative degree of long-term monitoring required (compare with other alternatives)	Minimum – 2 Moderate – 1 Extensive – 0	1	1	1	1
SUBTOTAL (MAXIMUM = 15)			4	8	9	8

TABLE 10-1
WEIGHTED-MATRIX SCORING SYSTEM FOR REMEDIAL ALTERNATIVES

C. REDUCTION OF TOXICITY, MOBILITY OR VOLUME (Weight = 15)

FACTOR	BASIS FOR EVALUATION	WEIGHT	ALTERNATIVE 1	ALTERNATIVE 2	ALTERNATIVE 3	ALTERNATIVE 4
1. Volume of hazardous waste reduced (reduction in volume or toxicity)	i. Quantity of hazardous waste destroyed or treated	100% – 10 80–99% – 8 60–80% – 6 40–60% – 4 20–40% – 2 <20% – 0	0	2	4	2
	ii. Are there any concentrated hazardous wastes produced as a result of (i)? (if no, go to factor 2)	Yes – 0 No – 2	2	2	2	2
(If subtotal = 12, go to factor 3)	iii. How is the concentrated hazardous waste stream disposed?	On-site land disposal – 0 Off-site secure land disposal – 1 On-site or off-site destruction or treatment – 2	–	–	–	–
2. Reduction in mobility of hazardous waste	i. Method of Reduction – Reduced mobility by containment – Reduced mobility by alternative treatment technology	 1 3	3	3	3	3
	ii. Quantity of wastes immobilized	<100% – 2 >60% – 1 <60% – 0	0	0	0	0
3. Irreversibility of the destruction or treatment of hazardous waste	– Completely irreversible – Irreversible for most of the hazardous waste constituents – Irreversible for only some of the hazardous waste constituents – Reversible for most of the hazardous waste constituents	3 2 1 0	2	2	2	3
SUBTOTAL (MAXIMUM = 15)			7	9	11	10

TABLE 10-1
WEIGHTED-MATRIX SCORING SYSTEM FOR REMEDIAL ALTERNATIVES

D. IMPLEMENTABILITY (Weight = 15)

FACTOR	BASIS FOR EVALUATION	WEIGHT	ALTERNATIVE			
			1	2	3	4
1. Technical Feasibility						
a. Ability to construct technology	i. Not difficult to construct. No uncertainties in construction ii. Somewhat difficult to construct. No uncertainties in construction iii. Very difficult to construct and/or significant uncertainties in construction	3 2 1	3	2	2	2
b. Reliability of technology	i. Very reliable in meeting the specified process efficiencies or performance goals ii. Somewhat reliable in meeting the specified process efficiencies or performance goals	3 2	3	3	3	3
c. Schedule of delays due to technical problems	i. Unlikely ii. Somewhat likely	2 1	2	1	1	1
d. Need of undertaking additional remedial action, if necessary	i. No future remedial action may be anticipated ii. Some future remedial actions may be necessary	2 1	1	2	2	2
2. Administrative Feasibility a. Coordination with other agencies	i. Minimal coordination is required ii. Required coordination is normal iii. Extensive coordination is required	2 1 0	2	1	1	1
3. Availability of Services and Materials						
a. Availability of prospective technologies	i. Are technologies under consideration generally commercially available for the site-specific application?	Yes – 1 No – 0	1	1	1	1
	ii. Will more than one vendor be available to provide a competitive bid?	Yes – 1 No – 0	1	1	1	1
b. Availability of necessary equipment and specialists	i. Additional equipment and specialists may be available without significant delay	Yes – 1 No – 0	1	1	1	1
SUBTOTAL (MAXIMUM = 15)			14	12	12	12

TABLE 10-1
WEIGHTED-MATRIX SCORING SYSTEM FOR REMEDIAL ALTERNATIVES

E. COMPLIANCE WITH ARARS (Weight = 10)

FACTOR	BASIS FOR EVALUATION	WEIGHT	ALTERNATIVE			
			1	2	3	4
1. Compliance with chemical-specific ARARs	Meets chemical-specific ARARs	Yes - 2.5 No - 0	0	0	2.5	2.5
2. Compliance with action-specific ARARs	Meets action-specific ARARs	Yes - 2.5 No - 0	2.5	2.5	2.5	2.5
3. Compliance with location-specific ARARs	Meets location-specific ARARs	Yes - 2.5 No - 0	2.5	2.5	2.5	2.5
4. Compliance with appropriate criteria, advisories and guidelines	The alternative meets all relevant and appropriate Federal and State guidelines that are not promulgated	Yes - 2.5 No - 0	0	0	0	0
SUBTOTAL (MAXIMUM = 10)			5.0	5.0	7.5	7.5

F. PROTECTION OF HUMAN HEALTH & THE ENVIRONMENT (Weight = 20)

FACTOR	BASIS FOR EVALUATION	WEIGHT	ALTERNATIVE			
			1	2	3	4
1. Use of site after remediation	Unrestricted use of the land and water (if yes, go to end of table)	Yes - 20 No - 0	0	0	0	0
2. Human health and the environment exposure after the remediation	i. Is the exposure to contaminants via air route acceptable?	Yes - 3 No - 0	3	3	3	3
	ii. Is the exposure to contaminants via groundwater/surface water acceptable?	Yes - 4 No - 0	0	4	4	4
	iii. Is the exposure to contaminants via sediments/ soil acceptable?	Yes - 3 No - 0	0	0	0	3
3. Magnitude of residual public health risks after the remediation	i. Health risk ii. Health risk	<1 in 1,000,000 - 5 <1 in 100,000 - 2	2	2	2	5
4. Magnitude of residual environmental risks after the remediation	i. Less than acceptable ii. Slightly greater than acceptable iii. Significant risk still exists	5 3 0	3	3	3	5
SUBTOTAL (MAXIMUM = 20)			8	12	12	20

G. COST (Weight = 15)

FACTOR	BASIS FOR EVALUATION	WEIGHT	ALTERNATIVE			
			1	2	3	4
Overall (MAXIMUM = 15)	Scored on a linear scale with 0 and 15 assigned to the highest and the least cost alternatives respectively.	Lowest - 15 Others - Relative	15	14	13	0

TABLE 10-1
WEIGHTED-MATRIX SCORING SYSTEM FOR REMEDIAL ALTERNATIVES

SUMMARY

	ALTERNATIVE			
	1	2	3	4
A. SHORT-TERM EFFECTIVENESS (Weight = 10)	10	9	7	7
B. LONG-TERM EFFECTIVENESS AND PERMANENCE (Weight = 15)	4	8	9	8
C. REDUCTION OF TOXICITY, MOBILITY OR VOLUME (Weight = 15)	7	9	11	10
D. IMPLEMENTABILITY (Weight = 15)	14	12	12	12
E. COMPLIANCE WITH ARARS (Weight = 10)	5	5	7.5	7.5
F. PROTECTION OF HUMAN HEALTH & THE ENVIRONMENT (Weight = 20)	8	12	12	20
G. COST (Weight = 15)	15	14	13	0

TOTAL SCORE (Maximum = 100)	63	69	71.5	64.5

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public health effects outlined in the baseline (qualitative) risk assessment of the RI.

B. Long-term Effectiveness and Permanence - Score: 4 out of 15

This alternative is neither an effective nor a permanent remedy to the potential risks posed by the contaminants in the groundwater at this site. The current potential environmental and health threats may continue, specifically the movement of groundwater into the aquifer and toward the Susquehanna River.

C. Reduction in Toxicity, Mobility, and Volume of Contaminants - Score: 7 out of 15

No significant percentage of onsite contaminants will be treated by the IRMs considered to be part of this alternative. Treatment is expected to be irreversible for contaminants of concern.

D. Implementability - Score: 14 out of 15

The no-action alternative is easily implemented compared to the other alternatives, although some additional remedial actions may be required in the future.

E. Compliance with ARARs and SCGs - Score: 5 out of 10

Implementation of this alternative would result in compliance with action-specific and location-specific ARARs and SCGs. It would not result in compliance with chemical-specific ARARs or SCGs, nor necessarily with all appropriate agency criteria, advisories, or guidelines.

F. Overall Protection of Human Health and the Environment - Score: 8 out of 20

Due to the IRMs considered to be part of this alternative, the alternative provides partial protection for human health. Some risk to human health and the environment will remain. Use of land and water following implementation of this alternative would not be unrestricted.

G. Cost - Score: 15 out of 15

This is the least costly alternative considered.

10.2.3 Alternative 2 - Groundwater Extraction, Onsite Treatment, Discharge to River

A. Short-term Impact and Effectiveness - Score: 9 out of 10

Short-term impact is expected to be low to non-existent. Should there in fact be a slight impact, mitigative controls may be required for greater than 2 years.

B. Long-term Effectiveness and Permanence - Score: 8 out of 15

The remedy is not considered permanent in accordance with Section 2.1 of the September 13, 1989, NYSDEC TAGM. This alternative may leave a large amount of untreated contaminants at the site. Both O&M and environmental controls will be required.

C. Reduction in Toxicity, Mobility, and Volume of Contaminants - Score: 9 out of 15

This alternative will effectively eliminate the flow of contaminated groundwater reaching the Susquehanna River and the aquifer. Treatment is expected to be irreversible for all contaminants of concern.

D. Implementability - Score: 12 out of 15

Some difficulties may be encountered in construction of this alternative. Some construction delays are likely. Some future remedial action may be required. Technologies and vendors are readily available, and the technology itself is highly reliable in meeting performance goals.

E. Compliance with ARARs and SCGs - Score: 5 out of 10

Implementation of this alternative would result in compliance with action-specific and location-specific ARARs and SCGs. It would not result in compliance with chemical-specific ARARs or SCGs, nor necessarily with all appropriate agency criteria, advisories, or guidelines.

F. Overall Protection to Human Health and the Environment - Score: 12 out of 20

This alternative will reduce the levels of contaminants in groundwater to acceptable levels. Implementation of this alternative, however, will not result in unrestricted use of land and water at the site.

G. Cost - Score: 14 out of 15

This alternative is the second least costly remedy of the four considered.

10.2.4 <u>Alternative 3 - Groundwater Extraction, Onsite Treatment, Reintroduction to Aquifer</u>

A. Short-term Impacts and Effectiveness - Score: 7 out of 10

Short-term impact may result from construction of berms and other project components, although such impact is expected to be slight. Mitigative controls may be required for greater than 2 years.

B. Long-term Effectiveness and Permanence - Score: 9 out of 15

The remedy is not considered permanent in accordance with Section 2.1 of the September 13, 1989, NYSDEC TAGM, although, since it is the only remedy by which an attempt is made to treat the source of contamination, it is the remedy that will leave the least amount of untreated hazardous waste at the site. Extensive long-term monitoring and environmental controls may be required.

C. Reduction in Toxicity, Mobility, or Volume of Contaminants - Score: 11 out of 15

Over the life of the project, this alternative will greatly reduce the volume of contaminants in groundwater flowing toward the Susquehanna River and into the aquifer. Treatment is expected to be irreversible for all contaminants of concern.

D. Implementability - Score: 12 out of 15

Because of the need to construct berms for reintroduction of treated wastewater, and to construct at the edge of a 100-year floodplain, some uncertainties in construction are likely to arise. Future remedial action may also be required. Technologies and vendors are readily available, and the technology itself is highly reliable. Required coordination is normal.

E. Compliance with ARARs and SCGs - Score: 7.5 out of 10

Implementation of this alternative would result in compliance with chemical-specific, action-specific, and location-specific ARARs and SCGS, but not necessarily with all appropriate agency criteria, advisories, and guidelines.

F. Overall Protection to Human Health and Environment - Score: 12 out of 20

This alternative will reduce the levels of contaminants in groundwater to acceptable levels. Use of land and water at the site following implementation of this alternative will not be unrestricted.

G. Cost - Score 13 out of 15

This alternative is the second most costly of the four considered.

10.2.5 <u>Alternative 4 - 6NYCRR Modified Part 360 Cap, Groundwater Extraction, Onsite Treatment, Discharge to River</u>

A. Short-term Impacts and Effectiveness - Score: 7 out of 10

The work required for construction of a Modified Part 360 cap and the extraction wells may create a short-term risk (e.g., fugitive dust emissions during fill movement, and grading operations for the cap). The risks can be easily controlled, and the control efforts would not be expected to impact the community. Mitigative methods would be employed to minimize short-term environmental risks during the construction of the cap and the extraction wells.

B. Long-term Effectiveness and Permanence - Score: 8 out of 15

The remedy is not considered permanent in accordance with Section 2.1 of the September 13, 1989, NYSDEC TAGM. A long-term operation and maintenance program would be required to ensure continued effectiveness of the Modified Part 360 cap, which may require periodic repair. Most contaminants would be left on site.

C. Reduction in Toxicity, Mobility, and Volume of Contaminants - Score: 10 out of 15

This alternative will reduce the volume of contaminants in groundwater flowing toward the Susquehanna River and into the aquifer. Treatment is expected to be irreversible for all contaminants of concern. This alternative will also reduce or eliminate the flow of contaminants to the Town of Kirkwood's raw water supply.

D. Implementability - Score: 12 out of 15

Implementation of this alternative is expected to be about as difficult as any capping and/or groundwater extraction and treatment alternative. Some difficulties and delays are anticipated. Technologies and vendors are readily available. Required coordination is normal.

E. Compliance with ARARs and SCGs - Score: 7.5 out of 10

This alternative will result in substantial compliance with chemical-specific, action-specific, and location-specific ARARs and SCGs. It may not necessarily comply with appropriate agency criteria, advisories, and guidelines.

F. Overall Protection of Human Health and Environment - Score: 20 out of 20

With its combination of cap and groundwater extraction and treatment, this alternative is expected to give maximum protection to human health and the environment.

G. Cost - Score: 0 out of 15

This alternative is the most costly of the four considered.

10.3 Economic Evaluation of Alternatives

10.3.1 General

To facilitate the evaluation of the cost-effectiveness of the alternatives, preliminary capital and annual operation and maintenance (O&M) costs were developed for individual components (i.e., technologies and process options) of the alternatives. Total capital and O&M costs for each alternative were then determined by combining the costs of the appropriate components.

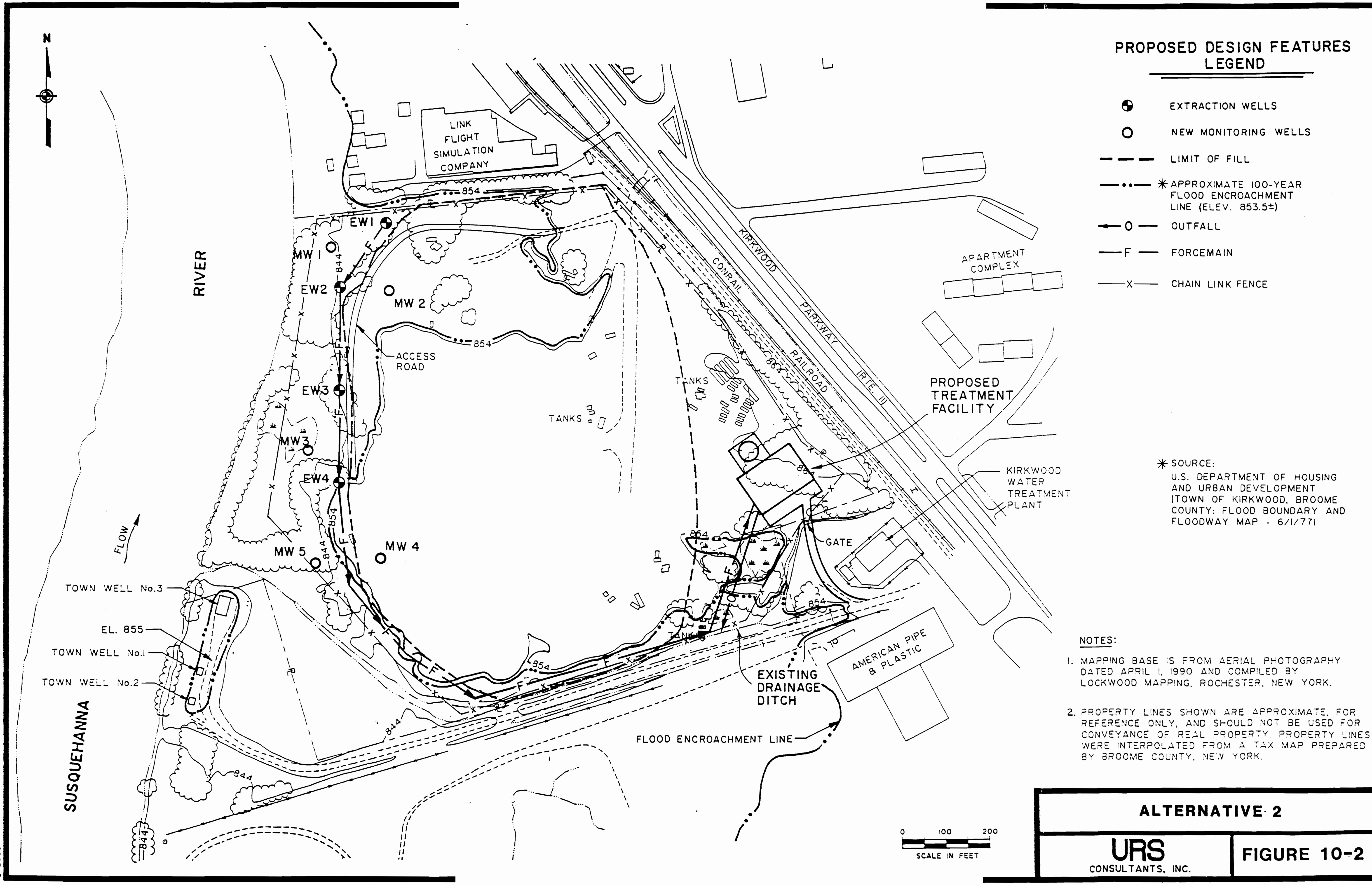
Quantities associated with remedial activities as they relate to the media of concern (e.g., groundwater collection and treatment) are developed initially to serve as the basis for this economic evaluation. Specific aspects and quantities of each component used as the basis for the capital and annual O&M costs of the selected remedial technologies are discussed in detail under each technology. The capital and annual O&M costs of each component are presented on separate tables accompanying these discussions. The sources of the unit prices are referenced on the tables. These sources include Means (1991), past URS experience at similar sites, and quotes from vendors. Several cost items are estimated as a percentage of the total capital cost based upon past URS experience. They include the following: mobilization/demobilization (5%); construction administration and design engineering (15%); bonds and insurance to reflect construction at sites containing hazardous waste (5%); escalation of 5% per year over two years to account for increased construction costs at the time construction is anticipated to occur (10.2%); contractor markups for overhead and profit (25%); and contingencies (20%). Consideration of the required provisions for health and safety using different levels of protection have been included in the unit prices in the cost estimate.

For the evaluation of the alternatives for cost-effectiveness, the capital and annual O&M costs are converted to their equivalent present worth. A 30-year performance period with a 10 percent annual interest rate is used in the determination of the present worth of the cost of each alternative. The accuracy of the estimated costs lies within a range of -30% to +50% of actual construction costs.

10.3.2 Estimation of Quantities

Long-term pumping rates were calculated for Alternatives 2, 3 and 4. The pumping rates are determined mainly by the onsite aquifer parameters (e.g., hydraulic conductivity), infiltration rate, horizontal flow from off site, upward flow from beneath the landfill, and the pattern of pumping from the Town well field.

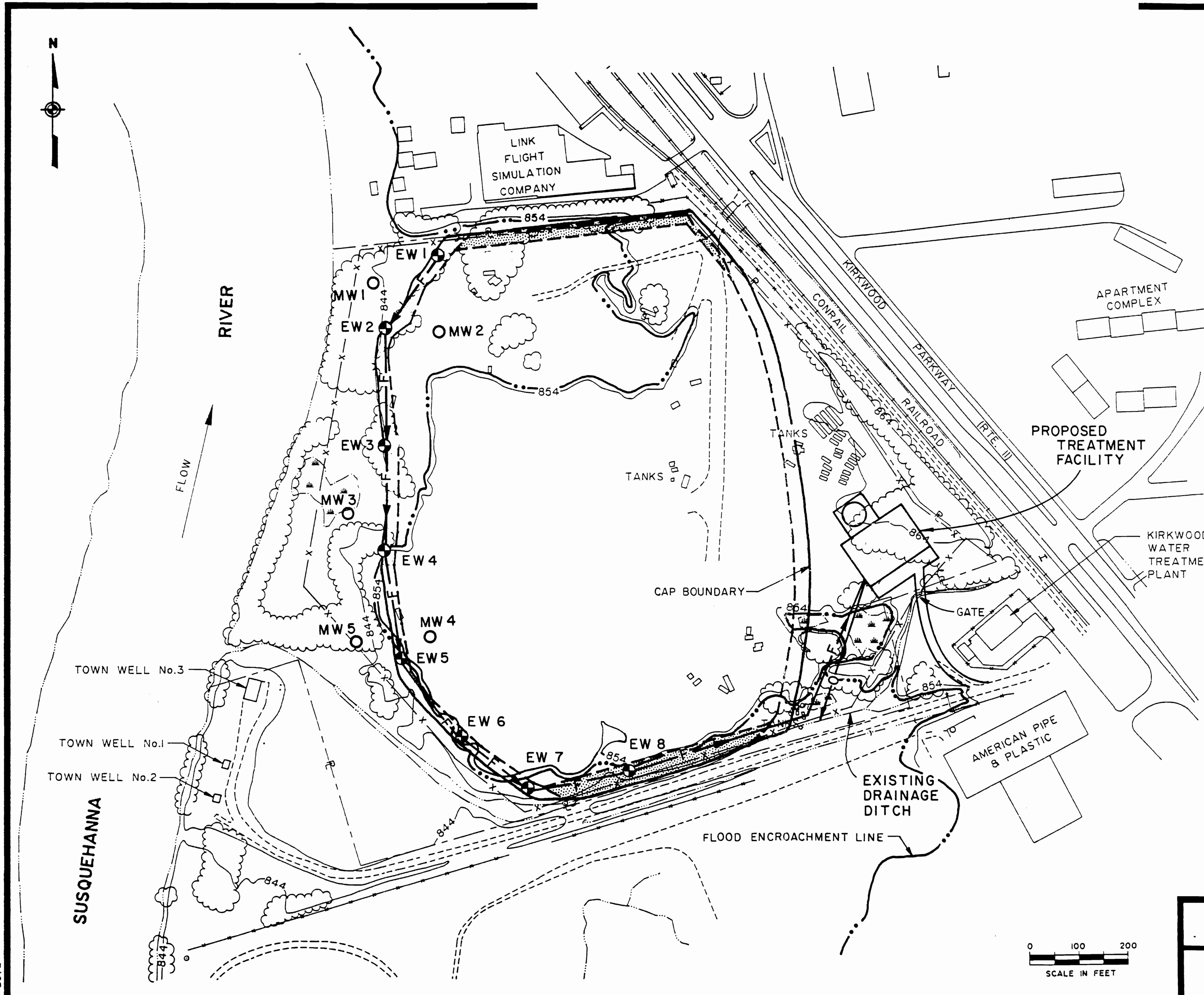
The results of the RI appear to indicate that the groundwater leaving the central and southern portion of the site is captured by the Town well field. The groundwater from the northern part of the landfill is flowing off site, reaching the Susquehanna River. Alternative 2 was proposed to prevent such offsite flow (Figure 10-2). It involves placing a series of 4 collection wells along the northwestern portion of the landfill between the landfill and the Susquehanna River. Alternative 4 provides for the capturing of all contaminated groundwater leaving the landfill, including the portion currently intercepted by the Town well field (Figure 10-4). To achieve this objective, a series of 8 extraction wells is proposed. The wells are located along the entire western edge of the landfill, including the area between the landfill and the Town's well field.



ALTERNATIVE 2

FIGURE 10-2

1=200 10/28/91



PROPOSED DESIGN FEATURES LEGEND

- EXTRACTION WELLS
- WASTE FILL TO BE RELOCATED
- LIMIT OF FILL
- LIMIT OF CAP (6NYCRR PART 360 MODIFIED)
- OUTFALL
- FORCEMAIN
- NEW MONITORING WELLS
- * APPROXIMATE 100-YEAR FLOOD ENCROACHMENT LINE (ELEV. 853.5±)
- CHAIN LINK FENCE

NOTES:

1. * SOURCE: U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT (TOWN OF KIRKWOOD, BROOME COUNTY: FLOOD BOUNDAR AND FLOODWAY MAP - 6/1/77)
2. MAPPING BASE IS FROM AERIAL PHOTOGRAPHY DATED APRIL 1, 1990 AND COMPILED BY LOCKWOOD MAPPING, ROCHESTER, NEW YORK.
3. PROPERTY LINES SHOWN ARE APPROXIMATE, FOR REFERENCE ONLY, AND SHOULD NOT BE USED FOR CONVEYANCE OF REAL PROPERTY. PROPERTY LINES WERE INTERPOLATED FROM A TAX MAP PREPARED BY BROOME COUNTY, NEW YORK.

ALTERNATIVE 4

URS CONSULTANTS, INC.

FIGURE 10-4

C-2372

Alternative 3 involves pumping the groundwater currently reaching the river from the northwestern portion of the landfill and recharging the aquifer through an infiltration pond (located on top of the landfill) after treatment. A series of collection wells between the northern part of the landfill and the river, as well as the infiltration pond, is included in this alternative (Figure 10-3).

In order to size the collection wells, treatment facilities, and the infiltration pond, to estimate costs, and to facilitate a cost comparison, the groundwater collection/reinjection rates were estimated for each of the alternatives. These calculations were based on data collected during the RI as well as on USGS groundwater modeling performed for this site. Details are presented in Appendix S. The anticipated withdrawal rates for all alternatives are listed in Table 10-2.

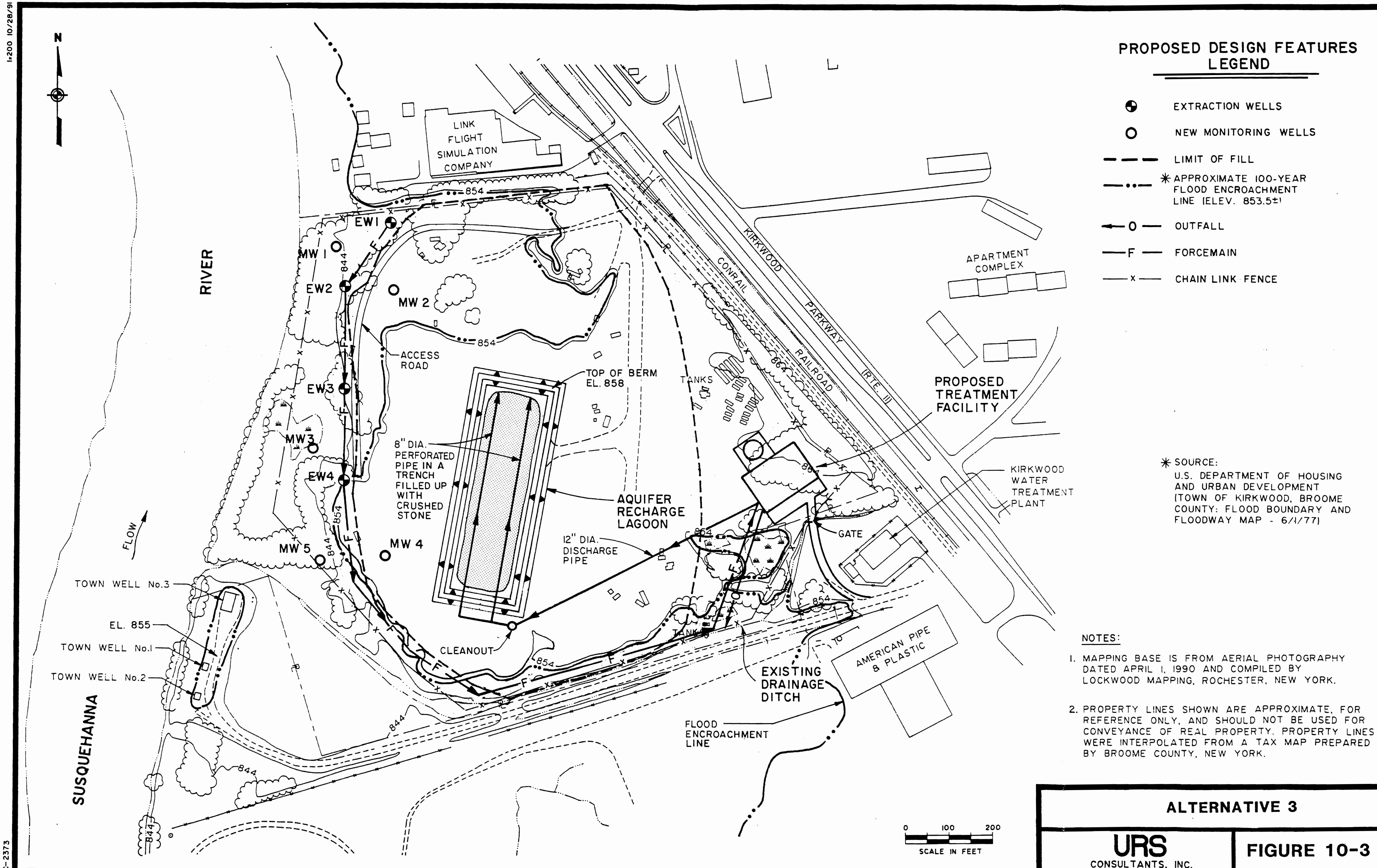
10.3.3 Cost Estimates for Individual Technologies

Detailed cost estimates are presented below for individual technologies that compose the various alternatives being evaluated. A summary of design quantities required to estimate costs for each technology is included in Table 10-3.

A. 6NYCRR Modified Part 360 Cap

A provision in 6NYCRR Part 360 allows for design variances, provided that the "proposed activity will have no significant adverse impact on the public health, safety, or welfare, the environment or natural resources and will be consistent with the provisions of the ECL [Environmental Conservation Law] and the performance expected from application of this Part." Part 360 stipulates that the following components are to be included in a Part 360 cap:

- o topsoil layer, minimum thickness 6 inches



ALTERNATIVE 3

URS CONSULTANTS, INC.

FIGURE 10-3

TABLE 10 - 2

GROUNDWATER TREATMENT QUANTITIES

Alternative	Description	Groundwater Pumping Rate (gpm)
1	Present IRM	-
2	Groundwater Collection and Treatment	170
3	Groundwater Collection, Treatment and Aquifer Recharge	350
4	Modified Part 360 Cap, Groundwater Collection and Full Groundwater Treatment	600

TABLE 10 – 3

Summary of Design Quantities

Item	Description	Units	Quantities			
			Alt. 1	Alt. 2	Alt. 3	Alt. 4
1	Modified Part 360 Cap	acres	–	–	–	21
2	Drainage Ditches	ft	–	–	–	4,000
3	Groundwater Collection Wells	No. of Wells	–	4	4	8
4	Groundwater Collection Rate	gpm	–	170	350	600
5	Chain Link Fence and Gates	l.f.	–	4020	4020	4020

- barrier protection, minimum thickness 24 inches
- low-permeability barrier soil, minimum thickness 18 inches, or geomembrane, minimum thickness 40 mils
- gas venting layer

Since no significant amounts of gas are produced by this landfill, it is proposed that the Part 360 cap designed for this site need not include a gas venting layer. This variance from Part 360 criteria would have no adverse impact on public health, safety, or welfare, the environment, or natural resources.

A second variance desirable at this site would relate to the membrane liner. An HDPE liner would be easier and less costly to construct than a low-permeability soil liner. An HDPE liner would not be subject to desiccation cracking, as a low-permeability barrier soil would. Therefore, the thickness of the barrier protection layer could be reduced to 12 inches. This is consistent with a recommendation made by NYSDEC on another proposed Part 360 cap, where it was suggested that a total of 18 inches of frost protection would be adequate to meet performance specifications (NYSDEC, September 20, 1991).

The Modified Part 360 cap proposed for the Gorick Landfill is therefore as follows (from top to bottom):

- vegetative cover
- 6 inches of topsoil
- 12 inches general fill layer
- 60-mil HDPE geomembrane
- Geonet between two layers of geotextile
- 6 inches minimum of sub-base above the regraded fill

Details of this Modified Part 360 cap are shown on Figure 10-1. The limits of the cap, including a minimum 4 percent slope, are shown on Figure 10-4. The cap will be constructed over the entire 21-acre site.

The capital cost for the Modified Part 360 cap will be based on the items listed above. Additional items, such as surface drainage ditches, were also considered in preparation of the capital cost for this item. Table 10-4 presents a capital cost estimate for the 6NYCRR Modified Part 360 cap. Cap maintenance must be continued for 30 years. O&M costs include inspection of the cap, as well as maintenance and repair of those items identified above. Table 10-5 presents an O&M cost estimate for a 6NYCRR Modified Part 360 cap.

B. <u>Groundwater Extraction Wells</u>

The number as well as the arrangement of withdrawal wells varies for each alternative. For Alternatives 2 and 3, 4 wells each are proposed, whereas for Alternative 4, 8 wells will be used. The wells will be screened to the top of the till unit, whose elevation varies depending on location. The average depth of these wells is assumed to be 40 feet (Figure 10-5). Each well will contain a submersible pump with variable capacity, depending on the alternative chosen. Two (2) spare pumps will be kept on site. A forcemain connecting the withdrawal wells to the groundwater collection and treatment system has been included.

The estimated capital cost of constructing these wells is shown on Table 10-6A for Alternatives 2 and 3, and 10-6B for Alternative 4. Annual operating and maintenance costs amount to $3,250 for each of Alternatives 2 and 3, and $6,500 for Alternative 4.

TABLE 10 - 4

Gorick C&D Landfill
Capital Cost Estimate

Modified Part 360 Cap

Component	Item	Units	Unit Cost	Source	Quantity	Total Cost
1. Clearing	Cut and Remove Trees and Large Obstacles	acre	$3,025.00	1	3	$9,100
2. Surface Preparation	Crush, Dismantle, & Bury Existing Debris	LS	$85,000.00	2	1	$85,000
3. Grading	a) Waste: Cut	yd^3	$7.00	2	20,000	$140,000
	b) Move and Grade	yd^3	$1.59	2	20,000	$31,800
	c) Borrow: Purchase	yd^3	$1.75	2	234,900	$411,100
	d) Haul	yd^3	$3.00	2	234,900	$704,700
	e) Place and Grade	yd^3	$0.85	2	234,900	$199,700
4. 6" Base for Geomembrane	a) Screen and Purchase	yd^3	$6.00	2	16,190	$97,100
	b) Haul	yd^3	$3.00	2	16,190	$48,600
	c) Place, Compact and Grade	yd^3	$11.79	2	16,190	$190,900
5. 60 mil HDPE Geomembrane	Furnish, Deliver, and Install	ft^2	$0.60	2	914,760	$548,900
6. General Fill Layer 12"	a) Purchase	yd^3	$7.00	2	32,380	$226,700
	b) Haul	yd^3	$3.00	2	32,380	$97,100
	c) Place and Grade	yd^3	$5.00	2	32,380	$161,900
7. 6" Topsoil Layer	a) Purchase	yd^3	$8.00	3	16,190	$129,500
	b) Haul	yd^3	$6.00	3	16,190	$97,100
	c) Place and Grade	yd^3	$3.46	3	16,190	$56,000
8. Perimeter Drainage Ditch	Fine grade & compact subgrade	acre	$5,082.00	1	1.7	$8,600
9. Vegetative Cover	Seed, Mulch and Fertilize	acre	$3,300.00	1	21	$69,300
SUBTOTAL						**$3,313,100**
Mobilization/Demobilization (5%)						$165,700
Contractor Markup (25%)						$828,300
Construction, Administration and Design Engineering (15%)						$497,000
Escalation to Midpoint of Construction (5% per year for 2 years)						$339,600
Bonds and Insurance (5%)						$165,700
Contingency (20%)						$662,600
SUBTOTAL						**$2,658,900**
TOTAL						**$5,970,000**

SOURCES :
1 - 1991 Means
2 - URS Estimate
3 - Ellery Landfill Actual Construction Cost

TABLE 10 - 5

Gorick C&D Landfill
Annual O&M Cost Estimate

Modified Part 360 Cap

Component	Item	Units	Unit Cost	Source	Quantity	Total Cost
1. Inspection	Inspection of Cap	hr	$20.00	1	50	$1,000
2. Maintenance	a) Cut Grass	yr	$3,500.00	1	1	$3,500
	b) Repair Drainage Ditch	yr	$2,000.00	1	1	$2,000
3. Repair Cap Breakthroughs	a) Excavation, Removal and Disposal of Damaged Cap	yd^3	$560.00	1	74	$41,400
	b) Replacement of Filter Fabric	ft^2	$0.59	1	1,000	$600
	c) Replacement of HDPE Liner	ft^2	$0.60	1	1,000	$600
	d) Replacement of General Fill	yd^3	$8.00	2	74	$600
	e) Replacement of Topsoil	yd^3	$8.00	2	19	$200
	f) Revegetate	acre	$4,340.00	1	0.02	$100

SUBTOTAL **$50,000**

Mobilization/Demobilization (5%)	$2,500
Contractor Markup for Overhead and Profit (25%)	$12,500
Bonds and Insurance (5%)	$2,500
Contingency (10%)	$5,000

SUBTOTAL **$22,500**

TOTAL **$72,500**

SOURCES:
1 - URS Estimate
2 - Ellery Landfill Actual Construction Cost

TABLE 10 - 6 A

Gorick C&D Landfill
Capital Cost Estimate

Groundwater Collection and Transfer

ALTERNATIVES - 2 & 3

Component	Item	Units	Unit Cost	Source	Quantity	Total Cost
1. Extraction System	Extraction Wells	ea	$5,835.00	1&2	4	$23,300
2. Force Main	3" Ø PVC Force Main	lf	$10.00	3	2,260	$22,600

SUBTOTAL **$45,900**

Mobilization/Demobilization (5%)	$2,300
Contractor Markup (25%)	$11,500
Construction, Administration and Design Engineering (15%)	$6,900
Escalation to Midpoint of Construction (5% per year for 2 years)	$4,700
Bonds and Insurance (5%)	$2,300
Contingency (20%)	$9,200

SUBTOTAL **$36,900**

TOTAL **$80,000**

SOURCES : 1 - NYSDEC Standby Drilling Contract
2 - 1991 Means

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WELLS2.WK1

TABLE 10 - 6 B

Gorick C&D Landfill
Capital Cost Estimate

Groundwater Collection and Transfer

ALTERNATIVE - 4

Component	Item	Units	Unit Cost	Source	Quantity	Total Cost
1. Extraction System	Extraction Wells	ea	$5,835.00	1&2	8	$46,700
2. Force Main	3" Ø PVC Force Main	lf	$10.00	3	2,260	$22,600

SUBTOTAL **$69,300**

Mobilization/Demobilization (5%)	$3,500
Contractor Markup (25%)	$17,300
Construction, Administration and Design Engineering (15%)	$10,400
Escalation to Midpoint of Construction (5% per year for 2 years)	$7,100
Bonds and Insurance (5%)	$3,500
Contingency (20%)	$13,900

SUBTOTAL **$55,700**

TOTAL **$130,000**

SOURCES :
1 - NYSDEC Standby Drilling Contract
2 - 1991 Means
3 - URS Estimate

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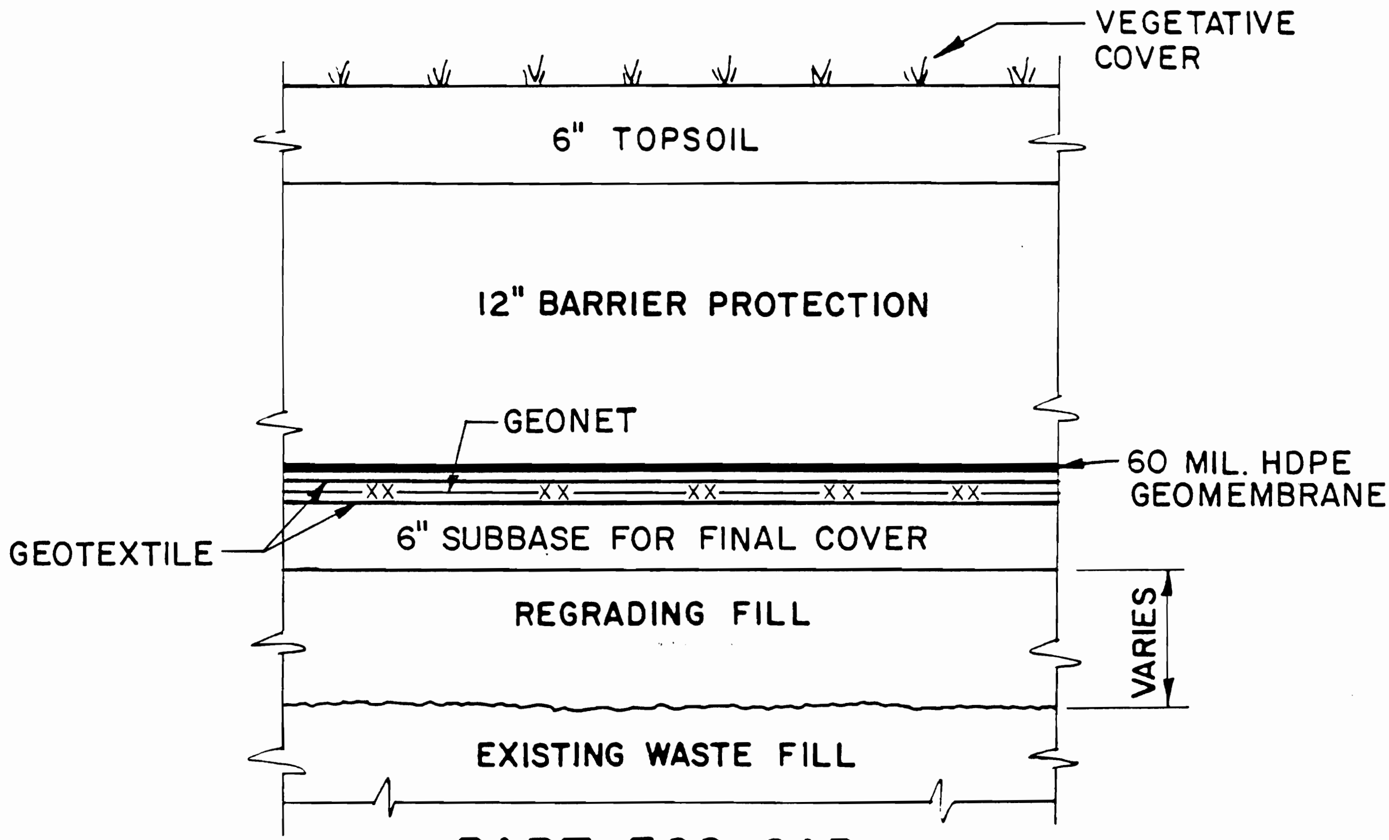
WELLS.WK1

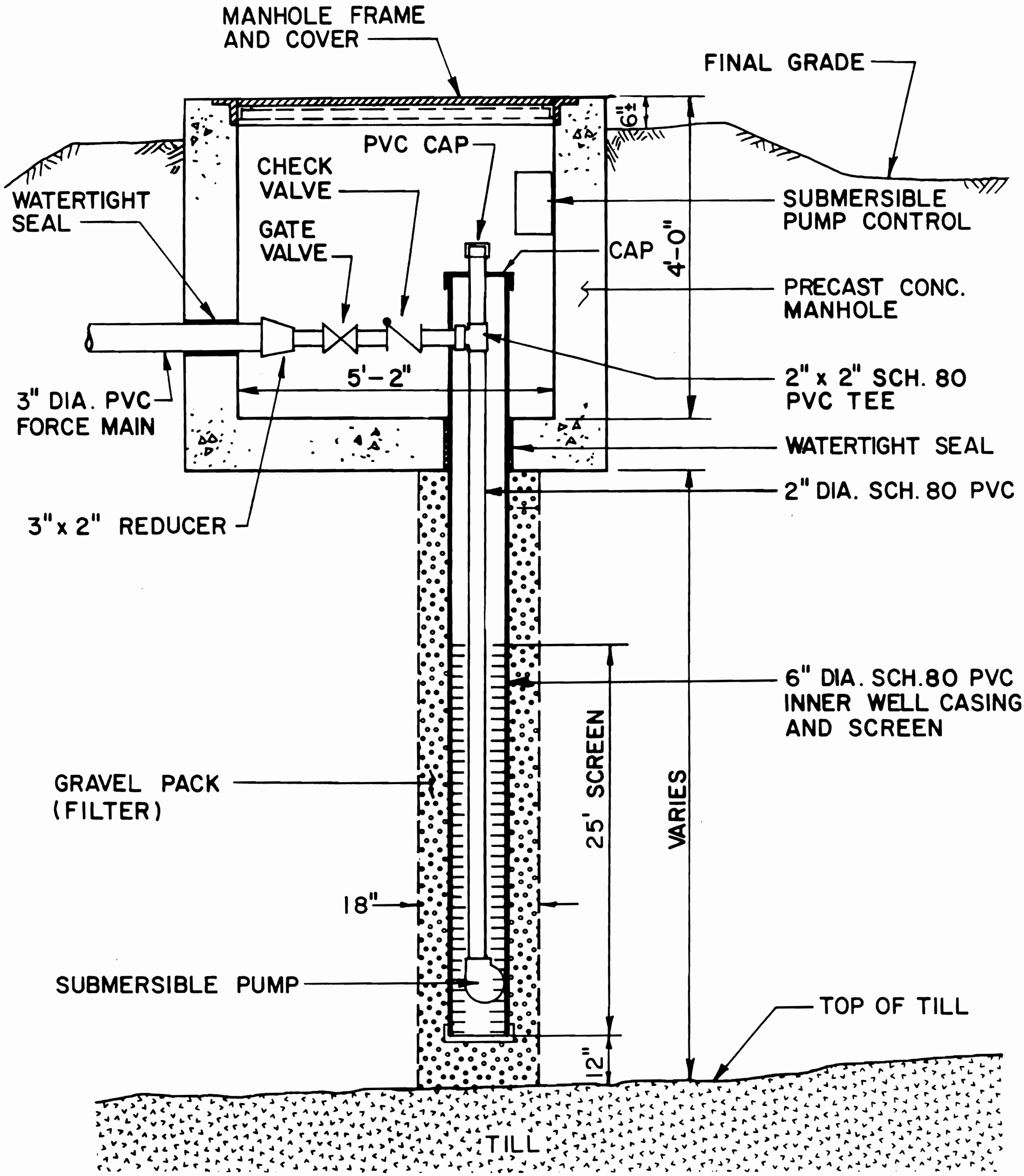


PART 360 CAP
(MODIFIED)

NOT TO SCALE

URS CONSULTANTS, INC.	LANDFILL CAP CROSS SECTION GORICK C&D LANDFILL	FIGURE 10-1

A-4120/A



NOTE: ALL DIMENSIONS ARE SUBJECT TO FINAL DESIGN.

NOT TO SCALE

URS CONSULTANTS, INC.	TYPICAL GROUNDWATER COLLECTION WELL DETAIL	FIGURE 10-5

A-4098/A

C. Groundwater Treatment

To determine the technologies and process options to be used for the treatment of groundwater from the Gorick C&D Landfill site, it is first necessary to determine the basis of design. This will include contaminant concentrations, groundwater extraction rates, and discharge requirements. Consideration must also be given to reintroduction of treated groundwater to the aquifer. Contaminant concentrations determined for the groundwater will remain constant for each of the remedial alternatives. However, different groundwater collection rates and effluent discharge requirements will be considered.

(1) Contaminant Concentrations - In order to establish a basis for the design of a groundwater treatment system, the groundwater data collected during the RI phase of the project and presented in the RI report were utilized to develop design influent concentrations for the contaminants expected to be present in groundwater at the site. Only data from those wells and well clusters located either within the area of fill, or downgradient of the fill towards the river, were used (MW-3, MW-4, MW-5, MW-6, MW-7, MW-8, MW-9, MW-10, MW-31, MW-32, MW-33, MW-34, MW-35, and MW-36). These wells were chosen as being representative of the quality of groundwater that would be withdrawn by the groundwater extraction wells. All wells that contained organic contaminants in exceedance of SCGs have been included, with the exception of MW-1S and MW-14D. Well MW-1S, which is located across Route 11 at the apartment complex, contained 44 ppb acetone, a common laboratory contaminant. Use of the data from this well was considered inappropriate. Well MW-14D, which is located across the Susquehanna River, contained 97 ppb acetone and 2 ppb benzene. Inclusion of any data from wells across the river to design a groundwater treatment system is considered impractical.

Samples from the three zones of the aquifer (shallow, intermediate, and deep) contained similar contaminant concentrations.

Therefore, data from all three of the zones were combined to determine representative groundwater concentrations. All representative wells, except for MW-6D (which was not installed until the second phase), were analyzed in both phases of the RI. Both rounds of data were given equal weight in determining the representative groundwater concentration. Average concentrations were calculated for all volatile organic contaminants and phenols that were detected in representative groundwater wells. A total of 11 organic contaminants was detected in the groundwater samples. For wells in which a contaminant was analyzed for but not detected, one-half of the method detection limit was used to make a conservative estimate of the average contaminant concentrations. If a groundwater treatment plant were to be designed based upon average contaminant concentrations, the plant would not be capable of adequately treating groundwater containing above-average concentrations of contaminants. Therefore, the design influent concentration for each contaminant was assumed to be either the maximum detected concentration, or four times the average concentration, whichever was less. This allows the plant to be designed on the highest contaminant concentrations reasonably expected to be collected, without overdesigning the plant on the basis of high contaminant concentrations that would be reduced when combined with groundwater from other areas of the site.

Design influent concentrations of metals and indicator parameters were estimated in a similar manner. These parameters were analyzed for only during the first phase of the RI. The same wells as were used for the organic parameters were used for the metals and indicator parameters. For the metals, as with the organics, one-half of the method detection limit was used as the contaminant level if the metal was analyzed for but not detected. Average indicator parameters were determined by averaging the actual detections among the number of wells in which the analyte was detected. The design concentration for these contaminants was also assumed to be either the maximum detected concentration or four times the average concentration, whichever was less.

For physical parameters such as temperature and pH, average values were used as the design value. Table 10-7 shows the numbers of analyses that were performed for each parameter, the number of detections, and the design concentrations that were determined for each of the groundwater parameters. Several of the inorganics and indicator parameters that appear in the table, such as phenols, copper, cyanide, and sulfide, were detected in only two or three samples and are not expected to be present at significant levels in the extracted groundwater. These parameters will not be addressed in any of the groundwater treatment alternatives at this conceptual design stage.

(2) Groundwater Extraction Rates - The amount of groundwater required to be collected and treated was determined as described in Section 10.3.2, Estimation of Quantities. Actual treatment rates for the system would need to be designed based upon more accurate determinations and would require that the plant be designed with adequate capacity to allow for plant downtime, treatment system recycle streams, and other factors that would affect the capacity of the plant. This is especially important for Alternative 4, which involves significantly more treatment of the groundwater than Alternatives 2 and 3. Operating rates of 170, 350, and 600 gpm were determined for Alternatives 2, 3 and 4, respectively. The groundwater treatment process train for Alternatives 2 and 3 would consist solely of an equalization tank and an automated air stripper discharging either to the river (Alternative 2) or back onto the site (Alternative 3) (Figure 10-6A). The process train for the groundwater treatment facility in Alternative 4 would consist of equalization, precipitation/flocculation/sedimentation, air stripping, and pH adjustment (Figure 10-6B). While the data from the RI are adequate to characterize the site, they are not sufficient for a design-level analysis. To develop the final design of a groundwater treatment system for Alternative 4, treatability studies would have to be a component of the remedial design. Such studies would have to include a more detailed

Table 10 - 7

Summary of Groundwater Treatment Design Data

Parameter	Type	Units	Design Concentration (Influent)
Vinyl Chloride	VOC	μg/L	7
1,1-Dichloroethene	VOC	μg/L	4
1,1-Dichloroethane	VOC	μg/L	6
1,2-Dichloroethene (Total)	VOC	μg/L	125
1,1,1-Trichloroethane	VOC	μg/L	24
Trichloroethene	VOC	μg/L	192
Benzene	VOC	μg/L	4
Tetrachloroethene	VOC	μg/L	3
Toluene	VOC	μg/L	3
Total Xylenes	VOC	μg/L	3
Total Phenols	MCP	μg/L	12
Aluminum	MCP	μg/L	734
Arsenic	MCP	μg/L	12
Barium	MCP	μg/L	131
Calcium	MCP	μg/L	374,000
Chromium	MCP	μg/L	56
Cobalt	MCP	μg/L	25
Copper	MCP	μg/L	13
Iron	MCP	μg/L	13,874
Lead	MCP	μg/L	18
Magnesium	MCP	μg/L	88,578
Manganese	MCP	μg/L	9,130
Nickel	MCP	μg/L	38
Potassium	MCP	μg/L	50,142
Sodium	MCP	μg/L	88,500
Zinc	MCP	μg/L	72
Cyanide	MCP	μg/L	29
Phenols	MCP	μg/L	12
BOD	MISC	mg/L	21
COD	MISC	mg/L	64
Bicarbonate	MISC	mg/L	637
Chloride	MISC	mg/L	113
Hardness	MISC	mg/L	1,640
Ammonia N	MISC	mg/L	1
TKN	MISC	mg/L	3
Alkalinity	MISC	mg/L	638
Acidity	MISC	mg/L	481
Nitrate-Nitrogen	MISC	mg/L	3
Phosphate	MISC	mg/L	1
Oil and Grease	MISC	mg/L	2
TOC	MISC	mg/L	17
TSS	MISC	mg/L	328
TDS	MISC	mg/L	2,580
Sulfate	MISC	mg/L	1,160
Sulfide	MISC	mg/L	1
pH	MISC	SU	7
Conductivity	MISC	μmho/cm	2,600
Temp	MISC	°C	9

TAB10.WK1 09-Jan-92

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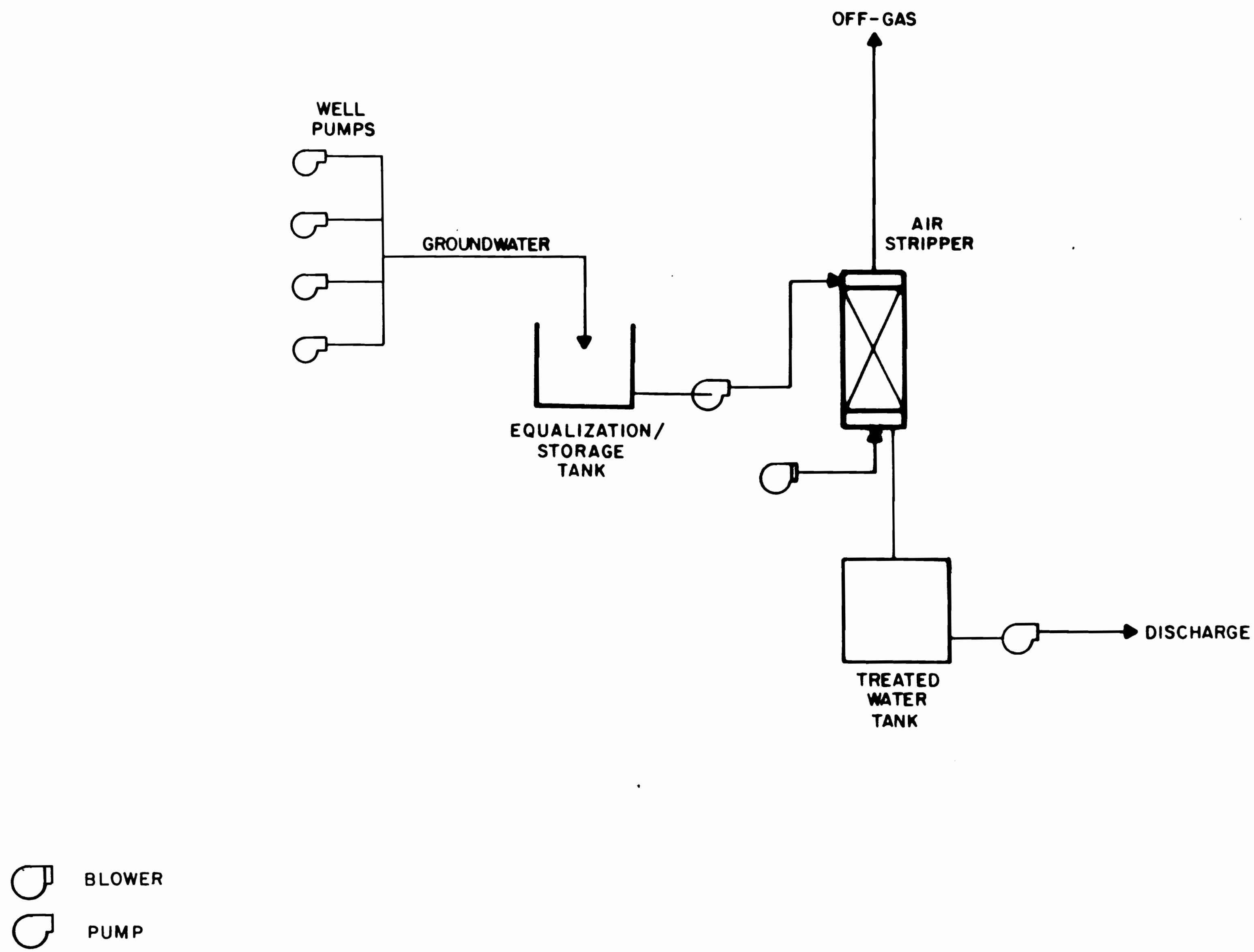

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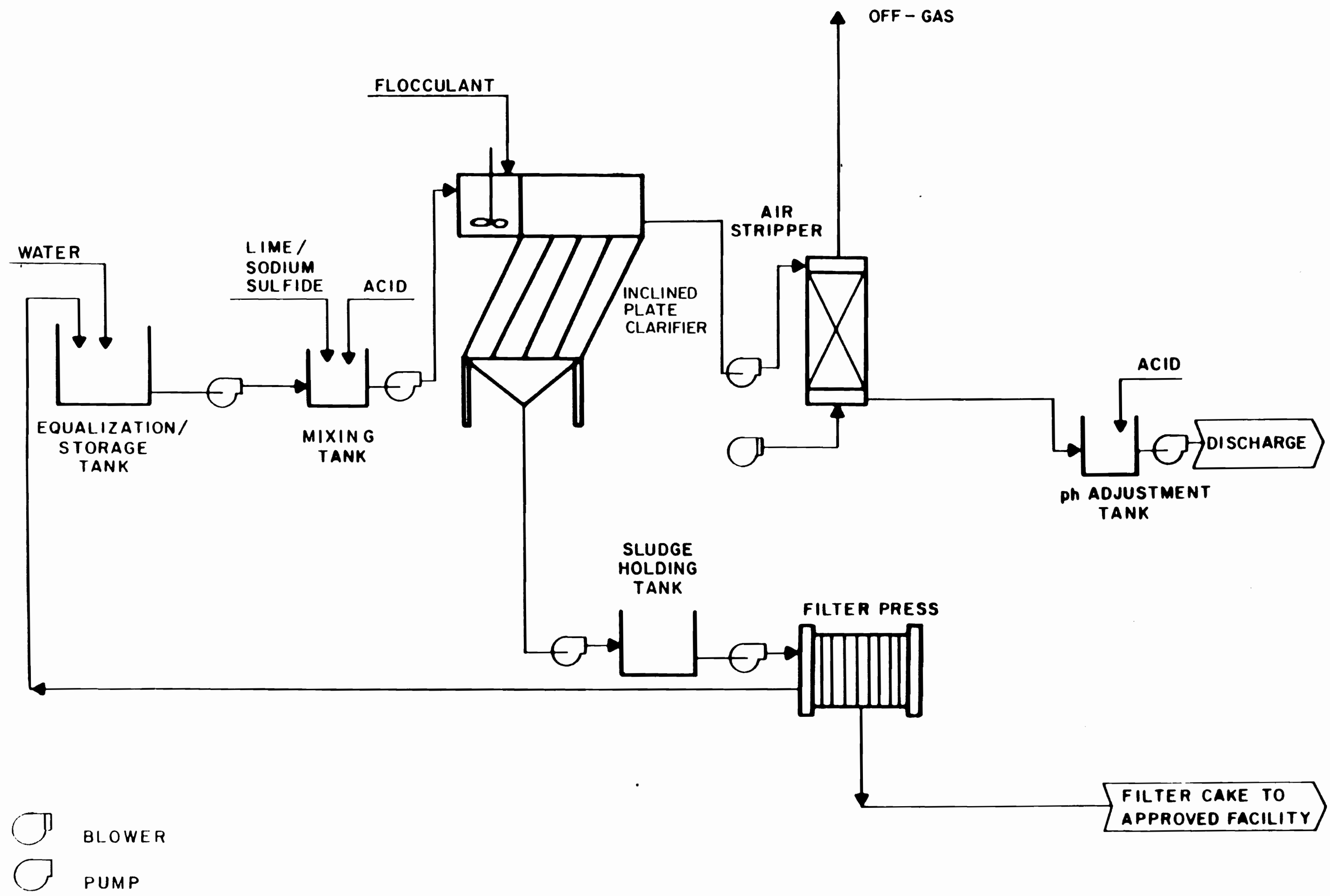
GROUNDWATER TREATMENT SYSTEM FOR ALTERNATIVES 2 AND 3

FIGURE 10-6A

A-4186



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GROUNDWATER TREATMENT SYSTEM FOR ALTERNATIVE 4

FIGURE 10-6B

analysis of groundwater quality and flow rates, as well as bench-scale testing of the treatment unit operations.

Preliminary sizing of the equipment and the basis upon which the equipment was sized are also shown in Table 10-9A, 9B, and 9C. The capital cost estimates for the systems are shown in Tables 10-10A, 10B, and 10C. The basis of the annual O&M cost estimates for groundwater treatment are shown in Tables 10-11A and 10-11B, while Tables 10-12A, 12B, and 12C contain the actual estimates of annual O&M costs.

(3) Discharge Requirements - Two potential discharge limitations were determined for the groundwater collected from the Gorick C&D Landfill site. Because one of the principal remedial action objectives is to prevent migration of TCE and DCE, air stripping would be the most applicable treatment process. The Town of Kirkwood currently uses air stripping to remove TCE, DCE, and other volatile organics from the Town water supply. Effluent limitations for discharge with air stripping were determined on the basis of the Best Professional Judgment (BPJ) methodologies discussed in NYSDEC's Division of Water Technical and Operational Guidance Series (1.3.4). For the metals and other inorganic parameters for which air stripping is not applicable, the most stringent limitation given was used as the effluent limitation. In Table 10-11A, the design concentrations were compared to the effluent limitations to determine which of the contaminants would require treatment for removal. Only three contaminants, all of which are volatile organics, were found to exceed the BPJ limitations. Treatment for Alternatives 2 and 3 will consist of air stripping to meet the BPJ effluent limitations.

Discharge limitations of potential applicability to Alternative 4 would be to remove all contaminants present in the groundwater so as to allow the treated water to meet New York State SCGs for a Class A stream. These would be the most stringent limitation for discharge to the "Class A" Susquehanna River.

TABLE 10 - 9 A

Groundwater Treatment Equipment Sizing & Design Criteria

Alternative 2 (170 gpm)

Equipment Description	Design Criteria	Size
Equalization/Storage Tank	8 Hour Retention Time	82,000 gal
Equalization Tank Agitator	0.15 HP per 1,000 gallon	15 HP
Air Stripper	Water Temperature = 55°F Air to Water Ratio = 30:1	Column Diameter = 3 ft Column Height = 10 ft
Blower	Air to Water Ratio = 30:1	685 cfm
Air Preheater	Preheat Air to 40° F	685 cfm
2 Process Pumps *		170 gpm

TABLE 10 - 9 B

Groundwater Treatment Equipment Sizing & Design Criteria

Alternative 3 (350 gpm)

Equipment Description	Design Criteria	Size
Equalization/Storage Tank	8 Hour Retention Time	168,000 gal
Equalization Tank Agitator	0.15 HP per 1,000 gallon	25 HP
Air Stripper	Water Temperature = 55°F Air to Water Ratio = 30:1	Column Diameter = 3 ft Column Height = 10 ft
Blower	Air to Water Ratio = 30:1	1410 cfm
Air Preheater	Preheat Air to 40° F	1410 cfm
2 Process Pumps *		350 gpm

* - It is assumed that standby pumps are installed.

TABLE 10 - 9 C

Equipment Sizing & Design Criteria

Groundwater Treatment (600 gpm)

Equipment Description	Design Criteria	Size
Equalization/Storage Tank	8 Hour Retention Time	288,000 gal
Equalization Tank Agitator	0.15 HP per 1,000 gallon	45 HP
Mixing Tank	30 Minute Retention Time	18,000 gal
Mixing Tank Agitator	2 HP per 1,000 gallon	36 HP
Inclined Plate Clarifier	Over Flow Rate = 0.25 gal/ft^2	2400 ft^2
Sludge Tank	Sludge Flowrate = 30 gpm 8 hour Retention Time	14,400 gal
Filter Press	Suspended Solids = 1000 mg/L 40% Solids in Filter Cake Cake Density = 70 lb/ft^3 Sludge Dewatered 1 time per shift	90 ft^3
Air Stripper	Water Temperature = 55°F Air to Water Ratio = 45:1	Column Diameter = 4 ft Column Height = 25 ft
Blower	Air to Water Ratio = 45:1	3610 cfm
Air Preheater	Preheat Air to 40° F	3610 cfm
pH Adjust Tank	10 Minute Retention Time	6,000 gal
pH Adjust Tank Agitator	3 HP per 1,000 gallon	20 HP
8 Process Pumps *		600 gpm
2 Sludge Pumps (Clarifier) *		30 gpm
2 Sludge Pumps (Filter Press) *		40 gpm
8 Chemical Metering Pumps *		20 gpm

* – It is assumed that standby pumps are installed.

TABLE 10 -10 A

Capital Cost Estimate

Groundwater Treatment – Alternative 2 (170 gpm)

Item	# Of Items	Unit Cost	Source	Total Cost
EQUIPMENT COSTS				
Equalization/Storage Tank	1	$32,877	1	$32,900
Equalization Tank Agitator	1	$17,054	1	$17,100
Air Stripper with Blower & Preheat	1	$51,370	1	$51,400
Process Pumps	2	$3,082	1	$6,200
SUBTOTAL EQUIPMENT				$107,600
ADDITIONAL DIRECT COSTS				
Equipment Installation (50% of Equipment)				$53,800
Instrumentation and Controls (20% of Equipment)				$21,500
Piping (60% of Equipment)				$64,600
Electrical (10% of Equipment)				$10,800
Buildings (40% of Equipment)				$43,000
Service Facilities and Yard Improvements (20% of Equipment)				$21,500
TOTAL DIRECT COSTS				$322,800

Mobilization/Demobilization (5%)	$16,100
Contractor Markup (25%)	$80,700
Construction, Administration and Design Engineering (15%)	$48,400
Escalation to Midpoint of Construction (5% per year for two years)	$33,100
Bonds and Insurance (5%)	$16,100
Contingency (20%)	$64,600
TOTAL	$581,800
say	$580,000

SOURCES: 1 - URS Estimate

TABLE 10 -10 B

Capital Cost Estimate

Groundwater Treatment – Alternative 3 (350 gpm)

Item	# Of Items	Unit Cost	Source	Total Cost
EQUIPMENT COSTS				
Equalization/Storage Tank	1	$42,226	1	$42,200
Equalization Tank Agitator	1	$42,900	1	$42,900
Air Stripper with Blower & Preheat	1	$72,270	1	$72,300
Process Pumps	2	$4,290	1	$8,600
SUBTOTAL EQUIPMENT				$166,000
ADDITIONAL DIRECT COSTS				
Equipment Installation (50% of Equipment)				$83,000
Instrumentation and Controls (20% of Equipment)				$33,200
Piping (60% of Equipment)				$99,600
Electrical (10% of Equipment)				$16,600
Buildings (40% of Equipment)				$66,400
Service Facilities and Yard Improvements (20% of Equipment)				$33,200
TOTAL DIRECT COSTS				$498,000

Mobilization/Demobilization (5%)	$24,900
Contractor Markup (25%)	$124,500
Construction, Administration and Design Engineering (15%)	$74,700
Escalation to Midpoint of Construction (5% per year for two years)	$51,000
Bonds and Insurance (5%)	$24,900
Contingency (20%)	$99,600
TOTAL	$897,600
say	$900,000

SOURCES: 1 – URS Estimate

TABLE 10 -10 C

Capital Cost Estimate

Groundwater Treatment – Alternative 4 (600 gpm)

Item	# Of Items	Unit Cost	Source	Total Cost
EQUIPMENT COSTS				
Equalization/Storage Tank	1	$70,067	1	$70,100
Equalization Tank Agitator	1	$36,347	1	$36,300
Mixing Tank	1	$7,883	1	$7,900
Mixing Tank Agitator	1	$36,347	1	$36,300
Inclined Plate Clarifier	1	$153,271	1	$153,300
Sludge Tank	1	$6,569	1	$6,600
Filter Press with Feed Pumps	1	$166,409	1	$166,400
Air Stripper with Blower & Preheat	1	$109,479	1	$109,500
pH Adjust Tank	1	$1,313	1	$1,300
pH Adjust Tank Agitator	1	$25,399	1	$25,400
Process Pumps	8	$6,569	1	$52,600
Sludge Pumps	2	$2,190	1	$4,400
Metering Pumps	8	$8,758	1	$70,100
SUBTOTAL EQUIPMENT				$740,200
ADDITIONAL DIRECT COSTS				
Equipment Installation (50% of Equipment)				$370,100
Instrumentation and Controls (20% of Equipment)				$148,000
Piping (60% of Equipment)				$444,100
Electrical (10% of Equipment)				$74,000
Buildings (40% of Equipment)				$296,100
Service Facilities and Yard Improvements (20% of Equipment)				$148,000
TOTAL DIRECT COSTS				$2,220,500

Mobilization/Demobilization (5%)	$111,000
Contractor Markup (25%)	$555,100
Construction, Administration and Design Engineering (15%)	$333,100
Escalation to Midpoint of Construction (5% per year for two years)	$227,600
Bonds and Insurance (5%)	$111,000
Contingency (20%)	$444,100
TOTAL	$4,002,400
say	<u>$4,000,000</u>

SOURCES: 1 – URS Estimate

COSTS\600T11B.WK1 09-Jan-92

TABLE 10 – 11 A

Groundwater Treatment O & M Cost Estimate Basis

Alternatives 2 & 3

Item	Basis	Unit Cost
Operating and Maintenance Labor	1 man 8 hrs per week	$25.00 per hour
Maintenance	3% of Capital Costs	3% of Capital Costs
Insurance and Taxes	1% of Capital Costs	1% of Capital Costs
Maintenance Reserve and Contingency Costs	1% of Capital Costs	1% of Capital Costs
Energy		
–Electricity	HP x .747 x hrs of operation	$0.10 per kWhr
Monitoring Costs		
–Conventional Parameters	Monthly	$300
–HSL Parameters	Quarterly	$1350

TABLE 10 -11 B

Groundwater Treatment O & M Cost Estimate Basis

Alternative 4

Item	Basis	Unit Cost
Operating and Maintenance Labor	2 men 24 hrs per day 7 days per week	$25.00 per hour
Maintenance	3% of Capital Costs	3% of Capital Costs
Insurance and Taxes	1% of Capital Costs	1% of Capital Costs
Maintenance Reserve and Contingency Costs	1% of Capital Costs	1% of Capital Costs
Energy		
-Electricity	HP x .747 x hrs of operation	$0.10 per kWhr
Chemicals		
-Calcium Hydroxide (Lime)	250 mg/l	$60.00 per Ton
-Sulfuric Acid	50 mg/l	$96.00 per Ton (100% Basis)
-Polymer	2 mg/l	$1.25 per lb
Filter Cake Disposal	1000 mg/l sludge 40% solids in cake Cake Density = 70 lb per ft^3	$200.00 per yd^3
Monitoring Costs		
-Conventional Parameters	Monthly	$300
-HSL Parameters	Quarterly	$1350

TABLE 10 – 12 A

Annual O & M Cost Estimate

Groundwater Collection and Treatment – Alternative 2 (170 gpm)

Item	Units	Quantity	Unit Cost	Total Costs
O & M Labor	hrs	416	$25.00	$10,400
Maintenance (3% Cap. Cost)			3%	$17,400
Insurance and Taxes (1% Cap. Cost)			1%	$5,800
Maintenance Reserve and Contingency Costs (1% Cap. Cost)			1%	$5,800
Energy				
-Electricity	kwh	32,629	$0.10	$3,300
Monitoring Costs				
-Conventional Parameters	ea	12	$300	$3,600
-HSL Parameters	ea	4	$1,350	$5,400
TOTAL O & M COST				**$52,000**

TABLE 10 – 12 B

Annual O & M Cost Estimate

Groundwater Collection and Treatment – Alternative 3 (350 gpm)

Item	Units	Quantity	Unit Cost	Total Costs
O & M Labor	hrs	416	$25.00	$10,400
Maintenance (3% Cap. Cost)			3%	$27,000
Insurance and Taxes (1% Cap. Cost)			1%	$9,000
Maintenance Reserve and Contingency Costs (1% Cap. Cost)			1%	$9,000
Energy				
–Electricity	kwh	52,206	$0.10	$5,200
Monitoring Costs				
–Conventional Parameters	ea	12	$300	$3,600
–HSL Parameters	ea	4	$1,350	$5,400
TOTAL O & M COST				**$70,000**

TABLE 10 -12 C

Annual O & M Cost Estimate

Groundwater Collection and Treatment - Alternative 4 (600 gpm)

Item	Units	Quantity	Unit Cost	Total Costs
O & M Labor	hrs	17,472	$25.00	$436,800
Maintenance (3% Cap. Cost)			3%	$120,000
Insurance and Taxes (1% Cap. Cost)			1%	$40,000
Maintenance Reserve and Contingency Costs (1% Cap. Cost)			1%	$40,000
Energy				
-Electricity	kwh	489,434	$0.10	$48,900
Chemicals				
-Calcium Hydroxide	lb	655,491	$0.03	$19,700
-Sulfuric Acid	lb	131,098	$0.048	$6,300
-Polymer	lb	2,622	$1.25	$3,300
Filter Cake Disposal	yd^3	2,000	$200	$400,000
Monitoring Costs				
-Conventional Parameters	ea	12	$300	$3,600
-HSL Parameters	ea	4	$1,350	$5,400
TOTAL O & M COST				**$1,124,000**

In Table 10-8, the design concentrations were compared to the standards for discharge to the Susquehanna River to determine which of the contaminants exceed the limitations. Final effluent limitations for discharge to the Susquehanna River would be determined through the New York State Pollution Discharge Elimination System (NYSPDES) permit program, which is based on the NYSDEC Ambient Water Quality Standards and Guidance Values (AWQSGV), as well as on receiving water flow, effluent loading, and anticipated concentrations in the river. As a conservative approach, the SCGs for a Class A stream, given in Table 5-2 of the RI report, were used as discharge limits to the river. Based on the Class A stream limitations, a treatment plant was conceptually designed. It is expected to remove all contaminants to acceptable discharge levels.

(4) Reintroduction of Treated Groundwater to Aquifer - Groundwater will be moved via forcemain from 4 extraction wells along the northwestern edge of the landfill to a treatment plant upgradient of the filled area. It will then be discharged by gravity outfall to a 5-acre rectangular bermed area constructed just beyond the limits of the 100-year floodplain. The berm, whose top elevation will be at least 3 feet higher than the 100-year flood level, will be 12 feet wide at the crest, so as to allow for movement of service vehicles. Two recharge trenches, within each of which will be a length of 8-inch perforated pipe, bedded in crushed stone, will run the length of the recharge basin bed.

The cost estimate for the bermed recharge area is presented in Table 10-15.

D. Groundwater Monitoring

It is assumed that existing URS monitoring wells outside the landfill may be used for long-term groundwater monitoring. It is also assumed that five new monitoring wells will be constructed. Table 10-13 provides the construction cost per well.

Table 10 - 8

Required Contaminant Removals

Parameter	Type	Units	Design Concentration (Influent)	Class A Stream SCGs	Required Removal
Vinyl Chloride	VOC	µg/L	7	0.3	95.71%
1,1-Dichloroethene	VOC	µg/L	4	0.07	98.25%
1,1-Dichloroethane	VOC	µg/L	6	5	16.67%
1,2-Dichloroethene (Total)	VOC	µg/L	125	5	95.99%
1,1,1-Trichloroethane	VOC	µg/L	24	5	78.92%
Trichloroethene	VOC	µg/L	192	2.7	98.60%
Benzene	VOC	µg/L	4	0.7	82.50%
Tetrachloroethene	VOC	µg/L	3	0.7	72.00%
Toluene	VOC	µg/L	3	5	0.00%
Total Xylenes	VOC	µg/L	3	5	0.00%
Total Phenols	MCP	µg/L	12	1	91.67%
Aluminum	MCP	µg/L	734	100	86.38%
Arsenic	MCP	µg/L	12	0.0022	99.98%
Barium	MCP	µg/L	131	1,000	0.00%
Calcium	MCP	µg/L	374,000		
Chromium	MCP	µg/L	56	50	11.10%
Cobalt	MCP	µg/L	25	5	80.00%
Copper	MCP	µg/L	13	12	4.00%
Iron	MCP	µg/L	13,874	300	97.84%
Lead	MCP	µg/L	18	50	0.00%
Magnesium	MCP	µg/L	88,578	35,000	60.49%
Manganese	MCP	µg/L	9,130	300	96.71%
Nickel	MCP	µg/L	38	1.30E-07	100.00%
Potassium	MCP	µg/L	50,142		
Sodium	MCP	µg/L	88,500		
Zinc	MCP	µg/L	72	300	0.00%
Cyanide	MCP	µg/L	29	5.2	82.01%
Phenols	MCP	µg/L	12	1	91.67%
BOD	MISC	mg/L	21		
COD	MISC	mg/L	64		
Bicarbonate	MISC	mg/L	637		
Chloride	MISC	mg/L	113		
Hardness	MISC	mg/L	1,640		
Ammonia, as N	MISC	mg/L	1	2	0.00%
TKN as N	MISC	mg/L	3		
Alkalinity	MISC	mg/L	638		
Acidity	MISC	mg/L	481		
Nitrate-Nitrogen	MISC	mg/L	3	10	0.00%
Phosphate	MISC	mg/L	1		
Oil and Grease	MISC	mg/L	2		
TOC	MISC	mg/L	17		
TSS	MISC	mg/L	328		
TDS	MISC	mg/L	2,580		
Sulfate	MISC	mg/L	1,160	250	78.44%
Sulfide	MISC	mg/L	1	0.05	96.15%
pH	MISC	SU	7		
Conductivity	MISC	µmho/cm	2,600		
Temp	MISC	°C	9		

TABLE 10 - 13

Gorick C&D Landfill
Capital Cost Estimate

Groundwater Monitoring

Component	Item	Units	Unit Cost	Source	Quantity	Total Cost
1. Well Installation (Per Well)	a) Drilling	LF	$17.00	1	50	$900
	b) 4" SS Riser, Installed	LF	$26.00	1	44	$1,100
	c) 4" SS Screen, Installed	LF	$66.00	1	10	$700
	d) Protective Casing	ea	$165.00	1	2	$300
	e) Drums for Residuals	ea	$44.00	1	5	$200
	f) Standby Time	hr	$99.00	1	4	$400
	g) Pressure Grouting	LF	$8.00	1	20	$200

SUBTOTAL **$3,800**

Mobilization/Demobilization (5%)	$200
Contractor Markup (25%)	$1,000
Construction, Administration and Design Engineering (15%)	$600
Escalation to Midpoint of Construction (5% per year for 2 years)	$400
Bonds and Insurance (5%)	$200
Contingency (20%)	$800

SUBTOTAL **$3,200**

TOTAL PER WELL **$7,000**

SOURCES : 1 - URS Estimate

TABLE 10 - 15

Gorick C&D Landfill
Capital Cost Estimate

RECHARGE AQUIFER

Component	Item	Units	Unit Cost	Source	Quantity	Total Cost
1. Excavation	Lagoon	yd^3	$3.56	1	5,556	$19,800
2. Recharge Trenches	a) Excavate	yd^3	$15.08	1	570	$8,600
	b) Crushed Stone: Purchase	yd^3	$14.00	1	570	$8,000
	c) Crushed Stone: Place	yd^3	$6.50	1	570	$3,700
	d) Haul	yd^3	$3.00	2	570	$1,700
	e) 18" PVC Pipe & Couplings	lf	$124.00	1	960	$119,000
3. Pipe from PTF to Lagoon	a) Trenching	lf	$5.77	1	825	$4,800
	b) 12" PVC Pipe	lf	$31.00	1	825	$25,600
	c) 12" PVC Couplings	ea	$130.00	1	83	$10,800
	d) Elbows, 12"	ea	$205.00	1	2	$400
	e) Tee, 12"	yd^3	$1,050.00	1	1	$1,100
4. Berm	a) Haul	yd^3	$3.00	2	4,800	$14,400
	b) Place and Grade	yd^3	$5.00	2	4,800	$24,000
	c) Compaction	yd^3	$0.28	1	4,465	$1,300
	d) Seed, Mulch and Fertilize	acre	$3,300.00	1	1	$2,900
	e) Gravel Roadway (8")	sy	$6.55	1	1,883	$12,300
5. Extraction System	Extraction Wells	ea	$5,835.00	1&2	4	$23,300
SUBTOTAL						**$281,700**
Mobilization/Demobilization (5%)						$14,100
Contractor Markup (25%)						$70,400
Construction, Administration and Design Engineering (15%)						$42,300
Escalation to Midpoint of Construction (5% per year for 2 years)						$28,900
Bonds and Insurance (5%)						$14,100
Contingency (20%)						$56,300

SUBTOTAL **$226,100**

TOTAL **$510,000**

SOURCES :
1 - 1992 Means
2 - URS Estimate
3 - Ellery Landfill Actual Construction Cost

Annual O&M costs for the groundwater monitoring for any alternative will be dependent on the technologies involved. Monitoring for Alternative 1, which does not have groundwater extraction and treatment, will be more extensive than for the other alternatives. Groundwater monitoring of both upgradient and downgradient wells is proposed to include 13 existing monitoring wells (MW-1S, 2S, 3S, 4S, 4I, 5S, 5I, 5D, 6S, 6I, 6D, 11S, 11I). In addition, three surface water samples should be collected from the Susquehanna River -- one upstream, one adjacent to the landfill, and one downstream. It is assumed that all samples will be collected annually and analyzed for the entire TCL as given in the New York State Analytical Services Protocol (ASP). QA/QC samples have been added. Labor charges for a data auditor to perform QA/QC validation of the laboratory results has also been included. Contingencies, administration and engineering, and bonds and insurance have been added for future evaluations and report preparation. Table 10-14 presents the annual O&M costs for monitoring under Alternative 1.

For Alternatives 2, 3, and 4, which include groundwater extraction and treatment, fewer groundwater samples will be collected. No surface water sampling is proposed for these alternatives. Annual sampling and TCL analysis of 10 existing monitoring wells (MW-1S, 2S, 3S, 4S, 4I, 6S, 6I, 6D, 11S, 11I) as well as QA/QC samples is proposed. Table 10-17 presents annual O&M costs for monitoring under Alternatives 2, 3, and 4.

The cost estimates for groundwater monitoring have been combined in Table 10-17 for each of the four alternatives.

E. Fencing

A chain link fence will be provided around the new installation to prevent unauthorized entry. The capital cost is given in Table 10-16. Maintenance cost is minimal and has been ignored.

TABLE 10 - 14

Gorick C&D Landfill
Annual O&M Cost Estimate

Longterm Monitoring (Alternative 1)

Component	Item	Units	Unit Cost	Source	Quantity	Total Cost
1. Sampling	a) Labor	Mandays	$500.00	1	4	$2,000
	b) Equipment	Misc.	$200.00	1	1	$200
2. Analysis	a) TCL	sample	$2,000.00	2	20	$40,000
	b) QA/QC Review	sample	$400.00	1	20	$8,000

NOTE: Involves annual sampling and analysis of groundwater and surface water.

SUBTOTAL **$50,200**

Administration, Engineering (15%)	$7,500
Bonds and Insurance (5%)	$2,500
Contingency (10%)	$5,000

SUBTOTAL **$15,000**

TOTAL **$65,200**

Longterm Monitoring (Alternatives 2,3 and 4)

Component	Item	Units	Unit Cost	Source	Quantity	Total Cost
1. Sampling	a) Labor	Mandays	$500.00	1	4	$2,000
	b) Equipment	Misc.	$200.00	1	1	$200
2. Analysis	a) TCL	sample	$2,000.00	2	13	$26,000
	b) QA/QC Review	sample	$400.00	1	13	$5,200

NOTE: Involves annual sampling and analysis of groundwater.

SUBTOTAL **$33,400**

Administration, Engineering (15%)	$5,000
Bonds and Insurance (5%)	$1,700
Contingency (10%)	$3,300

SUBTOTAL **$10,000**

TOTAL **$43,400**

SOURCES: 1 - URS Estimate
2 - Recent Laboratory Quote

TABLE 10 - 16

Gorick C&D Landfill
Capital Cost Estimate

FENCING

Component	Item	Units	Unit Cost	Source	Quantity	Total Cost
1. Perimeter Fence	a) Fence	lf	$15.45	1	4,020	$62,100
	b) Gate, 20'	ea	$725.00	1	1	$700
	c) Gate, 3'	ea	$235.00	1	2	$500
	c) Corner Posts	ea	$86.00	1	10	$900
SUBTOTAL						**$64,200**

Mobilization/Demobilization (5%)	$3,200
Contractor Markup (25%)	$16,100
Construction, Administration and Design Engineering (15%)	$9,600
Escalation to Midpoint of Construction (5% per year for 2 years)	$6,600
Bonds and Insurance (5%)	$3,200
Contingency (20%)	$12,800

SUBTOTAL **$51,500**

TOTAL **$120,000**

SOURCES :

1 - 1992 Means
2 - URS Estimate
3 - Ellery Landfill Actual Construction Cost

TABLE 10 – 17

Gorick C&D Landfill
Cost Estimates for Remedial Alternatives

ITEM	ALT. 1	ALT. 2	ALT. 3	ALT. 4
CAPITAL COSTS				
1. Modified Part 360 Cap				5,970,000
2. Groundwater Collection and Transfer		80,000	80,000	130,000
3. Groundwater Treatment		580,000	900,000	4,000,000
4. Groundwater Monitoring		35,000	35,000	35,000
5. Aquifer Recharge			470,000	
6. Fencing		120,000	120,000	120,000
TOTAL CAPITAL COST		$815,000	$1,605,000	$10,255,000
OPERATIONS AND MAINTENANCE COSTS				
1. Modified Part 360 Cap				$72,500
2. Groundwater Collection and Transfer		$4,000	$4,000	$6,500
2. Groundwater Treatment		$52,000	$70,000	$1,124,000
3. Longterm Monitoring	$65,200	$43,400	$43,400	$43,400
TOTAL ANNUAL O & M COST	$65,200	$99,400	$117,400	$1,246,400
PRESENT WORTH OF O & M COST	$616,000	$939,000	$1,109,000	$11,771,000
PRESENT WORTH OF TOTAL COST (CAPITAL PLUS O & M)	$616,000	$1,754,000	$2,714,000	$22,026,000

NOTE: Present worth analysis is based on a 30–year performance period at 10% interest per year

CAPSUM.WK1

10.4 Comparison of Alternatives

The following is a comparative evaluation of the alternatives described above. The purpose is to determine which alternative best meets the remedial action objectives defined in Section 8.3. Results of the weighted-matrix scoring system and cost estimates are used in this analysis.

10.4.1 Short-term Impacts and Effectiveness

The highest-scoring alternative in this category is Alternative 1, No Action, although none of the alternatives considered is expected to cause significant short-term community or environmental impacts that cannot be easily mitigated.

10.4.2 Long-term Effectiveness and Permanence

The highest-scoring alternative in this category is Alternative 3. This is so because under this option groundwater is more aggressively treated than under any other option. Alternative 1, the no-action option, scored the lowest under this category.

10.4.3 Reduction in Toxicity, Mobility, and Volume of Contaminants

The IRMs, which will be in place under any alternative, including the no-action alternative, supply a baseline level of reduction in toxicity, mobility, and volume of contaminants. Alternative 3, in which groundwater is subjected to retreatment, is the highest-scoring in this category.

10.4.4 Implementability

All alternatives can be implemented with relative ease. The most easily implementable alternative is the no-action option (Alternative 1).

10.4.5 Compliance with SCGs.

Alternative 3 and 4 comply with more SCGs than do the other two alternatives. All, however, meet the action-specific and location-specific SCGs.

10.4.6 Overall Protection to Human Health and the Environment

Alternative 4, which includes capping and groundwater treatment, is considered to be the most completely protective of human health and environment of the four alternatives considered. This is so because not only is remediation of contaminated groundwater addressed by this alternative, but the secondary RAO involving surficial soils is also addressed. Alternative 1 (No Further Action) is considered the least protective, although a certain level of protection is offered by the IRMs, considered to be part of this alternative.

10.4.7 Cost

The highest-scoring alternative from a cost standpoint is Alternative 1 (No Further Action). The highest cost and therefore the lowest scoring alternative is Alternative 4 (Modified Part 360 cap plus groundwater treatment).

11. CONCLUSIONS

11.1 Recommended Alternative

All four alternatives successfully accomplish the first Remedial Action Objective, reduction in levels of TCE and DCE in groundwater. Alternatives 2, 3, and 4 achieve both Remedial Action Objectives. Achieving the second Remedial Action Objective, reducing the potential flow of contaminated groundwater offsite and to the river, would therefore be the only additional benefit for the costs associated with Alternatives 2 through 4. For the following reasons, such expenditure appears to be unjustified:

- o Significant contaminant levels leaving the site have been measured only immediately adjacent to the site.

- o The quantity of groundwater leaving the site has been (crudely) estimated to be small.

- o The effect of the IRMs on the capture radius of the Town well field has not been determined. When the next IRM unit goes on line it will allow removal of almost twice the quantity of water presently removed from the aquifer. To the extent that additional water is pulled from the aquifer, less groundwater will leave the site via flow into the river.

- o No downgradient effect of contaminants leaving the site was found during the RI. Alternative 1 therefore addresses the only well documented threat to human health or the environment from the Gorick C&D landfill.

These facts, in addition to the relatively high cost associated with the implementation of the higher scoring alternatives, make Alternative 1 the recommended alternative.

This recommendation does not take into account the soil contamination at this site. Soil contamination is not within the scope of this Feasibility Study, but will be addressed at landfill closure.

11.2 Conceptual Design

The recommended alternative is Alternative 1, No Further Action. This alternative involves continuation of the existing IRMs without the addition of further remedial measures. No additional conceptual design is required to define this alternative or to prepare for any future action. The groundwater monitoring capital costs in this alternative are a contingent item.

FS REFERENCES

1. NYSDEC, Technical and Administrative Guidance Memorandum on the Selection of Remedial Actions, TAGM-HWR 89-4030, September 13, 1989.

2. USEPA Office of Solid Waste and Emergency Response, "Streamlining the RI/FS for CERCLA Municipal Landfill Sites", OSWER Directive #9355.3-11FS, September 1990.

3. R.S. Means Company, Inc., <u>Sitework Cost Data</u> 10th Annual Edition, 1991.

4. Draft Final Remedial Investigation of the Gorick C&D Landfill, URS Consultants, Inc., October 1991.

5. William Harrington, Binghamton-Johnson City Sewage Treatment Plant to James Lanzo, URS Consultants, Personal Communication, Novem,ber 12, 1991.

6. Letter from NYSDEC regarding elements to be considered for the feasibility study after the review of Gorick site Phase I and Phase II Remedial Investigation data by NYSDEC dated October 8, 1991.

7. K. McCue, NYSDEC to G. Ostertag, Town of Ramapo, September 20, 1991. RE: NYSDEC Review Comments on the Ramapo Landfill Feasibility Study.e Memorandum on the Selection of Remedial Actions, TAGM-HWR 89-4030, September 13, 1989.

8. USEPA Office of Solid Waste and Emergency Response, "Streamlining the RI/FS for CERCLA Municipal Landfill Sites", OSWER Directive #9355.3-11FS, S

APPENDIX S

APPENDIX S

The groundwater flows at the Gorick Landfill site were evaluated using analytical methods of calculation. The effort was focused on obtaining the groundwater withdrawal rates necessary to prevent the off-site migration of the contaminated groundwater.

The withdrawal rates were estimated for the different combinations of three remedial technologies:

- **Capping**: soil cap and Part 360 cap

- **Vertical cut-off walls**: fully enclosing slurry wall, downgradient slurry wall, and short slurry wall

- **Groundwater withdrawal/recirculation**: collection wells, infiltration ponds

A number of parameters had to be used in the calculation process. The values of those parameters were estimated based on the available sources and can be found in Section B of the calculation package. The majority of the required information was found in the following publications:

- "Remedial Investigation of the Gorick C&D Landfill," October 1991, by URS Consultants

- "Simulation of Ground-Water Flow and Infiltration from Susquehanna River to Shallow Aquifer at Kirkwood and Conklin, Broome County, New York," by USGS

As mentioned earlier, those parameters were utilized to analytically solve the groundwater flow problems on site. It has to be noted that the analytical methods of solving such problems are based on numerous simplifying assumptions, such as:

- o homogenous, isotropic aquifer properties
- o infinite or semi-infinite aquifer extent
- o straight line boundaries
- o horizontal flow

and others. Because of that, they cannot be treated as exact representations of the field problems, which usually are much more complicated. However, the analytical methods are useful in obtaining initial, rough estimates of the solutions for many field problems. Therefore, the numbers obtained in this calculation package have to be treated as approximate (order-of-magnitude estimates) and are subject to change upon the use of more exact methods (numerical groundwater flow models or field experiments).

<u>Withdrawal Rates Without the Use of Cut-Off Walls</u>

The objective here was to determine the withdrawal rates necessary to capture the groundwater from the landfill area (or its part) without the use of vertical cut-off wells. The groundwater from the site would be intercepted by a series of collection wells located between the site and Susquehanna River and/or Town Well Field.

The desired withdrawal rates were estimated using the analytical solutions for the case of wells in the uniform flow. The magnitude and direction of that flow were assumed after the USGS model. Four scenarios were constructed by creating different combinations of groundwater withdrawals and recirculation of treatment. This approach neglected the presence of the river as well as the Town Well Field. Next, the groundwater withdrawal rates obtained using the above procedure were utilized to determine the well capture zones for the case that takes into account the effects of the Town Well Field and the Susquehanna River. This was done utilizing the method of images. The location of the aquifer

- till boundary was assumed after the USGS model and the boundary was approximated by a straight line. The Susquehanna River was assumed to be a constant head boundary, located parallel to the aquifer - till interface. The constant head boundary was assumed to be at the center of the river. This was done in order to account for the effects of the river not being fully connected to the aquifer (see USGS model). The Town Well Field was approximately with a single well, located roughly in the middle of the well field. Its withdrawal rate was kept at 1.1 HGD, after the findings of the RI report. The area for which the equipotential lines were obtained was chosen to contain the entire landfill as well as the Town Well Field. For that area, the equipot lined were plotted based on the 100 x 100 ft grid. The plots were then used to obtain the well capture zones.

The detailed descriptions of the procedure is presented in Section D of the calculation package.

The following results were obtained based on the simulations:

- Scenario 1 - A withdrawal well was placed between the northern part of the site and the river. It was estimated that the well must pump about 150 gpm in order to intercept the groundwater from the north-most 400 ft of the landfill area, (this includes the infiltration water).

- Scenario 2 - Three withdrawal wells were placed between the river and Town Well Field and the landfill. It was estimated that the withdrawal rate needed to intercept the groundwater from the entire site is about 450 gpm (this includes the infiltration water).

- Scenario 3 - A pair of withdrawal/injection wells was placed in the northern [portion of the site. It was determined that to create an enclosed groundwater recirculation area encompassing the northern portion of the site, the withdrawal/injection rate must be about 320 gpm (this scenario is impossible to achieve if the infiltration is taken into account).

- o Scenario 4 - Three pairs of withdrawal/injection wells were placed on site. It was determined that the withdrawal/injection rate necessary to create a recirculation zone over the entire site is about 960 gpm (this scenario is impossible if infiltration is considered).

Scenarios 3 and 4 involve the recirculation of the extracted groundwater. This can be accomplished in several ways, (utilizing for example).

- o Injection Wells
- o Horizontal Drains
- o Infiltration Chambers
- o Infiltration Trenches
- o Infiltration Ponds

Here, only the infiltration trenches and ponds were considered. Their effectiveness depends mostly on the hydraulic conductivity of the matrix in which they are confined. At the Gorick site, the trenches and ponds would probably be excavated in fill, which is very inhomogeneous, and therefore, the hydrologic conductivity is difficult to determine. Also, the infiltration trenches and/or ponds utilized onsite would have to be fairly shallow to ensure that their bottoms remain above the groundwater table.

The details of the calculations can be found in Section D. A conservative "K" value for the fill was assumed (3E-4 to 3E-3 cm/sec). Also, the calculations were done based on the water depth of 5 ft. The results indicate the area of infiltration ponds of about 0.5 to 5.0 acres for the northern part of the landfill or 2.0 to 14.0 acres for the entire site.

If ten (10) foot wide trenches are utilized, from 3 to 30 trenches will have to be constructed along the area that require the groundwater recirculation.

Withdrawal Rates with the Use of Cut-Off Walls

The purpose here was to estimate withdrawal rates necessary to intercept groundwater from the landfill site with the aid of vertical flow barriers (slurry walls). Several alternatives can be considered, depending on the degree of enclosure and type of capping. They were treated using a general water balance method. The withdrawal wells were assumed to intercept all flows entering the site.

- Flow from the upgradient part of aquifer
- Seepage through slurry wall
- Recharge from infiltration
- Upward leakage through till
- Flow from the river to the collection wells

For each case, the applicable components were calculated based on site dimensions, capping type, slurry wall properties, and aquifer parameters. The details can be found in Section E of the calculation package.

The withdrawal rates vary widely for different alternatives: from about 10 GPM for full enclosure and Part 360 cap to about 100-250 GPM for a short slurry wall and withdrawal wells along the river.

In addition, the influence of the slurry wall on the town wells was assessed. It was determined that even for the most conservative case the operation of the Town Well Field will not be disrupted by the construction of a slurry wall. The details can be found in Section C of the calculation package.

Summary

The withdrawal rates for different combinations of remedial technologies vary, depending on scenario, from 10 GPM to 450 GPM.

a) Fully enclosing slurry wall, Part 360 cap
Q = 10 GPM

b) Fully enclosing slurry wall, soil cap
Q = 30 GPM

c) Downgradient slurry wall, Part 360 cap
Q = 40 GPM

d) Downgradient slurry wall, soil cap
Q = 70 GPM

e) Short slurry wall, Part 360 cap
Q = 80 - 220 GPM

f) Short slurry wall, soil cap
Q = 100 - 250 GPM

g) No slurry wall, groundwater intercepted from the northern portion of the landfill
Q = 150 GPM

h) No slurry wall, groundwater intercepted from the entire site
Q = 450 GPM

i) No slurry wall, groundwater recirculated in the northern portion of the landfill
Q = 320 GPM

j) No slurry wall, groundwater recirculated over entire site
Q = 960 GPM

Note: Flows rounded to nearest higher 10 GPM

SUMMARY OF FLOW TABLE

a) With the use of slurry walls

Containment/Capping	**Part 360 Cap**	**Soil Cap**
Fully enclosing slurry wall	10	30
Downgradient slurry wall	40	70
Short slurry wall	80-220	100-250

b) Without the use of slurry walls

Area	Recirculation	Withdrawal
Northern Portion	320	150
Entire Site	960	450

Note: Flows in GPM

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B.1) The following parameters will be used in calculations

Q_{tw} - Town Well Field discharge rate (B.2)
H_o - Avg. aquifer sat. thickness (B.3)
T - Avg. aquifer transmissivities (B.4)
K - Avg. hydraulic conductivities (B.5)
N - Recharge from infiltration (B.6)
R - Wells radius of influence (B.7)
N_{up} - Upward leakage (B.8)
D - Distance between Town Well Field and Landfill (B.9)
K_2 - Hydr. conductivity of till (B.10)
N_{360} - Infiltr. rate through P360 cap (B.11)
N_{SOIL} - Infiltr. rate through soil cap (B.11)
A - Landfill area (B.12)
P - Landfill perimeter (B.12)
TH_{SLW} - Thickness of slurry wall (B.13)
K_{SLW} - Hydr. conductivity of the slurry wall material (B.13)
T_I - Transmissivity of the upgr. inflow area (B.14)
B - width of the upgradient inflow area (B.15)
i - Avg. hydr. gradient of the inflow area (B.16)
h_0 - Head in Susquehanna River (B.17)
L - Distance from the River to landfill edge (B.18)

REF. PAGE

B.2) Withdrawal rate of Town Well Field (Q_{tw})
The rate was assumed after section 3.6.3. of the "Draft Remedial Investigation of the Gorick C&D Landfill" by URS consultants, April 1991 (Hereafter refered to as RI). See sheet BB-1

$$Q_{tw} = 1.1 \text{ MGD} \cong 150,000 \text{ FT}^3/\text{D}$$

B.3) Avg. aquifer saturated thickness (H_0)
The saturated thickness of the aquifer in the vicinity of the site varies between 0 and 70 ft. The source of this information is a groundwater model performed by USGS, published as "Simulation of Ground-Water Flow and Infiltration from the Susquehanna River to Shallow Aquifer at Kirkwood and Conklin, Broome County, NY", Report 86-4123 (Hereafter refered to as USGS model), Fig 5. See sheet BB-2. For the purpose of this calc, the avg. value of 50 ft was assumed based on the areal distribution

$$H_0 = 50 \text{ FT}$$

B.4) Avg. aquifer transmissivity (T)
The USGS model, Fig 15, indicates the values of transmissivity in the vicinity of the site as from less than 1,000 ft²/day to 250,000 ft²/day. The majority of the values for the area are 10,000 to 250,000 ft²/day. three values were assumed for the calculations: min, avg & max.

$$T_1 = 10,000 \text{ FT}^2/\text{D}$$
$$T_2 = 130,000 \text{ FT}^2/\text{D}$$
$$T_3 = 250,000 \text{ FT}^2/\text{D}$$

Shee sheet BB-3.

REF. PAGE

B.5) Avg hydraulic conductivities (K)
Based on avg. aquifer transmissivities and aquifer saturated thickness from sections B.3 & B.4, the hydraulic conductivities were calculated as follows

$K_1 = T_1/H_0 = 10{,}000/50 = 200$ FT/D

$K_2 = T_2/H_0 = 130{,}000/50 = 2{,}600$ FT/D

$K_3 = T_3/H_0 = 250{,}000/50 = 5{,}000$ FT/D

The RI section 3.8.4. shows values between 4E-3 cm/s and ≥ 3E-2 cm/s (11 to ≥ 85 FT/D) as measured by slug tests. Many values are given as ≥3E-2 cm/s because the recovery was to fast to interpret the test, suggesting a conductivity that could be much higher than 3E-2 cm/s. Because of that, the values from the USGS model were chosen as being more representative of the typical values of "K" for this aquifer.

B.6) Recharge (N)
Average recharge from precipitation was assumed after USGS model, page 20. See sheet BB-4.

$N = 22$ IN/YR $= 0.005$ FT/D

B.7) Wells' radius of influence (R)
Radius of influence was calculated using Lembke's formulae as given in "Hydraulics of Groundwater", J. Bear, 1979, p 306. See sheet BB-5.

$$R = H_0 \sqrt{\frac{K}{2N}}$$

Which is valid for any consistent set of units

Based on sections B.3, B.5 & B.6:

$$R_1 = 50 \cdot (200/2 \cdot 0.005)^{1/2} = 7071 \text{ FT}$$

$$R_2 = 50 \cdot (2{,}600/2 \cdot 0.005)^{1/2} = 25{,}495 \text{ FT}$$

$$R_3 = 50 \cdot (5{,}000/2 \cdot 0.005)^{1/2} = 35{,}355 \text{ FT}$$

B.8) Upward leakage (N_{UP})
Upward leakage to the aquifer from the underlying strata was assumed after the USGS model, p 20. See sheet BB-4.

$$N_{UP} = Q_{UP} / A$$

Q_{UP} - Upward flowrate [L^3/T]
A - Area of study [L^2]

$$Q_{UP} = 0.006 \text{ MGD} = 802 \text{ FT}^3/\text{D}$$

$$A = \frac{Q_N}{N}$$

N - Infiltration [L/T]
Q_N - Infiltration flowrate [L^3/T]

$$A = \frac{1 \text{ MGD}}{22 \text{ IN/YR}} = \frac{133{,}672}{0.005} \frac{\text{FT}^3/\text{D}}{\text{FT/D}} = 2.67E+7 \text{ FT}^2$$

$$N_{UP} = \frac{802 \text{ FT}^3/\text{D}}{2.67E+7 \text{ FT}^2} = 0.00003 \text{ FT/D}$$

B.9) Distance between Town wells and the landfill edge (D)
This was determined from the topo map. The Town well field was represented as a single well located roughly in the middle of a well field. The slurry wall was assumed

REF. PAGE

to be a straight line along the western edge of fill. See sheet BB-6.

$D = 350$ FT

B.10) Hydr. Conductivity of till (K_2)
Hydr. conductivities of till were assumed after "Foundation & Earth Structures" Design Manual 7.02 of the Naval Facilities Engineering Command, page 7.2-39. See sheet BB-7.

K range is 5E-5 to 5E-7 ft/min, which corresponds to 0.072 to 0.00072 ft/day. A conservative value of

$K_2 = 0.15$ FT/D

was assumed

B.11) Infiltration throug soil cap and part 360 cap (N_{SOIL}, N_{360})
Infiltration through the soil cap was assumed equal to the natural infiltration
See sheet BB-4

$N_{SOIL} = 0.005$ FT/D

Infiltration through the part 360 cap was assumed to be 10% of the natural infiltration

$N_{360} = 0.1 * N = 0.1 * 0.005$ FT/D

$N_{360} = 0.0005$ FT/D.

REF. PAGE

B.12) Landfill area (A) and perimeter (P)
Based on the topo map of the fill extent, the landfill was approximated as a rectangle 1200 × 800 ft. See sheet BB-6

$$A = 1{,}200 * 800 = 960{,}000 \ FT^2$$
$$P = 2 * (1{,}200 + 800) = 4{,}000 \ FT$$

B.13) Slurry wall thickness (TH_{SLW}) and hydr. cond. of the slurry wall material (K_{SLW})
The thickness of the slurry wall was assumed to be

$$TH_{SLW} = 3 \ FT$$

The conductivity of the slurry wall material was indicated as being ≈1E-7 cm/s ("Soil Mechanics Design Seepage Control" USACE Manual) See sheet BB-8.

Here, a value of one order of magnitude higher was assumed to account for cracks etc.

$$K_{SLW} = 1E{-}6 \ cm/s = 3E{-}3 \ FT/D$$

B.14) Transmissivity of the inflow area (T_I)
The area between the Five Mile Point and the till mound serves as an inflow route. The transmissivity of aquifer in that location was taken from the USGS model, Fig 15. See sheet BB-3.

$$T_I = 0 - 1{,}000 \ FT^2/D$$

Assume

$$T_I = 1{,}000 \ FT^2/D$$

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B.15) Width of the inflow area (B)
Width of the inflow area was assumed after USGS model Fig 23. See sheet BB-9

$B = 400$ FT

B.16) Hydr. gradient in the inflow area (i)
The hydr. gradient was assumed after USGS model, Fig 23. See sheet BB-9

$i \cong 0.010 - 0.020$

Assumed value was

$i = 0.015$

B.17) Head in Susquehanna River (h_o)
Head in the river will be assumed to be equal to the initial sat. depth of the aquifer

$h_o = H_o = 50$ ft

See B.3

B.18) Distance from the river to the landfill edge, north of the Tam Well Field (L)

This distance was determined based on topo map. See sheet BB-10

$L = 1000$ ft

B.19) Distance along the northern edge of landfill (B_w) - length of well line

From sheet BB-10

$B_w = 1,200$ FT

Sheet BB-1

per day and provide potable water for up to 100,000 people in the Town of Binghamton and neighboring communities.

The major groundwater user in the landfill area, though, is the Town of Kirkwood, utilizing wells on the property immediately adjacent to the landfill. These wells pumped an average of 1.1 million gallons per day in 1990 supplying water to the town. Approximately three quarters of the water is used by industry.

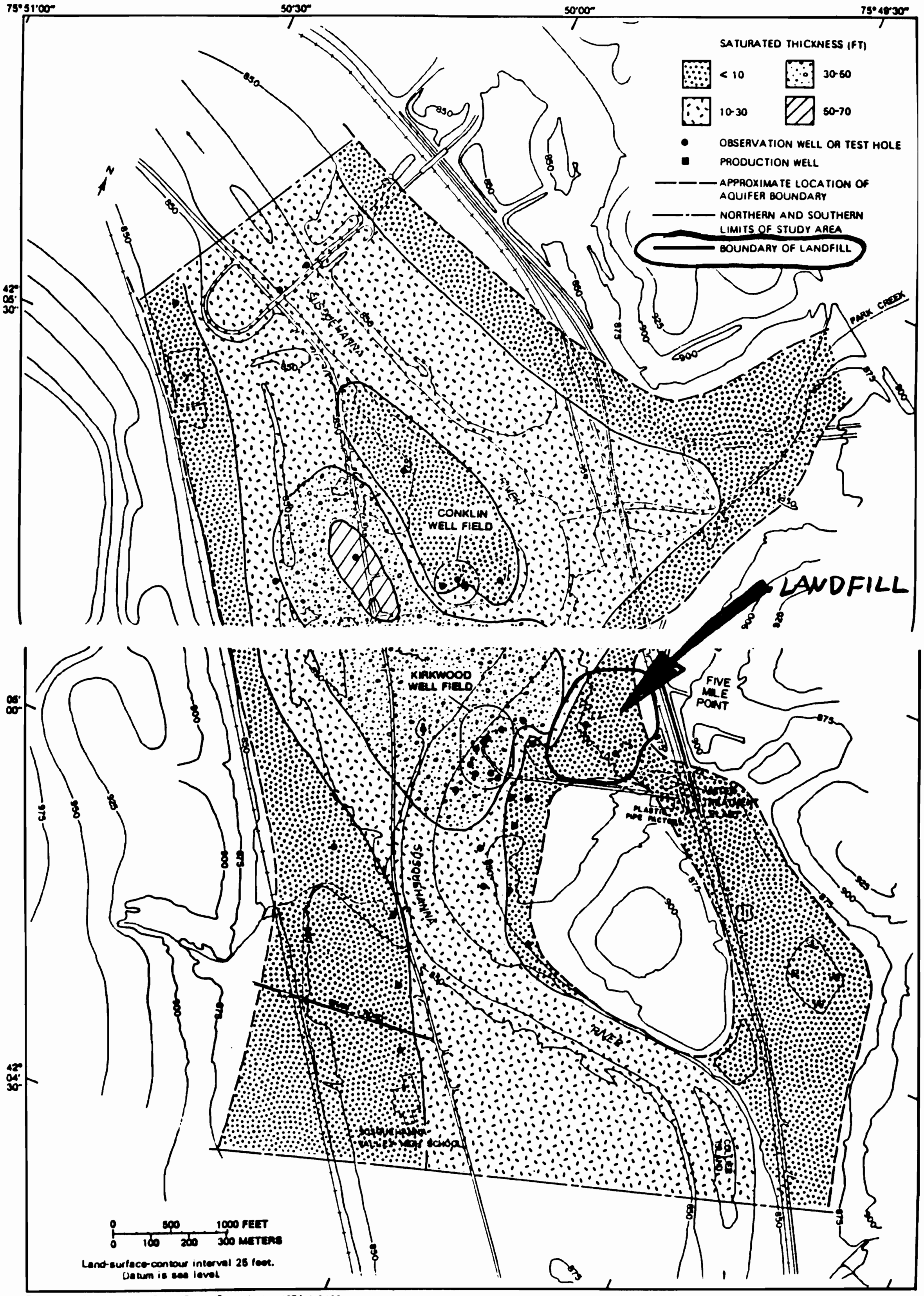
A number of other groundwater wells are located in the vicinity of the landfill. The Town of Conklin, on the opposite side of the river from the Town of Kirkwood, maintains one of its four municipal wells approximately three quarters of a mile northwest of the landfill (the other three wells are located at significant distances from the landfill, elsewhere in the town). This well pumps approximately 200 gallons per minute (when active) from the alluvial aquifer. The total withdrawal averages between 35,000 and 60,000 gallons per day. Approximately 2500 people are served by the town's four wells (Ref. 24).

There are potentially one or two residences still using private wells in the Town of Conklin within several thousand feet of the landfill, but on the opposite side of the Susquehanna River (Ref. 24).

The American Pipe and Plastics plant maintains two groundwater wells several hundred feet south of the Kirkwood wells as sources of non-contact cooling water. Only one (APP-N, Figure 1-3) is currently used. This well is the ultimate source of the effluent stream of cooling water discharged by the plant to the Susquehanna (Section 3.6.1). APP-N draws from 150 to 190 gallons per minute nearly 24 hours a day and is screened 30 to 50 feet below grade.

Though most of the residents in the landfill area are now on municipal water, one residence immediately north of the landfill still

Sheet BB-2



Base from Susquehanna River Basin Commission, 1974 1:2400

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Figure 5.--Saturated thickness of aquifer in Kirkwood-Conklin area.

sheet B

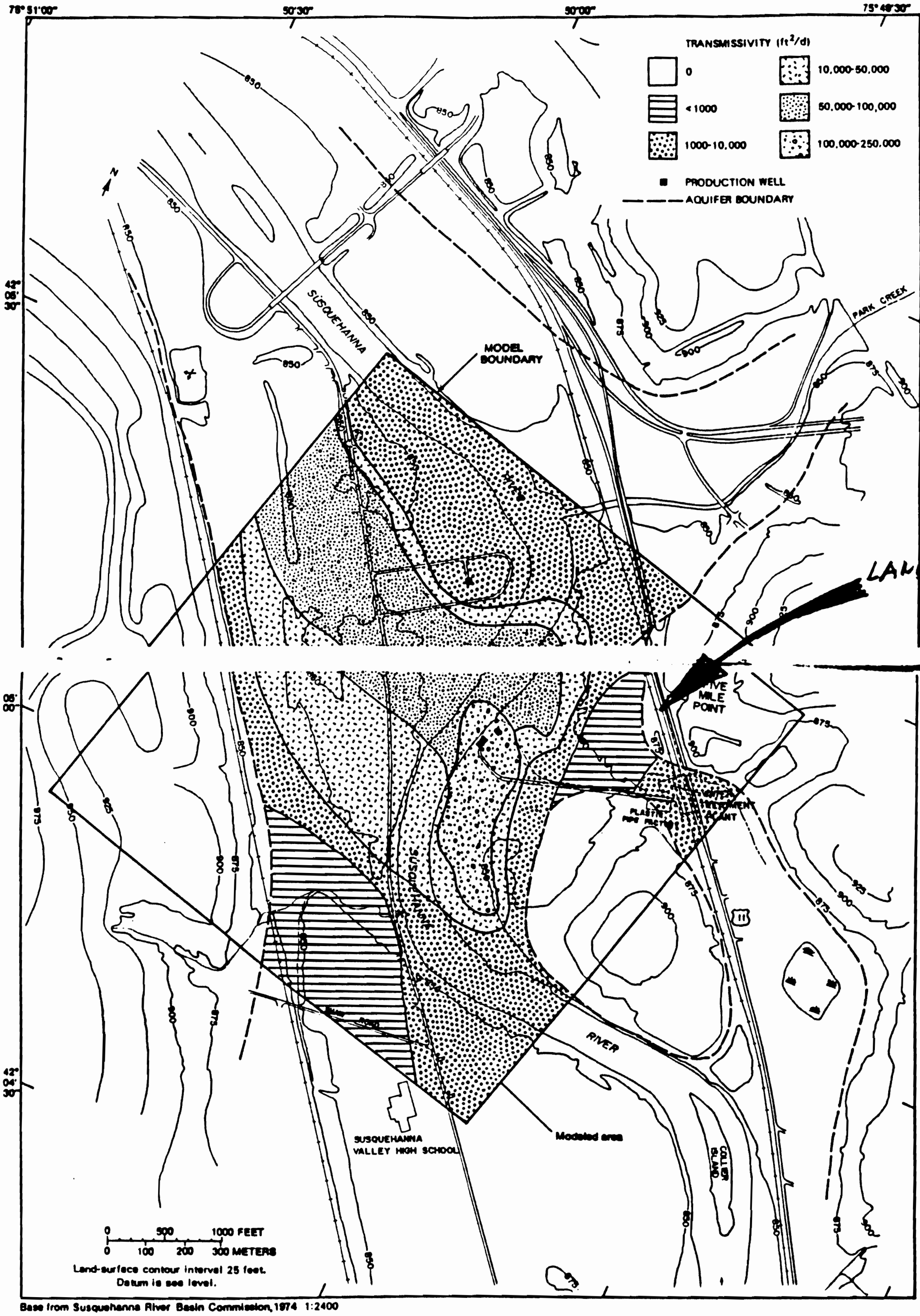


Figure 15.--Aquifer transmissivity values used in model simulations.

Sheet BB

from the aquifer to (1) production wells in Kirkwood and Conklin, (2) the northern (downvalley) part of the aquifer beyond the boundary of the study area, (3) the Susquehanna River, (4) tributary streams, and (5) the atmosphere through evapotranspiration. Losses into tributary streams and through evapotranspiration are assumed to be only a minor percentage of the total ground-water discharge because the water table is generally 8 to 12 ft below land surface, which is deeper than most stream channels and the rooting depth of most vegetation.

The annual volumes of ground-water recharge and discharge estimated from information obtained in previous studies and calculated directly from field measurements are summarized in table 1 for a section of the aquifer within the 1-mi^2 study area shown in figure 6. Recharge from precipitation on the flood plain was estimated to be 1.0 Mgal/d; this was based on a recharge rate of 22 in/yr reported by Randall (1977, p. 17).

Infiltration from tributary streams that drain upland areas was estimated by a method presented in MacNish and Randall (1982, p. 37). The method estimates the potential recharge rate from tributary streams by multiplying the length of channel crossing the aquifer with a gradient of less than 1 percent by 650 (gal/d)/ft. This potential rate is compared with the long-term flow duration of the stream taken from a plot of average flow duration for upland basins within the Susquehanna River basin, expressed per unit area (MacNish and Randall, 1982, fig. 15). Where streamflow is estimated to fall below the potential recharge rate, the estimate of average recharge is reduced to allow for periods of deficient flow. About 90 percent of the estimated 1.1 Mgal/d of infiltration from tributary streams is from the Park Creek valley (fig. 2). Infiltration along valley walls in areas not drained by streams was assumed to be equal to the 90-percent flow duration discharge for upland basins.

Upward leakage through the lacustrine sand and silt deposits that underlie the aquifer is extremely small because these deposits have low hydraulic conductivity. Randall (1985, pl. 3), using a ground-water-flow model, obtained vertical hydraulic-conductivity values of 1×10^{-5} to 5×10^{-5} ft/d for a silty sand layer beneath an aquifer in Johnson City, 7 mi downstream (fig. 1). Upward leakage in the Kirkwood-Conklin area was estimated from Darcy's law:

$$Q = KAi \quad (1)$$

where: Q is the volume of upward leakage, ft^3/d
K is the hydraulic conductivity, ft/d
A is the cross-sectional area of flow, ft^2
i is the hydraulic gradient, ft/ft (the difference between head in observation wells screened in the aquifer and in the underlying lacustrine deposit).

Using the estimate of vertical hydraulic conductivity reported by Randall (1985) and an average hydraulic gradient of 1.0 ft/ft yields an upward leakage value of 0.006 Mgal/d--negligible relative to the other recharge sources.

Underflow into and out of the study area was estimated by Darcy's law from saturated-thickness values shown in figure 5, an average hydraulic conductivity of 1,000 ft/d (calculated from aquifer-test data in the appendix), Sheet B6-5

By integrating (8-1) from r_w to R, we obtain

$$s_w = H - h_w = \phi(R) - \phi(r_w) = (Q_w/2\pi T)\ln(R/r_w) \tag{8-4}$$

Between any two distances r_1 and $r_2 (> r_1)$, we obtain

$$\phi(r_2) - \phi(r_1) = s(r_1) - s(r_2) = (Q_w/2\pi T)\ln(r_2/r_1) \tag{8-5}$$

Equation (8-5) is called the Thiem equation (Thiem, 1906).

Between any two distances r and R, we obtain

$$s(r) = \phi(R) - \phi(r) = (Q_w/2\pi T)\ln(R/r) \tag{8-6}$$

By dividing (8-3) by (8-4), we obtain

$$\phi(r) - h_w = (H - h_w)\frac{\ln(r/r_w)}{\ln(R/r_w)} \tag{8-7}$$

showing that the shape of the curve $\phi = \phi(r)$, given h_w and H at r_w and R, respectively, is independent of Q_w and T.

The distance R in (8-4), (8-6), and (8-7), where the drawdown is zero, is called the *radius of influence of the well*. Since we have established above that steady flow cannot prevail in an infinite aquifer, the distance R should be interpreted as a parameter which indicates the distance beyond which the drawdown is negligible, or unobservable. In general, this parameter has to be estimated from past experience. Fortunately, R appears in (8-6) in the form of $\ln R$ so that even a large error in estimating R does not appreciably affect the drawdown determined by (8-6). The same observation is true also for another parameter—the radius of the well r_w (Sec. 8-1).

Various attempts have been made to relate the radius of influence, R, to well, aquifer, and flow parameters in both steady and unsteady flow in confined and phreatic aquifers. Some relationships are purely empirical, others are semi-empirical. For example (Bear, Zaslavsky, and Irmay, 1968).

Semi-empirical formulas are

Lembke (1886, 1887):	$R = H(K/2N)^{1/2}$,	(8-8)
Weber (Schultze, 1924):	$R = 2.45\,(HKt/n_e)^{1/2}$,	(8-9)
Kusakin (Aravin and Numerov, 1953):	$R = 1.9\,(HKt/n_e)^{1/2}$	(8-10)

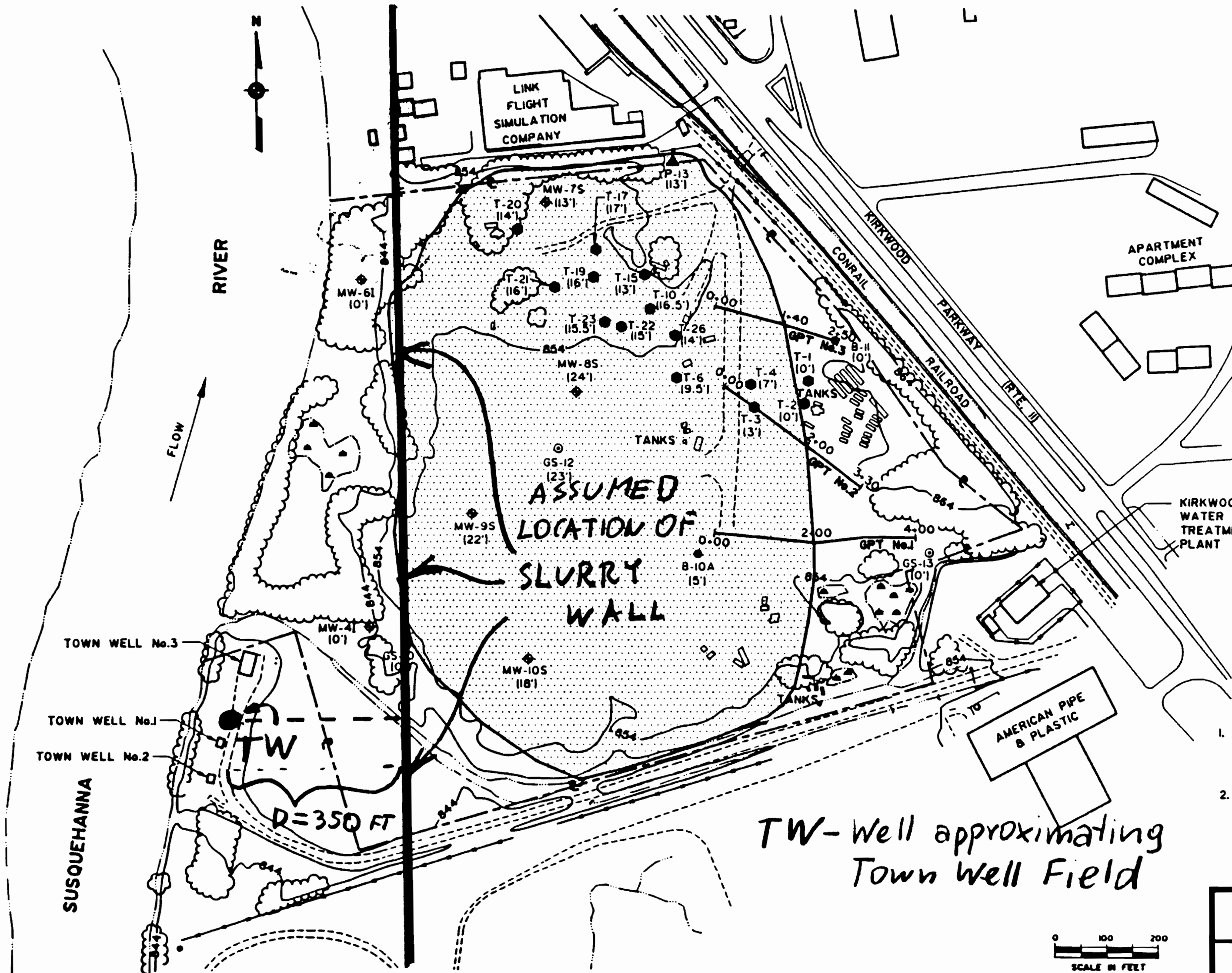
Empirical formulas are

Siechardt (Chertousov, 1962):	$R = 3000 s_w K^{1/2}$,	(8-11)
Kusakin (Chertousov, 1949):	$R = 575 s_w (HK)^{1/2}$	(8-12)

where R, s_w (= drawdown in pumping well), and H are in meters and K in meters per second.

In phreatic aquifers (Sec. 8-3) N, H, and n_e represent accretion from precipitation, the initial thickness of the saturated layer, and the specific yield (or effective porosity) of the aquifer, respectively. In confined aquifers, H and n_e have to be

Sheet BB-6



LEGEND

- (dotted area) APPROXIMATE AREA OF FILL
- GPT No. — GEOPHYSICAL TRANSECT LINE
- ◈ MONITORING WELL INSTALLED BY URS CONSULTANTS (1990)
- ⊙ WELL INSTALLED BY UNITED STATES GEOLOGICAL SURVEY (1984)
- ● SOIL BORING BY URS CONSULTANTS (1990)
- ▲ PIEZOMETERS BY URS CONSULTANTS (1991)
- ⬢ TEST TRENCH BY URS CONSULTANTS (1991)
- (13') APPROXIMATE CURRENT DEPTH OF FILL AT BORING/WELL OR TEST PIT/TRENCH LOCATION

NOTES:

1. MAPPING BASE IS FROM AERIAL PHOTOGRAPHY DATED APRIL 1, 1990 AND COMPILED BY LOCKWOOD MAPPING, ROCHESTER, NEW YORK.
2. PROPERTY LINES SHOWN ARE APPROXIMATE, FOR REFERENCE ONLY, AND SHOULD NOT BE USED FOR CONVEYANCE OF REAL PROPERTY. PROPERTY LINES WERE INTERPOLATED FROM A TAX MAP PREPARED BY BROOME COUNTY, NEW YORK.

FILL BOUNDARY MAP

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FIGURE 4-2

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Sheet BB-7

TABLE 1
Typical Properties of Compacted Soils

Group Symbol	Soil Type	Range of Maximum Dry Unit Weight, pcf	Range of Optimum Moisture, Percent	Typical Value of Compression: At 1.4 tsf (20 psi) (Percent of Original Height)	Typical Value of Compression: At 3.6 tsf (50 psi) (Percent of Original Height)	Typical Strength Characteristics: Cohesion (as compacted) psf	Typical Strength Characteristics: Cohesion (saturated) psf	Typical Strength Characteristics: ∅ (Effective Stress Envelope Degrees)	Typical Strength Characteristics: Tan ∅	Typical Coefficient of Permeability ft./min.	Range of CBR Values	Range of Subgrade Modulus k lbs/cu in.
GW	Well graded clean gravels, gravel-sand mixtures.	125 - 135	11 - 8	0.3	0.6	0	0	>38	>0.79	5×10^{-2}	40 - 80	300 - 500
GP	Poorly graded clean gravels, gravel-sand mix	115 - 125	14 - 11	0.4	0.9	0	0	>37	>0.74	10^{-1}	30 - 60	250 - 400
GM	Silty gravels, poorly graded gravel-sand-silt.	120 - 135	12 - 8	0.5	1.1	.....	.....	>34	>0.67	$>10^{-6}$	20 - 60	100 - 400
GC	Clayey gravels, poorly graded gravel-sand-clay.	115 - 130	14 - 9	0.7	1.6	.....	.....	>31	>0.60	$>10^{-7}$	20 - 40	100 - 300
SW	Well graded clean sands, gravelly sands.	110 - 130	16 - 9	0.6	1.2	0	0	38	0.79	$>10^{-3}$	20 - 40	200 - 300
SP	Poorly graded clean sands, sand-gravel mix.	100 - 120	21 - 12	0.8	1.4	0	0	37	0.74	$>10^{-3}$	10 - 40	200 - 300
SM	Silty sands, poorly graded sand-silt mix.	110 - 125	16 - 11	0.8	1.6	1050	420	34	0.67	$5 \times >10^{-5}$	10 - 40	100 - 300
SM-SC	Sand-silt clay mix with slightly plastic fines.	110 - 130	15 - 11	0.8	1.4	1050	300	33	0.66	$2 \times >10^{-6}$	5 - 30	100 - 300
SC	Clayey sands, poorly graded sand-clay-mix.	105 - 125	19 - 11	1.1	2.2	1550	230	31	0.60	$5 \times >10^{-7}$	5 - 20	100 - 300
ML	Inorganic silts and clayey silts.	95 - 120	24 - 12	0.9	1.7	1400	190	32	0.62	$>10^{-5}$	15 or less	100 - 200
ML-CL	Mixture of inorganic silt and clay.	100 - 120	22 - 12	1.0	2.2	1350	460	32	0.62	$5 \times >10^{-7}$	.....	
CL	Inorganic clays of low to medium plasticity.	95 - 120	24 - 12	1.3	2.5	1800	270	28	0.54	$>10^{-7}$	15 or less	50 - 200
OL	Organic silts and silt-clays, low plasticity.	80 - 100	33 - 21	.....	.....	.....	.....	.....	.....	.....	5 or less	50 - 100
MH	Inorganic clayey silts, elastic silts.	70 - 95	40 - 24	2.0	3.8	1500	420	25	0.47	$5 \times >10^{-7}$	10 or less	50 - 100
CH	Inorganic clays of high plasticity	75 - 105	36 - 19	2.6	3.9	2150	230	19	0.35	$>10^{-7}$	15 or less	50 - 150
OH	Organic clays and silty clays	65 - 100	45 - 21	.....	.....	.....	.....	.....	.....	.....	5 or less	25 - 100

Notes:

1. All properties are for condition of "Standard Proctor" maximum density, except values of k and CBR which are for "modified Proctor" maximum density.
2. Typical stength characteristics are for effective strength envelopes and are obtained from USBR data.
3. Compression values are for vertical loading with complete lateral confinement.
4. (>) indicates that typical property is greater than the value shown.
(..) indicates insufficient data available for an estimate.

(a) Design Considerations. The primary design parameters are blowout requirements, permeability, strength, and compressibility. The backfill material must not blow out into the surrounding pervious foundation under the maximum differential hydraulic head that will act on the slurry trench. The permeability is usually sufficiently low ($\approx 10^{-7}$ cm/sec for ≥ 1 percent bentonite) to reduce the seepage through the slurry trench cutoff to an acceptable value. Under most conditions, the only strength requirement for the slurry trench cutoff is to approximate the strength of the surrounding ground. The compressibility of the slurry trench cutoff, once consolidated under its own weight (usually within 6 months after placement), should be compatible with the compressibility of the surrounding ground to minimize differential movement of the dam and resultant stress concentrations in the embankment or its foundation (Ryan 1976 and Xanthakos 1979).

(b) Blowout Requirements. Once the slurry trench is installed, the dam has been constructed, and the reservoir filled, there is a substantial differential head acting on the slurry trench (see table 9-2 for typical values). Depending upon the characteristics of the backfill material and pervious foundation, the hydraulic gradient acting across the slurry trench may be sufficient to cause blowout or piping of backfill material into the surrounding pervious foundation. This is especially critical when the foundation contains openwork gravel where the piping process could result in the formation of channels and cavities that may breach the slurry wall. Based upon laboratory tests conducted on widely graded gravel containing no sand, the blowout gradient ranges from 25 to 35, depending on the properties of the backfill material (La Russo 1963 and Nash 1976). The factor of safety against blowout is

$$F = \frac{i_{allowable}}{i_{actual}} \qquad (9\text{-}9)$$

where

F = factor of safety against blowout

$i_{allowable}$ = allowable hydraulic gradient from laboratory blowout tests

i_{actual} = actual hydraulic gradient existing on slurry trench

Substituting for the actual hydraulic gradient

$$i_{actual} = \frac{\Delta h}{w} \qquad (9\text{-}10)$$

where

Δh = maximum differential hydraulic head acting on the slurry trench

w = slurry trench width

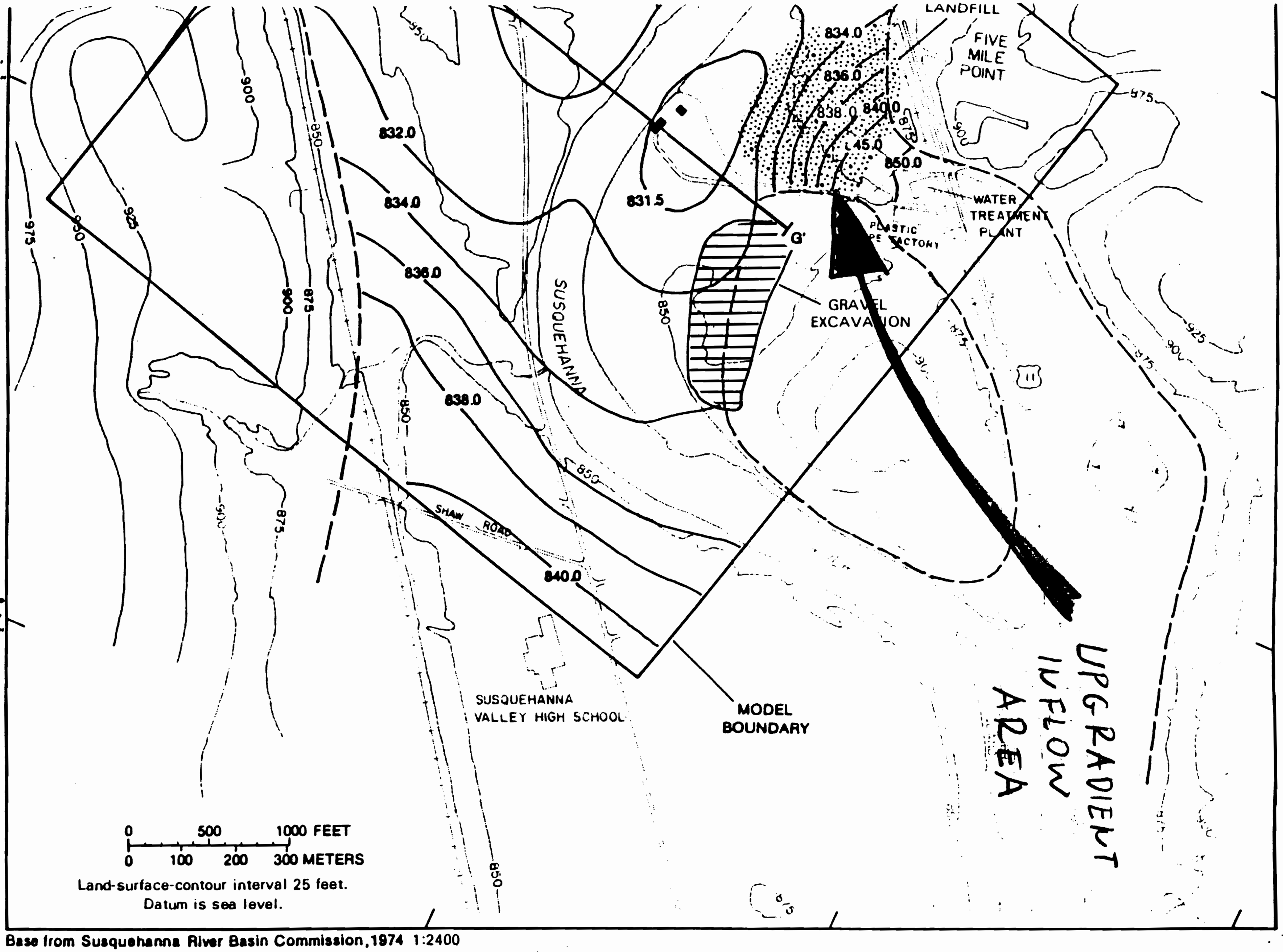
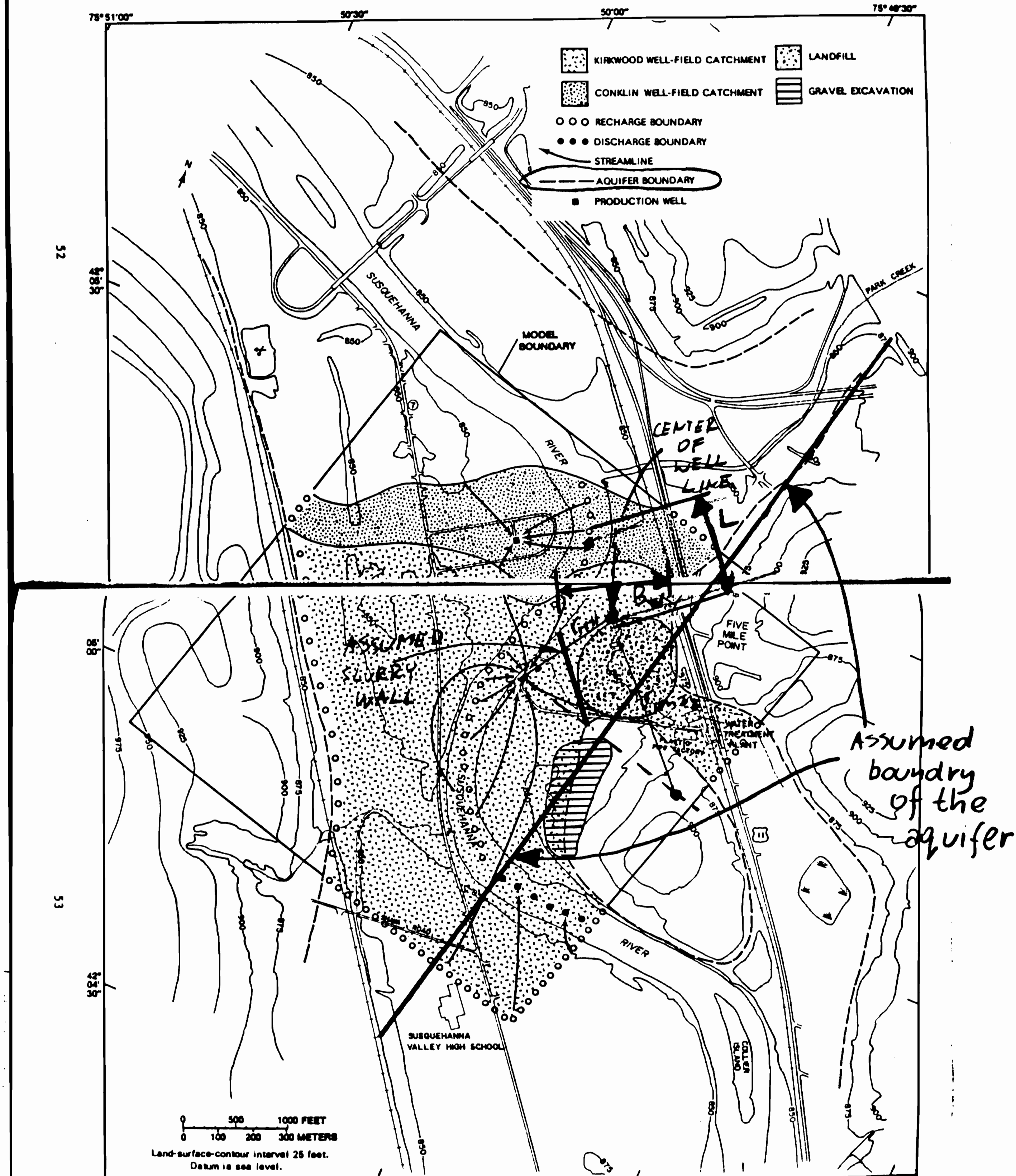


Figure 23.--Water-table contours derived from steady-state simulation of ground-water withdrawals.

Sheet BB-

Sheet BB-10



Base from Susquehanna River Basin Commission, 1974 1:2400

Figure 22.--Catchment areas for production wells and direction of ground-water flow derived from steady-state simulation of ground-water withdrawals.

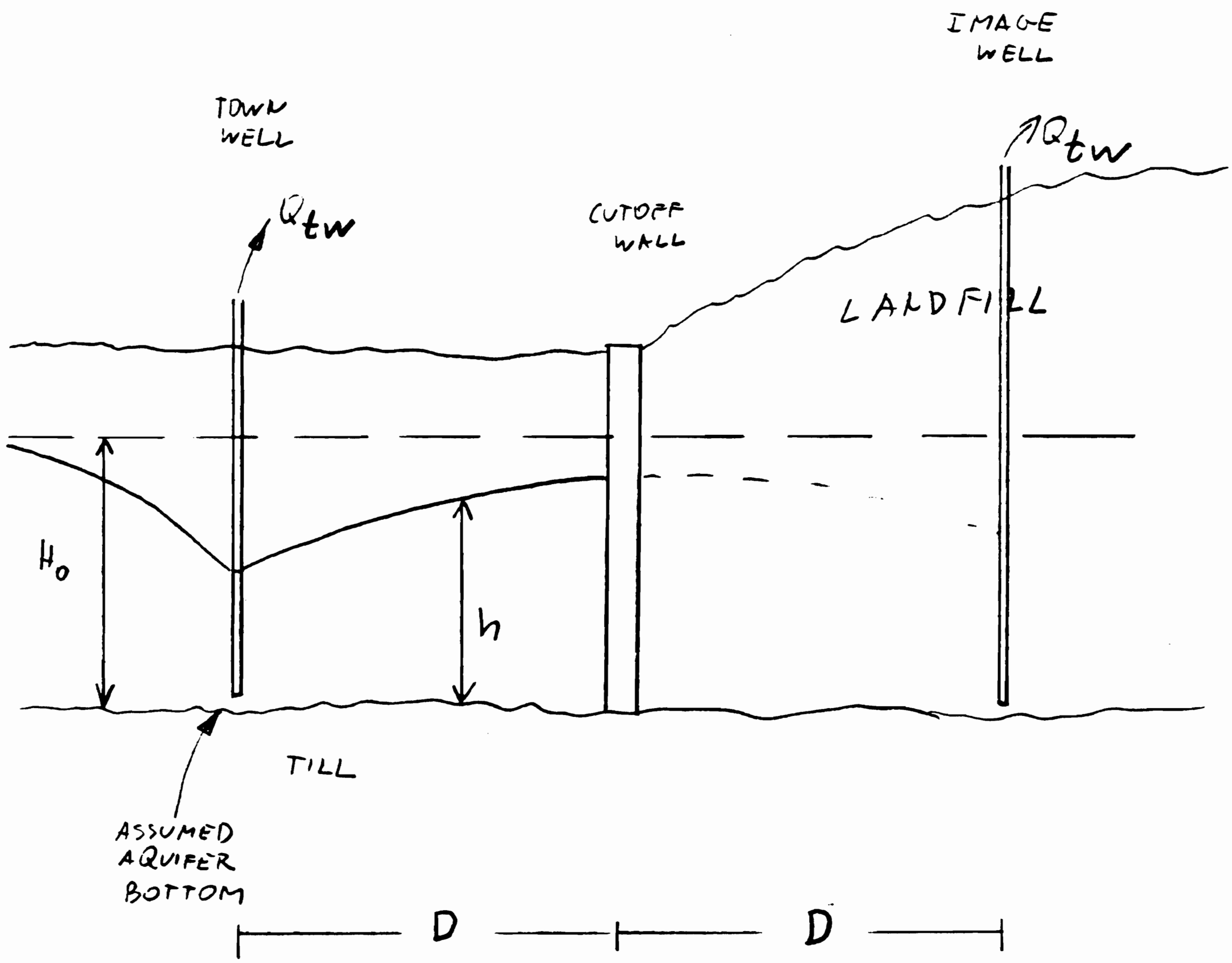
REF. PAGE

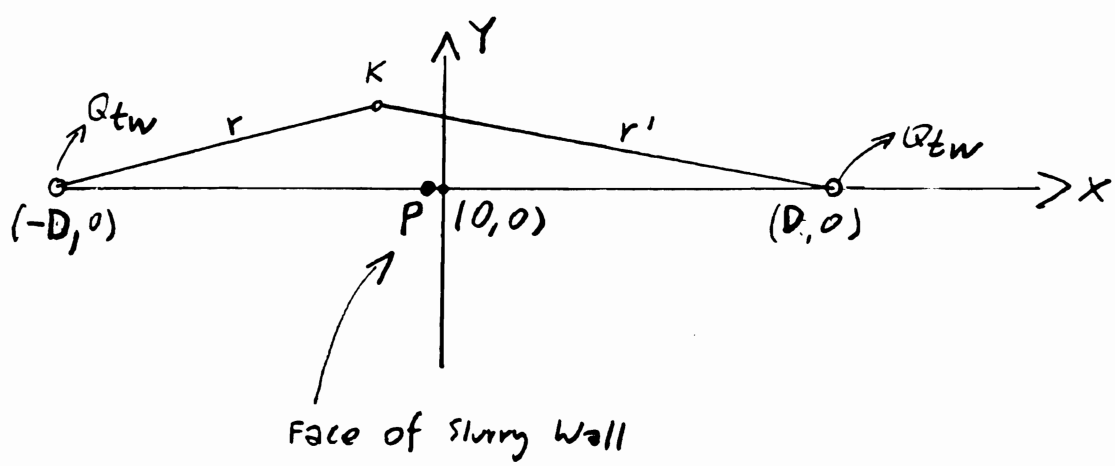
C.1) This calculation will investigate the influence of a vertical cut-off wall along the landfill perimeter on pumping of town wells. The parameters as determined in section B will be used. The pumping of town wells will be simulated using one well located roughly in the middle of the Town Well Field.
The purpose will be to find out what influence the slurry wall will have on the Town Wells' drawdown and to determine the level at wich the water within the enclosing slurry wall will have to be maintained in order to maintain inward flows.
Note: The slurry wall will be approximated as a continous line. This is not consistent with the field situation, where the slurry wall is of finite length. The infinite line assumption has to be made in order to use analytical methods of calculation. It will produce higher drawdowns, which in this case is a conservative assumption. Also, the slurry wall will be represented as an impervious barrier, which will also produce higher, conservative estimates of drawdowns

The method of images will be used. A towne well will be considered a pumping well near impervious, straight boundry. The drawdown produced by such a well is equal to the sum of drawdowns of two pumping wells of the same discharge, located symmetrically on both sides of the impervious boundry.
("Hydraulics of Groundwater", J. Bear, 1979, Chapter 8-10, p 356-367)

REF. PAGE

C.2) Consider the effect of the cutoff wall on pumping of the Town well Field.





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For the unconfined aquifer, drawdown produced by two such wells is defined as:

$$H_0^2 - h_{at\,K}^2 = \frac{Q_{tw}}{\pi K}\left(\ln\frac{R}{r} + \ln\frac{R}{r'}\right)$$

"Hydr. of GW", p 353
see sheet C-8.

$$h_{at\,K} = \sqrt{H_0^2 - \frac{Q_{tw}}{\pi K}\left(\ln\frac{R}{r} + \ln\frac{R}{r'}\right)}$$

Taking parameter values from section B, the minimum hydraulic head at the face of the slurry wall (Point "P" on sheet C-2) will be:

a) $K_1 = 200$ FT/D (B.5)
$R_1 = 7071$ FT (B.7)
$H_0 = 50$ FT (B.3)
$r = r' = D = 350$ FT (B.9)
$Q_{tw} = 150{,}000$ FT³/D (B.2)

$$h_1 = \sqrt{50^2 - \frac{150{,}000}{3.14 \cdot 200}\left(\ln\frac{7071}{350} + \ln\frac{7071}{350}\right)}$$

$$h_1 = 32.6 \text{ FT}$$

b) $K_2 = 2{,}600$ FT/D (B.5)
$R_2 = 25{,}495$ FT (B.7)

$$h_2 = \sqrt{50^2 - \frac{150{,}000}{3.14 \cdot 2600} \cdot 2\ln\frac{25{,}495}{350}}$$

$h_2 = 48.4$ FT

c) $K_3 = 5000$ FT/D (B.5)
$R_3 = 35{,}355$ FT (B.7)

$$h_3 = \sqrt{50^2 - \frac{150{,}000}{3.14 \cdot 5{,}000} 2\ln \frac{35{,}355}{350}}$$

$h_3 = 49.1$ FT

The above calcs. show that the the drawdown at the face of the slurry wall will not be significant enough to disrupt the operation of town wells. The saturated thickness will stay above 30 ft.
The water level within the enclosure, on the inner face of slurry wall will have to be maintained below the 30 ft (conservative).

d) the hydraulic head at the well location, assuming that the well diameter is 2 FT and the hydr cond. of the aquifer is 200 FT/DAY (most conservative case)

$r_w = 1$ FT
$K = 200$ FT/D $\rightarrow R = 7071$ FT
$r = r_w = 1$ FT
$r' = 2D = 700$ FT
$Q_{tw} = 150{,}000$ FT³/D

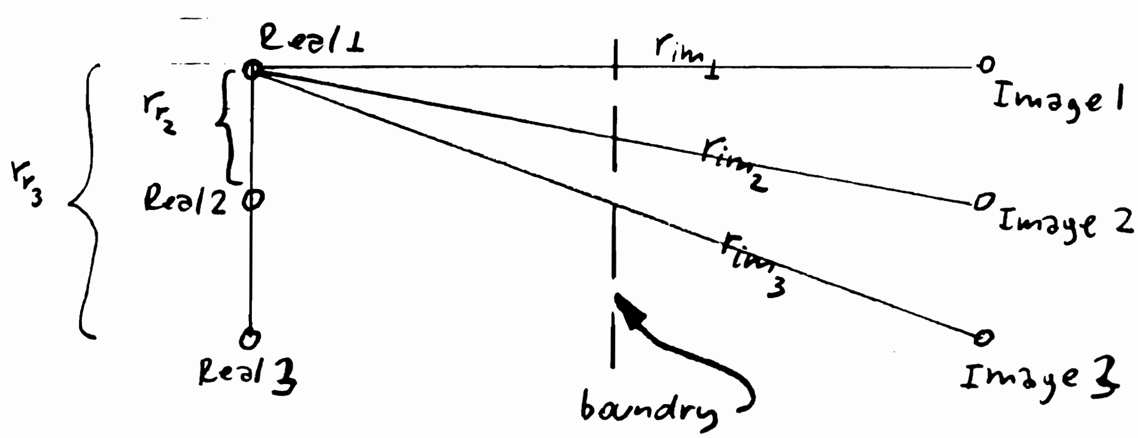
$$h_{WELL} = \sqrt{50^2 - \frac{150{,}000}{\pi \cdot 200}\left(\ln\frac{7071}{1} + \ln\frac{7071}{700}\right)}$$

$$h_{WELL} = \sqrt{\text{NEGATIVE}}$$

This indicates that a single well 350 FT from impervious boundry would not be able to pump 150,000 FT³/D.
Check 3 wells, 100 FT apart, $r_w = 0.5$ FT., $Q_i = \frac{Q_{tw}}{3}$

: Outside well

$$H_0^2 - h_{w_1}^2 = \frac{Q_{tw}}{3\pi K}\left(\ln\frac{R}{r_{w_1}} + \ln\frac{R}{r_{im_1}} + \ln\frac{R}{r_{r_2}} + \ln\frac{R}{r_{im_2}} + \ln\frac{R}{r_{r_3}} + \ln\frac{R}{r_{im_3}}\right)$$



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$$H_0^2 - h_{w_1}^2 = \frac{Q_{tw}}{3\pi K} \ln \frac{R^6}{r_{w_1} r_{im_1} r_{r_2} r_{im_2} r_{r_3} r_{im_3}}$$

$r_{w_1} = 0.5$ FT $r_{r_2} = 100$ FT $r_{r_3} = 200$ FT
$r_{im_1} = 700$ FT $r_{im_2} = 707$ FT $r_{im_3} = 728$ FT

$R = 7071$ FT
$K = 200$ FT/D
$Q_{tw} = 150{,}000$ FT³/D

$$h_{w_1} = \sqrt{50^2 - \frac{150{,}000}{3 \cdot \pi \cdot 200} \ln \frac{7071^6}{0.5 \cdot 700 \cdot 100 \cdot 707 \cdot 200 \cdot 728}}$$

$h_{w_1} = 24$ FT OK

- Middle well

$$H_0^2 - h_{w_2}^2 = \frac{Q_{tw}}{3\pi K} \ln \frac{R^6}{r_{r_1} r_{im_1} r_{w_2} r_{im_2} r_{r_3} r_{im_3}}$$

$r_{r_1} = 100$ FT $r_{w_2} = 0.5$ FT $r_{r_3} = 100$ FT
$r_{im_1} = 707$ FT $r_{im_2} = 700$ FT $r_{im_3} = 707$ FT

$$h_{w_2} = \sqrt{50^2 - \frac{150{,}000}{3\pi 200} \ln \frac{7071^6}{100 \cdot 707 \cdot 0.5 \cdot 700 \cdot 100 \cdot 707}}$$

$h_{w_2} = 23$ FT OK

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SUBJECT G.W FLOWS
TOWN WELLS - SLURRY WALL INTERACTION

REF. PAGE

LIST OF SYMBOLS

H_0 - Initial saturated thickness
$h_{at\,k}$ - Hydr head at point "K"

K - Hydr. conductivity
Q_{tw} - Town well discharge

R - Radius of influence
r - Distance from point "K" to "real" production well
r' - Distance from point "K" to "image" production well
h_w - Hydr. head in well

and when both wells are operating, and we assume $\phi_1(P_2) \ll \phi_2^-$ and $\phi_2(P_1) \ll \phi_1^-$. The same procedure can be applied to a larger number of wells.

Muskat (1937) discusses several arrangements of wells in a confined aquifer, and determines in each case the drawdown at the various wells, using (8-131) with $R_j = R$ = const. For example: for two wells of equal drawdown $s_1 = s_2 = s_w$ at a distance L apart, we have

$$Q_1 = Q_2 = \frac{2\pi T s_w}{\ln(R^2/r_w L)} \tag{8-135}$$

The total discharge $(Q_1 + Q_2)$ is that of a single well of radius $(r_w L)^{1/2} \gg r_w$. This shows that a multiple well system is more efficient than a single large well having the same total discharge.

For three wells of equal drawdown forming an equilateral triangle of side L

$$Q_1 = Q_2 = Q_3 = \frac{2\pi T s_w}{\ln(R^3/r_w L^2)} \tag{8-136}$$

In order that a single well of discharge $(Q_1 + Q_2 + Q_3)$ will give the same drawdown s_w, its radius has to be $(r_w L^2)^{1/3}$.

For an infinite *array of wells* at $P_k(ka, 0)$, $k = \dots, -2, -1, 0, 1, 2, \dots$ in a confined aquifer in the xy plane, with Q_k = const. $= Q_w$, and $\phi(x, \pm R)$ = const. $= H$, R being an equivalent distance of influence, Muskat (1937) gives

$$s(x, y) \equiv H - \phi(x, y) = \frac{Q_w}{4\pi T} \ln \frac{\cosh 2\pi(y - R)/a - \cos 2\pi x/a}{\cosh 2\pi(y + R)/a - \cos 2\pi x/a} \tag{8-137}$$

Figure 8-20 shows streamlines and equipotentials. At a distance of the order of the mutual spacing, $y > a$, the equipotentials become parallel to the array, as if the latter had been replaced by a continuous line sink.

For a line of three equally spaced wells a distance L apart, all having the same drawdown s_w, the outer wells discharge at

$$Q_1 = Q_3 = \frac{2\pi T s_w \ln(L/r_w)}{2\ln(R/L)\ln(L/R) + \ln(R^2/2r_w L)\ln R/r_w)} \tag{8-138}$$

while the middle well discharges at

$$Q_2 = \frac{2\pi T s_w \ln(L/2r_w)}{2\ln(R/L)\ln(L/R) + \ln(R^2/2r_w L)\ln(R/r_w)} \tag{8-139}$$

Figure 8-21 shows the individual and composite drawdown curves for the three wells for $Q_1 = Q_2 = Q_3$, $s_1 = s_3 \neq s_2$.

The discharge of each of four wells forming a square of side L, all having the same drawdown s_w, is

$$Q_1 = Q_2 = Q_3 = Q_4 = \frac{2\pi T s_w}{\ln(R^4/\sqrt{2}\, r_w L^3)} \tag{8-140}$$

When N wells are pumping in a phreatic aquifer with a horizontal bottom, and the Dupuit approximation is used to determine the drawdown (steady flow!) in an

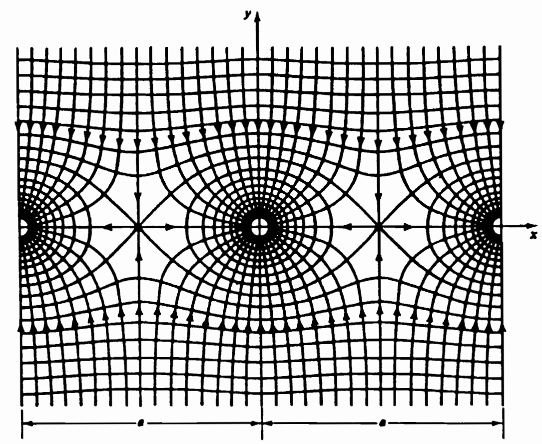


Figure 8-20 Streamlines and equipotentials about an infinite array of wells.

observation well, the principle of superposition (here with respect to h^2) leads to

$$H_0^2 - h_i^2 = \sum_{j=1}^{N} \frac{Q_j}{\pi K} \ln \frac{R_j}{r_{ij}} \tag{8-141}$$

where H_0 = const. is the initial (undisturbed) height of the water table above the impervious bottom, h_i is the height of the water table above the impervious bottom at the observation well (x_i, y_i), and the R_j's are the radii of influence of the pumping wells, (assuming that they are sufficiently large so that drawdown is produced at the observation well). When all R_j's are the same and all Q_j's are equal to Q/N, we obtain from (8-141)

$$H^2 - h_i^2 = \frac{Q}{\pi K} \ln(R/r^*); \qquad r^* = (r_{i1} r_{i2} r_{i3} \dots r_{iN})^{1/N} \tag{8-142}$$

One should note here that because we have initially the nonhomogeneous conditions $h = H_0$ (and not $h = 0$), the superposition is actually not with respect to h^2. Instead, because initially $H_0^2 - h^2 = 0$ everywhere, the superposition is with respect to the difference $H_0^2 - h^2$. In a similar way, if in a confined aquifer we have initially $\phi_0 \neq 0$, the superposition is with respect to $\phi_0 - \phi$ (i.e., with respect to s!).

REF. PAGE

D.1) The purpose of this calculation was to determine the withdrawal rates necessary to capture the ground water from the landfill area without the use of the cut-off walls.

D.2) Analytical solution using the wells in uniform flow.
It was assumed that a uniform flow exists between the aquifer boundry and the river. The magnitude of the uniform flow value was assumed after the USGS model. ~~(see sheet B7 for~~
For the case of a withdrawal well in the uniform flow, the following formula is given for the half-width of the capture zone:

$$y_s = \frac{Q_w}{2 q_o B} \qquad (1)$$

See "Hydraulics of G.W.", J. Bear, 1979 Chapt 8, p 368, Fig 8-29. (See sheet D-6A)

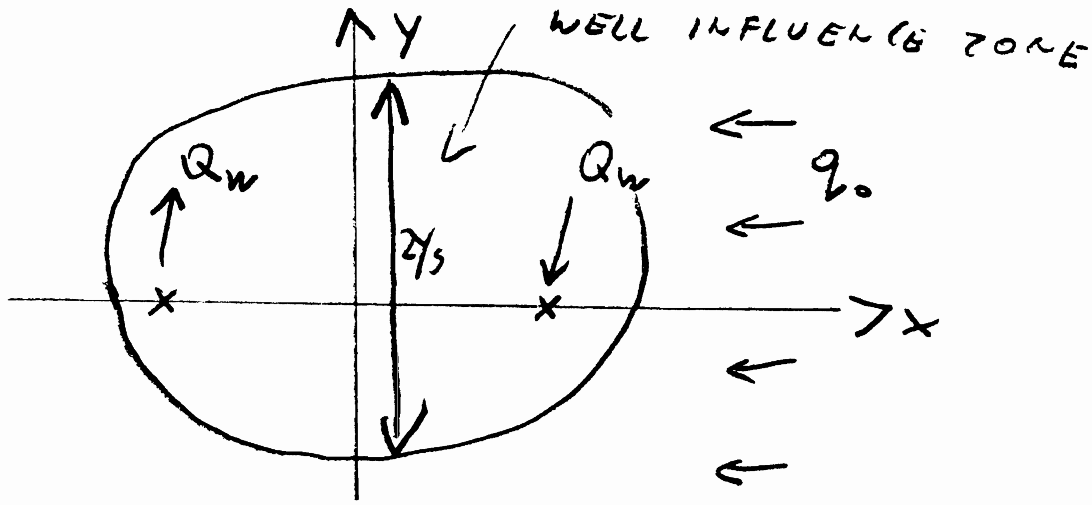
Q_w - Well discharge
q_o - Uniform flow value
B - Aquifer width

and $q_o = k \cdot i$

In case of two wells (pumping and recharge) operating in the uniform flow, the formula for the equipot. lines is given on page 370 of "Hydraulics of G.W." (See sheet D-6B)

$$\phi = -\frac{q_o B}{T}(x\cos\alpha + y\sin\alpha) + \frac{Q_w}{4\pi T}\ln\frac{(x+d)^2+y^2}{(x-d)^2+y^2}$$

T - Aquifer transmissivity
α - Angle between flow direction and (+)x-axis
d - Half-distance between wells
x, y - Coordinates



Here, $\alpha = 180°$

$$\phi = \frac{q_o B}{T}x + \frac{Q_w}{4\pi T}\ln\frac{(x+d)^2+y^2}{(x-d)^2+y^2}$$

From that:

$$q_x = \frac{\partial\phi}{\partial x} = \frac{q_o B}{T} + \frac{Q_w}{4\pi T}\left[\frac{2(x+d)}{(x+d)^2+y^2} - \frac{2(x-d)}{(x-d)^2+y^2}\right] =$$

$$= \frac{q_o B}{T} + \frac{Q_w}{4\pi T}\frac{4d(d^2+y^2)-4x^2d}{(y^2+d^2)^2+x^2(x^2+y^2-d^2)}$$

For $x = 0$

$$q_x\Big|_{x=0} = \frac{q_0 B}{T} + \frac{Q_w}{\pi T}\frac{d}{y^2+d^2}$$

The width of the influence zone $2y_s$ is found from the condition that flow Q_w must pass through the y axis at $x=0$.

$$Q_w = 2\cdot T\int_{y=0}^{y=y_s} q_x\,dy = 2T\int_{y=0}^{y=y_s}\left[\frac{q_0B}{T} + \frac{Q_w\,d}{\pi(y^2+d^2)}\right]dy =$$

$$= 2\int_{y=0}^{y=y_s}\left[q_0B + \frac{Q_w}{\pi}\frac{d}{(y^2+d^2)}\right]dy =$$

$$= 2\left(q_0By + \frac{Q_w d}{\pi}\frac{1}{d}\operatorname{arctg}\frac{y}{d}\right)\Big|_{y=0}^{y=y_s} =$$

$$= 2\left(q_0By + \frac{Q_w}{\pi}\operatorname{arc\,tg}\frac{y}{d}\right)\Big|_{y=0}^{y=y_s} =$$

$$= 2q_0By_s + \frac{2Q_w}{\pi}\operatorname{arc\,tg}\frac{y_s}{d}$$

$$Q_w = 2q_0By_s + \frac{2Q_w}{\pi}\operatorname{arc\,tg}\frac{y_s}{d}$$

$$Q_w = \frac{2q_0By_s}{1-\frac{2}{\pi}\operatorname{arc\,tg}\frac{y_s}{d}} \qquad (2)$$

Following aquifer parameters were assumed.

* Hydr. gradient in the upstream inflow area
  $i = 0.015$ (see B.16)
* Hydr. cond. in the inflow area
  $T = 1{,}000\ FT^2/D$ (see B.14)
  $H_{sat} = 10\ FT$ (See sheet BB-2)

$$k = \frac{T}{H_{sat}} = \frac{1000}{10} = 100\ FT/D$$

* Uniform flow (spec. discharge)

$$q_0 = k \cdot i = 0.015 * 100 = 1.5\ FT/D$$

* Aquifer thickness: section B.3 specifies the avg. ~~initial~~ sat. thickness of the aquifer about 50 FT. However, this calc. is performed for the area between the Susquehanna River and the aquifer boundry, where the avg. sat thickness was assumed to be

$$B = 35\ ft$$ (See sheet BB-2)

* It was assumed that the length of landfill area along the river is 1200 ft (See sheet BB-6). From the groundwater table map in the RI Report (Fig 3-13, 3-14) it was assumed, that currently about 1/3 of that drains into the river. Therefore, the neccessary width of the capture zone was assumed

$$2y_s = 500\ ft$$
$$\Downarrow$$
$$y_s = 250\ ft$$

* The distance from the river to the aquifer boundary is about (see sheet BB-10)
  $D = 1000\ FT$

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The infiltration is

$N = 0.005$ FT/D (see B.6)

So, the infiltration rate reaching the G.W between the aquifer boundary and the river is

$$Q_{INF} = A_{LANDFILL} * N$$

$$Q_{INF} = L_{Landfill} * D * N$$

$$Q_{INF} = 1200 * 1,000 * 0.005$$

$$Q_{INF} = 6,000 \text{ FT}^3/\text{D}$$

And in the area presently draining to the river

$$Q_{INF_{RIV}} = \frac{1}{3} Q_{INF} = 2,000 \text{ FT}^3/\text{D}$$

- For the scenario 1 - capturing the water reaching the river from the landfill area - the rate Q_R is:

$$Q_w = y_s 2 q_0 B \quad \text{from (1)}$$

$$Q_w = 250 \cdot 2 \cdot 1.5 \cdot 35$$

$$Q_w = 26,250 \text{ FT}^3/\text{D}$$

Plus the infiltration

$$Q_R = Q_w + Q_{INF_{RIV}} = 26,250 + 2,000$$

$$Q_R = 28,250 \text{ FT}^3/\text{D} \cong \underline{150} \text{ GPM}$$

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- For scenario 2 - capturing the water reaching both the river and the Town Wells - the rate Q_{RTW} is

$$Q_{RTW} = 3\ Q_R \cong \underline{450}\ \text{GPM}$$

- For scenario 3 - capturing the water from the landfill reaching the river and recycling it - the rate is

$$Q_{W_R} = \frac{2 q_0 B y_s}{1 - \frac{2}{\pi} \text{arc tg}\ y_s/d} \qquad \text{From (2)}$$

Assuming spacing between inj. and withdr. wells as

$$2d = 400\ ft$$
$$\downarrow$$
$$d = 200\ ft$$

$$Q_{W_R} = \frac{2 \cdot 1.5 \cdot 35 \cdot 250}{1 - \frac{2}{\pi} \text{arc tg} \frac{250}{200}}$$

$$Q_{W_R} = 61{,}110\ FT^3/D \cong \underline{320}\ \text{GPM}$$

- For scenario 4 - capturing water leaving landfill both towards river and Town Wells and recyrculating it the rate is

$$Q_{W_{RTW}} = 3\ Q_{W_R} = \underline{960}\ \text{GPM}$$

Note: Scenarios 3 & 4 are impossible to achieve if infiltration exists.

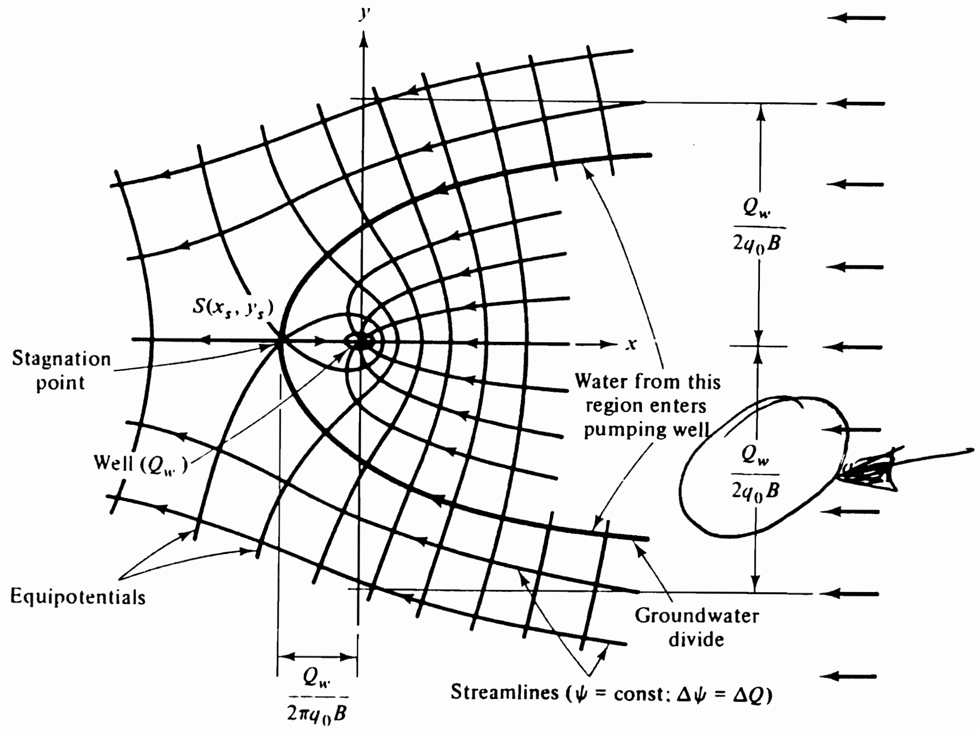


Figure 8-29 A single pumping well in uniform flow.

The water divide approaches asymptotically the lines $y = \pm Q_w/2q_0B$. A *stagnation point*, *S*, which is the point where the resultant velocity, produced by both the pumping well and the natural flow in the aquifer, vanishes, occurs at a point whose coordinates are

$$x_s = -Q_w/2\pi K q_0, \qquad y_s = 0 \tag{8-172}$$

Figure 8-30 shows the case of a recharge well in uniform flow. Again we have a water divide which delineates the aquifer region in which indigenous water will eventually be replaced by the recharged water. We also have a stagnation point $S(x_s, y_s)$, this time upstream of the recharging well. Note that in order to show the similarity of the two cases, we have reversed the direction of the uniform flow in the aquifer. The spreading of the injected water body is discussed in Sec. 7-10.

Figure 8-29 also shows the potential distribution described by (8-170). For the potentiai distribution shown in Fig. 8-30, we have to replace q_0 by $-q_0$ and Q_w by $-Q_w$ in (8-170).

When pumping produces an unsteady flow regime in an aquifer (i.e., aquifer storativity is taken into account), superimposed on a steady uniform flow, the appropriate drawdown equation should be used. For example, for a confined aquifer, the potential distribution for a single pumping well is

Example 2 A pumping and recharging pair of wells in uniform flow

Consider a recharging well at $(+d, 0)$ and a pumping well at $(-d, 0)$ in a homogeneous isotropic aquifer in which flow takes place at a constant specific discharge q_0 in a direction making an angle α with the $+x$ axis. Both wells are of equal strength Q_w = const. For this case

$$\left.\begin{aligned}\phi &= -\frac{q_0 B}{T}(x\cos\alpha + y\sin\alpha) + \frac{Q_w}{4\pi T}\ln\frac{(x+d)^2+y^2}{(x-d)^2+y^2}\\ \psi &= -\frac{q_0 B}{T}(y\cos\alpha - x\sin\alpha) + \frac{Q_w}{2\pi T}\left\{\tan^{-1}\frac{y}{x+d} - \tan^{-1}\frac{y}{x-d}\right\}\end{aligned}\right\} \tag{8-177}$$

Several examples of detailed flownets are described in Fig. 8-31 for different values of α. One may observe that under certain conditions (determined by the relationships between q_0, α, and Q_w) no streamline emerging from the recharging well terminates in the pumping well. This means that no injected fluid will ever reach the pumping well. Dacosta and Bennett (1960) study this problem in detail in connection with artificial recharge operations. They also determine the location of stagnation points and the amounts of interflow between the wells by taking twice the difference between the value of ψ passing through the origin of coordinates, and the value of ψ passing through one of the stagnation points (multiplied by K).

The shaded areas in Fig. 8-31 (pages 371–372) indicate regions of interflow. Groundwater divides and stagnation points can easily be determined for each case from (8-177).

The situations shown in Figs. 8-31a through d are not the only possible ones for the respective cases. As already indicated above, the resulting flownet depends in each case on the relationships between q_0, α and Q_w, with a possibility of different values of Q_w for the two wells. To illustrate this point, let us consider the case shown in Fig. 8-31a in which the shaded diamond-shaped area shows where recirculation takes place between the wells (with the pumping well located upstream of the recharging one). If however, the distance between the wells is made sufficiently large for a given well discharge, Q_w (equal to the rate of recharge) and a uniform specific discharge q_0, recirculation can be prevented entirely. This case is shown in Fig. 8-32a. As pumping and recharging rates increase, for the same distance, $2d$, and uniform specific discharge, q_0, a value of Q_w is reached such that the uniform groundwater flow is just balanced by the opposing flows produced by the two wells at a point midway between them (again for equal values of pumping and recharge) as shown in Fig. 8-31b. A further increase in Q_w will then produce the situation shown in Fig. 8-32a. In order to obtain the critical value of Q_w, we have to equate q_0 to the sum of the specific discharges induced by the two wells at that point

$$q_0 = \frac{Q_w}{2\pi dB} + \frac{Q_w}{2\pi dB} = \frac{Q_w}{\pi dB} \tag{8-178}$$

D.3) Checking the withdr. rates by method of images

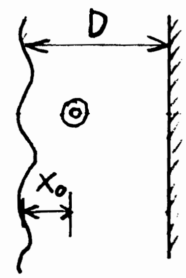
REF. PAGE

DERIVATION OF THE DRAWDOWN FORMULA

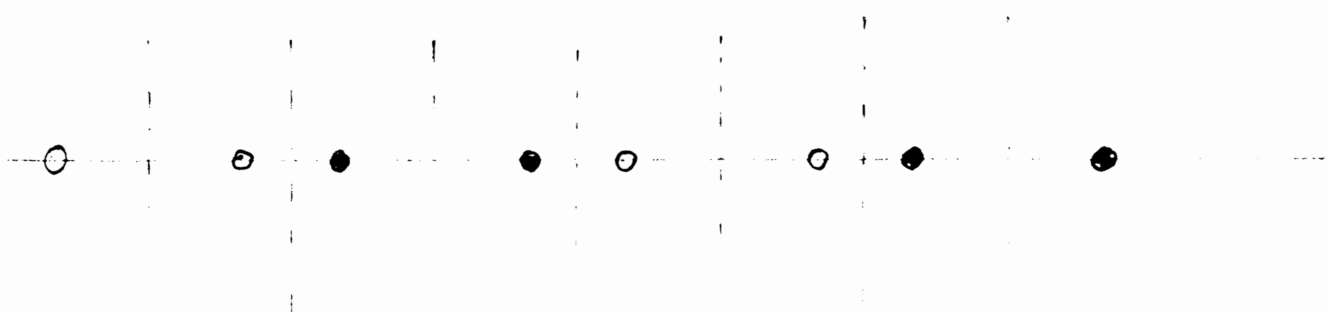
METHOD WILL BE DERIVED FOR OBTAINING DRAWDOWN FOR THE FOLLOWING CASE

- UNCONFINED AQUIFER
- CONSTANT HEAD BOUNDRY AT THE LEFT SIDE
- IMPERVIOUS BOUNDRY AT THE RIGHT SIDE
- STEADY STATE
- ISOTROPIC, HOMOGENOUS AQUIFER

A METHOD OF IMAGES WILL BE UTILIZED. FOR THE ABOVE CASE, A SINGLE PUMPING WELL CAN BE REPLACED BY AN INFINITE SERIES OF PUMPING AND RECHARGING WELLS OPERATING IN THE INFINITE AQUIFER. SO,



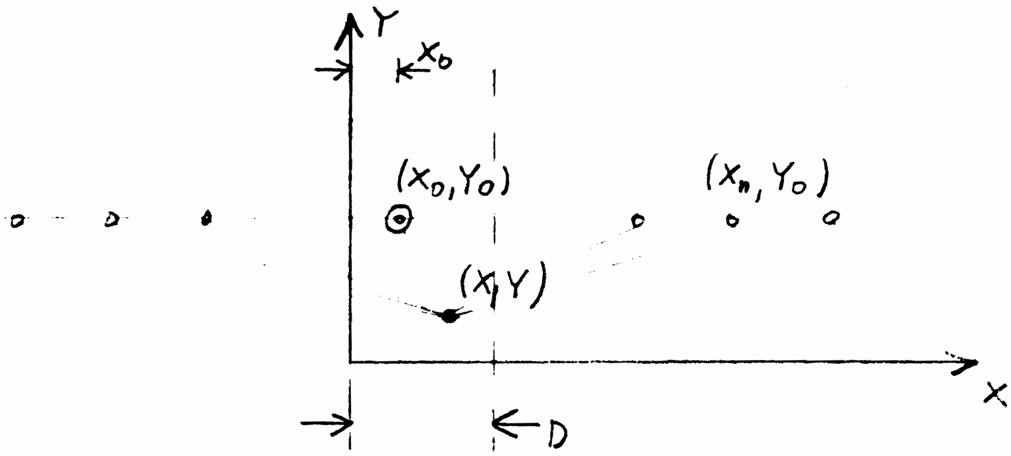
IS EQUIVALENT TO



WHERE: ◎ ORIGINAL PUMPING WELL
○ IMAGE PUMPING WELL
● IMAGE RECHARGE WELL
(hatched line) IMPERVIOUS BOUNDRY
(wavy line) CONSTANT HEAD BOUNDRY

"Hydr. of G.W." page 364, Fig 8-27 c, see sheet D-13A

SO, THE DRAWDOWN AT ANY POINT (X,Y) DUE TO THE OPERATION OF REAL PUMPING WELL IS EQUAL TO THE COMBINED DRAWDOWNS RESULTING FROM THE OPERATION OF THE INFINITE NUMBER OF IMAGE PUMING AND RECHARGING WELLS.



$$S_{AT(X,Y)\,\text{REAL WELL}} = \sum_{n=1}^{\infty} S_{AT(X,Y)} \text{ - } n^{th} \text{ IMAGE WELL}$$

X_0, Y_0 - COORDINATES OF REAL WELL
X_n, Y_0 - COORDINATES OF n^{th} IMAGE WELL
X, Y - COORDINATES OF OBSERV. POINT

"Hydr. of GW," p 353, formula 8-141 INDICATES THAT THIS CAN BE WRITTEN AS (See sheet D-13B)

$$H_0^2 - h^2 = \sum_{j=1}^{N} \frac{Q_j}{\pi K} \ln \frac{R_j}{r_j} \quad \text{at each obs. point "i"}$$

H_0 - INITIAL SAT. THICKNESS OF AQUIFER
h - SAT. THICKNESS AT OBS. POINT
Q_j - DISCHARGE RATE OF j^{th} WELL
K - HYDR. CONDUCTIVITY
R_j - RADIOUS OF INFLUENCE OF j^{th} WELL
r_j - DISTANCE FROM OBS POINT TO j^{th} WELL

ALL IMAGE WELLS HAVE THE SAME DISCHARGE RATES ($Q_j = Q$) AND RADII OF INFLUENCE ($R_j = R$) THEREFORE

$$H_0^2 - h^2 = \sum_{j=1}^{N} \frac{Q}{\pi K} \ln \frac{R}{r_j}$$

IN OUR CASE THERE IS AN INFINITE NUMBER OF PUMING WELLS ($Q_w = Q$) AND RECHARGING WELLS ($Q_w = -Q$). EACH WELL OF ONE KIND HAS ONE WELL OF THE OTHER KIND CORRESPONDING TO IT, THEREFORE

$$H_0^2 - h^2 = \sum_{j=1}^{\infty} \left(\frac{Q}{\pi K} \ln \frac{R}{r_{j_{PUMP}}} - \frac{Q}{\pi K} \ln \frac{R}{r_{j_{RECH}}} \right) =$$

$$= \frac{Q}{\pi K} \sum_{j=1}^{\infty} \left(\ln \frac{R}{r_{j_{PUMP}}} - \ln \frac{R}{r_{j_{RECH}}} \right) = \frac{Q}{\pi K} \sum_{j=1}^{\infty} \ln \frac{r_{j_{RECH}}}{r_{j_{PUMP}}}$$

SINCE

$$r_j = \sqrt{(X - X_j)^2 + (Y - Y_j)^2}$$

$$H_0^2 - h^2 = \frac{Q}{\pi K} \sum_{j=1}^{\infty} \ln \left[\frac{(X - X_{j_{RECH}})^2 + (Y - Y_{j_{RECH}})^2}{(X - X_{j_{PUMP}})^2 + (Y - Y_{j_{PUMP}})^2} \right]^{1/2} =$$

$$= \frac{Q}{\pi K} \sum_{j=1}^{\infty} \frac{1}{2} \ln \frac{(X - X_j)^2_{RECH} + (Y - Y_j)^2_{RECH}}{(X - X_j)^2_{PUMP} + (Y - Y_j)^2_{PUMP}} =$$

$$= \frac{Q}{2\pi K} \sum_{j=1}^{\infty} \ln \left[\frac{(X - X_j)^2_{RECH} + (Y - Y_j)^2_{RECH}}{(X - X_j)^2_{PUMP} + (Y - Y_j)^2_{PUMP}} \right]$$

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IN ORDER TO EVALUATE THE SERIES

$$\sum_{j=1}^{\infty} \ln \left[\frac{(x - x_{j_{RECH}})^2 + (Y - Y_{j_{RECH}})^2}{(x - x_{j_{PUMP}})^2 + (Y - Y_{j_{PUMP}})^2} \right]$$

THE X_j COORDINATES MUST BE KNOWN. THOSE WERE DETERMINED AS BEING:

$$x_{j_{RECH}} = D + \frac{|j|}{j}\left[(2|j|-1)D - (-1)^{|j|} X_0\right]$$

$$x_{j_{PUMP}} = D + \frac{|j|}{j}\left[(2|j|-1)D + (-1)^{|j|} X_0\right]$$

NOTE: SINCE WELLS STRETCH ON BOTH SIDES OF THE X AXIS (POS. AND NEG.), "j" NOW GOES FROM $-\infty$ TO ∞.

THE VALIDITY OF THE ABOVE SERIES WAS CHECKED GRAPHICALLY. A SYSTEM WAS PLOTTED AND THE MEASURED X_j VALUES WERE COMPARED TO THE CALCULATED VALUES. SEE SHEETS FOR REFERENCE.

NOTE: FOR THE REAL PUMPING WELL, THE TERMS IN THE NUMERATOR AND DENOMINATOR OF THE SERIES WOULD BE REVERSED. SO, MORE GENERALLY,

$$x_{j_{RECH}} = x_{j_A}, \quad x_{j_{PUMP}} = x_{j_B}$$

IMAGE ↓

A - WELL OF OPPOSITE DISCHARGE TO REAL WELL
B - IMAGE WELL OF SAME DISCH. AS REAL WELL

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PAGE OF
SHEET NO. D-11 OF
JOB NO. 35232
MADE BY MO DATE 12/27/91
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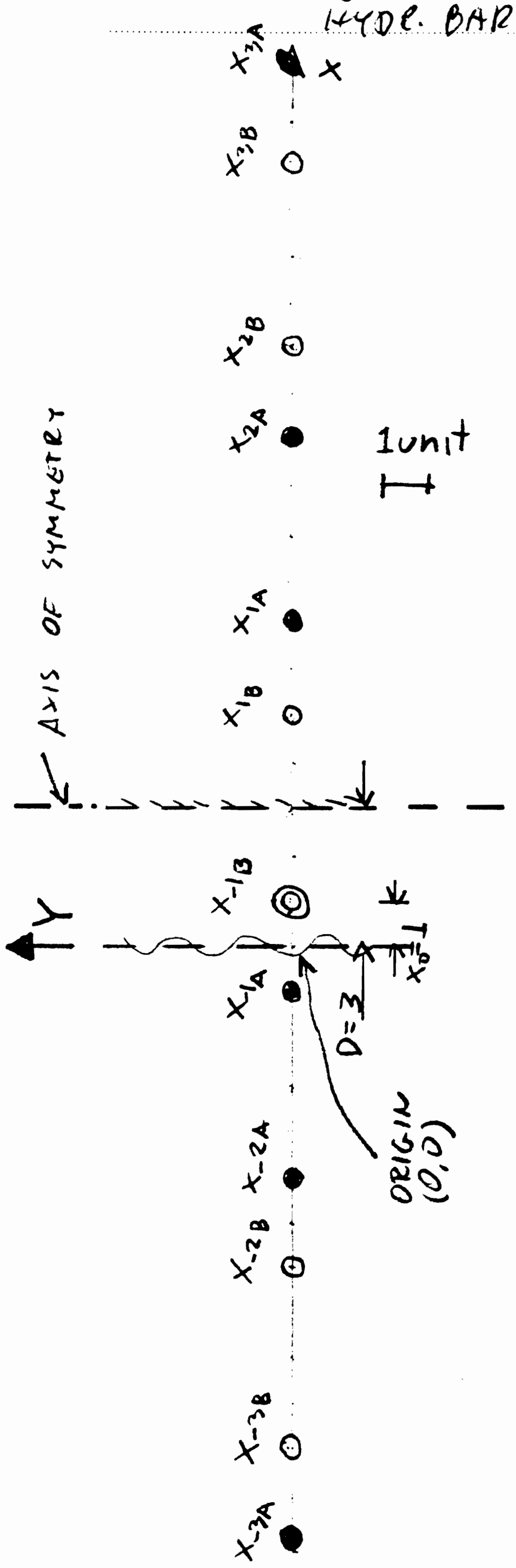

j	$x^M_{j_A} / x^c_{j_A}$	$x_{j_B} / x^c_{j_B}$
-3	-13 / -13	-11 / -11
-2	-5 / -5	-7 / -7
-1	-1 / -1	1 / 1
1	7 / 7	5 / 5
2	11 / 11	13 / 13
3	19 / 19	17 / 17

SUPERSCRIPTS
M - MEASURED
C - CALCULATED

CALCULATED AND MEASURED VALUES ARE IN AGREEMENT

REF. PAGE

TO ACCOUNT FOR THE MULTIPLE WELLS OPERATING WITHIN THE AQUIFER, THIS PROCEDURE HAS TO BE REPEATED FOR EACH WELL AND THE RESULTS SUPERIMPOSED

$$H_o^2 - h^2 = \sum_{i=1}^{M}\left[\frac{Q_i}{2\pi K}\sum_{j=-\infty}^{\infty}\ln\frac{(x-x_{ij_A})^2+(Y-Y_{ij_A})^2}{(x-x_{ij_B})^2+(Y-Y_{ij_B})^2}\right]$$

M - NUMBER OF OPERATING REAL WELLS
Q_i - DISCHARGE OF i^{th} REAL WELL
(x, y) - COORDINATES OF OBSERV. POINT
$x_{ij_{A(B)}}$ - X COORDINATE OF j^{th} IMAGE WELL OF TYPE "A" (OF THE i^{th} REAL WELL
$Y_{ij_{A(B)}}$ - Y —"— —"— —"— —"—
h - HEAD AT OBS. POINTS DUE TO COMBINED ACTION OF ALL REAL WELLS
H_o - INITIAL SAT. THICKNESS OF AQUIFER
K - HYDR. COND OF AQUIFER

SINCE ALL IMAGE WELLS OF REAL WELL "i" ARE LOCATED ON SAME HORIZONTAL LINE,

$$Y_{ij} = Y_i$$

WHERE Y_i IS A Y COORDINATE OF REAL WELL "i".

$$H_o^2 - h^2 = \sum_{i=1}^{M}\left[\frac{Q_i}{2\pi K}\sum_{j=-\infty}^{\infty}\ln\frac{(x-x_{ij_A})^2+(y-Y_{ij_A})^2}{(x-x_{ij_B})^2+(y-Y_{ij_B})^2}\right]$$

A SHORT FORTRAN PROGRAM WAS WRITTEN TO CALCULATE IT. THE WORKING OF THE PROGRAM WAS CHECKED

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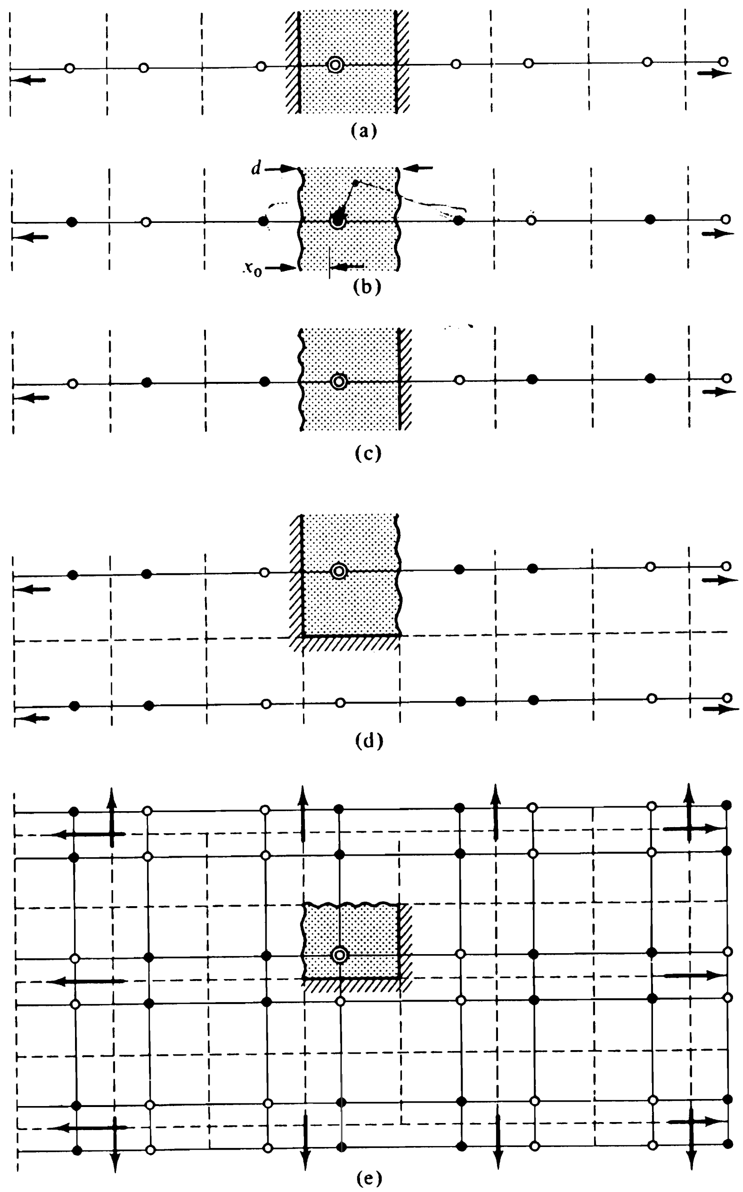
WITH A HAND CALCULATION FOR 1 OBSERV-ATION POINT AND 2 WELLS.
THE PROGRAM IS LISTED ON SHEETS D-14 TO D-16.
THE INPUT/OUTPUT USED IS SHOWN ON SHEET D-17. THE HAND CALCULATION, UTILIZING 100 TERMS TO CALCULATE THE SERIES, IS SHOWN ON SHEETS D-18 TO D-20

D-13A



- Impervious boundary
- Recharge boundary
- ◎ Real pumping well
- ○ Image pumping well
- ● Image recharge well

Figure 8-27 Example of image-well systems for a pumping well near various aquifer boundaries (arrows indicate that image-well system continues to infinity). (a) Infinite strip. (b) Infinite strip. (c) Infinite strip. (d) Semi-infinite strip. (e) Rectangle.

D-13B

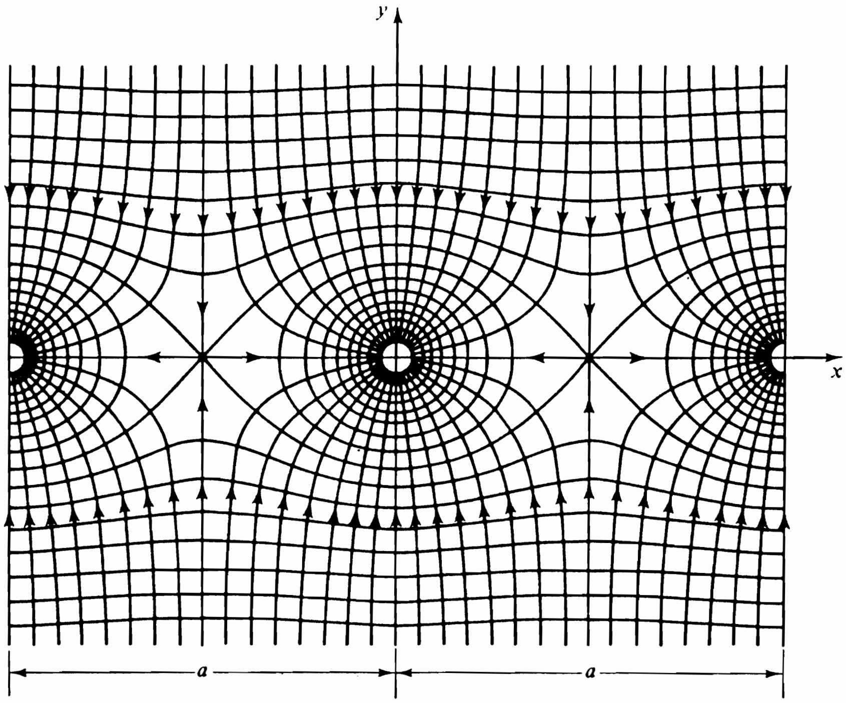


Figure 8-20 Streamlines and equipotentials about an infinite array of wells.

observation well, the principle of superposition (here with respect to h^2) leads to

$$H_0^2 - h_i^2 = \sum_{j=1}^{N} \frac{Q_j}{\pi K} \ln \frac{R_j}{r_{ij}} \tag{8-141}$$

where H_0 = const. is the initial (undisturbed) height of the water table above the impervious bottom, h_i is the height of the water table above the impervious bottom at the observation well (x_i, y_i), and the R_j's are the radii of influence of the pumping wells, (assuming that they are sufficiently large so that drawdown is produced at the observation well). When all R_j's are the same and all Q_j's are equal to Q/N, we obtain from (8-141)

$$H^2 - h_i^2 = \frac{Q}{\pi K} \ln(R/r^*); \qquad r^* = (r_{i1} r_{i2} r_{i3} \ldots r_{iN})^{1/N} \tag{8-142}$$

One should note here that because we have initially the nonhomogeneous conditions $h = H_0$ (and not $h = 0$), the superposition is actually not with respect to h^2. Instead, because initially $H_0^2 - h^2 = 0$ everywhere, the superposition is with respect to the difference $H_0^2 - h^2$. In a similar way, if in a confined aquifer we have initially $\phi_0 \neq 0$, the superposition is with respect to $\phi_0 - \phi$ (i.e., with respect to s!).

```
      PROGRAM IMAGE1
C THIS PROGRAM CALCULATES DRAWDOWNS DUE TO OPERATION OF WELLS IN AN UNCONFINED
C AQUIFER BOUNDED BY AN IMPERVIOUS BOUNDRY TO THE RIGHT AND A CONSTANT HEAD
C BOUNDRY TO THE LEFT. PROGRAM UTILZES THE METHOD OF IMAGES. THE COORDINATE
C SYSTEM USED IS: THE Y-AXIS COINCIDES WITH THE LEFT (CONST. HEAD) BOUNDRY, THE
C X-AXIS CAN BE AT ANY LOCATION.
C                  INPUT DATA
C AQUIFER PARAMETERS:
C   HK - HYDRAULIC CONDUCTIVITY [FT/DAY]
C   Ho - INITIAL SAT. THICKNESS [FT]
C    D - DISTANCE BETWEEN BOUNDRIES [FT]
C WELL DATA:
C   NWELL - NUMBER OF OPERATING WELLS [-]
C   XW(J) - X COORDINATE OF Jth WELL [FT]
C   YW(J) - Y COORDINATE OF Jth WELL [FT]
C    Q(J) - DISCHARGE RATE OF Jth WELL [FT^3/DAY]
C OBSERVATION POINTS DATA:
C   NOBS - NUMBER OF POINTS AT WHICH DRAWDOWNS WILL BE CALCULATED [-]
C   XOBS - X COORDINATES OF OBSERVATION POINTS [FT]
C   YOBS - Y COORDINATES OF OBSERVATION POINTS [FT]
C NUMERICAL PARAMETERS:
C   NTERMIN - NUMBER OF TERMS WITH WHICH TO START EVALUATION OF THE SERIES [-]
C       TOL - CLOSURE TOLERANCE FOR EVALUATING THE SERIES [-]
C TWO INPUT FILES ARE REQUIRED:
C   - FILE IMAG1.COR
C                       NOBS
C                       XOBS YOBS
C                       .........
C                       .........
C   - FILE IMAG1.INP
C                       HK  Ho  D
C                       NWELL
C                       XW(1)    YW(1)      Q(1)
C                       ..........................
C                       XW(NWELL) YW(NWELL) Q(NWELL)
C                       NTERMIN  TOL
C NOTE: ALL INPUT IS UNFORMATTED!
C                  OUTPUT
C THE OUTPUT FILE "IMAG1.OUT" CONTAINS OBSERVATION POINTS COORDINATES AND
C CORRESPONDING HYDRAULIC HEADS.
      REAL XW(30),YW(30),Q(30),DR(30)
      OPEN(UNIT=5,FILE='IMAG1.INP',STATUS='OLD')
      OPEN(UNIT=6,FILE='IMAG1.COR',STATUS='OLD')
      OPEN(UNIT=7,FILE='IMAG1.OUT',STATUS='NEW')
C READ AQUIFER PARAMETERS: HYDRAULIC CONDUCTIVITY, INITIAL SAT. THICKNESS
C AND WIDTH OF AQUIFER. WRITE THOSE PARAMETERS TO THE OUTPUT FILE.
      READ(5,*)HK,Ho,D
      WRITE(7,501)
      WRITE(7,502)HK,Ho,D
501   FORMAT(1X,10X,'AQUIFER PARAMETERS:')
502   FORMAT(/,1X,20X,'HYDR. COND.=',F8.2,' FT/DAY',/,1X,20X,
     +'INIT. SAT. THICK.=',F4.0,' FT',/,1X,20X,'WIDTH=',F7.0,' FT',//)
C READ NUMBER OF WELLS,WELL LOCATIONS AND DISCHARGES. WRITE WELL DATA TO
C THE OUTPUT FILE.
      WRITE(7,503)
503   FORMAT(1X,10X,'WELL DATA:',//,1X,20X,'DESIG.',5X,'X [FT]',5X,
     +'Y [FT]',4X,'   Q [FT^3/D]')
      READ(5,*)NWELL
      DO 50 J=1,NWELL
         READ(5,*)XW(J),YW(J),Q(J)
```

```
             WRITE(7,504)J,XW(J),YW(J),Q(J)
504          FORMAT(1X,22X,I3,7X,F6.0,4X,F6.0,8X,F8.0)
50        CONTINUE
C READ NUMBER OF OBSERVATION POINTS
          READ(6,*)NOBS
C READ PARAMETERS FOR EVALUATION OF THE SERIES: INIT. NUMBER OF TERMS AND
C CLOSURE TOLERANCE. ECHO CLOSURE TOL. TO THE OUTPUT FILE.
          READ(5,*)NTERMIN,TOL
          WRITE(7,601)
601       FORMAT(//,1X,10X,'CLOSURE TOLERANCE FOR SERIES EVALUATION:',/)
          WRITE(7,602)TOL
602       FORMAT(1X,20X,'TOLERANCE=',F8.6)
         WRITE(7,505)
505      FORMAT(//,1X,10X,'HYDRAULIC HEADS:',//,1X,19X,'X [FT]',7X,
     +'Y [FT]',4X,'HEAD [FT]')
C START CALCULATIONS
C
C READ COORDINATES OF OBS. POINT
          K=0
200       READ(6,*)XOBS,YOBS
          K=K+1
          write(*,777)k,nobs
777       format(//,1x/10x,'DOING POINT ',i5,' OF ',i5)
C CALCULATE DRAWDOWNS DUE TO Jth WELL
          DO 10 J=1,NWELL
             SUM=0
             NTERM=1
100          SUMF=SUM
C CALCULATE DRAWDOWNS DUE TO EACH IMAGE WELL OF REAL WELL J
             DO 11 I=-NTERM,NTERM,2*NTERM
                IF(I.NE.0)THEN
                XA=D+(ABS(I)/I)*((2*ABS(I)-1)*D-XW(J)*(-1)**ABS(I))
                XB=D+(ABS(I)/I)*((2*ABS(I)-1)*D+XW(J)*(-1)**ABS(I))
                S1=(XOBS-XA)**2+(YOBS-YW(J))**2
                S2=(XOBS-XB)**2+(YOBS-YW(J))**2
                S=LOG(S1/S2)
                ELSE
                S=0
                ENDIF
                SUM=SUM+S
11           CONTINUE
C             write(7,*)nterm,sum
C CHECK SERIES CONVERGENCE
             ERR=ABS(SUM-SUMF)/ABS(SUM)
             IF(ERR.GT.TOL)THEN
             NTERM=NTERM+1
             GO TO 100
             ELSE
             DR(J)=(Q(J)/(2*3.1416*HK))*SUM
             ENDIF
10        CONTINUE
C CALCULATE DRAWDOWN DUE TO COMBINED EFFECT OF EACH REAL WELL AT ONE OBS. POINT
          DO 12 J=1,NWELL
             DRTOT=DRTOT+DR(J)
12        CONTINUE
          HEAD=SQRT(Ho**2-DRTOT)
C WRITE RESULTS
         WRITE(7,506)XOBS,YOBS,HEAD
506      FORMAT(1X,20X,F5.0,8X,F5.0,5X,F6.2)
C CHECK THE NUMBER OF OBS. POINT
```

```
      IF(K.LT.NOBS)THEN
      DRTOT=0
      GO TO 200
      ELSE
      STOP
      ENDIF
      END
```

1.) INPUT FILES

- FILE IMAG1.INP

```
1000. 30. 1000.
2
200. 100. 100000.
400. 500. 50000.
10 0.01
```

- FILE IMAG1.COR

```
1
300. 300.
```

2.) OUTPUT FILE

AQUIFER PARAMETERS:

HYDR. COND.= 1000.00 FT/DAY
INIT. SAT. THICK.= 30. FT
WIDTH= 1000. FT

WELL DATA:

DESIG.	X [FT]	Y [FT]	Q [FT^3/D]
1	200.	100.	100000.
2	400.	500.	50000.

CLOSURE TOLERANCE FOR SERIES EVALUATION:

TOLERANCE= .010000

HYDRAULIC HEADS:

X [FT]	Y [FT]	HEAD [FT]
300.	300.	29.2

d=	1000	AQUIFER WIDTH
Xo=	200	WELL X COORDINATE
Yo=	100	WELL Y COORDINATE
X=	300	OBS. POINT X COORDINATE
Y=	300	OBS. POINT Y COORDINATE
Q=	100000	WELL DISCHARGE
k=	1000	AQUIFER HYDR. COND.

n	XA	XB	(X-XA)^2	(X-XB)^2	(Y-Yo)^2	ln	(Ho^2-h^2)n
100	2.00E+05	2.00E+05	4.0E+10	4.0E+10	40000	-0.004	-0.064
99	1.98E+05	1.98E+05	3.9E+10	3.9E+10	40000	0.004	0.064
98	1.96E+05	1.96E+05	3.8E+10	3.8E+10	40000	-0.004	-0.065
97	1.94E+05	1.94E+05	3.8E+10	3.7E+10	40000	0.004	0.066
96	1.92E+05	1.92E+05	3.7E+10	3.7E+10	40000	-0.004	-0.066
95	1.90E+05	1.90E+05	3.6E+10	3.6E+10	40000	0.004	0.067
94	1.88E+05	1.88E+05	3.5E+10	3.5E+10	40000	-0.004	-0.068
93	1.86E+05	1.86E+05	3.5E+10	3.4E+10	40000	0.004	0.069
92	1.84E+05	1.84E+05	3.4E+10	3.4E+10	40000	-0.004	-0.069
91	1.82E+05	1.82E+05	3.3E+10	3.3E+10	40000	0.004	0.070
90	1.80E+05	1.80E+05	3.2E+10	3.2E+10	40000	-0.004	-0.071
89	1.78E+05	1.78E+05	3.2E+10	3.2E+10	40000	0.005	0.072
88	1.76E+05	1.76E+05	3.1E+10	3.1E+10	40000	-0.005	-0.073
87	1.74E+05	1.74E+05	3.0E+10	3.0E+10	40000	0.005	0.073
86	1.72E+05	1.72E+05	2.9E+10	3.0E+10	40000	-0.005	-0.074
85	1.70E+05	1.70E+05	2.9E+10	2.9E+10	40000	0.005	0.075
84	1.68E+05	1.68E+05	2.8E+10	2.8E+10	40000	-0.005	-0.076
83	1.66E+05	1.66E+05	2.8E+10	2.7E+10	40000	0.005	0.077
82	1.64E+05	1.64E+05	2.7E+10	2.7E+10	40000	-0.005	-0.078
81	1.62E+05	1.62E+05	2.6E+10	2.6E+10	40000	0.005	0.079
80	1.60E+05	1.60E+05	2.5E+10	2.6E+10	40000	-0.005	-0.080
79	1.58E+05	1.58E+05	2.5E+10	2.5E+10	40000	0.005	0.081
78	1.56E+05	1.56E+05	2.4E+10	2.4E+10	40000	-0.005	-0.082
77	1.54E+05	1.54E+05	2.4E+10	2.4E+10	40000	0.005	0.083
76	1.52E+05	1.52E+05	2.3E+10	2.3E+10	40000	-0.005	-0.084
75	1.50E+05	1.50E+05	2.2E+10	2.2E+10	40000	0.005	0.085
74	1.48E+05	1.48E+05	2.2E+10	2.2E+10	40000	-0.005	-0.086
73	1.46E+05	1.46E+05	2.1E+10	2.1E+10	40000	0.005	0.087
72	1.44E+05	1.44E+05	2.1E+10	2.1E+10	40000	-0.006	-0.089
71	1.42E+05	1.42E+05	2.0E+10	2.0E+10	40000	0.006	0.090
70	1.40E+05	1.40E+05	1.9E+10	2.0E+10	40000	-0.006	-0.091
69	1.38E+05	1.38E+05	1.9E+10	1.9E+10	40000	0.006	0.093
68	1.36E+05	1.36E+05	1.8E+10	1.8E+10	40000	-0.006	-0.094
67	1.34E+05	1.34E+05	1.8E+10	1.8E+10	40000	0.006	0.095
66	1.32E+05	1.32E+05	1.7E+10	1.7E+10	40000	-0.006	-0.097
65	1.30E+05	1.30E+05	1.7E+10	1.7E+10	40000	0.006	0.098
64	1.28E+05	1.28E+05	1.6E+10	1.6E+10	40000	-0.006	-0.100
63	1.26E+05	1.26E+05	1.6E+10	1.6E+10	40000	0.006	0.101
62	1.24E+05	1.24E+05	1.5E+10	1.5E+10	40000	-0.006	-0.103
61	1.22E+05	1.22E+05	1.5E+10	1.5E+10	40000	0.007	0.105
60	1.20E+05	1.20E+05	1.4E+10	1.4E+10	40000	-0.007	-0.106
59	1.18E+05	1.18E+05	1.4E+10	1.4E+10	40000	0.007	0.108
58	1.16E+05	1.16E+05	1.3E+10	1.3E+10	40000	-0.007	-0.110
57	1.14E+05	1.14E+05	1.3E+10	1.3E+10	40000	0.007	0.112
56	1.12E+05	1.12E+05	1.2E+10	1.3E+10	40000	-0.007	-0.114
55	1.10E+05	1.10E+05	1.2E+10	1.2E+10	40000	0.007	0.116
54	1.08E+05	1.08E+05	1.2E+10	1.2E+10	40000	-0.007	-0.118
53	1.06E+05	1.06E+05	1.1E+10	1.1E+10	40000	0.008	0.121
52	1.04E+05	1.04E+05	1.1E+10	1.1E+10	40000	-0.008	-0.123
51	1.02E+05	1.02E+05	1.0E+10	1.0E+10	40000	0.008	0.125
50	9.98E+04	1.00E+05	9.9E+09	1.0E+10	40000	-0.008	-0.128
49	9.82E+04	9.78E+04	9.6E+09	9.5E+09	40000	0.008	0.130
48	9.58E+04	9.62E+04	9.1E+09	9.2E+09	40000	-0.008	-0.133
47	9.42E+04	9.38E+04	8.8E+09	8.7E+09	40000	0.009	0.136
46	9.18E+04	9.22E+04	8.4E+09	8.4E+09	40000	-0.009	-0.139
45	9.02E+04	8.98E+04	8.1E+09	8.0E+09	40000	0.009	0.142
44	8.78E+04	8.82E+04	7.7E+09	7.7E+09	40000	-0.009	-0.145
43	8.62E+04	8.58E+04	7.4E+09	7.3E+09	40000	0.009	0.149
42	8.38E+04	8.42E+04	7.0E+09	7.0E+09	40000	-0.010	-0.152
41	8.22E+04	8.18E+04	6.7E+09	6.6E+09	40000	0.010	0.156
40	7.98E+04	8.02E+04	6.3E+09	6.4E+09	40000	-0.010	-0.160
39	7.82E+04	7.78E+04	6.1E+09	6.0E+09	40000	0.010	0.164
38	7.58E+04	7.62E+04	5.7E+09	5.8E+09	40000	-0.011	-0.168
37	7.42E+04	7.38E+04	5.5E+09	5.4E+09	40000	0.011	0.173
36	7.18E+04	7.22E+04	5.1E+09	5.2E+09	40000	-0.011	-0.178
35	7.02E+04	6.98E+04	4.9E+09	4.8E+09	40000	0.011	0.183
34	6.78E+04	6.82E+04	4.6E+09	4.6E+09	40000	-0.012	-0.188
33	6.62E+04	6.58E+04	4.3E+09	4.3E+09	40000	0.012	0.194
32	6.38E+04	6.42E+04	4.0E+09	4.1E+09	40000	-0.013	-0.200
31	6.22E+04	6.18E+04	3.8E+09	3.8E+09	40000	0.013	0.206

d=	1000	AQUIFER WIDTH
Xo=	400	WELL X COORDINATE
Yo=	500	WELL Y COORDINATE
X=	300	OBS. POINT X COORDINATE
Y=	300	OBS. POINT Y COORDINATE
Q=	50000	WELL DISCHARGE
k=	1000	AQUIFER HYDR. COND.

n	XA	XB	(X-XA)^2	(X-XB)^2	(Y-Yo)^2	ln	Ho^2-h^2)
100	2.00E+05	2.00E+05	4.0E+10	4.0E+10	40000	-0.008	-0.064
99	1.98E+05	1.98E+05	3.9E+10	3.9E+10	40000	0.008	0.064
98	1.96E+05	1.96E+05	3.8E+10	3.8E+10	40000	-0.008	-0.065
97	1.94E+05	1.94E+05	3.8E+10	3.7E+10	40000	0.008	0.066
96	1.92E+05	1.92E+05	3.7E+10	3.7E+10	40000	-0.008	-0.066
95	1.90E+05	1.90E+05	3.6E+10	3.6E+10	40000	0.008	0.067
94	1.88E+05	1.88E+05	3.5E+10	3.5E+10	40000	-0.009	-0.068
93	1.86E+05	1.86E+05	3.5E+10	3.4E+10	40000	0.009	0.069
92	1.84E+05	1.84E+05	3.4E+10	3.4E+10	40000	-0.009	-0.069
91	1.82E+05	1.82E+05	3.3E+10	3.3E+10	40000	0.009	0.070
90	1.80E+05	1.80E+05	3.2E+10	3.2E+10	40000	-0.009	-0.071
89	1.78E+05	1.78E+05	3.2E+10	3.1E+10	40000	0.009	0.072
88	1.76E+05	1.76E+05	3.1E+10	3.1E+10	40000	-0.009	-0.073
87	1.74E+05	1.74E+05	3.0E+10	3.0E+10	40000	0.009	0.073
86	1.72E+05	1.72E+05	2.9E+10	3.0E+10	40000	-0.009	-0.074
85	1.70E+05	1.70E+05	2.9E+10	2.9E+10	40000	0.009	0.075
84	1.68E+05	1.68E+05	2.8E+10	2.8E+10	40000	-0.010	-0.076
83	1.66E+05	1.66E+05	2.8E+10	2.7E+10	40000	0.010	0.077
82	1.64E+05	1.64E+05	2.7E+10	2.7E+10	40000	-0.010	-0.078
81	1.62E+05	1.62E+05	2.6E+10	2.6E+10	40000	0.010	0.079
80	1.60E+05	1.60E+05	2.5E+10	2.6E+10	40000	-0.010	-0.080
79	1.58E+05	1.58E+05	2.5E+10	2.5E+10	40000	0.010	0.081
78	1.56E+05	1.56E+05	2.4E+10	2.4E+10	40000	-0.010	-0.082
77	1.54E+05	1.54E+05	2.4E+10	2.4E+10	40000	0.010	0.083
76	1.52E+05	1.52E+05	2.3E+10	2.3E+10	40000	-0.011	-0.084
75	1.50E+05	1.50E+05	2.3E+10	2.2E+10	40000	0.011	0.085
74	1.48E+05	1.48E+05	2.2E+10	2.2E+10	40000	-0.011	-0.086
73	1.46E+05	1.46E+05	2.1E+10	2.1E+10	40000	0.011	0.087
72	1.44E+05	1.44E+05	2.1E+10	2.1E+10	40000	-0.011	-0.089
71	1.42E+05	1.42E+05	2.0E+10	2.0E+10	40000	0.011	0.090
70	1.40E+05	1.40E+05	1.9E+10	2.0E+10	40000	-0.011	-0.091
69	1.38E+05	1.38E+05	1.9E+10	1.9E+10	40000	0.012	0.093
68	1.36E+05	1.36E+05	1.8E+10	1.9E+10	40000	-0.012	-0.094
67	1.34E+05	1.34E+05	1.8E+10	1.8E+10	40000	0.012	0.095
66	1.32E+05	1.32E+05	1.7E+10	1.7E+10	40000	-0.012	-0.097
65	1.30E+05	1.30E+05	1.7E+10	1.7E+10	40000	0.012	0.098
64	1.28E+05	1.28E+05	1.6E+10	1.6E+10	40000	-0.013	-0.100
63	1.26E+05	1.26E+05	1.6E+10	1.6E+10	40000	0.013	0.101
62	1.24E+05	1.24E+05	1.5E+10	1.5E+10	40000	-0.013	-0.103
61	1.22E+05	1.22E+05	1.5E+10	1.5E+10	40000	0.013	0.105
60	1.20E+05	1.20E+05	1.4E+10	1.4E+10	40000	-0.013	-0.106
59	1.18E+05	1.18E+05	1.4E+10	1.4E+10	40000	0.014	0.108
58	1.16E+05	1.16E+05	1.3E+10	1.3E+10	40000	-0.014	-0.110
57	1.14E+05	1.14E+05	1.3E+10	1.3E+10	40000	0.014	0.112
56	1.12E+05	1.12E+05	1.2E+10	1.3E+10	40000	-0.014	-0.114
55	1.10E+05	1.10E+05	1.2E+10	1.2E+10	40000	0.015	0.116
54	1.08E+05	1.08E+05	1.2E+10	1.2E+10	40000	-0.015	-0.118
53	1.06E+05	1.06E+05	1.1E+10	1.1E+10	40000	0.015	0.121
52	1.04E+05	1.04E+05	1.1E+10	1.1E+10	40000	-0.015	-0.123
51	1.02E+05	1.02E+05	1.0E+10	1.0E+10	40000	0.016	0.125
50	9.96E+04	1.00E+05	9.9E+09	1.0E+10	40000	-0.016	-0.128
49	9.84E+04	9.76E+04	9.6E+09	9.5E+09	40000	0.016	0.130
48	9.56E+04	9.64E+04	9.1E+09	9.2E+09	40000	-0.017	-0.133
47	9.44E+04	9.36E+04	8.9E+09	8.7E+09	40000	0.017	0.136
46	9.16E+04	9.24E+04	8.3E+09	8.5E+09	40000	-0.017	-0.139
45	9.04E+04	8.96E+04	8.1E+09	8.0E+09	40000	0.018	0.142
44	8.76E+04	8.84E+04	7.6E+09	7.8E+09	40000	-0.018	-0.145
43	8.64E+04	8.56E+04	7.4E+09	7.3E+09	40000	0.019	0.149
42	8.36E+04	8.44E+04	6.9E+09	7.1E+09	40000	-0.019	-0.152
41	8.24E+04	8.16E+04	6.7E+09	6.6E+09	40000	0.020	0.156
40	7.96E+04	8.04E+04	6.3E+09	6.4E+09	40000	-0.020	-0.160
39	7.84E+04	7.76E+04	6.1E+09	6.0E+09	40000	0.021	0.164
38	7.56E+04	7.64E+04	5.7E+09	5.8E+09	40000	-0.021	-0.168
37	7.44E+04	7.36E+04	5.5E+09	5.4E+09	40000	0.022	0.173
36	7.16E+04	7.24E+04	5.1E+09	5.2E+09	40000	-0.022	-0.178
35	7.04E+04	6.96E+04	4.9E+09	4.8E+09	40000	0.023	0.183
34	6.76E+04	6.84E+04	4.5E+09	4.6E+09	40000	-0.024	-0.188
33	6.64E+04	6.56E+04	4.4E+09	4.3E+09	40000	0.024	0.194
32	6.36E+04	6.44E+04	4.0E+09	4.1E+09	40000	-0.025	-0.200
31	6.24E+04	6.16E+04	3.9E+09	3.8E+09	40000	0.026	0.206

30	5.98E+04	6.02E+04	3.5E+09	3.6E+09	40000	-0.013	-0.213
29	5.82E+04	5.78E+04	3.4E+09	3.3E+09	40000	0.014	0.221
28	5.58E+04	5.62E+04	3.1E+09	3.1E+09	40000	-0.014	-0.229
27	5.42E+04	5.38E+04	2.9E+09	2.9E+09	40000	0.015	0.237
26	5.18E+04	5.22E+04	2.7E+09	2.7E+09	40000	-0.015	-0.246
25	5.02E+04	4.98E+04	2.5E+09	2.5E+09	40000	0.016	0.256
24	4.78E+04	4.82E+04	2.3E+09	2.3E+09	40000	-0.017	-0.267
23	4.62E+04	4.58E+04	2.1E+09	2.1E+09	40000	0.018	0.279
22	4.38E+04	4.42E+04	1.9E+09	1.9E+09	40000	-0.018	-0.292
21	4.22E+04	4.18E+04	1.8E+09	1.7E+09	40000	0.019	0.305
20	3.98E+04	4.02E+04	1.6E+09	1.6E+09	40000	-0.020	-0.321
19	3.82E+04	3.78E+04	1.4E+09	1.4E+09	40000	0.021	0.338
18	3.58E+04	3.62E+04	1.3E+09	1.3E+09	40000	-0.022	-0.357
17	3.42E+04	3.38E+04	1.1E+09	1.1E+09	40000	0.024	0.378
16	3.18E+04	3.22E+04	9.9E+08	1.0E+09	40000	-0.025	-0.402
15	3.02E+04	2.98E+04	8.9E+08	8.7E+08	40000	0.027	0.429
14	2.78E+04	2.82E+04	7.6E+08	7.8E+08	40000	-0.029	-0.460
13	2.62E+04	2.58E+04	6.7E+08	6.5E+08	40000	0.031	0.496
12	2.38E+04	2.42E+04	5.5E+08	5.7E+08	40000	-0.034	-0.537
11	2.22E+04	2.18E+04	4.8E+08	4.6E+08	40000	0.037	0.587
10	1.98E+04	2.02E+04	3.8E+08	4.0E+08	40000	-0.041	-0.647
9	1.82E+04	1.78E+04	3.2E+08	3.1E+08	40000	0.045	0.720
8	1.58E+04	1.62E+04	2.4E+08	2.5E+08	40000	-0.051	-0.811
7	1.42E+04	1.38E+04	1.9E+08	1.8E+08	40000	0.058	0.930
6	1.18E+04	1.22E+04	1.3E+08	1.4E+08	40000	-0.068	-1.089
5	1.02E+04	9.80E+03	1E+08	9E+07	40000	0.082	1.313
4	7.80E+03	8.20E+03	6E+07	6E+07	40000	-0.104	-1.654
3	6.20E+03	5.80E+03	3E+07	3E+07	40000	0.140	2.233
2	3.80E+03	4.20E+03	1E+07	2E+07	40000	-0.216	-3.436
1	2.20E+03	1.80E+03	3610000	2250000	40000	0.466	7.423
-1	-2.00E+02	2.00E+02	250000	10000	40000	1.758	27.991
-2	-1.80E+03	-2.20E+03	4410000	6250000	40000	-0.346	-5.510
-3	-4.20E+03	-3.80E+03	2E+07	2E+07	40000	0.186	2.958
-4	-5.80E+03	-6.20E+03	4E+07	4E+07	40000	-0.127	-2.021
-5	-8.20E+03	-7.80E+03	7E+07	7E+07	40000	0.096	1.534
-6	-9.80E+03	-1.02E+04	1.0E+08	1.1E+08	40000	-0.078	-1.236
-7	-1.22E+04	-1.18E+04	1.6E+08	1.5E+08	40000	0.065	1.036
-8	-1.38E+04	-1.42E+04	2.0E+08	2.1E+08	40000	-0.056	-0.891
-9	-1.62E+04	-1.58E+04	2.7E+08	2.6E+08	40000	0.049	0.781
-10	-1.78E+04	-1.82E+04	3.3E+08	3.4E+08	40000	-0.044	-0.696
-11	-2.02E+04	-1.98E+04	4.2E+08	4.0E+08	40000	0.039	0.627
-12	-2.18E+04	-2.22E+04	4.9E+08	5.1E+08	40000	-0.036	-0.571
-13	-2.42E+04	-2.38E+04	6.0E+08	5.8E+08	40000	0.033	0.524
-14	-2.58E+04	-2.62E+04	6.8E+08	7.0E+08	40000	-0.030	-0.484
-15	-2.82E+04	-2.78E+04	8.1E+08	7.9E+08	40000	0.028	0.450
-16	-2.98E+04	-3.02E+04	9.1E+08	9.3E+08	40000	-0.026	-0.420
-17	-3.22E+04	-3.18E+04	1.1E+09	1.0E+09	40000	0.025	0.394
-18	-3.38E+04	-3.42E+04	1.2E+09	1.2E+09	40000	-0.023	-0.371
-19	-3.62E+04	-3.58E+04	1.3E+09	1.3E+09	40000	0.022	0.351
-20	-3.78E+04	-3.82E+04	1.5E+09	1.5E+09	40000	-0.021	-0.333
-21	-4.02E+04	-3.98E+04	1.6E+09	1.6E+09	40000	0.020	0.316
-22	-4.18E+04	-4.22E+04	1.8E+09	1.8E+09	40000	-0.019	-0.301
-23	-4.42E+04	-4.38E+04	2.0E+09	1.9E+09	40000	0.018	0.288
-24	-4.58E+04	-4.62E+04	2.1E+09	2.2E+09	40000	-0.017	-0.275
-25	-4.82E+04	-4.78E+04	2.4E+09	2.3E+09	40000	0.017	0.264
-26	-4.98E+04	-5.02E+04	2.5E+09	2.6E+09	40000	-0.016	-0.253
-27	-5.22E+04	-5.18E+04	2.8E+09	2.7E+09	40000	0.015	0.244
-28	-5.38E+04	-5.42E+04	2.9E+09	3.0E+09	40000	-0.015	-0.236
-29	-5.62E+04	-5.58E+04	3.2E+09	3.1E+09	40000	0.014	0.226
-30	-5.78E+04	-5.82E+04	3.4E+09	3.4E+09	40000	-0.014	-0.219
-31	-6.02E+04	-5.98E+04	3.7E+09	3.6E+09	40000	0.013	0.211
-32	-6.18E+04	-6.22E+04	3.9E+09	3.9E+09	40000	-0.013	-0.204
-33	-6.42E+04	-6.38E+04	4.2E+09	4.1E+09	40000	0.012	0.198
-34	-6.58E+04	-6.62E+04	4.4E+09	4.4E+09	40000	-0.012	-0.192
-35	-6.82E+04	-6.78E+04	4.7E+09	4.6E+09	40000	0.012	0.187
-36	-6.98E+04	-7.02E+04	4.9E+09	5.0E+09	40000	-0.011	-0.181
-37	-7.22E+04	-7.18E+04	5.3E+09	5.2E+09	40000	0.011	0.176
-38	-7.38E+04	-7.42E+04	5.5E+09	5.6E+09	40000	-0.011	-0.171
-39	-7.62E+04	-7.58E+04	5.9E+09	5.8E+09	40000	0.010	0.167
-40	-7.78E+04	-7.82E+04	6.1E+09	6.2E+09	40000	-0.010	-0.163
-41	-8.02E+04	-7.98E+04	6.5E+09	6.4E+09	40000	0.010	0.159
-42	-8.18E+04	-8.22E+04	6.7E+09	6.8E+09	40000	-0.010	-0.155
-43	-8.42E+04	-8.38E+04	7.1E+09	7.1E+09	40000	0.009	0.151
-44	-8.58E+04	-8.62E+04	7.4E+09	7.5E+09	40000	-0.009	-0.148
-45	-8.82E+04	-8.78E+04	7.8E+09	7.8E+09	40000	0.009	0.144
-46	-8.98E+04	-9.02E+04	8.1E+09	8.2E+09	40000	-0.009	-0.141
-47	-9.22E+04	-9.18E+04	8.6E+09	8.5E+09	40000	0.009	0.138
-48	-9.38E+04	-9.42E+04	8.9E+09	8.9E+09	40000	-0.008	-0.135
-49	-9.62E+04	-9.58E+04	9.3E+09	9.2E+09	40000	0.008	0.132
-50	-9.78E+04	-9.82E+04	9.6E+09	9.7E+09	40000	-0.008	-0.130
-51	-1.00E+05	-9.98E+04	1.0E+10	1.0E+10	40000	0.008	0.127

30	5.96E+04	6.04E+04	3.5E+09	3.6E+09	40000	-0.027	-0.213
29	5.84E+04	5.76E+04	3.4E+09	3.3E+09	40000	0.028	0.221
28	5.56E+04	5.64E+04	3.1E+09	3.1E+09	40000	-0.029	-0.229
27	5.44E+04	5.36E+04	2.9E+09	2.8E+09	40000	0.030	0.237
26	5.16E+04	5.24E+04	2.6E+09	2.7E+09	40000	-0.031	-0.246
25	5.04E+04	4.96E+04	2.5E+09	2.4E+09	40000	0.032	0.256
24	4.76E+04	4.84E+04	2.2E+09	2.3E+09	40000	-0.034	-0.267
23	4.64E+04	4.56E+04	2.1E+09	2.1E+09	40000	0.035	0.279
22	4.36E+04	4.44E+04	1.9E+09	1.9E+09	40000	-0.037	-0.292
21	4.24E+04	4.16E+04	1.8E+09	1.7E+09	40000	0.038	0.305
20	3.96E+04	4.04E+04	1.5E+09	1.6E+09	40000	-0.040	-0.321
19	3.84E+04	3.76E+04	1.5E+09	1.4E+09	40000	0.042	0.338
18	3.56E+04	3.64E+04	1.2E+09	1.3E+09	40000	-0.045	-0.357
17	3.44E+04	3.36E+04	1.2E+09	1.1E+09	40000	0.047	0.378
16	3.16E+04	3.24E+04	9.8E+08	1.0E+09	40000	-0.050	-0.402
15	3.04E+04	2.96E+04	9.1E+08	8.6E+08	40000	0.054	0.429
14	2.76E+04	2.84E+04	7.5E+08	7.9E+08	40000	-0.058	-0.460
13	2.64E+04	2.56E+04	6.8E+08	6.4E+08	40000	0.062	0.496
12	2.36E+04	2.44E+04	5.4E+08	5.8E+08	40000	-0.068	-0.538
11	2.24E+04	2.16E+04	4.9E+08	4.5E+08	40000	0.074	0.587
10	1.96E+04	2.04E+04	3.7E+08	4.0E+08	40000	-0.081	-0.647
9	1.84E+04	1.76E+04	3.3E+08	3.0E+08	40000	0.090	0.720
8	1.56E+04	1.64E+04	2.3E+08	2.6E+08	40000	-0.102	-0.811
7	1.44E+04	1.36E+04	2.0E+08	1.8E+08	40000	0.117	0.930
6	1.16E+04	1.24E+04	1.3E+08	1.5E+08	40000	-0.137	-1.089
5	1.04E+04	9.60E+03	1.0E+08	9E+07	40000	0.165	1.313
4	7.60E+03	8.40E+03	5E+07	7E+07	40000	-0.208	-1.655
3	6.40E+03	5.60E+03	4E+07	3E+07	40000	0.281	2.236
2	3.60E+03	4.40E+03	1E+07	2E+07	40000	-0.433	-3.446
1	2.40E+03	1.60E+03	4410000	1690000	40000	0.945	7.522
-1	-4.00E+02	4.00E+02	490000	10000	40000	2.361	18.797
-2	-1.60E+03	-2.40E+03	3610000	7290000	40000	-0.697	-5.551
-3	-4.40E+03	-3.60E+03	2E+07	2E+07	40000	0.372	2.965
-4	-5.60E+03	-6.40E+03	3E+07	4E+07	40000	-0.254	-2.023
-5	-8.40E+03	-7.60E+03	8E+07	6E+07	40000	0.193	1.535
-6	-9.60E+03	-1.04E+04	1E+08	1.1E+08	40000	-0.155	-1.237
-7	-1.24E+04	-1.16E+04	1.6E+08	1.4E+08	40000	0.130	1.036
-8	-1.36E+04	-1.44E+04	1.9E+08	2.2E+08	40000	-0.112	-0.891
-9	-1.64E+04	-1.56E+04	2.8E+08	2.5E+08	40000	0.098	0.782
-10	-1.76E+04	-1.84E+04	3.2E+08	3.5E+08	40000	-0.087	-0.696
-11	-2.04E+04	-1.96E+04	4.3E+08	4.0E+08	40000	0.079	0.628
-12	-2.16E+04	-2.24E+04	4.8E+08	5.2E+08	40000	-0.072	-0.571
-13	-2.44E+04	-2.36E+04	6.1E+08	5.7E+08	40000	0.066	0.524
-14	-2.56E+04	-2.64E+04	6.7E+08	7.1E+08	40000	-0.061	-0.484
-15	-2.84E+04	-2.76E+04	8.2E+08	7.8E+08	40000	0.057	0.450
-16	-2.96E+04	-3.04E+04	8.9E+08	9.4E+08	40000	-0.053	-0.420
-17	-3.24E+04	-3.16E+04	1.1E+09	1.0E+09	40000	0.050	0.394
-18	-3.36E+04	-3.44E+04	1.1E+09	1.2E+09	40000	-0.047	-0.371
-19	-3.64E+04	-3.56E+04	1.3E+09	1.3E+09	40000	0.044	0.351
-20	-3.76E+04	-3.84E+04	1.4E+09	1.5E+09	40000	-0.042	-0.333
-21	-4.04E+04	-3.96E+04	1.7E+09	1.6E+09	40000	0.040	0.316
-22	-4.16E+04	-4.24E+04	1.8E+09	1.8E+09	40000	-0.038	-0.301
-23	-4.44E+04	-4.36E+04	2.0E+09	1.9E+09	40000	0.036	0.288
-24	-4.56E+04	-4.64E+04	2.1E+09	2.2E+09	40000	-0.035	-0.275
-25	-4.84E+04	-4.76E+04	2.4E+09	2.3E+09	40000	0.033	0.264
-26	-4.96E+04	-5.04E+04	2.5E+09	2.6E+09	40000	-0.032	-0.253
-27	-5.24E+04	-5.16E+04	2.8E+09	2.7E+09	40000	0.031	0.244
-28	-5.36E+04	-5.44E+04	2.9E+09	3.0E+09	40000	-0.029	-0.235
-29	-5.64E+04	-5.56E+04	3.2E+09	3.1E+09	40000	0.028	0.226
-30	-5.76E+04	-5.84E+04	3.4E+09	3.4E+09	40000	-0.027	-0.219
-31	-6.04E+04	-5.96E+04	3.7E+09	3.6E+09	40000	0.027	0.211
-32	-6.16E+04	-6.24E+04	3.8E+09	3.9E+09	40000	-0.026	-0.204
-33	-6.44E+04	-6.36E+04	4.2E+09	4.1E+09	40000	0.025	0.198
-34	-6.56E+04	-6.64E+04	4.3E+09	4.4E+09	40000	-0.024	-0.192
-35	-6.84E+04	-6.76E+04	4.7E+09	4.6E+09	40000	0.023	0.187
-36	-6.96E+04	-7.04E+04	4.9E+09	5.0E+09	40000	-0.023	-0.181
-37	-7.24E+04	-7.16E+04	5.3E+09	5.2E+09	40000	0.022	0.176
-38	-7.36E+04	-7.44E+04	5.5E+09	5.6E+09	40000	-0.022	-0.171
-39	-7.64E+04	-7.56E+04	5.9E+09	5.8E+09	40000	0.021	0.167
-40	-7.76E+04	-7.84E+04	6.1E+09	6.2E+09	40000	-0.020	-0.163
-41	-8.04E+04	-7.96E+04	6.5E+09	6.4E+09	40000	0.020	0.159
-42	-8.16E+04	-8.24E+04	6.7E+09	6.8E+09	40000	-0.019	-0.155
-43	-8.44E+04	-8.36E+04	7.2E+09	7.0E+09	40000	0.019	0.151
-44	-8.56E+04	-8.64E+04	7.4E+09	7.5E+09	40000	-0.019	-0.148
-45	-8.84E+04	-8.76E+04	7.9E+09	7.7E+09	40000	0.018	0.144
-46	-8.96E+04	-9.04E+04	8.1E+09	8.2E+09	40000	-0.018	-0.141
-47	-9.24E+04	-9.16E+04	8.6E+09	8.4E+09	40000	0.017	0.138
-48	-9.36E+04	-9.44E+04	8.8E+09	9.0E+09	40000	-0.017	-0.135
-49	-9.64E+04	-9.56E+04	9.4E+09	9.2E+09	40000	0.017	0.132
-50	-9.76E+04	-9.84E+04	9.6E+09	9.7E+09	40000	-0.016	-0.130
-51	-1.00E+05	-9.96E+04	1.0E+10	1.0E+10	40000	0.016	0.127

-52	-1.02E+05	-1.02E+05	1.0E+10	1.1E+10	40000	-0.008	-0.125
-53	-1.04E+05	-1.04E+05	1.1E+10	1.1E+10	40000	0.008	0.122
-54	-1.06E+05	-1.06E+05	1.1E+10	1.1E+10	40000	-0.008	-0.120
-55	-1.08E+05	-1.08E+05	1.2E+10	1.2E+10	40000	0.007	0.118
-56	-1.10E+05	-1.10E+05	1.2E+10	1.2E+10	40000	-0.007	-0.115
-57	-1.12E+05	-1.12E+05	1.3E+10	1.3E+10	40000	0.007	0.113
-58	-1.14E+05	-1.14E+05	1.3E+10	1.3E+10	40000	-0.007	-0.111
-59	-1.16E+05	-1.16E+05	1.4E+10	1.3E+10	40000	0.007	0.110
-60	-1.18E+05	-1.18E+05	1.4E+10	1.4E+10	40000	-0.007	-0.108
-61	-1.20E+05	-1.20E+05	1.5E+10	1.4E+10	40000	0.007	0.106
-62	-1.22E+05	-1.22E+05	1.5E+10	1.5E+10	40000	-0.007	-0.104
-63	-1.24E+05	-1.24E+05	1.6E+10	1.5E+10	40000	0.006	0.102
-64	-1.26E+05	-1.26E+05	1.6E+10	1.6E+10	40000	-0.006	-0.101
-65	-1.28E+05	-1.28E+05	1.7E+10	1.6E+10	40000	0.006	0.099
-66	-1.30E+05	-1.30E+05	1.7E+10	1.7E+10	40000	-0.006	-0.098
-67	-1.32E+05	-1.32E+05	1.8E+10	1.7E+10	40000	0.006	0.096
-68	-1.34E+05	-1.34E+05	1.8E+10	1.8E+10	40000	-0.006	-0.095
-69	-1.36E+05	-1.36E+05	1.9E+10	1.9E+10	40000	0.006	0.093
-70	-1.38E+05	-1.38E+05	1.9E+10	1.9E+10	40000	-0.006	-0.092
-71	-1.40E+05	-1.40E+05	2.0E+10	2.0E+10	40000	0.006	0.091
-72	-1.42E+05	-1.42E+05	2.0E+10	2.0E+10	40000	-0.006	-0.090
-73	-1.44E+05	-1.44E+05	2.1E+10	2.1E+10	40000	0.006	0.088
-74	-1.46E+05	-1.46E+05	2.1E+10	2.1E+10	40000	-0.005	-0.087
-75	-1.48E+05	-1.48E+05	2.2E+10	2.2E+10	40000	0.005	0.086
-76	-1.50E+05	-1.50E+05	2.3E+10	2.3E+10	40000	-0.005	-0.085
-77	-1.52E+05	-1.52E+05	2.3E+10	2.3E+10	40000	0.005	0.084
-78	-1.54E+05	-1.54E+05	2.4E+10	2.4E+10	40000	-0.005	-0.083
-79	-1.56E+05	-1.56E+05	2.4E+10	2.4E+10	40000	0.005	0.082
-80	-1.58E+05	-1.58E+05	2.5E+10	2.5E+10	40000	-0.005	-0.080
-81	-1.60E+05	-1.60E+05	2.6E+10	2.6E+10	40000	0.005	0.079
-82	-1.62E+05	-1.62E+05	2.6E+10	2.6E+10	40000	-0.005	-0.078
-83	-1.64E+05	-1.64E+05	2.7E+10	2.7E+10	40000	0.005	0.078
-84	-1.66E+05	-1.66E+05	2.8E+10	2.8E+10	40000	-0.005	-0.077
-85	-1.68E+05	-1.68E+05	2.8E+10	2.8E+10	40000	0.005	0.076
-86	-1.70E+05	-1.70E+05	2.9E+10	2.9E+10	40000	-0.005	-0.075
-87	-1.72E+05	-1.72E+05	3.0E+10	3.0E+10	40000	0.005	0.074
-88	-1.74E+05	-1.74E+05	3.0E+10	3.0E+10	40000	-0.005	-0.073
-89	-1.76E+05	-1.76E+05	3.1E+10	3.1E+10	40000	0.005	0.072
-90	-1.78E+05	-1.78E+05	3.2E+10	3.2E+10	40000	-0.004	-0.071
-91	-1.80E+05	-1.80E+05	3.3E+10	3.2E+10	40000	0.004	0.071
-92	-1.82E+05	-1.82E+05	3.3E+10	3.3E+10	40000	-0.004	-0.070
-93	-1.84E+05	-1.84E+05	3.4E+10	3.4E+10	40000	0.004	0.069
-94	-1.86E+05	-1.86E+05	3.5E+10	3.5E+10	40000	-0.004	-0.068
-95	-1.88E+05	-1.88E+05	3.6E+10	3.5E+10	40000	0.004	0.068
-96	-1.90E+05	-1.90E+05	3.6E+10	3.6E+10	40000	-0.004	-0.067
-97	-1.92E+05	-1.92E+05	3.7E+10	3.7E+10	40000	0.004	0.066
-98	-1.94E+05	-1.94E+05	3.8E+10	3.8E+10	40000	-0.004	-0.066
-99	-1.96E+05	-1.96E+05	3.9E+10	3.8E+10	40000	0.004	0.065
-100	-1.98E+05	-1.98E+05	3.9E+10	3.9E+10	40000	-0.004	-0.064

UNCONF. DRAWDOWN Ho^2-h^2= 29.50

-52	-1.02E+05	-1.02E+05	1.0E+10	1.1E+10	40000	-0.016	-0.125
-53	-1.04E+05	-1.04E+05	1.1E+10	1.1E+10	40000	0.015	0.122
-54	-1.06E+05	-1.06E+05	1.1E+10	1.1E+10	40000	-0.015	-0.120
-55	-1.08E+05	-1.08E+05	1.2E+10	1.2E+10	40000	0.015	0.118
-56	-1.10E+05	-1.10E+05	1.2E+10	1.2E+10	40000	-0.015	-0.115
-57	-1.12E+05	-1.12E+05	1.3E+10	1.3E+10	40000	0.014	0.113
-58	-1.14E+05	-1.14E+05	1.3E+10	1.3E+10	40000	-0.014	-0.111
-59	-1.16E+05	-1.16E+05	1.4E+10	1.3E+10	40000	0.014	0.110
-60	-1.18E+05	-1.18E+05	1.4E+10	1.4E+10	40000	-0.014	-0.108
-61	-1.20E+05	-1.20E+05	1.5E+10	1.4E+10	40000	0.013	0.106
-62	-1.22E+05	-1.22E+05	1.5E+10	1.5E+10	40000	-0.013	-0.104
-63	-1.24E+05	-1.24E+05	1.6E+10	1.5E+10	40000	0.013	0.102
-64	-1.26E+05	-1.26E+05	1.6E+10	1.6E+10	40000	-0.013	-0.101
-65	-1.28E+05	-1.28E+05	1.7E+10	1.6E+10	40000	0.012	0.099
-66	-1.30E+05	-1.30E+05	1.7E+10	1.7E+10	40000	-0.012	-0.098
-67	-1.32E+05	-1.32E+05	1.8E+10	1.7E+10	40000	0.012	0.096
-68	-1.34E+05	-1.34E+05	1.8E+10	1.8E+10	40000	-0.012	-0.095
-69	-1.36E+05	-1.36E+05	1.9E+10	1.8E+10	40000	0.012	0.093
-70	-1.38E+05	-1.38E+05	1.9E+10	1.9E+10	40000	-0.012	-0.092
-71	-1.40E+05	-1.40E+05	2.0E+10	2.0E+10	40000	0.011	0.091
-72	-1.42E+05	-1.42E+05	2.0E+10	2.0E+10	40000	-0.011	-0.090
-73	-1.44E+05	-1.44E+05	2.1E+10	2.1E+10	40000	0.011	0.088
-74	-1.46E+05	-1.46E+05	2.1E+10	2.2E+10	40000	-0.011	-0.087
-75	-1.48E+05	-1.48E+05	2.2E+10	2.2E+10	40000	0.011	0.086
-76	-1.50E+05	-1.50E+05	2.2E+10	2.3E+10	40000	-0.011	-0.085
-77	-1.52E+05	-1.52E+05	2.3E+10	2.3E+10	40000	0.011	0.084
-78	-1.54E+05	-1.54E+05	2.4E+10	2.4E+10	40000	-0.010	-0.083
-79	-1.56E+05	-1.56E+05	2.5E+10	2.4E+10	40000	0.010	0.082
-80	-1.58E+05	-1.58E+05	2.5E+10	2.5E+10	40000	-0.010	-0.080
-81	-1.60E+05	-1.60E+05	2.6E+10	2.6E+10	40000	0.010	0.079
-82	-1.62E+05	-1.62E+05	2.6E+10	2.6E+10	40000	-0.010	-0.078
-83	-1.64E+05	-1.64E+05	2.7E+10	2.7E+10	40000	0.010	0.078
-84	-1.66E+05	-1.66E+05	2.8E+10	2.8E+10	40000	-0.010	-0.077
-85	-1.68E+05	-1.68E+05	2.8E+10	2.8E+10	40000	0.010	0.076
-86	-1.70E+05	-1.70E+05	2.9E+10	2.9E+10	40000	-0.009	-0.075
-87	-1.72E+05	-1.72E+05	3.0E+10	3.0E+10	40000	0.009	0.074
-88	-1.74E+05	-1.74E+05	3.0E+10	3.1E+10	40000	-0.009	-0.073
-89	-1.76E+05	-1.76E+05	3.1E+10	3.1E+10	40000	0.009	0.072
-90	-1.78E+05	-1.78E+05	3.2E+10	3.2E+10	40000	-0.009	-0.071
-91	-1.80E+05	-1.80E+05	3.3E+10	3.2E+10	40000	0.009	0.071
-92	-1.82E+05	-1.82E+05	3.3E+10	3.3E+10	40000	-0.009	-0.070
-93	-1.84E+05	-1.84E+05	3.4E+10	3.4E+10	40000	0.009	0.069
-94	-1.86E+05	-1.86E+05	3.5E+10	3.5E+10	40000	-0.009	-0.068
-95	-1.88E+05	-1.88E+05	3.6E+10	3.5E+10	40000	0.008	0.068
-96	-1.90E+05	-1.90E+05	3.6E+10	3.6E+10	40000	-0.008	-0.067
-97	-1.92E+05	-1.92E+05	3.7E+10	3.7E+10	40000	0.008	0.066
-98	-1.94E+05	-1.94E+05	3.8E+10	3.8E+10	40000	-0.008	-0.066
-99	-1.96E+05	-1.96E+05	3.9E+10	3.8E+10	40000	0.008	0.065
-100	-1.98E+05	-1.98E+05	3.9E+10	3.9E+10	40000	-0.008	-0.064

UNCONF. DRAWDOWN Ho^2-h^2= 20.36

$$(H_o^2 - h^2) = 29.50 + 20.36 = 49.86 \text{ FT}^2$$

FOR BOTH WELLS OPERATING

For $H_o = 30$ FT

$$h = \sqrt{H_o^2 - 49.86} = \sqrt{30^2 - 49.86}$$

$$= \underline{\underline{29.2}} \text{ FT}$$

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PAGE OF
SHEET NO. D-21 OF
JOB NO. 35232
MADE BY 140 DATE 12/27/91
CHKD. BY DATE

PROJECT GORICK
SUBJECT G.W. FLOWS
HYDR. BARRIERS / NO CUT-OFF WALLS

REF. PAGE

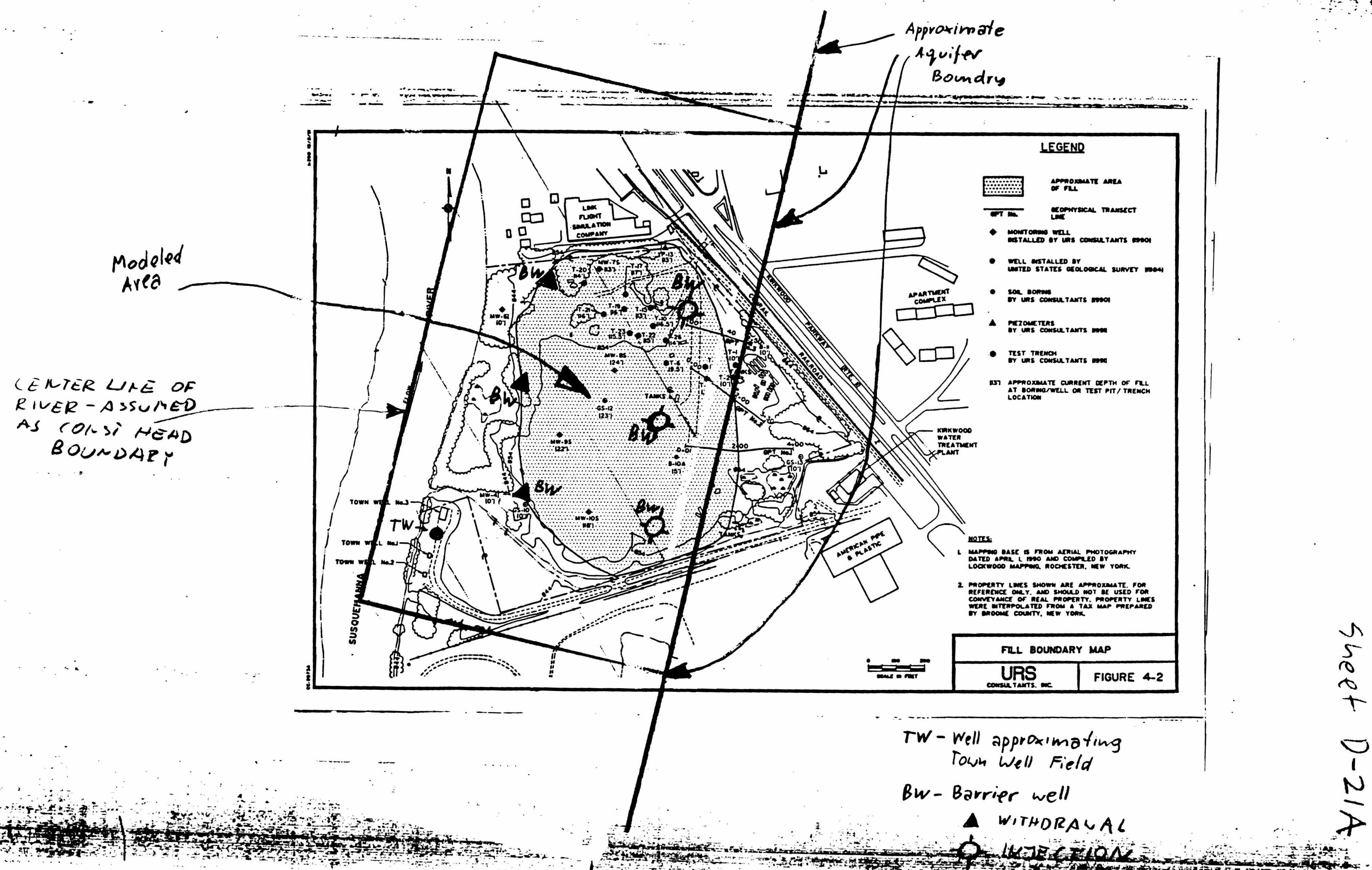
The withdrawal rates obtained in section D.2 were used to run the program. The aquifer parameters utilized (qo, B etc.) were as determined in section D.2. The hydr. cond. used was 3000 FT/D.
Here, also 4 scenarios were checked. They were the same as used in section D.2
It can be observed that most of the withdrawal rates determined in section D.2 are sufficient to achieve the desired objectives. Only for scenario 4, the presence of the Town Well Field makes the analytical solution of D.2 inaccurate in the southern portion of the landfill. To account for that, the withdrawal rate of the barrier well closest to the Town Well Field should be increased.

The modeled area is shown on sheet D-21A

The graphical presentations of solutions are shown on:

Scenario	Sheet
1	D-28
2	D-35
3	D-42
4	D-49

Sheet D-21A



Approximate Aquifer Boundry
Modeled Area
CENTER LINE OF RIVER - ASSUMED AS CONST HEAD BOUNDARY
LEGEND
APPROXIMATE AREA OF FILL
GEOPHYSICAL TRANSECT LINE
MONITORING WELL INSTALLED BY URS CONSULTANTS (1990)
WELL INSTALLED BY UNITED STATES GEOLOGICAL SURVEY (1984)
SOIL BORING BY URS CONSULTANTS (1990)
PIEZOMETERS BY URS CONSULTANTS (1990)
TEST TRENCH BY URS CONSULTANTS (1990)
APPROXIMATE CURRENT DEPTH OF FILL AT BORING/WELL OR TEST PIT/TRENCH LOCATION
NOTES:
1. MAPPING BASE IS FROM AERIAL PHOTOGRAPHY DATED APRIL 1, 1990 AND COMPILED BY LOCKWOOD MAPPING, ROCHESTER, NEW YORK.
2. PROPERTY LINES SHOWN ARE APPROXIMATE, FOR REFERENCE ONLY, AND SHOULD NOT BE USED FOR CONVEYANCE OF REAL PROPERTY. PROPERTY LINES WERE INTERPOLATED FROM A TAX MAP PREPARED BY BROOME COUNTY, NEW YORK.
FILL BOUNDARY MAP
URS CONSULTANTS, INC.
FIGURE 4-2
SCALE IN FEET
LINK FLIGHT SIMULATION COMPANY
APARTMENT COMPLEX
KIRKWOOD PARKWAY RTE. 11
RAILROAD
KIRKWOOD WATER TREATMENT PLANT
AMERICAN PIPE & PLASTIC
TANKS
SUSQUEHANNA RIVER
TOWN WELL No.3
TOWN WELL No.1
TOWN WELL No.2
TW
BW
TW - Well approximating Town Well Field
BW - Barrier well
WITHDRAWAL
INJECTION

3000. 35. 1100.	HK, HO, D
12	NWELL
218. 290. 150000.	XW1, YW1, QW1
380. 1272. 30000.	XW2, YW2, QW2
1090. 100. -10500.	
1090. 300. -10500.	
1090. 500. -10500.	
1090. 700. -10500.	
1090. 900. -10500.	
1090. 1100. -10500.	
1090. 1300. -10500.	
1090. 1500. -10500.	
1090. 1700. -10500.	
1090. 1900. -10500.	
10 0.01	

INPUT FILE FOR CASE 1

AQUIFER PARAMETERS:

HYDR. COND.= 3000.00 FT/DAY
INIT. SAT. THICK.= 35. FT
WIDTH= 1100. FT

WELL DATA:

DESIG.	X [FT]	Y [FT]	Q [FT^3/D]
1	218.	290.	150000.
2	380.	1272.	30000.
3	1090.	100.	-10500.
4	1090.	300.	-10500.
5	1090.	500.	-10500.
6	1090.	700.	-10500.
7	1090.	900.	-10500.
8	1090.	1100.	-10500.
9	1090.	1300.	-10500.
10	1090.	1500.	-10500.
11	1090.	1700.	-10500.
12	1090.	1900.	-10500.

CLOSURE TOLERANCE FOR SERIES EVALUATION:

TOLERANCE= .010000

HYDRAULIC HEADS:

X [FT]	Y [FT]	HEAD [FT]
10.	0.	34.99
100.	0.	34.95
200.	0.	34.91
300.	0.	34.90
400.	0.	34.92
500.	0.	34.94
600.	0.	34.97
700.	0.	35.00
800.	0.	35.03
900.	0.	35.06
1000.	0.	35.09
1100.	0.	35.10
10.	100.	34.99
100.	100.	34.90
200.	100.	34.84
300.	100.	34.83
400.	100.	34.87
500.	100.	34.92
600.	100.	34.97
700.	100.	35.01
800.	100.	35.04
900.	100.	35.08
1000.	100.	35.12
1100.	100.	35.20
10.	200.	34.98
100.	200.	34.84
200.	200.	34.69
300.	200.	34.73

OUTPUT FILE FOR CASE 1

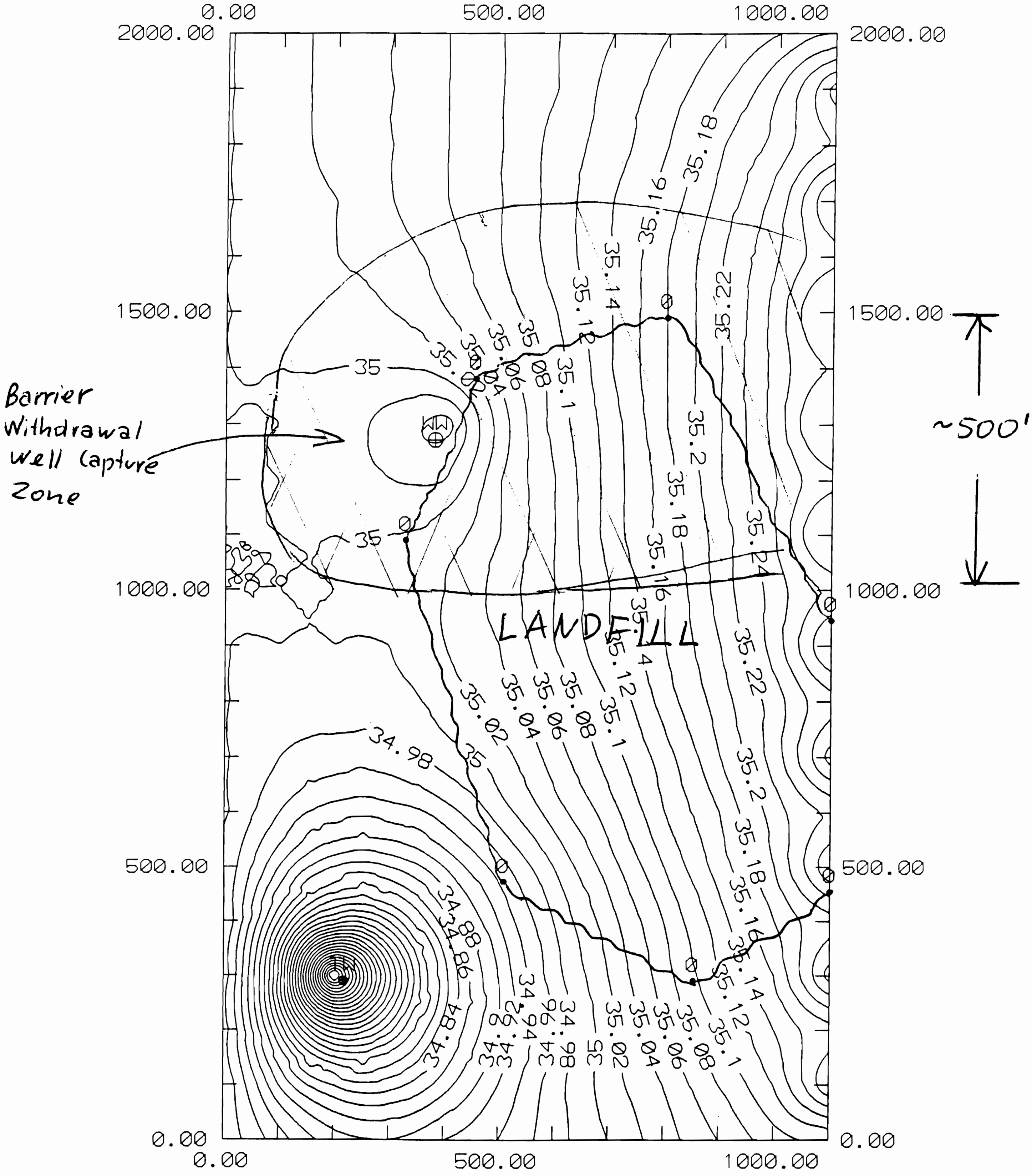
400.	200.	34.83
500.	200.	34.90
600.	200.	34.96
700.	200.	35.01
800.	200.	35.06
900.	200.	35.10
1000.	200.	35.14
1100.	200.	35.17
10.	300.	34.98
100.	300.	34.80
200.	300.	34.36
300.	300.	34.65
400.	300.	34.81
500.	300.	34.90
600.	300.	34.97
700.	300.	35.02
800.	300.	35.07
900.	300.	35.12
1000.	300.	35.16
1100.	300.	35.25
10.	400.	34.99
100.	400.	34.86
200.	400.	34.74
300.	400.	34.76
400.	400.	34.85
500.	400.	34.92
600.	400.	34.98
700.	400.	35.03
800.	400.	35.08
900.	400.	35.13
1000.	400.	35.18
1100.	400.	35.21
10.	500.	34.99
100.	500.	34.92
200.	500.	34.86
300.	500.	34.86
400.	500.	34.90
500.	500.	34.95
600.	500.	35.00
700.	500.	35.05
800.	500.	35.10
900.	500.	35.15
1000.	500.	35.20
1100.	500.	35.28
10.	600.	35.00
100.	600.	34.96
200.	600.	34.93
300.	600.	34.93
400.	600.	34.95
500.	600.	34.99
600.	600.	35.03
700.	600.	35.07
800.	600.	35.12
900.	600.	35.16
1000.	600.	35.21
1100.	600.	35.24
10.	700.	35.00
100.	700.	34.98
200.	700.	34.97
300.	700.	34.97

400.	700.	34.99
500.	700.	35.01
600.	700.	35.05
700.	700.	35.09
800.	700.	35.13
900.	700.	35.18
1000.	700.	35.23
1100.	700.	35.31
10.	800.	35.00
100.	800.	34.99
200.	800.	34.99
300.	800.	34.99
400.	800.	35.01
500.	800.	35.03
600.	800.	35.06
700.	800.	35.10
800.	800.	35.15
900.	800.	35.19
1000.	800.	35.23
1100.	800.	35.27
10.	900.	35.00
100.	900.	35.00
200.	900.	35.00
300.	900.	35.00
400.	900.	35.02
500.	900.	35.04
600.	900.	35.08
700.	900.	35.12
800.	900.	35.16
900.	900.	35.20
1000.	900.	35.25
1100.	900.	35.33
10.	1000.	35.00
100.	1000.	35.00
200.	1000.	35.00
300.	1000.	35.01
400.	1000.	35.02
500.	1000.	35.05
600.	1000.	35.08
700.	1000.	35.12
800.	1000.	35.16
900.	1000.	35.21
1000.	1000.	35.25
1100.	1000.	35.28
10.	1100.	35.00
100.	1100.	35.00
200.	1100.	35.00
300.	1100.	35.00
400.	1100.	35.01
500.	1100.	35.04
600.	1100.	35.08
700.	1100.	35.13
800.	1100.	35.17
900.	1100.	35.21
1000.	1100.	35.26
1100.	1100.	35.35
10.	1200.	35.00
100.	1200.	35.00
200.	1200.	34.99
300.	1200.	34.98

400.	1200.	34.98
500.	1200.	35.04
600.	1200.	35.08
700.	1200.	35.13
800.	1200.	35.17
900.	1200.	35.22
1000.	1200.	35.26
1100.	1200.	35.29
10.	1300.	35.00
100.	1300.	35.00
200.	1300.	34.99
300.	1300.	34.97
400.	1300.	34.95
500.	1300.	35.03
600.	1300.	35.09
700.	1300.	35.13
800.	1300.	35.18
900.	1300.	35.22
1000.	1300.	35.27
1100.	1300.	35.35
10.	1400.	35.00
100.	1400.	35.00
200.	1400.	35.00
300.	1400.	35.00
400.	1400.	35.01
500.	1400.	35.05
600.	1400.	35.09
700.	1400.	35.14
800.	1400.	35.18
900.	1400.	35.22
1000.	1400.	35.27
1100.	1400.	35.30
10.	1500.	35.00
100.	1500.	35.01
200.	1500.	35.01
300.	1500.	35.02
400.	1500.	35.04
500.	1500.	35.07
600.	1500.	35.10
700.	1500.	35.14
800.	1500.	35.18
900.	1500.	35.22
1000.	1500.	35.27
1100.	1500.	35.35
10.	1600.	35.00
100.	1600.	35.01
200.	1600.	35.02
300.	1600.	35.03
400.	1600.	35.05
500.	1600.	35.08
600.	1600.	35.11
700.	1600.	35.14
800.	1600.	35.18
900.	1600.	35.22
1000.	1600.	35.26
1100.	1600.	35.29
10.	1700.	35.00
100.	1700.	35.01
200.	1700.	35.02
300.	1700.	35.04

400.	1700.	35.06
500.	1700.	35.08
600.	1700.	35.11
700.	1700.	35.14
800.	1700.	35.17
900.	1700.	35.21
1000.	1700.	35.25
1100.	1700.	35.33
10.	1800.	35.00
100.	1800.	35.01
200.	1800.	35.03
300.	1800.	35.04
400.	1800.	35.06
500.	1800.	35.08
600.	1800.	35.11
700.	1800.	35.13
800.	1800.	35.16
900.	1800.	35.20
1000.	1800.	35.23
1100.	1800.	35.26
10.	1900.	35.00
100.	1900.	35.01
200.	1900.	35.03
300.	1900.	35.04
400.	1900.	35.06
500.	1900.	35.08
600.	1900.	35.10
700.	1900.	35.13
800.	1900.	35.15
900.	1900.	35.18
1000.	1900.	35.22
1100.	1900.	35.29
10.	2000.	35.00
100.	2000.	35.01
200.	2000.	35.03
300.	2000.	35.04
400.	2000.	35.06
500.	2000.	35.08
600.	2000.	35.10
700.	2000.	35.12
800.	2000.	35.14
900.	2000.	35.16
1000.	2000.	35.18
1100.	2000.	35.20

CASE 1, CAPTURING G.W. FROM THE NORTH SIDE



```
3000.  35.  1100.
14
218. 290. 150000.
480. 501. 30000.
380. 890. 30000.
380. 1272. 30000.
1090. 100. -10500.
1090. 300. -10500.
1090. 500. -10500.
1090. 700. -10500.
1090. 900. -10500.
1090. 1100. -10500.
1090. 1300. -10500.
1090. 1500. -10500.
1090. 1700. -10500.
1090. 1900. -10500.
10 0.01
```

INPUT FILE
FOR
CASE 2

AQUIFER PARAMETERS:

HYDR. COND.= 3000.00 FT/DAY
INIT. SAT. THICK.= 35. FT
WIDTH= 1100. FT

WELL DATA:

DESIG.	X [FT]	Y [FT]	Q [FT^3/D]
1	218.	290.	150000.
2	480.	501.	30000.
3	380.	890.	30000.
4	380.	1272.	30000.
5	1090.	100.	-10500.
6	1090.	300.	-10500.
7	1090.	500.	-10500.
8	1090.	700.	-10500.
9	1090.	900.	-10500.
10	1090.	1100.	-10500.
11	1090.	1300.	-10500.
12	1090.	1500.	-10500.
13	1090.	1700.	-10500.
14	1090.	1900.	-10500.

CLOSURE TOLERANCE FOR SERIES EVALUATION:

TOLERANCE= .010000

HYDRAULIC HEADS:

X [FT]	Y [FT]	HEAD [FT]
10.	0.	34.99
100.	0.	34.93
200.	0.	34.88
300.	0.	34.86
400.	0.	34.86
500.	0.	34.88
600.	0.	34.91
700.	0.	34.93
800.	0.	34.96
900.	0.	34.99
1000.	0.	35.01
1100.	0.	35.03
10.	100.	34.99
100.	100.	34.89
200.	100.	34.80
300.	100.	34.78
400.	100.	34.81
500.	100.	34.85
600.	100.	34.89
700.	100.	34.92
800.	100.	34.96
900.	100.	35.00
1000.	100.	35.04
1100.	100.	35.12
10.	200.	34.98
100.	200.	34.82

OUTPUT FILE FOR CASE 2

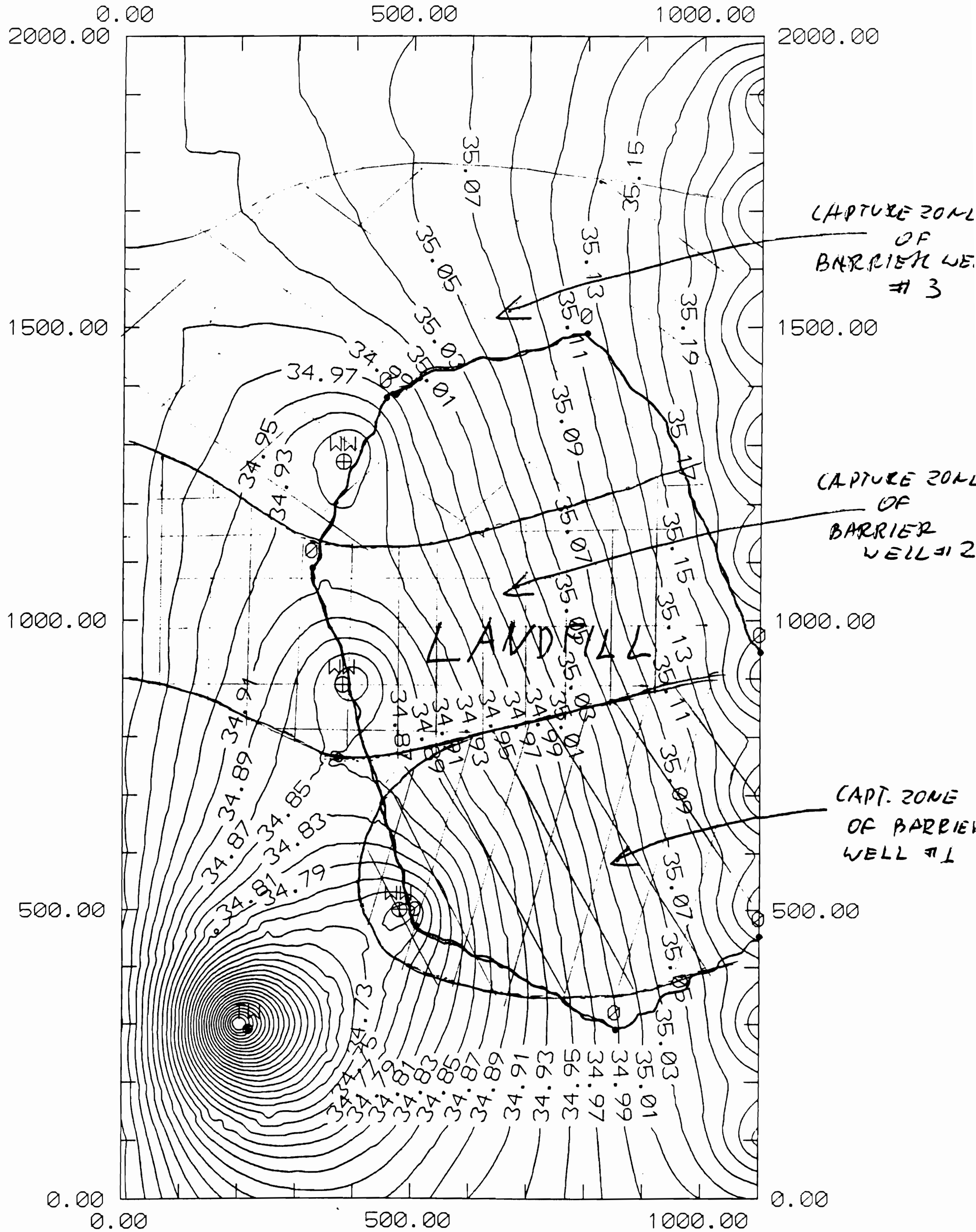
200.	200.	34.65
300.	200.	34.66
400.	200.	34.75
500.	200.	34.82
600.	200.	34.87
700.	200.	34.92
800.	200.	34.96
900.	200.	35.01
1000.	200.	35.05
1100.	200.	35.08
10.	300.	34.98
100.	300.	34.77
200.	300.	34.30
300.	300.	34.57
400.	300.	34.71
500.	300.	34.79
600.	300.	34.85
700.	300.	34.91
800.	300.	34.96
900.	300.	35.01
1000.	300.	35.06
1100.	300.	35.15
10.	400.	34.98
100.	400.	34.83
200.	400.	34.67
300.	400.	34.67
400.	400.	34.72
500.	400.	34.77
600.	400.	34.84
700.	400.	34.91
800.	400.	34.97
900.	400.	35.02
1000.	400.	35.07
1100.	400.	35.10
10.	500.	34.99
100.	500.	34.88
200.	500.	34.80
300.	500.	34.76
400.	500.	34.74
500.	500.	34.72
600.	500.	34.85
700.	500.	34.92
800.	500.	34.98
900.	500.	35.03
1000.	500.	35.09
1100.	500.	35.17
10.	600.	34.99
100.	600.	34.92
200.	600.	34.86
300.	600.	34.82
400.	600.	34.80
500.	600.	34.82
600.	600.	34.87
700.	600.	34.93
800.	600.	34.99
900.	600.	35.05
1000.	600.	35.09
1100.	600.	35.13
10.	700.	34.99
100.	700.	34.94

200.	700.	34.89
300.	700.	34.85
400.	700.	34.84
500.	700.	34.86
600.	700.	34.91
700.	700.	34.95
800.	700.	35.01
900.	700.	35.06
1000.	700.	35.11
1100.	700.	35.20
10.	800.	34.99
100.	800.	34.95
200.	800.	34.90
300.	800.	34.86
400.	800.	34.85
500.	800.	34.88
600.	800.	34.93
700.	800.	34.97
800.	800.	35.02
900.	800.	35.07
1000.	800.	35.12
1100.	800.	35.15
10.	900.	35.00
100.	900.	34.96
200.	900.	34.92
300.	900.	34.87
400.	900.	34.81
500.	900.	34.89
600.	900.	34.94
700.	900.	34.99
800.	900.	35.04
900.	900.	35.09
1000.	900.	35.14
1100.	900.	35.23
10.	1000.	35.00
100.	1000.	34.96
200.	1000.	34.93
300.	1000.	34.90
400.	1000.	34.89
500.	1000.	34.92
600.	1000.	34.96
700.	1000.	35.01
800.	1000.	35.06
900.	1000.	35.11
1000.	1000.	35.15
1100.	1000.	35.18
10.	1100.	35.00
100.	1100.	34.97
200.	1100.	34.94
300.	1100.	34.92
400.	1100.	34.92
500.	1100.	34.94
600.	1100.	34.98
700.	1100.	35.03
800.	1100.	35.07
900.	1100.	35.12
1000.	1100.	35.17
1100.	1100.	35.25
10.	1200.	35.00
100.	1200.	34.97

200.	1200.	34.95
300.	1200.	34.92
400.	1200.	34.91
500.	1200.	34.95
600.	1200.	35.00
700.	1200.	35.04
800.	1200.	35.09
900.	1200.	35.13
1000.	1200.	35.18
1100.	1200.	35.21
10.	1300.	35.00
100.	1300.	34.98
200.	1300.	34.96
300.	1300.	34.92
400.	1300.	34.89
500.	1300.	34.97
600.	1300.	35.01
700.	1300.	35.06
800.	1300.	35.10
900.	1300.	35.14
1000.	1300.	35.19
1100.	1300.	35.28
10.	1400.	35.00
100.	1400.	34.99
200.	1400.	34.97
300.	1400.	34.96
400.	1400.	34.96
500.	1400.	34.99
600.	1400.	35.03
700.	1400.	35.07
800.	1400.	35.11
900.	1400.	35.15
1000.	1400.	35.20
1100.	1400.	35.23
10.	1500.	35.00
100.	1500.	34.99
200.	1500.	34.99
300.	1500.	34.99
400.	1500.	35.00
500.	1500.	35.02
600.	1500.	35.05
700.	1500.	35.08
800.	1500.	35.12
900.	1500.	35.16
1000.	1500.	35.21
1100.	1500.	35.29
10.	1600.	35.00
100.	1600.	35.00
200.	1600.	35.00
300.	1600.	35.01
400.	1600.	35.02
500.	1600.	35.04
600.	1600.	35.06
700.	1600.	35.09
800.	1600.	35.13
900.	1600.	35.16
1000.	1600.	35.20
1100.	1600.	35.23
10.	1700.	35.00
100.	1700.	35.00

200.	1700.	35.01
300.	1700.	35.02
400.	1700.	35.03
500.	1700.	35.05
600.	1700.	35.07
700.	1700.	35.10
800.	1700.	35.13
900.	1700.	35.16
1000.	1700.	35.21
1100.	1700.	35.29
10.	1800.	35.00
100.	1800.	35.01
200.	1800.	35.01
300.	1800.	35.02
400.	1800.	35.04
500.	1800.	35.05
600.	1800.	35.07
700.	1800.	35.10
800.	1800.	35.12
900.	1800.	35.16
1000.	1800.	35.19
1100.	1800.	35.22
10.	1900.	35.00
100.	1900.	35.01
200.	1900.	35.02
300.	1900.	35.03
400.	1900.	35.04
500.	1900.	35.06
600.	1900.	35.07
700.	1900.	35.09
800.	1900.	35.12
900.	1900.	35.15
1000.	1900.	35.18
1100.	1900.	35.26
10.	2000.	35.00
100.	2000.	35.01
200.	2000.	35.02
300.	2000.	35.03
400.	2000.	35.04
500.	2000.	35.05
600.	2000.	35.07
700.	2000.	35.09
800.	2000.	35.11
900.	2000.	35.13
1000.	2000.	35.15
1100.	2000.	35.16

CASE 2, CAPTURING G.W. FROM ENTIRE SITE



```
3000.  35.  1100.
13
218. 290. 150000.
380. 1272. 60000.
850. 1272. -60000.
1090. 100. -10500.
1090. 300. -10500.
1090. 500. -10500.
1090. 700. -10500.
1090. 900. -10500.
1090. 1100. -10500.
1090. 1300. -10500.
1090. 1500. -10500.
1090. 1700. -10500.
1090. 1900. -10500.
10 0.01
```

HK, HO, D
NWELL
XWI, YWI, QWI

INPUT FILE FOR CASE 3

AQUIFER PARAMETERS:

HYDR. COND.= 3000.00 FT/DAY
INIT. SAT. THICK.= 35. FT
WIDTH= 1100. FT

WELL DATA:

DESIG.	X [FT]	Y [FT]	Q [FT^3/D]
1	218.	290.	150000.
2	380.	1272.	60000.
3	850.	1272.	-60000.
4	1090.	100.	-10500.
5	1090.	300.	-10500.
6	1090.	500.	-10500.
7	1090.	700.	-10500.
8	1090.	900.	-10500.
9	1090.	1100.	-10500.
10	1090.	1300.	-10500.
11	1090.	1500.	-10500.
12	1090.	1700.	-10500.
13	1090.	1900.	-10500.

CLOSURE TOLERANCE FOR SERIES EVALUATION:

TOLERANCE= .010000

HYDRAULIC HEADS:

X [FT]	Y [FT]	HEAD [FT]
10.	0.	34.99
100.	0.	34.95
200.	0.	34.92
300.	0.	34.92
400.	0.	34.94
500.	0.	34.97
600.	0.	35.00
700.	0.	35.04
800.	0.	35.07
900.	0.	35.10
1000.	0.	35.13
1100.	0.	35.15
10.	100.	34.99
100.	100.	34.91
200.	100.	34.85
300.	100.	34.85
400.	100.	34.90
500.	100.	34.95
600.	100.	35.00
700.	100.	35.05
800.	100.	35.09
900.	100.	35.13
1000.	100.	35.17
1100.	100.	35.25
10.	200.	34.98
100.	200.	34.84
200.	200.	34.71

OUTPUT FILE FOR CASE 3

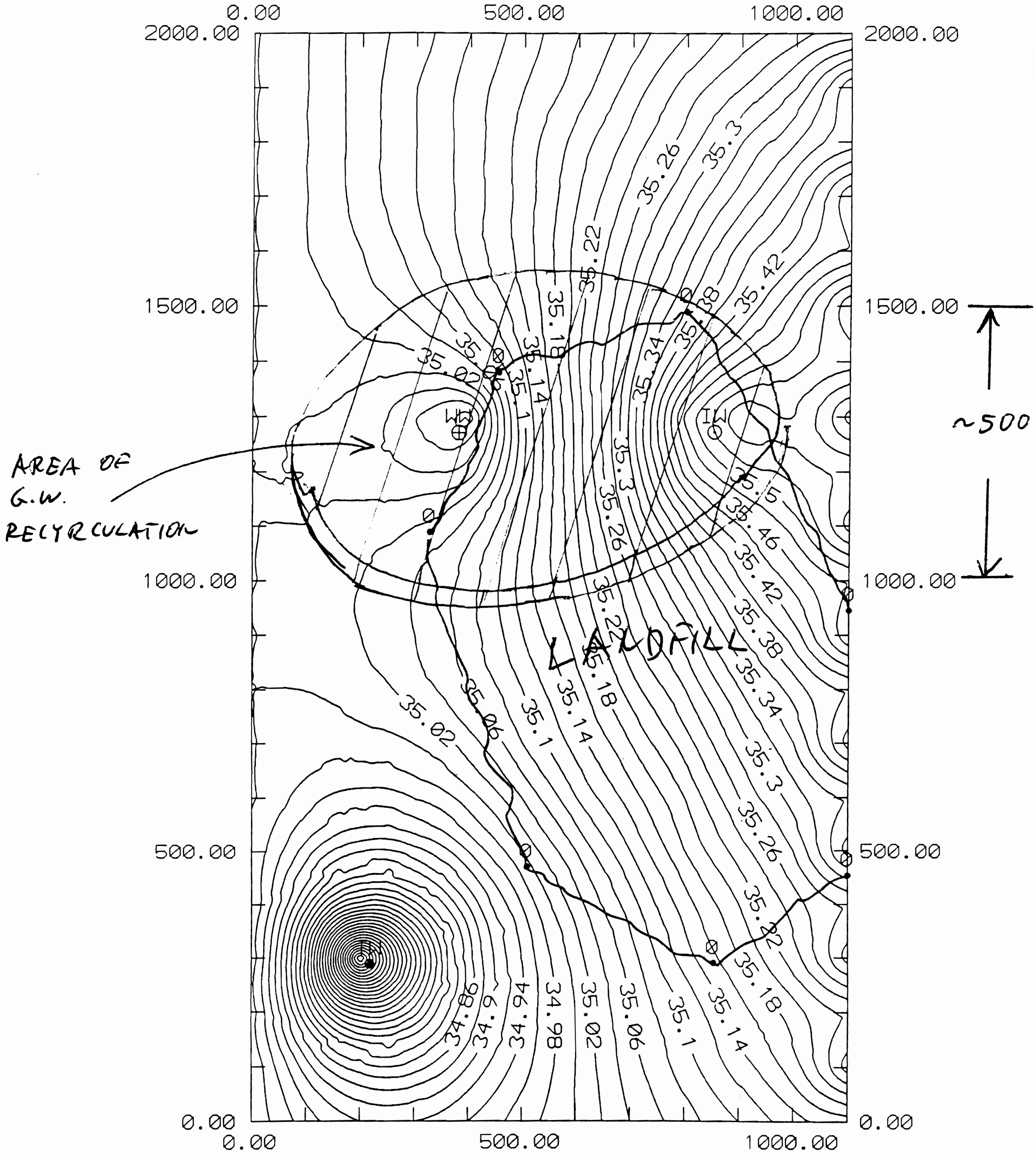
300.	200.	34.75
400.	200.	34.86
500.	200.	34.94
600.	200.	35.00
700.	200.	35.06
800.	200.	35.10
900.	200.	35.15
1000.	200.	35.19
1100.	200.	35.22
10.	300.	34.98
100.	300.	34.80
200.	300.	34.37
300.	300.	34.67
400.	300.	34.85
500.	300.	34.94
600.	300.	35.01
700.	300.	35.07
800.	300.	35.13
900.	300.	35.18
1000.	300.	35.23
1100.	300.	35.31
10.	400.	34.99
100.	400.	34.87
200.	400.	34.75
300.	400.	34.79
400.	400.	34.88
500.	400.	34.96
600.	400.	35.03
700.	400.	35.09
800.	400.	35.15
900.	400.	35.20
1000.	400.	35.25
1100.	400.	35.28
10.	500.	34.99
100.	500.	34.93
200.	500.	34.88
300.	500.	34.89
400.	500.	34.94
500.	500.	35.00
600.	500.	35.06
700.	500.	35.12
800.	500.	35.18
900.	500.	35.23
1000.	500.	35.28
1100.	500.	35.37
10.	600.	35.00
100.	600.	34.97
200.	600.	34.95
300.	600.	34.96
400.	600.	34.99
500.	600.	35.04
600.	600.	35.10
700.	600.	35.15
800.	600.	35.20
900.	600.	35.26
1000.	600.	35.31
1100.	600.	35.34
10.	700.	35.00
100.	700.	34.99
200.	700.	34.99

300.	700.	35.00
400.	700.	35.03
500.	700.	35.08
600.	700.	35.13
700.	700.	35.18
800.	700.	35.23
900.	700.	35.29
1000.	700.	35.34
1100.	700.	35.43
10.	800.	35.00
100.	800.	35.00
200.	800.	35.01
300.	800.	35.03
400.	800.	35.06
500.	800.	35.10
600.	800.	35.15
700.	800.	35.21
800.	800.	35.26
900.	800.	35.32
1000.	800.	35.37
1100.	800.	35.40
10.	900.	35.00
100.	900.	35.01
200.	900.	35.02
300.	900.	35.04
400.	900.	35.07
500.	900.	35.12
600.	900.	35.17
700.	900.	35.24
800.	900.	35.29
900.	900.	35.36
1000.	900.	35.41
1100.	900.	35.50
10.	1000.	35.00
100.	1000.	35.01
200.	1000.	35.02
300.	1000.	35.04
400.	1000.	35.07
500.	1000.	35.13
600.	1000.	35.19
700.	1000.	35.26
800.	1000.	35.33
900.	1000.	35.40
1000.	1000.	35.45
1100.	1000.	35.48
10.	1100.	35.00
100.	1100.	35.00
200.	1100.	35.01
300.	1100.	35.02
400.	1100.	35.05
500.	1100.	35.12
600.	1100.	35.20
700.	1100.	35.29
800.	1100.	35.38
900.	1100.	35.44
1000.	1100.	35.49
1100.	1100.	35.57
10.	1200.	35.00
100.	1200.	35.00
200.	1200.	34.99

300.	1200.	34.98
400.	1200.	34.99
500.	1200.	35.10
600.	1200.	35.21
700.	1200.	35.32
800.	1200.	35.45
900.	1200.	35.51
1000.	1200.	35.53
1100.	1200.	35.54
10.	1300.	35.00
100.	1300.	35.00
200.	1300.	34.99
300.	1300.	34.96
400.	1300.	34.93
500.	1300.	35.10
600.	1300.	35.21
700.	1300.	35.33
800.	1300.	35.49
900.	1300.	35.56
1000.	1300.	35.54
1100.	1300.	35.61
10.	1400.	35.00
100.	1400.	35.01
200.	1400.	35.01
300.	1400.	35.01
400.	1400.	35.04
500.	1400.	35.12
600.	1400.	35.22
700.	1400.	35.31
800.	1400.	35.41
900.	1400.	35.48
1000.	1400.	35.51
1100.	1400.	35.53
10.	1500.	35.00
100.	1500.	35.01
200.	1500.	35.03
300.	1500.	35.05
400.	1500.	35.09
500.	1500.	35.14
600.	1500.	35.21
700.	1500.	35.29
800.	1500.	35.36
900.	1500.	35.42
1000.	1500.	35.48
1100.	1500.	35.56
10.	1600.	35.00
100.	1600.	35.02
200.	1600.	35.04
300.	1600.	35.07
400.	1600.	35.11
500.	1600.	35.15
600.	1600.	35.21
700.	1600.	35.27
800.	1600.	35.33
900.	1600.	35.39
1000.	1600.	35.43
1100.	1600.	35.46
10.	1700.	35.00
100.	1700.	35.02
200.	1700.	35.05

300.	1700.	35.08
400.	1700.	35.11
500.	1700.	35.15
600.	1700.	35.20
700.	1700.	35.25
800.	1700.	35.30
900.	1700.	35.35
1000.	1700.	35.40
1100.	1700.	35.48
10.	1800.	35.00
100.	1800.	35.02
200.	1800.	35.05
300.	1800.	35.08
400.	1800.	35.11
500.	1800.	35.15
600.	1800.	35.19
700.	1800.	35.23
800.	1800.	35.27
900.	1800.	35.32
1000.	1800.	35.36
1100.	1800.	35.39
10.	1900.	35.00
100.	1900.	35.02
200.	1900.	35.05
300.	1900.	35.08
400.	1900.	35.11
500.	1900.	35.14
600.	1900.	35.17
700.	1900.	35.21
800.	1900.	35.25
900.	1900.	35.28
1000.	1900.	35.32
1100.	1900.	35.40
10.	2000.	35.00
100.	2000.	35.02
200.	2000.	35.05
300.	2000.	35.07
400.	2000.	35.10
500.	2000.	35.13
600.	2000.	35.16
700.	2000.	35.19
800.	2000.	35.22
900.	2000.	35.25
1000.	2000.	35.27
1100.	2000.	35.29

CASE 3, RECYRCULATING G.W. ON NORTH SIDE



```
3000.  35.  1100.
17
218. 290. 150000.
480. 501. 60000.
930. 501. -60000.
380. 890. 60000.
850. 890. -60000.
380. 1272. 60000.
850. 1272. -60000.
1090. 100. -10500.
1090. 300. -10500.
1090. 500. -10500.
1090. 700. -10500.
1090. 900. -10500.
1090. 1100. -10500.
1090. 1300. -10500.
1090. 1500. -10500.
1090. 1700. -10500.
1090. 1900. -10500.
10 0.01
```

INPUT FILE FOR CASE 4

AQUIFER PARAMETERS:

HYDR. COND.= 3000.00 FT/DAY
INIT. SAT. THICK.= 35. FT
WIDTH= 1100. FT

WELL DATA:

DESIG.	X [FT]	Y [FT]	Q [FT^3/D]
1	218.	290.	150000.
2	480.	501.	60000.
3	930.	501.	-60000.
4	380.	890.	60000.
5	850.	890.	-60000.
6	380.	1272.	60000.
7	850.	1272.	-60000.
8	1090.	100.	-10500.
9	1090.	300.	-10500.
10	1090.	500.	-10500.
11	1090.	700.	-10500.
12	1090.	900.	-10500.
13	1090.	1100.	-10500.
14	1090.	1300.	-10500.
15	1090.	1500.	-10500.
16	1090.	1700.	-10500.
17	1090.	1900.	-10500.

CLOSURE TOLERANCE FOR SERIES EVALUATION:

TOLERANCE= .010000

HYDRAULIC HEADS:

X [FT]	Y [FT]	HEAD [FT]
10.	0.	35.00
100.	0.	34.96
200.	0.	34.93
300.	0.	34.93
400.	0.	34.97
500.	0.	35.01
600.	0.	35.07
700.	0.	35.12
800.	0.	35.17
900.	0.	35.22
1000.	0.	35.25
1100.	0.	35.28
10.	100.	34.99
100.	100.	34.91
200.	100.	34.86
300.	100.	34.86
400.	100.	34.92
500.	100.	34.99
600.	100.	35.06
700.	100.	35.14
800.	100.	35.20
900.	100.	35.27
1000.	100.	35.32

OUTPUT FILE FOR CASE 4

1100.	100.	35.41
10.	200.	34.98
100.	200.	34.84
200.	200.	34.70
300.	200.	34.75
400.	200.	34.87
500.	200.	34.97
600.	200.	35.07
700.	200.	35.16
800.	200.	35.25
900.	200.	35.33
1000.	200.	35.39
1100.	200.	35.43
10.	300.	34.98
100.	300.	34.80
200.	300.	34.36
300.	300.	34.66
400.	300.	34.83
500.	300.	34.95
600.	300.	35.07
700.	300.	35.18
800.	300.	35.30
900.	300.	35.40
1000.	300.	35.47
1100.	300.	35.56
10.	400.	34.99
100.	400.	34.85
200.	400.	34.73
300.	400.	34.75
400.	400.	34.82
500.	400.	34.92
600.	400.	35.07
700.	400.	35.22
800.	400.	35.36
900.	400.	35.50
1000.	400.	35.57
1100.	400.	35.59
10.	500.	34.99
100.	500.	34.91
200.	500.	34.85
300.	500.	34.84
400.	500.	34.84
500.	500.	34.81
600.	500.	35.08
700.	500.	35.26
800.	500.	35.42
900.	500.	35.65
1000.	500.	35.68
1100.	500.	35.73
10.	600.	34.99
100.	600.	34.95
200.	600.	34.91
300.	600.	34.90
400.	600.	34.92
500.	600.	34.99
600.	600.	35.14
700.	600.	35.30
800.	600.	35.45
900.	600.	35.60
1000.	600.	35.68

1100.	600.	35.70
10.	700.	35.00
100.	700.	34.97
200.	700.	34.94
300.	700.	34.93
400.	700.	34.97
500.	700.	35.06
600.	700.	35.19
700.	700.	35.34
800.	700.	35.49
900.	700.	35.61
1000.	700.	35.68
1100.	700.	35.77
10.	800.	35.00
100.	800.	34.97
200.	800.	34.95
300.	800.	34.93
400.	800.	34.96
500.	800.	35.08
600.	800.	35.23
700.	800.	35.39
800.	800.	35.55
900.	800.	35.66
1000.	800.	35.71
1100.	800.	35.73
10.	900.	35.00
100.	900.	34.98
200.	900.	34.96
300.	900.	34.92
400.	900.	34.86
500.	900.	35.10
600.	900.	35.26
700.	900.	35.42
800.	900.	35.63
900.	900.	35.73
1000.	900.	35.73
1100.	900.	35.80
10.	1000.	35.00
100.	1000.	34.99
200.	1000.	34.97
300.	1000.	34.97
400.	1000.	35.01
500.	1000.	35.13
600.	1000.	35.28
700.	1000.	35.43
800.	1000.	35.58
900.	1000.	35.68
1000.	1000.	35.72
1100.	1000.	35.75
10.	1100.	35.00
100.	1100.	34.99
200.	1100.	34.99
300.	1100.	35.00
400.	1100.	35.04
500.	1100.	35.15
600.	1100.	35.29
700.	1100.	35.43
800.	1100.	35.57
900.	1100.	35.66
1000.	1100.	35.72

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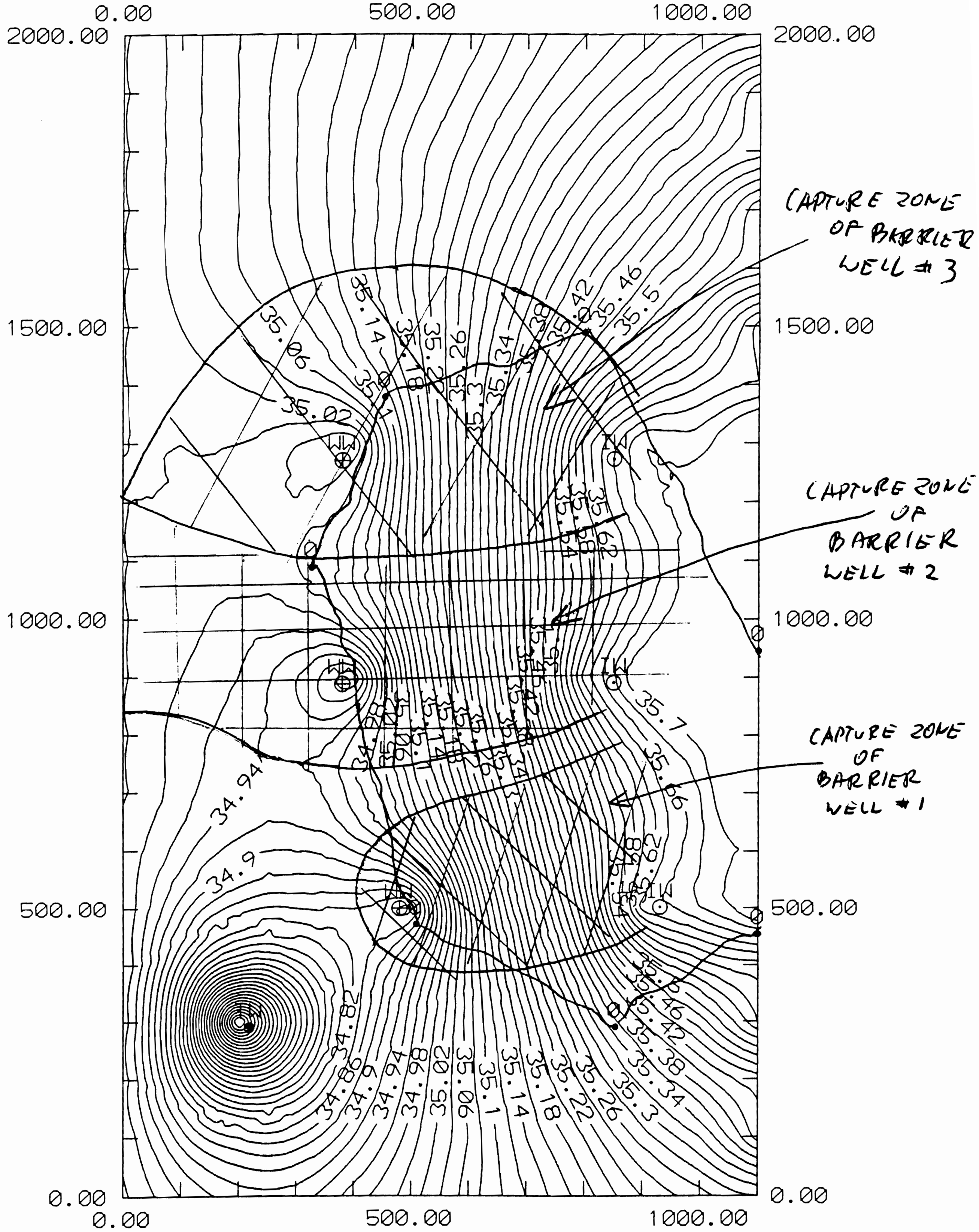
1100.	1100.	35.80
10.	1200.	35.00
100.	1200.	35.00
200.	1200.	34.99
300.	1200.	34.98
400.	1200.	35.01
500.	1200.	35.15
600.	1200.	35.29
700.	1200.	35.44
800.	1200.	35.60
900.	1200.	35.69
1000.	1200.	35.71
1100.	1200.	35.73
10.	1300.	35.00
100.	1300.	35.00
200.	1300.	35.00
300.	1300.	34.98
400.	1300.	34.96
500.	1300.	35.15
600.	1300.	35.29
700.	1300.	35.43
800.	1300.	35.61
900.	1300.	35.70
1000.	1300.	35.69
1100.	1300.	35.76
10.	1400.	35.00
100.	1400.	35.01
200.	1400.	35.02
300.	1400.	35.04
400.	1400.	35.08
500.	1400.	35.17
600.	1400.	35.29
700.	1400.	35.40
800.	1400.	35.52
900.	1400.	35.60
1000.	1400.	35.64
1100.	1400.	35.66
10.	1500.	35.00
100.	1500.	35.02
200.	1500.	35.04
300.	1500.	35.07
400.	1500.	35.12
500.	1500.	35.19
600.	1500.	35.28
700.	1500.	35.37
800.	1500.	35.45
900.	1500.	35.52
1000.	1500.	35.58
1100.	1500.	35.67
10.	1600.	35.00
100.	1600.	35.03
200.	1600.	35.06
300.	1600.	35.09
400.	1600.	35.14
500.	1600.	35.20
600.	1600.	35.27
700.	1600.	35.34
800.	1600.	35.41
900.	1600.	35.47
1000.	1600.	35.52

1100.	1600.	35.55
10.	1700.	35.00
100.	1700.	35.03
200.	1700.	35.06
300.	1700.	35.10
400.	1700.	35.14
500.	1700.	35.19
600.	1700.	35.25
700.	1700.	35.31
800.	1700.	35.37
900.	1700.	35.42
1000.	1700.	35.48
1100.	1700.	35.56
10.	1800.	35.00
100.	1800.	35.03
200.	1800.	35.06
300.	1800.	35.10
400.	1800.	35.14
500.	1800.	35.19
600.	1800.	35.23
700.	1800.	35.28
800.	1800.	35.33
900.	1800.	35.38
1000.	1800.	35.42
1100.	1800.	35.45
10.	1900.	35.00
100.	1900.	35.03
200.	1900.	35.06
300.	1900.	35.10
400.	1900.	35.13
500.	1900.	35.17
600.	1900.	35.21
700.	1900.	35.25
800.	1900.	35.29
900.	1900.	35.33
1000.	1900.	35.38
1100.	1900.	35.46
10.	2000.	35.00
100.	2000.	35.03
200.	2000.	35.06
300.	2000.	35.09
400.	2000.	35.12
500.	2000.	35.16
600.	2000.	35.19
700.	2000.	35.23
800.	2000.	35.26
900.	2000.	35.29
1000.	2000.	35.32
1100.	2000.	35.34

CASE 4, RECIRCULATING G.W. ON ENTIRE SITE



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D.4) Infiltration trenches

As determined in D.2 and D.3, about 960 GPM will have to be recharged ~~at upstream~~ at the upstream side of the landfill in order to maintain the circulation of G.W.

$$Q = 960 \text{ GPM} \cong 185{,}000 \text{ FT}^3/\text{D}$$

The length of the landfill is about 1200 FT so, each linear foot of trenches will have to recharge

$$q_{INF} = \frac{185{,}000}{1{,}200} = 154 \ \frac{\text{FT}^3/\text{DAY}}{\text{LFT}} \ [\text{FT}^2/\text{D}]$$

"Groundwater and Seepage", M.E. Harr, 1962 indicates seepage quantity from a trapezoidal ditch as (page 239, form 15a)

$$q = k(B + AH)$$ (See sheet D-52)

q - Seepage quantity
k - Coeff. of permeability
B - Width of water surf. in a ditch
H - Depth of water in ditch
A - Correction factor

Take ditch with side slope $\alpha = 45°$, with $B = 10$ FT, $H = 3$ FT

$$q = k(10 + A \cdot 3)$$

From fig. 9.6 (See sheet D-52),

$$A(\alpha = 45°, B/H = 3.3) = 2.5$$

$$q = k \cdot (10 + 2.5 \cdot 3)$$

$$q = 17.5\ k$$

The permeability of fill is not known, however, it is usually assumed as

$$K_{fill} = 1E{-}4 - 1E{-}3\ cm/s$$

$$K_{fill} = 0.3 - 3.0\ FT/D$$

$$q = \underset{FT/D}{(0.3 - 3.0)} \cdot \underset{FT}{17.5} \quad [FT^2/D]$$

$$q = 5.25 \text{ to } 52.5\ FT^2/D$$

In order to obtain $q = 154\ FT^2/D$, from 3 to 30 ditches would have to be built.

IF A POND (300 FT WIDE, 5 FT DEEP) IS USED

CASE	REQUIRED INFILTR [FT³/D]	K [FT/D]	POND DIMENSIONS [WIDTH × LENGTH × DEPTH]	AREA [ACRES]
3-RECIRC. IN NORTH. PART	62,000	0.3	300 × 640 × 5	4.4
		3.0	300 × 70 × 5	0.5
4-RECIRC ON ENTIRE SITE	185,000	0.3	300 × 1920 × 5 *	13.2
		3.0	300 × 190 × 5	1.3

* $L_{POND} > L_{SITE}$ – TWO PONDS ≈ 960 FT IN LENGTH WILL HAVE TO BE USED

Along the bottom of the ditch, where $0 < t < \beta$,

$$z = -\frac{q}{k\pi J_2 \cos \pi\sigma}\left\{\sin^{-1} t\left[\int_0^t \frac{t\,dt}{(1-t^2)^{1/2+\sigma}(\beta^2-t^2)^{1-\sigma}} - J_1\right] - \int_0^t \frac{t \sin^{-1} t\,dt}{(1-t^2)^{1/2+\sigma}(\beta^2-t^2)^{1-\sigma}}\right\} \tag{10a}$$

At points c, where $t = \beta$ and $z = B_1/2$, we find

$$\frac{B_1}{2} = \frac{q}{\pi k J_2 \cos \pi\sigma}\int_0^\beta \frac{t \sin^{-1} t\,dt}{(1-t^2)^{1/2+\sigma}(\beta^2-t^2)^{1-\sigma}} \tag{10b}$$

Along the side of the ditch bc, where $\beta < t < 1$,

$$z = \frac{B_1}{2} + \frac{q}{k\pi J_2 \cos \pi\sigma} e^{\pi\sigma i}\left[\sin^{-1} t \int_\beta^t \frac{t\,dt}{(1-t^2)^{1/2+\sigma}(t^2-\beta^2)^{1-\sigma}} - \int_\beta^t \frac{t \sin^{-1} t\,dt}{(1-t^2)^{1/2+\sigma}(t^2-\beta^2)^{1-\sigma}}\right] \tag{11a}$$

At points b, where $t = 1$ and $z = B/2 + iH$, we obtain

$$\frac{B - B_1}{2} = \frac{q}{k\pi J_2}\left[\frac{\pi}{2}J_2 - \int_\beta^1 \frac{t \sin^{-1} t\,dt}{(1-t^2)^{1/2+\sigma}(t^2-\beta^2)^{1-\sigma}}\right] \tag{11b}$$

$$H = \frac{q}{k\pi J_2}\tan \pi\sigma\left[\frac{\pi}{2}J_2 - \int_\beta^1 \frac{t \sin^{-1} t\,dt}{(1-t^2)^{1/2+\sigma}(t^2-\beta^2)^{1-\sigma}}\right] \tag{11c}$$

Along the free surface ba, where $1 < t < \infty$, from Eq. (11a) we find

$$z = \frac{B}{2} + Hi + \frac{q}{k\pi J_2 \cos \pi\sigma}\left[-\cosh^{-1} t \int_1^t \frac{t\,dt}{(t^2-1)^{1/2+\sigma}(t^2-\beta^2)^{1-\sigma}} - iJ_2 e^{\pi\sigma i}\cosh^{-1} t + \int_1^t \frac{t \cosh^{-1} t\,dt}{(t^2-1)^{1/2+\sigma}(t^2-\beta^2)^{1-\sigma}}\right] \tag{12a*}$$

Separating this equation into real and imaginary parts, we obtain for the equation of the free surface ba,

$$x - \frac{B}{2} = \frac{q}{k\pi J_2 \cos \pi\sigma}\left[\int_1^t \frac{t \cosh^{-1} t\,dt}{(t^2-1)^{1/2+\sigma}(t^2-\beta^2)^{1-\sigma}} + J_2 \sin \pi\sigma \cosh^{-1} t - \cosh^{-1} t \int_1^t \frac{t\,dt}{(t^2-1)^{1/2+\sigma}(t^2-\beta^2)^{1-\sigma}}\right] \tag{12b}$$

We shall now derive the expression for the discharge from the ditch. Defining

$$\int_0^\beta \frac{t \sin^{-1} t\,dt}{(1-t^2)^{1/2+\sigma}(t^2-\beta^2)^{1-\sigma}} = f_1(\sigma,\beta)$$
$$\int_\beta^1 \frac{t \sin^{-1} t\,dt}{(1-t^2)^{1/2+\sigma}(t^2-\beta^2)^{1-\sigma}} = f_2(\sigma,\beta) \tag{13}$$

* We note that $(1 - t^2)^{1/2+\sigma} = ie^{\pi\sigma i}(t^2 - 1)^{1/2+\sigma}$. Also for real values of $t > 1$, $\sin^{-1} t = \pi/2 - i \cosh^{-1} t$.

we have, in place of Eq. (10b),

$$B_1 = \frac{2q}{k\pi J_2 \cos \pi\sigma} f_1(\sigma,\beta) \tag{14a}$$

and in place of Eqs. (11b) and (11c),

$$\frac{B - B_1}{2} = \left[\frac{\pi}{2}J_2 - f_2(\sigma,\beta)\right]\frac{q}{\pi k J_2}$$
$$H = \frac{q}{\pi k J_2}\tan \pi\sigma\left[\frac{\pi}{2}J_2 - f_2(\sigma,\beta)\right] \tag{14b}$$

whence

$$B = B_1 + \frac{q}{k}\left[1 - \frac{2f_2(\sigma,\beta)}{\pi J_2}\right]$$
$$H = \frac{q}{2k}\tan \sigma\pi\left[1 - \frac{2f_2(\sigma,\beta)}{\pi J_2}\right] \tag{14c}$$

We note in Eqs. (14c) that the quantity of seepage is dependent upon the parameters σ and β and one of the dimensions B, B_1, or H, which are related by $B - B_1 = 2H \cot \sigma\pi$. As was done in the previous sections, Vedernikov takes the quantity of seepage in the form

$$q = k(B + AH) \tag{15a}$$

where, from Eqs. (14c), A is given by

$$A = \frac{2}{\tan \sigma\pi}\,\frac{f_2(\sigma,\beta) - f_1(\sigma,\beta)/\cos \sigma\pi}{J_2\pi/2 - f_2(\sigma,\beta)} \tag{15b}$$

Taking a series of values for α and β, Vedernikov obtained the correspondence between A and B/H as given in Fig. 9-6. In this figure $m = \cot \alpha$ is the side slope of the ditch.

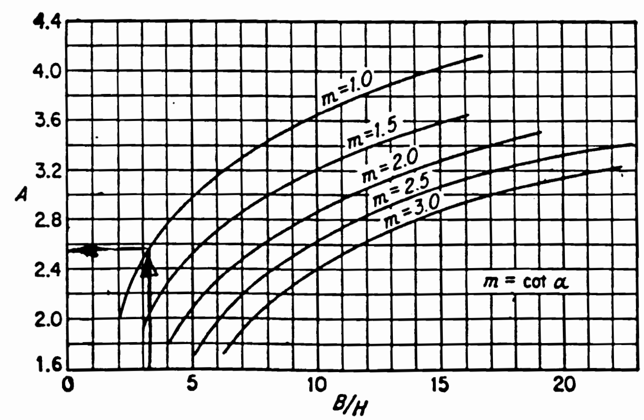

FIG. 9-6. (*After Vedernikov* [151].)

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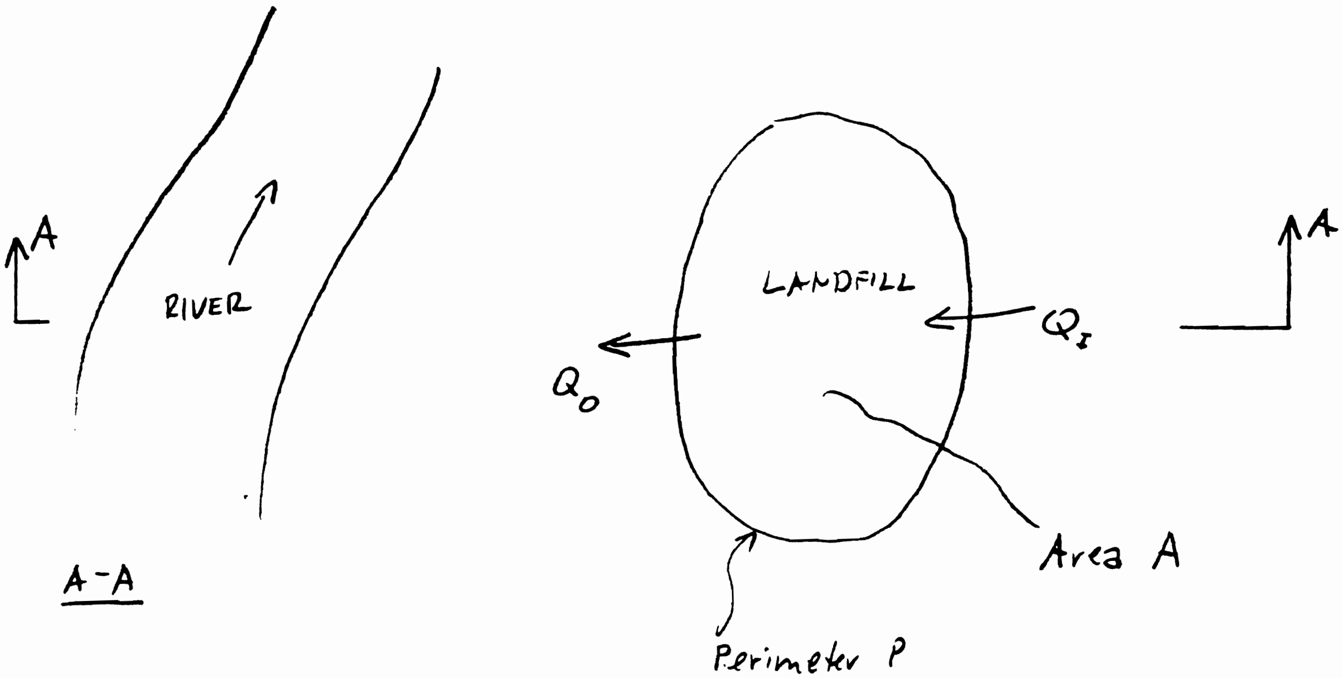
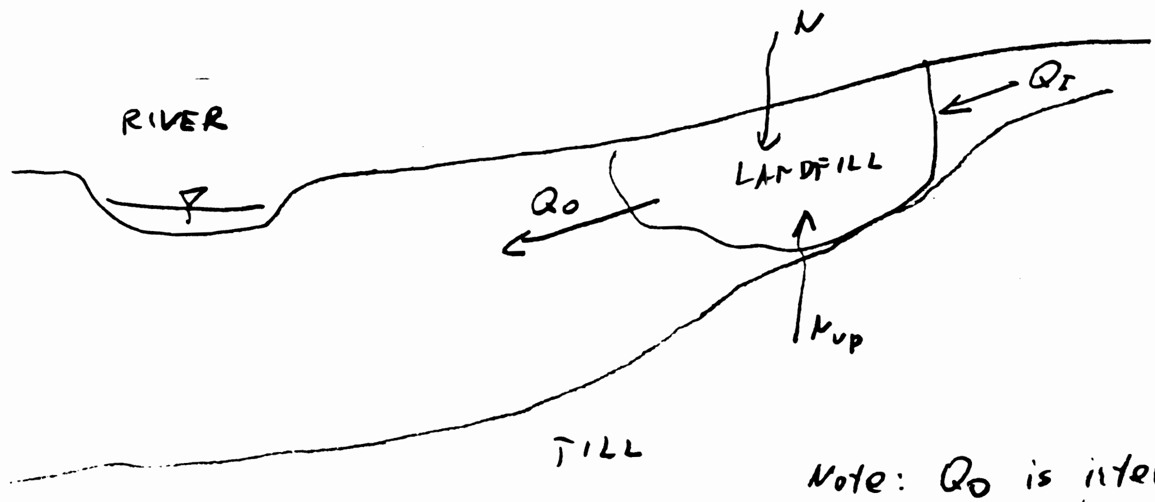
E.1) The purpose of this calc. was to estimate the withdrawal rates needed to intercept the groundwater from the site, with aid of vertical cut-off walls (slurry walls).

E.2) The water balance for the site





Note: Q_O is intercepted by withdrawal wells

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E.3) Different containment cases were considered

a) Part 360 cap, fully enclosed slurry wall

For this case, the withdrawal rate will be equal to the sum of infiltration through the cap, upward flow through till and flow through the slurry wall

$$Q_{INFILTR} = N_{360} \cdot A$$

$$Q_{UPW} = N_{UP} \cdot A$$

$$Q_{SLW} = P \cdot H_{AVG\,SAT} \cdot \frac{K_{SLW}}{TH_{SLW}} \cdot \Delta H$$

$$Q_{TOT} = Q_{INFILTR} + Q_{UPW} + Q_{SLW}$$

$Q_{INFILTR}$ - Infiltration through cap
N_{360} - Infiltration rate through part 360 cap
A - Landfill are
N_{UP} - Upward leakage from till
P - Landfill perimeter
$H_{AVG\,SAT}$ - Avg. saturated thickness of slurry wall
K_{SLW} - Hydr. conductivity of slurry wall
TH_{SLW} - thickness of slurry wall
ΔH - Difference in hydr. heads between inner & outer faces of slurry wall

N_{360} = 0.0005 FT/DAY (B.11)
A = 960,000 FT² (B.12)
N_{UP} - 20-fold increase assumed due to the lowering of water table

$$N_{UP} = 20 \cdot 0.00003 = 0.0006 \text{ FT/DAY} \quad (B.11)$$

P = 4,000 FT (B.12)
$H_{AVG\,SAT}$ = 45 FT (Value assumed)

TH_{SLW} = 3 FT (B.13)
ΔH = 2 FT (Value assumed)
K_{SLW} = 1E-6 cm/s = 0.003 FT/DAY

$Q_{TOT} = 0.0005 * 960{,}000 + 0.0006 * 960{,}000 +$

$+ 4{,}000 * 45 * 0.003 * 2/3$

$Q_{TOT} = 480 + 576 + 360$

$Q_{TOT} = 1416$ FT³/D $= \underline{\underline{8}}$ GPM

b) Part 360 cap, downgr. slurry wall
For this case, the inflow from off site will have to be added to case a)

$Q_I = B \cdot T_I \cdot i$

Q_I - Inflow from off site
B - Width of inflow area
T_I - Aquifer transmissivity in inflow area
i - Avg. hydr. gradient in inflow area

$B = 400$ FT (B.15)
$T_I = 1{,}000$ FT²/D (B.14)
$i = 0.015$ (B.16)

$Q_I = 400 * 1{,}000 * 0.015$ FT³/D

$Q_I = 6{,}000$ FT³/D

$Q_{TOT} = 1{,}416 + 6{,}000 = 7{,}416$ FT³/D $= \underline{\underline{39}}$ GPM

c) Soil cap, full enclosure
The only difference between this case and case a) is the infiltration. The infiltration rate for the soil cap is

$N_{SOIL} = 0.005$ FT/D (B.11)

And

$$Q_{INFILTR} = N_{SOIL} \cdot A = 0.005 \cdot 960,000 \quad FT^3/D$$

$$Q_{INFILTR} = 4,800 \quad FT^3/D$$

$$Q_{TOT} = 4,800 + 576 + 360 \quad FT^3/D$$

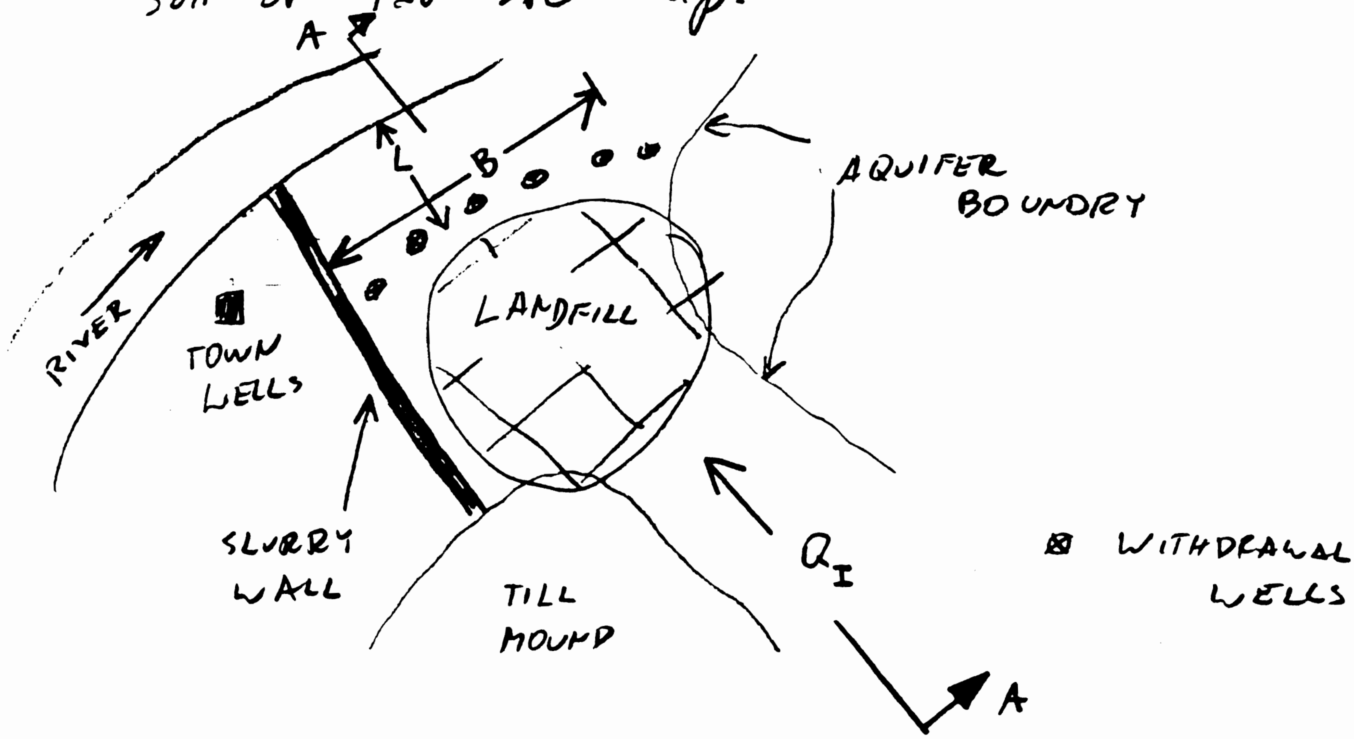
$$Q_{TOT} = 5,736 \quad FT^3/D = \underline{\underline{30}} \quad GPM$$

d) Soil cap, downgradient slurry wall
In this case, the flow from off-site will have to be added to case c)

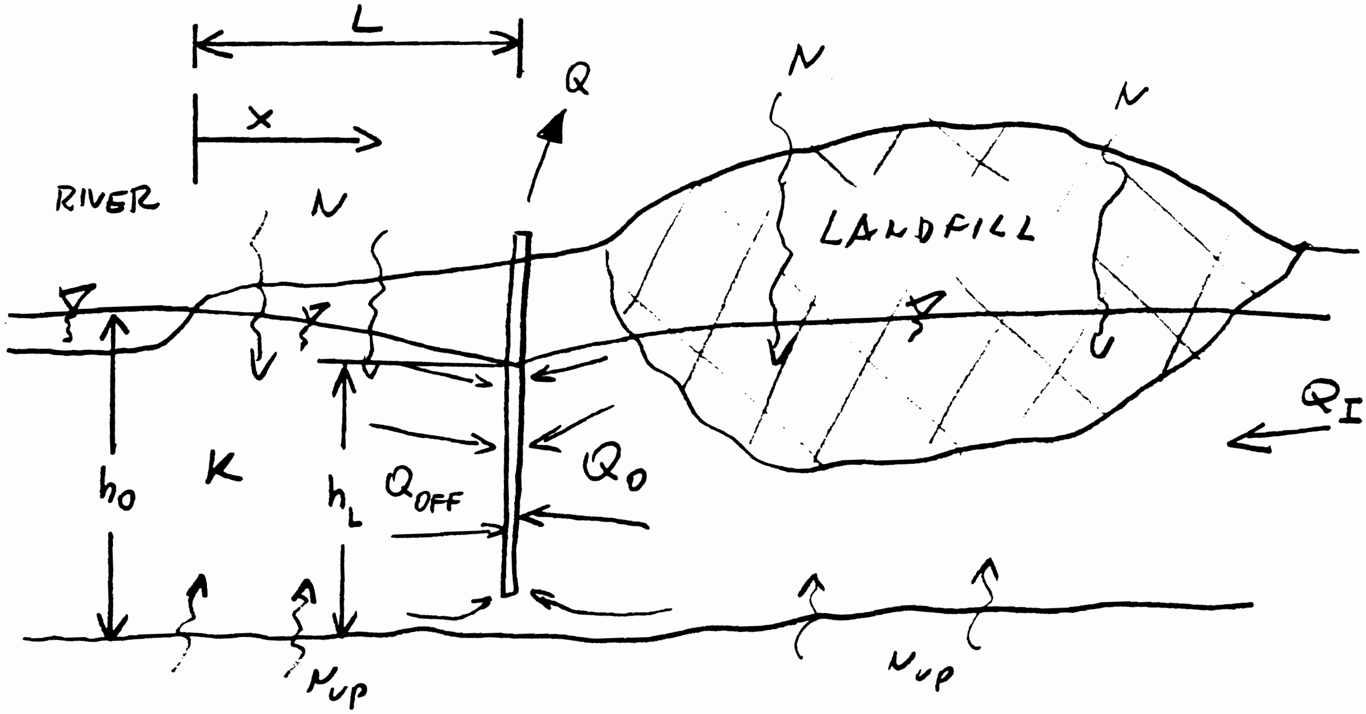
$$Q_{TOT} = 5,736 + 6,000 \quad FT^3/D$$

$$Q_{TOT} = 11,736 \quad FT^3/D = \underline{\underline{61}} \quad GPM$$

e) Cut-off wall from the till mound to the river, withdrawal wells between river and landfill, soil or pavt 360 cap.



A-A



The river will be assumed to be a constant head boundry, which will produce higher, conservative withdrawal rates. The flow from the site will be assumed as calculated in sections E.3a – E.3d. ($Q_{TOT} = Q_0$) Flow from the off-site will be calculated using a Dupuit formula

$$Q\Big|_{x=L} = \frac{(N+N_{up})L}{2} + \frac{K}{2 \cdot L}\left(h_0^2 - h_L^2\right)$$

"Hydr. of Groundwater"
J. Bear, 1979
See sheet E-11

This is a 2-D flow. In order to obtain a 3-D flow, it has to be multiplied by the width B_w (Length of well line)

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$N = 0.005$ FT/D (B.6)
$N_{up} = 0.00003$ FT/DAY (B.8)

$$N + N_{up} = 0.00503 \text{ FT/D}$$

$L = 1000$ FT (B.18)
$h_0 = 50$ FT (B.17) $\longrightarrow h_L = h_0 - 0.1 = 49.9$ FT
$B_w = 1200$ FT (B.19)
(h_L assumed 0.1 FT lower than h_0)

- $K = K_1 = 200$ FT/D

$$Q_{3D} = \left\{ \frac{0.00503}{2} \cdot 1000 + \frac{200}{2 \cdot 1000} \left[50^2 - 49.9^2 \right] \right\} \cdot 1{,}200$$

$$Q_{3D} = 4{,}217 \text{ FT}^3\text{/D}$$

- $K = K_2 = 2{,}600$ FT/D

$$Q_{3D} = \left\{ \frac{0.00503}{2} \cdot 1000 + \frac{2{,}600}{2 \cdot 1000} \left(50^2 - 49.9^2 \right) \right\} \cdot 1{,}200$$

$$Q_{3D} = 18{,}602 \text{ FT}^3\text{/D}$$

- $K = K_3 = 5{,}000$ FT/D

$$Q_{3D} = \left\{ \frac{0.00503}{2} \times 1000 + \frac{5{,}000}{2 \cdot 1000} \left(50^2 - 49.9^2 \right) \right\} \cdot 1{,}200$$

$$Q_{3D} = 32{,}988 \text{ FT}^3\text{/D}$$

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withdrawals from the site were calculated in sections E.3a - E.3d. Here, they are combined with the off-site withdrawal rates

$Q_I = 6{,}000\ FT^3/DAY$ – ALL CASES (E.3b)

$Q_{INFILTR\ SOIL\ CAP} = 4{,}800\ FT^3/D$ (E.3c)

$Q_{INFILTR\ 360\ CAP} = 480\ FT^3/D$ (E.3.a)

Flow through slurry wall was assumed to be negligible because of the very short lenght of slurry wall in this alternative

SOIL CAP

$$Q = Q_{3D\ OFF\ SITE} + Q_I + Q_{INFLTR\ SOIL\ CAP}$$

$$Q_{K_1} = 4{,}217 + 6{,}000 + 4{,}800 = 15{,}017\ FT^3/D$$

$$Q_{K_2} = 18{,}602 + 6{,}000 + 4{,}800 = 29{,}402\ FT^3/D$$

$$Q_{K_3} = 32{,}988 + 6{,}000 + 4{,}800 = 43{,}788\ FT^3/D$$

PART 360 CAP

$$Q = Q_{3D\ OFF\ SITE} + Q_I + Q_{INFILTR\ 360\ CAP}$$

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$Q_{K_1} = 4,217 + 6,000 + 480 = 10,697$ FT³/D

$Q_{K_2} = 18,602 + 6,000 + 480 = 25,082$ FT³/D

$Q_{K_3} = 32,988 + 6000 + 480 = 39,468$ FT³/D

So, the range of flows for soil cap is

15,017 – 43,788 FT³/D
78 – 227 GPM

and for Part 360 cap

10,697 – 39,468 FT³/D
56 – 205 GPM

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E.4) Summary of flows

	Part 360 Cap	Soil Cap
Full Enclosure	8 (10)	30 (30)
Downgr. Slurry Wall	39 (40)	61 (70)
Short Slurry Wall	(60 – 210) 56 – 205	(80 – 230) 78 – 227

Flows in GPM. Numbers in parantheses are rates rounded off to the nearest higher ten.

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LIST OF SYMBOLS

A - Landfill area
P - Landfill perimeter
N_{360} - Infiltration through Part 360 Cap
N_{up} - Upward flow from till
$H_{AVG\ SAT}$ - Avg. saturated thickness of slurry wall
K_{SLW} - Hydr. conductivity of the slurry wall material
TH_{SLW} - Thickness of slurry wall
ΔH - Difference in hydr. head between outer and inner parts of slurry wall
$Q_{INFILTR}$ - Flow through part 360 cap or soil cap
Q_{UPW} - Flow through till
Q_{SLW} - Flow through slurry wall
Q_{TOT} - Total flow into the landfill
Q_I - Flow into the landfill from off-site
B - Width of inflow area
T_I - Transmissivity of inflow area
i - Hydr. gradient in inflow area
N_{SOIL} - Infiltr. through soil cap
L - Distance from river to well line
h_0 - Hydr. head in river
h_L - Hydr. head on the well line
B_w - Length of well line
$Q_{30\ OFF\ SITE}$ - Withdrawal rate from off-site

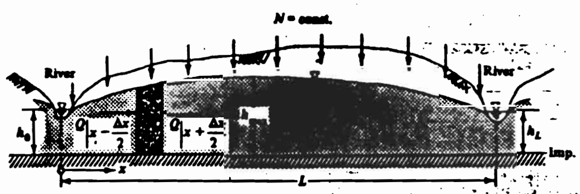

Figure 5-40 Flow in a phreatic aquifer with accretion.

bearing formation we assume that at $x = 0$ and $x = L$ we have vertical equipotentials $\phi = h_0$ ($\ll L$) and $\phi = h_L$ ($\ll L$), respectively, and that everywhere the flow is essentially horizontal. We know that in the vicinity of the water table peak and under the streams this assumption is incorrect (in fact the flow in these places is along the vertical), yet the regions of error are relatively small and the results based on the assumption of horizontal flow should be considered a good estimate for all practical purposes.

The continuity equation is obtained either from (5-70), or from a water balance written for the control box shown in Fig. 5-40

$$Q\Big|_{x-\Delta x/2} + N\,\Delta x - Q\Big|_{x+\Delta x/2} = 0; \qquad -\frac{dQ}{dx} + N = 0;$$

$$K\frac{d}{dx}\left(h\frac{dh}{dx}\right) + N = 0 \qquad (5\text{-}210)$$

By integration, we obtain

$$\frac{Kh^2}{2} + \frac{Nx^2}{2} + C_1x + C_2 = 0 \qquad (5\text{-}211)$$

Using the boundary conditions $x = 0$, $h = h_0$; $x = L$, $h = h_L$, we obtain

$$C_2 = -\frac{K}{2}h_0^2; \qquad C_1 = -\frac{K}{2L}(h_L^2 - h_0^2) - \frac{NL}{2}$$

Hence

$$K(h^2 - h_0^2) - Nx(L - x) + K\frac{x}{L}(h_0^2 - h_L^2) = 0 \qquad (5\text{-}$$

gives the shape of the water table $h = h(x)$. By differentiating (5-212), we

$$Kh\frac{dh}{dx} = -Q(x) = N\left(\frac{L}{2} - x\right) - \frac{K}{2L}(h_0^2 - h_L^2)$$

$q(x) = -\frac{NL}{2} + Nx + \frac{K}{2L}(h_0^2 - h_L^2)$

$= -Nx + \frac{K}{2L}(h_0^2 - h_L^2) - \frac{NL}{2} = \ldots \frac{1}{2}\left[\frac{K}{L}(h_0^2 - h_L^2) - NL\right]$

Hence

$$Q\Big|_{x=0} = -\frac{NL}{2} + \frac{K}{2L}(h_0^2 - h_L^2)$$

$$Q\Big|_{x=L} = +\frac{NL}{2} + \frac{K}{2L}(h_0^2 - h_L^2) \qquad (5\text{-}213)$$

where positive Q means flow in the $+x$ direction. The water table peak is obtained from $dh/dx = 0$ (or $Q(x) = 0$); it occurs at

$$x\Big|_{h=h_{max}} = \frac{L}{2} - \frac{K}{2NL}(h_0^2 - h_L^2) \qquad (5\text{-}214)$$

When a gallery is placed at $x = a$, $0 < a < L$, and water is withdrawn from it at a rate Q_P (per unit length), producing there a water table at elevation h_a, we follow the usual procedure of solving once for the region $0 \le x < a$ and then for $a \le x \le L$. We require that at $x = a$, $h = h_a$ when approached from both sides and that the total withdrawal be equal to the sum of the flows to the gallery from both sides.

(d) Flow in a Leaky Phreatic Aquifer

Consider the case shown in Fig. 5-41a. From a water balance written for the control box shown in this figure, we obtain the continuity equation

$$Q\Big|_{x-\Delta x/2} + N\,\Delta x - Q\Big|_{x+\Delta x/2} - q_v(x)\,\Delta x = 0; \qquad \frac{\partial Q}{\partial x} - N + q_v(x) = 0,$$

$$Q = -Kh\frac{dh}{dx}; \qquad q_v = \frac{h + B'}{\sigma'}; \qquad \frac{K}{2}\frac{d^2h^2}{dx^2} + N - \frac{h + B'}{\sigma'} = 0 \qquad (5\text{-}215)$$

We have assumed $p = 0$ along the bottom of the semipervious layer. Equation (5-215) can also be written as

$$\frac{d^2h^2}{dx^2} - 2Ah - 2B = 0; \qquad A = \frac{1}{K\sigma'}; \qquad B = \frac{B' - N\sigma'}{K\sigma'} \qquad (5\text{-}216)$$

Although this equation is nonlinear in h, integration in *this special case* is possible as is shown below. We multiply both sides of (5-216) by $h\,dh/dx$ and obtain

$$2\left(h\frac{dh}{dx}\right)\frac{d}{dx}\left(h\frac{dh}{dx}\right) - 2Ah\left(h\frac{dh}{dx}\right) - 2Bh\frac{dh}{dx} = 0$$

$$\frac{d}{dx}\left(h\frac{dh}{dx}\right)^2 - \frac{2}{3}A\frac{d}{dx}(h^3) - B\frac{d}{dx}(h^2) = 0$$

which, when integrated, yields

$$\left(h\frac{dh}{dx}\right)^2 = \tfrac{2}{3}Ah^3 + Bh^2 + C, \qquad h\frac{dh}{dx} = -(\tfrac{2}{3}Ah^3 + Bh^2 + C)^{1/2}$$