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KENTEC
CORRECTIVE ACTION PLAN

Prepared for
E.I. duPont deNemours Co. Inc.

July 11, 1991

R-12003-K REV. 1-88

DU PONT
REG US PAT & TM OFF
ESTABLISHED 1802

E. I. DU PONT DE NEMOURS & COMPANY
INCORPORATED

KINSTON PLANT
KINSTON, NORTH CAROLINA 28502-0800

FIBERS DEPARTMENT

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July 12, 1991

Mr. James Mulligan
Regional Supervisor, Northeastern Region
Department of Environment, Health and
Natural Resources
1424 Carolina Avenue
Washington, North Carolina 27889

RE: Corrective Action Plan/Du Pont-Kentec

Dear Mr. Mulligan:

Enclosed please find a corrective action plan for the Kentec site, in accordance with paragraph #3 of the February 4, 1991 Notice of Violation.

If there are any questions which arise during your review of this corrective action plan, please feel free to contact me at (919) 522-6263. Thank you for your prompt attention to this matter.

Sincerely,

Jimmy F. Garris

Jimmy F. Garris
Planning Specialist

Enclosure

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WDCR556/039.51

EXECUTIVE SUMMARY

This document presents the elements of the corrective action plan (CAP) for remediation of shallow groundwater on the Du Pont Kentec facility. The facility location is shown in Figure ES-1.

Kentec began operation in 1969 as a parts-cleaning facility for the Du Pont Kinston Plant. The facility was owned and operated by James Enterprises from 1969 until Du Pont purchased the facility in late 1981. Between 1969 and 1982, the Kentec facility discharged approximately 2,000 gallons per day of wastewater containing triethylene glycol (TEG) and 1,4-dioxane to a drainageway immediately south of the main facility building. The wastewater was treated biologically in a state-permitted drainfield system on the site from 1982 to 1986. Wastewater has been shipped offsite for treatment and disposal since the closure of the drainfields in 1986.

Three phases of groundwater assessments have been conducted at the Kentec facility beginning in November 1986. The results of these assessments are summarized in the Kentec Groundwater Assessment report (CH2M HILL, 1991). The hydrogeologic system at the site includes a surficial aquifer (water-bearing unit) consisting of sand and silty sand which is approximately 4 to 10 feet thick. The depth to the water table is approximately 4 feet. Beneath this uppermost layer lies the Peedee formation. The upper part of the Peedee consists of a 20-foot-thick, clayey, sandy silt layer overlying a sandy aquifer. Surficial groundwater is reportedly not used for potable supply in the vicinity of the Kentec site. The Peedee aquifer is used locally and regionally for water supply.

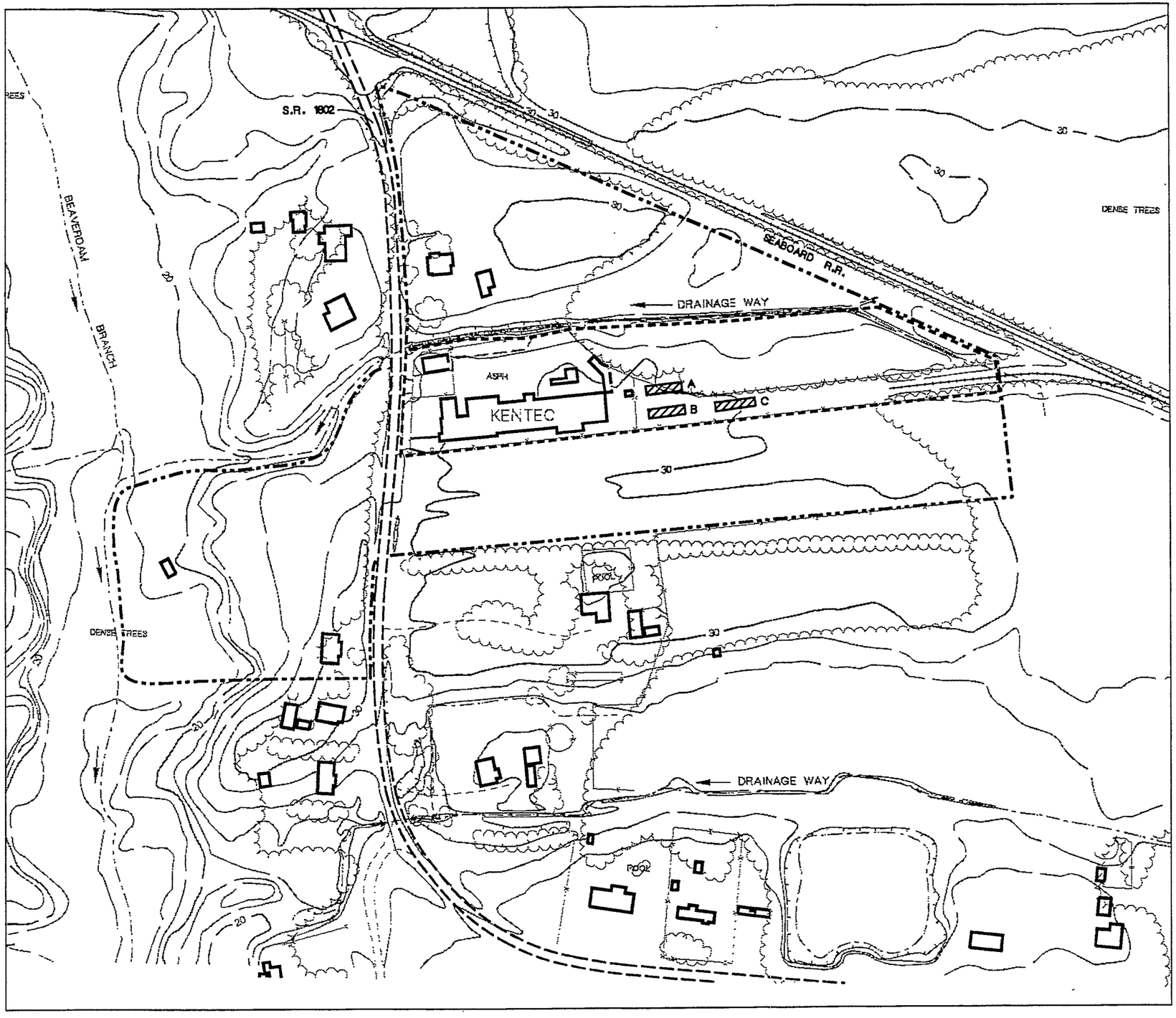
The groundwater assessments have shown that the surficial aquifer beneath the Kentec facility is contaminated by three organic compounds: 1,4-dioxane, 1,1-dichloroethene (DCE), and 1,1-dichloroethane (DCA) (see Figure ES-2).

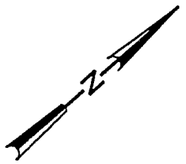
In July 1990 an audit was conducted of the wastewater sources, wastewater handling operations, and the physical facilities at Kentec. Through this audit the potential sources of groundwater contamination were identified and remediated.

A Notice of Violation (NOV) was issued to Du Pont from the State Department of Environment, Health and Natural Resources on February 4, 1991. Preparation of this CAP is a specific requirement of the NOV. The following are the corrective action objectives:

1. Prevent further migration of contaminants within the source area.

2. Remove and treat the contaminants in the source area to the established clean-up levels.





LEGEND

- 1969-1989 KENTEC PROPERTY BOUNDARY
- CURRENT KENTEC PROPERTY BOUNDARY
- WASTEWATER DRAINFIELD

NOTE: BASE MAP COMPILED FROM AERIAL PHOTOGRAPHY FLOWN ON 2/10/89.

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SCALE: 1"=200'

ES - 1

SITE MAP
Du Pont Kentec Facility

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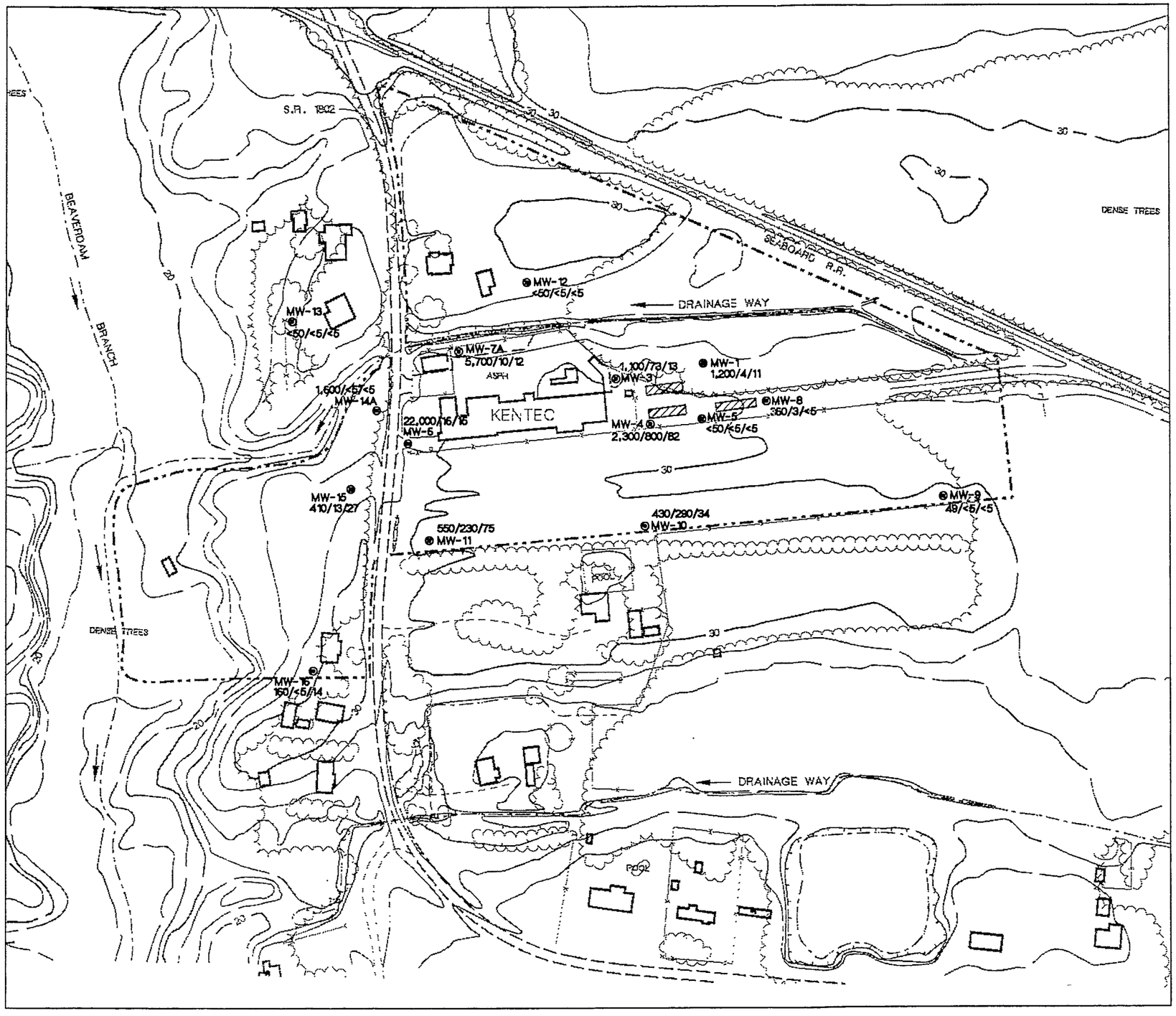

LEGEND

◉ MONITORING WELL

1,100/73/13 1,4-DIOXANE/1,1-DICHLOROETHANE/ 1,1-DICHLOROETHYLENE

CONCENTRATIONS IN ug/l

NOTE: BASE MAP COMPILED FROM AERIAL PHOTOGRAPHY FLOWN ON 2/10/89.

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SCALE: 1"=200'

ES - 2

CONCENTRATIONS OF 1,4-DIOXANE, 1,1-DICHLOROETHANE & 1,1-DICHLOROETHYLENE IN SHALLOW GROUNDWATER JANUARY 1990

Du Pont Kentec Facility

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3. Achieve a timely cleanup.

As indicated, this corrective action addresses only groundwater in the source area. The source area is shown in Figure ES-3 and is defined by the following boundaries: to the north by the existing ditch; to the south by the property fence line; and to the west by State Road 1802. Within the source area, this CAP addresses groundwater in the surficial aquifer. The cleanup levels that will be achieved are as follows: 1,4-dioxane- 150 μg/l; DCE-7 μg/l; DCA-7 μg/l; and iron-500 μg/l.

The corrective action consists of four primary components: groundwater collection, groundwater treatment, discharge of treated water, and monitoring.

GROUNDWATER COLLECTION

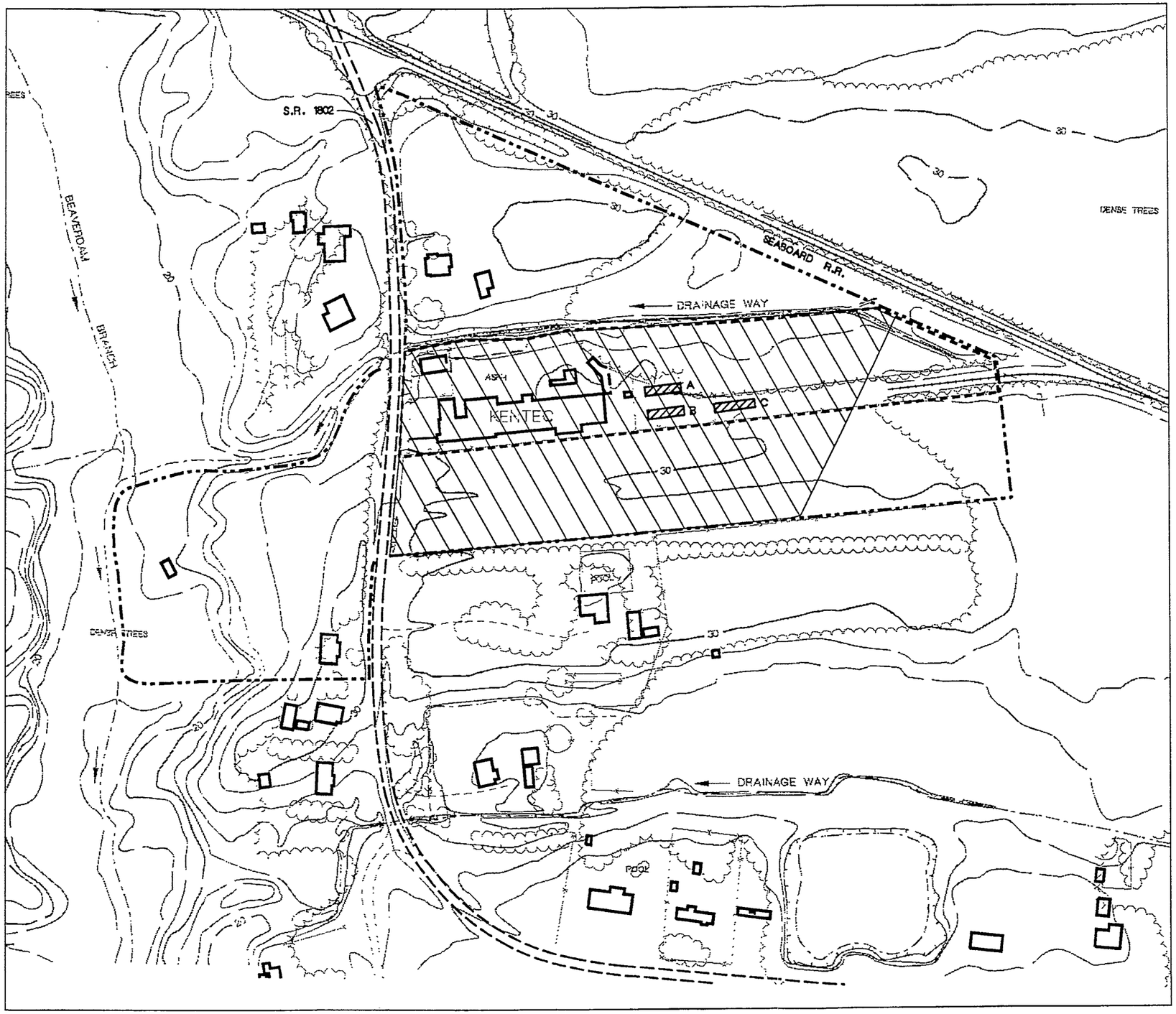
Surficial groundwater will be collected and removed using a groundwater interceptor trench (GIT). The location of GIT is shown in Figure ES-4 and a typical cross section is presented in Figure ES-5. As shown, the GIT will be completed in the silt layer of the upper part of the Peedee. This design will prevent further migration of contaminants from the source area as well as providing for the rapid removal of groundwater contamination. The ditch on the north side of the facility will be re-routed to provide access for constructing this segment of the GIT. Groundwater collected in the GIT will flow to a single sump where it will be pumped to the groundwater treatment system. The expected groundwater flow from the trench is 3,400 to 6,000 gallons per day (gpd).

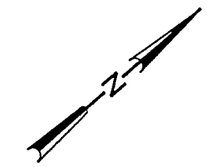
GROUNDWATER TREATMENT

Groundwater will be treated to the established cleanup levels using a chemical oxidation system. A schematic of the chemical oxidation system is shown in Figure ES-6. The system operates by oxidizing the organic compounds using a combination of ozone, UV light, and hydrogen peroxide. Iron will be removed by a filtering system. A carbon system will also be used to provide a final polishing step prior to discharge.

DISCHARGE OF TREATED GROUNDWATER

Three methods will be used to discharge treated groundwater. The primary method will be to reuse the treated groundwater in the Kentec parts cleaning process. Process water usage at the facility is currently about 2,000 gpd. It is likely, especially during the wet season, that water in excess of what can be reused will be generated. Du Pont will proceed with a NPDES permit to discharge excess treated water to the newly constructed drainage ditch north of the facility. Considering the low flows and the cleanup levels, no impacts to the stream are anticipated.





LEGEND

- - - - - - - - 1969-1989 KENTEC PROPERTY BOUNDARY

- · - · - · - · CURRENT KENTEC PROPERTY BOUNDARY

WASTEWATER DRAINFIELD

SOURCE AREA

NOTE: BASE MAP COMPILED FROM AERIAL PHOTOGRAPHY FLOWN ON 2/10/89.

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SCALE: 1"=200'

ES - 3

SOURCE AREA
Du Pont Kentec Facility

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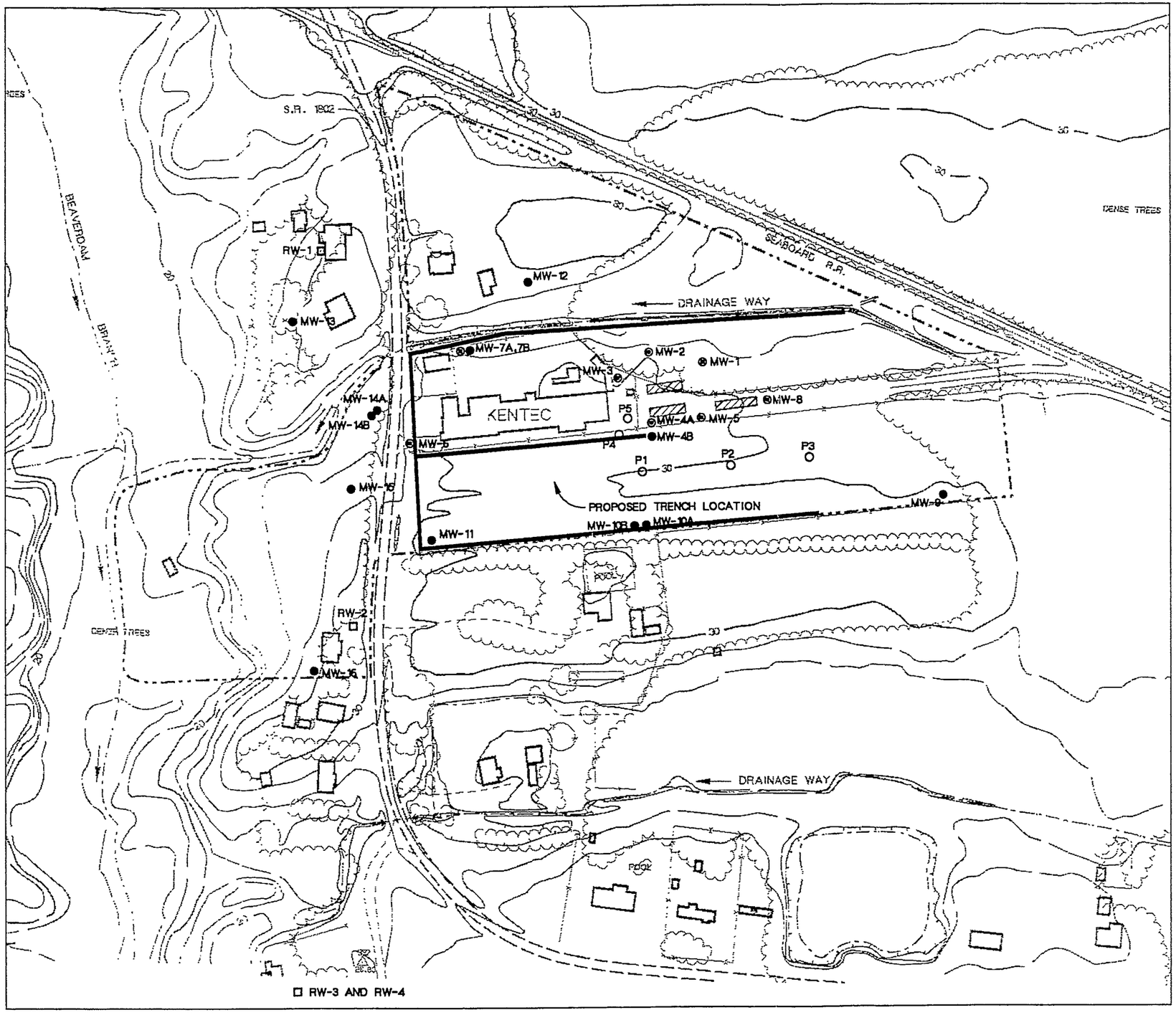

LEGEND

- PHASE 1 AND 2 MONITORING WELL
- PHASE 3 MONITORING WELL
- RESIDENTIAL WELL
- PIEZOMETERS

NOTE: BASE MAP COMPILED FROM AERIAL PHOTOGRAPHY FLOWN ON 2/10/89.

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SCALE: 1"=200'

ES - 4

LOCATION OF GROUNDWATER INTERCEPTOR TRENCH
Du Pont Kentec Facility

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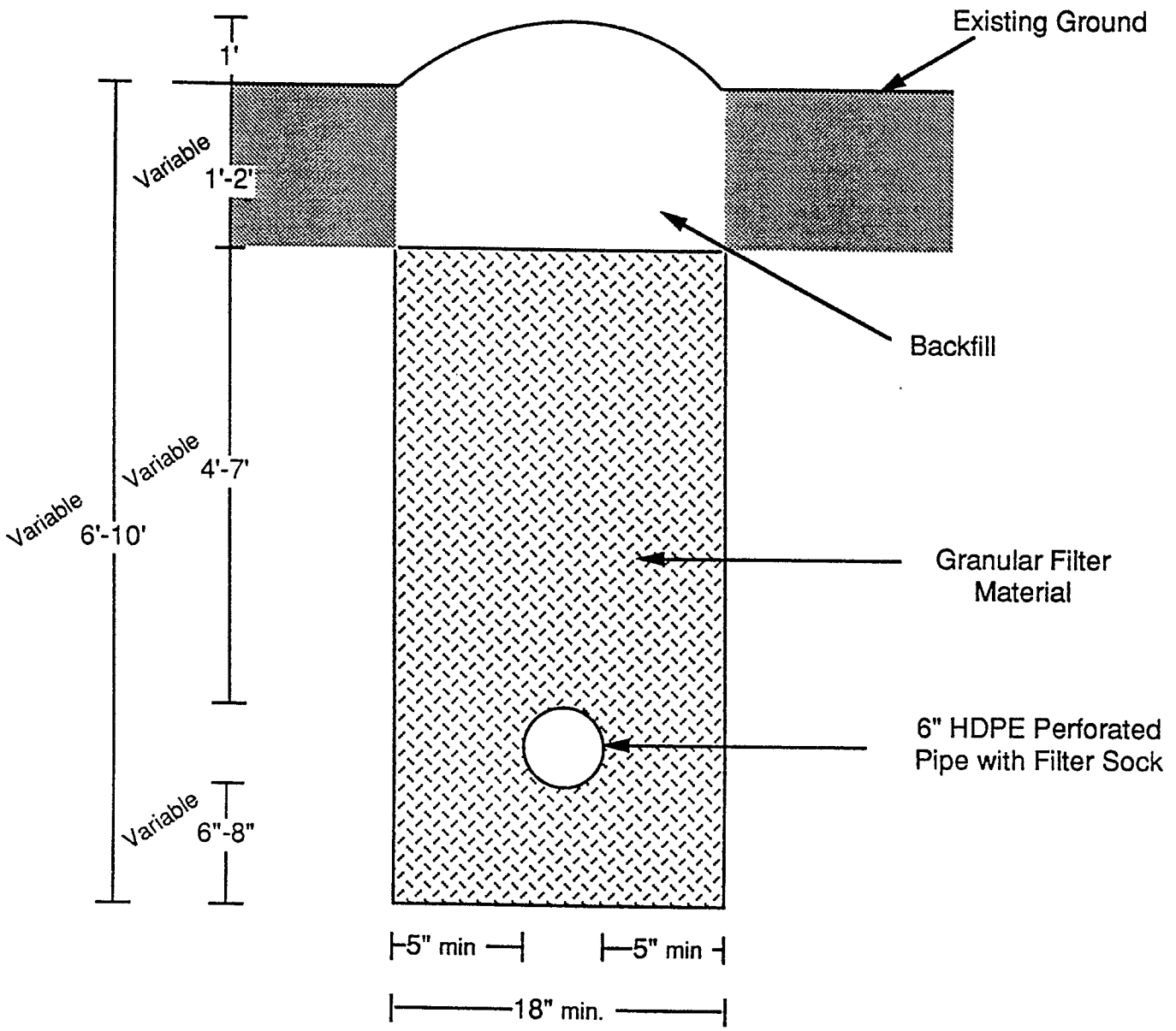


Figure ES-5
Typical Cross-Section of
Groundwater Interceptor Trench

Du Pont is planning to implement the corrective action at Kentec in the fall of 1991. It is unlikely that a NPDES permit can be obtained prior to this time. In the interim, therefore, water in excess of what can be reused may be discharged in one of two methods. It may be possible to discharge the treated water to the drainageway at Kentec under the terms of the Special Order of Consent (SOC), or it may be collected in a tank truck and transported offsite to a wastewater treatment facility, either a POTW or the Du Pont Kinston Wastewater Treatment Plant (WWTP) approximately 1.5 miles to the south. Du Pont will obtain a pump and haul permit for this activity and, if required, modification of their Kinston WWTP NPDES permit.

MONITORING

The monitoring plan for the corrective action includes monitoring of the treatment system and monitoring of the surficial groundwater. Monitoring of the effluent from the treatment system is necessary to determine whether the cleanup levels are being achieved. During startup, groundwater will be collected, treated, and analyzed prior to reuse or discharge. In this manner, effective operation of the treatment system can be obtained prior to full operation.

During full operation, effluent samples will be collected daily. The frequency of analysis will be dependent of the level of treatment obtained and the operational nature of the system. If daily analysis shows that cleanup levels are being consistently achieved, samples will be analyzed on a less frequent basis. Conversely, after system disruption, samples may be analyzed on a daily basis.

Samples taken during normal operation will be analyzed for DCA as a surrogate for system effectiveness, as DCA is the most difficult contaminant to oxidize. After system disruption and at least biweekly, samples will be analyzed for 1,4-dioxane, DCE, DCA, and iron.

Surficial groundwater monitoring will be conducted during and after remediation to evaluate the effectiveness of the groundwater collection system. Figure ES-7 shows the wells that will be used for monitoring. In total, 14 shallow groundwater monitoring wells, 5 deep monitoring wells, two surface water locations, and the sump will be used for monitoring. Prior to start up of the groundwater collection system, one round of samples will be collected and analyzed from all of the monitoring locations. During the first year of operation samples will be analyzed from this location quarterly, and subsequently on an anticipated semi-annual basis.

Remediation will be considered complete when for a two-week period contaminant concentrations in the influent to the treatment system and concentrations within the seven interior groundwater monitoring wells are below cleanup levels or reach an asymptotic state of reduction as agreed to by the State. At the conclusion of

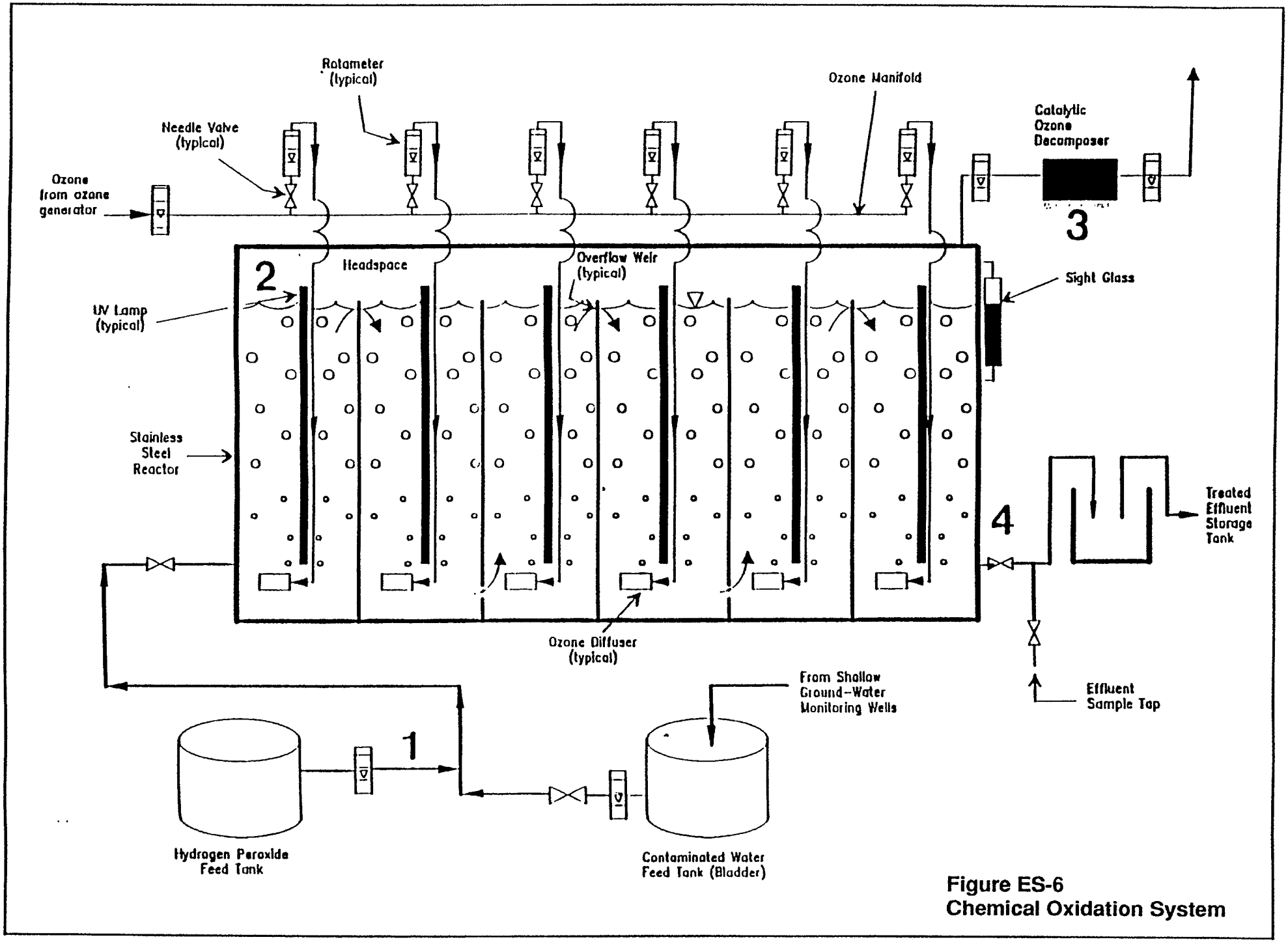
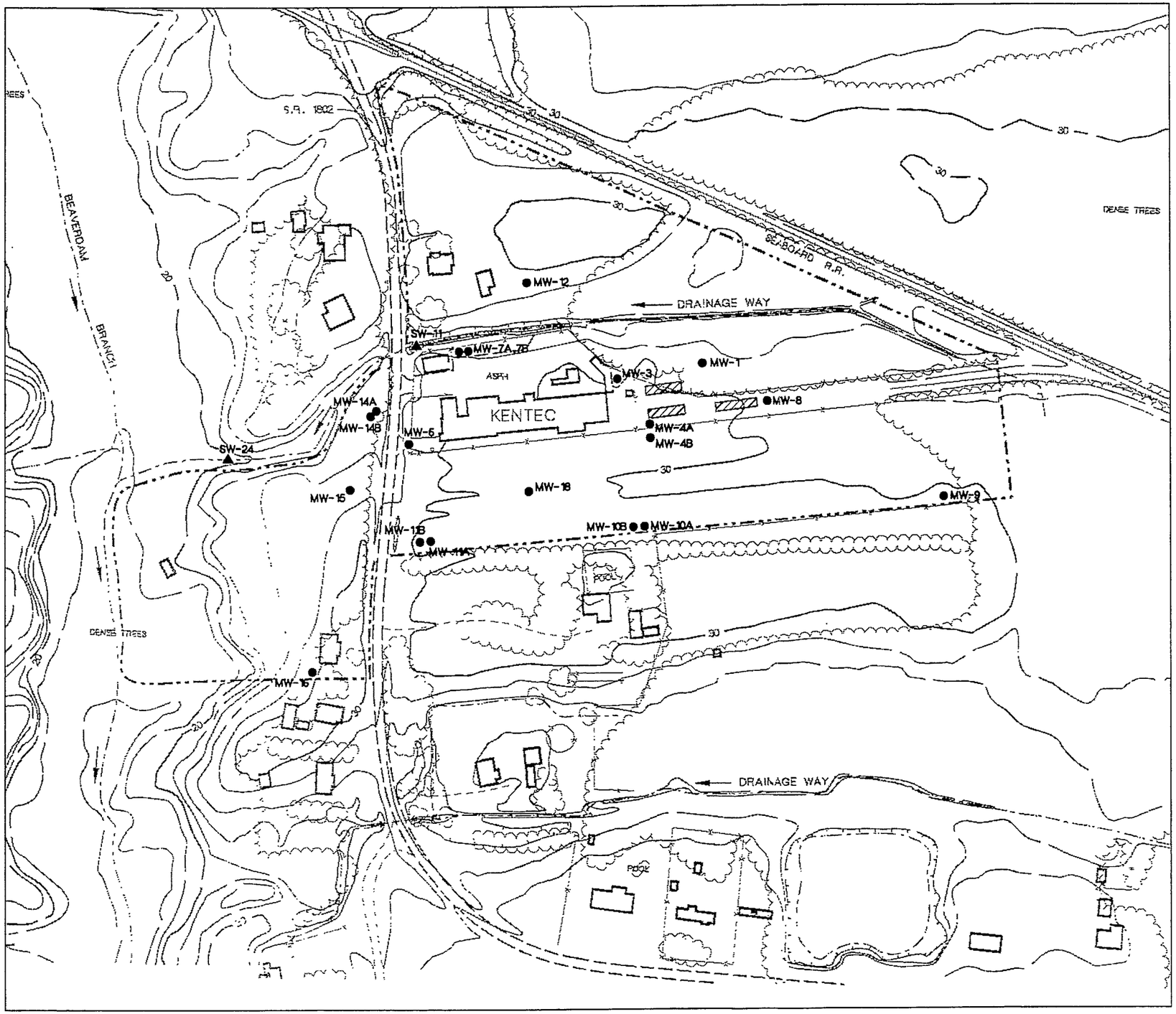


Figure ES-6
Chemical Oxidation System



LEGEND

- ● MONITORING WELL
  'A'- MONITORING WELLS ARE IN THE SHALLOW AQUIFER
  'B'- MONITORING WELLS ARE IN THE PEEDEE AQUIFER
- ▲ SURFACE WATER MONITORING POINT

NOTE: BASE MAP COMPILED FROM AERIAL PHOTOGRAPHY FLOWN ON 2/10/89.

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SCALE: 1"=200'

Figure ES-7

COLLECTION TRENCH MONITORING SYSTEM
Du Pont Kentec Facility

CH2M HILL

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remediation, groundwater samples will be collected and analyzed from all the monitoring locations on an annual basis for three years.

PERMITS AND SCHEDULE

Several permits will be required for the corrective action. Table ES-1 summarizes these permits.

Table ES-1
REQUIRED PERMITS

Permit	Purpose
Wetlands Construction Permit	Required to backfill existing ditch and construct new drainage ditch.
Non-Utility Encroachment Permit	Required to construct trench along State Road 1802 right-of-way.
Septic Field Permit	Required to re-locate existing sanitary septic field.
Air Permit	Required for chemical oxidation system ozone destruction unit.
Pump and Haul Permit	Required to transport treated groundwater to Kinston WWTP.
Kentec NPDES Permit	Required to discharge treated groundwater to drainage ditch.
Modifications of Kinston WWTP NPDES Permit	May be required to accept treated groundwater from Kentec.

Table ES-2 summarizes the tentative construction schedule for the Kentec corrective action. One of Du Pont's primary objectives is the timely implementation of the corrective action. The schedule is contingent, however, on several factors, including the timely review and response by the state and the availability of contractors and equipment.

Table ES-2 CONSTRUCTION SCHEDULE	
Action	**Date**
State Approval of CAP	July 26, 1991
Du Pont Issues Bids for Construction	September 27, 1991
Du Pont Selects Contractors	October 28, 1991
Permits Obtained	October 30, 1991
Construction Initiated	November 4, 1991
Construction Complete	November 22, 1991
Startup Complete	November 29, 1991
Full-Scale Operation	December 2, 1991

WDCR556/038.51

Section 1
INTRODUCTION

E.I. du Pont de Nemours was issued a Notice of Violation (NOV) from the State of North Carolina Department of Environment, Health and Natural Resources on February 4, 1991, for the Du Pont-Kentec parts cleaning facility. The NOV contains three general requirements related to the onsite groundwater contamination at the facility:

1. Identification and elimination of the source of groundwater contamination.

2. Performance of a Site Assessment to characterize groundwater contamination.

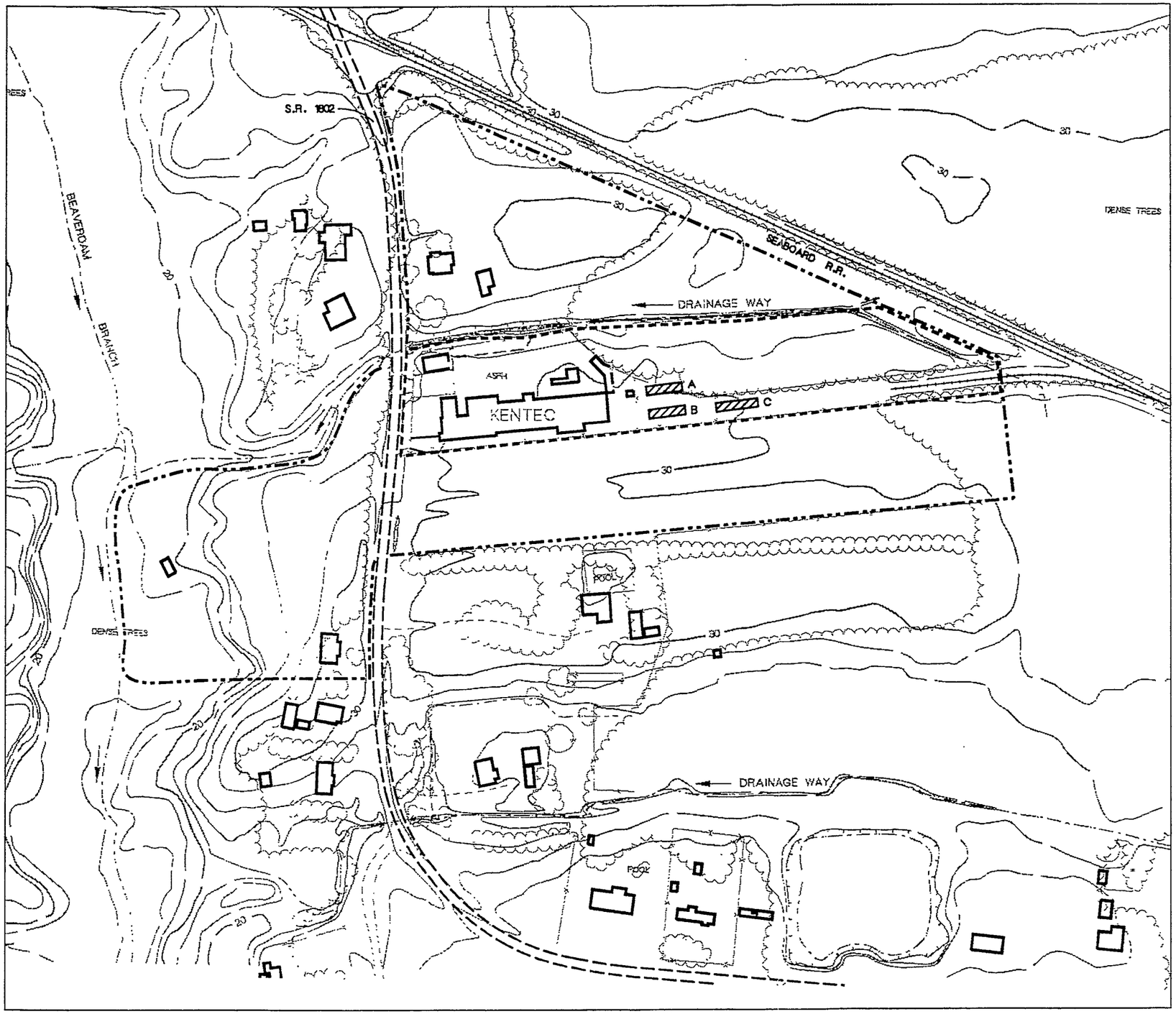
3. Development of a Corrective Action Plan (CAP) for remediation of groundwater contamination.

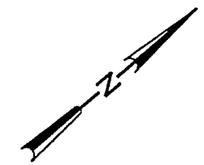
The identification and elimination of potential sources of groundwater contamination at the Kentec facility has been successfully completed through a detailed facility audit which is summarized in this document. NOV requirements regarding the characterization of onsite, shallow contamination have been addressed and previously submitted to the State as part of the Kentec Groundwater Assessment (CH2M HILL, 1991).

This document contains the details of the CAP for groundwater remediation at the Kentec facility. This introductory section provides summary information on the site history, waste generation and management practices, and previous actions at the site. Also included in this section is a discussion of the corrective action objectives and the format and content of the CAP.

SITE HISTORY

The Kentec facility (Figure 1-1) began operation in 1969 as a parts cleaning facility for the Du Pont Kinston Plant. The facility was owned and operated by James Enterprises from 1969 until late 1981. Du Pont purchased Kentec from James Enterprises in late 1981. The major items cleaned at Kentec include packs, powdered metal, and spinerettes, all of which are employed in the production and spinning of Dacron®. The cleaning process consists of dipping parts in triethylene glycol (TEG) to remove accumulated Dacron® polyesters and byproducts. Spent TEG is recovered and transported offsite for recycling. The parts are then rinsed with water to remove any traces of TEG and Dacron®. This rinsewater represents the primary wastewater stream at the facility. Constituents likely to be in this rinsewater include polyethylene glycols (such as TEG), 1,4-dioxane (a byproduct of heating TEG), and byproducts of esterification and polymerization of Dacron®. 1,1,1-Trichloroethane (TCA) is used in





LEGEND

- - - - - - - - 1969-1989 KENTEC PROPERTY BOUNDARY

—·—·—·— CURRENT KENTEC PROPERTY BOUNDARY

WASTEWATER DRAINFIELD

NOTE: BASE MAP COMPILED FROM AERIAL PHOTOGRAPHY FLOWN ON 2/10/89.

0 100 200 300

SCALE: 1"=200'

Figure 1-1

SITE MAP

Du Pont Kentec Facility

CH2M HILL

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the ultrasonic room at Kentec as a drying agent to remove traces of water from the parts prior to their return to the Kinston plant.

Until 1982, the Kentec facility discharged approximately 2,000 gallons per day of rinsewater containing TEG and 1,4-dioxane to a drainageway lying between the plant and State Route 1802. A biological treatment facility comprised of a holding tank and three subsurface drainfields was permitted by the state and installed onsite in June 1982. The drainfields were closed in February 1986, ostensibly because their retention time was insufficient to allow degradation of the organic compounds. Drainfield A (Figure 1-1) is reportedly the only one of the three that received rinsewater. Rinsewater has been shipped offsite for treatment and disposal at Du Pont's Chambers Works facility since February 1986.

A tank truck spilled process TEG between State Road 1802 and the southwest side of the plant on April 7, 1987. Du Pont sampled water and contained and removed the water and soil from the spill area between April 7 and 8, 1987.

The following discusses the groundwater investigations initiated by Du Pont through their contractor, CH2M HILL. These are brief summaries, and the reader is directed to the Kentec Groundwater Assessment (CH2M HILL, 1991) for a more detailed discussion.

PHASE 1

In November 1986, CH2M HILL was contracted to assess possible groundwater contamination resulting from the disposal of rinsewater in Drainfield A. Six shallow monitoring wells were installed in April of 1987 to study the groundwater beneath the drainfield. Surface water and soils were also sampled in and near the drainageways at the site.

1,4-Dioxane was observed in groundwater samples from all of the monitoring wells. Several other volatile organic compounds (VOCs) were detected in one well. The concentrations of iron and manganese were elevated in all groundwater samples. Chemical oxygen demand (COD), an indicator of organic contamination, and coliform bacteria were elevated in surface water samples on and off the Kentec property.

The Phase 1 report recommended (1) an inventory of all nearby residences to determine if property owners were using shallow well water; (2) sampling and analysis of surface waters adjacent to the property; (3) additional sampling of groundwater from the monitoring wells for 1,4-dioxane, VOCs and TEG; (4) additional sampling of surface water for coliforms; and (5) installation of a background monitoring well.

PHASE 2

Phase 2 of the assessment was conducted from May to October of 1988. Nearby residences were inventoried, and none reported using shallow groundwater for potable purposes. However, some reported using shallow groundwater to water lawns. Two additional shallow monitoring wells were installed on the Kentec property during Phase 2, and additional samples of groundwater and surface water were obtained. Five of the wells were used to measure hydraulic conductivity in the shallow aquifer.

1,4-Dioxane was again detected in samples from all of the monitoring wells in Phase 2. 1,1-Dichloroethane (DCA) and 1,1-dichloroethylene (DCE), which are both natural degradation products of TCA, were detected in samples from two wells. The major constituent of the rinsewater, TEG, was not detected in the groundwater near the drainfield.

The Phase 2 report recommended (1) analysis of soil samples from the drainfield area, (2) expansion of the monitoring program to include deeper wells and additional downgradient shallow wells, (3) analysis of additional surface water and sediment samples, (4) sampling of any residential wells downgradient of Kentec, even if not in use, and (5) preparation of a topographic map of the site.

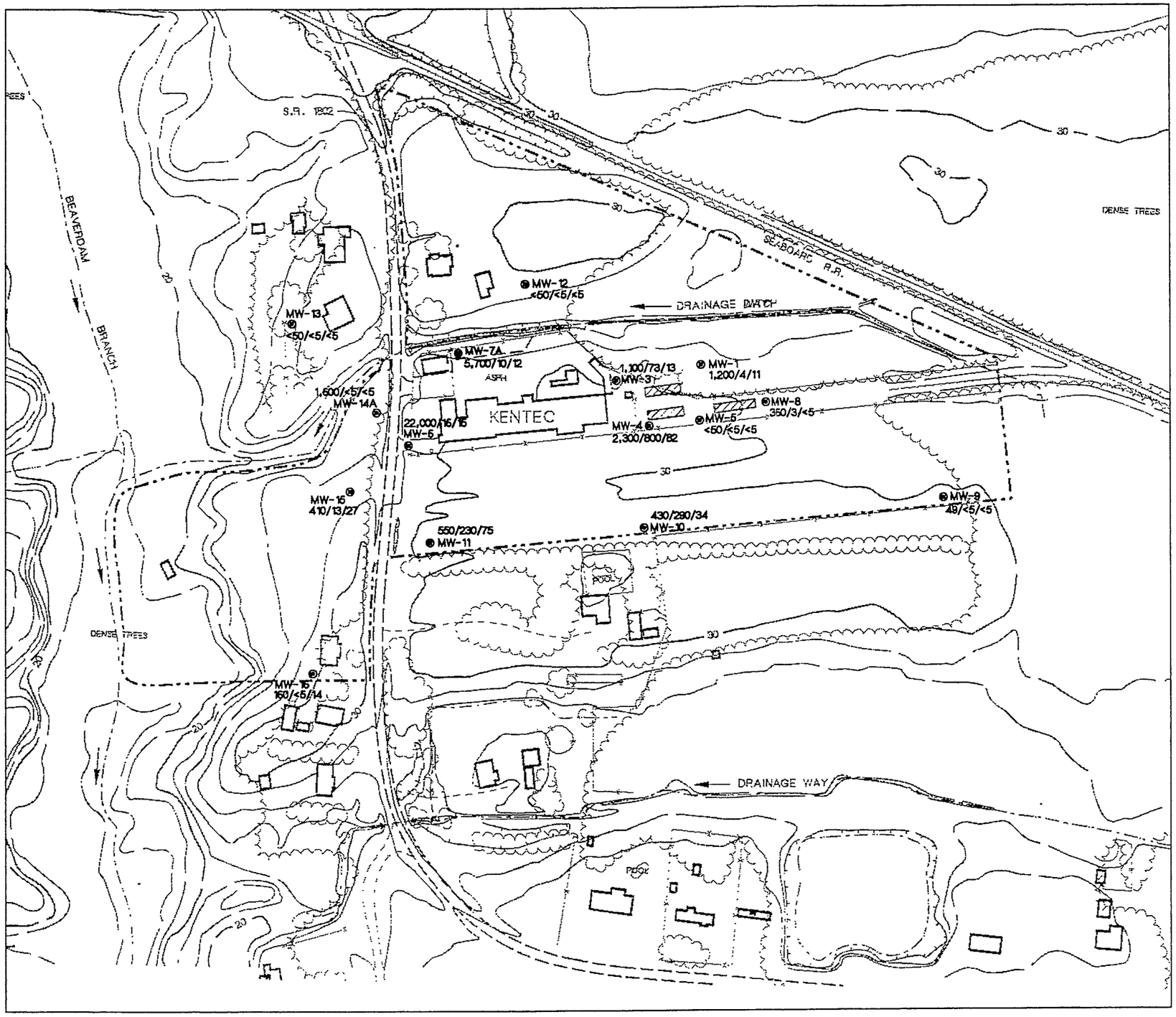
PHASE 3

The current phase of the assessment began in October of 1989, implementing the recommendations of the Phase 2 report. A facility audit was also conducted to identify potential sources of groundwater contamination at Kentec. Between Phases 2 and 3, Du Pont acquired property adjacent to Kentec; the current property boundary is shown in Figure 1-1.

Figure 1-2 shows the distribution of the three major contaminants detected during the three phases of groundwater investigations: 1,4-dioxane, DCA, and DCE. These data represent the level and distribution of contaminants in January, 1990, and are the data upon which the CAP is based. A more detailed discussion of the groundwater investigation, including sampling and analytical methods and results, can be found in the Kentec Groundwater Assessment (CH2M HILL, 1991).

PREVIOUS CORRECTIVE ACTIONS

On July 23, 1990, CH2M HILL audited wastewater sources, wastewater handling operations, and the physical facilities at Kentec. There were two primary objectives of the audit: 1) to identify potential sources of groundwater contamination from existing and past operations, and 2) to identify methods that could be used to confirm and quantify potential contaminant sources. In addition, Du Pont used the results of the audit to guide immediate corrective actions at some locations.



LEGEND

◉ MONITORING WELL

1,100/73/13 1,4-DIOXANE/1,1-DICHLOROETHANE/ 1,1-DICHLOROETHYLENE

CONCENTRATIONS IN ug/l

NOTE: BASE MAP COMPILED FROM AERIAL PHOTOGRAPHY FLOWN ON 2/10/89.

0 100 200 300

SCALE: 1"=200'

Figure 1-2

CONCENTRATIONS OF 1,4-DIOXANE, 1,1-DICHLOROETHANE & 1,1-DICHLOROETHYLENE IN SHALLOW GROUNDWATER JANUARY 1990

Du Pont Kentec Facility

CH2M HILL

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The audit indicated a number of potential sources of groundwater contamination. These potential sources, together with sampling results and corrective actions, are described below. Sample locations and analytical results are presented in detail in the Kentec Groundwater Assessment (CH2M HILL, 1991).

DRAINFIELDS

The three drainfields, installed in 1982 and inactive since 1986, were considered a possible source of continuing releases to groundwater. A water sample was collected from each of the three drainfield distribution boxes (A, B, and C) and two soil samples (DL-1 and DL-2) were collected directly beneath Drainfield A.

Elevated concentrations of contaminants were not detected in these samples or in the 10 drainfield soil samples collected earlier during Phase 3. ("Elevated" concentrations are defined here as concentrations sufficient to cause groundwater contamination similar to that seen in adjacent monitoring wells.)

WASTEWATER SETTLING TANKS (UNDERGROUND)

Two underground concrete tanks (ST1 and ST2), located adjacent to the southern end of the main Kentec building, were used as settling chambers to remove filter wash grit solids from the rinsewater. At the time of the audit they were no longer in service; however, they had not been cleaned out and each was nearly full of solids. A third tank (ST3), located approximately 100 feet from ST1 and ST2, was permitted as a septic tank in 1982 and disconnected in 1988. This tank was one-half full of liquid.

Samples of the solids were collected from ST1 and ST2, and one liquid sample was collected from ST3. Analysis of the samples indicated elevated concentrations of organic compounds, including TEG, 1,4-dioxane, TCA, DCA and DCE.

Du Pont contracted to have the solids and liquid pumped out of the tanks and hauled offsite for treatment and disposal. After the tanks were removed, the soil beneath and adjacent to the tanks was sampled and analyzed. At ST1 and ST2, one pair of soil samples was collected from each tank location. One member of each pair was a composite of soil from around the joint connecting the two halves of the tank, while the other (ST1-2 and ST2-2) was collected from directly beneath the tank. ST3-1 was collected from the tank's effluent pipe and ST3-2 was collected from directly beneath the tank. Low concentrations of 1,4-dioxane were detected in all of the soil samples from ST1 and ST2. Soil was removed from the two locations for offsite disposal; the holes were then backfilled with clean sand.

WET WELL

A wet well located near the northeastern corner of the main Kentec building is a collection point for wastewater piping. The wet well is constructed of reinforced

concrete and has a standing wastewater level typically above the level of the water table. Measurements of changes in water levels within the wet well and in two nearby piezometers over a 24-hour period suggested that the wet well may be leaking. Du Pont installed a fiberglass liner within the wet well to prevent any future leakage.

PIPING

The six-inch, PVC underground pipe that conveys all wastewater to the wet well was found to be cracked in two places. The cracked pipe was replaced and a soil sample was collected from beneath each of the two locations (SS1 and SS2) for analysis. The analyses did not indicate any substantial contamination remaining in the soil near these cracks.

The underground pipe for conveying wastewater from the storage tank to the rail car was replaced with an above-ground line.

SUBSURFACE POWDERED METAL

In the early years of Kentec's operation under James Enterprises, uncleaned, powdered metal was disposed on the ground north of the main Kentec building. In the mid-1980s, this disposed metal was mined and reclaimed. During this audit, three soil borings (SB1, SB2, and SB3) were drilled to the water table in this area to determine whether contamination was evident in the soil. Two soil samples were collected from each boring and analyzed; no elevated levels of contamination were found.

SURFACE DISPOSAL OF WASTEWATER

From 1969 until 1982, wastewater from the facility was disposed in a drainageway between State Road 1802 and the facility. A spill of TEG occurred in the same area in April 1987. In November 1990, Du Pont excavated soil and sludge from this area and disposed of it offsite. Two samples of the sludge (S1 and S2) were analyzed and found to be contaminated with the constituents typically found in the wastewater. After excavation, a sample of the remaining soil (S3) was collected and analyzed. It was found to contain low levels of 1,4-dioxane.

CONTAINMENT AREAS

The cleaning areas in the main Kentec building and in the above-ground storage tank area are generally contained by concrete dikes to collect leaks or spills. There were cracks at several locations in these concrete containments at the time of the audit. All cracks and dikes have recently been sealed with epoxy by Du Pont.

A summary of previous corrective actions is given in Table 1-1.

Table 1-1
PREVIOUS CORRECTIVE ACTIONS

Action	Completion Date
Remove Buried Rinsewater Tanks and Sludge.	November, 1990
Remove Three Underground Settling Tanks.	December 20, 1990
Install Fiberglass Sleeve in Wet Well.	January 18, 1991
Replace Cracked Pipe Section, Install Above-Ground Rinsewater Line to Railcar.	February 22, 1991
Clean and Seal Dikes and Floors.	March 15, 1991

CORRECTIVE ACTION OBJECTIVES AND CLEANUP LEVELS

The overall objective of this CAP is to meet the requirements specified in the "Outline For Evaluation of Site Characterization Data and Remedial Action Plans For Groundwater Restoration," which is included in the NOV. The following are the specific corrective action objectives:

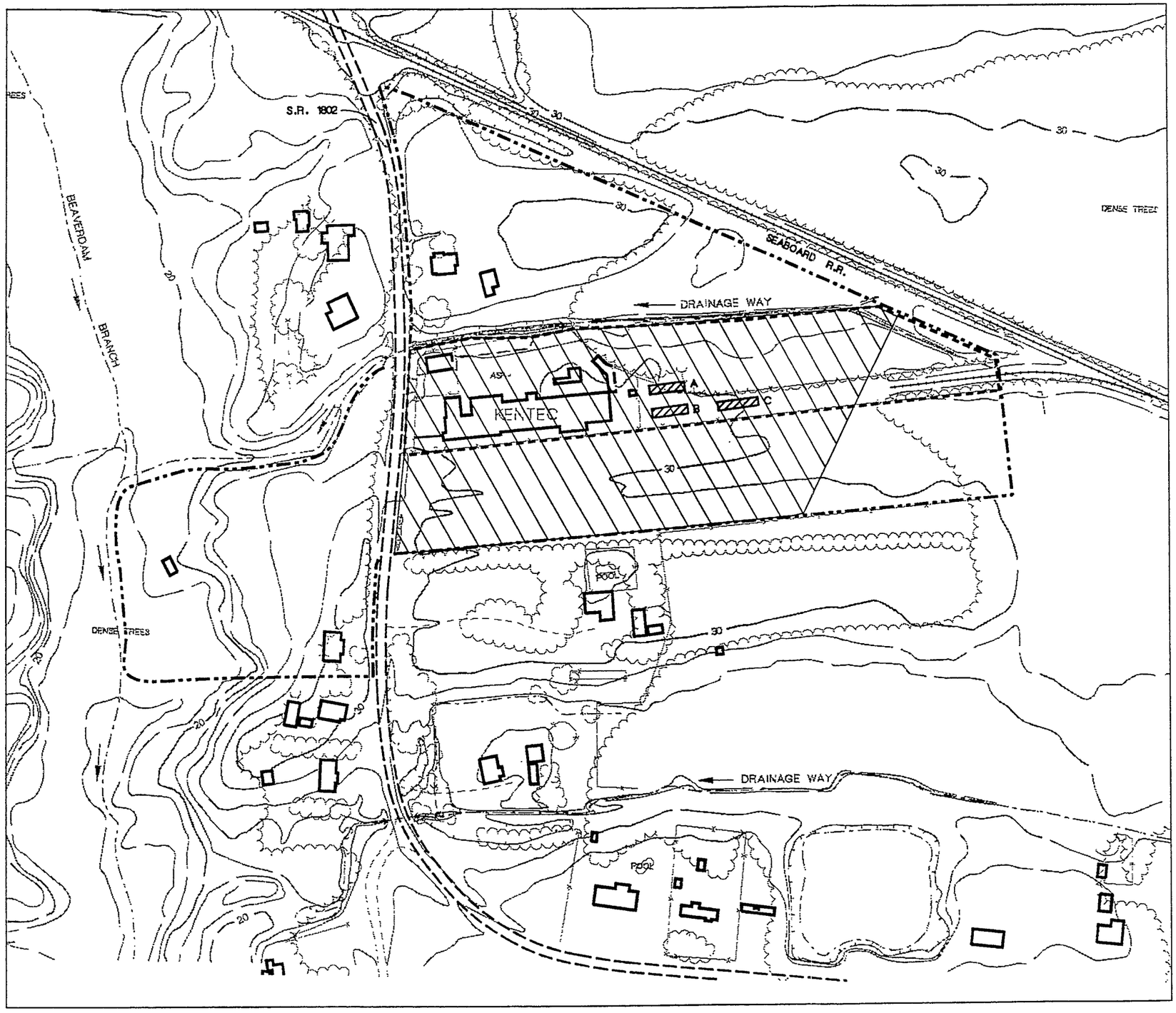
1. Prevent further migration of contaminants within the source area.

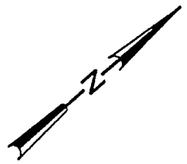
2. Remove and treat the contaminants in the source area to the established cleanup levels.

3. Achieve a timely cleanup.

As specified above, this corrective action addresses only groundwater in the source area. The source area is shown in Figure 1-3 and is defined by the following boundaries: to the north by the existing ditch; to the south by the property fence line; and to the west by State Road 1802. Within the source area, this CAP addresses groundwater in the surficial aquifer. Two other groundwater regimes have or are currently being studied: 1) deep groundwater and 2) offsite groundwater. Characterization of the deep groundwater (Peedee aquifer) and the offsite groundwater is ongoing and subsequent site assessment reports and corrective action plans will be developed for these areas if necessary.

As discussed previously, the contaminants identified during the groundwater investigations and addressed in this CAP are 1,4-dioxane, DCA, and DCE. Although not directly released from the facility, iron is also addressed due to its apparent





LEGEND

- - - - - - - - 1969-1989 KENTEC PROPERTY BOUNDARY

—·—·—·— CURRENT KENTEC PROPERTY BOUNDARY

WASTEWATER DRAINFIELD

SOURCE AREA

NOTE: BASE MAP COMPILED FROM AERIAL PHOTOGRAPHY FLOWN ON 2/10/89.

0 100 200 300

SCALE: 1"=200'

Figure 1-3

SOURCE AREA
Du Pont Kentec Facility

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increased solubility within the groundwater as a result of facility releases and its potential to disrupt the groundwater collection, treatment, and discharge systems.

This CAP responds to the requirements of the February 4, 1991 NOV issued by the State of North Carolina. The specific violations contained in this notice refer to North Carolina Administrative Code Title 15A Subchapter 2L - Classifications and Water Quality Standards Applicable to the Groundwaters of North Carolina. The pertinent part of these regulations address the water quality standards which must be met during groundwater restoration (Section .0202). The following paragraphs discuss these regulations and target cleanup levels for each of the contaminants of concern.

Section .0202 states:

> "Where groundwater quality standards have been exceeded due to man's activities, restoration efforts shall be designed to restore groundwater quality to the level of the standard or as closely thereto as is practicable."

Section .0202 (b)(1)of the regulations also states:

> "Where the maximum allowable concentration of a substance is less than the limit of detectability, the substance shall not be permitted in detectable concentrations."

Section .0102 defines limit of detectability as:

> "... the method detection limit established for the U.S. EPA approved test procedure providing the lowest method detection limit for the substance being monitored."

Based on these regulations, target cleanup levels were set for each of the four contaminants of concern.

The state water quality standard for DCE is 7 μg/l. This will be the target clean up level for both DCE and DCA, as DCA does not have a water quality standard.

Section .0202 stipulates a water quality standard for 1,4-dioxane of 7 μg/l (ppb). Section 0.0112 lists the analytical procedures that can be used to determine compliance with the water quality standards. None of the listed citations include analytical methods for 1,4-dioxane. The only federal citation that contains a suggested analytical method and detection limit for 1,4-dioxane is 40 CFR Part 264 "Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities" Appendix IX. The suggested analytical method is EPA Method 8015 and the Practical Quantitation Limit (PQL) listed is 150 μg/l. Method 8015 refers to analytical procedure numbers used in EPA Report SW-846 "Test Methods for Evaluating Solid

Waste." This reference is one of the citations listed in Section 0.0112 of the state regulation. The target cleanup level for 1,4-dioxane is therefore 150 μg/l.

The water quality standard for iron is listed as 300 μg/l. However, the background concentration of iron is naturally high in the area and is estimated from onsite groundwater samples that have not been impacted by the contamination to be approximately 800 μg/l. Iron will be removed, through oxidation and filtration to 500 μg/l, to meet background levels and prevent fouling of the groundwater treatment system.

CORRECTIVE ACTION PLAN CONTENTS

The remainder of this document is organized into six sections, which correlate to specific components of the corrective action. The following section on groundwater collection presents a summary of the relevant geological and hydrogeological characteristics of the site and discusses in detail the interceptor trench that will be used to remove groundwater. The results of the trench and groundwater modeling are also discussed in this section. The groundwater treatment system, including treatability testing, is discussed in Section 3. Section 4 presents the methods to be used for the discharge of the treated groundwater. Section 5 includes the monitoring methods that will be used to determine the effectiveness of the interceptor trench and the treatment system. Section 6 presents the facility layout, including the location of all components of the removal, treatment, and discharge systems. The details of the groundwater modeling are also discussed in Appendix A. Appendix B presents the screening of groundwater treatment technologies.

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Section 2
GROUNDWATER COLLECTION

Included in this section is a discussion of the geological and hydrogeological characteristics of the facility that are relevant to the collection and removal of groundwater. This is followed by a discussion of the conceptual design and operational characteristics of the interceptor trench.

SITE GEOLOGY AND HYDROGEOLOGY

GEOLOGY

Three sedimentary units were encountered during drilling at the site. The uppermost unit consists of yellowish brown to yellowish orange, fine to very coarse sand and silty sand. This unit appears to be absent in the bed of the drainageway just west of the Kentec buildings, but is from 4 to 10 feet thick elsewhere at the site. The unit tends to be finer-grained and more silty in the upper 3 feet and denser and coarser at its base; it contained pebbles at and near its base in some boreholes. This uppermost unit is believed to correspond to the surficial deposits that overlie the Peedee Formation regionally.

Underlying these sands is a deposit of gray to greenish gray, stiff, clayey and sandy silts; there is a notable variation in the relative proportions of sand and clay from place to place in the unit. The sand fraction of the unit appears to increase with depth. The deposit is flat-lying and is approximately 20 feet thick; its base lies at an elevation of approximately mean sea level. This unit appears to be part of the upper portion of the Peedee Formation.

The clayey, sandy silt is underlain by a deposit of loose, fine to medium, greenish-gray to dark gray, glauconitic sand with some interfingered sand and silt layers and fragments of calcareous sandstone and shells. The upper portion of this unit contains some stiff, clayey silts and clayey sands. This unit is also considered to be part of the Peedee Formation. A typical geological cross section is shown in Figure 2-1.

SURFICIAL GROUNDWATER

The surficial aquifer at the site is within the surficial deposits that overlie the Peedee Formation. The depth to the water table is approximately 4 feet, with a fluctuation between 1 and 1.5 feet. The highest water levels are consistently in an area just to the north and east of the main Kentec building, whereas the lowest water levels were in and adjacent to the drainageway which passes west of the buildings. This pattern, in which the shape of the water table mimics surface topography, is typical of shallow,

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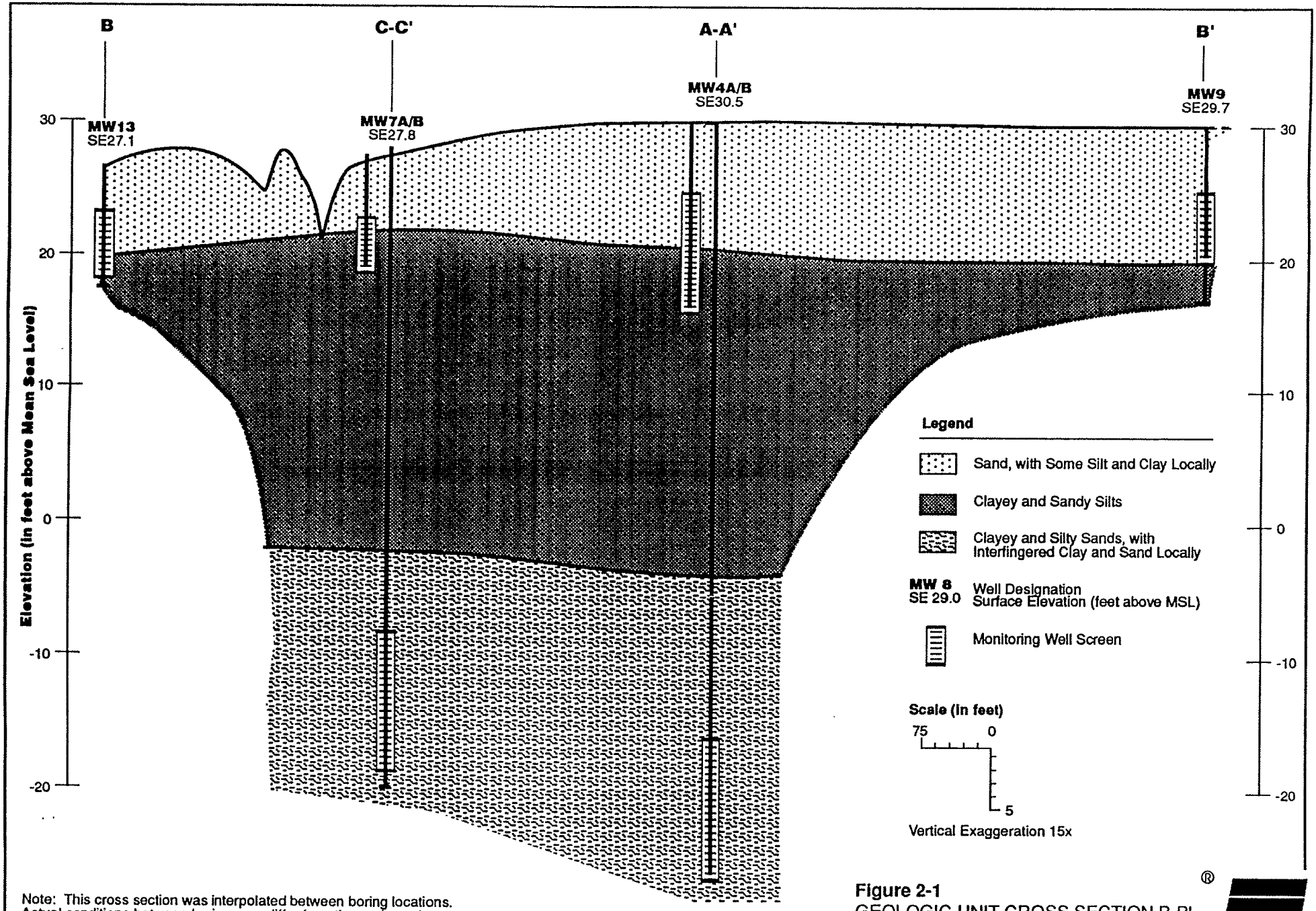

Note: This cross section was interpolated between boring locations. Actual conditions between boring may differ from those shown here.

(Refer to Kentec Groundwater Assessment Report for Section Location)

Figure 2-1
GEOLOGIC UNIT CROSS SECTION B-B'
DuPont Kentec Facility

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unconfined aquifers. The water level distribution in the surficial aquifer is shown in Figure 2-2.

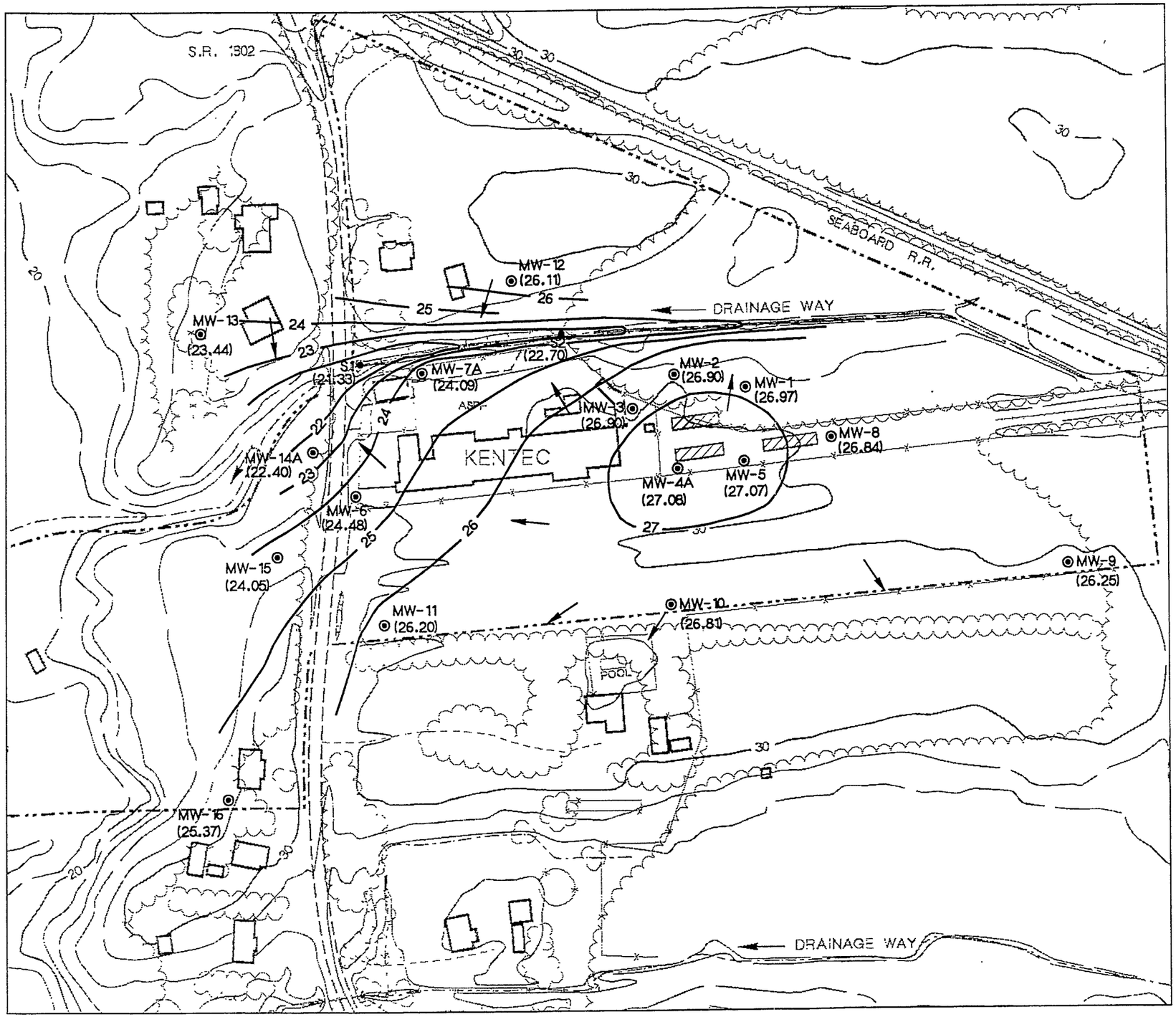
Surficial groundwater beneath the Kentec facility was found to be contaminated, primarily by the three organic compounds, 1,4-dioxane, DCE, and DCA. The majority of surficial groundwater contamination appears to have originated in an area near the northeastern corner of the main Kentec building. The distribution of this contamination is complex, in part because groundwater flows radially away from the area (see Figures 2-2 and 2-3). Groundwater contaminated with 1,4-dioxane flows westward from the northwestern corner and discharges to the drainageway which passes west of the Kentec buildings. Lower concentrations of 1,4-dioxane are found in surficial groundwaters north of the area. Groundwater contaminated with 1,4-dioxane, DCA, and DCE flows south and east from the northeastern corner, to the boundaries of the Kentec property.

There is a second, separate area of high 1,4-dioxane concentrations in surficial groundwater at the southern end of the main Kentec building; this contamination migrates south and west, discharging into the drainageway to the south.

GROUNDWATER COLLECTION SCREENING

Two primary options were evaluated for the removal of contaminated groundwater: interceptor trenches and extraction wells. Evaluation of extraction wells showed them not to be effective due to the thin saturated thickness of the surficial aquifer. With the saturated thickness of the surficial aquifer only 1 to 6 feet thick, the zone of influence of a single well would be extremely small. Calculations indicated that the zone of influence for a single extraction well may only be 0.5 feet. Extraction wells would, therefore, not meet the corrective action objectives of preventing further migration of contaminants within the source area.

The thin saturated thickness of the surficial aquifer and the depth of the silt layer (maximum depth 10 feet below grade) suggested that interceptor trenches would be effective. The trench could be keyed into the silt layer which would effectively intercept the entire thickness of the surficial aquifer. Construction of the interceptor trench would be straightforward and cost-effective due to the relatively shallow depth of the silt layer. Development of the interceptor trench option is presented in the following section.



LEGEND

- • SURFACE WATER MEASURING POINT
- (21.33) WATER LEVEL MEASURED
- ⊙ SHALLOW MONITORING WELL
- (26.65) WATER LEVEL MEASURED
- —26— EQUIPOTENTIAL LINE (IN FEET ABOVE MSL)
- ← APPROXIMATE DIRECTION OF GROUNDWATER FLOW

EQUIPOTENTIAL LINES ARE INTERPOLATED BETWEEN DATA POINTS.

0 75 150 225

SCALE: 1"=150'

NOTE: BASE MAP COMPILED FROM AERIAL PHOTOGRAPHY FLOWN ON 2/10/89.

Figure 2-2

POTENTIOMETRIC SURFACE IN SURFICIAL AQUIFER FEBRUARY 1, 1990 Du Pont Kentec Facility

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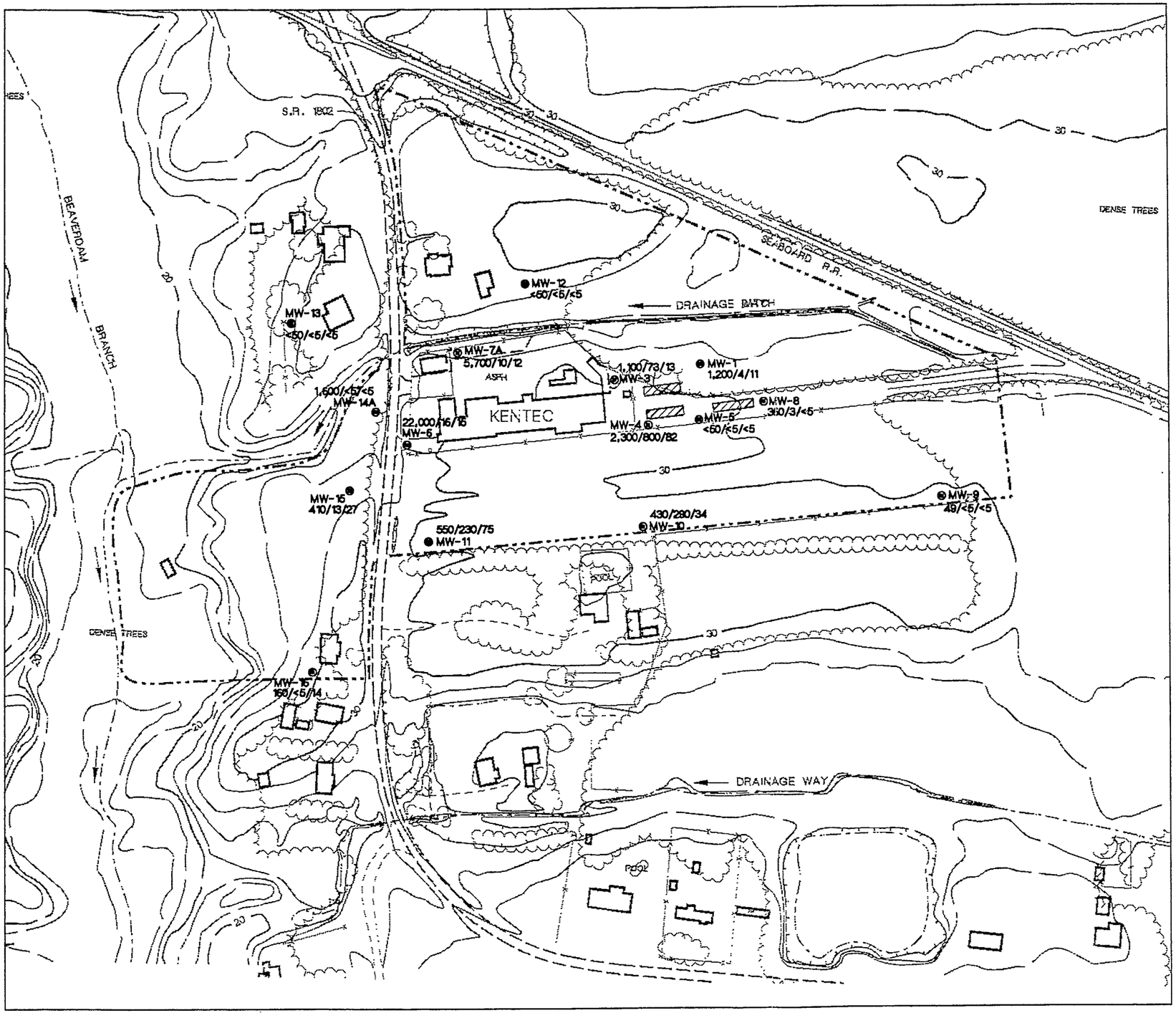

LEGEND

◉ MONITORING WELL

1,100/73/13 1,4-DIOXANE/1,1-DICHLOROETHANE/ 1,1-DICHLOROETHYLENE

CONCENTRATIONS IN ug/l

NOTE: BASE MAP COMPILED FROM AERIAL PHOTOGRAPHY FLOWN ON 2/10/89.

0 100 200 300

SCALE: 1"=200'

Figure 2-3

CONCENTRATIONS OF 1,4-DIOXANE, 1,1-DICHLOROETHANE & 1,1-DICHLOROETHYLENE IN SHALLOW GROUNDWATER JANUARY 1990

Du Pont Kentec Facility

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GROUNDWATER INTERCEPTOR TRENCH

The two primary objectives of the groundwater interceptor trench (GIT) are:

- To prevent contaminated groundwater from migrating beyond the source area
- To collect contaminated groundwater for treatment

The following sections present the conceptual design of the GIT and discuss the operational characteristics, including a summary of the groundwater modeling that was performed.

CONCEPTUAL DESIGN

Figure 2-4 is a diagram of a typical cross-section of the GIT. The GIT consists of three primary components: the perforated drainage pipe (drain line), the granular filter material, and backfill. The drain line is designed to channel contaminated groundwater to the collection sump from where it can be pumped to the treatment system. The granular filter material will serve as a high permeability zone increasing flow to the drainage pipe while filtering out soil particles from surrounding native soils. The backfill will be made up of excavated soil generated during construction of the GIT.

The GIT will be constructed along three sides of the facility as shown in Figure 2-5. In addition, a trench segment will be constructed along the southern border of the Kentec building. The total length of the GIT is approximately 2,500 feet. The southern trench will be located approximately 10 ft from the Kentec property line. This leg of the trench will intercept and prevent further offsite migration of contaminated groundwater as well as collect groundwater south of the property boundary. The western trench leg is situated along the facility side of State Road 1802. Because this is within the road right-of-way, a non-utility encroachment permit will be obtained. The northern leg of the trench will be located along the existing drainageway. This will be accomplished by backfilling the existing ditch and constructing a new drainageway to the north. This new drainageway will function as a groundwater divide, minimizing the collection and treatment of uncontaminated groundwater to the north and west of the GIT. The trench will be excavated through the surficial deposits at a minimum to the top of the silt layer.

It is estimated that the total depth of the GIT will range from 6 to 10 feet depending on the depth to the silt layer and the design grade of the drainage pipe. Soil borings along the length of the trench prior to construction will provide elevation data for the top of the silt layer. The GIT will be installed by licensed contractors with specialized installation equipment with oversite provided by Du Pont. A combination trencher, drainage pipe, and sand filter installation machine (continuous trencher) is the type of trench machine planned for use, and places the GIT at a specified depth without the

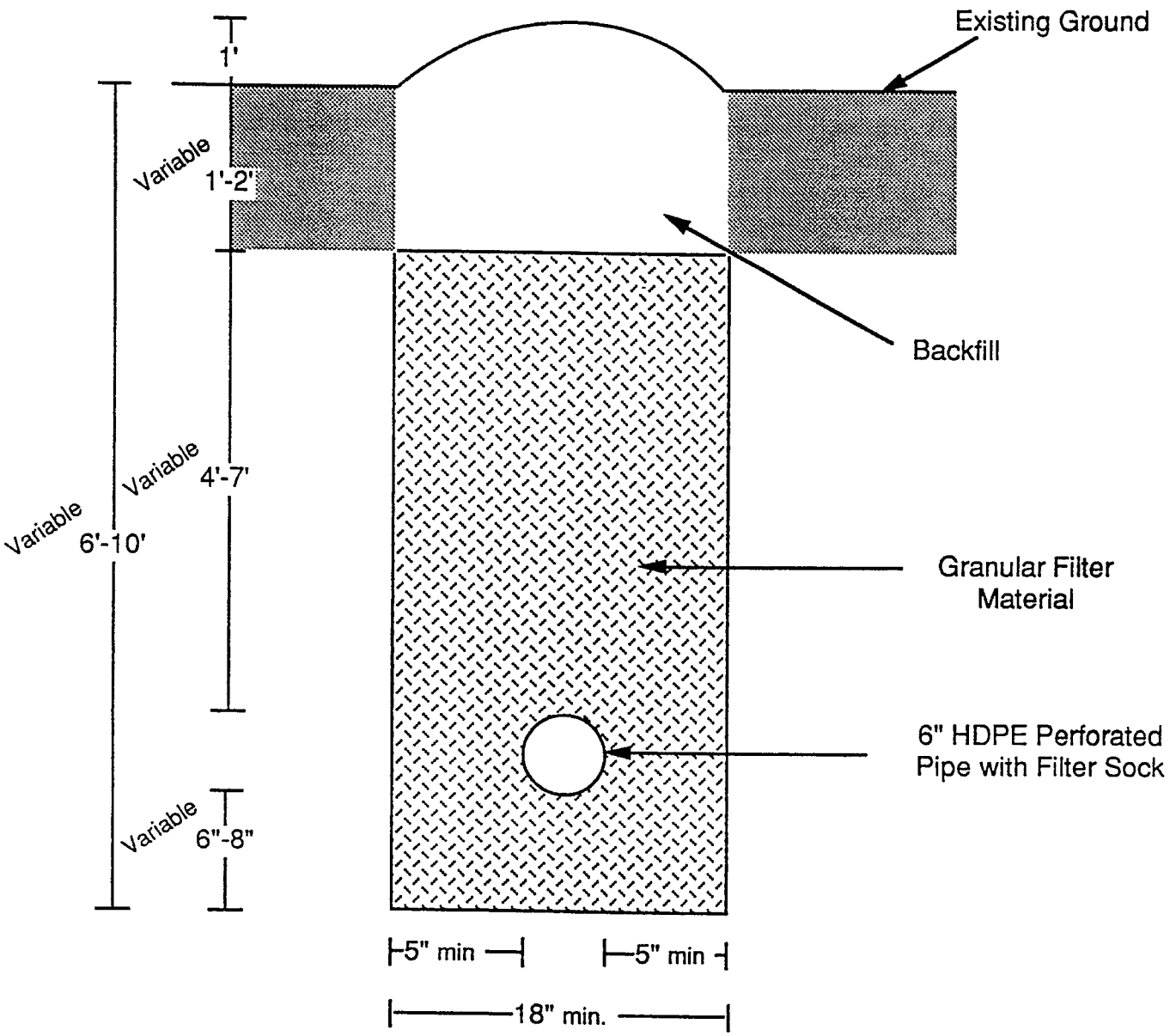
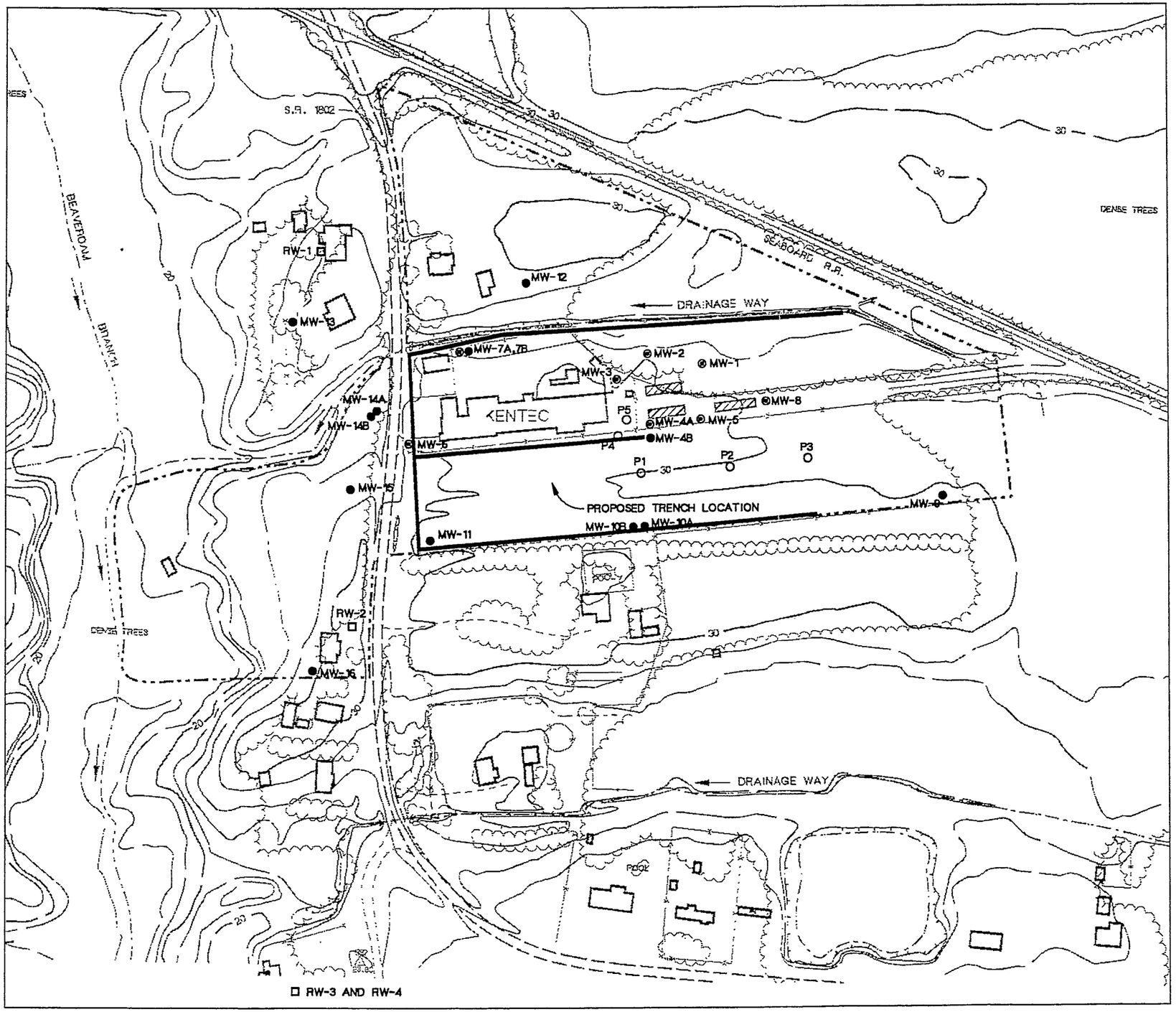


Figure 2-4
Typical Cross-Section of
Groundwater Interceptor Trench



LEGEND

- ⊙ PHASE 1 AND 2 MONITORING WELL
- ● PHASE 3 MONITORING WELL
- □ RESIDENTIAL WELL
- ○ PIEZOMETERS

NOTE: BASE MAP COMPILED FROM AERIAL PHOTOGRAPHY FLOWN ON 2/10/89.

0 100 200 300

SCALE: 1"=200'

Figure 2-5

LOCATION OF GROUNDWATER INTERCEPTOR TRENCH
Du Pont Kentec Facility

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need for shoring. Accurate control of the drain line slope during installation is often handled by a laser system that is part of the continuous trencher. This installation method will not require any workers to enter the trench during construction.

The GIT will include a total of five manholes and a total of three cleanouts (see Facility Layout in Appendix C). Manhole number 2 located at the southwest corner connecting the southern and western trenches will function as the primary sump where contaminated groundwater will be collected and pumped to the treatment system. The remaining four manholes and three cleanouts will provide access to the trench for maintenance purposes. Manhole 2 will contain two 5- to 30-gpm submersible pumps. Two pumps will provide the redundancy necessary to maintain water withdrawal from the groundwater collection should one of the pumps fail.

The sump pumps are recommended to be submersible mine or construction-type electric-driven centrifugal pumps of heavy duty construction suitable for continuous and intermittent on-off service. The pumps will be controlled by water level switches installed in the sump. Because organic vapors may exist in the sump, it is recommended that the pumps, level switches, and other electrical equipment within the sump be approved for installation in NEC Class I, Division I hazardous areas.

The drain line will be placed on a design grade at the silt layer such that the drain line will effectively intercept all groundwater flowing from the facility within the surficial aquifer. The drain line will be composed of perforated high density polyethylene (HDPE) drainage pipe, within the perforations sized to allow groundwater flow to enter the drainage pipe. A 6-inch diameter pipe will be sufficient to handle the anticipated flows at the given slope and will allow access for flushing the system. The pipe will be enveloped in a filter sock composed of geotextile filter fabric, which will minimize the entrance of the granular filter material into the drainage pipe. The drainage pipe will maintain a minimum slope of 0.12 percent (0.0012 ft/ft). Since the exact surface of the silt layer along the GIT is not known, the GIT may penetrate as much as 2 feet into the silt layer. Consequently, the drainage pipe will be installed with a minimum of six to eight inches of granular filter material beneath it. Soil borings drilled along the actual GIT line before design will provide data describing the existing grade of the silt layer surface along the trench.

The granular filter material will fill the majority of the GIT and surround the drainage pipe. The depth of the surface of the granular filter material will range from 1 to 2 feet below grade. The granular filter material will function as a high permeability zone increasing the flow of groundwater to the drainage pipe while filtering out soil particles from the surrounding native soils. The granular filter material commonly consists of a typical concrete sand. The optimum gradation will be determined using SCS design criteria as presented and modified in the Drainage Design and Management Proceedings of the Fifth National Drainage Symposium. Sieve analysis of the silt layer and surficial aquifer will be necessary to perform this analysis. Core

samples from borings drilled along the GIT line will be used to perform these sieve analyses.

The backfill material will consist of native soil excavated during the installation of the GIT. The function of the backfill layer is to minimize infiltration of surface water into the GIT. The backfill layer will be approximately two to three feet thick. The backfill layer will not be compacted so as not to compact the granular filter material below and decrease its permeability. Consequently, the backfill material will be mounded roughly one foot above grade (see Figure 2-1) to allow for settling.

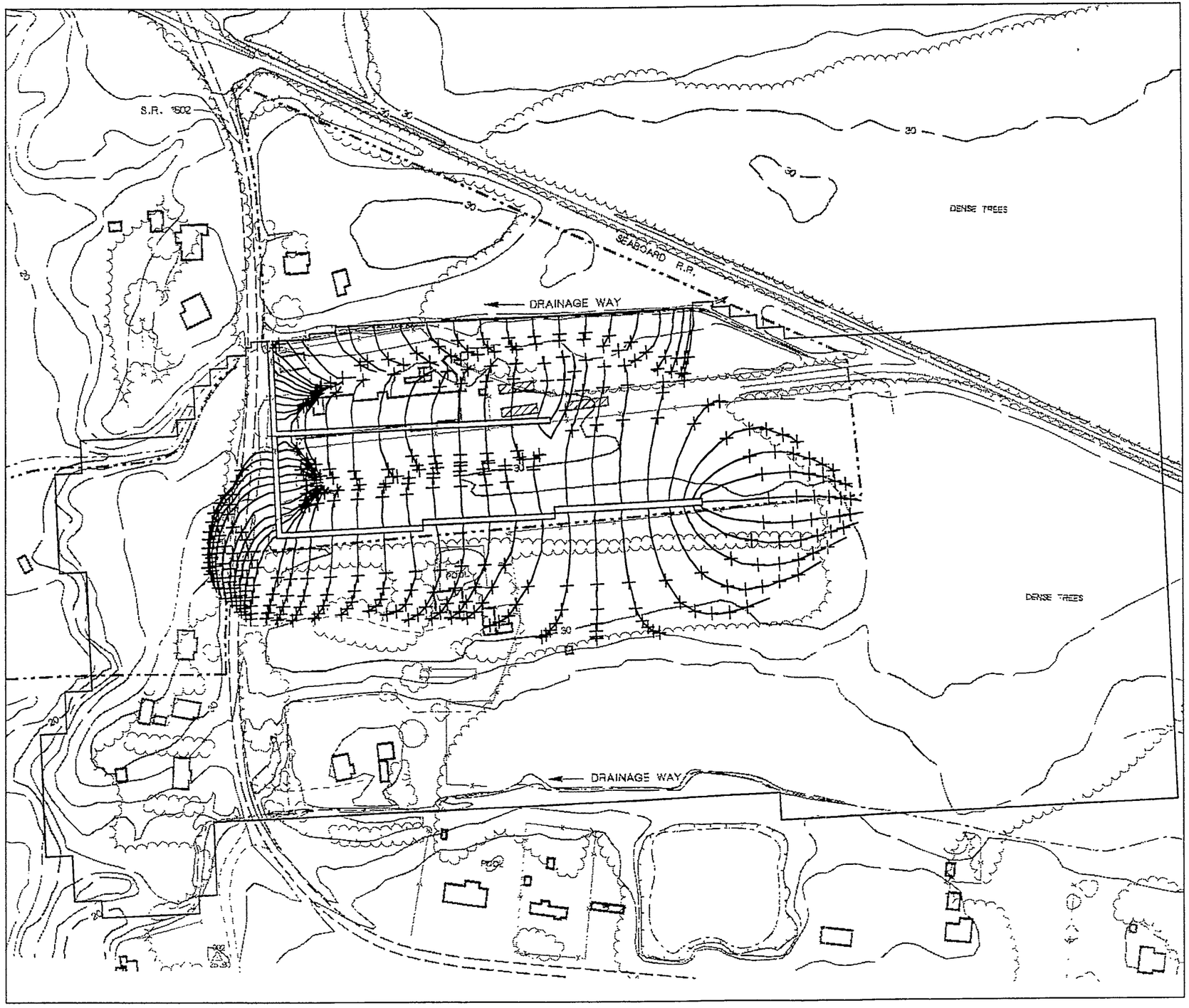
OPERATIONAL CHARACTERISTICS

Groundwater modeling was performed to assist in the selection of the most advantageous configuration of the GIT and to investigate its potential effectiveness. The major questions addressed by the model were:

- The appropriate trench location and length necessary to capture surficial groundwater within the source area.
- The extent to which groundwater outside the source area would be captured.
- The quantity of groundwater that the trench would be expected to produce.
- The approximate time required for contaminated groundwater to flow to the trench.
- The degree to which remediation could be enhanced by recharging treated groundwater to increase flow velocities.

A comprehensive discussion of the groundwater modeling is presented in Appendix A. Results of the modeling that relate to the operational characteristics of the trench are presented below.

As shown in Figure 2-5, the optimum GIT location is along the north, south, and west boundaries of the facility with an additional interior trench segment along the southern border of the facility building. Figure 2-6 shows the groundwater modeling results for this GIT configuration for wet season conditions. This simulation illustrates the effective area of the GIT. The south trench segment should capture shallow groundwater both within the site boundary as well as south of the facility boundary. The interior trench segment removes shallow groundwater from the interior of the facility, especially under the facility building. The crosses marked on the pathlines represent yearly travel times. Figure 2-6 indicates that the maximum travel time is slightly more



NOTE: BASE MAP COMPILED FROM AERIAL PHOTOGRAPHY FLOWN ON 2/10/89.

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SCALE: 1"=200'

Figure 2-6

GROUNDWATER MODELING OF COLLECTION TRENCH
Du Pont Kentec Facility

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than two years for particles within the source area, except at the open northwestern end of the site where it is 3 to 4 years.

Steady-state flow to the GIT was calculated for both the dry season and wet season conditions. The total steady-state flow to the GIT in the dry season is expected to be approximately 3,400 gallons per day (gpd). The expected flow under wet season conditions is expected to be approximately 6,000 gpd. Depending on the actual hydrogeological conditions, larger flows could be collected from the GIT. However, flow from the GIT will be regulated to a level that can be effectively treated.

Several scenarios were modeled that included recharge of the treated groundwater. It was originally thought that recharge would enhance groundwater capture from the GIT and reduce travel times. However, two characteristics of the site reduced the effectiveness of the GIT using recharge. First, the amount of treated water that could be recharged was limited by the geological and hydraulic properties at the site. Secondly, the modeling indicated that the most effective area for recharge was directly under the existing facility building and this was clearly not feasible. For these reasons, and the fact that the addition of the interior trench segment results in a capture zone encompassing the entire source area, recharge of treated groundwater is not recommended.

Clogging of the drainage pipe and granular filter material is an important maintenance issue. Because of the low flows, suspended solids in the collected groundwater will likely be deposited in the drain lines. In addition, the high iron content of the groundwater may present a problem. Iron bacteria, which feeds on the iron oxide precipitate (rust) can form iron okra, which is a fibrous material that may clog the drain lines and granular filter material. For these reasons the drain lines must be flushed routinely to maintain flow and the effectiveness of the GIT. The drain lines are typically flushed using jet-cleaning equipment to flush out the sediments and iron okra. Iron precipitate concentrations in the groundwater are anticipated to be highest at early stages of groundwater collection when the formation is dewatered in the vicinity of the trench. Also sediments tend to be deposited in drain lines as a result of construction. Consequently, it is recommended that the drain lines be flushed within the first thirty days following construction and for the first year and every 6 months thereafter. Long-term operation performance will best define the flushing frequency required to maintain flow in the drain lines.

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Section 3
GROUNDWATER TREATMENT

GROUNDWATER CHARACTERISTICS AND TREATMENT GOALS

The contaminants in the shallow groundwater at Kentec targeted for treatment include 1,4-dioxane, DCA, DCE, and iron. 1,4-Dioxane has been detected at levels ranging from less than the detection limit to 22,000 μg/l with an average concentration of approximately 2,500 μg/l. DCE has been detected at levels of less than the detection limit to 82 μg/l with concentrations averaging roughly 20 μg/l. DCA concentrations indicate a range from less than the detection limit to 800 μg/l with an average concentration of approximately 100 μg/l. Iron was detected in groundwater at concentrations ranging from 100 to 39,300 μg/l, averaging approximately 6,500 μg/l. Average contaminant concentrations were estimated by calculating a flow-weighted average of the data from the monitoring wells near the trenches for the most recent sampling event. Physical and chemical characteristics of these compounds are presented in Appendix B, Table B-1.

Groundwater from each of the GIT segments will be channeled to one common sump. The design will promote the mixing of the groundwater collected from all areas of the facility. For this reason, along with the high solubilities of the target compounds, the flow-weighted average concentration of the contaminants collected during the groundwater investigation should be representative of the actual concentrations entering the treatment system. However, some variability in the influent concentration is anticipated because of higher flows from certain areas or actual differences in groundwater contaminant concentrations. Table 3-1 presents the anticipated influent concentrations of the target compounds.

Table 3-1
TREATMENT SYSTEM INFLUENT AND EFFLUENT CONCENTRATIONS

Target Compound	Anticipated Average Influent Concentration (Flow = 6,000 gpd)	Required Effluent Concentration
1,4-Dioxane	2,500	150
1,1-Dichloroethane (DCA)	100	7
1,1-Dichloroethylene (DCE)	20	7
Iron (Fe)	6,500	500

Note: All concentrations given as μg/l (ppb).

Table 3-1 also includes required effluent concentrations for the target compounds along with influent and effluent concentrations for iron. The required effluent concentrations for the target compounds were discussed in Section 1. Iron is included because its presence may impact groundwater collection (discussed in Section 2) as well as groundwater treatment. Iron oxidizes to form an iron oxide precipitate (rust). This precipitate can impact the effectiveness of different treatment technologies (e.g., oxidation, biological treatment, carbon adsorption, etc.).

SUMMARY OF TREATMENT SCREENING

Five different treatment technologies were evaluated and screened for treatment of the contaminated groundwater at Kentec. The technology screening was based on the technology's anticipated effectiveness in attaining the required effluent concentrations for the target compounds. The technologies considered included carbon adsorption, air stripping, biological degradation, chemical oxidation, and reverse osmosis. These technologies were selected for screening based on their historical success treating organic contaminants in groundwater. Appendix B includes a discussion of the groundwater treatment screening performed at Kentec. Conclusions of the screening are presented below.

Of these five technologies, chemical oxidation appears to be the most applicable technology for remediating contaminated groundwater at Kentec. Although carbon adsorption and air stripping have been proven effective with DCE and DCA, due to the high solubility of 1,4-dioxane in water, along with its low vapor pressure, Henry's law constant and octanol/water partition coefficient, neither air stripping nor carbon adsorption alone appear to be viable alternatives for groundwater remediation at Kentec. Reverse osmosis may be a viable treatment alternative. However, if proven successful, the process would simply concentrate the contaminants into a lower volume of water still requiring treatment. Chemical oxidation and biological treatment both break down organic compounds, thus eliminating the need for further treatment. However, no information was identified in the technical literature that indicated biological treatment was effective for 1,4-dioxane. For these reasons, chemical oxidation was selected for further evaluation. A chemical oxidation treatability study treating groundwater collected from Kentec formed the basis of this evaluation.

CHEMICAL OXIDATION TREATABILITY STUDY

Chemical oxidation exploits oxidation-reduction or "redox" reactions in which the oxidation state of at least one reactant is raised while that of another is lowered by electron transfer from one ion to another. Through this process, hazardous constituents can be converted by oxidation to less toxic oxidation states. Some oxidations proceed readily to CO_2 and water. However, the reaction is dependent on oxidant dosage, pH, oxidation potential of the oxidant, and formation of stable

intermediates. Of the many oxidizing agents (oxidants) that exist, peroxide (H_2O_2), ultraviolet (UV) light, and ozone (O_3) were examined in this treatability study.

TREATABILITY STUDY DESIGN

CH2M HILL contracted Ultrox International to perform bench-scale chemical oxidation treatability tests using their ultraviolet oxidation systems. Ultraviolet oxidation is an enhanced oxidation process using UV light with O_3 and/or H_2O_2. Ultraviolet light, when combined with O_3 and/or H_2O_2, produces a highly oxidative environment significantly more destructive than that created with O_3 or H_2O_2 by themselves or in combination. UV light improves the reactivity of ozone or H_2O_2 by the following processes:

- Transformation of O_3 or H_2O_2 to highly reactive hydroxyl (OH) radicals
- Excitation of the target organic solute to a higher energy level
- Initial attack of the target organic solute by UV light

The treatability study was comprised of four different treatability test runs. The primary difference between each run was the oxidant, combination of oxidants, or concentration of oxidant(s) used. The oxidants used in each test run are listed below.

- Test Run 1--UV with 800 mg/l of H_2O_2
- Test Run 2--UV with 1,000 mg/l of H_2O_2
- Test Run 3--UV with 120 mg/l of H_2O_2 and 4 mg/l O_3/minute
- Test Run 4--UV with 180 mg/l of H_2O_2 and 6 mg/l O_3/minute

The bench scale treatability tests employed the following equipment and materials:

- A 2.4 liter cylindrical glass batch reactor
- A 40 watt ultraviolet radiation lamp
- Hydrogen peroxide (H_2O_2)
- Ozone and a 2 lb/day model 8341 Matheson Gas Products ozone generator

The reactor was sealed to minimize incidental releases of excess ozone and VOCs. The UV radiation was provided by one low pressure mercury arc lamp inside a quartz sheath placed in the center of the vessel. The 2 liters of groundwater charged into the reactor were stirred by a magnetic stirrer. Hydrogen peroxide was added before the ultraviolet radiation exposure using a source which is 30 percent hydrogen peroxide and 70 percent water. Ozone is generated with the ozone generator from a commercial oxygen source and is introduced as a ratio of oxygen and ozone using a coarse frit gas dispersion tub (sparger) at the bottom of the reactor.

For each test run, the glass reactor was charged with 2 liters of the filtered groundwater sample. The desired volume of 30 percent H_2O_2 solution was added and mixed for five minutes before introducing UV or ozone. A quartz sheath containing one 40 watt low pressure UV lamp was placed in the middle of the reactor and illuminated for the duration of the test run. For tests in which ozone is used (tests 3 and 4) the measured quantity of oxygen-ozone (O_2-O_3) gas mixture was introduced through the sparger at the predetermined O_2-O_3 flow rate. At the beginning of each working period the ozone output of the ozone generator was determined by titrating an acidified (H_2SO_4) potassium iodide (KI) solution with sodium thiosulfate solution to the starch end point. Samples of treated groundwater were collected at 20 minute intervals and analyzed for the target compounds, iron, total organic carbon (TOC), chemical oxygen demand (COD), and pH. The total retention time of each test run was 60 minutes.

SAMPLE COLLECTION

Groundwater samples were collected at Kentec on April 30, 1991. One 5-gallon groundwater sample was collected by Du Pont from MW4A and shipped overnight to the Ultrox facility in Santa Ana, California, in a cooler packed in ice. Ultrox shipped two 40 milliliter (ml) split samples taken from the groundwater samples to CH2M HILL's laboratory in Montgomery, Alabama, on May 7. The samples were contained in 40 ml VOC vials and received by CH2M HILL on May 9, 1991.

ANALYTICAL PROCEDURES

DCE and DCA concentrations were measured by gas liquid chromatography using EPA Method 601. A Perkin-Elmer 8500 Gas Chromatograph equipped with Tekman LSC-2 Liquid Sample Concentrator (purge and trap) and Model 1000 Hall Detector (electrolytic conductivity detector) was used. The following equipment was used for these analyses:

- GLC Column: 25' x 1/8" SS column packed with 20 percent OV-101 plus 0.1 percent 1500 ON
- 100/120 MESH CHROM WHP
- Syringe: 5 ml gas tight
- Volumetric Flasks: 10, 50, 100, 500, and 1,000 ml with ground glass stoppers
- Microsyringe: μg and 100 μl (Hamilton 701-N)
- Standards: Reagent grade chemicals
- Bottle: Glass with teflon lined screw-caps

1,4-Dioxane concentrations were determined using a Perkin-Elmer gas chromatograph with purge and trap and a flame Ionization Detector. Table 3-2 lists the analytical methods employed with the associated detection limits.

Table 3-2
ANALYTICAL METHODS AND DETECTION LIMITS

Compounds	Method	Detection Limit µg/l
1,4 Dioxane	G.C. w/F.I.D. with purge and trap	100
1,1-DCA	EPA 601	3.0
1,1-DCE	EPA 601	3.0
Iron	EPA 600 2361	500

Iron was analyzed in accordance with EPA method EPA-600 2361 and was performed by Core Laboratories in Anaheim, California.

TREATABILITY STUDY RESULTS

Table 3-3 presents the treatability study test results. The analytical data suggests that DCA is the most difficult compound to oxidize of the target compounds. The DCA clean up level of 7 µg/l was not attained in both runs 1 and 2. These runs did not include ozone as an oxidant. The use of ozone in addition to UV/H_2O_2 in test runs 3 and 4 reduced DCA levels well below the clean up level. This was accomplished with significant decreases in the H_2O_2 levels from those used in runs 1 and 2.

All test runs reduced DCE, 1,4-dioxane and iron concentrations below the required clean up levels. DCE and 1,4-dioxane clean up levels were attained after 40 minutes in all test runs. This may have been true with iron, however, no sample was collected and analyzed for iron at the 20 and 40 minute intervals.

The oxidation of the target compounds produces many by-products. Complete oxidation results in the production of carbon dioxide (CO_2). However, a number of intermediate compounds are formed during the oxidation of the target compounds. TOC data can be used as a surrogate parameter indicating the presence of intermediate compounds. It is anticipated that 1,4-dioxane will oxidize to form oxalic, formic, and glyoxylic acids and eventually CO_2. DCE is expected to oxidize quite rapidly to form CO_2. DCA will likely oxidize to acetic acid and oxalic acid. The acetic acid may then oxidize to formic acid. The oxalic acid and formic acid eventually oxidize to form CO_2. Analytical results show a 50 to 60 percent reduction in TOC.

Table 3-3
TREATABILITY TEST RESULTS

Test Run	Retention Time (min)	O_3 mg/l	H_2O_2 mg/l	COD mg/l	TOC mg/l	1,4-Dioxane ug/l	DCA ug/l	DCE ug/l	Total Iron mg/l	Comments
(1) UV/H_2O_2	0'	-	0	188	91	1,115	225	50	5.4	Filtered, pH adjusted to 7
	20'	-	400	-	-	-	116	<15	-	
	40'	-	800	-	-	<100	75	<5	-	
	60'		800	58	46	<100	20	<5	<0.5	
(2) UV/H_2O_2	0'	-	0	188	91	1,115	225	50	5.4	Filtered, pH adjusted to 7
	20'	-	500	-	-	-	116	<15	-	
	40'	-	1,000	-	-	<100	75	<5	-	
	60'	-	1,000	71	44	<100	20	<5	<0.5	
(3) $UV/O_3/H_2O_2$	0'	0	0	188	91	1,115	225	50	5.4	Filtered, pH adjusted to 7
	20'	80	120	-	-	-	50	<15	-	
	40'	160	120	-	-	<100	10	<5	-	
	60'	240	120	54	37	<100	<3	<3	<0.5	
(4) $UV/O_3/H_2O_2$	0'	0	0	188	91	1,115	225	50	5.4	Filtered, pH adjusted to 7
	20'	120	180	-	-	<100	46	<15	-	
	40'	240	180	-	-	<100	8	<5	-	
	60'	360	180	40	37	<100	<3	<3	<0.5	

Note:
" - " = Not analyzed

The remaining 40 to 50 percent of TOC is likely comprised of traces of the target compounds and mostly the intermediate compounds. The intermediate compounds are not regulated hazardous substances. The fact that the TOC is being reduced by 50 to 60 percent indicates that much of the target compounds are oxidizing to CO_2.

Iron removal is accomplished by the precipitation of iron oxide (rust). The iron is oxidized to form iron oxide. The iron oxide is not as soluble as the dissolved iron and subsequently precipitates out of solution.

The initial pH of the groundwater samples was 8.7 before each test run the pH was lowered to seven using concentrated sulfuric acid. This was done to enhance the oxidation process.

CONCLUSIONS

Results of the treatability study indicate that a $UV/O_3/H_2O_2$ treatment system can effectively reduce all of the target compounds to the required clean up levels. The UV/H_2O_2 system alone was unable to reduce DCA in the groundwater sample to the required clean up level. In addition to the treatability test results, the $UV/O_3/H_2O_2$ system offers three important advantages over the UV/H_2O_2 system. These include:

- Flexibility in treating variable flows
- Iron removal
- Cost

It is anticipated that some variability in the flowrate and the contaminant concentrations in the groundwater will occur. Treating the variability will require some flexibility in the treatment system. The use of ozone combined with low concentrations of H_2O_2 will allow for more flexibility than using high concentrations of H_2O_2 only. If necessary, either the O_3 or H_2O_2 concentrations can be increased or lowered with the $UV/O_3/H_2O_2$ system. Only the H_2O_2 can be increased or lowered if required with the UV/H_2O_2 system. In addition, increasing the H_2O_2 concentration is limited and less effective if the H_2O_2 concentration is already high.

Iron will be removed primarily by filtering the iron oxide precipitate from the groundwater before treatment. The iron oxide precipitate (rust) is generated by the oxidation of dissolved iron. Hence, oxidizing the water before filtering increases the formation of the precipitate and improves iron removal. However, if the iron is not removed prior to entering the treatment system iron oxide may deposit on the UV lamps decreasing their effectiveness and life expectancy. Therefore, O_3 can be added on-line and upstream of the filtration unit promoting iron oxide precipitation and iron removal. H_2O_2 would not be as effective as ozone with this on-line system since it is not as strong of an oxidant and would likely require a longer retention time. H_2O_2 would also have to be added as a solution, thus increasing the volume in the pressurized influent line. O_3 is added as a dissolved gas with a negligible increase in

volume. For these reasons, the $UV/O_3/H_2O_2$ system is more appropriate for iron removal than the UV/H_2O_2 system.

The total cost associated with employing the $UV/O_3/H_2O_2$ treatment system is anticipated to be less than the UV/H_2O_2 system. Although capital costs will be higher for the $UV/O_3/H_2O_2$ system, daily costs associated with the high concentration of H_2O_2 required for the UV/H_2O_2 system are more than twice those for the $UV/O_3/H_2O_2$ system. Since the treatment system is anticipated to operate for roughly five years, these higher daily costs will exceed the capital cost associated with the O_3 generator given the anticipated duration of the project.

Treatability study test results indicate that the $UV/O_3/H_2O_2$ system will effectively reduce DCA and DCE below the required clean up levels. However, the tests also indicate that DCA is not as readily oxidized as DCE and 1,4-Dioxane. A carbon adsorption unit will therefore be added to the treatment system for removal of any residual DCA and DCE.

The contaminated groundwater at Kentec will be treated with an ULTROX® F-325 UV/oxidation reactor with a 14 lb/day O_3 generator and H_2O_2 feed system. The treatment system will also be equipped with an in-line filtration module placed upstream of the UV/oxidation reactor with a slip stream of ozone injected ahead of the filter to assist in oxidation and removal of iron. Two polyethylene carbon unit containing 165 pounds of granular activated carbon (GAC) will be placed in series at the effluent end of the UV/oxidation reactor.

Based on the effectiveness achieved in the treatability studies, the maximum flow that can be treated by this system will be 7,500 gpd. A schematic of the chemical oxidation system is shown in Figure 3-1.

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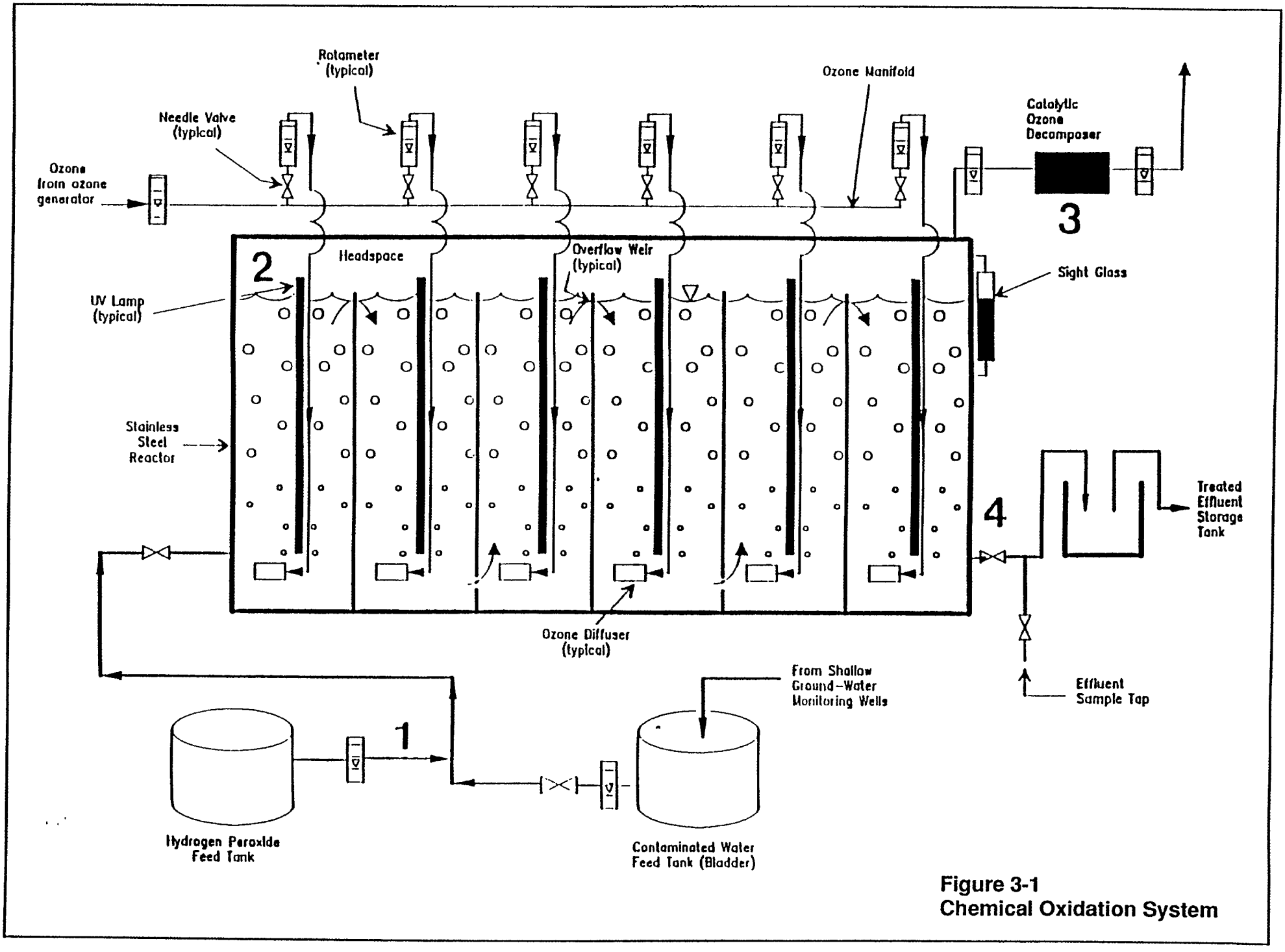

Figure 3-1
Chemical Oxidation System

Section 4
DISCHARGE OF TREATED GROUNDWATER

This section discusses the options that were considered for the discharge of treated groundwater. Several different options were considered and selected for use in combination. The rationale for this selection and the order of preference that will be used are also discussed.

The maximum flow of groundwater to be treated by the oxidation system is 7,500 gpd. As discussed previously, this is a conservative estimate and the actual flow coming from the GIT will likely be significantly less, especially in the drier seasons of the year. However, the treatment system and the discharge options have been developed to handle up to 7,500 gpd.

Five groundwater discharge options were considered:

- Reuse of the treated groundwater in the Kentec parts cleaning process.
- Use of the treated groundwater to recharge the surficial aquifer.
- Discharge to the existing drainageway (and ultimately Beaverdam Branch) through a NPDES permit.
- Transportation and discharge of the treated groundwater to the Kinston wastewater treatment plant or a POTW.
- Discharge to the existing drainageway under the terms of the SOC.

The following sections discuss each of these options.

REUSE OF TREATED GROUNDWATER

In this option the treated groundwater is piped to the Kentec process area and reused in the parts cleaning process. Water is used in the cleaning process to remove TEG and cool the parts prior to further processing. Du Pont process engineers have reviewed the characteristics of the treated groundwater and determined that it can be used in the cleaning process. Process water usage at the facility is currently about 2,000 gpd.

Reuse of the treated groundwater is the most preferred option. Kentec will continue to use county water for other purposes at the facility.

RECHARGE OF THE SURFICIAL AQUIFER

Use of the treated groundwater to recharge the surficial aquifer was considered as a means of enhancing groundwater flow and reducing the cleanup time. As discussed in Appendix A, recharge in several areas was considered and modeled. The two areas that appeared to offer the best opportunity for recharge were the existing drainfields and the area along the south side of the facility. The modeling indicated that recharge along the south side of the facility provided both positive and negative results. Groundwater and contaminant flow to the south trench would be greatly enhanced, but the time required for water to flow to the north leg of the trench would be increased. The reasons for this are discussed in Appendix A. It was determined however that recharge to the existing drainfields (drainfields A and B) would be beneficial. Recharge in this area would enhance the flow of the apparent groundwater mound that was shown in Figure 2-2.

However, model simulations of the interior trench segment without recharge indicated better effectiveness and shorter travel times. Therefore, recharge was not considered further as a discharge option.

DISCHARGE THROUGH NPDES PERMIT

It is likely, especially during the wet season, that water in excess of what can be reused will be generated. Discharge of this treated water to the drainageway that is to be constructed on the north side of the property is a straightforward method. This ditch flows to Beaverdam Branch. Considering the relatively low flows (between 2.5 and 5 gpm) and the target cleanup levels, no impacts to the stream are anticipated.

As discussed in the following section on facility layout and operation, Du Pont is planning to implement the corrective action at Kentec in the fall of 1991. It is unlikely that a NPDES permit can be obtained prior to this time. Therefore, procurement of a NPDES permit will be initiated, but another interim method must be included to handle the excess water before the NPDES permit is obtained.

TRANSPORT AND DISCHARGE TO KINSTON WWTP OR POTW

This option represents a viable and readily implementable method for the disposal of the treated water until a NPDES permit can be obtained. Water that cannot be reused would be collected in a tank truck or rail car and transported to the Kinston plant WWTP approximately 1.5 miles to the south. There the water could be discharged directly to the WWTP aeration basin. The 1,000 to 5,000 gpd that may require disposal in this fashion would have a negligible impact on the 2.5 million gpd WWTP. Du Pont will obtain a pump and haul permit for this activity, and if required, modification of their Kinston plan NPDES permit.

A variation of this option would be to pump and haul the treated water to either the Kinston or Greenville POTW.

DISCHARGE UNDER THE SOC

On an interim basis, the treated water can be discharged to the drainageway at Kentec under the terms of the SOC. When the time frame established in the SOC runs out, then other discharge options, such as the NPDES permit, will have to be used.

SUMMARY OF OPTIONS AND SELECTED APPROACH

Reuse is the most attractive option for the discharge of treated groundwater. Under this option the water is utilized rather than simply disposed. Because excess water will likely be generated during certain times of the year, a NPDES permit will be pursued to discharge this excess water to the onsite drainageway. In the interim, prior to obtaining the NPDES permit, excess water may be discharged to the drainageway under the terms of the SOC or may be transported and disposed of in the Kinston plant WWTP or POTW.

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Section 5
MONITORING PLAN

TREATMENT SYSTEM MONITORING

Monitoring of effluent from the treatment system is necessary to ensure the system is operating properly and that the target cleanup levels are met. Monitoring of the treatment system has been divided into a startup phase and full operation phase. During the startup phase, a specified volume of groundwater will be collected, treated, and analyzed prior to discharge. In this manner, effective operation of the treatment system can be obtained before groundwater is reused or discharged.

During full operation, effluent samples will be taken daily. The frequency of analysis will be dependent on the level of treatment obtained and the operational nature of the system. If the analysis shows that cleanup levels are being consistently achieved, samples will be analyzed on a less frequent basis. Conversely, after system disruption (e.g., changing of a UV lamp) samples may be analyzed on a daily basis.

The daily effectiveness of the treatment system will be monitored by analyzing effluent samples for DCA and DCE. These two compounds are more difficult to oxidize than 1,4-dioxane. Therefore, effective removal of 1,4-dioxane can be inferred if DCA and DCE are destroyed in the oxidation system. In addition, DCA and DCE can be analyzed with a gas chromatograph (GC) whereas 1,4-dioxane requires a GC and a mass spectrometer. Samples will be analyzed for 1,4-dioxane, DCA, DCE, and iron on a biweekly basis. Less frequent analysis may be required if the system is continuously meeting effluent requirements.

GROUNDWATER MONITORING

This section describes the shallow aquifer groundwater monitoring plan during and after remediation to evaluate the effectiveness of the groundwater collection system. Monitoring components contained within the plan include: 1) measuring water levels to determine the capture zone of the GIT, 2) collecting shallow aquifer groundwater samples and surface water samples from locations beyond the sources of contamination and the GIT, and 3) collecting shallow aquifer groundwater samples from locations between the sources of contamination and the GIT.

Primary elements of the groundwater monitoring plan include sampling locations, sample frequency, sample collection, and analytical protocol and quality control procedures.

SAMPLING LOCATIONS

Shallow aquifer groundwater sampling locations have been selected to provide monitoring points that will evaluate the progress of groundwater remediation. Groundwater samples will be collected from 14 locations (see Figure 5-1). All groundwater samples will be collected from existing monitoring wells and one new monitoring well (MW18). Descriptions of the monitoring well's construction are given in the Kentec Groundwater Assessment (CH2M HILL, 1991). Seven of the monitoring wells (MWs 1, 3, 4A, 6, 7A, 8, and 18) are between the contaminant source areas and the perimeter groundwater collection system. These wells will monitor the effectiveness of the groundwater cleanup within the contained area of the facility property. The remaining seven monitoring wells are located beyond the groundwater collection system (MWs 9, 10A, 11A, 12, 14A, 15, and 16). These wells will monitor the effectiveness of the groundwater collection system at limiting any further migration of contaminants beyond the property boundary. They will also evaluate the effectiveness of reclaiming any contaminated groundwater that has moved beyond the southern property boundary.

In addition, 1 sample will be collected from the trench at the time of groundwater sampling to correlate with contaminant concentration measurements currently being collected for treatment. Two surface water samples (SW11 and SW24) will be collected and analyzed during each round of sampling (see Figure 5-1). The five 50-foot deep monitoring wells (4B, 7B, 10B, 11B, and 14B) that monitor the upper portion of the Peedee aquifer should also be sampled.

SAMPLING FREQUENCY

Prior to the start up of the groundwater collection system, one round of samples will be collected and analyzed from all of the monitoring locations. For the first year of operation of the groundwater remediation system a round of samples will be collected and analyzed from all of the monitoring locations every 3 months. After the first year of remediation, it is anticipated that the frequency of groundwater sample collection will be reduced, possibly to a semi-annual basis until the end of remediation. The end of remediation will be when the concentrations of the target compounds are at or below the actions discussed previously within the collection trench and the seven interior monitoring wells or an asymptotic level is reached that has been agreed upon by the state.

At the conclusion of remediation, groundwater samples will be collected and analyzed from all of the monitoring locations on an annual basis for 3 years for post-remediation monitoring.

SAMPLE COLLECTION

Sample collection procedures are discussed in three steps: water-level measurement, purging, and sample collection.

Water-Level Measurements

Prior to each round of sampling, water levels should be measured in all existing monitoring wells, piezometers onsite, and at surface water bench masks as indicated on Figure 5-1. All water levels should be measured to the nearest 0.01 foot. Groundwater levels should be measured to the top of the protective steel casing.

Purging

Standing water should be purged from the groundwater monitoring wells, allowing formation water representative of in-situ conditions to flow into the well for sampling. A dedicated, positive displacement bladder pump will be installed in each of the monitoring wells 6 inches from bottom. The bladder pumps will have a stainless steel and PVC body with a Teflon bladder. These pumps will be used to purge the standing water from the wells. Purging procedures vary depending on the yield of the well. A high yielding well recharges rapidly enough to be purged continuously until it is sampled. A low yielding well is purged until the well is dry; the water level is then allowed to recover sufficiently so that an adequate volume of water for sampling reenters the well.

Measure the following field parameters after each well volume of purge water or after the well has recharged from being pumped dry: pH, specific conductivity, and temperature. Continue purging until the conductivity, temperature, and pH values vary by less than ±10 percent for three consecutive well volumes, or until the well is purged dry.

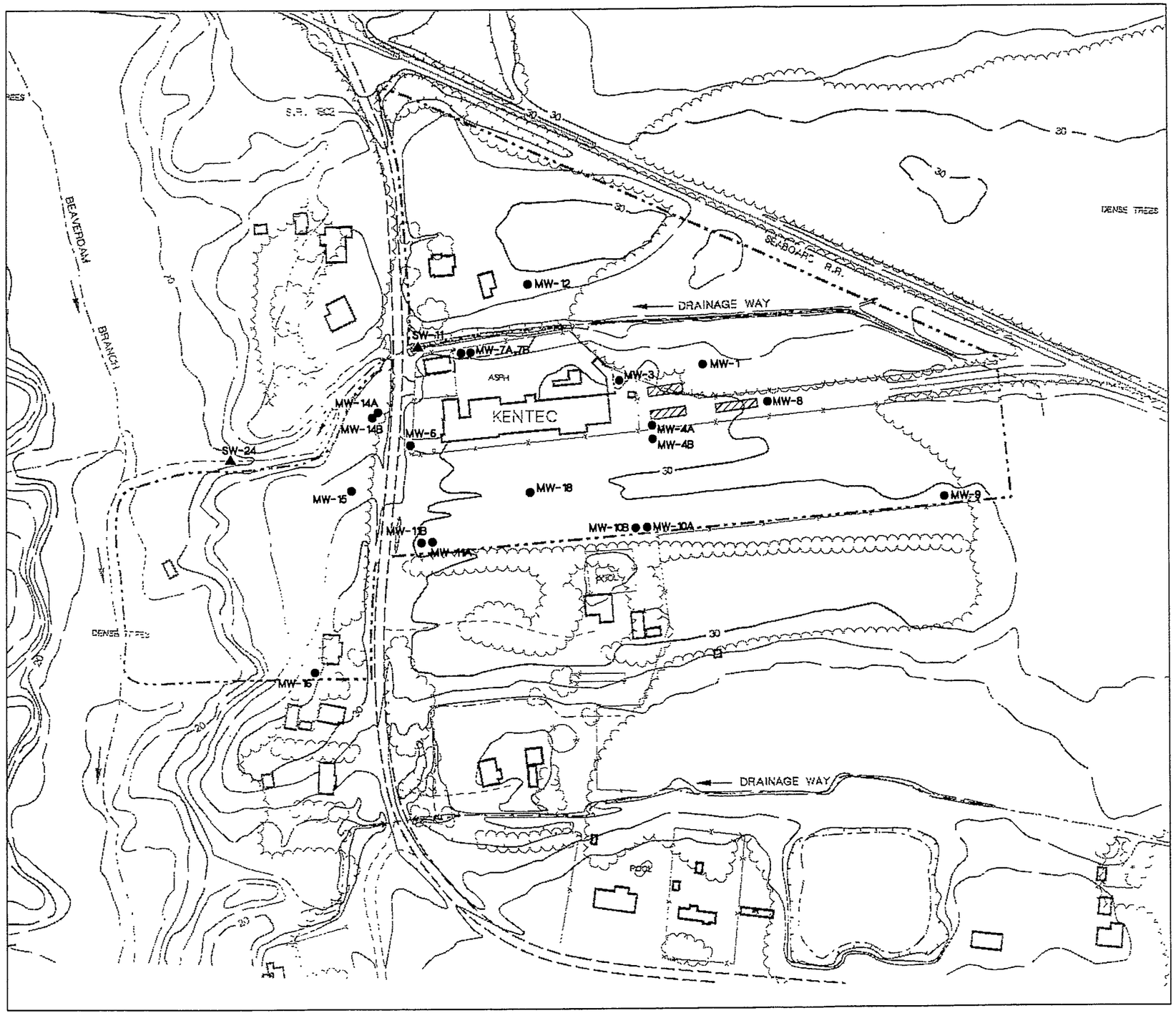
Sample Collection

When the purging has been completed or the monitoring well pumped dry and then allowed to recover to near static conditions, a groundwater sample will be collected from the bladder pump through the tubing and directly into the appropriate sample containers.

Surface water and trench water samples will be collected and transferred directly into the sample containers.

ANALYTICAL PROTOCOL AND QUALITY CONTROL PROCEDURES

All groundwater, surface water and water samples from the trench will be analyzed for the target compounds (1,4-dioxane, DCE, and DCA) at the action levels discussed previously. 1,4-Dioxane will be analyzed using EPA method 8015 and DCE and DCA will be analyzed using EPA method 601.



LEGEND

- ● MONITORING WELL
  'A'- MONITORING WELLS ARE IN THE SHALLOW AQUIFER
  'B'- MONITORING WELLS ARE IN THE PEEDEE AQUIFER
- ▲ SURFACE WATER MONITORING POINT

NOTE: BASE MAP COMPILED FROM AERIAL PHOTOGRAPHY FLOWN ON 2/10/89.

0 100 200 300

SCALE: 1"=200'

Figure 5-1

COLLECTION TRENCH MONITORING SYSTEM
Du Pont Kentec Facility

CH2M HILL

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Two duplicate samples will be collected and analyzed to provide a check on the quality of the laboratory analyses. Any equipment that is reused at each well for groundwater sampling will be cleaned to limit the possibility of cross-contamination between samples.

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Section 6
PERMITS AND SCHEDULE

This section identifies the permits that will be required for the corrective action and summarizes the proposed preparation and implementation schedule.

PERMITS

Several permits were referred to in the previous sections, Table 6-1 summarizes these permits and what they address.

Table 6-1
REQUIRED PERMITS

Permit	Purpose
Wetlands Construction Permit	Required to backfill existing ditch and construct new drainage ditch.
Non-Utility Encroachment Permit	Required to construct trench along State Road 1802 right-of-way.
Septic Field Permit	Required to re-locate existing sanitary septic field.
Air Permit	Required for chemical oxidation system ozone destruction unit.
Pump and Haul Permit	Required to transport treated groundwater to Kinston WWTP.
Kentec NPDES Permit	Required to discharge treated groundwater to drainage ditch.
Modifications of Kinston WWTP NPDES Permit	May be required to accept treated groundwater from Kentec.

SCHEDULE

Table 6-2 summarizes the tentative construction schedule for the Kentec corrective action. One of Du Pont's primary objectives is the timely implementation of the corrective action. The schedule is contingent, however, on several factors, including the timely review and response by the state and the availability of contractors and equipment.

Table 6-2 CONSTRUCTION SCHEDULE	
Action	**Date**
State Approval of CAP	July 26, 1991
Du Pont Issues Bids for Construction	September 27, 1991
Du Pont Selects Contractors	October 28, 1991
Permits Obtained	October 30, 1991
Construction Initiated	November 4, 1991
Construction Complete	November 22, 1991
Startup Complete	November 29, 1991
Full-Scale Operation	December 2, 1991

WDCR556/040.51

Appendix A
GROUNDWATER FLOW MODELING

Appendix A
GROUNDWATER FLOW MODELING

MODELING OBJECTIVES

A numerical groundwater flow model was used as an analytical tool to help select the most advantageous configuration of the proposed groundwater recovery trench and to investigate its potential effectiveness. The major questions addressed by the model were:

- The location of the trench and the length necessary to capture all source area contamination
- The extent to which offsite contaminated groundwater would be captured
- The quantity of groundwater, requiring treatment, that the trench could be expected to produce
- The approximate time required for contaminated groundwater from all parts of the site to flow to the trench
- The degree to which the remediation could be speeded up by reinjecting treated groundwater to increase flow velocities

Numerical modeling was chosen as the appropriate analytical tool for this task because it has the capability to represent multi-dimensional flow in a heterogeneous system with less conceptual idealization than would be required by any other analytical technique. However, it was recognized from the outset that there will always be some uncertainty in the hydrogeologic understanding of the site, and that the modeling analysis can only give approximate answers to the questions listed above.

This appendix gives a summary of the numerical modeling procedures and the results as they pertain to the above-listed objectives. More detailed description of the model setup, calibrator, and sensitivity analysis is provided in a technical memorandum on the development and application of the groundwater model.

SITE CONCEPTUAL MODEL

The first step in the analytical process is to select the essential features of the problem that must be considered and to determine how they can best be represented in the analysis. This selection process produces a conceptual model of the site, which then forms the framework for setup of the numerical model.

The essential features of the Kentec site include the unconfined surficial aquifer, the underlying clayey silt layer, and the semi-confined Peedee aquifer below the silt. Groundwater remediation efforts will be limited to the surficial aquifer. However, because the silt layer is not completely impermeable, it was considered necessary to include it and the underlying Peedee aquifer in the model. Consequently, a quasi-three-dimensional model setup was used in which horizontal flow in the surficial and Peedee aquifers and vertical flow in the semi-confining silt layer were represented.

NUMERICAL MODEL SETUP

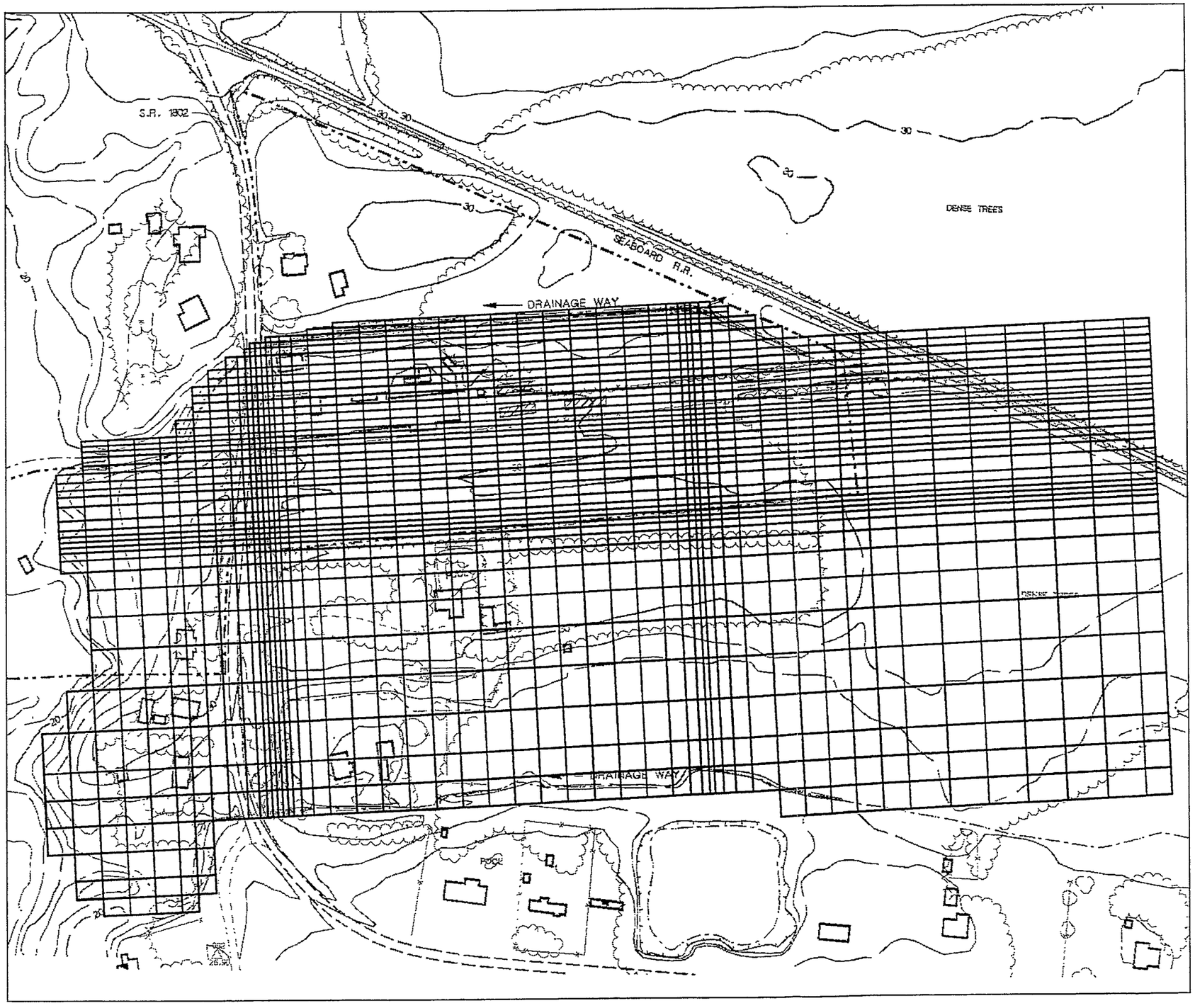
Code Selection

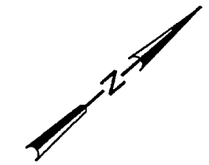
The primary computer code used in the numerical modeling was the modular three-dimensional finite-difference groundwater flow code, MODFLOW (McDonald and Harbaugh, 1988). This program is capable of simulating transient and steady-state flow in combinations of confined, unconfined, and semi-confined aquifers with a variety of boundary conditions and hydrologic stresses. This code has been in widespread use in the hydrogeologic profession since it was first introduced by the U.S Geological Survey in 1984. It has been thoroughly peer reviewed, and is considered highly reliable as a numerical solver of the basic equations of saturated flow in porous media.

Also used in the modeling was a particle tracking code called MODPATH (Pollock, 1989), which computes and displays pathlines in the groundwater flow fields produced by MODFLOW simulations. MODPATH has not been as widely used a MODFLOW because it is a newer program, but it has been peer reviewed by the U. S. Geological Survey and is considered a reliable post-processor for MODFLOW simulations. It produces three-dimensional pathline trajectories, but is limited to use in steady-state flows.

Grid Delineation and Boundary Conditions

The MODFLOW groundwater model was set up as a two layer model using the computational grid shown in Figure A-1. The upper model layer represents the unconfined surficial aquifer, and the lower layer represents the Peedee aquifer. The semi-confining silt unit was not assigned a separate layer, but is represented through the vertical conductance properties of the upper layer. This is a convention used in quasi-three-dimensional applications of the MODFLOW code, which permits economical representation of multiple aquifers separated by semi-confining units. It corresponds to the assumption that flow in the aquifers is predominantly horizontal, while flow between them is vertical. For the present application, this is thought to be a good assumption.





NOTE: BASE MAP COMPILED FROM AERIAL PHOTOGRAPHY FLOWN ON 2/10/89.

0 100 200 300

SCALE: 1"=200'

Figure A-1

DELINEATION OF THE COMPUTATIONAL GRID
Du Pont Kentec Facility

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The grid consists of 52 columns and 34 rows of rectangular cells. The cell dimensions range 10 to 75 feet, with the smaller cells in the areas where the proposed recovery trench is to be located. The edge of the grid on the northwest side corresponds to the location of the existing drainage ditch adjacent to the Kentec plant. The southeast side of the grid is also located along a drainage feature; and to the southwest, the grid borders on the floodplain of Beaverdam Branch. Along these three sides, the groundwater elevations are assumed to be controlled by the surface drainage features. Therefore, fixed-head boundary conditions were used on these edges of the grid in the top model layer. The northeast edge of the grid does not correspond to a surface drainage feature. However, it is approximately aligned with an inferred groundwater streamline, based on regional topographic trends. Consequently, no-flow boundary conditions were used along this edge in the upper model layer.

For the lower model layer, representing the Peedee aquifer, fixed-head boundary conditions were used around all edges of the grid. The potentiometric head values assigned to these boundary cells were selected to produce a uniform flow across the site as measured by the deep monitoring wells MW-4B, MW-7B, and MW14B. For simulation of wet season conditions, the potentiometric surface measurements taken in the Spring of 1990 were used to set the Peedee aquifer boundary conditions. For dry season simulations the boundary heads were based on measurements taken in the late Summer of 1990. The dry season water levels were approximately 2 feet lower than the wet season levels, but the direction and velocity of the flow were nearly the same. The difference in Peedee aquifer heads between the two seasons was found, during model calibration, to affect the flows in the surficial aquifer in approximately the same way as a 1/2 inch-per-year change in recharge.

Initial Parameter Selection

The aquifer parameters used in the initial setup of the model were based on the best available estimates derived from field measurements. The necessary parameters were the hydraulic conductivity and bottom elevation of the surficial aquifer, the vertical conductance (hydraulic conductivity divided by thickness) of the semi-confining silt layer, the transmissivity of the Peedee aquifer, and the net recharge rate due to the infiltration of precipitation at the ground surface. The specification of these parameters, along with the boundary conditions described above, is sufficient to support a steady-state run of the model.

The bottom elevation of the surficial aquifer corresponds to the top of the semi-confining silt layer. It varies somewhat across the site, as indicated by the boring logs for the monitoring wells and piezometers that have been installed. A structure map of the top of the silt, produced by contouring the measured elevation values, was used to define the bottom of the surficial aquifer in the model input. This description of the bottom elevation was based on direct field measurement and was, therefore, not altered during model calibration.

The hydraulic conductivity of the surficial aquifer was estimated from the results of in-situ hydraulic conductivity tests performed in eight of the shallow monitoring wells. The geometric mean of the hydraulic conductivity values measured in these eight tests was approximately 4 feet per day. On the basis of the field tests, this was considered the best estimate for a single hydraulic conductivity value to be assigned uniformly across the top layer of the model. It was expected that in the calibration stage of the modeling process a non-uniform distribution of hydraulic conductivity would be arrived at through iterative adjustment of the model.

The capacity of the semi-confining silt layer to transmit water between the upper and lower aquifers is represented in the model by the vertical conductance of the silt. This is defined as the vertical component of hydraulic conductivity in the silt divided by the thickness of the layer. The boring logs of the monitoring wells that penetrate the silt layer indicate that it is generally about 20 feet thick. The vertical component of hydraulic conductivity was estimated from laboratory test run on 3 Shelby tube samples taken from the silt layer. The results of the three tests were 0.1 feet per day for the samples from wells MW-4B and MW-7B, and 0.0009 feet per day for the sample taken from well MW-14B. Consideration of the physical characteristics of the silt samples suggested that its hydraulic conductivity should be less than 0.1 feet per day. Furthermore, the potentiometric head difference between the upper and lower aquifers is normally about 5 feet. If the hydraulic conductivity of the silt layer were as high as 0.1 feet per day, a net recharge rate of more than 100 inches per year would be necessary to maintain this head difference. Therefore, it was decided that the two high test values were not representative of the majority of the silt layer, and a lower value of 0.001 feet per day, which approximates the third test result, was used.

The transmissivity of the Peedee aquifer was estimated as the product of the average hydraulic conductivity values measured in the deep monitoring wells and the estimated thickness of the aquifer. The geometric mean of the hydraulic conductivity values measured in deep monitoring wells MW-4B, MW-7B, and MW-14B is approximately 20 feet per day. The thickness of the aquifer at the Kentec site has not been measured, but it is thought to be at least 60 feet thick. The estimated transmissivity used in the model was 1,200 square feet per day. It should be pointed out that the value used for transmissivity in the lower aquifer has very little influence on the model results because the head distribution in this layer is almost entirely determined by the boundary conditions.

The final parameter needed for the initial model run was the net recharge to the unconfined aquifer. It has been estimated on a regional basis that recharge to the surficial aquifer is approximately 20 percent of the total annual precipitation. The average annual precipitation is 45.9 inches per year, of which approximately 9 inches would then recharge the aquifer. This was the estimated recharge used in the initial setup of the model.

The simulations produced by the model with these initial parameter estimates were not realistic and served only as the starting point for model calibration.

CALIBRATION AND SENSITIVITY ANALYSIS

Calibration

Model calibration is an interactive process in which certain model parameters are adjusted to produce simulations that closely match observed groundwater flow conditions. Usually, the parameters adjusted are those that have not been accurately measured in the field and that have a strong influence on the simulation results.

The primary calibration parameters in the Kentec modeling were the hydraulic conductivity and the net recharge of the surficial aquifer. The surficial aquifer hydraulic conductivity was measured by running slug tests in several of the shallow monitoring wells. However, the slug test results varied considerably from one part of the site to another, and the results are considered valid only for the immediate vicinity of each tested well. The calibration process was used to develop a non-uniform distribution of hydraulic conductivity that corresponded approximately to the slug test values at the individual wells, and produced a close match between simulated and measured water levels across the site. Adjustment of net recharge was necessary because no direct measurements of infiltration at the site have been made.

The calibration process requires that an appropriate set of water level measurements be available to serve as a target for adjustment of the model. Several rounds of water level measurements were conducted at the site, and significant variations in water level between wet and dry seasons were observed. Therefore, two calibration targets were selected. For dry season simulations the round of water level measurements conducted on November 15, 1990 was used. For wet season simulations the calibration target was the round of measurements made on February 1, 1990.

The adjustment of hydraulic conductivity and recharge in the surficial aquifer was done in a series of steady-state model runs for both dry season and wet season conditions. The goal was to achieve a pair of runs, one for the dry season and one for the wet season, that closely matched both of the calibration targets. Both runs would use the same hydraulic conductivity distribution. The only differences between the two runs of the pair should be the boundary conditions applied in the lower aquifer and the recharge rate applied to the upper aquifer.

The result of this process was a model in which the hydraulic conductivity of the surficial aquifer was divided into zones with three different values of hydraulic conductivity. The values selected were 1, 3, and 10 feet per day. Generally, the lower hydraulic conductivities were used along part of the drainage way on the northwest edge of the grid and in the area adjacent to Beaverdam Branch. The higher hydraulic conductivity value was assigned in most of the northern and eastern area of the surficial

aquifer. The intermediate value of 3 feet per day was used in the western grid area including the central portion of the Du Pont property and the area directly south of the site. The delineation of hydraulic conductivity zones was developed primarily through model adjustment, but the distribution of values is compatible with the slug test results.

The recharge rate used for the dry season calibration was 4 inches per year. For the wet season calibration the recharge rate was 6.5 inches per year.

Table 1 presents a summary of the calibration error analysis for these calibration runs. The calibration error is calculated by subtracting the water levels measured in monitoring wells in the surficial aquifer from the simulated water levels at the corresponding points in the top layer of the computational grid. The summary shows that the simulated water levels were generally within 0.3 feet of the measurements for the dry season and within 0.5 feet for the wet season.

Sensitivity Analysis

Sensitivity analysis is frequently used to study the sensitivity of model results to changes in input parameters. This is done, even though the model is well calibrated, because it is recognized that the calibration may not be unique. There may be more than one combination of parameters that produce equally good agreement between simulation results and field measurements. The normal procedure for sensitivity analysis is to vary individual input parameters, such as recharge rate or hydraulic conductivity, and observe the amount of resulting variation in simulation results. The resulting information on model sensitivity may be used as a guide for additional data collection or to help quantify the degree of uncertainty associated with the model results.

For the Kentec model, the model parameters with the greatest degree of uncertainty are the vertical conductance of the silt layer, the hydraulic conductivity distribution in the surficial aquifer, and the recharge rate. It was found through sensitivity analysis that doubling the vertical conductance of the silt layer lowers the simulated water table near the center of the site by approximately 0.6 feet. This is approximately the same effect that is caused by decreasing the simulated recharge rate by 1 inch per year. It was also found that, if the vertical conductance were doubled, it was possible to compensate by increasing the recharge rate by 1 inch per year without significantly degrading the calibration. This means that it is difficult to accurately determine either the recharge rate or the vertical conductance of the silt layer through model calibration. The primary effect of inaccurate estimation of vertical conductance will be faulty simulation of the rate of vertical flow through the silt. Poor calibration with respect to water levels in the surficial aquifer probably would not be obvious unless the estimated vertical conductance were wrong by an order of magnitude or more.

Sensitivity analysis was also used to study the effects of a general increase in the hydraulic conductivity of the surficial aquifer. It was found that doubling the hydraulic

Table 1
SUMMARY OF CALIBRATION ERROR
(Water Levels in Feet)

Well	Dry Season Water Level			Wet Season Water Level		
	Simulated	Measured[1]	Error	Simulated	Measured[2]	Error
MW-1	25.44	25.33	0.11	26.70	26.97	-0.27
MW-2	25.21	25.41	-0.20	26.42	26.90	-0.48
MW-3	25.33	-	-	26.62	26.90	-0.28
MW-4	25.67	25.5	0.17	27.11	27.08	0.03
MW-5	25.56	25.4	0.16	26.91	27.07	-0.16
MW-6	23.79	23.76	0.03	24.86	24.48	0.38
MW-7	22.88	23.58	-0.70	23.58	24.09	-0.51
MW-8	25.34	25.10	0.24	26.54	26.84	-0.30
MW-9	24.92	24.69	0.23	26.03	26.65	-0.62
MW-10	25.41	25.33	0.08	26.84	26.81	0.03
MW-11	24.82	25.36	-0.54	26.31	26.20	0.11
MW-14	22.63	22.23	0.40	23.38	22.40	0.98
MW-15	23.53	23.60	-0.07	24.75	24.05	0.70
MW-16	23.95	-	-	25.37	25.37	0.00
	Mean Error = -0.01 feet Mean Square Error = 0.10 ft^2 Root Mean Square Error = 0.31 feet			Mean Error = -0.03 feet Mean Square Error = 0.20 ft^2 Root Mean Square Error = 0.44 feet		

[1]Water levels measured on November 15, 1990
[2]Water levels measured on February 1, 1990

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conductivity specified for every cell in the top layer resulted in a decrease in the simulated water table of up to 1 foot near the center of the site. Again, this effect could be partially compensated for by increasing the recharge rate, but the quality of the compensated simulation was not as good as in the case of increased vertical conductance.

These sensitivity runs suggested that it might be possible to get reasonably good calibrations with higher values of both hydraulic conductivity and recharge rate than those used in the base calibration. It was recognized that the hydraulic conductivity distribution used in the original calibration was based on field measurements. However, these measurements could conceivably be wrong by as much as a factor of two. Therefore, it was decided to develop an alternative calibration with higher hydraulic conductivities than those measured in the field as a form of extended sensitivity analysis. Runs with both calibrations would then be carried through the predictive simulations to provide a quantitative estimate of the effects of parameter uncertainty. The original calibration would be considered to give the most likely predictions, and the alternative calibration would represent the likely upper bound of uncertainty.

After repeated iterative adjustment of the model, an alternative hydraulic conductivity distribution for the surficial aquifer with values of 1.5, 6, and 15 feet per day was developed. These hydraulic conductivities were used with a recharge rate of 5.5 inches per year for the dry season and 10 inches per year for the wet season. Table 2 gives a summary of the calibration error for this alternative calibration. The table shows that the quality of the alternative calibration was about the same as for the original calibration.

BASIC RECOVERY TRENCH ANALYSIS

Basic Trench Configuration

The recovery trench that has been proposed for the Kentec site is intended to prevent further offsite migration of contaminated groundwater in the surficial aquifer and to remove the contaminated groundwater that presently exists onsite as rapidly as practical. To achieve these goals, the basic trench configuration shown in Figure A-2 was initially selected.

On the northwest side of the property, the trench is situated adjacent to the existing drainage ditch. This will prevent the flow of contaminated groundwater into the ditch. In turn, the drainage ditch will intercept the flow of clean groundwater from offsite, which would otherwise be collected by the recovery trench, and which would unnecessarily burden the groundwater treatment system. Along State Road 1802, on the southwest side of the plant area, the trench will intercept the flow of contaminated

Table 2
SUMMARY OF CALIBRATION ERROR FOR THE ALTERNATIVE CALIBRATION
(Water Levels in Feet)

Well	Dry Season Water Level			Wet Season Water Level		
	Simulated	Measured[1]	Error	Simulated	Measured[2]	Error
MW-1	25.39	25.33	0.06	26.78	26.97	-0.19
MW-2	25.17	25.41	-0.24	26.52	26.90	=0.38
MW-3	25.23	-	-	26.63	26.90	-0.27
MW-4	25.55	25.50	0.05	27.12	27.08	0.04
MW-5	25.50	25.40	0.10	27.00	27.07	-0.07
MW-6	23.70	23.76	-0.06	24.85	24.48	0.37
MW-7	22.74	23.58	-0.84	23.45	24.09	-0.64
MW-8	25.31	25.10	0.21	26.64	26.84	-0.20
MW-9	24.92	24.69	0.23	26.16	26.65	-0.49
MW-10	25.35	25.33	0.02	26.92	26.81	0.11
MW-11	24.64	25.36	-0.72	26.22	26.20	0.02
MW-14	22.55	22.23	0.32	23.36	22.40	0.96
MW-15	23.37	23.60	-0.23	24.67	24.05	0.62
MW-16	23.86	-	-	25.36	25.37	-0.01
	Mean Error = -0.09 feet Mean Square Error = 0.13 ft^2 Root Mean Square Error = 0.36 feet			Mean Error = -0.01 feet Mean Square Error = 0.17 ft^2 Root Mean Square Error = 0.41 feet		

[1]Water levels measured on November 15, 1990
[2]Water levels measured on February 1, 1990

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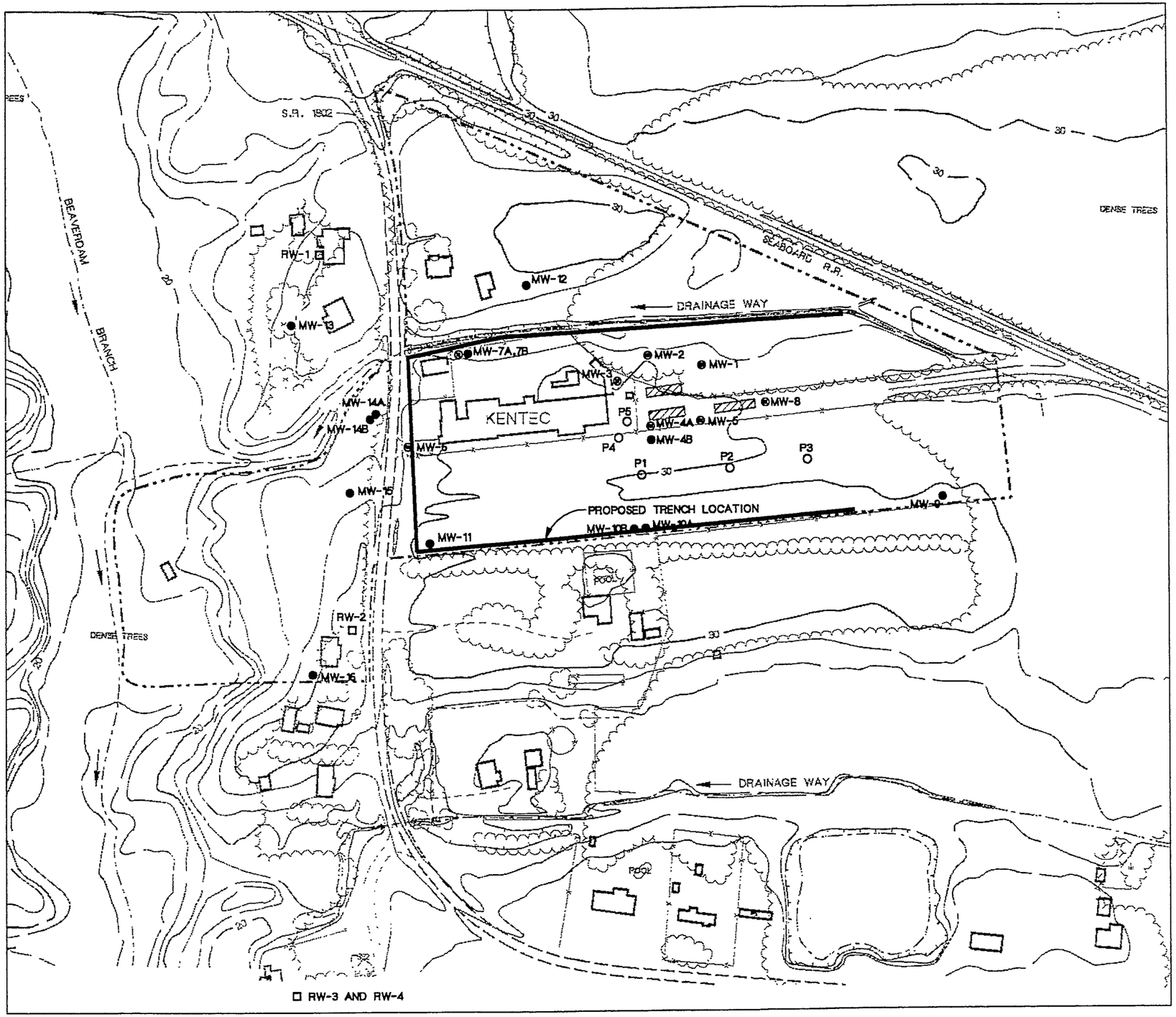

LEGEND

- ◉ PHASE 1 AND 2 MONITORING WELL
- ● PHASE 3 MONITORING WELL
- □ RESIDENTIAL WELL
- ○ PIEZOMETERS

NOTE: BASE MAP COMPILED FROM AERIAL PHOTOGRAPHY FLOWN ON 2/10/89.

0 100 200 300

SCALE: 1"=200'

Figure A-2

PROPOSED LOCATION OF THE BASIC RECOVERY TRENCH
Du Pont Kentec Facility

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groundwater discharging to Beaverdam Branch. On the southeast side of the site, the ditch is positioned adjacent to the property boundary. The lengths of the northwest and southeast arms of the trench were determined, with the help of the flow model, to ensure that contaminated groundwater will not escape from the open northeast end.

The trench is to be excavated to the bottom of the surficial aquifer, and as far into the top of the silt layer as necessary to provide the required hydraulic gradients in the collection pipe. For modeling purposes it was assumed that the trench would be deep enough to lower the water table in the surficial aquifer to within 1/2 a foot of the top of the silt layer at the edge of the trench.

The hydraulic effects of the recovery trench were modeled by converting the computational cells along the line of the trench to fixed-head cells. The heads specified for these cells were 0.5 feet above the top of the silt layer.

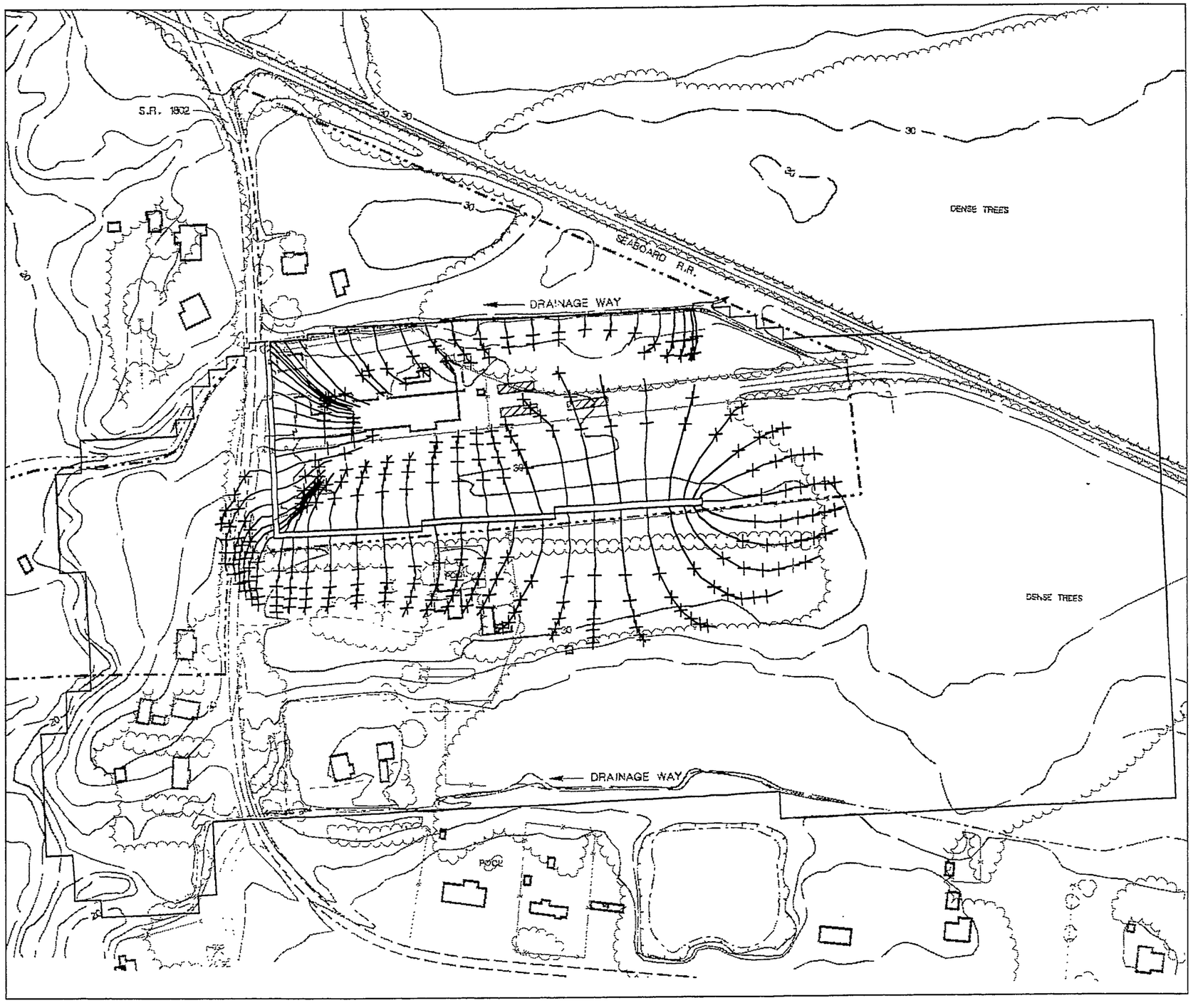
Dry Season Trench Simulations

The calibrated groundwater flow model was used to simulate the water level distribution in the surficial aquifer for dry season conditions with the recovery trench in operation. The water budget calculations performed by the flow model indicated that the groundwater recovery rate of the trench under these conditions would be 3,332 gallons per day, or 2.3 gallons per minute.

The flow model results were used as input to the MODPATH particle tracking code to analyze the capture effectiveness of the trench. With this program the flow trajectories of imaginary water particles can be traced either forward or backward along their pathlines. For the present application, the backward tracking option was used. Pathline endpoints were specified along the edges of the recovery trench at the bottom of the surficial aquifer. The pathlines were then traced backwards to the water particle's point of entry at the water table.

The pathline trajectories for the dry season simulation are shown in Figure A-3. The crosses marked on the pathlines indicate the travel time of the particles. The distance between the crosses is the distance covered in one year. The effective porosity used in these travel time calculations was 0.2.

Figure A-3 indicates that the travel time for particles to reach the trench from locations interior to it varies from 1 year to approximately 4 years under dry season flow conditions. It should also be noted that there is an elongated zone in the central plant area that is not reached by pathlines ending either at the northeast trench or the southwest trench. Apparently, water particles that originate in this zone are entrained by the downward flow through the silt layer before they reach the recovery trench.



NOTE: BASE MAP COMPILED FROM AERIAL PHOTOGRAPHY FLOWN ON 2/10/89.

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SCALE: 1"=200'

Figure A-3

PATHLINES OF PARTICLES CAPTURED BY THE BASIC RECOVERY TRENCH UNDER DRY SEASON CONDITIONS, BASE CALIBRATION

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The pathlines in Figure A-3 show that the recovery trench should prevent the escape of contaminated groundwater across the southeast site boundary and through the open northeast end of the protected area.

The simulation illustrated in Figures A-3 was produced using the basic calibration of the flow model. This calibration is considered to provide the best estimate of the performance of the proposed trench because it is based on in-situ measurements of hydraulic conductivity. However, to give a probable upper bound to the quantity of water to be pumped from the trench, the same simulation was performed using the alternative calibration, which had higher hydraulic conductivities and recharge rate. For dry season conditions this simulation produced an estimate of 5,002 gallons per day, or 3.5 gallons per minute.

The particle trajectories calculated using the alternative model calibration for dry season conditions are shown in Figure A-4. In comparison to the base calibration, the alternative calibration of the model indicates greater capture effectiveness for the trench and a more rapid aquifer cleanup.

Wet Season Trench Analysis

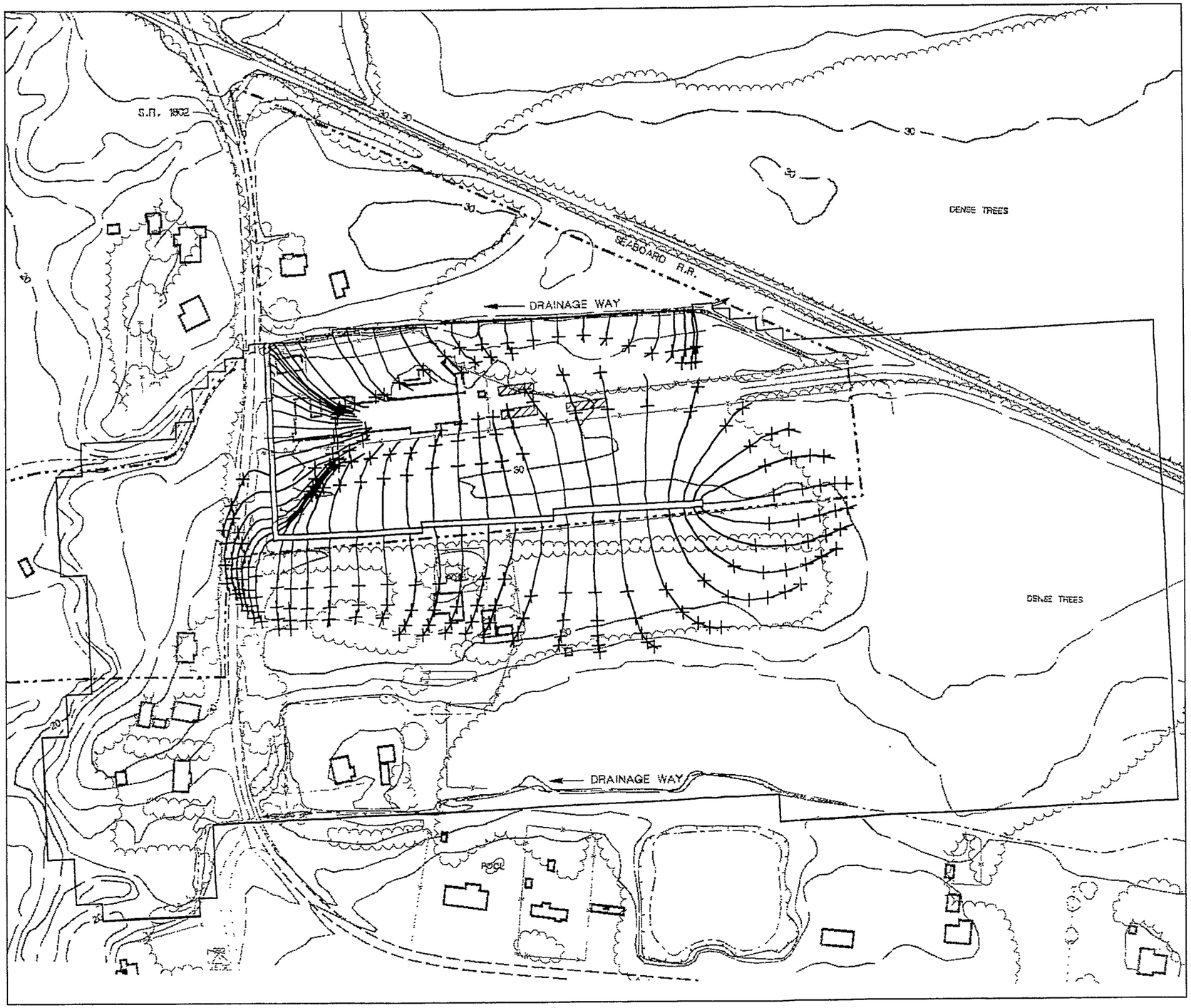
The groundwater flow model was also used to simulate the water levels in the surficial aquifer as affected by the recovery trench under wet season conditions. Using the base calibration of the model, the estimated quantity of water flowing into the trench in this simulation was 5,949 gallons per day, or 4.1 gallons per minute.

Figure A-5 shows the simulated pathlines of particles that flow to the trench under wet season conditions. The region under the Kentec plant from which particles can not reach the trench is much smaller in this figure than in the dry season run. In other respects, as well, the trench is apparently more effective in wet weather than in dry.

A wet season simulation was also performed with the alternative model calibration. It indicated an estimated flow of 9,528 gallons per day, or 6.6 gallons per minute, to the trench.

Simulation of Augmented Recharge

Recharge of treated groundwater to the surficial aquifer was considered as a means of speeding up groundwater flow and reducing the cleanup time. The idea was to use the existing abandoned drain field north of the plant building for recharge augmentation. The extra water would raise the water table in this area and produce higher flow velocities. It was noticed during the particle tracking simulations, such as the one shown in Figure A-3, that low flow velocities were predicted during the dry season directly under the Kentec building as well as in the area to the north of it. Therefore, consideration was also given to installing a new drain field adjacent to the southeast side of the building.



NOTE: BASE MAP COMPILED FROM AERIAL PHOTOGRAPHY FLOWN ON 2/10/89.

0 100 200 300

SCALE: 1"=200'

Figure A-4

PATHLINES OF PARTICLES CAPTURED BY THE BASIC RECOVERY TRENCH UNDER DRY SEASON CONDITIONS, ALTERNATIVE CALIBRATION
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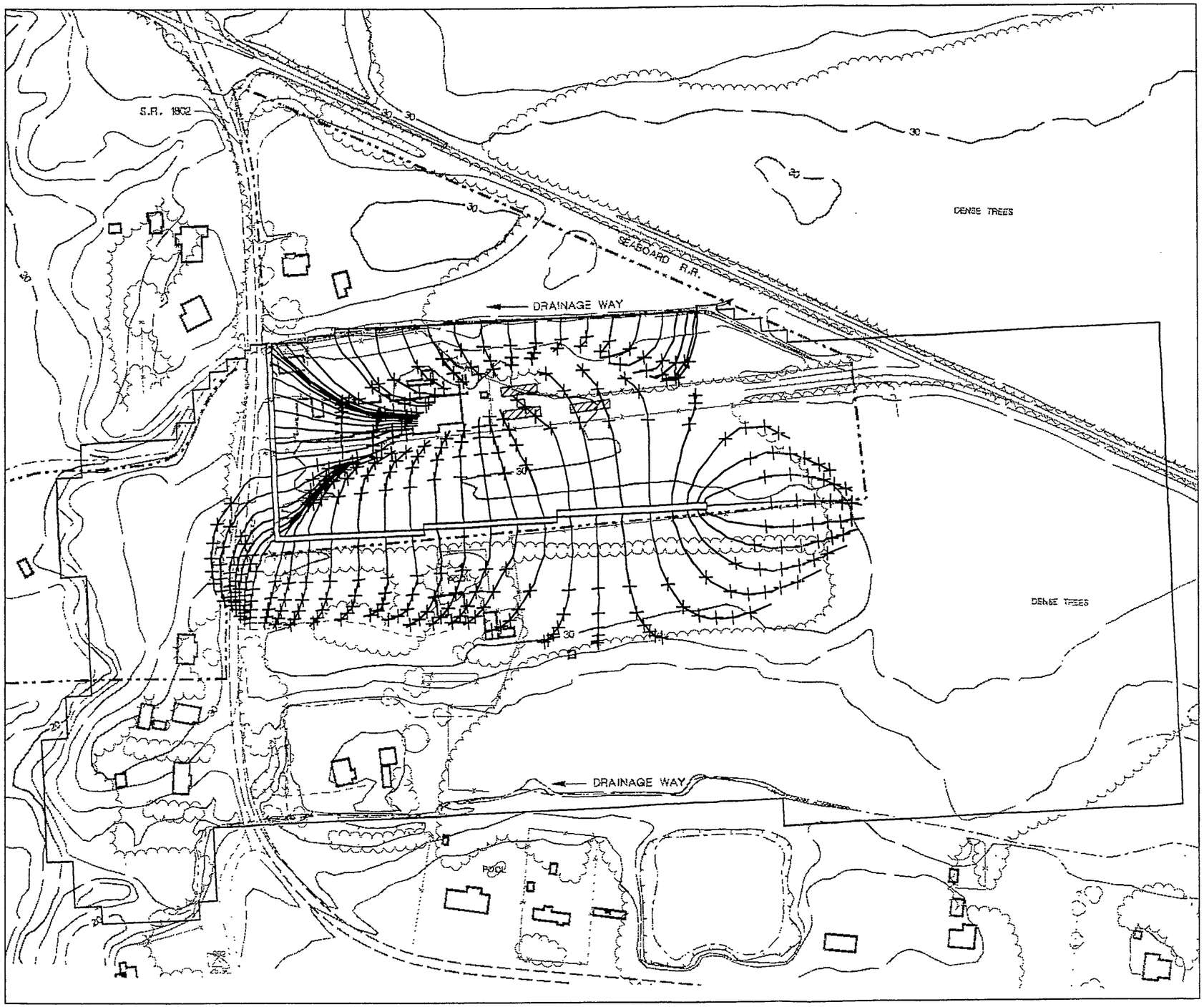

NOTE: BASE MAP COMPILED FROM AERIAL PHOTOGRAPHY FLOWN ON 2/10/89.

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SCALE: 1"=200'

Figure A-5

PATHLINES OF PARTICLES CAPTURED BY THE BASIC RECOVERY TRENCH UNDER WET SEASON CONDITIONS, BASE CALIBRATION

Du Pont Kentec Facility

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Figure A-6 shows the results of a particle tracking run for dry season conditions with augmented recharge in the new drain field adjacent to the building and in the existing drain fields north of it. The figure shows that the particle travel times between the drain fields and the southeast arm of the trench have been reduced to less than 3 years in most areas. However, the travel times of the particles captured by the northwest arm of the trench have been increased to as much as 4 years by the added recharge. This counter-intuitive result can be attributed to the change in flow pattern generated by the recharge, which increases the lengths of the flow paths traveled by some of the particles. This could, perhaps, be avoided if treated groundwater were recharged directly under the Kentec building, but the construction of the required drain field is not practical.

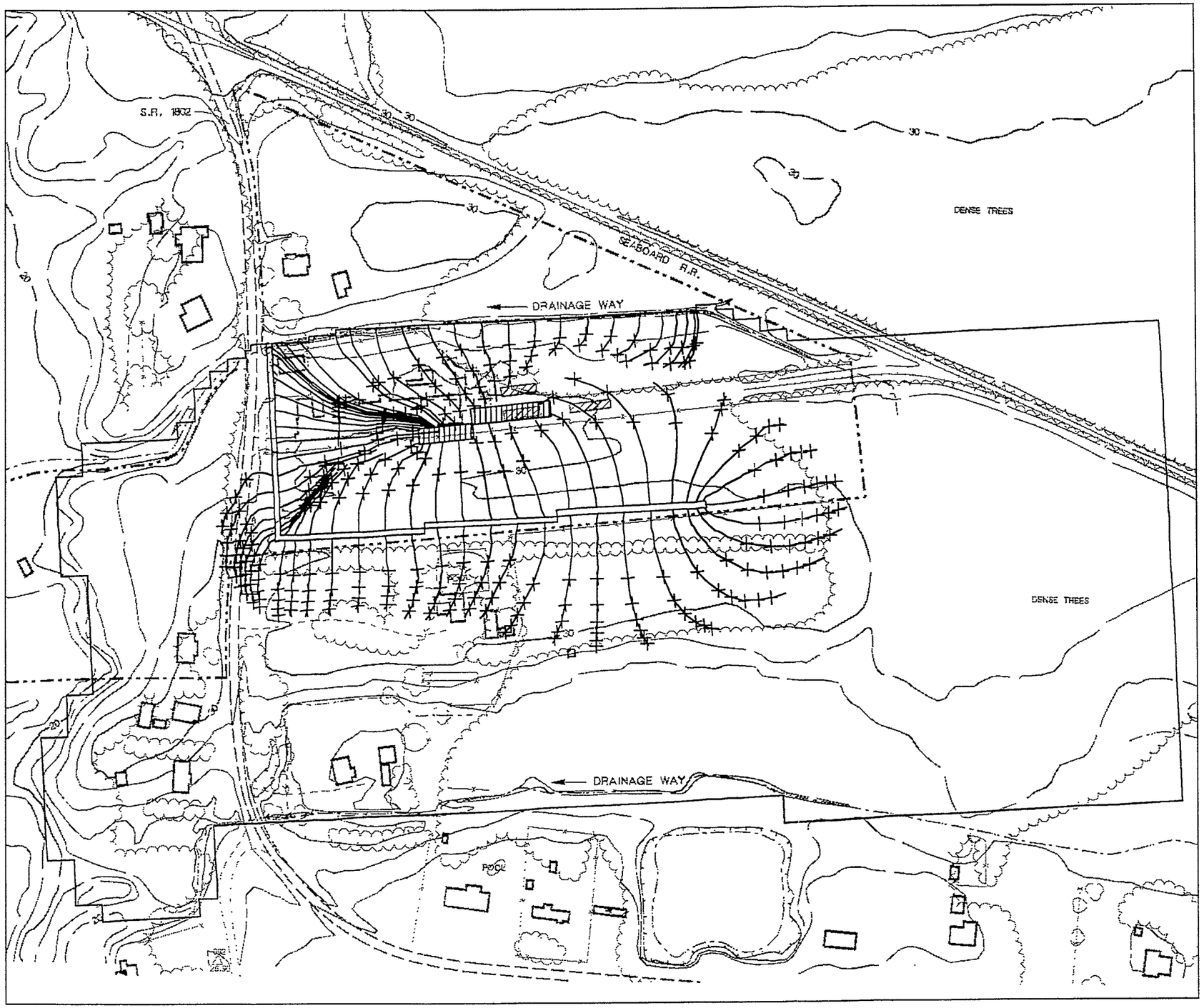
Many other recharge configurations were tested, but none of them gave a significant overall increase in the rate of aquifer cleanup. During these tests, it was found that excessive recharge augmentation could cause contaminated groundwater to flow offsite through the open end of the recovery area. The increased water levels in the central part of the site would also increase the vertical gradients across the semi-confining silt layer, thus promoting the migration of contaminated groundwater into it. For these reasons, and also because it would add to the operational complexity of the remediation system, recharge augmentation was not recommended for the Kentec site.

THREE-LEGGED TRENCH ANALYSIS

Groundwater flow and particle tracking simulation of the basic recovery trench configuration showed that travel times from some areas interior to the trench could be as long as four years under dry season flow conditions. Furthermore, the trench might not be able to recover some of the groundwater in the central plant area before the downward component of migration velocity drove it into the underlying silt layer. The recovery performance of the trench would be better under wet season flow conditions, but more effective groundwater recovery was still desired.

To shorten the flow paths from the interior site areas to the recovery system, an alternative trench layout with three nearly parallel legs was developed. The configuration of the three-legged trench is shown in Figure A-7. The outer legs are the same as for the basic layout, but a third leg has been added in the hard-to-reach central plant area.

Groundwater flow simulations of the three-legged system showed that the quantity of water that would have to be pumped from the trench and treated was only about 1 percent greater than for the basic trench. The expected rates using the base calibration model were 3370 gallons per day (2.3 gpm) for the dry season and 5989 gallons per day (4.2 gpm) for wet season conditions.



N

AUGMENTED RECHARGE

NOTE: BASE MAP COMPILED FROM AERIAL PHOTOGRAPHY FLOWN ON 2/10/89.

0 100 200 300

SCALE: 1"=200'

Figure A-6

PATHLINES WITH AUGMENTED RECHARGE UNDER DRY SEASON CONDITIONS

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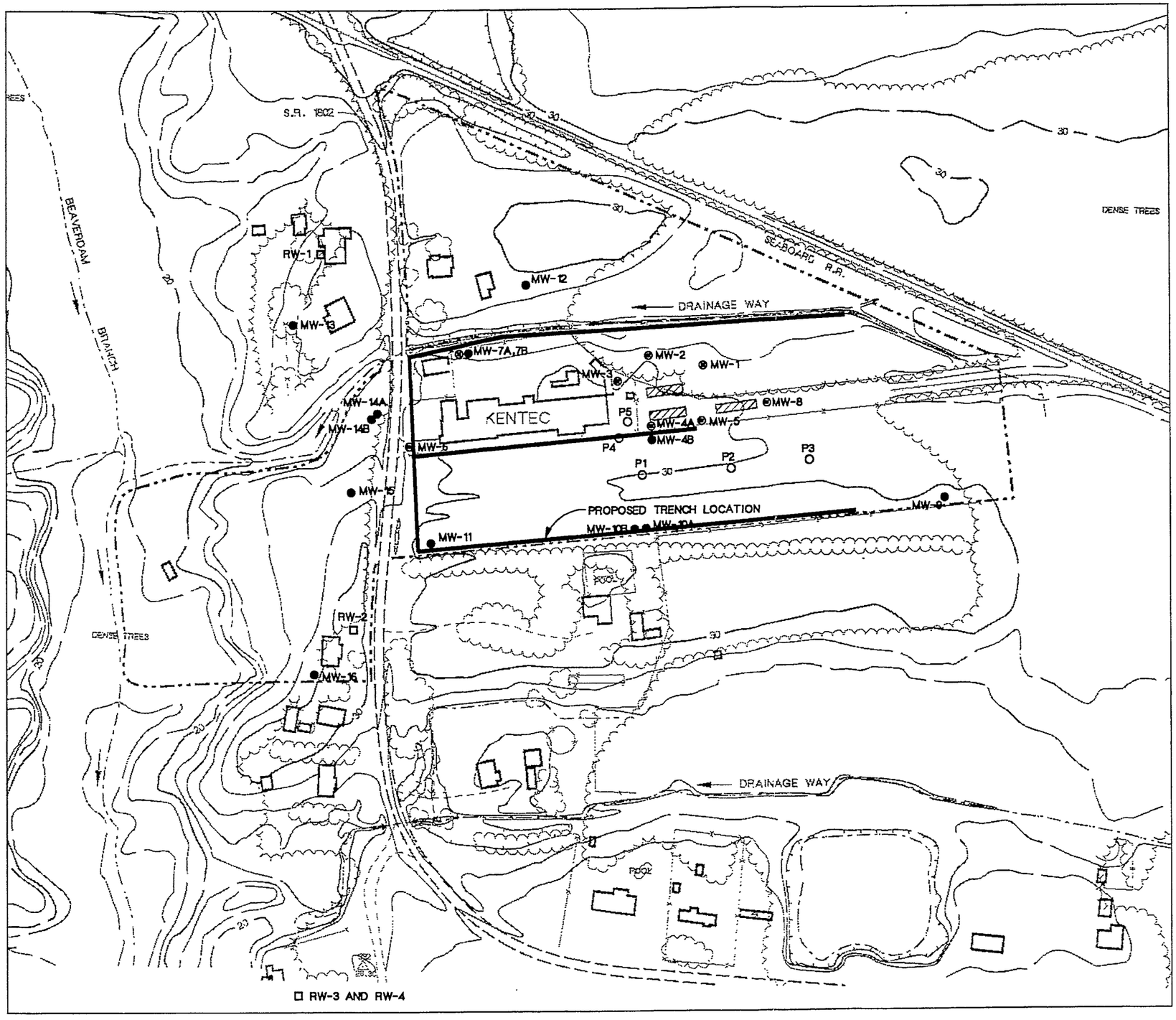

LEGEND

- PHASE 1 AND 2 MONITORING WELL
- PHASE 3 MONITORING WELL
- RESIDENTIAL WELL
- PIEZOMETERS

NOTE: BASE MAP COMPILED FROM AERIAL PHOTOGRAPHY FLOWN ON 2/10/89.

0 100 200 300

SCALE: 1"=200'

Figure A-7

PROPOSED LOCATION OF THE THREE-LEGGED RECOVERY TRENCH
Du Pont Kentec Facility

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Figures A-8 and A-9 show the simulated pathlines of groundwater particles captured by the trench under dry and wet season conditions. In both cases, the travel times from the interior of the site to the trench are shorter than they were with the basic trench configuration. The maximum travel time from the interior areas is approximately three years for wet season conditions. For dry season conditions, the travel times are shorter because the capture zones between the parallel legs of the trench do not reach all the way to the groundwater divides, where migration velocities are extremely slow. However, the uncaptured interior areas shown for the dry season run in Figure A-8 are much smaller than the uncaptured zones simulated for the basic trench configuration.

In general, the simulations indicate that the three-legged recovery trench would be significantly more effective than the basic trench. The length of trench to be constructed would be greater by approximately 500 feet, but the quantity of groundwater to be pumped and treated would be approximately the same.

SUMMARY

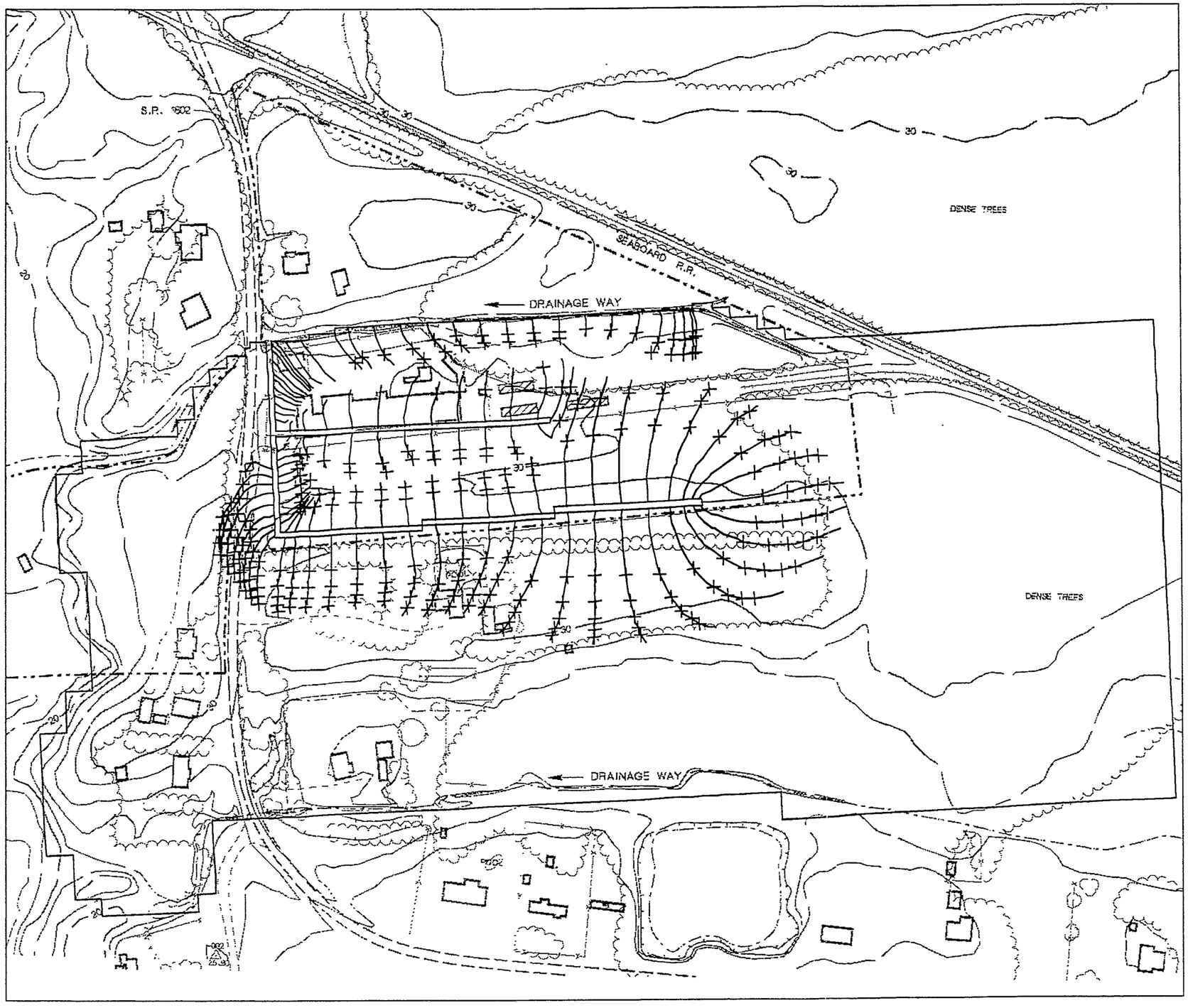
MODELING RESULTS

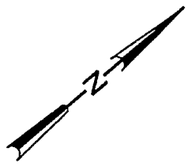
The groundwater flow modeling indicated that the proposed three-legged recovery trench would be capable of preventing further offsite migration of contaminated groundwater in the surficial aquifer. It would achieve this result by reversing the direction of horizontal groundwater flow at the site boundaries and by intercepting contaminated flow in the surficial aquifer.

The modeling also indicated that some contaminated groundwater from the surficial aquifer will continue to flow vertically into the underlying silt layer. However, the rate of this flow has apparently been very slow in the past, and the general lowering of the water table caused by the recovery trench will reduce it even further. The three-legged trench configuration lowers the water table more and results in less flow through the silt than the basic trench design.

The quantities of groundwater flow captured by the recovery trench are expected to range from 2.3 to 3.5 gallons per minute in dry weather and from 4.1 to 6.6 gallons per minute in wet weather. The lower figure in each range is thought to be more probable, because it is based on field measurements of hydraulic conductivity.

Travel time calculations indicate that contaminant particles travelling from the interior of the site with the velocity of the average groundwater flow should be captured by the three-legged trench in a maximum of approximately 3 years. The retarding effects of contaminant sorption and small-scale heterogeneity of the surficial aquifer would be expected to increase the cleanup time somewhat. Maximum travel times for the basic trench design are estimated at approximately 4 years.





NOTE: BASE MAP COMPILED FROM AERIAL PHOTOGRAPHY FLOWN ON 2/10/89.

0 100 200 300

SCALE: 1"=200'

Figure A-8

PATHLINES OF PARTICLES CAPTURED BY THREE-LEGGED TRENCH UNDER DRY SEASON CONDITIONS

Du Pont Kentec Facility

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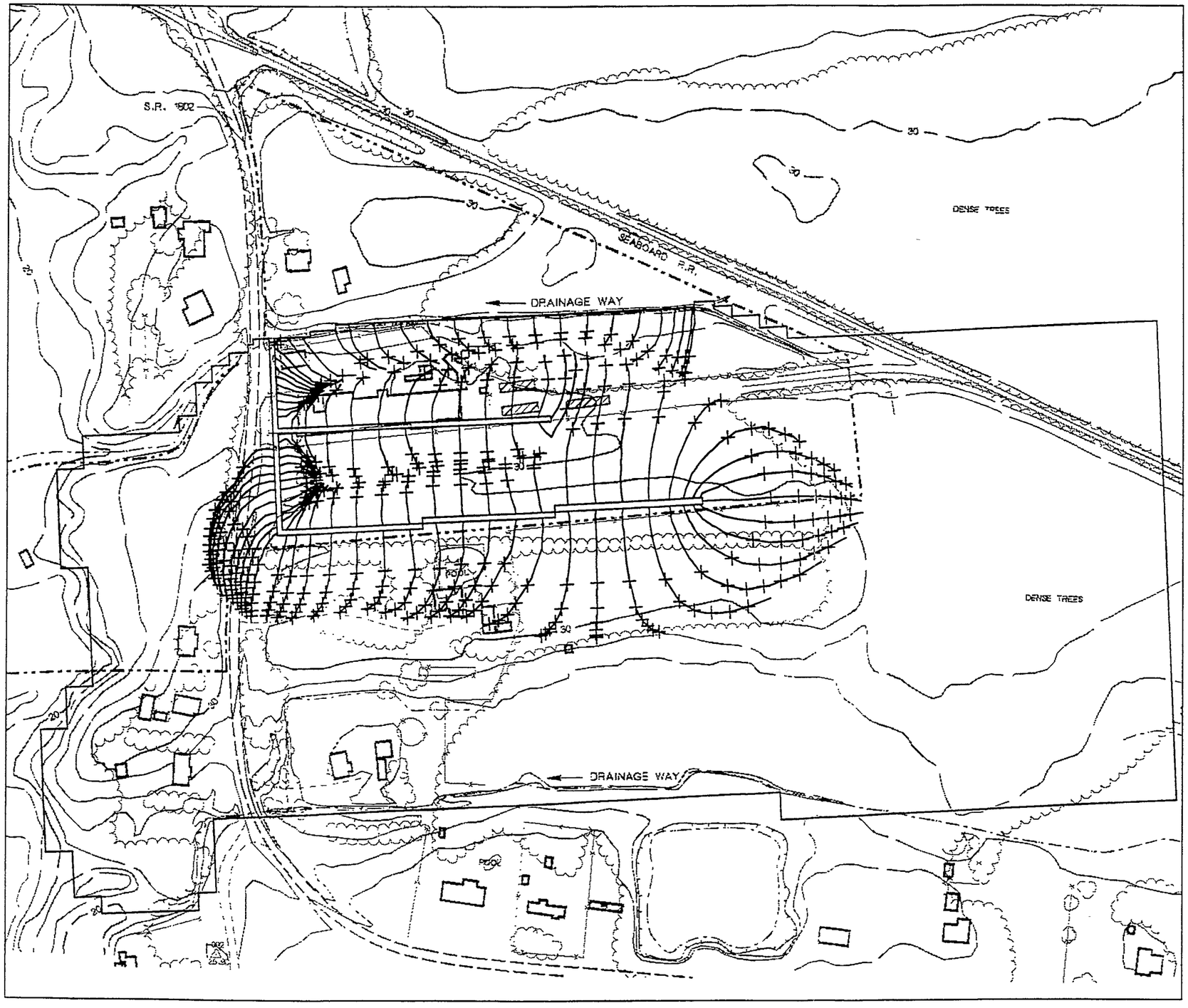
11-Jul-1991 2388wm29.dgn



NOTE: BASE MAP COMPILED FROM AERIAL PHOTOGRAPHY FLOWN ON 2/10/89.

0 100 200 300

SCALE: 1"=200'

Figure A-9

PATHLINES OF PARTICLES CAPTURED BY THE THREE-LEGGED TRENCH UNDER WET SEASON CONDITIONS
Du Pont Kentec Facility

CH2M HILL

10-Jul-1991 2398wm28.dgn

Reinjection of treated groundwater does not seem to be practically advisable as a means of speeding up groundwater remediation.

MODELING LIMITATIONS

All of the simulations performed in the modeling program were steady-state. Transient simulations would require that a realistic sequence of varying recharge rates be supplied as model input. Furthermore, the MODPATH particle tracking program is limited to steady-state flow fields. It is expected that the flow results generated by a time-variant simulation would generally be bounded by the steady-state simulations for the dry and wet seasons. However, the flow of groundwater to the recovery trench at initial startup could be somewhat higher than that predicted in the wet season simulations.

The model was found to be relatively insensitive to the vertical hydraulic conductivity of the semi-confining silt layer. Variation of the value used as model input could be partially compensated for by appropriate changes in recharge. This means that a reasonable degree of error in the hydraulic conductivity of the silt has little effect on the prediction of horizontal flow in the surficial aquifer. However, it has a direct effect on the amount of vertical flow occurring through the silt layer. Fortunately, the vertical flow rate is quite small (on the order of 2 inches per year) so that reasonable variations in the predicted rate may not be very significant.

The recharge rate in the model was applied uniformly over the area of the surficial aquifer. Because of variations in land use and soil characteristics from point to point, the actual distribution of recharge is naturally non-uniform. However, modeling experiments performed during this project indicate that this is not the major source of uncertainty in model results.

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Pollock, D. W. Documentation of Computer Programs to Compute and Display Pathlines Using Results from the U.S. Geological Survey Modular Three-Dimensional Finite-Difference Ground-Water Flow Model. U.S. Geological Survey Open File Report 89-381, 1989.

WDCR272/089.51

Appendix B
GROUNDWATER TREATMENT SCREENING

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GROUNDWATER TREATMENT SCREENING

The results of the groundwater investigation at Kentec indicate the presence of three organic contaminants. These include 1,4-Dioxane, 1,1-Dichloroethane (DCA) and 1,1-Dichloroethylene (DCE). 1,4-Dioxane was detected at the highest concentration levels ranging from less than 50 parts per billion (ppb or ug/l) to 22,000 ppb with an average concentration of approximately 2,500 ppb. DCE has been detected at levels of less than 5 ppb to 82 ppb with concentrations averaging roughly 20 ppb. Analytical data representing DCA concentrations indicate a range from less than 5 ppb to 800 ppb with an average concentration of approximately 100 ppb.

Review of these analytical results indicate that 1,4-Dioxane, DCE, and DCA all occur at relatively low levels with average concentrations of 2.5, 0.02, and 0.1 parts per million (ppm or mg/l), respectively. In addition, 1,4-Dioxane exists at concentrations 1 to 2 orders of magnitude greater than DCE and DCA. The chemical and physical properties of the three compounds are listed in Table B-1.

Five different treatment technologies were evaluated and screened for treatment of the contaminated groundwater at Kentec. These include carbon adsorption, air stripping, biological degradation, chemical oxidation, and reverse osmosis. These technologies were selected for screening based on their historical success treating organic contaminants in water.

CARBON ADSORPTION

Carbon adsorption is used to remove water and wastewater constituents by their contact with and their adherence to the surface of the activated carbon. Carbon adsorption is a physical process by which a substance is removed by accumulation at an interface between phases. For water treatment, adsorption occurs at a solid-liquid interface. Carbon adsorption has been widely used in water treatment for the control of tastes and odors due to naturally occurring organics and their chlorination byproducts. Carbon adsorption has found application for the removal of oxidizable organics, toxic organics, and some heavy metals from wastewater and contaminated groundwater to meet environmental standards or to allow water reuse. Carbon adsorption is also used to recover valuable materials from dilute solutions by adsorption with recovery by elution. Applications involving organic solutes are most effective when the solutes have a high molecular weight, low water solubility, low polarity, and a low degree of ionization.

Table B-1			
Chemical and Physical Properties	**1,4-Dioxane**	**DCE**	**DCA**
Molecular Weight	88.10	96.94	98.96
Melting Point (C)	11.7	-122.6	-97.0
Boiling Point (C)	101.2	31.6	57.3
Vapor Pressure @ T(C), TORR	37 @ 25	591 @ 25	234 @ 25
Solubility in Water @ T(C), mg/l	∞	210 @ 25	5,500 @ 20
Log Octanol/Water Partition Coefficient	-0.42	1.48	1.79
Henry's Law Constant, ATM x M^3MOLE^{-1}	N/A	1.49 E-2 @ 25	5.45 E-3 @ 25
∞ - Soluble at all proportions N/A - Not applicable			

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AIR STRIPPING

Air stripping removes volatile compounds from a liquid stream. This occurs when water contaminated with volatile compounds is fed into the top of a tower while a large air stream is forced into the bottom. The tower is usually filled with a packing medium that provides a large surface area for contact between the air and water. The air leaves through the top of the tower with the volatile compound. If sufficiently low concentrations are involved, the air can be discharged to the atmosphere. Otherwise, air pollution control devices may be needed. State air pollution regulations must be followed for emission controls. Common applications include removal of volatile contaminants from groundwater and removal of ammonia and volatile organic solvents from industrial process water and wastewater.

When water containing a volatile compound is brought to equilibrium conditions with air, some portion of the volatile compound transfers from the water to the air. The resulting concentrations of the volatile compound in the air and in the water are a function of the beginning concentration in the water, the temperature, the pressure, and the degree of volatility of the compound. The volatility of the compound, its tendency to leave the water and enter the air, is expressed by Henry's law constant for the particular compound. The Henry's law constant is the ratio of the concentration of the compound in the air to its concentration in water at equilibrium conditions. Henry's law constants are generally applicable only for low concentrations, typically up to a few percent mole fraction. Many hazardous waste applications, for example, groundwater remediation, involve concentrations in this range.

BIOLOGICAL TREATMENT

Biological treatment is applicable to the treatment of wastewaters with contaminants that are biodegradable organic compounds. It has been used extensively in the treatment of municipal and certain industrial wastewaters. Biological treatment has been used successfully in treating groundwaters contaminated with biodegradable organic compounds.

Biological treatment involves contacting a wastewater with a culture of microorganisms either suspended in the wastewater or attached to a solid medium. The organic compounds in the wastewater are metabolized by the organisms as a food and energy source. The result is the removal of organics from solution and the production of biomass and metabolic waste gases such as carbon dioxide and methane. Biological treatment systems are configured as fixed growth, suspended growth, or a combination of both. They can be designed to treat hundreds-of-millions-of-gallons per day to less than 1 gallon per minute.

Biological treatment systems are subject to inhibition of upset by heavy metals or certain organics above toxic concentrations. Microorganisms can sometimes be acclimated to elevated concentrations of toxic substances. However, wastewaters with

highly variable compositions can be difficult to treat with biological systems because changes in biomass composition require fairly long times to develop. Equalization of the feed to the biological treatment unit can increase treatment efficiency by reducing perturbations.

CHEMICAL OXIDATION

Chemical oxidation exploits oxidation-reduction or "redox" reactions in which the oxidation state of at least one reactant is raised while that of another is lowered by electron transfer from one ion to another. Hazardous constituents can be converted by this process to less toxic oxidation states. Some oxidations proceed readily to CO2 and water. However, the reaction is dependent on oxidant dosage, pH, oxidation potential of the oxidant, and formation of stable intermediates.

There are many oxidizing agents, however, only a few are convenient to use. Some common ones include ozone, chlorine containing agents, permanganate, and peroxide. Ultraviolet radiation can be used in conjunction with the oxidant to increase the reaction efficiency. Chemical oxidation should be considered for dilute aqueous wastes and gases but has limited application to slurries, not more than a few thousand ppm.

REVERSE OSMOSIS

Reverse Osmosis (RO) is used to remove dissolved organic and inorganic materials and to control such wastewater parameters as soluble metals, TDS, and TOC. Applications include the preparation of pure and process feed water, reclamation of electroplating chemicals, and reduction of wastewater volume prior to treatment or disposal. RO separates dissolved materials in solution by forcing water through a semipermeable membrane at a pressure greater than the osmotic pressure of the feed solution. Operating pressures vary from 150 to 1,000 psig. Products are one purified stream with dissolved material removed, and one concentrate stream containing all removed material. Removal levels obtainable are dependent on membrane type, operating pressure, and the pollutant properties.

CONCLUSION

Of these five technologies, chemical oxidation appears to be the most applicable technology for remediating contaminated groundwater at Kentec. Although carbon adsorption and air stripping have been proven effective with DCE and DCA, due to the high solubility of 1,4-Dioxane in water, along with its subsequent low vapor pressure, Henry's law constant and octanol/water partition coefficient neither air stripping nor carbon adsorption appear to be viable alternatives for ground water remediation at Kentec. This is compounded by 1,4-Dioxane's low molecular weight in the case of carbon adsorption. Reverse osmosis may present a viable alternative. However, if proven successful, the process would simply concentrate the contaminants into a lower volume of water still requiring treatment. Chemical oxidation and

biological treatment both break down organic compounds, thus eliminating the need for further treatment. Biological treatment is an effective technology for homogeneous groundwater with organic contaminants. However, previous treatability study data indicate 1,4-Dioxane is not significantly degraded using an acclimated activated sludge. For these reasons, along with the molecular structures of 1,4-Dioxane, DCE, and DCA, chemical oxidation was selected for further evaluation. A chemical oxidation treatability study treating groundwater samples collected from Kentec formed the basis of this evaluation.

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