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Hydrogeology and Stable Isotope Investigations of a Landfill Impacted Site in Southwest Michigan

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HYDROGELOGY AND STABLE ISOTOPE INVESTIGATIONS OF A LANDFILL IMPACTED SITE IN SOUTHWEST MICHIGAN

by

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HYDROGELOGY AND STABLE ISOTOPE INVESTIGATIONS OF A LANDFILL IMPACTED SITE IN SOUTHWEST MICHIGAN

Eliot Anong Atekwana, Ph.D.

Western Michigan University, 1996

The Cork Street landfill in the City of Kalamazoo is unlined and constructed in glacial drift material. Although water quality in some of the landfill monitoring wells is poor, the degree of the landfill's influence to groundwater, wetlands and Davis Creek located downgradient of the landfill is unknown. The objective of this study is to evaluate the degree of the landfill's impact in this region through hydrologic and stable isotope analysis.

Site characterization using geophysical surveys and specific conductance measurements indicates highly conductive shallow groundwater probably attributable to groundwater contamination. Hydrologic evaluation of this region shows that groundwater flows towards the creek with a strong upward gradient. A hydrologic budget for the wetlands using both a water budget and hydrogen isotope mass balance shows that the wetlands and the entire site is dominated by groundwater discharge conditions.

As part of this study, a new technique was developed to measure dissolved inorganic carbon (DIC) in water samples. The technique is capable of DIC extraction efficiency of 99 $\pm$ 1% and a reproducible carbon isotope measurements of better than

0.01%. Measurements of stable isotopes of hydrogen and carbon in landfill gases along with DIC measurements in water samples were used to evaluate DIC production in the landfill and to assess the landfill's influence in the study area.

Analysis of methane and carbon dioxide in landfill gases suggests that about 60% of the carbon dioxide from methane production is dissolved in the water in the landfill. This landfill-influenced water with a unique carbon isotopic signature was detected in water samples downgradient of the landfill and proved that the landfill was influencing the groundwater and wetlands prior to discharging into Davis Creek.

Application of mass balance calculations to the carbon isotope results verifies that groundwater and surface water discharging into Davis Creek from the landfill side contained between 18 and 90 % landfill-derived water. The groundwater to the east of the creek showed no evidence of landfill influence. Based on the present study, it is believed that the stream is the farthest downgradient location of the landfill's impact to surface and groundwater at the site.

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Eliot Anong Atekwana

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CHAPTER I

INTRODUCTION

Statement of the Problem

The Cork Street landfill is located within the corporate boundaries of the City of Kalamazoo (S36, T2S, R11W). The property occupies an area of 28 ha of which 19 ha has been used for disposal activities (Canonie Environmental, 1989). The landfill (Figure 1) is wedge-shaped and bounded on the north by Cork Street, on the west by Conrail Railroad, on the south by Interstate Highway 94 (I-94), and on the east by Davis Creek which is contiguous with and parallels the Grand Trunk Railroad.

The landfill is located in glacial drift approximately 46 m thick (Schmaltz, 1978). The glacial drift consists of fine sands, gravels and some cobbles interbedded with discontinuous clay rich till layers of varying thickness (Geological Services, Inc., 1981; Leja, 1983). The groundwater aquifer in the area is considered to be a single unit due to the discontinuous nature of the clay rich till layers (Allen et al., 1972). Regionally, groundwater flows to the north towards the Kalamazoo River (Allen et al., 1972). However, a local groundwater flow system exists at the site with the groundwater flowing towards the east and discharging into Davis Creek (Geological Services Inc., 1981; Canonie Environmental, 1989).

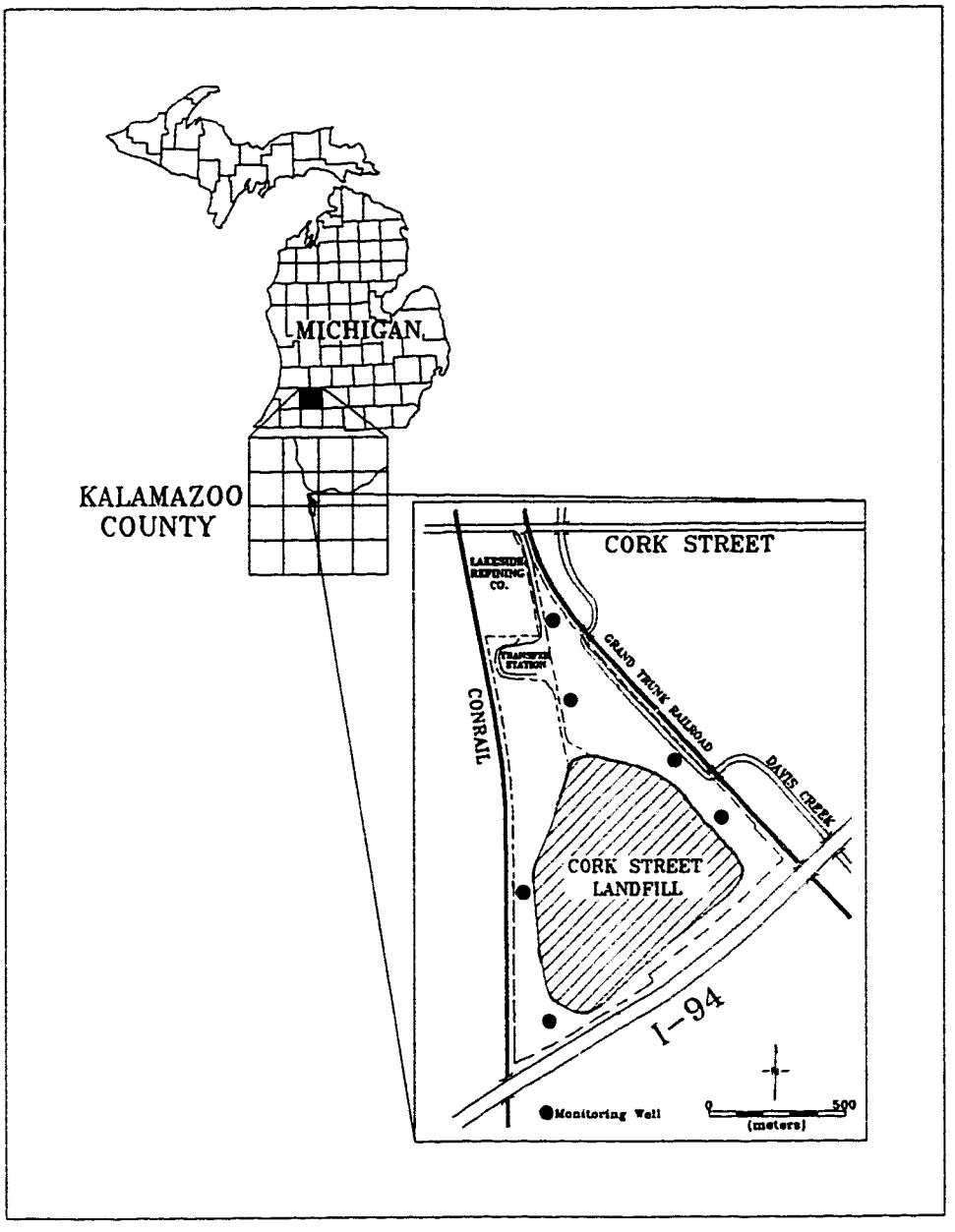


Figure 1. Location of Cork Street Landfill, Kalamazoo, Michigan.

Thus Davis Creek represents a local groundwater divide that intercepts shallow groundwater flow at the study site. In addition to Davis Creek, surface water bodies at the site include small wetlands located between the creek and the filled area (Figure 2).

The landfill which has been in operation since 1925 has been used at different times for the disposal of incinerator ash from an on-site incinerator, municipal waste, household waste, paper waste and other inert materials. Little is known about the exact types and amounts of waste disposed in the landfill. While the total amount of refuse or the types of materials disposed in the landfill is unknown, estimates of refuse thickness range from about 0 to 8 m, which is covered with variable thickness of sandy fill and other inert material (Geological Service Inc., 1981; Leja, 1983; Canonie Environmental, 1989).

The landfill has no natural or artificial barrier isolating the disposed waste from the groundwater system below the site. Water quality results from previous investigations (Geological Services Inc., 1981; Pogoncheff, 1982; Wilkins & Wheaton Testing Laboratory, Inc., 1985; Canonie Environmental, 1989) show consistently poor water quality for some monitoring wells downgradient from the landfill. Because of consistently poor water quality from a monitoring well located in the southwest corner of the landfill, a leachate collection system (Figure 2) was constructed to intercept migrating leachate in an attempt to improve water quality in this region. This leachate

collection system consists of trench drains that intercept, collect and discharge leachate to the municipal sanitary sewer system for subsequent treatment.

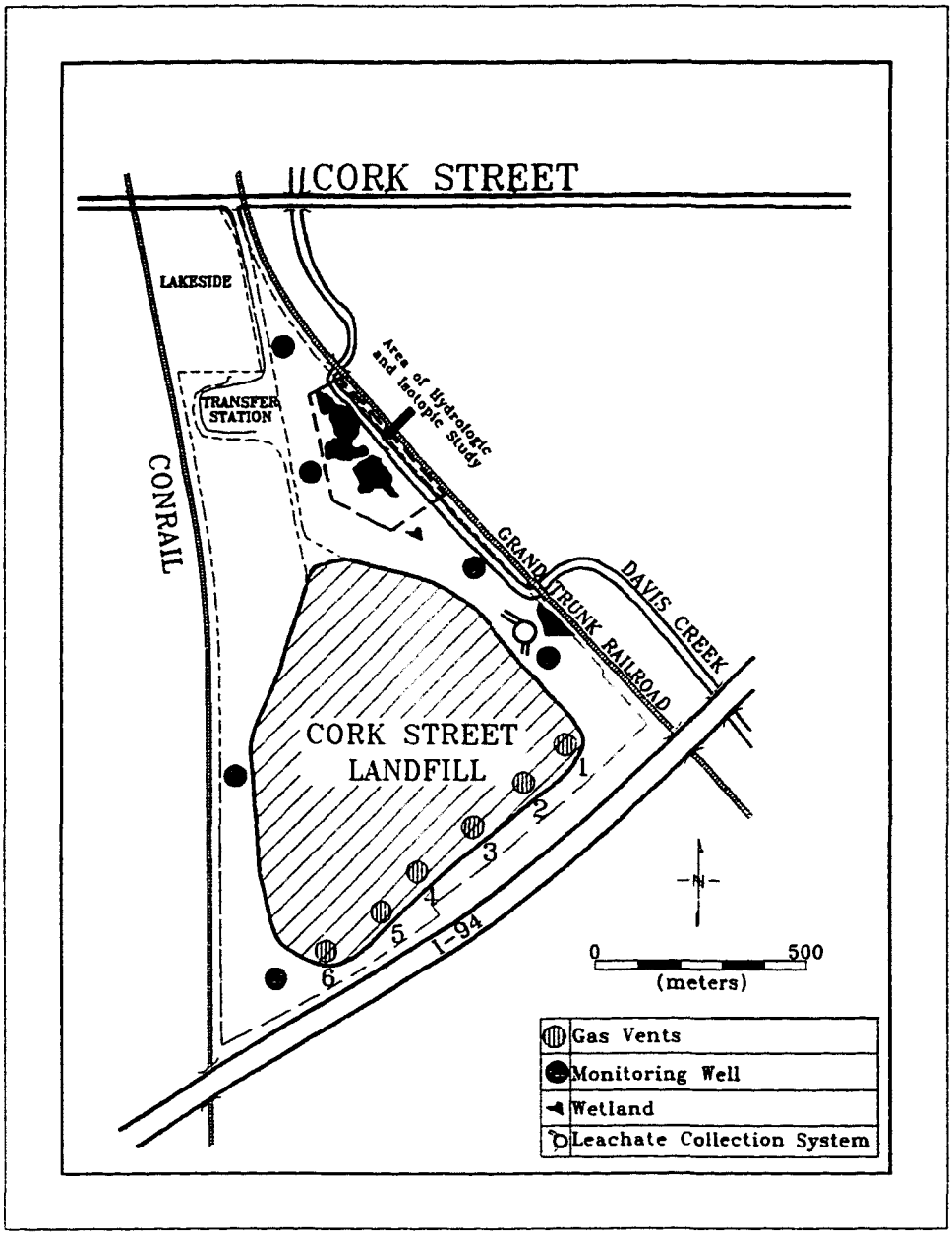


Figure 2. Map of Cork Street Landfill.

An assessment of Davis Creek by the Michigan Department of Natural Resources (MDNR) Water Quality Division in 1979 and 1985 judged the stream water quality to be poor (MDNR, 1979, 1986). However, the reports concluded that there were no detectable impacts to the stream that could be attributed to the landfill. A study by Canonie Environmental (1989) examined both surface water and sediments in Davis Creek for U. S. Environmental Protection Agency (U.S. EPA) priority pollutants and arrived at conclusions similar to the MDNR study.

There has been no evidence from previous investigations to suggest the presence of a low permeability barrier such as clay that may prevent leachate contaminated groundwater from discharging into Davis Creek. It is unclear why leachate from the landfill is not detected in Davis Creek as would be expected based on the local groundwater flow direction, the proximity of the creek to the landfill, and the of the creek as a local groundwater discharge zone. Therefore, it is important to understand the generation of leachate and its migration downgradient of the landfill in order to assess the degree to which the leachate might be impacting the groundwater below the site and surface water in the nearby wetlands and stream ecosystem.

Objectives of the Study

Some monitoring wells downgradient from the fill area show geochemical evidence of landfill leachate contamination. However, the spatial distribution of existing monitoring wells and acquired quarterly water level elevation data preclude a

groundwater in this area, as well as the interaction between groundwater and surface water in the wetlands and Davis Creek. The lack of significant impact to Davis Creek water quality by potential landfill-contaminated groundwater is based on studies of physical and inorganic chemical parameters (Geological Services Inc., 1981; MDNR 1975, 1986; Canonie Environmental, 1989) and stream sediment samples (Canonie Environmental, 1989).

With no natural or artificial mechanism to prevent potential leachate-contaminated groundwater from migrating off the fill area and impacting the adjacent wetlands and stream ecosystem, the objective of this study was two fold. The first was to monitor groundwater and surface water downgradient of the landfill and to use the resulting data to determine the groundwater hydrodynamics and the interaction of groundwater and surface water within the wetlands and Davis Creek. The second part was to take advantage of the unique isotopic signature of various carbon pools and to use a stable carbon isotope approach to evaluate dissolved inorganic carbon production in the landfill leachate, and monitor for the presence of pollutant carbon in the groundwater and surface water at the study site.

Achievement of these objectives involved the following:

1. Conduction of non-invasive electromagnetic surveys to map possible subsurface conductivity associated with the presence of migrating leachate in the region downgradient of the landfill. Measurement of the specific conductance in

2. Monitoring of the hydrology and stable isotopes of hydrogen in groundwater, surface water at the site and seepage into Davis Creek for evaluation of the dominant source of water within the wetlands in this region.

3. Measurement of stable isotopes of hydrogen and carbon in landfill vent gases from the landfill, groundwater and surface water in order to evaluate DIC production in the leachate and to assess the degree of leachate impact to the groundwater, wetlands and Davis Creek.

Importance of Study

In this study, groundwater hydrodynamics, isotopic analysis of hydrogen and carbon, and reconnaissance water quality provide a framework for constraining models that seek to explain the nature of groundwater flow downgradient from this landfill, the interaction between groundwater and surface water and the mechanism that governs transport of contaminants for this system. It is hoped that techniques developed in this study will serve as a model for the examination of sites where the nature of groundwater/surface water interaction and contaminant studies are undertaken.

CHAPTER II

THE STUDY AREA

Site Characteristics

Land Use

Land use in the immediate vicinity of the Cork Street landfill is industrial and commercial. Land south of I-94 is occupied by the Upjohn Company, west of the site by Consumers Power Company, north of the site by the Lakeside Refinery and east by Precast-Schokbeton Inc.

Topography

The Cork Street landfill is located within a small valley occupied by Davis Creek. The valley is oriented generally northwards and is a tributary of the Kalamazoo River valley to the north. A topographic map of the Kalamazoo Quadrangle shows a low elevation of the valley of about 244 m above sea level along Davis Creek. Elevations increase to about 262 m within 2 km to the east and west of the valley. Elevations at the landfill property (Canonie Environmental, 1989) show the maximum relief at the site to be approximately 21 m, with a maximum elevation of 267 in the southwest corner of the fill area. The fill area slopes to a minimum elevation of about

246 m along Davis Creek to the east, 259 m to the south along I-94, 254 m to the west near the Conrail railroad tracks and 248 m at Cork Street to the north.

Soils

Austin (1978) mapped the soils of the Cork Street landfill as part of the Kalamazoo-Schoolcraft Association. These soils are formed on level to rolling topography, are well drained with a loamy and sandy subsoil formed in glacial outwash and morainic deposits. The soils of the Cork Street landfill and the immediate vicinity are mapped as urban land forming a complex with soil units which are intricately mixed and thus cannot be resolved on the county soil maps. Five soil series mapped at the site include: udipsaments (Ua), Urban land-Kalamazoo complex (UkB), Urban land-Oshtemo complex (UoD), Urban land-Glendora complex (Ug) and Urban land-Kalamazoo complex (UkC). The udipsaments (Ua) is located to the south of the site and extend about 245 m towards the north from I-94. These soils occupy level to steep areas and are moderate to well drained soils that have been disturbed. North of the udipsaments are the Urban land-Kalamazoo complex (UkB) to the west, the Urban land-Oshtemo complex (UoD) in the center and the Urban land-Glendora complex (Ug) to the east and the Urban land-Kalamazoo complex (UkC) to the southeast. These units have been significantly altered by urban activities making it difficult to identify indigenous soils and/or reducing the area occupied by these soils. It is therefore not practical to map them as soil series. The Kalamazoo soil series would

typically occupy level to undulating upland areas and are well drained. This series would have a surface layer of dark grayish brown loam underlain by a dark yellowish brown and dark brown soil. The Oshtemo series are well drained soils found on hilly upland areas. The surface layer is dark brown sandy loam which overlies a subsoil layer of yellowish brown sandy loam. The Glendora series are poorly drained and occupy nearly level land surfaces. The soils have a surface layer of black sandy loam over a subsurface soil layer of alternating layers of multicolored sand and muck. The Glendora is typically found along streams and are subject to flooding.

Geology

The Cork Street landfill is located in a glacial outwash plain. The outwash plain consists of glacial drift deposited during the Pleistocene Epoch over the Coldwater Shale bedrock (Schmaltz, 1978). Detail studies of the glacial geology of Kalamazoo County indicated that the resulting outwash deposits could result from direct deposition from melting glaciers, fluvial deposition from glacial melt waters and deposition in lacustrian systems (Deutsch et al.; 1960, Shah, 1972; Allen et al., 1972). Although the thickness of glacial outwash is variable, estimates of glacial outwash thickness in this portion of Kalamazoo County range from 60 to 76 m (Ibrahim, 1970; Schmaltz, 1978). The glacial outwash in the study area is composed of a mixture of discontinuous layers of clay rich till, sand, gravel and sometimes cobbles (Geological

Service Inc., 1981; Leja, 1983; Canonie Environmental, 1989) and is most likely the result of direct ice deposition.

Surface Water Hydrology

The Cork Street landfill lies in the Davis Creek drainage basin. The creek drains the entire area of the site, moving the water north and discharging into the Kalamazoo River. At the landfill, the land surface slopes away from the fill area to the surrounding areas, causing surface runoff at the site to flow radially away from the fill area. Runoff discharges to the west of the site into a valley-like depression where it infiltrates into the groundwater system. In high precipitation events, the discharge may pond in this area causing intermittent wetland conditions (Stevens, 1993). Runoff to the east and northeast discharges into Davis Creek, to the south into a topographic low area along I-94 which eventually drains to the east into Davis Creek.

Surface water bodies in the immediate vicinity of the fill area include standing water in small basins within wetlands to the east and northeast. The wetlands and the adjacent Davis Creek therefore receive surface runoff from the landfill to the south, west and from areas to the northeast of the property. The standing water within the wetlands discharges into Davis Creek through gullies and as sheet flow during high precipitation events.

Groundwater Hydrology

The groundwater bearing unit of importance in Kalamazoo is mainly the glacial drift material. Within this portion of Kalamazoo, the glacial drift material consists for the most part of sands, gravels and cobbles interbedded with discontinuous clay till layers and is considered a single aquifer system (Allen et al., 1972), especially since the underlying Coldwater shale bedrock is essentially impermeable (Straw, 1978). Regionally, groundwater at the site is part of the Kalamazoo-Portage aquifer system with groundwater flowing towards the Kalamazoo River to the north (Allen et al., 1972). Locally, a flow system controlled by mounding of groundwater within the filled area exists, with groundwater flowing towards the east-northeast. Recharging conditions are believed to exist within the fill and discharging conditions in areas adjacent to Davis Creek. (Geological Services Inc., 1981; Pogoncheff, 1982; Canonie Environmental, 1989).

Previous Studies

Summary

The Cork Street landfill is unlined and thus potential pollution of the underlying glacial drift aquifer is of concern from the standpoint of groundwater quality. There are also serious ecological implications to wetlands at the site and Davis Creek if they receive landfill leachate contaminated water. Groundwater quality

is of particular importance because the main water bearing unit below the site is part of the Kalamazoo-Portage groundwater reservoir (Allen et al., 1972). This aquifer is heavily developed and is used for water supply. The City of Kalamazoo has two well fields in the vicinity of the landfill. Well field Station 13 is located about 1.2 km to the southeast; Station 18 is located 0.4 km to the southwest. The aquifer at the site is believed to be in hydraulic connection with Davis Creek, thus the concern for potential groundwater and surface water contamination from the landfill has resulted in several investigations. These investigations conducted by several agencies can be categorized under the following broad headings: site characterization, waste characterization, hydrologic characterization, water quality characterization and ecological impact analysis.

Site Characterization Studies

The subsurface geology of the site has been investigated through several exploratory soil borings and soil borings for monitoring well construction (Geological Services Inc., 1981, Canonie Environmental, 1989). All borings, including those that penetrate refuse and filled areas, terminate in a silty clay layer and extend from a depth of about 5.8 to 13.7 m. Although the exploratory borings and monitoring well borings do not encounter bedrock, most show a complex subsurface geology below the site. In general, the borings penetrate a subsurface layer of fill material or refuse and may sometimes encounter native soils below them. Below the fill material, refuse

and native soils, the borings encounter fine sand which overlie a layer of discontinuous clay rich till. Below the clay rich till is a layer of sands and gravels which overlie a silty clay layer. Neither the thickness of the underlying silty-clay layer nor its lateral continuity is known. Geoelectric sections, while not resolving the nature of the upper discontinuous silty clay layer and underlying sands and gravel units, show a possible till layer that may extend to bedrock (Leja, 1983). Vertical electrical sounding (VES) also indicates a possible sand-dominated layer in the western portion of the landfill that exists between 9 to 67 m below ground surface (Leja, 1983).

Although the lack of deep drill holes or borings can not confirm the VES results, the general concept of a one layer aquifer (Allen et al., 1972) appears to be valid for this site. Lateral changes in the subsurface geology observed in both the drill holes and the VES also indicate discontinuity of various layers within the subsurface. From the description of soil samples from exploratory borings, monitoring well drillholes, electrical resistivity surveys and laboratory hydraulic conductivity tests the site has been divided into three hydrologic units: a near surface layer consisting of fine sands directly below the native soils and fill material, a layer below the fine sands composed of gray silty clays, and a layer of sand and gravel below the silty clays (Canonie Environmental, 1989). All of the above layers are underlain by till which acts as an aquitard and may represent the lower boundary of water bearing units at the site.

Waste Characterization Studies

Although characterization of the types of waste deposited at the site is difficult, it is believed that waste deposited at the site include domestic, commercial and industrial types. Fill material and refuse were observed by visual inspection of materials retrieved from excavated test pits, exploratory and monitoring well borings (Geological Services Inc., 1981; Canonie Environmental, 1989). The "fill material" is mainly various soils and construction debris. The refuse includes trash, garbage, metal cans, glass, black and white ash-like material, large wooden timbers or posts, some (55-gallon) drums, cellulose-like material suggested to be paper mill sludge, etc. In addition to information obtained from borings, magnetic and electrical resistivity surveys (Leja, 1983) and electromagnetic and ground penetrating radar surveys (Canonie Environmental, 1989) provided data used to distinguish between areas of ordinary fill (mainly soils) and areas where refuse was disposed. From boreholes and geophysical studies, it is believed that as much as 8 m of refuse is deposited in the landfill which is covered with various types of heterogeneous fill material.

Hydrologic Characterization Studies

Groundwater at the site has been monitored periodically and continuously on a quarterly basis. Analysis and contouring of water level elevations have been used to determine the groundwater flow direction and the horizontal flow gradient, as well as to determine the direction of the vertical hydraulic gradient in nested wells at the site.

Contour maps of the piezometric surface (Geological Services Inc., 1981; Pogoncheff, 1982; Wilkins and Wheaton Environmental, Inc., 1988; Canonie Environmental 1989) show that horizontal flow in the shallow groundwater bearing unit is towards the northeast. Estimated average horizontal flow gradient for the shallow unit is 0.017 (Geological Services Inc., 1981) and 0.11 to 0.17, with the flatter gradient in the southwestern portion of the site and the steeper gradient adjacent to Davis Creek (Canonie Environmental, 1989). Vertical flow direction inferred from nested wells is upward along Davis Creek, with the strongest upward gradient in the northeast portion of the landfill site. The water level elevations and gradient data are used to conclude that the shallow groundwater at the site is recharged in the fill area, flows toward the east and northeast and discharges into Davis Creek. Monitored groundwater hydraulic head from sets of nested wells show the deeper wells or wells located within the lower sand and gravel units may be locally confined by the overlying silty clay, resulting in artesian conditions.

Seasonal dynamics of water levels show inconsistent aquifer recharge and discharge relationships. The aquifer at the site was discharging from June to December 1983, recharged in early-to-mid May of 1984, discharging from July 1984 to October 1985, and recharged from March 1986 to November 1987 (Wilkins and Wheaton Environmental, Inc., 1988). Weekly static water level elevations measured for the landfill monitoring wells between June 1992 and June 1993 show recharge conditions in July-August, December-January and March and April (Stevens, 1993).

Aquifer analysis by Canonie Environmental (1989), using data from distance drawdown curves from pump tests conducted at the City of Kalamazoo Well Stations 18 and 13, located 1.2 and 0.4 km from the landfill, respectively, suggest a radius of influence of about 1.5 km. Although this distance encompasses part or all of the landfill site, lack of significant water level elevation changes in monitoring wells at the site were used as evidence that pumping at the well fields did not influence either the deep or shallow aquifer at the site.

Water Quality Characterization Studies

Surface Water Quality

The water quality of surface water from Davis Creek, leachate springs, surface discharge into Davis Creek and groundwater has been monitored at the site. Of these water systems, only groundwater and leachate have been monitored on a consistent quarterly basis.

Davis Creek water quality was assessed by the MDNR (1979, 1986). The purpose of the assessment was to evaluate stream quality as part of an ecological evaluation. Visual observations along with dissolved oxygen and temperature measurements were obtained from a number of stations along Davis Creek. The only discernible point source impact was attributed to the Lakeside Refinery Company. Oil was observed in stream sediments upstream from the landfill. The report concluded that while the stream quality was judged to be poor, any impact from the Cork Street

landfill could not be readily detected in the stream. Water and sediment quality of Davis Creek was also assessed by Canonie Environmental (1989). In their study, no semi-volatile organic compounds (SVOCs), organochlorine pesticides (OCP), or polychorinated biphenyls (PCBs) were detected in the stream water. The only volatile organic compounds (VOCs) detected in the stream were acetone and xylene at low concentrations of 3.0 μg/l or less. Results of tests for Ar, Ba, Fe, Mn and Zn in Davis Creek showed only Mn at concentrations above the Maximum Contaminant Level (MCL). The detection of some of the above-measured parameters in the laboratory blank and no detection of other parameters were used by Canonie Environmental (1989) as evidence that Davis Creek was not impacted by either organic or inorganic chemicals.

Analyses of sediment from various locations along Davis Creek show a pattern of decreasing concentration in the downstream locations. The organic compounds detected in the sediments were attributed to a possible June 1979 oil spill at Kilgore road to the south. Inorganic chemical species detected at higher concentrations in the upstream locations relative to the downstream location included Ar, Ba, Cd, Co, Pb, Mn and Zn. Al, Ca, Cu, Fe, Ma, Na and Va were higher in the downstream locations. Although Cu, Na and Va were detected in laboratory blanks, no explanation was advanced for the occurrence or the distribution of the detected inorganic species.

Groundwater Quality

From the time of initial monitoring of groundwater quality in 1981 by Geological Services Inc. (1981) water from the monitoring wells has been sampled for chemical species on consistent quarterly basis. Most of the analyses compiled and included in reports (Geological Services Inc., 1981; Wilkins & Wheaton Environmental Services, Inc., 1988; Canonie Environmental, 1989) show significant variation in measured water quality parameters for different sampling periods for individual wells, between wells as well as for different locations in the landfill. Sample-specific reports show benzene as the only VOC detected above its MCL in wells at the site (Canonie Environmental, 1989). SVOCs detected were usually below the MCLs and no OCP/PCBs were detected in the water samples. Heavy metals in concentrations greater than background groundwater included Ar, Fe, Pb, Se, Mn and Zn. In addition, water quality indicators such as chemical oxygen demand (COD), total dissolved solids (TDS), chlorides and alkalinity are indicative of poor water quality. Comparisons between wells show that most of the organic, inorganic and physical parameters indicative of poor water quality predominate in the downgradient wells of the landfill, with the highest concentration for most of the parameters found in monitoring well M-1 located at the southwest corner of the landfill. Weekly specific conductance measurements from groundwater monitoring wells for June 1992 through June 1993 have values that range from 500 to 4000 μS/cm, with some wells downgradient of the landfill showing apparent seasonal dependence (Stevens, 1993).

The results also show that monitoring well M-1 downgradient of the landfill has the highest specific conductance value and the most fluctuations in specific conductance.

Leachate Characterization

Because of consistently poor water quality from monitoring well M-1, located in the southwest corner of the landfill, a leachate collection system (Figure 2) was constructed to intercept migrating leachate in an attempt to improve water quality in this region. This leachate collection system consists of trench drains that intercept, collect and discharges leachate to the municipal sanitary sewer system for subsequent treatment. The water collected by the leachate collection system, along with samples from leachate springs that periodically appear on the slopes of the fill area, have been analyzed for various water quality parameters. Water quality was poor for the leachate from the leachate collection system. The physical parameters, organic, inorganic and heavy metal content of the leachate were similar to those in the most impacted well at the site. VOCs, SVOCs, and no OCP/PCBs were detected from analysis of leachate from seeps and a test pit (Canonie Environmental, 1989). The organic compounds detected in leachate seeps ranged in concentration from 2 to 920 µg/l. The VOCs concentrations were less than the U.S. EPA limits for Primary or Secondary Drinking Water Regulations. SVOCs concentrations were highest for Naphthalene and 4-Methyphenol. Of all the inorganic chemical species analyzed for in

leachate, Cr, Fe, Mn and Hg were the only substances detected at levels higher than their respective MCLs and thus did not meet U.S. EPA drinking water standards.

Ecological Impact Analysis

Concerns for the ecological impact of the Cork Street landfill prompted a stream assessment of Davis Creek (MDNR, 1979, 1986). This assessment examined the relationship of the stream water quality and the abundance of microinverterbrates and fish. Although the water quality results showed poor stream conditions, fish, principally minnow, were more abundant in upstream locations than in downstream locations of the Lakeside Refinery property.

A more comprehensive environmental assessment of the landfill's impact to the surrounding environment was carried out by Gove Associates Inc. (1981). The study involved the compilation of existing information on the hydrology, soils and climate of the site and field observation and compilation of information on the terrestrial and aquatic flora and fauna native to the site.

Flora

The flora observed on the site included terrestrial and aquatic type vegetation. Trees and shrubs that have been documented at the landfill property included Willow (Salix sp.), Cottonwood (Populus deltoides), Honeysuckle (Ionicera sp.), Cherry (Prunus sp.), Slippery Elm (Ulmus rubra), Chinese Elm, Staghorn Sumac (Rhu

typhina), Mapple (Acer sp.), Lilac (Syringa vulgaris), and Box Elder (Acer negundo), and several species of herbs. Aquatic vegetation is not well developed along Davis Creek at the landfill site. Most of the tree and shrub type vegetation growing along the banks consists of similar varieties reported for the terrestrial system with notable additions of Common Elderberry (Sambucus canadensis), Honeysuckle (lonicera sp.) and Sycamore (Plantanus occidentalis).

The wetlands adjacent and west of Davis Creek is dominated by Cattail (Typha angustifolia) and Purple looseetrife (lythrum salicaria). Along the edges of the wetlands are tall grasses that are believed to be Reed Canary (Phalaris arundinacea).

Fauna

The fauna observed on the landfill site include birds, American Goldfinch (Spinus tristus), Eastern Kingbirds (Tyrranus tyrranus), Morning Doves (Zenaida macroura), Red Wing Blackbirds (Agelaius phoeniceus), Chardrius vociferus (Killdeers); mammals, mainly White Tail Deer (Odocoileus viginianus) and reptiles, mainly Gartersnakes (Thamnophis sp.).

CHAPTER III

SITE CHARACTERIZATION

Geophysical Site Characterization

Near surface geophysical investigations are increasingly being used at contaminated sites in conjunction with hydrogeological investigations. Geophysical methods have a tremendous potential for rapid non-invasive evaluation of contaminated sites and can be used to delineate the lateral and vertical extent of contaminated zones, as well as to characterize the subsurface geology. As such, they accelerate the investigative process of the subsurface at sites about to undergo remediation, leading to significant cost savings. Also, the results of geophysical investigations done at the onset of hydrogeological investigations can result in the strategic placement of exploratory wells and maximize information return with a minimum number of wells.

At landfill sites, such as in the study area, geophysical investigations can be used to map the extent and thickness of covered wastes as well as map the lateral extent of groundwater contamination. Commonly used geophysical surveys at landfill sites include seismic refraction (e.g., for determining the depth to bedrock (Lankston, 1990)), electrical resistivity (e.g., for mapping the extent of the leachate (Buselli et al.,

1995) and monitoring leaks from landfill liners)), electromagnetic induction methods (e.g., for locating sand and gravel lenses (Barrows, 1995), mapping leachate plumes (Russell and Higer, 1988; Monier-Williams et al., 1990; McNeil, 1990)), gravity (for mapping the limits of landfills and determining the thickness of the fill (Roberts et al. 1990)), and magnetic methods (for detecting buried ferrous objects and the limits of landfills (Hinze et al., 1990)).

The area selected for hydrologic and stable isotope study in the groundwater, wetland and Davis Creek is located in the northeast portion of the landfill property (Figure 3). This area has the same boundary as the property to the east, the fill area to the west and south and an unpaved lot to the northwest. This region of the landfill was selected because it was located along the groundwater flow path and downgradient of three sets of landfill monitoring wells. The area also had wetlands and dry areas and provide the best access to Davis Creek at the site.

Geophysical investigations have been conducted at the Cork Street landfill to characterize the nature of the subsurface geology, the nature of the waste and the location of buried drums. Geophysical surveys over the entire landfill (Leja, 1983) employed vertical electrical soundings (VES) to determine the nature of the subsurface lithology, the magnetic method to determine the limits of the landfill and distribution of waste and electrical resistivity profiling to map landfill leachate distribution. Electromagnetic and ground penetrating radar was used successfully by Canonie Environmental (1989) to locate buried drums northeast of the main fill area.

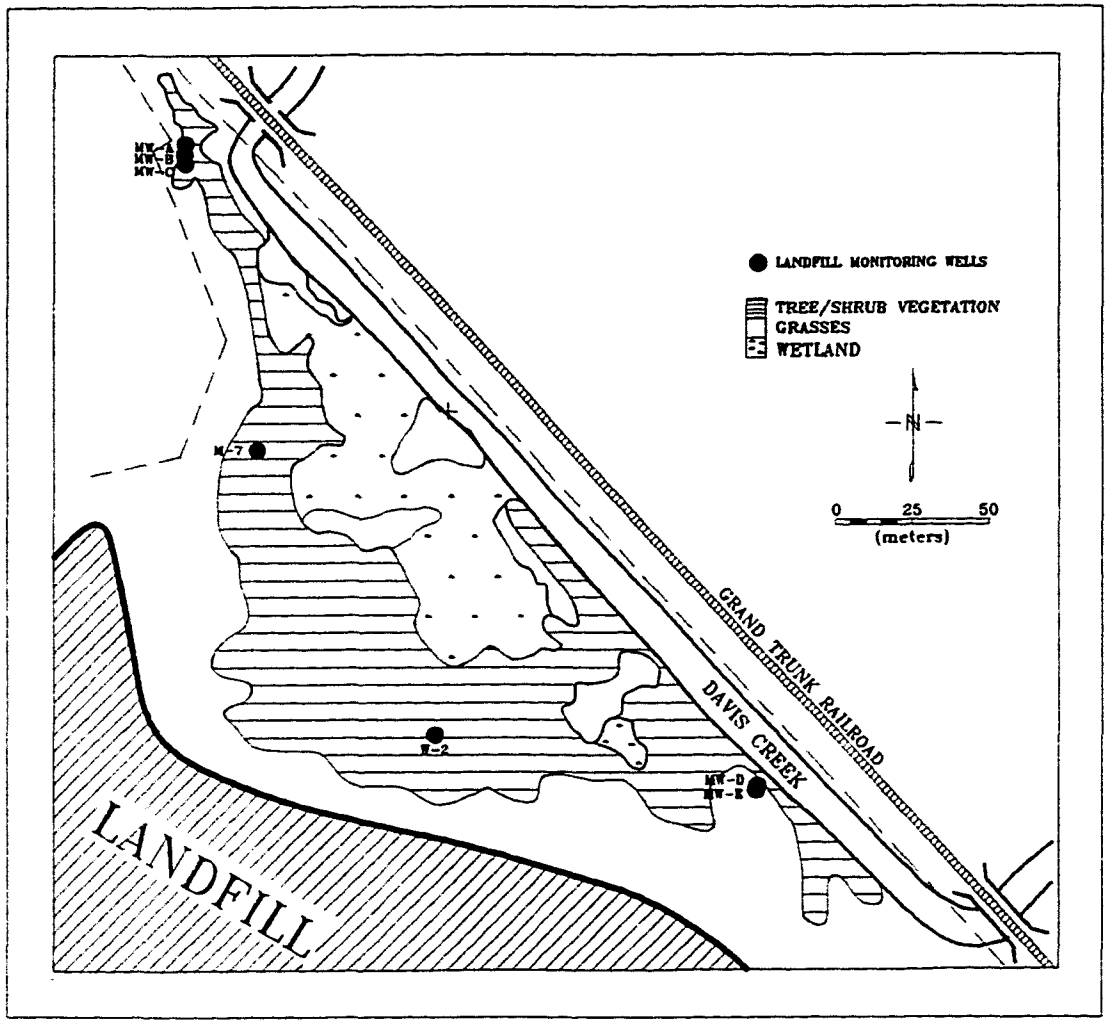


Figure 3. Area Downgradient of the Cork Street Landfill Selected for Hydrologic and Stable Isotope Monitoring.

For the most part these geophysical surveys were designed to either determine the general geophysical character of the landfill or for the location of buried drums. Therefore, the area selected for this study was sparsely covered by any of the previous geophysical investigations.

Since the main objective in this study was to detect and evaluate leachate impact to the groundwater and surface water downgradient of the landfill, geophysical investigations were undertaken in order to select potential areas for the placement of monitoring stations. The electromagnetic (EM) and magnetic methods were chosen because of their relative ease of use and the ability to rapidly cover large areas, even over rough and vegetated terrain. EM surveys were also undertaken to determine subsurface conductivity distribution associated with possible leachate migration from the landfill and thus aid for the placement of monitoring wells for subsequent hydrologic and geochemical studies. The magnetic survey was conducted to locate buried ferrous objects and to verify that EM conductivities were not associated with detected ferrous objects.

Electromagnetic (EM) Surveys

Electromagnetic surveying methods measure the ground's response to the propagation of electromagnetic waves. In this technique a primary electromagnetic field is produced by an alternating current in a transmitter coil. In the presence of a subsurface conductor the magnetic component of the primary field penetrating the

ground induces eddy currents that flow in the conductor. The eddy currents induce secondary electromagnetic fields which travel to the receiver. In the presence of a subsurface conductor, the receiver detects the resultant field made up of the primary field and the secondary field, which is different in phase and amplitude from the primary field. This difference in phase and amplitude reveals the presence of the subsurface conductor and provides information on the conductor's geometry and electrical properties (Keary and Brooks, 1984). The secondary field can therefore be resolved into two components with respect to the primary field, a real component (inphase) that is 180^0 out of phase with the primary field and an imaginary (out of phase or quadrature) component that is 90^0 out of phase with the primary field. With EM field measurement systems such as the Geonics EM-31 and EM-34, the inphase component is measured in parts per thousand (ppt) and is sensitive to large metallic objects, hence it can be used as a metal detector. The quadrature component is calibrated to give readings in conductivity measured in milliSiemens/m (mS/m).

EM Field Survey

EM surveys were carried out in June 1994 using a Geonics EM-31 conductivity meter. Survey stations were laid out in an approximately 6 x 6 m grid designed to intersect possible contaminated and uncontaminated areas. The EM survey was conducted in both a vertical dipole (VD) and horizontal dipole (HD) modes. In the vertical dipole mode, the meter measures the apparent ground

conductivity to a depth of approximately 6 m (for a perfect conductor), while in the horizontal dipole mode, the meter measures the apparent ground conductivity to a depth of about 3 m. In both of these survey modes, the EM meter is measuring the cumulative response of the earth to that depth of exploration. Surveys conducted using both VD and HD modes allow for the evaluation of electrical properties with depth. In December 1994, another ground conductivity survey was conducted over the study site. The purpose was to extend the EM survey beyond the primary monitoring area. The survey was extended 12 to 18 m west and about 40 m south of the June survey. Only VD quadrature measurements were obtained for this survey.

EM Results

The station location and their associated electromagnetic values for the survey of June and December 1994 are complied in a table (Appendix A). The conductivity values (quadrature component) for the VD of the June and December survey ranged from -47 to 198 mS/m. Values for the HD survey for June ranged from 19.5 to 193 mS/m. The inphase values in the VD and HD modes for the June survey ranged from -16 to 15 ppt and from -19 to 19 ppt respectively. The EM measurements along with their corresponding coordinates were arranged into a XYZ data format, gridded using GEOSOFT™, a computer mapping package. The gridded results were superimposed on the basemap of the site for analysis. The results are shown in Figures 4, 5 and 6.

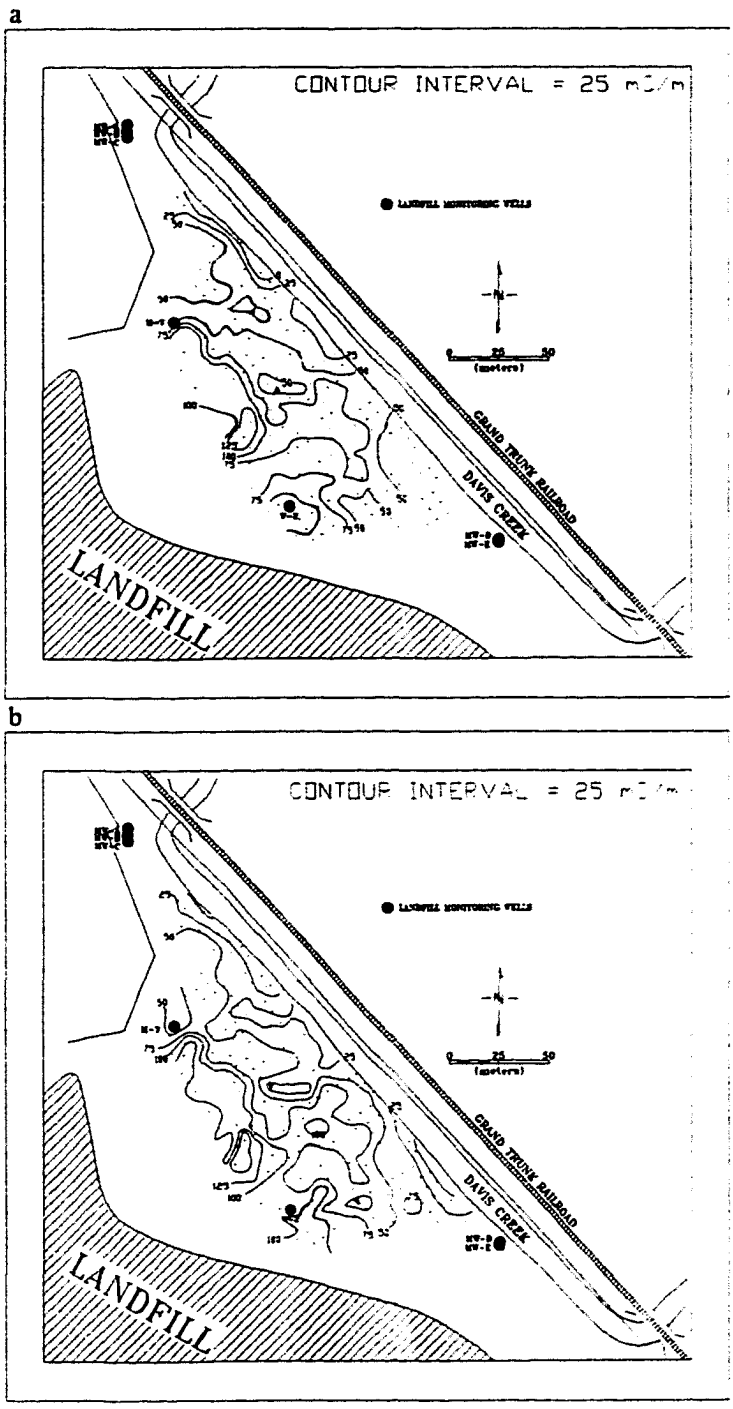


Figure 4. Map of EM31 Conductivity (Quadrature Component) in the Vertical Dipole Survey Mode for June (a) and December (b) 1994. Survey Stations Locations Are Shown as Dots.

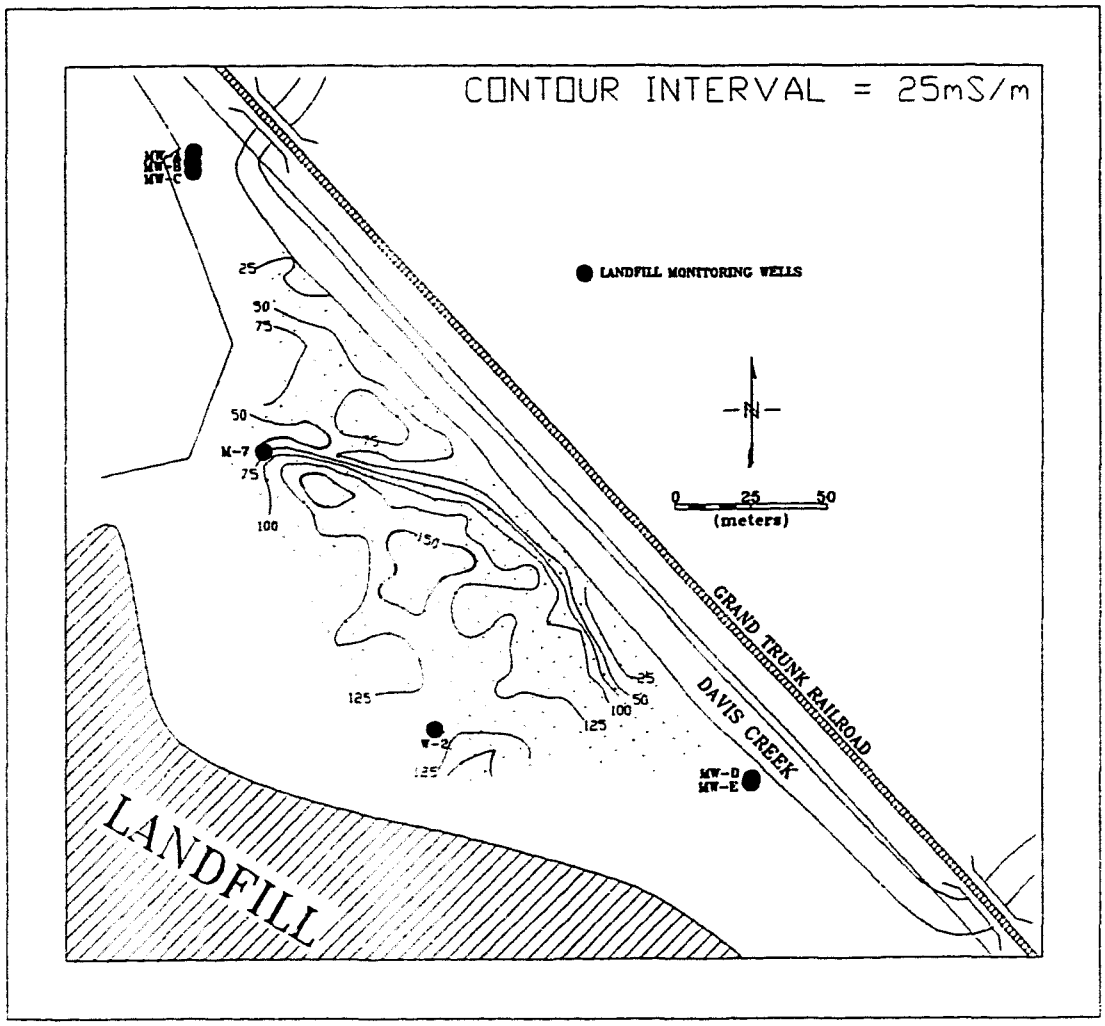


Figure 5. Map of EM31 Conductivity (Quadrature Component) in the Horizontal Survey Mode for June 1994. Survey Stations Locations Are Shown as Dots.

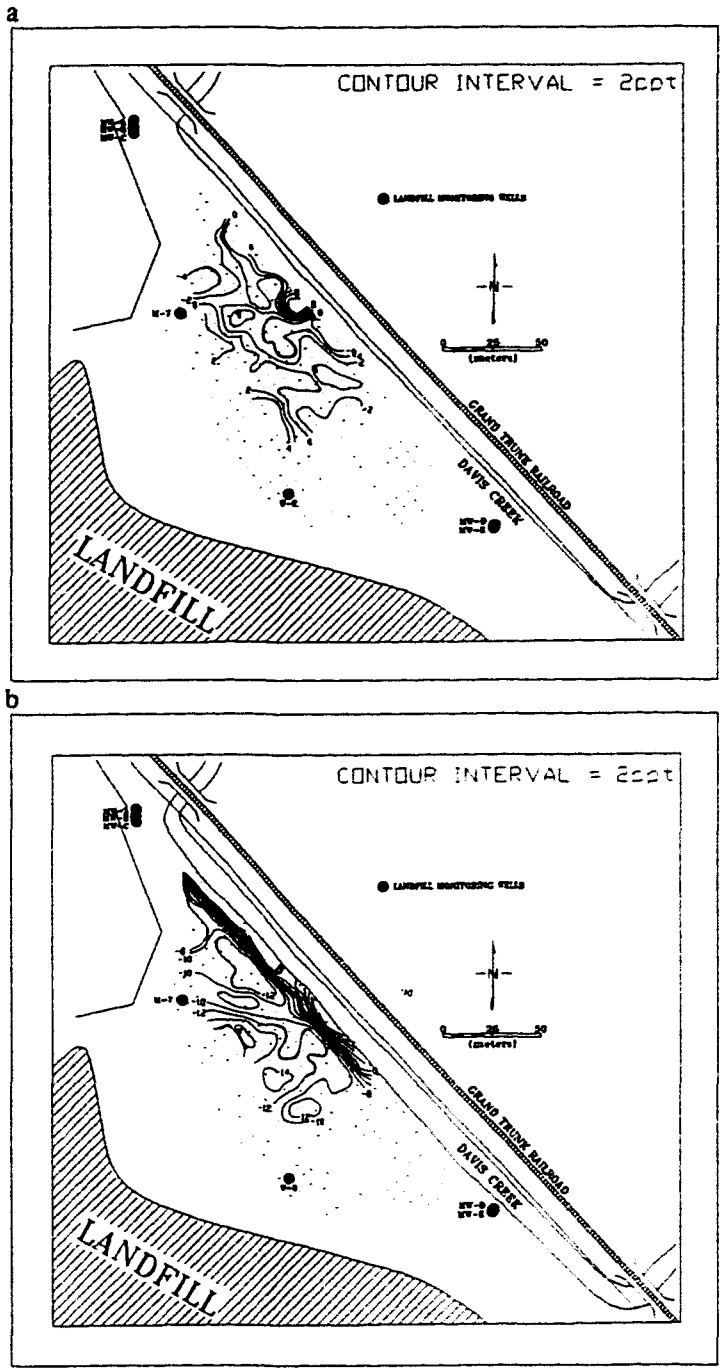


Figure 6. Map of EM31 Inphase Component in the Vertical Survey Mode (a) and The Horizontal Survey Mode (b) for June 1994. Survey Stations Locations Are Shown as Dots.

Magnetic Survey

During the construction of several of the monitoring wells at the study site, metallic objects (cans, wires, sheets, etc.) were encountered. Therefore a magnetic survey was conducted to evaluate the extent of buried waste and to detect the presence of any buried metallic objects. Also, the magnetic method would verify if the high subsurface conductivity measured by the EM method was independent of the distribution of ferrous objects disposed at the site. A Scintrex proton precession magnetometer was used for the survey. Details on the principles of operation of the proton precession magnetometers can be obtained from most standard geophysics text books (e.g., Telford et. al., 1990). The instrument used in this survey measures only the total magnetic field intensity. This comprises the earth's field strength at that location (which usually varies with latitude) plus a much smaller field caused by any local magnetic anomaly in the near-surface crust of the earth (e.g., buried ferrous objects). Thus, magnetic surveys are used to detect rock bodies or materials having high susceptibilities, such as those containing high concentrations of the mineral magnetite.

Magnetic Field Survey

Magnetic measurements were obtained over the same grid used for the electromagnetic survey. During the survey, a base station was established at the site. Repeated readings were taken at the base station after the completion of each survey

line to monitor the changes of the earth's magnetic field with time (diurnal variations). Three readings and the time of the reading were recorded for each station. At least one station was repeated per line to check for anomalous instrument drift errors.

Magnetic Results

The results of the magnetic survey are compiled and presented in Appendix B. The readings obtained for each station were averaged and used for interpretation. The magnetic values for the site range from 54127 to 59570 nT. Because of the wide range in the magnetic values, corrections for magnetic drift was considered unnecessary since changes in base station magnetic values were less than 100 nT and would not affect the interpretation of the data. The magnetic data were arranged into an XYZ file format, gridded and analyzed in a manner similar to the electromagnetic data. The result is shown in Figure 7.

Specific Conductivity Survey of Water Samples

Specific Conductivity Survey

After monitoring wells were constructed in the study area, (see hydrologic monitoring and assessment chapter for information on monitoring wells) specific conductance measurements were made for groundwater and surface water samples from the study area, and water samples from the leachate collection system at the landfill.

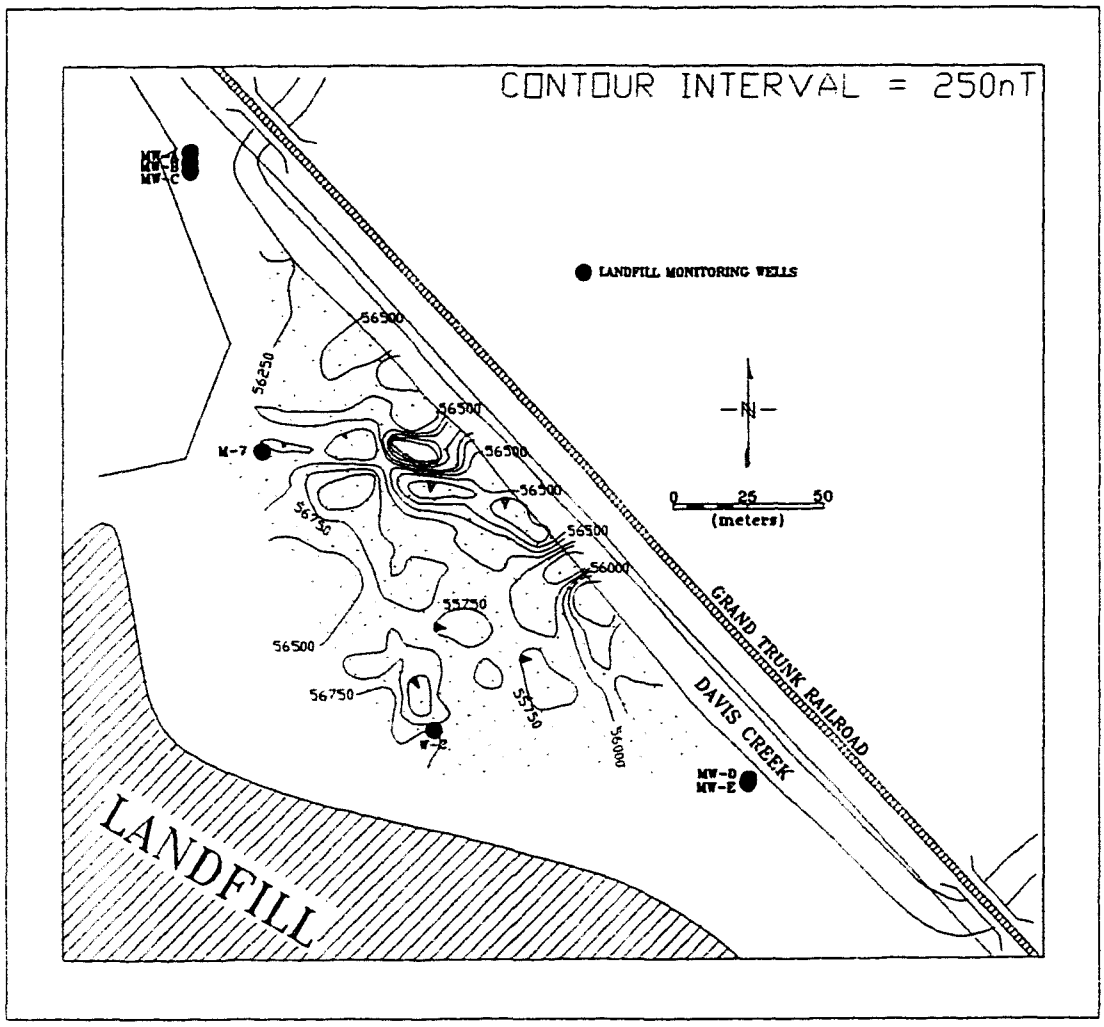


Figure 7. Map of Magnetic Distribution in the Study Area. Survey Stations Locations Are Shown as Dots.

The survey utilized a conductivity meter and measurements were made in the field. Prior to making conductivity measurements, the monitoring wells were purged of stagnant water in the well bore by removing all of the water in the well bore or at least five pore volumes.

Results of Specific Conductance Surveys

The specific conductance measurements for selected surveys are shown in Table 1. The results show that the specific conductance for groundwater and surface water for samples west of Davis Creek ranged from 600 to 3000 μS/cm. Groundwater east of Davis Creek had conductivity values in the 700 to 1000 μS/cm range. Water from the leachate collection system ranged in conductivity from 2000 to 4000 μS/cm while Davis Creek had values in the 400 to 700 μS/cm range. The distribution of specific conductivity for 12/5/95 survey is shown in Figure 8.

Discussion

The maximum conductivity values of 193 mS/m measured at the site are 2-3 times higher than conductivities for sands, gravels or tills of glacial drift of 1.5 $x10^4$ ohm-cm (McNeill, 1980). Both the June (Figure 4a) and December (Figure 4b) vertical dipole mode survey results are essentially the same and show regions of pronounced electromagnetic anomalies. The main difference between the surveys is in the recorded conductivity values. The December conductivity values for all the

Table 1

Selected Specific Conductance (μS/cm) of Water Samples From the Study Site

DATE	10/15/94	11/17/94	1/14/95	6/15/95	8/31/95	10/1/95	12/5/95
W1A	1660	1792	1396	2910	3120	1782	1761
W1C	1915	1959	1430	3000	3010	2860	1824
W2A	1326	1346	1700	4170	4150	1529	1650
W2C	1450	1479	1327	2750	2760	2830	1642
W3A	1002	1192	1050	1451	1191	1163	1331
W3C	690	-	966	1358	1576	1320	1196
W4A	1134	1450	1235	1605	1420	1331	1411
W4C	1249	1388	1289	1624	1474	1273	1349
W5A	731	820	-	1026	1044	1005	916
W5C	761	-	-	904	915	893	820
W6A	1560	1494	1314	1742	2620	1596	1603
W6C	1480	-	1279	1677	2520	1591	1551
W7A	1351	1307	1153	1566	1485	1358	1295
W7C	1380	1378	1117	1541	1481	1447	1395
E8A	750	859	570	1074	1061	1039	884
E8C	797	-	807	879	878	818	812
W9A	1177	1007	840	1497	2640	1072	906
W9C	-	1024	851	1228	1170	1125	1090
E10A	865	900	-	952	923	891	897
E10C	834	-	-	948	921	883	846
W11A	1945	2120	1650	3350	3210	1809	2032
W11C	1898		1540	3020	2750	1768	1633
W12A	1905	2010	1520	3080	3080	3040	1979
W13A	-	-	-	-	-	-	784
W14A	-	-	-	-	-	-	1303
W15A	-	-	-	-	-	-	1742
DC1	1215	1195	1042	1340	1555	1303	1231
DC2	933	1035	783	1091	1157	1101	1028
DC3	-	-	-	-	-	-	500
D CRK	623	618	457	694	655	643	739
S1	1710	2000	-	3110	3030	3070	2016
S2	1570	1721	-	2670	2440	1533	1742
S3	1098	1294	1047	1339	1279	1089	1178
S4	1485	1457	-	1496	1536	1567	1610
SP	1650	1747	-	2630	2750	2600	1741
SS	1578	1678	-	2780	2430	1437	1704
SN	-	-	-	-	1082	1041	1073
SW1	-	-	-	-	-	752	874
SW2	-	-	-	-	-	1430	1306
SW3	-	-	-	-	-	648	650
SW4	-	-	-	-	-	454	489
LCS	-	-	-	-	-	-	3730

The - Indicates no Determinations were Made

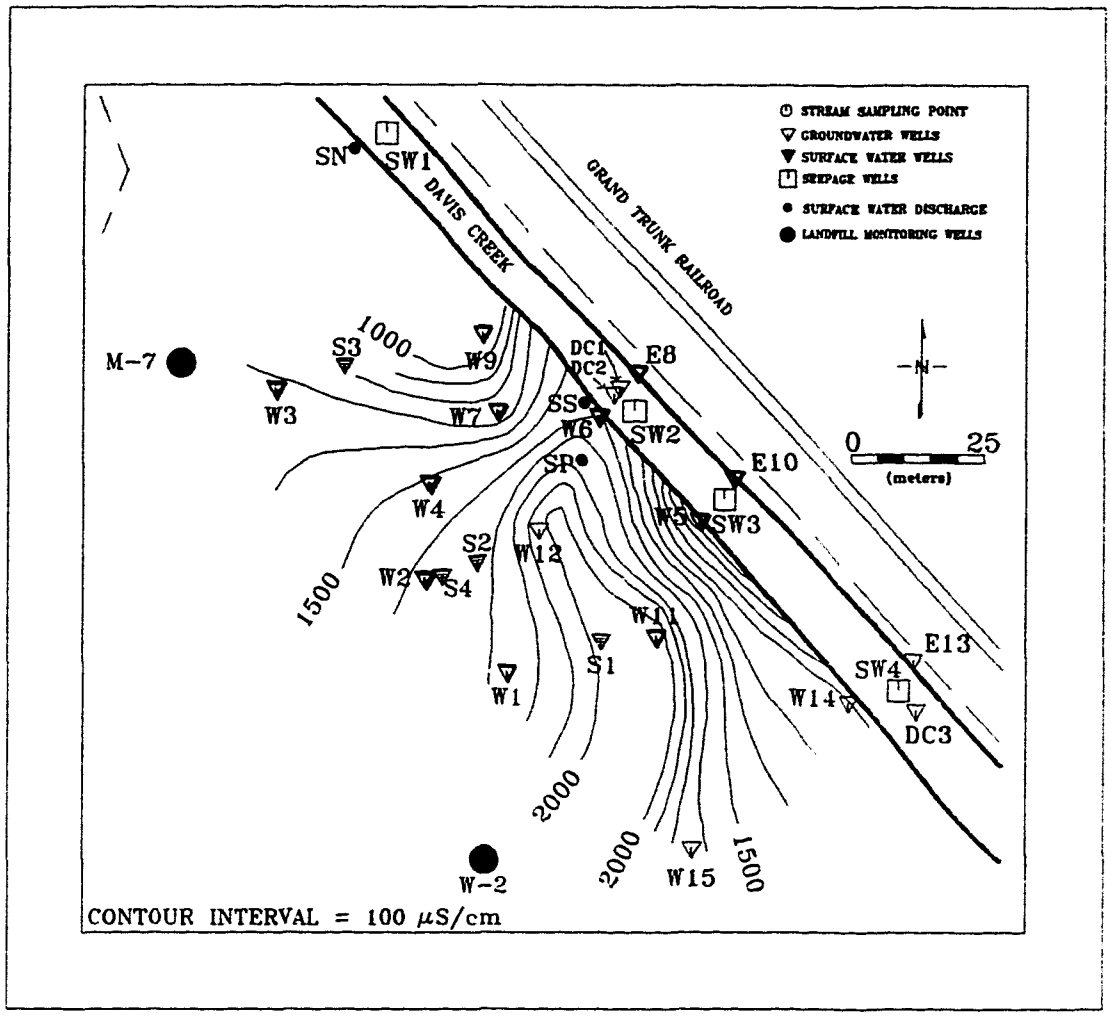


Figure 8. Map of the Distribution of Specific Conductance for Shallow Monitoring Wells in the Study Area.

stations are slightly higher than those of the June survey. The difference in the ground conductivity values between these surveys may be reflective of seasonal changes if the EM signature is attributed to conductivity associated with groundwater. The highest conductivity values are observed in the south-central portion of the survey area

(extending south of monitoring well M-7 to just south of W-2). The conductivity values within the anomaly are highest close to the landfill boundary on the west, reducing to the north and the east towards Davis Creek. The lowest values obtained for the entire site are for stations next to Davis Creek and to the north of the survey area.

When compared to the vertical dipole EM survey of June and December, the horizontal dipole conductivity component (Figure 5) shows a more pronounced and continuous EM anomaly. The pronounced anomaly is located in the southern portion of the survey area and is separated from a less pronounced one to the north. The separation of the pronounced anomaly to the south and north is defined by the 75 mS/m contour which stretches from a location close to monitoring well M-7 in a southeasterly direction towards Davis Creek. Although the conductive anomaly is better outlined on the horizontal dipole mode, the difference in the conductivity suggest variations with depth.

The EM conductivity was verified with the survey of groundwater conductivity in monitoring wells in this region. The specific conductance of groundwater and water in the wetlands and surface water discharging from the wetlands are high. In the measured range of 600 to 3000 μS/cm, more than 90% of the samples had values of greater than 1000 μS/cm for the entire period of the study. These values are higher than the 400 to 600 μS/cm measured for background monitoring wells at the landfill site and Davis Creek. The unusually high specific conductance is attributed to

groundwater contamination, since the highest values measured for the site fall in the range of 2000 to 4000 μS/cm measured for leachate from the leachate collection system. The map of specific conductance distribution (Figure 8) shows that the highest specific conductance values are near the landfill and decreases towards Davis Creek. Although this map shows the distribution for the specific conductance of the 12/5/95 survey, the overall pattern of the map would be similar for all other surveys. The region of high specific conductance (Figure 8) is similar to that of the EM conductivity maps (Figures 4 and 5). Not only does this similarity validate the EM conductivity measurements, it allows the EM conductivity to be attributed to highly conductive contaminated groundwater below the study area.

Results of the inphase data are presented in Figure 6a and 6b. In the vertical dipole mode, areas of discontinuous positive and negative anomalies are observed (Figure 6a). The horizontal dipole shows a similar distribution, except for a linear belt of positive anomalies along Davis Creek (Figure 6b). This anomaly corresponds to the low or negative anomaly observed with the same trend in the EM quadrature horizontal mode (Figure 5). The presence of a sewage pipe running along Davis Creek may be responsible for this anomaly.

The average magnetic values for the site are in the 5600 nT range. In general, values in excess of 2000 nT above the background are observed in this region. The magnetic distribution map (Figure 7) show anomalous magnetic regions coincident with those observed in the conductivity maps (Figures 4 and 5). As should be the

case, there is a fairly good agreement between the magnetic anomalies and those observed on the inphase map (vertical dipole, Figure 6a). Although the magnetic signature can be influenced by small discrete objects lying on the ground surface, there is poor correlation between the magnetic and the inphase data in the horizontal dipole mode, suggesting deeper sources than the depth that the EM-31 in this mode could effectively sample. The deeper source for the magnetic anomalies is also supported by the EM inphase vertical dipole data.

The results of the geophysical survey, especially the magnetic data, confirm that this area has been used for disposal activities. The difference in the EM inphase horizontal mode compared with the vertical mode and magnetic results also suggests that the waste is covered for the most part with fill material that is less magnetic than the disposed material. The EM and magnetic data, as separated by the southeast linear trend from monitoring well M-7 towards Davis Creek, indicate that the area to the south and north of this trend may represent two separate disposal cells. The EM results show that high subsurface ground conductivities in the survey area may extend beyond the site to the fill area. The shape of the shallow conductive anomaly (Figure 5) and its abrupt termination along the trend defining the disposal cells, is consistent with the nature and distribution of the disposed materials.

Conclusions

Geophysical studies have been quite successful in mapping anomalous areas within the study area. Generally, high apparent conductivities occur near the landfill and decrease towards Davis Creek. EM inphase and magnetic data suggest that this area was used for disposal activities. The EM and magnetic data sets indicate the presence of two main cells in which the material disposed may be different. The anomalies observed in the data complement each other and show similar distribution. The agreement of the EM conductivity anomalies with groundwater specific conductance is indicative of groundwater contamination at the site. The extension of the EM anomalies and groundwater specific conductance contours towards the landfill to the west indicate a possible landfill source for this contamination. However, the presence of refuse disposed in the surveyed region suggests that the landfill is not the sole source of the anomaly. It is believed that this area could in itself be the source of the anomaly or could enhance a source from the landfill. The EM data show a strong conductive gradient towards Davis Creek suggesting that the highly conductive groundwater may be discharging into the creek.

CHAPTER IV

HYDROLOGIC MONITORING AND ASSESSMENT

Introduction

The objective of the hydrologic evaluation of the study area was to understand groundwater dynamics. It was important to know both the seasonal and precipitation influence on the hydrology of this area. An understanding of the hydrodynamics of the site is required in order to apply or develop a hydrologic water balance model for the wetlands. This model would allow the determination of the dominant water source for the wetlands and thus allow the assessment of the potential role any contaminated groundwater would have in the wetland. The information was also considered valuable to evaluate the relationship of groundwater at the site to Davis Creek.

It was believed that the electromagnetic and magnetic results at the site combined with the distribution of vegetation were a reflection of the hydrology and water quality. Thus, based on the distributions of the electromagnetic and magnetic signatures and the distribution of dominant vegetation types, sampling locations were selected for all the hydrologic investigations. Sampling locations included groundwater, surface water within wetlands, surface water runoff from the site into Davis Creek, Davis Creek, groundwater below Davis Creek, and seepage into Davis

Creek (Figure 9). The same sampling locations were subsequently utilized for stable isotope studies and water quality monitoring.

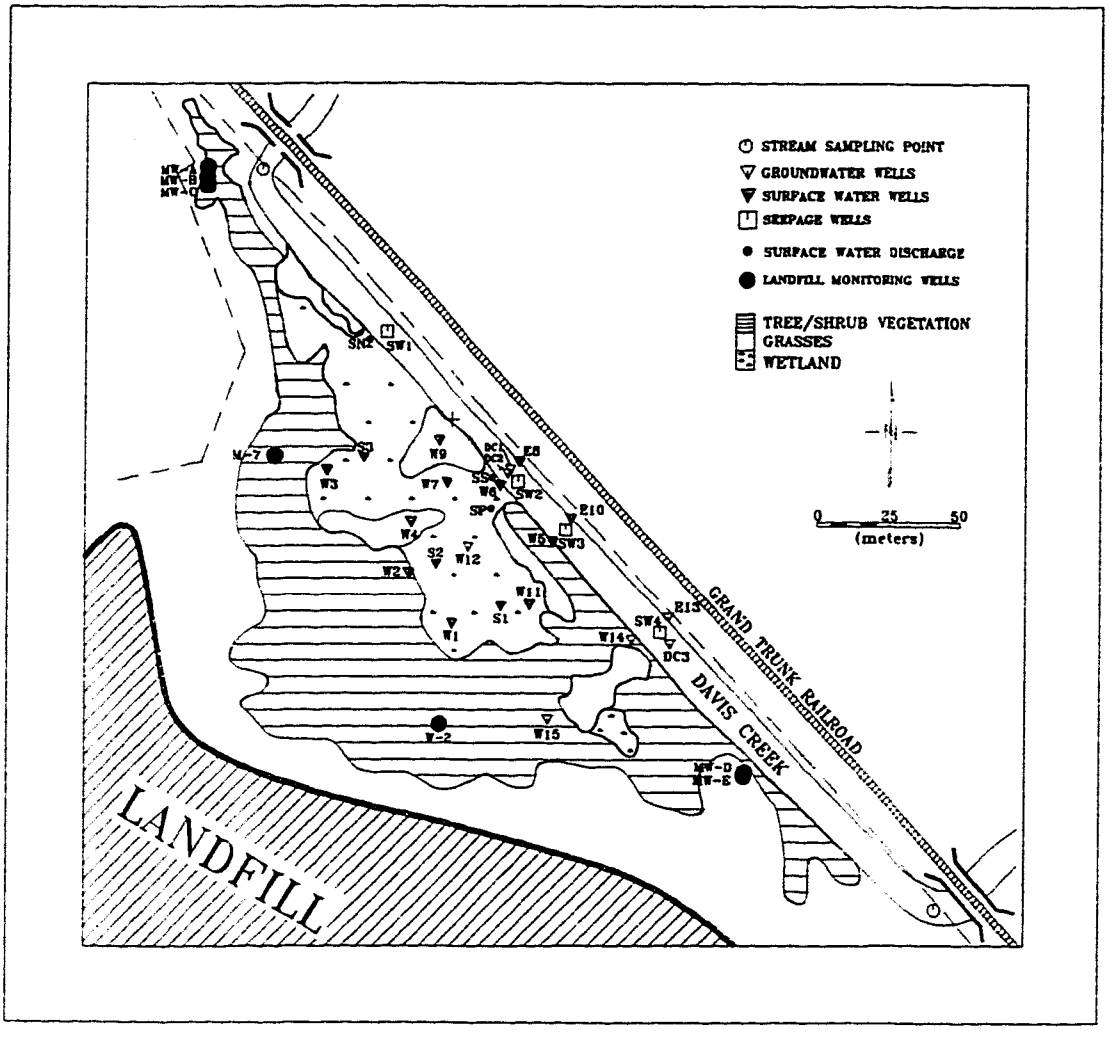


Figure 9. Map Showing Sampling Locations for Groundwater, Wetlands and Surface Water in the Study Area.

The locations selected for monitoring were distributed to monitor groundwater in areas of high and low electromagnetic conductivity, monitor groundwater as it flowed from the fill area towards Davis Creek, monitor surface water within the wetland areas and monitor groundwater below Davis Creek. Many wells were constructed; 37 wells for groundwater monitoring, 4 wells for monitoring surface water in a portion of the wetland area, and 3 wells and 4 seepage wells for monitoring groundwater and seepage into Davis Creek.

Methods and Results

Groundwater Monitoring

Construction of Groundwater Wells and Piezometers

All the shallow groundwater monitoring wells were constructed of 76 cm long screens attached to 5.1-cm diameter PVC plastic pipes. They were sunk using a hand auger, and are identified with an "A" extension. In some locations, nested peizometers were constructed similar to the shallow wells but fitted with 6.3-cm long screens. The shallow peizometers in each nest was designated "B" and the deeper ones "C". The shallow wells and piezometers were installed to depths ranging from 150 cm to 300 cm, and the deeper piezometers from 240 to 300 cm below the ground surface. During well and piezometer construction, changes in the character of the material with depth were noted. All the wells and piezometers except for those in Davis Creek were

gravel packed and grouted with bentonite to the ground surface. The extent of the well riser above the ground surface (stick-up) was measured with a tape. The elevation of the ground surface at each well location was measured by surveying techniques from a known elevation (monitoring well M7) at the study site. The well construction details are given in Appendix C.

After the construction of the wells, they were developed by repeated pumping or by removal of water from the wells using a bailer. The process was repeated several times until the water obtained from the wells was clear. Davis Creek was considered a local water divide and used as a basis for naming the wells. All wells west of Davis Creek were given the W-prefix.

Static Water Elevation Measurements

Water levels in the wells were measured using an electronic water level measuring tape. The same electronic water level measuring tape was used for all water level measurements in this study and is capable of measuring water levels to better than 2.5 mm. The depth to static water level in each monitoring well was measured at the same location at the top of casing (TOC) for consistency. Water level measurements were made at random intervals from July 1994 through January 1996. Subsequently, depths to static water obtained in the field were converted to water level elevations and are compiled in Appendix D.

Monitoring Surface Water Within the Wetlands

Monitoring the hydrology of the surface water in the wetlands was limited to the basins or depressions. Four 76-cm PVC well screens, 5.1 cm in diameter, were pushed into the organic muck layer. The elevation of the top of screen was determined by surveying techniques. The four wells, S1, S2, S3 and S4, were measured periodically and with the same frequency as the groundwater wells using an electronic water level tape measure. The water depths were measured from the top of casing and the water level elevations were obtained in the same manner as described for the groundwater wells.

Monitoring Surface Discharge From the Study Area Into Davis Creek

After observing the wetlands area for several months, it was concluded that surface discharge from the site into Davis Creek was persistent and was an important hydrologic component of the site. The water at the site that occupied the two main wetland depressions drained into Davis Creek through gullies. Also, a spring located about 6 m west of Davis Creek discharged into the creek through a gully. Surface discharge into Davis Creek was monitored at these three locations, one associated with the spring, and the others with surface runoff from the two main wetlands basins. Although surface water discharges occurred at several additional locations, they were only significant in very heavy precipitation events and were more often associated with sheet flow rather than channelized flows.

Monitoring began in the spring of 1995. Locations of discharge measurements for the wetland, surface discharge south (SS) and surface discharge north (SN) and from the spring (SP) are shown in Figure 9. A 5-gallon plastic container was cut in half along the long axis. The cut-off piece was buried at the discharge point into the creek. The runoff was collected in a marked 10-liter container. The time it took to fill the container to the 5-liter mark was measured. A discharge rate was obtained by converting the field measurements to flow rate per unit time. The results of the flow rates for each point of measurement are compiled and presented in Appendix E.

Monitoring of Davis Creek Stage

The purpose for the measurement of Davis Creek stream stage was to obtain information about stream flow conditions for use in comparing the relative changes in the hydrology of the site in response to both seasonal and individual precipitation events. Davis Creek stage was measured at a location near the middle of the site. A stilling well (DC1) was constructed of a 76-cm long screen attached to a 5.1-cm diameter PVC riser installed in the creek to a depth of about 63 cm. The level of water in the DC1 was measured with an electronic tape. The stage of the stream (D CRK) was measured against well DC1 using an installed staff gauge. The results of the stage measurements are included in the water level measurements in Appendix D.

Monitoring Groundwater Below Davis Creek

Groundwater below the creek was sampled through wells. Two wells were constructed and installed below the stream bed. The wells DC2 and DC3 (Figure 9) fitted with 6.3-cm long screens were installed to depths of 120 and 70 cm below the stream bed (see well construction details in Appendix C). Static water elevation measurements from these wells obtained using an electronic water level measuring tape are compiled and presented with similar data in Appendix D.

Evaluating Groundwater Seepage Into Davis Creek

Traditionally, the direction of movement of water at surface water/groundwater boundaries has been evaluated using seepage meters (Lee, 1977; Lee and Cherry, 1978). The seepage meter technique appears to be successful if the conditions for installation are met. The requirements that the seepage metering device be completely submersed in water (Lee 1977; Lee and Cherry, 1978), is usually not satisfied in shallow streams. Davis Creek is a small stream and during periods of normal and low flow, complete submergence of a seepage meter is difficult. This renders the use of seepage meters impractical. With this in mind, a new device, a "seepage well" was designed and installed to evaluate the seepage across Davis Creek stream bed.

Construction and Installation of Seepage Wells

The seepage wells were constructed from two main components (Figure 10a), a 5.1-cm PVC pipe and a "five-gallon" plastic container. The plastic container was cut approximately 20 cm from the base. A threaded PVC flange was inserted from the inside through a hole cut in the base and secured with a threaded coupling on the outside. Leakage across the joint was prevented by the use of rubber gaskets. The PVC pipe was secured to the coupling. The length of the PVC riser in this experiment was cut to about 1 m above the base. The seepage wells were installed in the stream bed by pushing the base about 20 cm into the stream sediments. Attempts were made to ensure that the device was installed in a level position.

The device works on the same principle as a seepage meter (Lee, 1977). If groundwater seeps into the stream, it flows into the device and the water level rises in the pipe and can be measured (Figure 10b). Once seeping groundwater enters the device, it is trapped and can only get out in conditions of seepage reversal or if water is withdrawn from the device. Therefore, the static water level measured in the device represents the head at the base of the device and thus the potential rate of seepage for any given water level measurement. Changes in the static water level in the seepage well should provide temporal variations in the seepage potential if measured over time.

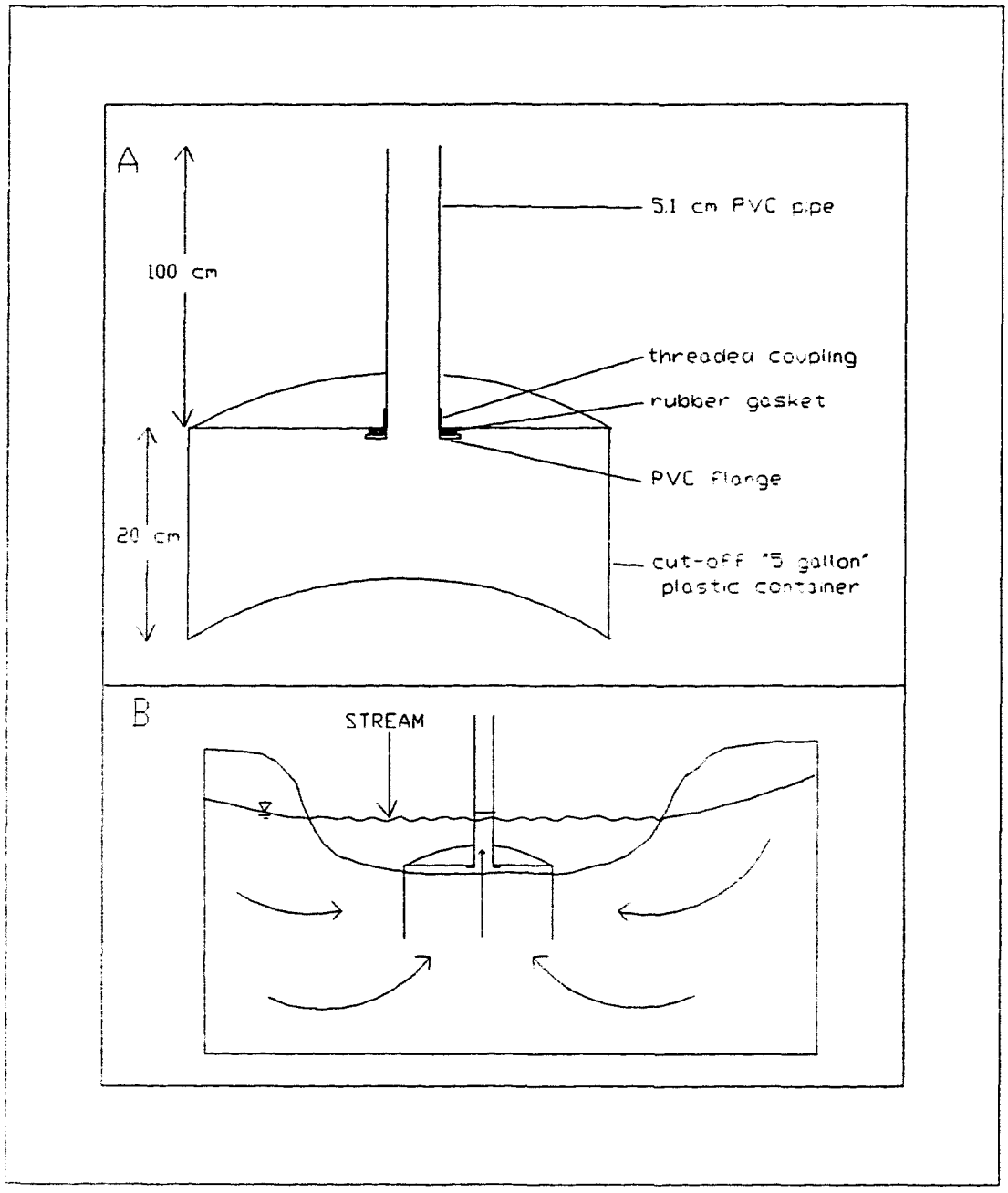


Figure 10. Components Utilized for the Construction of Seepage Wells (a). Schematic Showing the Installation and Principle of Operation of a Seepage Well. The Arrows Show the Direction of Groundwater Flow Into the Stream and Seepage Well.

The seepage well can be sampled in situ for physical groundwater quality parameters such as temperature, pH, conductivity and dissolved oxygen using downhole probes. Water samples can also be collected for laboratory analysis.

Verification of the Operation of the Seepage Wells

To verify the proper operation of the seepage well, four of the devices (SW1, SW2, SW3 and SW4) were installed at the site (see Figure 9 for installed locations). Preliminary investigations at the site indicated that the specific conductance of groundwater west of Davis Creek was different from that to the east as well as that of the stream. It is known that during the winter, the utilization of road salt for road deicing would elevate the specific conductance of the stream with little immediate influence on the groundwater at the site. It was believed that sampling for specific conductance in these seepage wells under varying stream flow conditions and road salt input would allow any possible shifts in the specific conductance of the seepage wells to be interpreted in light of surface water or groundwater inflow into the devices.

Sampling was conducted from October 1995 through January 1996. During each sampling event, measurements were made of the static water levels in each seepage well and of the creek stage of Davis Creek next to the seepage well. The specific conductance was measured for the seepage wells, monitoring wells installed below Davis Creek stream bed and monitoring wells adjacent to Davis Creek. Prior to

measuring the specific conductance, the seepage and monitoring wells were purged. In purging the seepage wells, at least 10 liters of water were removed from the device.

Results and Discussions. The results of seven sampling events conducted for this experiment are presented in Table 2. Plots of the static water elevations, Davis Creek stage at each seepage well installation and specific conductance from the seepage wells and monitoring wells are shown in Figures 11 and 12. In each of the plots changes in the creek discharge is represented by changes in the elevation of the creek stage.

It is interesting to note that increases in Davis Creek stage are mimicked by similar increases in the static water elevation in the seepage wells. However, changes in the specific conductance of the creek are not mimicked by similar changes in the seepage wells. The specific conductance values for the seepage wells remained fairly constant during low as well as high stream flow conditions. Two winter snow melt events of 12/14/95 and 1/22/96 show an increase in the creek stage and more than twice the specific conductance of the stream from the previous measurements. The static water elevation increased in the seepage wells, but the specific conductance did not show any appreciable change. If the seepage wells were sampling stream water rather than groundwater below the stream, significant shifts in the specific conductance would be observed during high stream flow conditions. These shifts would result in a reduction (dilution from direct precipitation) or an increase (runoff with high road salt content) in the specific conductance. Also the fact that the seepage

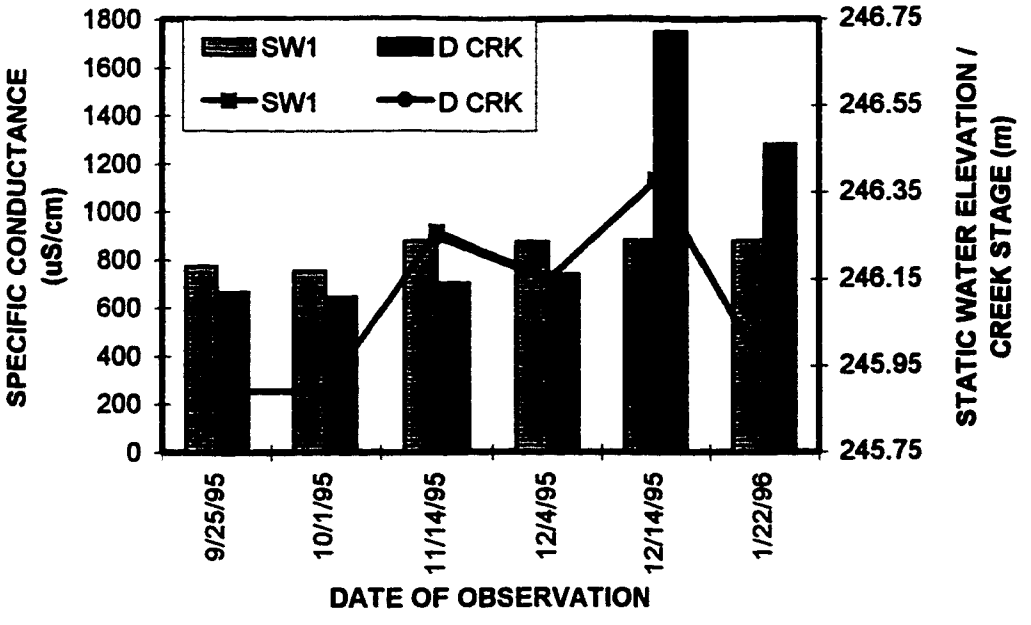
Table 2

Water Level Measurements and Specific Conductance's for Seepage Wells, Monitoring Wells Below Davis Creek and Groundwater Monitoring Wells Adjacent to Davis Creek (See Figure 9 for Locations of Sampling Points).

DATE	Level (m)	Stage (m)	Specific Conductance (μS/m)					
	SW4	Creek	SW4	Creek	W14A	DC3	E13A	
9/25/95	-	-	-	665	-	-	-	
10/1/95	-	-	454	643	-	-	-	
11/14/95	265.430	265.427	478	702	-	-	-	
12/4/95	265.360	265.354	489	739	1303	480	784	
12/14/95	265.555	265.543	477	1747	1279	470	774	
1/22/96	265.320	265.308	477	1279	1137	487	763	
	SW3	Creek	SW3	Creek	W5A	E10A		
9/25/95	265.140	-	633	665	1050	938		
10/1/95	265.131	-	648	643	1005	891		
11/14/95	265.375	265.384	701	702	896	891		
12/4/95	265.287	265.290	650	739	916	897		
12/14/95	265.500	265.506	709	1747	908	884		
1/22/96	265.159	265.155	693	1279	903	890		
	SW2	Creek	SW2	Creek	W6A	DC1	DC2	E8A
9/25/95	265.122	-	1151	665	2640	1320	906	938
10/1/95	265.116	-	1430	643	1596	1303	1101	1039
11/14/95	265.427	265.405	1381	702	1668	1250	1063	878
12/4/95	265.308	265.302	1306	739	1603	1231	1028	884
12/14/95	265.527	265.530	1478	1747	1639	1276	980	876
1/22/96	265.174	265.171	1345	1279	1581	1234	959	732
	SW1	Creek	SW1	Creek				
9/25/95	264.893	-	772	665				
10/1/95	264.890	-	752	643				
11/14/95	265.259	265.247	876	702				
12/4/95	265.149	265.146	874	739				
12/14/95	265.378	265.375	878	1747				
1/22/96	264.942	264.939	875	1279				

The - Indicates no Determinations were Made

a



b

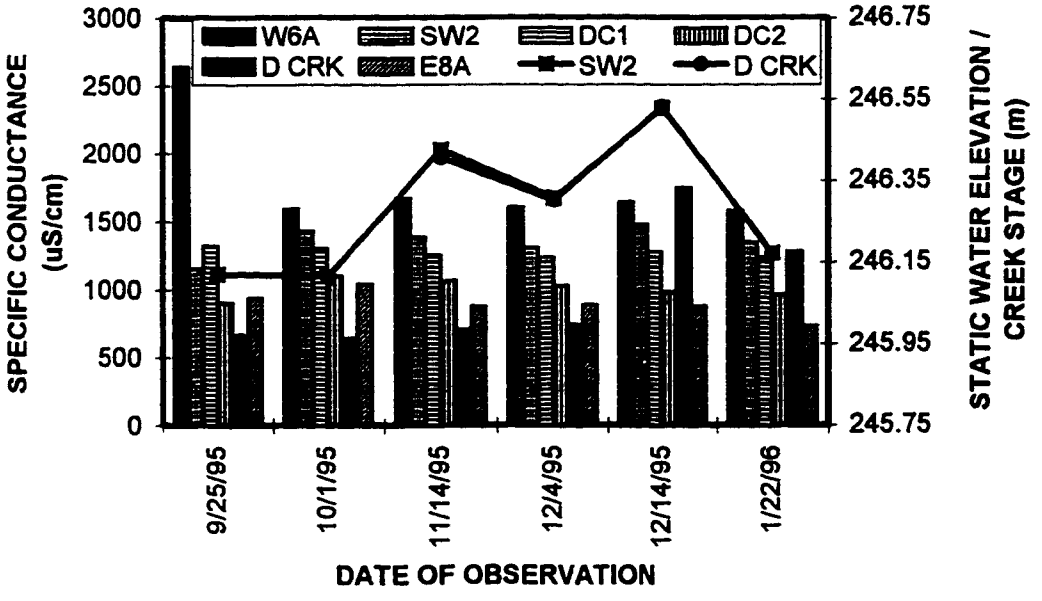
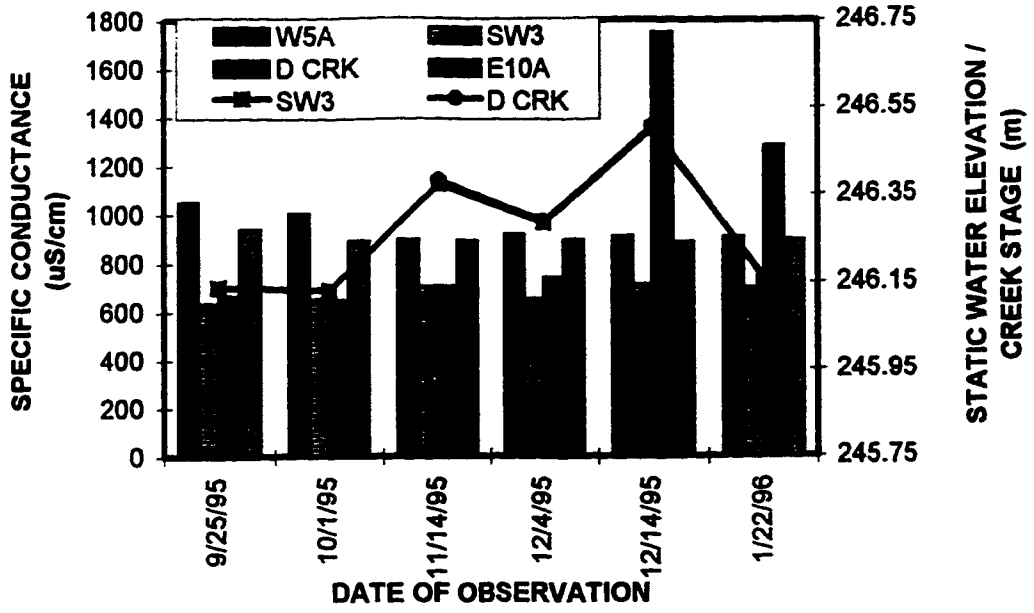


Figure 11. Specific Conductance (Bars), Water Level and Creek Stage (Lines) for Seepage Wells (SW1 (a) and SW2 (b)).

a



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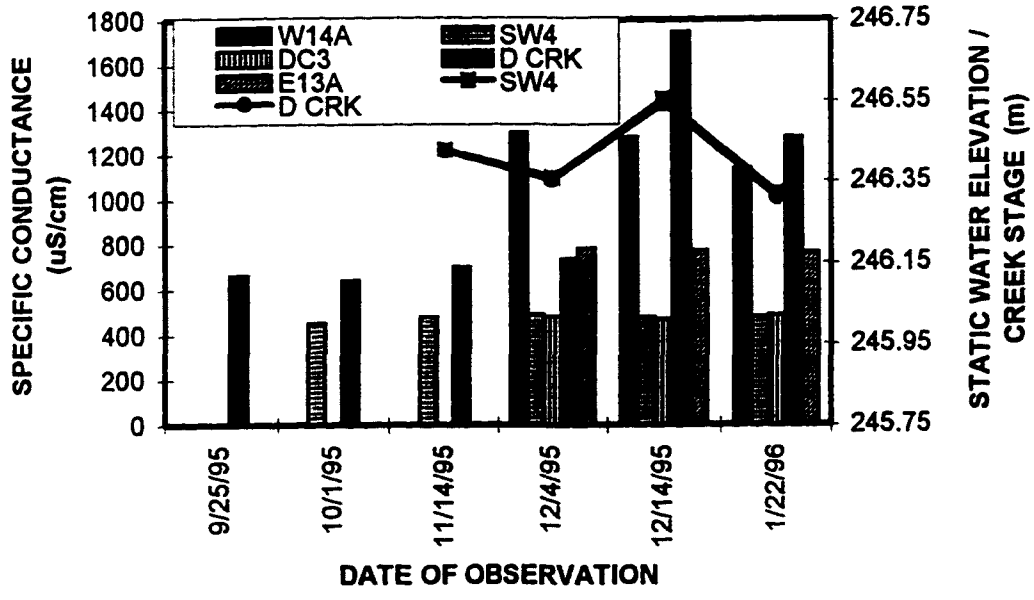


Figure 12. Specific Conductance (Bars), Water Level and Creek Stage (Lines) for Seepage Wells (SW3 (a) and SW4 (b)).

wells mimic changes in the specific conductance of the wells installed below the creek (SW2 and DC2, SW4 and DC3) or those adjacent to the creek (Figures 11b and 12a and 12b) constitute further verification of the proper operation of the seepage wells. The experiment not only demonstrates the ability of the device to evaluate seepage across the stream bed but also verifies seepage across this boundary from groundwater into the creek.

In conclusion, the seepage wells show that temporal variation in seepage flux across stream/groundwater boundary can be evaluated qualitatively. Sampling the device for water after purging provided representative samples of water seeping across the stream groundwater interface. The results of the Specific conductance measurements validates the use of seepage wells as a means of verifying seepage across a stream-groundwater interface.

Measurement of Stable Isotopes of Hydrogen

Introduction

Isotopes are nuclides which occupy the same position in the periodic table but differ in their nuclear properties. They have different atomic weights which consist of the same numbers of protons but different number of neutrons. Isotopes that do not undergo nuclear disintegrations are stable isotopes. Of more than 300 stable isotopes in nature, H, C, O, N and S are considered the light element isotopes because of their

low position in the periodic table. Because of physical, chemical and biological processes, stable isotope ratios of elements vary among natural substances.

The changes in the abundance caused by these processes is called fractionation. The degree of fractionation for a particular element depends on the relative mass of the isotope in question and on the nature of the fractionation process. Since the relative isotopic mass differences increase with decrease in atomic number, the degree of isotopic fractionation increases with decrease in atomic number. It is the degree to which fractionation occurs in nature that allows for detection and monitoring of natural systems by the use of stable isotopes, mostly the light element isotopes.

In general, most isotopic abundance measurement of light elements are carried out in gaseous species prepared from the sample. The gas is introduced into a mass spectrometer which separates and measures the isotopes based on their masses. The mass spectrometric measurements are reported as a deviation from an international standard by the use of the delta (δ) notation in per mil ($^0/_{00}$) units as:

$$\delta\,‰ = [(R_{sample}/R_{standard}) - 1]\,10^3$$

where R denotes the ratio of heavy over light isotopes of any element such as D/H, $^{18}O/^{16}O$, $^{13}C/^{12}C$ etc., in the sample and the standard respectively. Internationally accepted reference standards are used for uniform reporting; VSMOW for H and O, PDB for C etc.

Use of stable isotopes in the hydrologic system is possible because of their conservative nature. They are not altered by the normal inorganic chemical reactions in the hydrologic system and are thus effective tracers. The hydrologic evaluation at this study site made use of stable isotopes of hydrogen. Water has two independent hydrogen isotopes D (deuterium) and H. These hydrogen isotopes combine with ^{18}O or ^{16}O in water. The relative abundance of each of these isotopes in various stages of the hydrologic system allows for the effective use of the stable isotopes of hydrogen and oxygen for hydrologic evaluation. The monitoring of the hydrologic system by use of stable isotopes H-O pair is common (e.g., Fritz et al., 1976; Fritz et al., 1987; Yurtserver and Gat, 1981). Isotopes of hydrogen and oxygen have been used to assess patterns of flow and mixing, leading to the differentiation between background groundwater, overland flow waste water from treatment operations and groundwater from a class III landfill (Mohr et al., 1992). Hackley et al., (1996) advocate the use of deuterium for tracking leachate migration from landfill sites. While both hydrogen and oxygen provide the same information in hydrologic evaluations, the D-H pair is more sensitive. This is because of the smaller mass relative to the ^{18}O-^{16}O system allowing the D-H pair to undergo greater fractionation for the same hydrologic changes in the system. In addition, ^{18}O-^{16}O can exchange water with heavy rocks.

Measurements of Stable Isotopes of Hydrogen in Water Samples

Water samples were obtained from groundwater, surface water and a leachate collection system at the study site (see Figures 2 and 9 for locations). The samples were collected after purging of the wells in airtight 20 ml scintillation vials. In the laboratory, 3-4 μl was converted into hydrogen via the uranium reduction method of Bigeleisen et al (1952). The isotope ratios were determine in a Fisons Optima Isotope ratio mass spectrometer. The precision of δD measurements is $\pm$ 1 $^{0}/_{00}$ based on an internal laboratory hydrogen standard. The results of the hydrogen isotope analysis are shown in Table 3. Significance of the hydrogen isotope measurements are discussed in subsequent sections.

Discussions

Subsurface Characterization of the Study Area

From information compiled during the construction of the monitoring wells, the site is underlain by trash and fill material. The nature of the trash and fill varies across the site and confirms the results obtained from the EM inphase and magnetic survey. Below areas that are predominantly wet (i.e., wetlands), the material is mainly trash, while in the dry areas, the material is mainly soil mixed with glass ceramics. Some of the deeper wells at the site encountered what appeared to be hard soil,

Table 3

δD Measurements for Water Samples From the Study Site

	5/14/95		10/2/95	10/3/95	1/22/96	2/8/92
		REPEAT				
W1A	-62	-61	-	-61	-	-
W1C	-60	-	-	-59	-	-
W2A	-65	-64	-	-61	-58	-58
W2C	-60	-	-	-60	-	-
W3A		-	-	-62	-	-
W3C	-60	-	-	-	-	-
W4A	-61	-	-	-60	-	-
W4C	-	-	-	-59	-	-
W5A	-	-	-	-63	-61	-60
W5C	-61	-	-	-64		-60
W6A	-61	-62	-	-62	-59	-59
W6C	-60	-	-	-61	-	-59
W7A	-	-	-	-63	-	-
W7C	-58	-	-	-61	-	-
E8A	-67	-67	-	-57	-62	-61
E8C	-59	-	-	-59	-	-63
W9A	-68	-	-	-54	-59	-59
W9C	-62	-	-	-60	-	-59
E10A	-	-	-	-64	-61	-60
E10C	-63	-	-	-64	-	-60
W11A	-59	-	-		-	-
W11C	-59	-	-	-59	-	-59
W12A	-62	-	-	-61	-	-
E13A	-	-	-	-	-64	-63
W14A	-	-	-	-	-63	-61
W15 A	-	-	-	-	-61	-59
DC1	-60	-	-	-62	-59	-60
DC2	-61	-	-	-64	-58	-57
DC3	-	-	-		-58	-57
D CRK	-59	-	-59	-58	-59	-60
S1	-	-	-	-	-	-
S2	-63	-	-	-59	-	-
S3		-	-	-60	-	-
SP	-58	-59	-	-62	-58	-58
SS	-60	-	-	-62	-60	-60
S N	-	-		-61	-58	-60
SW1	-	-	-62	-61	-62	-59
SW2	-	-	-63	-62	-60	-58
SW3	-	-	-61	-61	-60	-59
SW4	-	-	-	-	-58	-56
LEACHATE	-60	-58	-	-60	-59	-58
LAB 5	-66 ± 1	n =10				

The - Indicates no Determinations were Made

disintegrated wood and peat-like material at about 3 m. It is believed that the soil, disintegrated wood pieces and peat-like material represent the original surface of the study area prior to disposal and filling activities. Because the areas that are wet are depressed and predominantly underlain by trash and covered with low permeability fill, it is inferred that the wetlands resulted from subsidence and pooling of water within these basins.

Groundwater Evaluation

The results of water elevation determinations for groundwater wells are plotted in Figure 13. Although water in some of the wells was frozen during the winter, this plot shows higher water levels from September through December and April through June. The lowest water levels are recorded from July through September. A similar pattern is seen in the shallow and deeper piezometers with 6.2-cm long screens (Figures 14 and 15).The plots also show that, except for wells along Davis Creek, well group W9 exhibits the most fluctuation in water level. This well group is located in a non-wetland area and shows a response in water levels that appears to reflect individual precipitation events superimposed on seasonal fluctuations. This would indicate that the material in this area is of a different hydraulic character than the rest of the site. Thus it is believed that this well group is semi-isolated from the rest of the site.

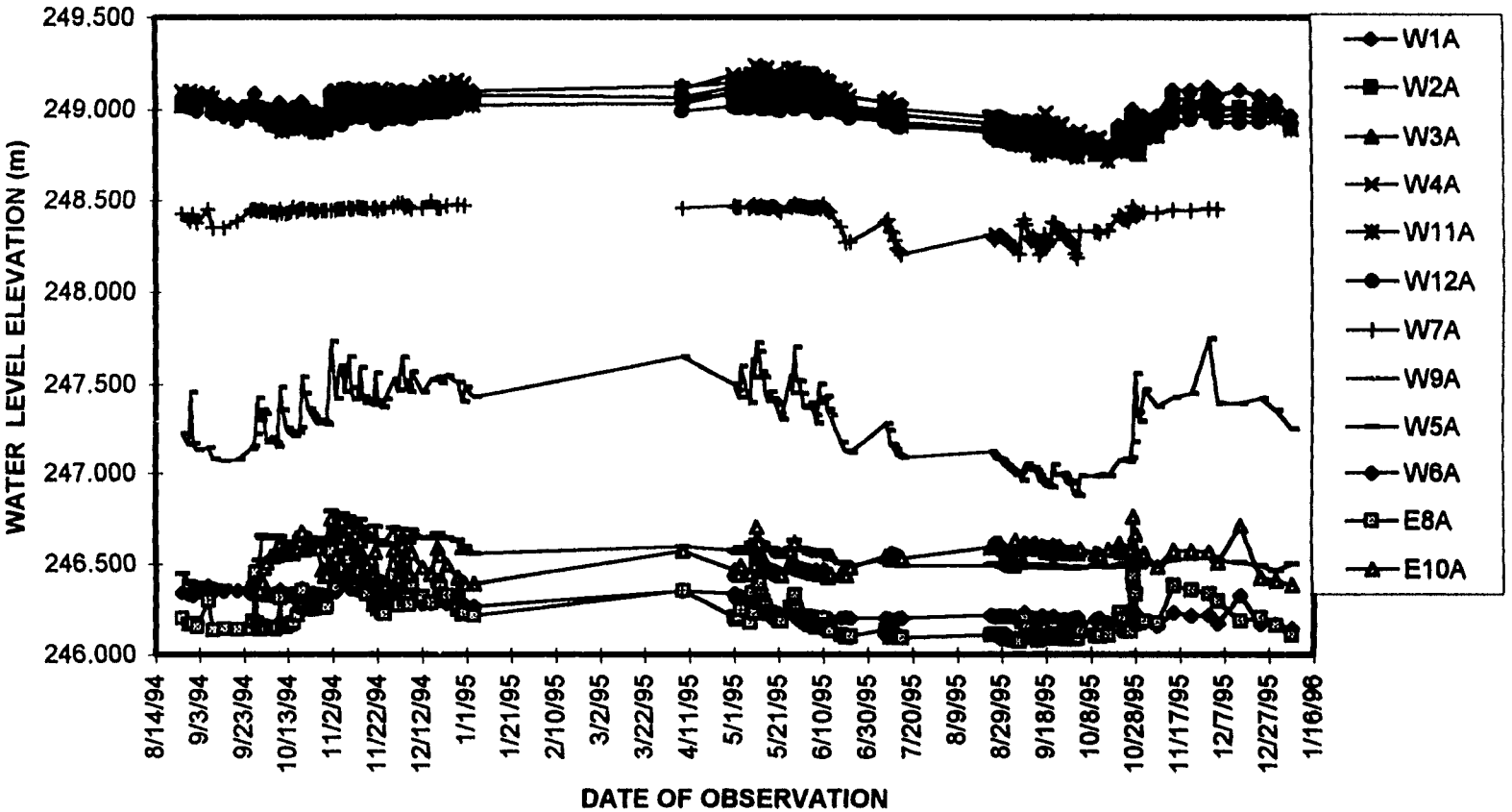


Figure 13. Hydrographs for Shallow Wells at the Study Site.

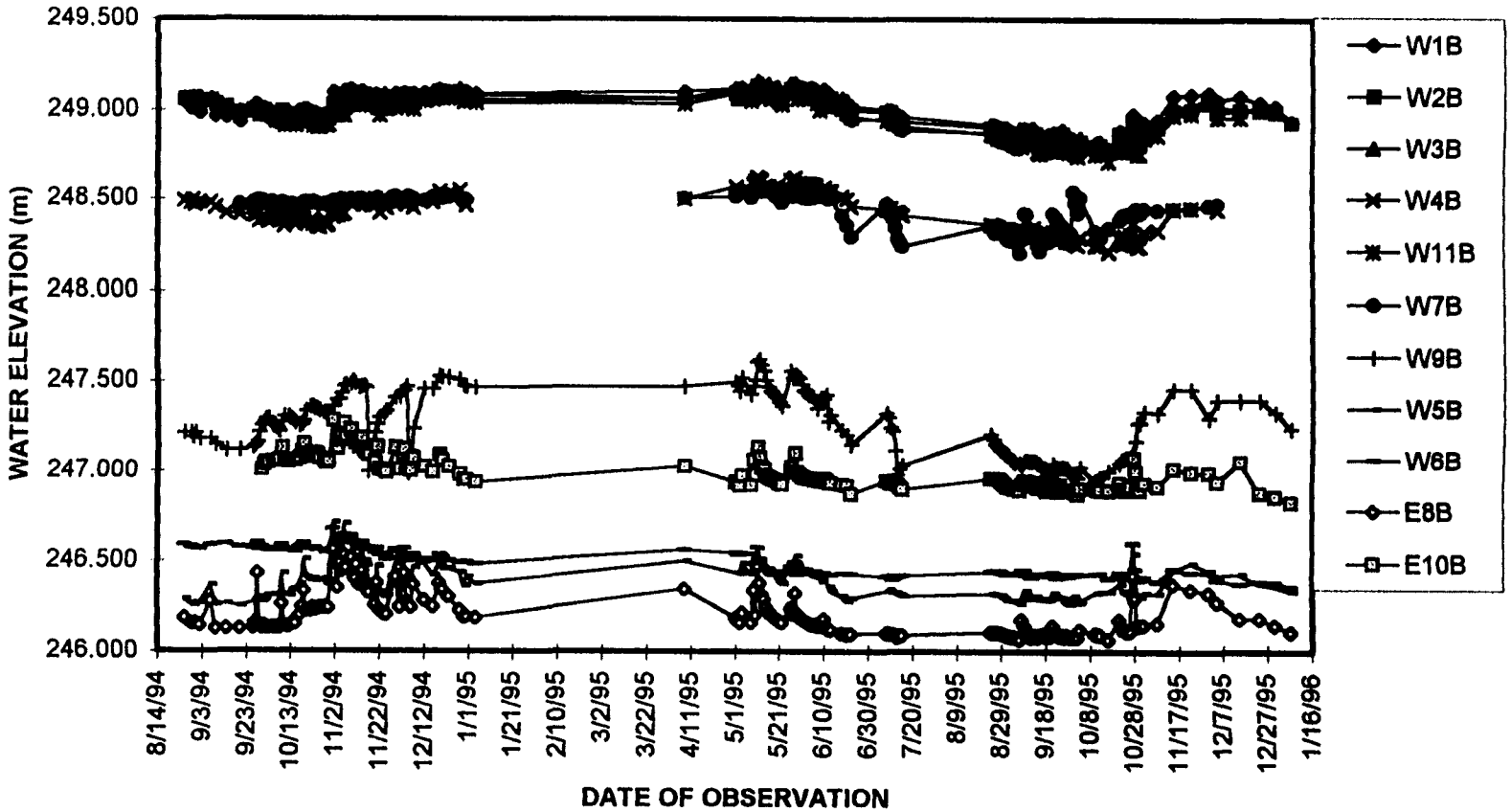


Figure 14. Hydrographs for Shallow Piezometers at the Study Site.

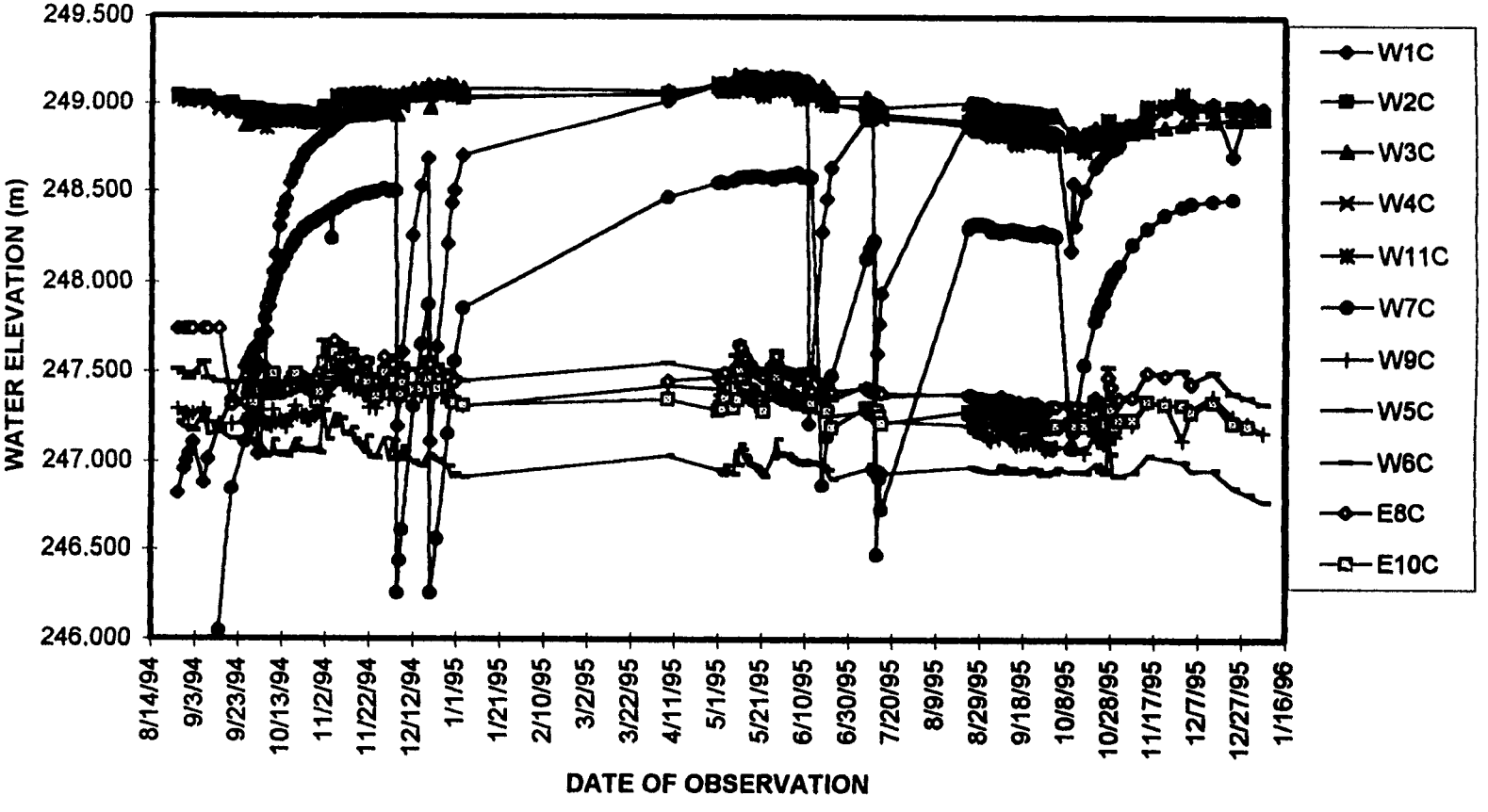


Figure 15. Hydrographs for Deeper Piezometers at the Study Site.

Figure 15 shows that during sampling events in which all the water from the deeper piezometer was removed, E8C, W1C and W7C were slow to recover to their original water levels. While E8C recovered after a few days, W1C and W7C took more than a month to recover. It can be inferred from the hydrographs that these piezometers especially W1C and W7C, are tapping less permeable material. The material is different from the overlying trash/fill material and thus it appears that the trash/fill below the site does not extend significantly below 3 m.

All the plots (Figures 13, 14 and 15) also show groundwater flow towards Davis Creek as seen by the decrease in static water elevation towards the creek. A contour map of water elevation distribution for the site shows a plan view direction of groundwater flow (Figure 16).

Vertical Hydraulic Gradient Analysis

The nested piezometers at the site were used for vertical hydraulic gradient analysis. Ground elevation, piezometer depth and head in the peizometers were used to calculate the vertical hydraulic gradient at each nest based on the method employed by Fetter (1994). The calculations were performed such that piezometer nests with upward hydraulic gradients had a positive sign. The results of the vertical hydraulic gradient calculations are shown in Figure 17. Missing in this plot are data from piezometer nest W1 and W7. For these nests, the deeper piezometers took several months to recover when purged for other measurements and thus the head values are

considered unreliable. From Figure 17, the predominant direction of the vertical hydraulic gradient is upwards. The magnitude of the upward vertical hydraulic gradient increases towards Davis Creek and is highest for the nests next to the creek. Because the vertical hydraulic gradient in most of the piezometer nests is positive, flow is upwards and thus the site is dominated by groundwater discharge.

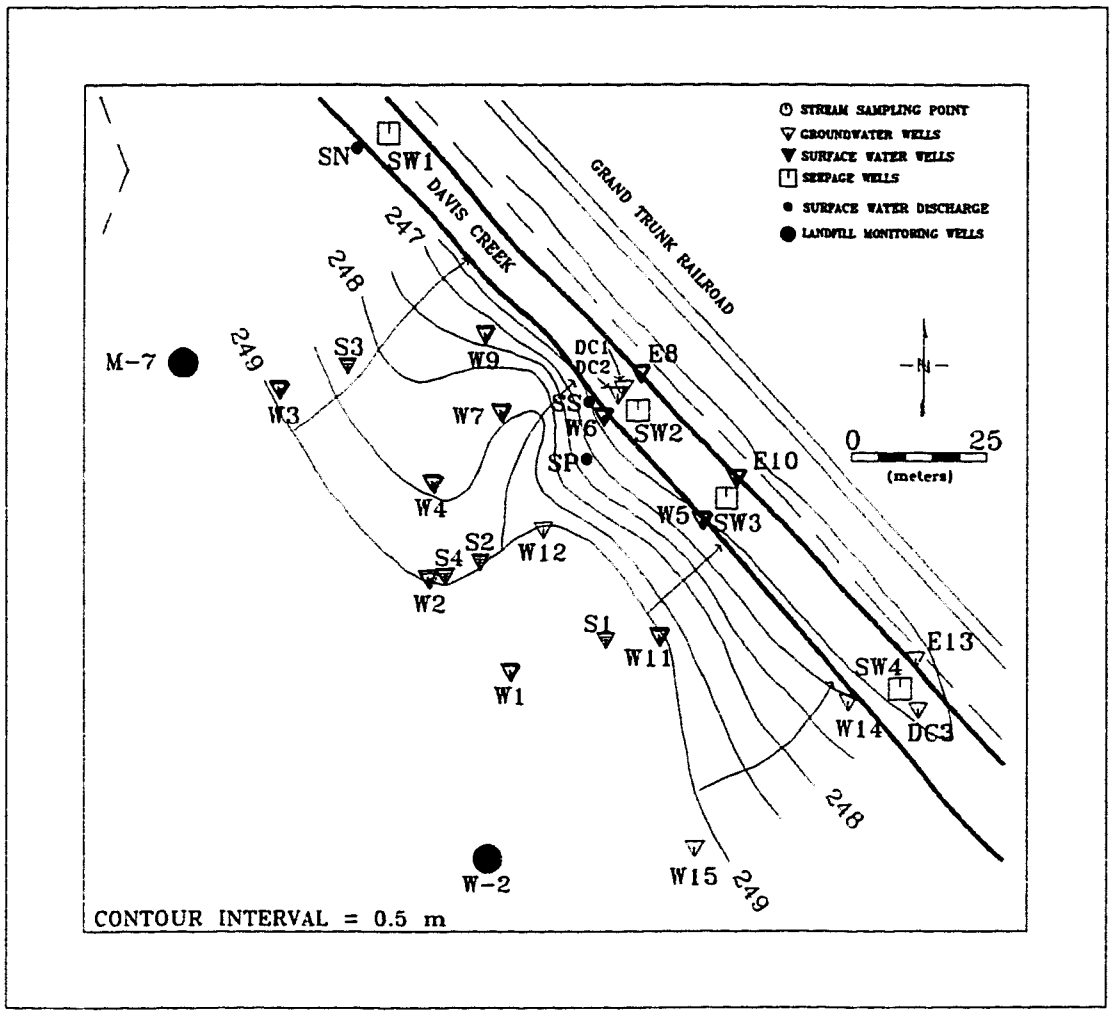


Figure 16. Groundwater Contour Map Showing Water Level Elevations and Groundwater Flow Direction (Arrows) in the Shallow Aquifer at the Study Site.

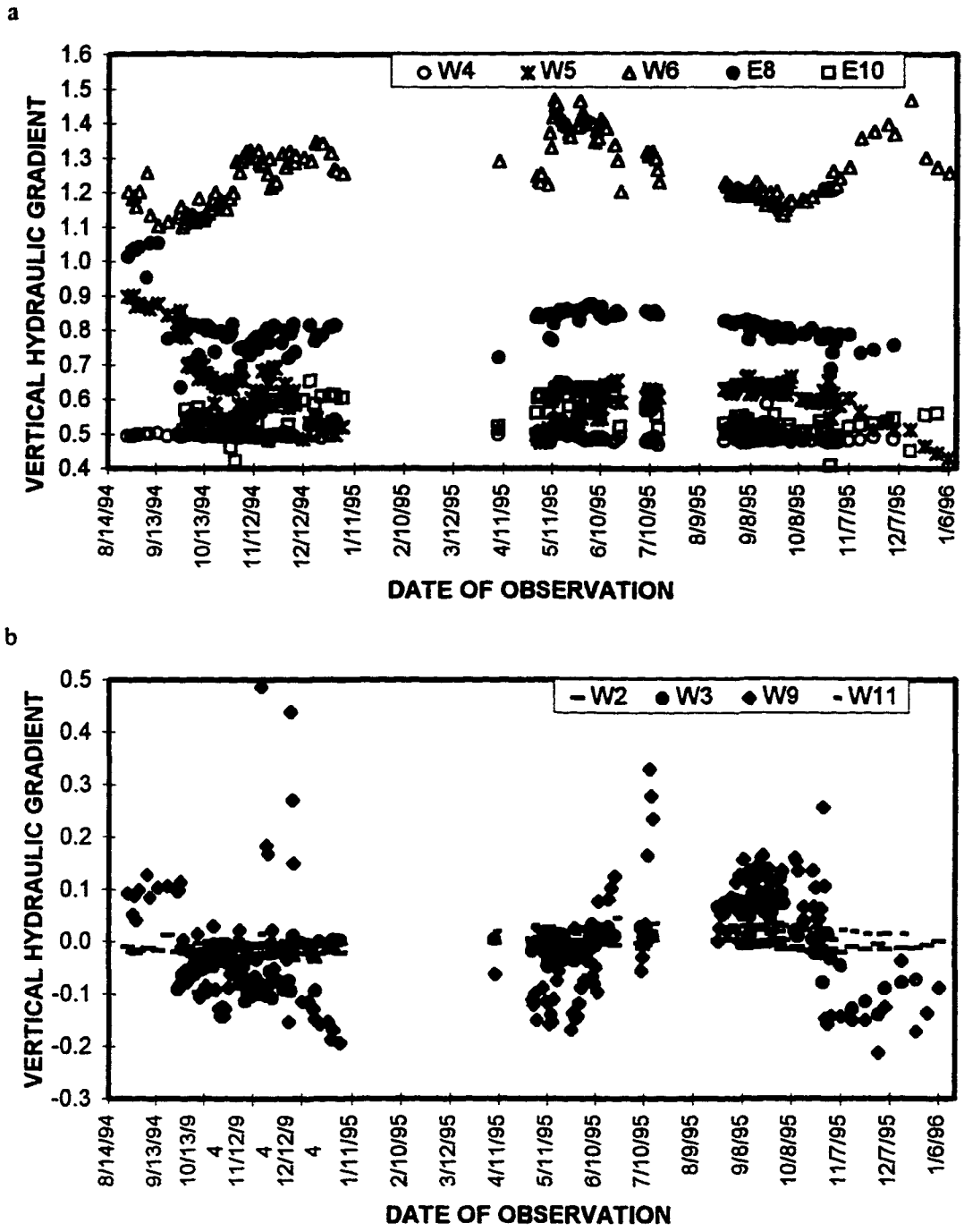


Figure 17. Temporal Variations in Vertical Hydraulic Gradient From Nested Peizometers at the Study Site.

Temporal variations in the vertical hydraulic gradient for all the nests show seasonality for some nests. Nests next to Davis Creek (W6, E8, E10) show the strongest temporal variation reflecting the dynamic nature of the groundwater/stream interaction. Piezometer nests W3 and W9 west of the Creek show seasonality. Here, the seasonality results in the reversal of the direction of the vertical hydraulic gradient. Although the data are not continuous through the seasons, these nests appear to have upward vertical gradients during the spring and summer and downward gradients in fall and winter. These two nests are expected to be influenced by direct precipitation recharge when the vertical hydraulic gradients are downwards and would result in precipitation influence on the chemistry and stable isotope measurements. In contrast, those piezometers that show little temporal variation in the vertical hydraulic gradient or seasonal variations with predominantly upward vertical gradients should reflect both a hydrology and chemistry dominated by groundwater.

Wetland Surface Water

The results of surface water elevations for wells in the wetland are shown in Figure 18. Overall, only a slight variation in the water levels are observed. Decrease in the water elevations occurs mainly in the months of August through November. When the temporal water elevations of the shallower wells (W2A, W1A, W3A, W7A, W11A and W12A) within and near the wetlands at the site (Figure 13) are compared to the wetland wells, they show similar trends. However, the actual magnitudes of

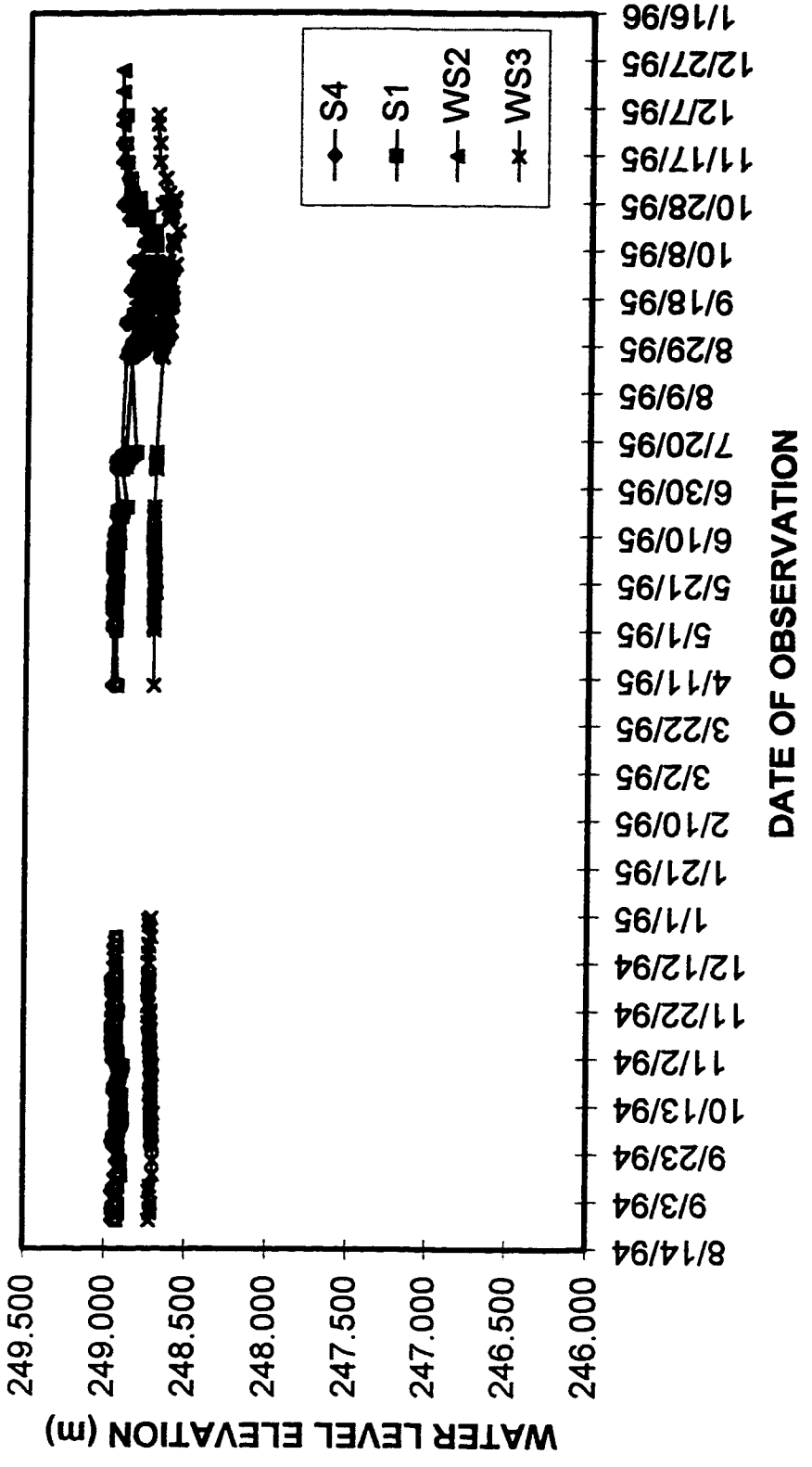


Figure 18. Hydrograph for Wetland Wells.

changes for the wetland wells is smaller than expected for the summer given the high evapotranspiration rates during this period. The implications of these small water level changes will be evaluated in light of surface water/groundwater interaction for the study area.

Surface Water Discharge Into Davis Creek

Surface water discharge into Davis Creek from the site is shown in Figure 19. Direct discharge from the wetlands (SS and SN) decreases continuously from May through October. Discharge from the spring at the site (SP) appears nearly constant through time. The spring is assumed to reflect ambient groundwater flow conditions below the site. The continuous decrease in wetlands water levels which coincides with the emergence and growth of wetland vegetation can be explained by increased evapotranspiration in the summer months. The slight increase in wetlands water levels in November coincided with dying off of wetland vegetation; the subsequent decrease in the winter is due to the freezing of the wetland surface water.

Spikes in the discharge of SS and SN reflect periods of basin overflow since the wetlands occupy depressions. A comparison of the temporal response in the static water elevations in the wetlands wells (Figure 18) and the spikes in the surface water discharge curves from the wetlands (Figure 19), leads to the inference that most of the spring snow melt and significant precipitation events mainly contribute to runoff from the wetlands. This allows a qualitative interpretation of groundwater dominance in

this hydrologic system, a view further explored in hydrologic water balance for the wetland.

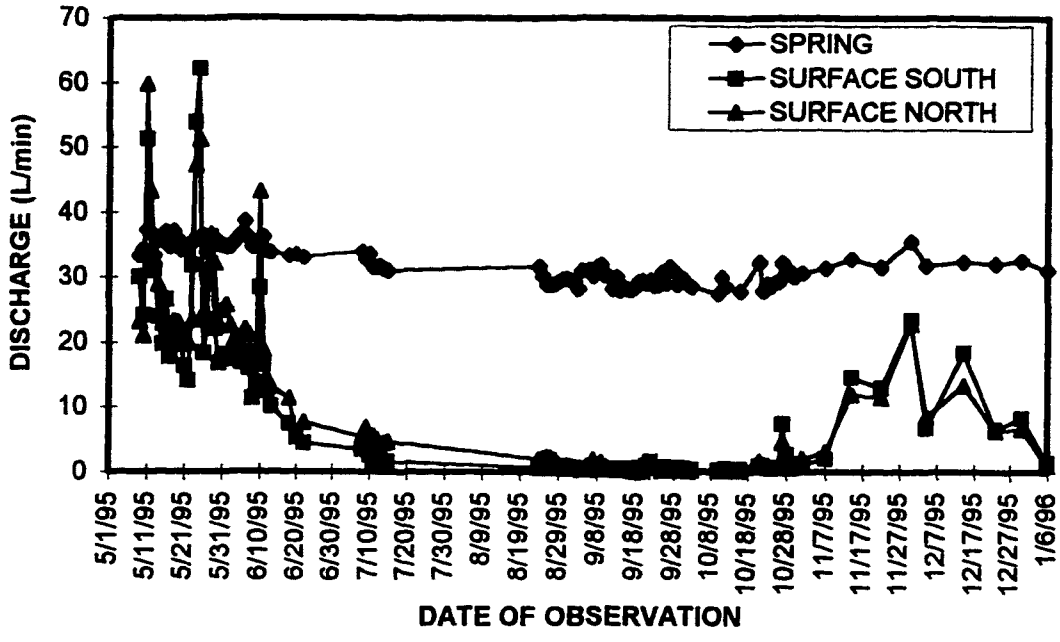


Figure 19. Hydrograph of Surface Water Discharge From Wetland Area Into Davis Creek.

Davis Creek Stage and Groundwater Below Davis Creek

Davis Creek stage and groundwater below the creek show similar temporal water elevation changes (Figure 20). The creek stage obtained from static water elevation in the stilling well (DC1) and the staff gauge are the same as expected. Temporal variations in precipitation are observed in the fluctuations of the stream stage. However, the static water elevation of well DC2, 120 cm below the creek bed, is higher than the creek stage throughout the period of measurement. A higher head in

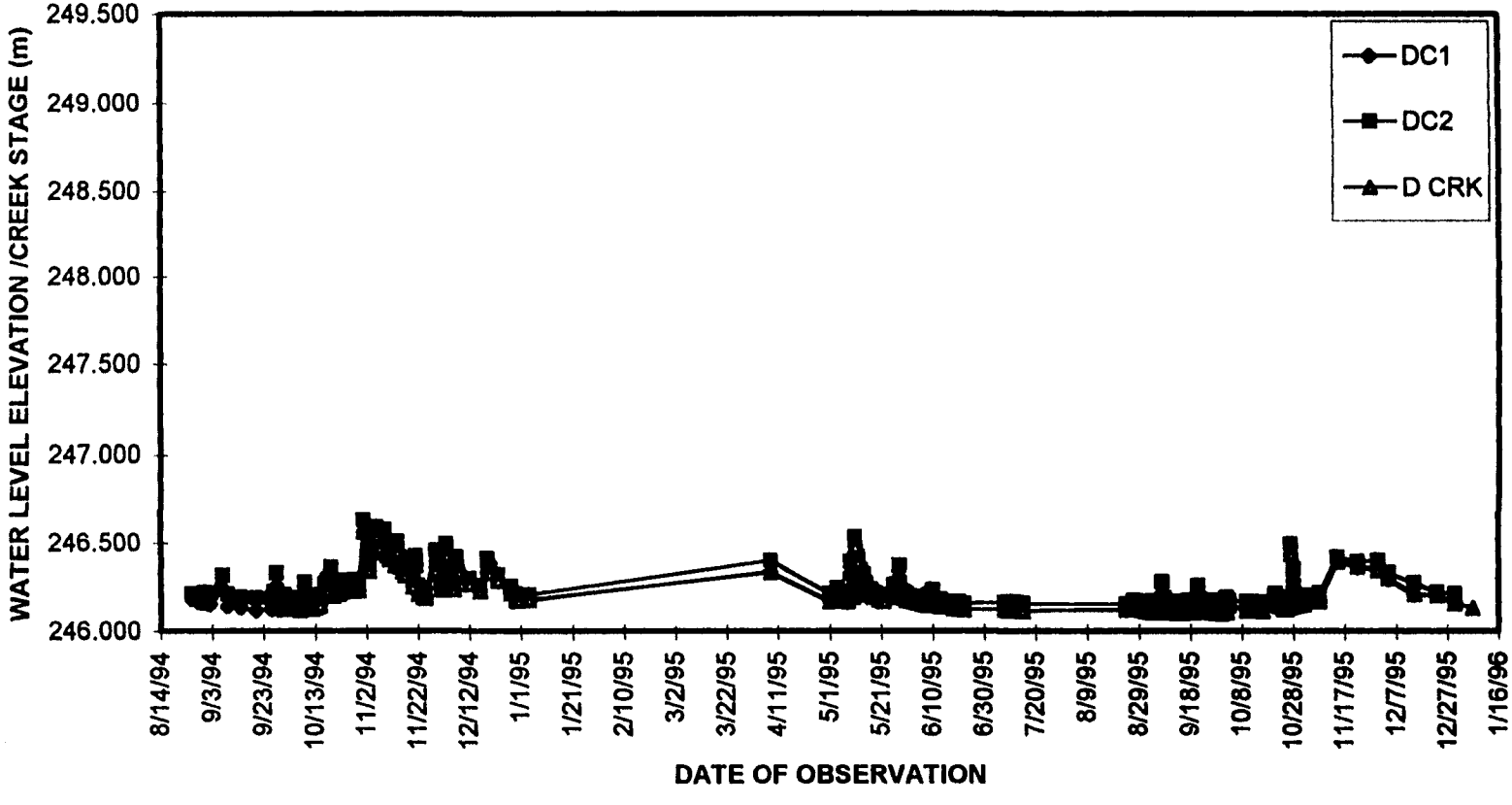


Figure 20. Hydrograph of Davis Creek Stage and Wells Located Below Davis Stream Bed.

well DC2 compared to the creek stage indicates an upward flow gradient. The higher heads in wells DC2 and DC3, along with the results from the seepage wells, indicate that seepage across the creek bed is from the groundwater reservoir into the stream.

Surface Water/Groundwater Interaction in the Study Area

Stream/Groundwater Interaction

To evaluate the interaction between groundwater and Davis Creek, Davis Creek stage is plotted against the elevation of groundwater wells. Since significant changes in Davis Creek stage result from precipitation events, such a plot is useful for comparing groundwater elevational changes in response to that of the stream stage. Such a plot for a stilling well and groundwater well in Davis Creek is shown in Figure 21. The stilling well DC1 shows a 1:1 relationship with Davis Creek stage. This is to be expected since the stilling well is another way of measuring the creek stage.

Well DC2 with a 6.3-cm long screen installed about 120 cm below the stream bed also shows a linear correspondence with changes in the stream stage (Figure 21). A regression through the data points representing DC1 and DC2 is shown in Figure 21. The slope of the line representing DC2 is close to 1. It is also evident that the water elevation of DC2 is higher than the creek stage throughout the study. The higher water elevation and a higher slope in the regression equation for DC2 indicates upward movement of groundwater into the stream bed. This strengthens the results obtained from the seepage wells which indicated groundwater seepage into the creek.

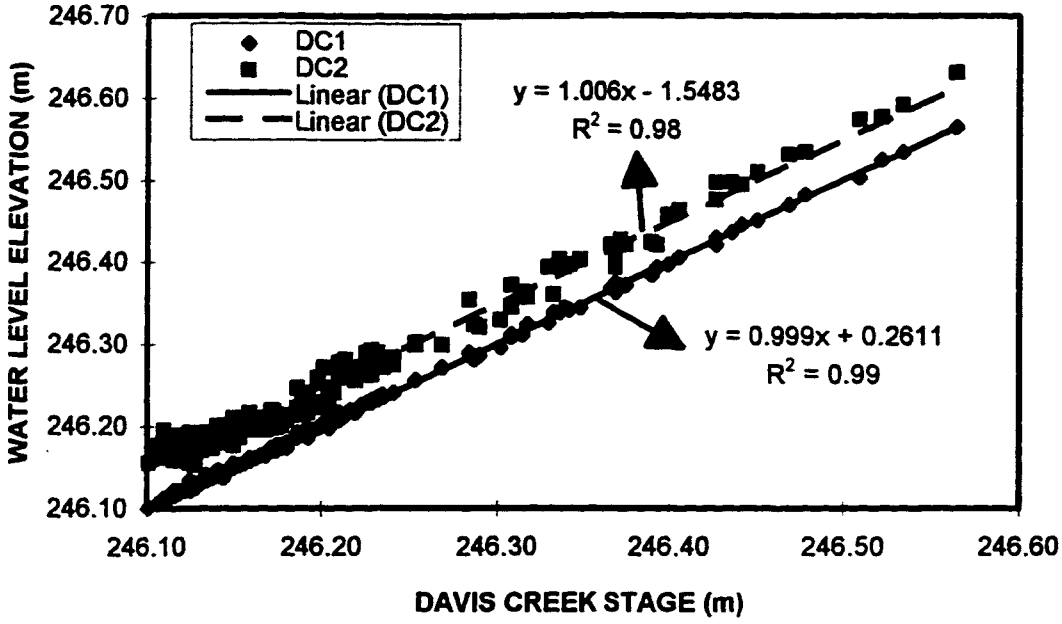
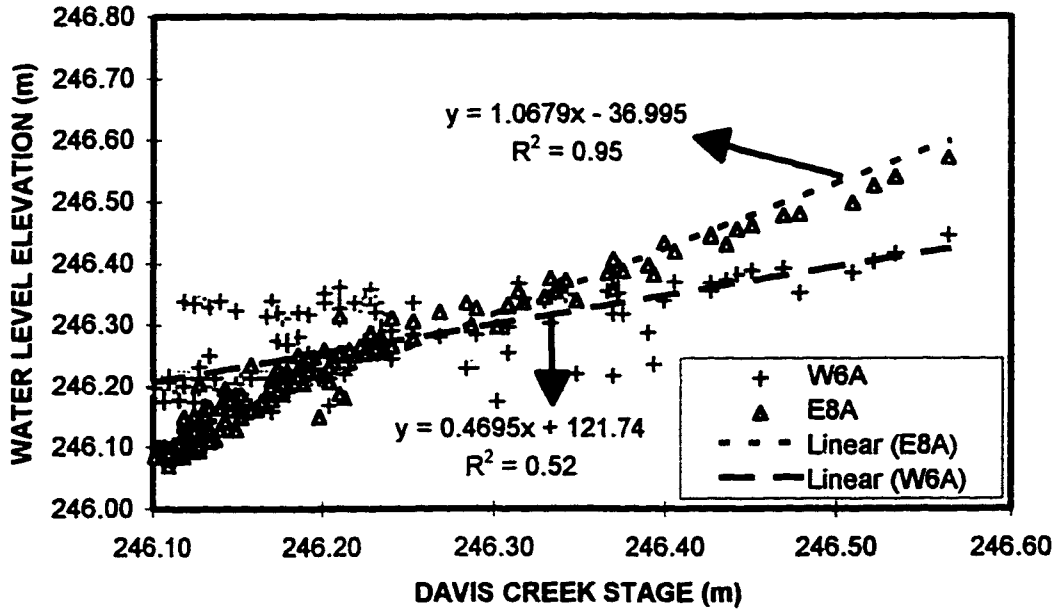


Figure 21. Davis Creek Stage vs. Water Level Elevation of DC2 Below Davis Creek Stream Bed.

A similar plot for shallow groundwater wells located next to Davis Creek is shown in Figure 22. Although the plot shows a general increase for the water level elevations in these wells for increases in Davis Creek stage, slopes for E8, W5A, W6A and E10A are 1.06 (r^2= .95), 0.58 (r^2= .63), 0.46 (r^2= .52), and 0.24 (r^2= .11) respectively. Only well E8 and to a lesser degree well W5 appear to have any significant correlation with changes in the creek stage.

The specific conductance results from the verification of the seepage well experiments showed that creek stage increases were sometimes accompanied by dramatic increases in the specific conductance due to road salt. However, the wells below and next to the creek did not show a significant increase in specific conductance

a.



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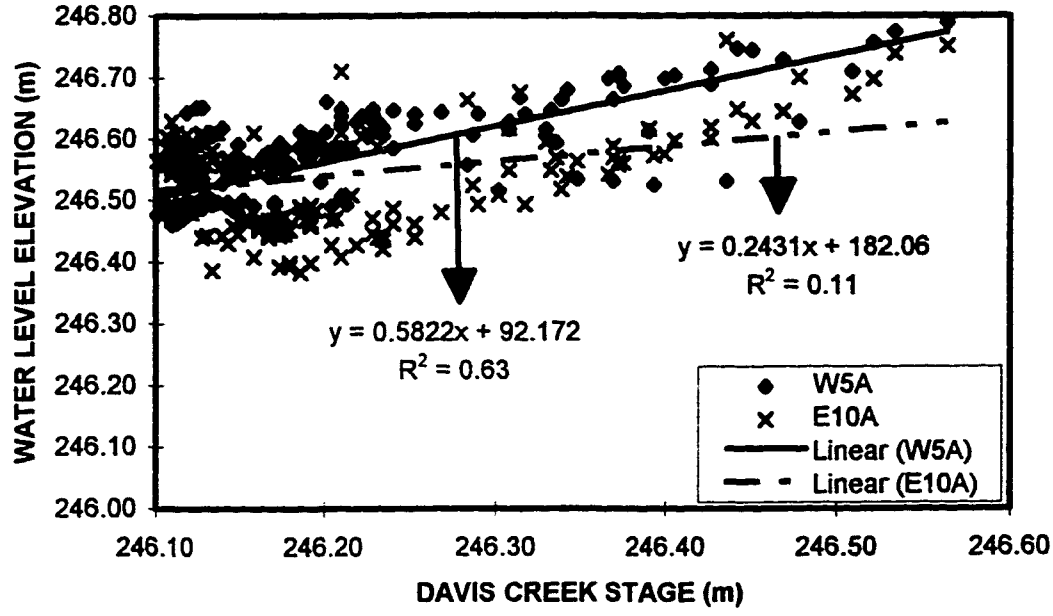

Figure 22. Davis Creek Stage vs. Water Level Elevation of Wells Adjacent to Davis Creek.

that could be associated with stream inflow into the groundwater system (Figures 11 and 12). Because it is reasonable to conclude that the stream chemistry is not affecting that of groundwater, the rise in water levels in these well is believed to be caused by physical factors imposed on groundwater flow due to an increase in the stream stage. It is speculated here that an increase in the stream stage increases the pressure that groundwater has to overcome in order to flow into the stream, leading to mounding. The mounding which occurs next to the stream manifests as an increase in the water level in wells next to the stream. This then provides sufficient pressure to drive groundwater into the stream. Another explanation that is consistent with water level mounding on the sides of the creek is resistance to subsurface storm flow into a stream that is attempting to flow into the aquifer at high stage.

Figure 22 also provides insight as to the nature of stream/groundwater dynamics at low stage and high creek stage. Wells with predominantly lower head at low stream stage have higher heads at higher stream stage. Between the well pair E8A and W6A, W6A has a higher head at lower stage while E8A has the higher head at higher stream stage. The same is true for E10A and W5, with E10A having the higher head at low creek stage. This appears to be reflected in the chemistry of the groundwater seeping into the creek (see Figures 11 and 12, and Table 2). For specific conductance measurements, W6A has a higher value than E8A. Well DC2 and seepage well SW2 show high specific conductance reflective of groundwater flow from W6A. A similar trend is observed for the well pair W5 and E10A for the

chemistry of SW3. SW3 is more reflective of groundwater contribution from E10A than W5A. The stable isotope results show a similar trend for water samples from seepage and groundwater wells below Davis Creek.

Wetland/Groundwater Interaction

A plot of Davis Creek stage versus the water elevation in wells S1, S2, S3, and S4 (Figure 23) provides an opportunity to examine the influence of precipitation in the wetlands. Increases in the stage of Davis Creek correspond to direct precipitation events or snow melts that generate runoff. Water levels in the wetlands if influenced by similar events should show an increase in water elevation in the wetland wells.

Figure 23 shows no relationship to increase in the creek stage. At low creek stage, small increases in the creek stage result in a maximum increase in the water levels in the wetlands wells. Further increases do not result in any appreciable water elevational changes, as seen by the flatness of the curves for maximum water elevation in the wetlands. Field observations indicate that these wetlands occupy basins or depressions which generate runoff only after the basin overflows. From measurements of surface water discharge (Figure 19), there is almost persistent discharge from the wetlands throughout the year. This leads to the conclusion that the water levels in the wetland have to be maintained by groundwater inflow in order to sustain such persistent surface water outflow from the wetlands. It is believed that the effects of precipitation or runoff and snow melt do not contribute significantly to the hydrology

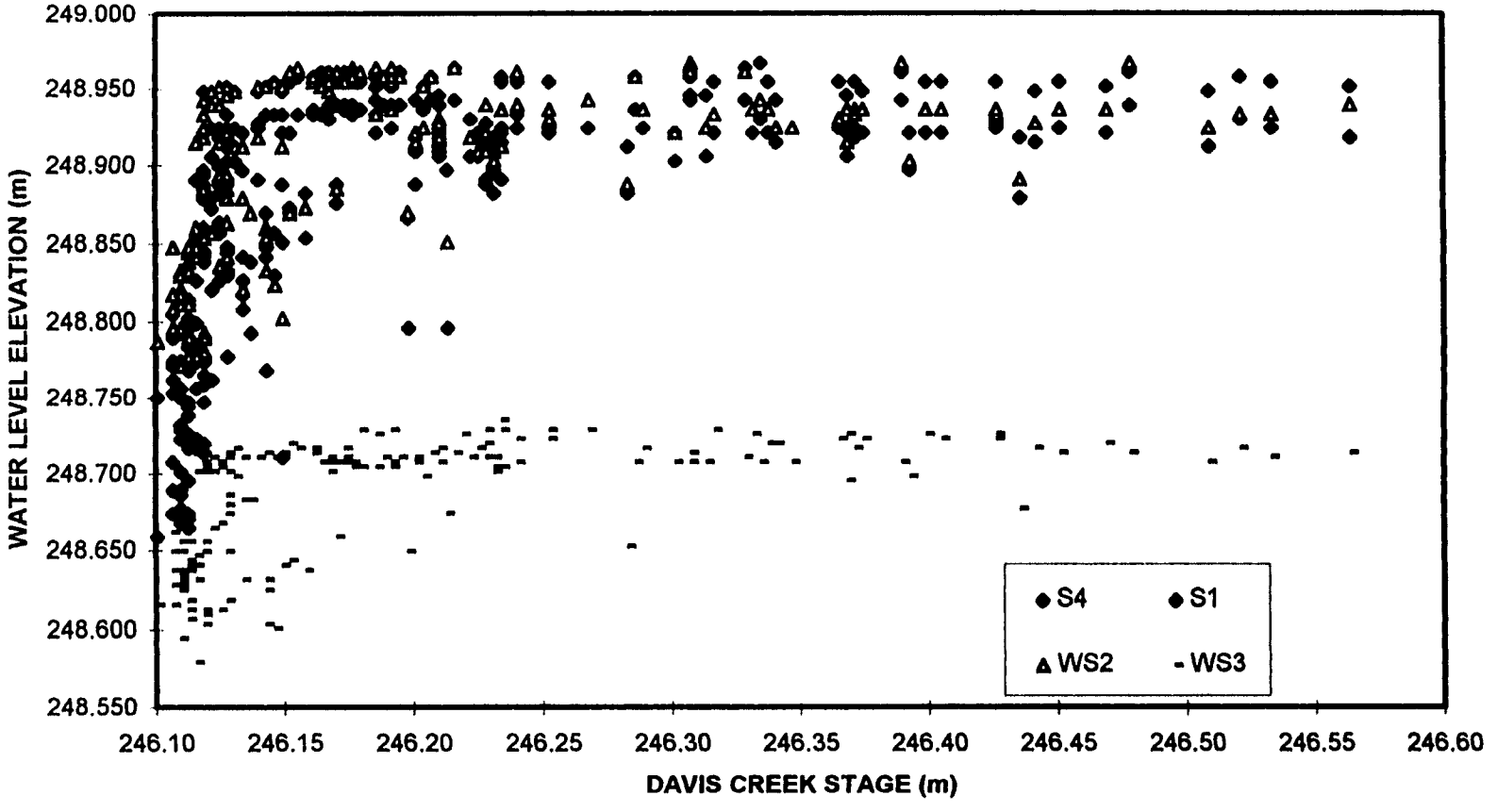

Figure 23. Davis Creek Stage vs. Water Elevations in Wetland Wells.

of the wetlands. This implies that the water chemistry of the wetland should be dominated by that of groundwater, a fact that is observed in the specific conductance measurements (Table 1). The specific conductance in the wetland wells and surface water discharging from the wetlands is high and similar to that of groundwater in this area. Stable isotope results to be discussed show little precipitation influence in the wetlands hydrology. The surface water in the wetlands directly interacts with the groundwater, a relationship dominated by groundwater discharge into the wetlands.

Stable Isotopes of Hydrogen

From Table 3, the δD values for water samples measured from the site range from -68 to -54 $^{0}/_{00}$. The δD value that is measured in groundwater is controlled by the value in precipitation. In recharge zones, preferential aquifer recharge might lead to isotopic stratification. In discharge areas, water discharging has been mixed within the aquifer resulting in isotopic homogenization. The range in the δD measured for water samples from the study area is rather narrow for the difference expected from a strong seasonal precipitation input signal in Kalamazoo (Machavaram and Krishnamurthy, 1994; 1995) The δD for Davis Creek for the entire sampling period ranges from -60 to -58 $^{0}/_{00}$. Davis Creek is a base flow stream, thus its isotopic value can be assumed to represent that of groundwater for the catchment basin. Table 3 also shows that there is little variation in the δD values with depth (except for well groups W9 and E8). Because there is little variation in the δD values with depth and because

δD of groundwater for the entire site is nearly constant and similar to that of Davis Creek, it can be concluded that the δD variations in precipitation observed for this area (Machavaram and Krishnamurthy, 1994; 1995) are not reflected in the groundwater and surface water at the site. The δD from water samples appears to reflect the annual mean δD for precipitation for the Kalamazoo area. This average δD of the annual precipitation value is an indication that the study area is receiving mainly isotopically homogenized groundwater.

The δD of surface water from the wetlands does not significantly change for spring and summer. This is in contrast to other wetlands in the Kalamazoo area that show significant evaporative enrichment during the summer months (Lovett et al., 1995). The decrease in the volume of water discharging from the wetlands from spring to the summer (Figure 19) is attributed to evapotranspiration. The δD of SS is similar to that of the wetlands surface water. The narrow δD values measured for the groundwater, surface water in the wetlands and surface water discharging from the wetlands can only mean that its hydrology is dominated by groundwater, a fact reflected by the upward hydraulic gradients in nested well piezometers.

Hydrogen Isotopes and Leachate Tracking

Hackley et al. (1996) advocate the use of deuterium as a tracer in migrating landfill leachate. This is because deuterium enrichment of 30 to 60 $^{0}/_{00}$ has been observed in landfill leachate and groundwater contaminated with landfill leachate.

Deuterium enrichment relative to background groundwater has been observed at other landfills (Fritz et al., 1976; Baedecker and Black, 1979; Rank et al., 1992; Lui et al., 1992). The cause of deuterium enrichment is attributed to very active formation of microbial methane within the closed system of a landfill over time. During the formation of microbial methane, the lighter hydrogen isotopes from water in the leachate are preferentially incorporated in the methane, resulting in deuterium enrichment in the leachate (Hackley et al., 1996).

The results of deuterium analysis in this study do not seem to show deuterium enrichment associated with any of the water samples at the site, including water from the leachate collection system. The lack of deuterium enrichment, which in principle could occur, is probably due to the nature of the prevailing hydrology of this system. Strong seasonal response to precipitation recharge has been observed in the landfill monitoring wells (Stevens, 1993) and leachate flow (Pogencheff, 1993). Although the magnitude of the recharge to the landfill is not known, high recharge can mask any leachate deuterium enrichment. Mixing in a predominantly groundwater discharge zone allows for significant contribution from deeper groundwater. This will result in damping any possible deuterium enrichment in migrating landfill leachate. The results of the δD distribution for the site can be interpreted in this light. It is believed that the utility of deuterium for leachate tracking at this landfill requires a future detailed study.

Hydrologic Water Balance

One of the hydrologic objectives of this study was to evaluate the possibility of landfill impacted groundwater discharging into the wetlands ecosystem. While static groundwater levels measured for the site allowed for determining flow conditions at the site, the contribution of possible leachate impacted groundwater to the wetlands and Davis Creek could not be identified by deuterium isotope ratios. Another way to assess the landfill's possible impact is to conduct a hydrologic water balance for the site. If the water source to the wetlands is dominated by groundwater, then it is likely that migrating leachate impacted groundwater would be part of the water supplied to the wetlands. Estimates of groundwater contribution to the wetlands requires quantification of groundwater inflow. Among the several methods available to estimate groundwater inflow, the isotopic mass balance method is believed to be the most accurate (Hunt et al., 1996). A water budget and isotopic mass balance method (Hunt et al., 1996) was used in this study for the evaluation of groundwater inflow into the wetlands.

Figure 24a shows a schematic representation of the hydrology of the wetlands in the study area. In this schematic, the various inputs and outputs of water in the wetlands are shown. Possible input sources for water to the wetland are: precipitation (P), and groundwater inflow (Gi) and surface water inflow (Si). Output source for the wetland include surface runoff from the wetlands (SS), groundwater outflow into the creek (Go), and evapotranspiration from the wetland (ET). By using estimates and

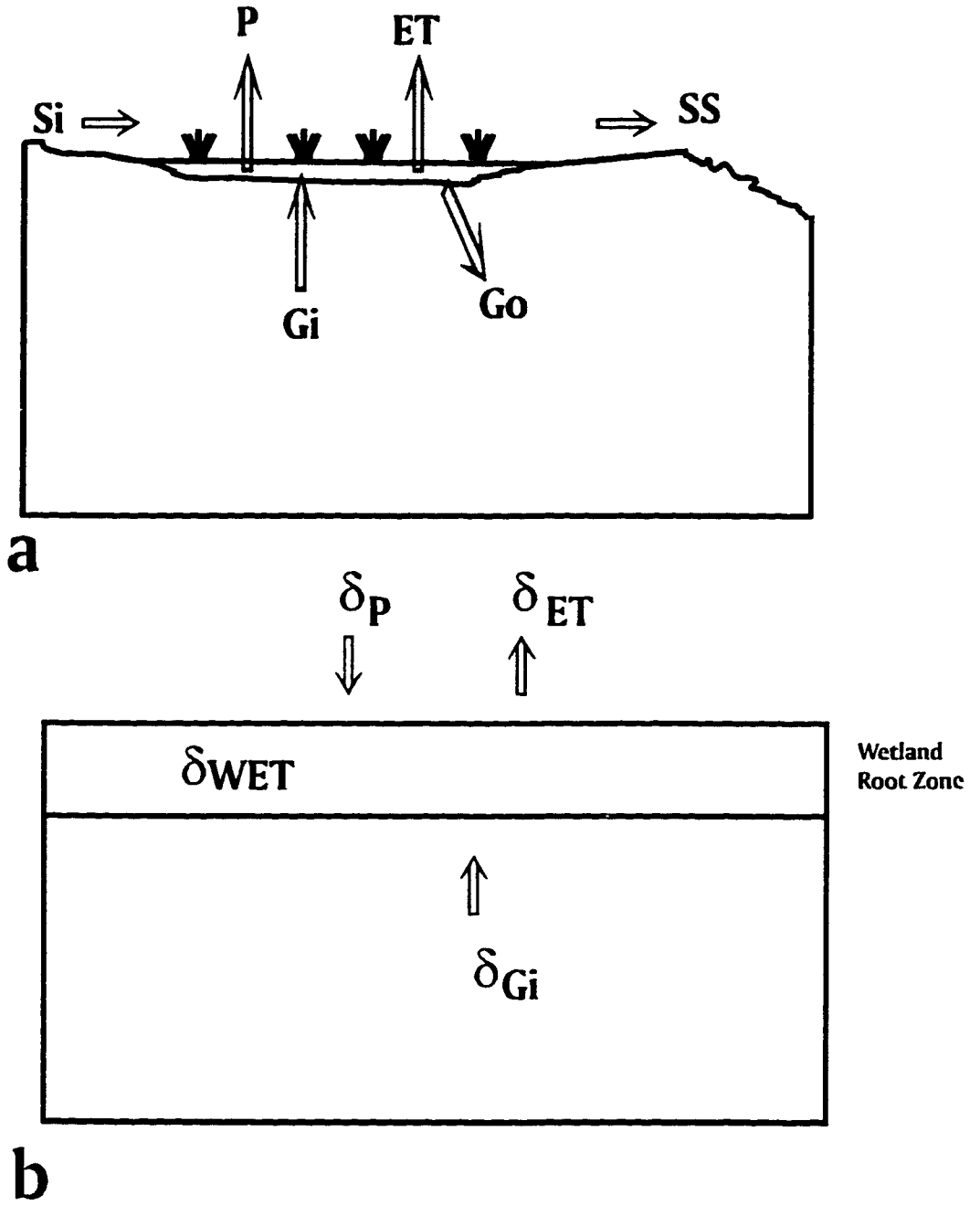

Figure 24. Schematic Cross Section of Wetland Showing the Hydrologic Input/Output Source for the Water Budget Method (a) and the Isotopic Mass Balance Method (b).

measurements of the input/output, a hydrologic water balance for the wetlands can be obtained.

Water Budget Method

A simplified hydrologic water balance using the water budget method for the wetland requires that water in = water out, thus:

$$Gi + P + Si = ET + SS + Go$$

where: Gi is the groundwater inflow into the wetland; P is precipitation input into the wetland; SS is surface outflow from the wetland, ET is evapotranspiration from the wetland and Go is groundwater output from the wetland. A simplified water budget to estimate groundwater inflow based on the surface water discharge measurements from the wetland (SS) uses the following equation:

$$SS = Gi + Si + P - ET - Go$$

Because only SS and P were measured, a simplified equation was used for the water budget estimate

$$SS - P = Gi$$

The following assumptions were made in utilizing the simplified equation:

1. Surface inflow (Si) into the wetland can be ignored and assumed to be a component of precipitation.

2. Because ET was not directly measured, removal of ET from the equation will result in an underestimate of the inflow component. Thus estimates of Gi based on the above equation is a minimum groundwater inflow to the wetlands.

In estimating Gi, from the above equation, if SS - P is zero or negative, then there is no groundwater inflow into the wetland and SS is influenced primarily by P. If the result is positive, SS > P, then the difference is the groundwater inflow component to the wetland Gi. The volume of discharge for SS measured from May to September along with values of P for the same period were utilized to the above equations. An area of 1414 m^2 was used to estimate the volume of precipitation that would accumulate in a portion of the wetlands over the period used for the water budget estimation. In addition all the measurements were normalized to daily rates. The groundwater inflow (Gi) data from the water budget estimate for May through September 1995 (183 days) is shown in Table 4.

Table 4

Groundwater Inflow Volume (SS-P) Into the Wetland From the Water Budget Method

WET AREA (m^3)	P cm/d	P VOL. m^3/day	SS VOL. m^3/day	SS-P VOL. m^3/day
1414	0.27	3.82	13.64	9.82

Isotopic Mass Balance Method

An isotopic mass balance similar to that used by Hunt et al. (1996) was developed for the wetlands (Figure 24b). An isotopic mass balance for this system can be written as:

$$Gi = [P(\delta_{Wet} - \delta P) + ET(\delta_{ET} - \delta_{Wet})]/(\delta_{Gi} - \delta_{Wet})$$

P and ET are precipitation and evapotranspiration rates and δ_{Wet} ,δP, δ_{ET} and δ_{Gi} are the isotopic composition of the wetland root zone, precipitation, evapotranspiration and groundwater inflow respectively.

The overriding assumption in the utilization of an isotopic mass balance is hydrologic and isotopic steady state (Hunt et al., 1996). Hydrologic steady state is assumed to exist at the site based on the observation that there is little temporal variation of the measured discharge of the spring (SP) downgradient of the wetland (Figure 20). This is believed to be an indication of a steady influx of groundwater into the site and thus the wetland. Isotopic steady state is demonstrated at the site by the little temporal variation in the δD values of the wetlands wells and surface water (SS) discharging from the wetlands (Table 3).

In the application of the isotopic mass balance, ET was not measured and cannot be measured directly. However, based on previous suggestions (Zimmerman et al., 1967) ET can be assumed to be nonfractionating. Therefore, δ_{ET} can be

approximated by the soil water in the wetland root zone (Hunt et al., 1996). This assumption allows for the removal of ET component for the above equation by setting δ_{ET} equal to δ_{Wet} giving rise to the following equation (Hunt et al., 1996):

$$Gi = [P(\delta_{Wet} - \delta P)/(\delta_{Gi} - \delta_{Wet})$$

Note that if the errors associated with the elimination of the ET term in the above equations are large, there would be a significant difference in the groundwater inflow estimates obtained from the water budget and isotopic mass balance models.

For the application of the model the weighted mean δD of -49 $^{0}/_{00}$ for precipitation measured for Kalamazoo was used. A δ_{Wet} of -59 and δ_{Gi} of -62 $^{0}/_{00}$ was used. The δ_{Wet} was an average of well S2 within the wetlands and δ_{Gi} was an average value of shallow monitoring wells upgradient of the wetlands. The results of the groundwater inflow component into the wetlands Gi are presented along with that of the water budget model in Table 5.

From Table 4, the S-P is positive (9.82 m^3/day) and Gi determinations for isotopic mass balance method (0.9 cm/day) indicate groundwater inflow into the wetlands. A comparison of the volume of groundwater inflow into the wetland per day from April through September for both the water budget method (9.82 m^3/d) and isotopic mass balance (12.71 m^3/d) are comparable and in good agreement (Table 5). However, the lower groundwater inflow volume for the water budget method does not account for ET from the wetlands. In the water budget method, So < P + Gi since ET

is not accounted for. In the water budget method, estimates of $P + Gi \geq SS$ and thus the estimate of SS is a minimum estimate of Gi + P. It is argued that the difference between the groundwater inflow volume estimated from the isotopic mass balance and water budget method of 2.9 m^3/day is a reasonable estimate of the ET component for the entire period of the measurement.

Table 5

Groundwater Inflow Component of the Isotopic Mass Balance (Gi) and Comparison of Groundwater Inflow Volume (SS) From the Isotopic Mass Balance Method With Estimates Using the Water Budget Method

	Gi cm/d	Gi Vol. (m^3/d)	SS Vol. (m^3/d)
ISOTOPIC MASS BALANCE	0.90	12.71	16.53
WATER BUDGET	-	9.82	13.64*

* = Measured

Conclusions

From the hydrologic analysis of the site, the following conclusions are evident:

1. The site is underlain by trash and fill material that appear to exercise significant influence on the hydrology. The area dominated by wetlands is underlain by trash covered with a layer of less permeable fill. The settling of the underlying trash has created depressions and ponding of water leading to the establishment of wetland vegetation in these water filled depressions.

2. Well hydrographs and static water monitoring show flow toward Davis Creek. Vertical hydraulic gradient analysis shows a predominantly discharging groundwater regime at the site.

3. Seepage wells and monitoring wells below Davis Creek show groundwater discharge into the creek.

4. An analysis of water levels in the wetlands, deuterium distribution and hydrologic water balance indicate that the wetlands, which occupy depressions at the site, are dominated by a groundwater source.

5. δD values did not indicate any modification that may arise from intense biogeochemical processes in the landfill. This observation warrants detailed future study since in some landfill dominated sites, such effects have been observed (Fritz et al., 1976; Baedecker and Back, 1979b; Rank et al., 1992; Lui et al., 1992). This might therefore provide a unique opportunity to monitor the movement of groundwater impacted by landfill leachate.

6. Hydrologic water balance analyses show strong agreement between the water budget and hydrogen isotope mass balance methods. Both methods show groundwater inflow into wetlands at the study site.

CHAPTER V

STABLE ISOTOPES OF CARBON AND LEACHATE

Stable Isotopes of Carbon

Introduction

Pollutant carbon is prevalent in urban areas as a result of human activities. During the past three decades, the study of $\delta^{13}C$ of natural waters has received special attention in terms of its potential applications in groundwater pollution studies (Calder and Parker, 1968; Degens, 1969; Games and Hayes, 1974, 1977; Baedecker and Back, 1979a; Suchomel et al., 1990; Van Dover et al, 1992; Walsh et al., 1993; Hackley et al., 1996). Pollutant carbon in the environment results from the improper disposal of materials that contain carbon extraneous to the native hydrologic system. Carbon generated by biogeochemical processes acting on disposed materials can be indirectly linked to the pollutant source. The detection of pollutant carbon in the hydrologic system assumes that the CO_2 derived from the transformation of the pollutants has $\delta^{13}C$ signatures that are different from the background and thus distinguishable in the measured $\delta^{13}C$ of dissolved inorganic carbon in water samples. One specific environment where this assumption is likely to be valid is when methanogenesis occurs, since it is accompanied by large isotopic fractionation between CH_4 and CO_2

(Rosenfeld and Silverman, 1959; Games and Hayes, 1976a, 1978; Blair et al, 1987; Baedecker and Back, 1979b; Whiticar et al. 1986; Hackley et al., 1996). Introduction of the CO_2 produced by methanogenesis into the surrounding water bodies is expected to modify the $\delta^{13}C$ of the DIC unequivocally.

Dissolved Inorganic Carbon (DIC)

Formation of DIC in the natural water environment can be represented by the following reactions (Garrels and Christ, 1965):

$$CO_{2(g)} + H_2O \longleftrightarrow H_2CO_3 \qquad (1a)$$

$$H_2CO_3 \longleftrightarrow H^+ + HCO_3^- \qquad (1b)$$

$$HCO_3^- + Ca^{2+} \longleftrightarrow H^+ + CaCO_3 \qquad (1c)$$

The $CO_{2(g)}$ that initiates the above reaction (1a) is often biogenic, resulting predominantly from root respiration and/or oxidation of organic matter. The carbonate (1c) is usually derived from the aquifer material. The concentrations of various species of inorganic carbon in a given natural water are indicative of its evolutionary history as dictated by the thermodynamic constraints under the given conditions. Thus thermodynamic techniques can be used to define the terminal evolutionary stage and therefore the ultimate concentrations of inorganic carbon species in these natural waters. In addition, the carbon isotopic ratio ($\delta^{13}C$) is often a

useful parameter that has been utilized in the study of the processes that control the carbon chemistry of natural waters (Dienes et al, 1974; Wigley et al, 1978; Chapelle and Knobel, 1985; Chapelle et al, 1985, 1988; Sheppard, 1986; White and Chuma, 1987; Landmeyer and Stone 1995; Yang et al., 1996). Hackley et al. (1996) advocate the use of stable isotopes of environmental isotopes of the major landfill constituents of landfill gas (CO_2 and CH_4) and leachate (water and dissolved inorganic carbon (DIC)) as a technique for definitively identifying landfill leachate contamination. The production of DIC in the landfill was assessed through the measurement of CO_2 and CH_4 in vent gases. Leachate and the degree of leachate impacted at the downgradient portion of the landfill was estimated through the analysis of DIC.

DIC Analysis

Two methods, the direct precipitation and gas evolution techniques, have been traditionally used for DIC analysis. In the direct precipitation technique (Gleason et al., 1969; Friedman, 1970; Deines et al., 1974; Barnes et al., 1978; Pearson et al., 1978; Hassan, 1982; Heathcote, 1985; Bishop, 1990), the DIC is precipitated in the form of strontium carbonate and later converted into CO_2 gas by reacting the precipitate with phosphoric acid under vacuum. The problems inherent in this technique range from atmospheric CO_2 contamination of the ammoniacal strontium chloride solution used for precipitating the DIC in water samples, atmospheric CO_2 contamination of the precipitate during filtration, oven drying, and storage and

improper homogenization of the precipitate aliquot used for analysis. In addition, Hassan (1982) showed experimentally that coprecipitation of $SrSO_4$ in normal to high sulfate-bearing waters can lead to incomplete precipitation of DIC, causing low CO_2 yields. These problems can lead to erroneous DIC and $\delta^{13}C$ of the DIC determinations in natural water samples.

The gas evolution technique (Mook, 1968; Tan et al., 1973; Games and Hayes, 1976b; Reardon et al., 1979; Hassan, 1982; Graber and Aharon, 1991; Holt et al., 1995) requires the collection of water sample from the field and reaction of the sample with phosphoric acid under vacuum. Hassan (1982) summarizes the problems associated with some variants of this technique. These include CO_2 gain/loss in the water sample container during shipping and laboratory storage prior to analysis of DIC and incomplete transfer of exolved gas phase in the sample container to the vacuum line for extraction. Also, the problem of storage can be compounded by bacterial activity (including photosynthesis and decay) which could alter the DIC and the isotopic ratios of DIC in the water samples if not preserved with a bactericide (Mook, 1968). The most serious problems in the gas evolution technique can be attributed to the lack of a suitable sampling device and limitations imposed in sample transfer due to the method used for sampling water (Hassan, 1982).

For this study a modification of the gas evolution extraction technique was used for DIC analysis. The modification focused on selecting a suitable sampling and DIC extraction technique that would overcome the problems associated with sample

collection, storage and the limitation imposed by sample transfer in some variants of the gas evolution technique. Glass septum tubes (VACUTAINER® Serum Tubes, Becton Dickson & Company, Franklin Lakes, NJ 07417) were found to be suitable for sampling and extraction of DIC. The acid-DIC reaction was carried out entirely within the septum tubes and remained in this closed system until CO_2 extraction in the laboratory vacuum system. In order to determine the optimal extraction procedure, a standard solution of Na_2CO_3 was used.

Extraction of Solid Na_2CO_3

The septa of the tubes were removed and pre-weighed Na_2CO_3 solid samples were placed into the tubes and the septa put back in place. An additional precaution was taken by sealing the septum tube with household adhesive and sealant (Goop household adhesive and sealant, Eclectic products, Inc. USA) although this would normally be unnecessary. The septum tube containing the sample was evacuated on a vacuum line using an extraction needle assembly (Figure 25, insert A). For this, a 26-gauge needle (~12 mm long) was attached to a luer ground joint and connected to a 9-mm pyrex tube. This assembly was attached to the vacuum line using a cajon union. The tube was evacuated by pushing the needle through the septum. Approximately 0.5 ml of 85% phosphoric acid was injected into the pre-evacuated tube containing the solid sample and allowed to react for 30 to 60 minutes.

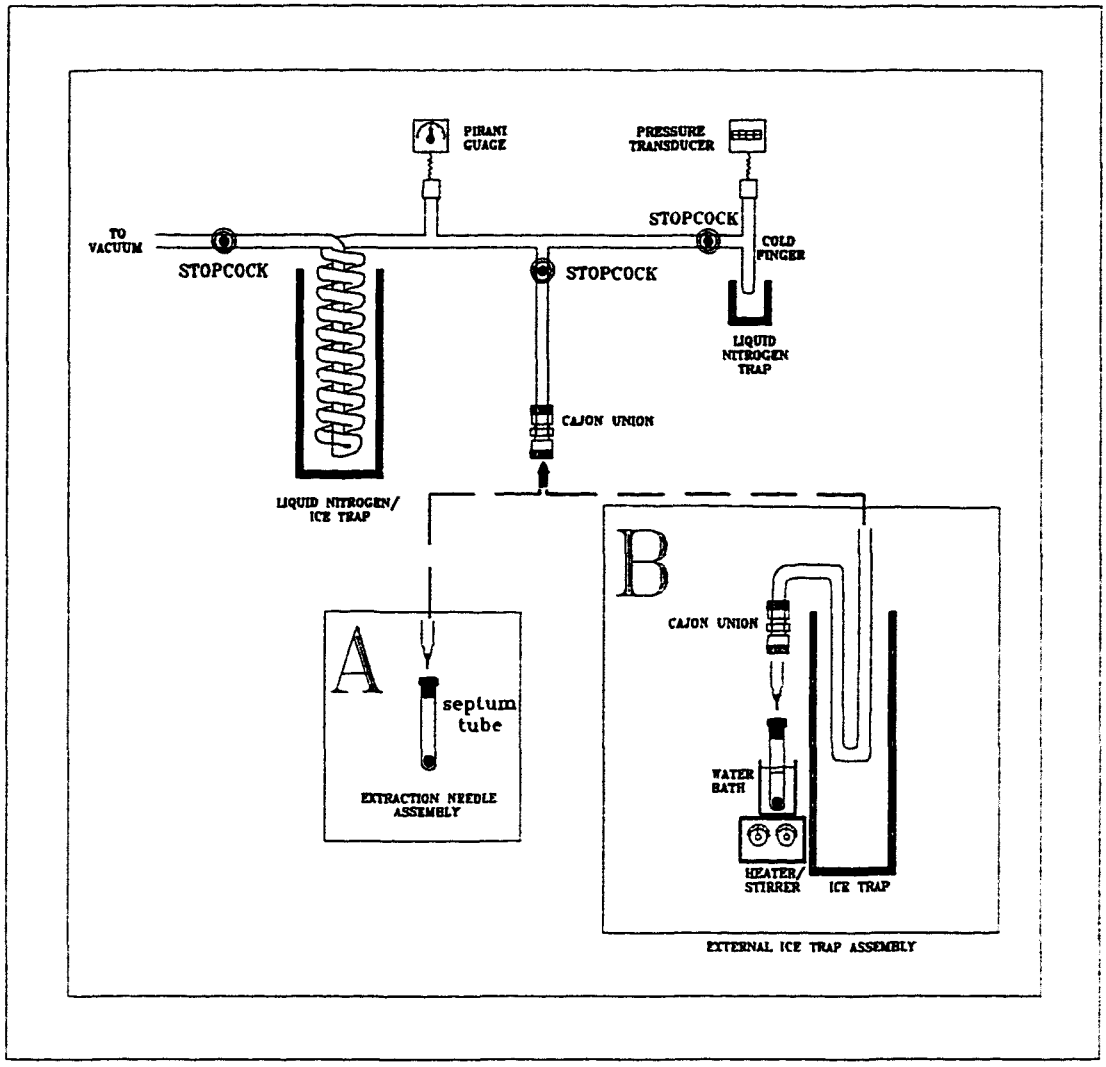

Figure 25. Schematic of the Vacuum System used for DIC Extraction. Insert A Shows the Needle Assembly. Insert B Shows the External Dry Ice Trap.

CO_2 Extraction From Septum Tubes. The CO_2 produced by the phosphoric acid reaction with solid Na_2CO_3 in the septum tubes was extracted under vacuum using the setup shown in Figure 25. The extraction needle assembly (Figure 25, insert A) was attached to the vacuum line by way of a cajon union. The septum of the tube

was inserted into the needle deep enough to cover the needle's opening but not penetrate into the tube. This step allowed for evacuating air contained in the needle assembly. After evacuation, the needle was pushed all the way through the septum and the released CO_2 was dynamically trapped and purified cryogenically. CO_2 yield estimates were made using a calibrated cold finger. Isotope measurements of both $\delta^{13}C$ and δD (see analysis of landfill vent gases below) were made with a Fision Optima mass spectrometer.

Five samples representing different amounts of solid Na_2CO_3 were extracted using this extraction method. The samples were extracted under vacuum for approximately 10 minutes. The experimental CO_2 yields, compared with theoretical yields for complete CO_2 extraction and the determined $\delta^{13}C$ of the extracted CO_2, are presented in Table 6. The table shows that the extraction efficiency of the procedure

Table 6

Results of CO_2 Yield and $\delta^{13}C$ From Solid Na_2CO_3 Standard

Run #	Theoretical Yield (μ moles)	Experimental Yield (μ moles)	% Theoretical CO_2 Yield	$\delta^{13}C$
1	167.1	166.7	99.8	-7.6
2	121.7	119.9	98.5	-7.6
3	109.1	107.4	98.4	-7.5
4	86.9	86.2	99.2	-7.5
5	75.7	76.4	100.9	-7.4
			99.4 ± 1.0	-7.5 ± 0.1

applied to the solid standard is better than 99%. The $\delta^{13}C$ of the standard shows a variation of less than $0.1^{0}/_{00}$.

Extraction of Water Samples

In the initial experiments, a standard solution prepared by dissolving Na_2CO_3 in deionized water as well as natural water samples was used. The septum of the tube was removed, approximately 0.5 ml of 85% phosphoric acid was dispensed into the tube, the septum replaced, sealed and evacuated in the same manner as for solid samples. A plastic syringe with a luer lok tip fitted with a 26-gauge needle (~12 mm long) was used to collect the water samples. Water samples were collected by removing the needle, withdrawing water into the syringe at the sampling location, and quickly replacing the needle. Air bubbles if present were removed by tapping the syringe gently, excess water expelled to obtain the volume desired and the sample injected into the pre-evacuated septum tube containing phosphoric acid. Sampling of groundwater was accomplished after appropriate purging of the wells. During sampling, the pump discharge rate was reduced, and one end of a 5-mm plastic tube was coupled to the pump's exit hose and the other placed in the luer lok tip of the syringe allowing the sample to be collected directly into the syringe. In some instances, water samples were collected directly from the pump's exit hose depending on the type of pump used. In all cases, the water samples in the syringe are exposed to

the atmosphere for less than 20 seconds from the time of collection to injection into the septum tube.

CO_2 Extraction From Septum Tubes

CO_2 in septum tubes containing the mixture of water samples and phosphoric acid were extracted using an external modification to the vacuum system (Figure 26, insert B). The septum tubes were placed in a water bath at about 50^0 C. An external U-tube dry ice trap (-85^0 C) was used to ensure that the bulk of the moisture was trapped in this removable trap. The extraction needle assembly was connected to the external ice trap which was connected to the vacuum line by way of a cajon union. The septum of the tube containing the reacted sample was partially inserted into the needle, the assembly evacuated, after which the needle was pushed all the way into the septum tube and the CO_2 dynamically collected using the same procedure as described before. The following two methods were employed to extract the CO_2 produced by phosphoric acid reaction with the water samples.

I. CO_2 Extraction by Vacuum Degassing. 5 ml of the prepared Na_2CO_3 solution was extracted by this procedure. The samples were extracted by vacuum degassing at 50^0 C for periods of 10, 20, 30, 40, 50 and 60 minutes. The percentage theoretical CO_2 yield, and the $\delta^{13}C$ for each sample is presented in Table 7. The results show that after an extraction time of 60 minutes, the extraction efficiency is about 94%. Simple degassing is not able to extract all the CO_2 after 60 minutes extraction,

apparently due to the small transmission coefficient of CO_2 in water at moderate temperatures (C. J. Yapp, *pers. comm.* 1996).

Table 7

Time Series Extraction of Na_2CO_3 Solution at 50° C

Solution #	Extraction Time (minutes)	% Theoretical CO_2 yield (μ moles)	$\delta^{13}C$ (‰)
1	10	74.8	-7.3
2	20	82.2	-7.4
3	30	86.9	-7.5
4	30	85.7	-7.5
5	30	87.9	-7.5
6	30	88.6	-7.6
7	40	87.4	-7.6
8	40	86.1	-7.6
9	50	90.2	-7.6
10	60	93.0	-7.6

II. CO_2 Extraction by Simultaneous Vacuum Degassing and Stirring. It is apparent from Table 7 that simple vacuum degassing was not efficient in CO_2 removal from water samples in the septum tube. Subsequently, magnetic stir bars were placed in the septum tubes along with phosphoric acid prior to introducing the water samples. The CO_2 was extracted from the septum tube while the reaction mixture was being stirred continuously by a magnetic stirrer. The extractions were carried out for 5, 10, 15 and 20 minutes. In this set of experiments, field samples were also extracted along with the Na_2CO_3 solution. These included tap water from the isotope laboratory,

surface water samples and water obtained from a landfill leachate collection system from the study site. The results of the time series extraction of the Na_2CO_3 standard solution and the natural water samples are shown in Table 8. From the table, it is observed that more than 98% of the theoretical CO_2 yield from the standard is extracted from the septum tube reaction mixture in the first five minutes. Also, the $\delta^{13}C$ of the Na_2CO_3 standard is measurable to within $0.1^0/_{00}$. The natural water samples extracted by this technique also yield highly reproducible isotopic results similar to the standard. With a standard deviation of CO_2 yields of less than 1 μmole, at least 98% of the DIC was extracted from the natural samples. The $\delta^{13}C$ values of the various natural water samples do not vary by more than $0.2^0/_{00}$.

Extraction Efficiency and $\delta^{13}C$ Precision of the Extraction Technique

Since the experiments conducted above suggested that an extraction period of 10 minutes and an extraction temperature of 50^0 C are sufficient, a batch of 10 samples of Na_2CO_3 standard solution was extracted at 50^0 C for 10 minutes to verify the precision of the DIC extraction at 50^0 C while stirring. The results are presented in Table 9. The results show that the extraction process is 99 $\pm$ 1% efficient and that the $\delta^{13}C$ can be measured to better than $0.1^0/_{00}$. Therefore, based on the series of experiments discussed here, an optimum extraction period of 10 minutes at 50^0 C with constant stirring can provide highly reproducible DIC concentrations and $\delta^{13}C$ values from natural water samples.

Table 8

Time Series Extraction of Na_2CO_3 Solution and Select Natural Water Samples at 50° C While Stirring (For Identification of Natural Sample Locations See Figure 9 - Tap Water Represents Water Collected From the Tap in the Laboratory)

SAMPLE	Extraction Time (minutes)	CO_2 Yield (μ moles)	% Theoretical CO_2 Yield (μ moles)	$\delta^{13}C$ (‰)
Na_2CO_3				
1	5	101.3	100.0	-7.4
2	10	101.1	99.8	-7.5
3	15	99.8	98.5	-7.5
4	20	101.0	99.7	-7.5
		100.8 ± 0.7	99.5 ±0.7	-7.5 ± 0.1
TAP WATER				
1	5	25.4		-10.6
2	10	25.4		-10.7
3	15	25.6		-10.5
4	20	25.9		-10.9
		25.6 ± 0.2		-10.7 ± 0.2
LCS				
1	5	131.7		3.6
2	10	131.0		3.8
3	15	131.3		3.7
4	20	130.6		3.7
		131.2 ± 0.5		3.7 ± 0.1
DAVIS CRK				
1	5	22.3		-10.8
2	10	22.0		-11.1
3	15	21.8		-11.3
4	20	21.9		-11.0
		22.0 ± 0.2		-11.1 ± 0.2
SP				
1	5	101.0		7.7
2	10	101.5		7.9
3	15	101.3		7.9
4	20	101.5		8.0
		101.3 ± 0.2		7.9 ± 0.1
SS				
1	5	96.2		4.8
2	10	95.6		5.0
3	15	95.2		5.0
4	20	94.3		5.0
		95.3 ± 0.8		5.0 ± 0.1

Table 9

CO_2 Yield and $\delta^{13}C$ of Na_2CO_3 Standard Extracted at 50 ° C While Stirring (Extraction Time for All Runs Was 10 Minutes)

Solution #	% Theoretical CO_2 Yield (μ moles)	$\delta^{13}C$ (‰)
A	97.6	-7.6
B	100.5	-7.5
C	99.3	-7.5
D	99.4	-7.5
E	97.1	-7.7
F	99.8	-7.5
G	98.8	-7.5
H	99.1	-7.5
I	98.7	-7.5
J	99.7	-7.5
K	97.5	-7.6
L	99.6	-7.6
	98.9 ± 1.0	-7.5 ± 0.1

Sample Storage in Septum Tubes at Room Temperature

Tap water samples along with samples from the study site were collected and extracted after storage at room temperature for varying lengths of time. These samples were extracted at 50^0 C for 30 minutes without stirring. The storage time ranged from a few hours to 43 days. The results of the effect of storage are shown in Table 10. The results show a near consistency in both the yield of CO_2 and the $\delta^{13}C$ of DIC. The maximum variation in the CO_2 yield is 5 μmoles for the leachate. This amounts to a variation of about 3.6%. The variation is easily accounted for by the fact

Table 10

CO_2 Yields and $\delta^{13}C$ of Natural Water Samples Extracted After Storage at Room Temperature for Different Lengths of Time

Time (days)	TAP WATER		DAVIS CRK		SS		SP		LCS	
	CO_2 Yield (μ moles)	$\delta^{13}C$ (‰)	CO_2 Yield (μ moles)	$\delta^{13}C$ (‰)	CO_2 Yield (μ moles)	$\delta^{13}C$ (‰)	CO_2 Yield (μ moles)	$\delta^{13}C$ (‰)	CO_2 Yield (μ moles)	$\delta^{13}C$ (‰)
0.5	24.53	-10.9	20.68	-9.4	80.19	8.3	94.93	7.6	140.58	5.3
3.5	22.44	-11	21.89	-9.3	83.82	8.1	90.75	7.8	137.94	5.6
4.2	24.86	-11	23.21	-9.1	84.37	8.3	96.91	7.5	145.97	5.5
10.8	22.88	-10.9	20.9	-9.3	84.26	8	94.49	7.5	132.55	5.3
43.5	23.32	-10.8	19.36	-9.3	82.17	8.3	88.44	7.9	136.95	5.5
	23.6 ± 1.0	-10.9 ± 0.1	21.2 ± 1.4	-9.3 ± 0.1	83.0 ± 1.8	8.2 ± 0.1	93.1 ± 3.4	7.7 ± 0.2	138.8 ± 4.9	5.4 ± 0.1

that the samples were extracted by a less efficient process. The maximum variation in the $\delta^{13}C$ of DIC for all the samples stored for up to 43 days is $0.2^0/_{00}$. It is clear that the septum tubes are suitable sampling devices in which water samples can be reacted and stored for a reasonable length of time.

Stable Isotope Analysis of Samples From the Cork Street Landfill

Carbon and Hydrogen Isotopes of Landfill Vent Gases

Wells consisting of 15.2 cm diameter PVC pipes installed for venting gases produced in the landfill were sampled for landfill produced gases. A 3 m long flexible plastic hose attached to prevacuated gas samplers was inserted into the vents after allowing the landfill gas to flow through the tube for about 1 minute. The gases were also allowed to flow through the sample bottle for 3 minutes before collection. The gases collected were prepared for isotopic analysis on a multipurpose vacuum extraction line. Aliquots of the vent gases were passed through a liquid nitrogen trap where moisture and CO_2 was trapped. The noncondensable gases were passed through a cupric oxide furnace at 950^0 C and the CO_2 and H_2O from methane oxidation trapped in liquid nitrogen. Both the free CO_2 and the CO_2 from methane oxidation were purified cryogenically, collected, their yields measured manometrically and their $\delta^{13}C$ determined. The water trapped from the methane combustion was passed over hot uranium at 760^0 C and converted to hydrogen gas. The gas yield was

measured manometrically, collected and used to measure the δD of the methane. The CO_2:CH_4 ratio in the gas aliquots and the H:C ratio of the combusted CH_4 (to verify the CH_4 stoichiometry) were calculated.

DIC Analysis of Water Samples

Samples from the landfill leachate collection system (Figure 2) groundwater and surface water (Figure 9) were used for determination of the concentrations and $\delta^{13}C$ of DIC at the study site. Septum tubes were prepared for sample collection by dispensing approximately 0.5 ml of 85% phosphoric acid, placing a magnetic stir bar in the septum tube and evacuating it of air as described in the experimental procedure.

All groundwater and surface water samples were collected and reacted in prepared septum tubes. During sampling, the wells were purged by removing all of the water from the wells that were being sampled and then allowing sampling each well after recovery. This was the case for most of the groundwater wells except for those with high water yield. These high yield wells and wells that were installed in the surface water bodies were pumped for about 5 to 10 minutes at a rate of 3 to 5 liters per minute to remove at least five pore volumes from the surrounding media through the well.

The concentrations of DIC and $\delta^{13}C$ of DIC of the water samples were determined using the extraction procedure in which the samples were extracted at 50^0 C while stirring for 10 minutes.

Results

Carbon and Hydrogen Isotopes From Landfill Vent Gases

The results of the chemical and isotopic analysis are shown in Table 11. The $\delta^{13}C$ of CO_2 and CH_4 from landfill vent gases range from -11.3 to 4.5 and from -57.3 to - 49.5 $^0/_{00}$ respectively. The δD for CH_4 ranges from -341 to -301$^0/_{00}$. The H:C ratio of the CH_4 range from 4.2 to 3.8 verifying the stoichiometry of the CH_4. The CO_2:CH_4 ratio in the landfill gases from the vents range from 0.56 to 0.87.

Concentrations and $\delta^{13}C$ Ranges in the DIC of Water Samples

The results of the DIC analysis are presented in Table 12. The concentrations of DIC and the $\delta^{13}C$ of water samples from the study site range from 51 to 343 mg C/l and -16.9 to 16.6$^0/_{00}$ respectively. Groundwater and surface water west of the creek have a DIC concentration range of 102 to 333 mg C/l and a $\delta^{13}C$ ranging from -11.9 to 16.6$^0/_{00}$. Groundwater east of Davis Creek has DIC concentration ranging from 55 to 118 mg C/l and $\delta^{13}C$ in the range of -16.9 to -9.7$^0/_{00}$. Groundwater below Davis Creek has DIC concentration ranging from 54 to 192 mg C/l and $\delta^{13}C$ in the range of -14.6 to 3.2$^0/_{00}$. Davis Creek stream has DIC concentration ranging from 51 to 58 mg C/l and $\delta^{13}C$ in the range of -11 to -9.3$^0/_{00}$.

Table 11

Results of Stable Isotope Analysis of Carbon and Hydrogen of CO_2 and CH_4 From Landfill Vent Gases

		CO_2	CH_4		
Sample	CO_2/CH_4	$\delta^{13}C$ (‰)	$\delta^{13}C$ (‰)	δD(‰)	H/C
4/4/96					
VENT #2	0.67	0.4	-54.4	-325	4.1
6/23/96					
VENT #1	0.87	-11.3	-51.1	-328	3.8
VENT #2	0.74	-9.2	-55.6	-340	3.8
VENT #3	0.61	3.3	-57.3	-341	3.8
VENT #4	0.59	4.5	-49.5	-301	4.2
VENT #5	0.56	2.0	-55.2	-340	3.9
VENT #6	0.59	2.3	-53.4	-340	3.8

Discussion

Source of Heavy CO_2

A plot of $\delta^{13}C$ vs. DIC concentration for all water samples is shown in Figure 26. Only the analyses of samples collected on June 26, 1996 are plotted because they represent a complete analysis of all sampling locations at the study site. The $\delta^{13}C$ values of water from the landfill leachate collection system and most of groundwater and all surface water samples west of the creek are relatively high. It is obvious that there must be a source of heavy CO_2 in these water samples.

Heavy $\delta^{13}C$ in the vicinity of landfills have been attributed to landfill leachate contamination (Games and Hayes, 1974, 1977; Baedecker and Back, 1979a; Walsh et

Table 12

Results of DIC Concentration and $\delta^{13}C$ of DIC Analysis of Water Samples From the Study Site (for Sample Locations See Figure 9)

	MARCH 28 1996		APRIL 2 1996		APRIL 12 1996		MAY 30 1996		JUNE 26 1996	
Sample ID.	$\delta^{13}C$ (‰)	DIC mg C/l	$\delta^{13}C$ (‰)	DIC mg C/l	$\delta^{13}C$ (‰)	DIC mg C/l	$\delta^{13}C$ (‰)	DIC mg C/l	$\delta^{13}C$ (‰)	DIC mg C/l
W 1A	-	-	-	-	4.1	176.2	-	-	6.4	200.6
W 1C	-	-	-	-	-	-	-	-	16.6	172.6
W 2A	-	-	-	-	-	-	0.5	188.6	0.2	200.2
W 2C	-	-	-	-	-	-	-	-	7.7	212.6
W 3A	-	-	-	-	-6.4	101.8	-	-	-5.1	182.7
W 3C	-	-	-	-	-	-	-	-	3.2	158.2
W 4A	-	-	-	-	3.3	207.4	-	-	4.2	220.8
W 4C	-	-	-	-	-	-	-	-	5.3	237.3
W 5A	-2.1	113	-	-	-	-	-	-	-0.1	109.0
W 5C	-	-	-	-	-	-	-	-	-1.6	110.4
W 6A	5.8	245	-	-	-	-	6.9	218.6	5.3	205.0
W 6C	-	-	-	-	-	-	-	-	5.7	211.5
W 7A	-	-	-	-	6.1	179.2	-	-	7.1	187.5
W 7C	-	-	-	-	-	-	-	-	7.8	180.3
W 9A	-5.6	114	-	-	-3.8	115.9	-7.7	139.9	-10.2	130.9
W 9C	-	-	-	-	-	-	-	-	3.3	167.4
W 11A	-	-	-	-	-	-	-	-	9.9	327.8
W 11C	-	-	-	-	-	-	-	-	12.7	213.5
W 12A	-	-	-	-	-	-	-	-	13.7	245.3
W 14A	-	-	-	-	-	-	-	-	-11.9	155.7
W 15 A	-14.8	155	-	-	-	-	-	-	-5.1	209.3
SS	6.2	190	8.2	180.9	8.2	221.7	5.7	236.8	5.0	224.0
SN	-	-	-	-	-0.9	119.8	-2.0	141.0	-4.0	142.2
SP	7.8	225	7.7	223.5	7.6	217.2	7.8	250.1	7.2	238.1
LCS	5.2	261	5.4	333.1	4.8	310.6	4.5	342.8	3.6	318.1
S1	-	-	-	-	-	-	-	-	1.3	332.8
S2	-	-	-	-	-	-	7.8	237.6	10.7	228.9
S3	2.6	172	-	-	2.2	-	-0.1	186.2	-2.8	196.2
E 13A	-9.7	66	-	-	-	-	-	-	-10.0	55.0
E 10A	-13.6	98	-	-	-	-	-	-	-14.0	102.0
E 10C	-	-	-	-	-	-	-	-	-13.2	86.1
E 8A	-15.3	97	-	-	-	-	-16.3	118.8	-16.9	117.9
E 8C	-	-	-	-	-	-	-	-	-14.4	89.2
DC1	-	-	-	-	-	-	-	-	-1.7	105.8
DC2	-	-	-	-	-	-	-3.7	80.2	-2.3	101.5
DC3	-	-	-	-	-	-	-	-	-11.5	54.1
SW1	-	-	-	-	-	-	-	-	1.0	124.1
SW2	2.2	92	-	-	-	-	3.5	192.4	3.2	185.2
SW3	-	-	-	-	-	-	-6.8	76.9	-8.8	61.5
SW4	-14.6	58	-	-	-	-	-	-	-11.3	56.7
D CRK	-9.5	52	-9.3	50.9	-10.0	54.9	-10.7	58.2	-11.0	52.1

The - Indicates no Determinations were Made

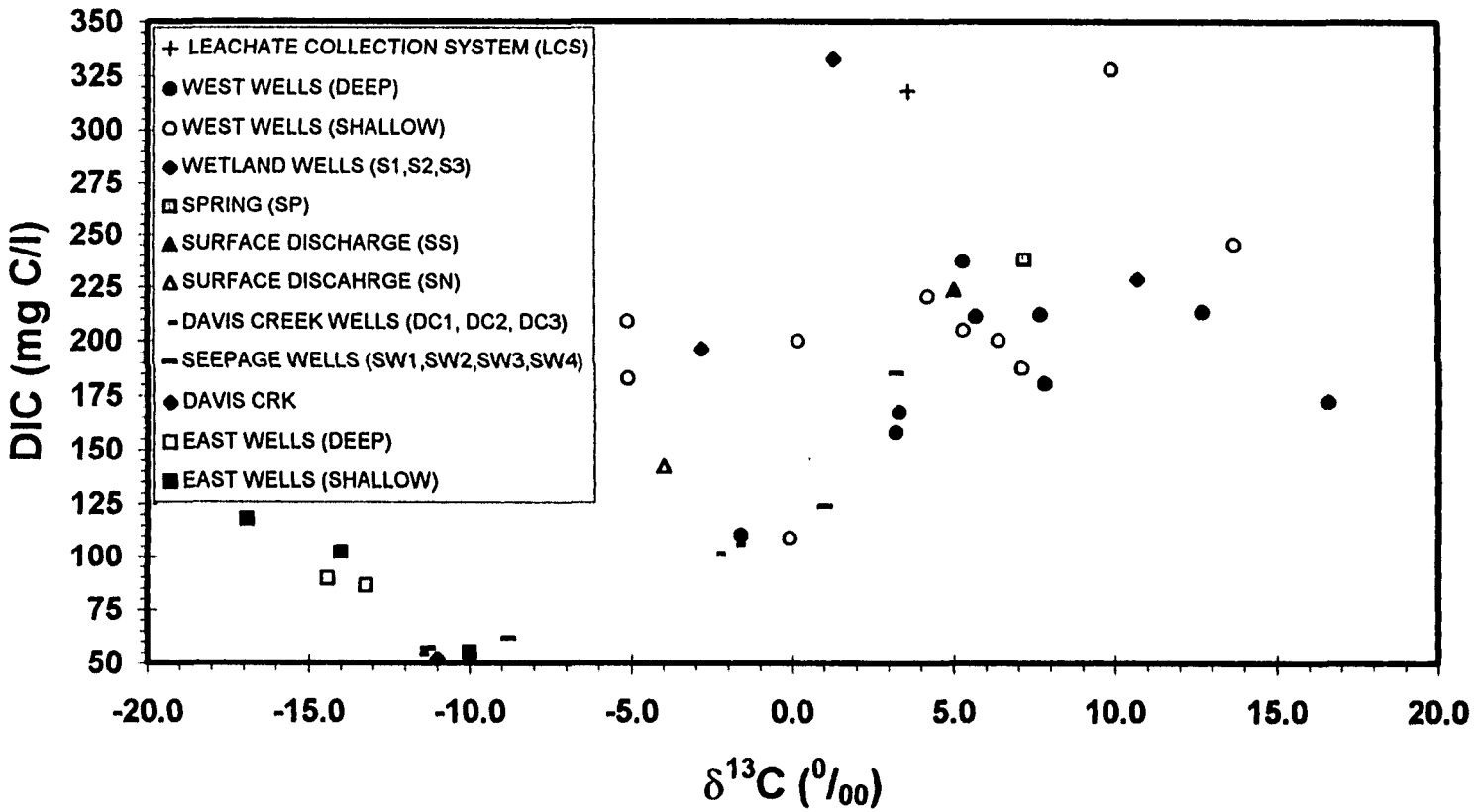

Figure 26. $\delta^{13}C$ vs. DIC for Water Samples From the Study Site.

al., 1993). CO_2 production in landfills results from bacterial transformation of organic matter. While the actual bacterial metabolic process is complex, the overall stoichiometry of the principal reactions in the metabolization of carbon in an anaerobic environment such as a landfill can be represented in a simplified form (Klass, 1984).

$$CH_3CO_2^- + H^+ \longrightarrow CH_4 + CO_2 \qquad (2a)$$

$$\text{and } CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O \qquad (2b)$$

Both the above processes involve isotopic fractionation between CH_4 and CO_2 (Games and Hayes, 1976a, 1978; Barker and Fritz, 1981; Carothers and Kharaka, 1980). Analysis of CH_4 and CO_2 from the landfill vent gases offers a unique opportunity in determining the origin of heavy CO_2 in the water samples at the study site. Ranges in δD and $\delta^{13}C$ range of -400 to $-250^0/_{00}$ and -65 to $-50^0/_{00}$ respectively have been reported for methane generated through acetate assimilation (Eqn. 2a) in fresh water environments (Wolmate et al., 1984; Whiticar et al., 1986). From Table 11, the δD and $\delta^{13}C$ of CH_4 from the vents lie in this range, suggesting acetate assimilation to be the most likely mechanism of methane formation in the study area. However, the $\delta^{13}C$ of CO_2 associated with methane is not high enough to account for the heavy leachate values encountered in the study area. The implications of the vent gas analysis are discussed in a later section.

DIC and $\delta^{13}C$ of Water in the Leachate Collection System

The most positive $\delta^{13}C$ for water samples from the site is in groundwater from well W1C. It has a $\delta^{13}C$ of $16.6^{0}/_{00}$ and a DIC concentration of 173 mg C/l. This $\delta^{13}C$ value is much higher than that of the water samples from the leachate collection system (LCS), which has a $\delta^{13}C$ that ranges from of 3.6 to $5.4^{0}/_{00}$ and a DIC concentration ranging between 261 to 343 mg C/l. The LCS intercepts water much closer to the landfill than downgradient well W1C. Thus the LCS is expected to represent a less modified leachate as it migrates away from the main fill area. $\delta^{13}C$ values in landfill leachate higher than $16.6^{0}/_{00}$ have been reported in the literature (Games and Hayes, 1974, 1977; Baedecker and Back, 1979a; Walsh et al., 1993). Because the $\delta^{13}C$ of water samples closer to the landfill is expected to be much more enriched than those further away, the concentrations and $\delta^{13}C$ values of DIC of the LCS and W1C samples appear to be inconsistent with a single source of leachate. Investigation of the LCS revealed that the capture trenches are lined with rubble that includes concrete. Analysis of a sample of concrete material showed that it contained carbonate with a $\delta\ ^{13}C$ value of $-4.5^{0}/_{00}$. It can be inferred that the samples obtained from the LCS are modified by the carbonate in the capture trench. This modification results in a high DIC concentration from carbonate dissolution and more negative $\delta^{13}C$ values than samples obtained in well W1C further downgradient of the landfill.

Distribution of DIC and its $\delta^{13}C$ in Groundwater and Surface Water

The distribution of $\delta^{13}C$ and DIC of the aquifer system covered in the present study area can be explained on the basis of a mixing process between landfill leachate and background groundwater that has undergone varying degrees of carbonate dissolution. To identify the $\delta^{13}C$ of the source carbon, the $\delta^{13}C$ is plotted against DIC^{-1} (Figure 27). Such a plot reveals the evolution of waters, and because mixing between two endmembers appears as a straight line, the y-intercept can be considered to represent the $\delta^{13}C$ of the DIC prior to carbonate dissolution and mixing (Grossman et al., 1989). A regression line through groundwater samples east of Davis Creek (line 1) represents the normal evolution of groundwater DIC (Grossman et al., 1989; Herczeg et al., 1991). $\delta^{13}C$ of organic carbon prior to commencement of carbonate dissolution along this trend as obtained from the regression equation shown in Figure 27 is $-19.6^{0}/_{00}$. This somewhat higher value might result from diffusion of CO_2 from the vadoze zone (fractionation of $\sim 4.5^{0}/_{00}$, Cerling, 1984). This might also be due to the fact that the study area represents a mixture of C3-C4 vegetation. The $\delta^{13}C$ values measured for aquifer carbonates in the Kalamazoo area is $\sim 1.5^{0}/_{00}$ (Nascimento et al., unpublished data), which is in the -3 to $5^{0}/_{00}$ range reported for the parent carbonates in the Michigan basin range (Middleton et al., 1990). Normal groundwater evolving by carbonate dissolution and influenced primarily by soil respired CO_2 (taking a value of $-19.6^{0}/_{00}$) yield groundwater $\delta^{13}C$ values of $-9.1^{0}/_{00}$. Measured concentrations and $\delta^{13}C$ of DIC for shallow groundwater samples around the Kalamazoo area cluster

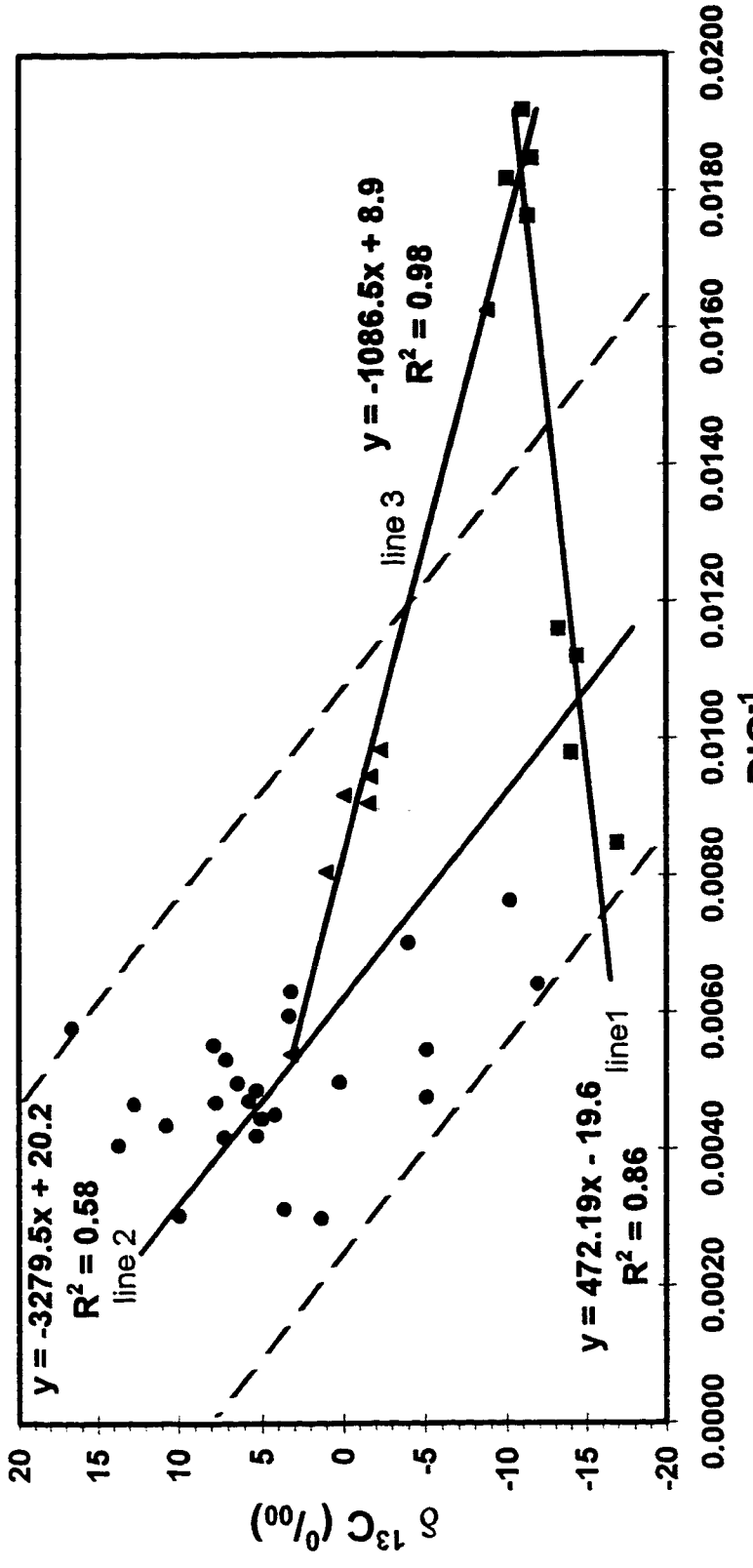

Figure 27. DIC^{-1} vs. $\delta^{13}C$ for Water Samples From the Study Site.

around 55 mg C/l and -10$^0/_{00}$ respectively (Atekwana and Krishnamurthy, unpublished data). This is an indication that the trend demonstrated in this figure adequately describes the evolution of natural unpolluted shallow groundwater in the Kalamazoo area. It is noteworthy to mention that Davis Creek water samples fall at the evolved end of the trend. This is to be expected since Davis Creek is a baseflow stream which derives its water from the local catchment groundwater. A regression through points representing water samples from the west of the creek and coincident with samples below the trend on the evolving groundwater trend (line 1) was carried out. The regression line (line 2) extrapolates to a carbon endmember in the leachate with a $\delta^{13}C$ of CO_2 of 20.2$^0/_{00}$, a reasonable starting $\delta^{13}C$ value of carbon in the landfill.

$\delta^{13}C$-DIC Mass Balance

If the distribution of $\delta^{13}C$ and DIC of the aquifer can be explained on the basis of a mixing process between landfill leachate and background groundwater, it should be possible to apply a simple mass balance of the form:

$$X_{final} = fX_l + (1 - f)X_g$$

where X is the $\delta^{13}C$ or DIC concentration, f is the fraction in the mixture, *g* is the contribution from the mixing groundwater and *l* the contribution from leachate. The fraction of leachate in each water sample is given by:

$$f_l = (X_{final} - X_g)/ X_l - X_g)$$

$\delta^{13}C$ Mass Balance

In order to apply a $\delta^{13}C$ mass balance calculation for samples defined by line 2 (Figure 27), the extrapolated carbon endmember value in leachate of $20.2^{0}/_{00}$ and the intersection of this line with that of evolving groundwater at $-15^{0}/_{00}$ is used. The results of this calculation are shown in Figure 28. Based on this, it can be argued that

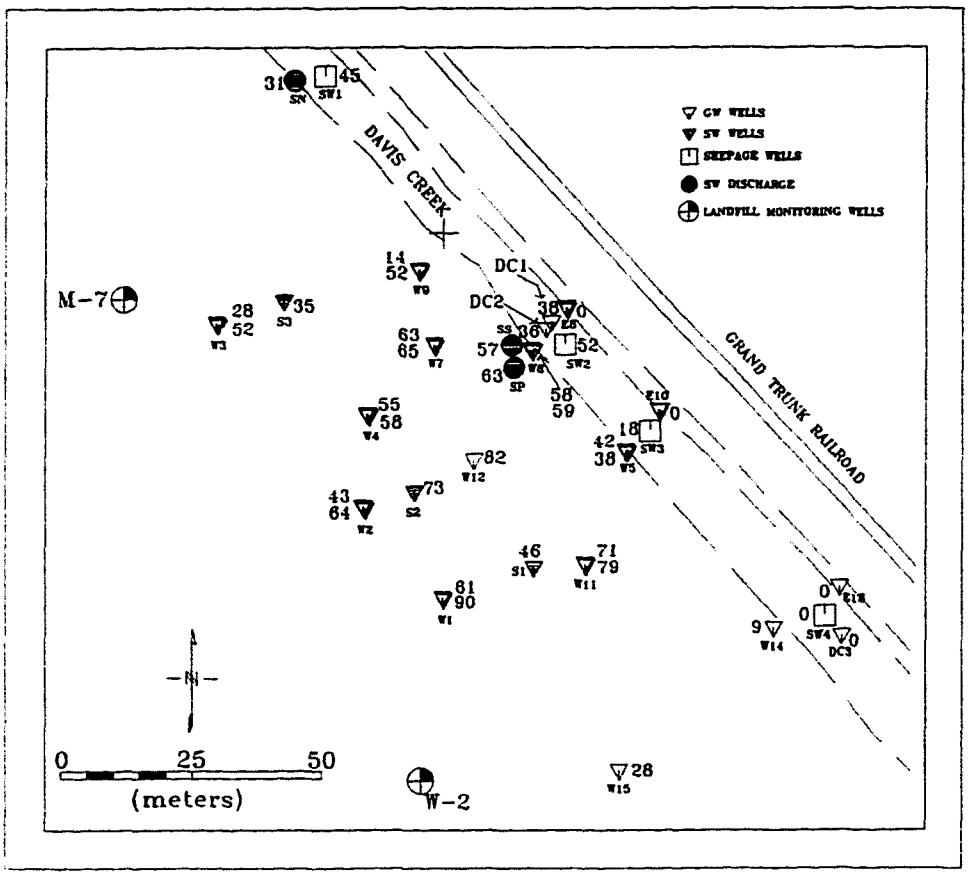

Figure 28. Map Showing the Percentage Leachate Content of Water Samples Obtained From $\delta^{13}C$ Mass Balance. For Locations With two Values, the Upper Number Applies to Shallower Wells.

the samples from the west of the creek must represent a mixture of landfill derived carbon and evolving background groundwater. From Figure 27, it can also be seen that samples obtained from the groundwater below the Davis Creek stream bed and water samples from wells W5 west of the creek define a mixing line between leachate influenced and finally evolved groundwaters (line 3). The y-intercept of this line gives a $\delta^{13}C$ value of $8.9^0/_{00}$ for the leachate influenced component. It is interesting to note that the spring (SP, Figure 9) issuing close to the creek gave consistently constant $\delta^{13}C$ values of $\sim 7.4^0/_{00}$. It is believed that both these values represent the final ^{13}C value of leachate influenced water seeping into Davis Creek. From Figure 28, it is observed that the percentage leachate for shallow wells are lower than their deeper counterparts. This is consistent with the interpretation that groundwater flow conditions west of the creek are predominantly discharging.

DIC Mass Balance

Similar to the $\delta^{13}C$ mixing scenario, it can be deduced from Figure 27 that the DIC concentrations in water samples west of Davis Creek are a mixture of leachate influenced water and groundwater that has undergone varying degrees of evolution (line 2). Unlike the case of $\delta^{13}C$ mass balance, two well-defined end members for DIC concentrations are not permissible given the gentle $\delta^{13}C$-DIC^{-1} slope (line 1). Several endmembers for evolving groundwater can be defined within the region enclosed by the intersection of the dashed lines (parallel to line 2) with the evolving groundwater

(line 1). The samples from groundwater below Davis Creek do, however fall on a well defined DIC mixing line (line 3, Figure 27). It is likely that the gentle $\delta^{13}C$-DIC slope means that the isotopic signatures are more appropriate than DIC in mass balance applications in carbonate rich aquifers.

DIC and Specific Conductance

When DIC is plotted against specific conductance of water samples obtained from similar water samples downgradient of the landfill, a linear relationship is observed (Figure 29). This linear relationship correlated at r^2 of 0.83 signifies similar

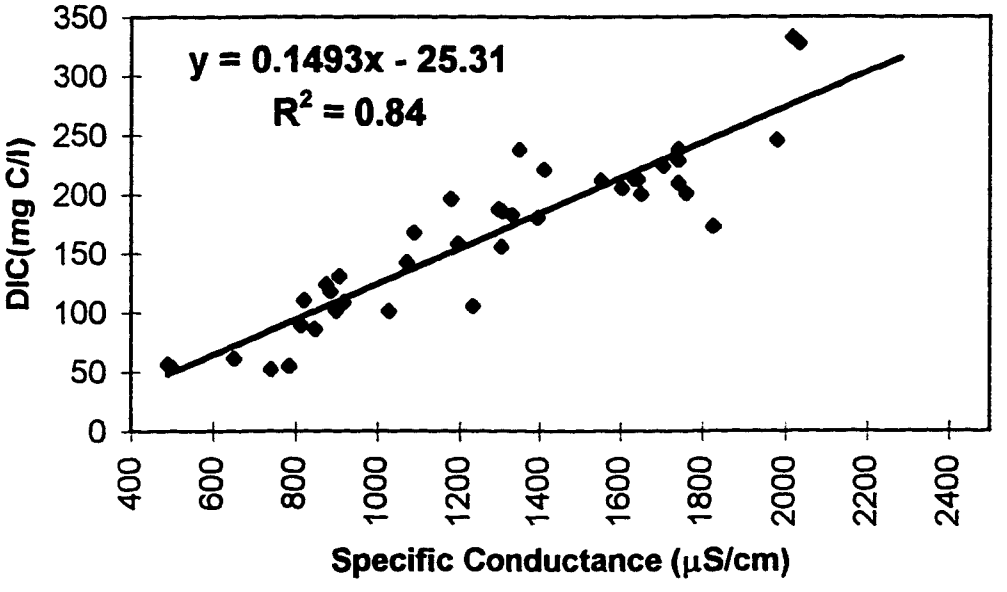

Figure 29. DIC vs. Specific Conductance of Water Samples in the Downgradient Region of Cork Street Landfill.

evolutionary history of both the DIC and specific conductance. The dissolution of aquifer solids by carbonic and other organic acids by migrating leachate increases both the DIC and the specific conductance of the water. Since the specific conductance results also correlate with the EM conductivity data, the DIC analysis provides additional support that the EM conductivity measurements are detecting the presence of leachate in the downgradient region of the landfill.

Implications of Vent Gas Analysis

The $\delta^{13}C$ values of CO_2 from vent gases range from -11 to 4.5 $^0/_{00}$ (Table 11). As discussed previously, the $\delta^{13}C$ of CO_2 is lower than might be expected on the basis of fractionation during acetate assimilation. This lower value can be explained on the basis of Figure 30 which shows a linear relationship between the CO_2:CH_4 ratio and $\delta^{13}C$ of the CO_2. This linear relationship can arise if additional CO_2 is added to the system which is enriched in ^{12}C. One possible mechanism by which this can occur is through the oxidation of methane and carbon under aerobic conditions. Evidence for oxidation of methane is seen in the linear relationship between $\delta^{13}C$ and δD of methane as shown in Figure 31 (Coleman et al., 1981; Barker and Fritz, 1981; Alperin et al., 1988).

The relationship shown in Figure 30 can be used to obtain rough estimates of landfill derived CO_2 that is incorporated as DIC in the leachate. Using an extrapolated value of 20.2$^0/_{00}$ for the initial landfill leachate (Figure 27) and a CO_2-bicarbonate

fractionation of $6.7^0/_{00}$ at 40^0 C (Lesniak and Sakai, 1989), the landfill CO_2 in equilibrium with DIC should have a value of $13.5^0/_{00}$. In using this fractionation, it is assume that the temperature at the CO_2 production site is close to 40^0 C.

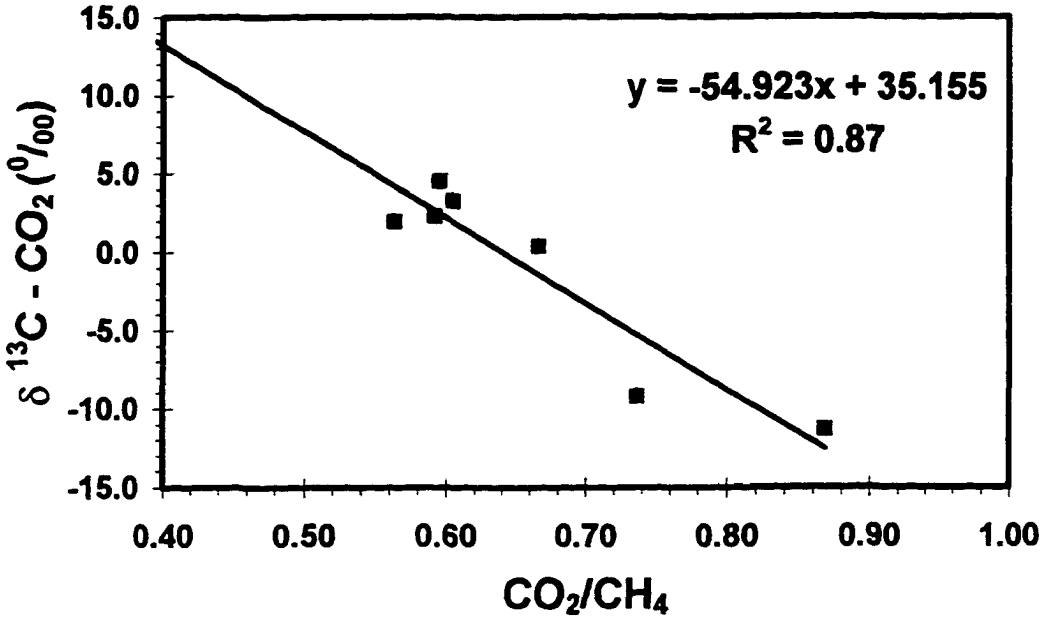

Figure 30. CO_2/CH_4 Ratio vs. $\delta^{13}C$ in Landfill Gases.

Extrapolation of the regression line in Figure 30 to the y-axis gives a $\delta^{13}C$ value of about $13.2^0/_{00}$ and CO_2:CH_4 of 0.4. This would indicate that about 60% of the landfill derived CO_2 via methanogenesis is involved in the production of DIC in the leachate.

Summary and Conclusions

Collection of water samples in the field in pre-evacuated septum tubes containing phosphoric acid and a magnetic stir bar minimizes sample exposure to

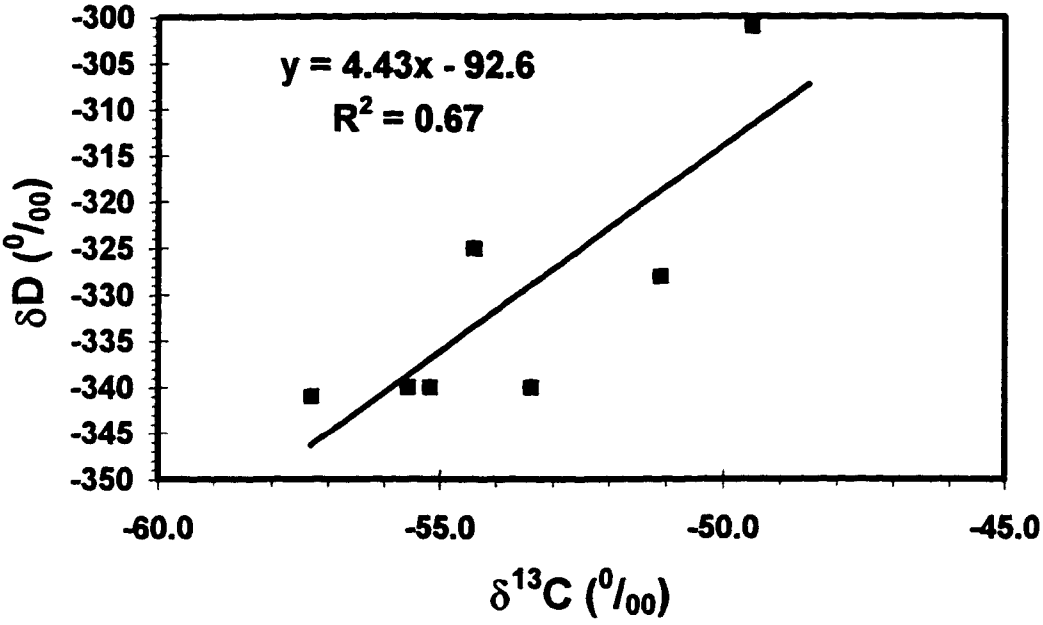

Figure 31. $\delta^{13}C$ vs. $\delta^{13}D$ of Methane in Landfill Gases.

atmospheric CO_2. and allows for the determination of reliable DIC measurements in the samples. CO_2 extraction from the septum tubes at 50° C while stirring is better than 98 % efficient with reproducible $\delta^{13}C$ of $\pm$ 0.1‰. This extraction procedure is simple and readily applicable for routine DIC analysis of natural water samples.

DIC analysis of water obtained from the landfill leachate collection system, groundwater and surface water samples downgradient of the Cork Street landfill shows that leachate impacted ground and surface waters can be readily identified based on the concentration and $\delta^{13}C$ of DIC. A simple leachate evolutionary model based on the observed data requires the production of leachate with heavy CO_2. The

formation of heavy CO_2 in the landfill is achieved through methane generation. Analysis of $\delta^{13}C$ of CO_2 and CH_4, δD of CH_4, and the CO_2:CH_4 ratio from gas vents at the landfill provides evidence of acetate assimilation as the dominant biological process responsible for the isotopically enriched CO_2 in the landfill. There is also evidence for methane oxidation taking place in the aerobic portion of the landfill. From the CO_2:CH_4 ratio measured, about 60% of the CO_2 produced by methanogenesis is used for DIC production in leachate.

The $\delta^{13}C$ values of 3.6 to 5.5$^0/_{00}$ for samples obtained from the leachate collection system are much lighter than expected when compared to more positive downgradient groundwater samples. The low $\delta^{13}C$ and relatively high DIC concentration of the LCS are indicative of modification of the leachate in this collection system by carbonate in the concrete rubble which depresses the $\delta^{13}C$ and increases the DIC concentration. Obviously the leachate collection system does not represent the true leachate.

A mass balance calculation of the $\delta^{13}C$ results allows for leachate impact analysis. In general all groundwater and surface water downgradient from the landfill and west of Davis Creek is impacted by leachate. The aquifer system can be treated as a mixing line between landfill influenced water and background groundwater that has undergone varying degrees of carbonate dissolution. Because of the gentle $\delta^{13}C$-DIC^{-1} slope observed in the case of evolving background waters, the isotopic signature seems to be a better tool to monitor carbon pollution in this and perhaps other similar areas.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Site Characterization

The electromagnetic (EM) inphase data, magnetic survey data and subsurface material observed during well construction suggest that the area downgradient of the landfill and west of Davis Creek has been used for disposal. The distribution of both the EM inphase and magnetic results suggests that the nature of the material disposed of at the site varies. Observations of cuttings from well borings show that the material consists of household trash, garbage and soil fill. The high magnetic and EM anomalies correspond to areas with mostly trash and garbage. The distribution of the EM and magnetic anomalies suggests that there may be two disposal cells in the area.

The electromagnetic conductivity (inphase component) shows areas of pronounced ground conductivity. The conductivity was more pronounced in the horizontal dipole mode indicating a shallow source for the anomalies. A groundwater specific conductance survey at the site shows a similar distribution to the EM conductivity anomalies, suggesting that high groundwater specific conductance is responsible for the high EM conductivity anomalies. The high groundwater specific conductance is attributed to groundwater contamination. Although the conductivity

extension of the high conductivity anomalies towards the fill area suggests that the landfill could also be responsible for the observed groundwater conductivity. The conductivity anomalies decreased towards Davis Creek suggesting that high conductivity water is discharging into Davis Creek.

Site Hydrology

Groundwater-Surface Water Hydrology

Water elevation measurements in shallow monitoring wells and nested piezometers show groundwater flow towards Davis Creek. The vertical hydraulic gradients in nested piezometers are upwards indicating a predominant groundwater discharge regime at the site.

Groundwater flow from the site and its eventual discharge into Davis Creek was confirmed by monitoring wells installed below Davis Creek and measurements of seepage across the creek bed. Water levels in wells installed below the creek are higher than the creek stage indicating groundwater discharge into the creek. Water samples of groundwater seeping across the stream bed sampled for specific conductance showed no influence due to high stream specific conductance associated with road salt. Stream/groundwater interaction is dominated by groundwater. There is no evidence of stream flow into the aquifer at high stream stage.

The Wetlands

The areas occupied by the wetlands are mainly underlain by trash and garbage covered with a thin layer of soil fill. It is believed that the wetlands originated from subsidence of these areas allowing for ponding of water leading to the wetland conditions at the site.

Monitoring of water levels in the wetland basins showed little fluctuation except in late summer. Deuterium distribution in the wetland surface water is similar to that of groundwater below the wetlands and surface water discharge from the wetlands. This similarity of wetland water δD to groundwater δD, and the lack of any significant evaporative enrichment expected during the summer, is indicative of groundwater dominance in the wetlands hydrology.

A hydrologic water balance for the wetlands at the site using both a water budget and isotopic mass balance shows groundwater inflow into the wetlands dominates the hydrology of the wetlands.

Leachate Impact Analysis

Stable isotope analysis of carbon used to evaluate leachate impact showed the presence of landfill leachate in water samples at the site.

A new gas evolution dissolved inorganic carbon (DIC) extraction technique was developed for analysis of water samples. In the technique, water samples are collected in the field in pre-evacuated septum tubes containing phosphoric acid and a

magnetic stir bar to minimize sample exposure to atmospheric CO_2. The vacuum tight septum tubes allow samples to be stored for a reasonable amount of time at room temperature before CO_2 extraction with no loss or gain in CO_2. The CO_2 is extracted from the septum tubes under vacuum at 50° C while stirring. CO_2 extraction from water samples is better than 98 % efficient and measured $\delta^{13}C$ of the DIC is reproducible to $\pm$ 0.1‰. This extraction procedure is simple and readily applicable for routine DIC analysis of natural water samples.

Analysis of carbon isotopes in carbon dioxide and methane in vent gases from the landfill provided evidence of acetate assimilation as the dominant biological process responsible for methane generation at the landfill. From the carbon dioxide and methane ratio in the landfill vent gases, it is estimated that of about 60% of the carbon dioxide produced via methanogenesis is used for the production of dissolved inorganic carbon (DIC) in the landfill leachate.

Using the newly developed DIC analysis technique, water samples from the leachate collection system at the landfill, groundwater and surface samples in the downgradient portion of the landfill showed evidence of DIC enriched in ^{13}C. Since methane generation in the landfill is responsible for producing isotopically heavy carbon in landfill leachate, the heavy carbon detected in DIC analysis in water samples at the site is thus linked to the landfill.

The evolution of migrating leachate was assessed through mixing and mass balance relationships. The distribution of the carbon isotopic signature west of Davis

Creek can be explained by mixing landfill leachate with background groundwater. The carbon isotope values of groundwater below Davis Creek and water seeping into the creek could be explained by mixing of leachate-impacted water west of the creek with non-impacted water east of the creek. The degree of leachate impact from a carbon mass balance allowed for determining the leachate content in water samples. Groundwater west of Davis Creek ranged in leachate content from 14 to 90%. The leachate content of water within the wetlands and surface water flowing out of the wetlands into Davis Creek ranged from 48 to 82%. Groundwater seeping into Davis Creek shows evidence of leachate only in the north of the study area. Here the leachate content varied from 18 to 52 %.

There was no measurable leachate impact to Davis Creek stream water or groundwater east of the creek. Although landfill derrived water was detected in the water discharging from both surface and groundwater, the lack of any measurable impact to the creek water is believed to be the result of dilution. The volume of the creek is large compared to the volume of leachate impacted water input from both surface and groundwater from the site.

Despite the detection of leachate in the downgradient portion of the landfill by DIC analysis, deuterium analyses shows no evidence of enrichment associated with migrating leachate. Although deuterium enrichment has been observed at other landfills, it is suggested here that in a predominantly groundwater discharge regime

such as exists in the study area, the volume of discharging groundwater is sufficiently large to mask any deuterium enrichment associated with leachate production.

Appendix A

Electromagnetic Survey Data

JUNE 1994						DECEMBER 1994		
		SURVEY DIPOLE MODE						Vertical Dipole
		Horizontal		Vertical				
Northing	Easting	conductivity (mS/m)	inphase (ppt)	conductivity (mS/m)	inphase (ppt)	Northing	Easting	conductivity (mS/m)
5040.549	6106.697	90.9		96.3		5277.381	6134.149	55
5060.611	6121.514	86.2		109.8		5260.880	6126.138	48
5079.269	6131.544	82.7		98.6		5242.975	6115.229	40
5095.569	6143.007	36.1		165.4		5227.377	6106.600	31
5115.631	6155.447	27.4		169.5		528.418	6095.918	8
5134.289	6164.988	57.1		139.2		5180.833	6101.682	5
5150.539	6177.428	80.6		100.5		5196.682	6112.364	42
5169.698	6187.913	30.5		107.0		5215.440	6123.240	38
5185.447	6196.999	36.0		63.9		5231.088	6131.674	30
5202.700	6207.029	39.1		22.3		5249.194	6142.584	28
5014.218	6114.806	104.3		93.2		5265.243	6150.594	0
5029.515	6124.836	103.6		100.9		5167.542	6117.248	5
5046.267	6134.898	79.9		97.5		5185.046	6129.655	5
5063.019	6145.384	74.3		116.1		5203.904	6140.434	38
5083.582	6156.879	31.1		150.9		5219.552	6148.934	32
5103.193	6171.664	68.5		120.6		5237.508	6159.713	28
5121.851	6181.726	46.8		149.1		5253.959	6167.756	0
5138.101	6193.645	78.1		99.5		5156.157	6133.205	70
5156.758	6204.652	19.7		123.5		5172.507	6145.156	40
5172.557	6213.249	47.8		57.9		5191.365	6156.000	111
5190.713	6223.767	27.8		19.5		5207.016	6164.467	30
4988.890	6122.947	105.1		137.6		5224.918	6175.213	28
5003.234	6131.056	122.9		122.9		5241.269	6183.224	0
5023.798	6142.518	124.1		111.5		5051.070	6089.891	100
5035.735	6151.115	105.5		127.6		5068.586	6101.943	80
5052.035	6161.634	44.2		152.5		5089.350	6113.568	80
5072.598	6172.641	55.6		132.5		5110.064	6125.064	80
5092.209	6187.913	48.6		131.9		5126.114	6139.197	70
5110.365	6198.432	93.5		97.8		5144.621	6149.194	80
5126.164	6209.895	59.9		105.5		5161.072	6161.145	28
5145.273	6220.413	42.9		106.4		5179.980	6172.022	50
5161.072	6229.987	27.1		91.6		5195.528	6180.456	45
5178.776	6240.961	39.9		21.7		5213.283	6191.430	30
4976.903	6139.685	133.2		136.2		5229.884	6199.343	0
4995.560	6149.715	115.9		128.4		5025.704	6097.123	115
5011.309	6159.257	87.9		129.9		5040.549	6106.697	110
5023.748	6167.886	90.1		143.5		5060.611	6121.514	80
5040.499	6177.916	69.8		135.5		5079.269	6131.544	88
5061.063	6189.379	75.9		115.4		5095.569	6143.007	80
5081.175	6204.196	80.9		122.8		5115.631	6155.447	10
5099.331	6215.659	80.0		87.5		5134.289	6164.988	70
5115.581	6227.121	82.5		110.5		5150.539	6177.428	72
5134.239	6232.640	55.7		114.6		5169.698	6187.913	18
5150.038	6246.725	35.1		98.4		5185.447	6196.999	21
5168.194	6257.244	31.1		21.6		5202.700	6207.029	32
4985.028	6165.965	110.3		121.9		5219.452	6215.626	0

JUNE 1994						DECEMBER 1994		
		SURVEY DIPOLE MODE						Vertical Dipole
		Horizontal		Vertical				
Northing	Easting	conductivity (mS/m)	inphase (ppt)	conductivity (mS/m)	inphase (ppt)	Northing	Easting	conductivity (mS/m)
4999.874	6175.506	100.5		128.7		4997.015	6103.343	130
5012.814	6184.103	100.6		119.4		5014.218	6114.806	98
5029.515	6194.622	91.4		131.1		5029.515	6124.836	122
5069.740	6221.390	57.6		126.5		5046.267	6134.898	115
5087.394	6231.420	82.3		102.7		5063.019	6145.384	80
5102.742	6242.427	65.5		115.6		5083.582	6156.879	41
5122.352	6253.401	77.0		123.0		5103.193	6171.664	45
5138.101	6262.975	35.7		114.3		5121.851	6181.726	55
5156.307	6273.493	48.9		27.5		5138.101	6193.645	68
4953.430	6173.129	93.0		146.6		5156.758	6204.652	28
4972.088	6184.136	92.5		130.5		5172.557	6213.249	35
4992.652	6192.487	73.1		137.3		5190.713	6223.767	40
5003.686	6205.140	66.7		150.1		5207.014	6231.878	0
5020.889	6215.659	64.6		154.5		4988.890	6122.947	80
5037.139	6226.177	71.4		134.8		5003.234	6131.056	120
5057.702	6237.151	47.5		133.3		5023.798	6142.518	90
5075.909	6248.646	83.6		103.1		5035.735	6151.115	76
5093.613	6260.565	89.6		101.4		5052.035	6161.634	63
5112.271	6271.084	85.6		97.3		5072.598	6172.641	75
5127.067	6279.681	75.8		80.1		5092.209	6187.913	72
5145.273	6290.199	51.1		31.9		5110.365	6198.432	81
4940.541	6192.245	49.8		132.5		5126.164	6209.895	72
4957.292	6203.251	88.0		105.9		5145.273	6220.413	12
4977.856	6214.714	63.9		130.8		5161.072	6229.987	40
4990.294	6223.311	73.5		137.5		5178.776	6240.961	40
5005.591	6232.853	85.7		129.5		5195.027	6249.102	0
5022.795	6243.371	44.7		143.4		4976.903	6139.685	110
5039.045	6253.401	52.1		130.7		4995.560	6149.715	85
5059.658	6265.352	74.5		160.9		5011.309	6159.257	90
5081.175	6276.359	91.5		118.5		5023.748	6167.886	100
5097.877	6286.389	86.5		110.2		5040.499	6177.916	130
5118.942	6297.363	61.4		108.5		5061.063	6189.379	70
5135.693	6307.426	56.9		42.5		5081.175	6204.196	71
4931.914	6206.573	59.2		98.9		5099.331	6215.659	78
4948.164	6216.603	74.0		86.8		5115.581	6227.121	65
4969.229	6228.098	41.2		127.1		5134.239	6232.640	48
4984.526	6240.017	74.8		137.5		5150.038	6246.725	10
5000.325	6249.591	66.2	1.4	138.1	-9.9	5168.194	6257.244	40
5017.077	6260.109	61.0	0.2	111.8	-8.2	5184.494	6265.352	0
5033.829	6270.139	94.4	-6.3	83.4	-6.4	4950.572	6143.984	80
5054.392	6281.602	93.0	-1.3	103.5	-9.9	4967.825	6154.014	75
5068.737	6292.609	92.0	-3.5	115.7	-9.7	4985.028	6165.965	65
5086.441	6302.150	69.2	-3.2	124.0	-8.3	4999.874	6175.506	78
5106.052	6312.669	64.5	-3.3	124.5	-9.9	5012.814	6184.103	68
5123.255	6324.620	57.5	0.7	59.9	-4.0	5029.515	6194.622	85
4920.428	6223.800	59.4		106.2		5050.079	6206.085	70

JUNE 1994						DECEMBER 1994		
		SURVEY DIPOLE MODE						Vertical Dipole
		Horizontal		Vertical				
Northing	Easting	conductivity (mS/m)	inphase (ppt)	conductivity (mS/m)	inphase (ppt)	Northing	Easting	conductivity (mS/m)
4955.838	6244.348	88.1		128.5		5069.740	6221.390	60
4966.370	6252.945	99.3		126.0		5087.394	6231.420	85
4983.122	6262.975	71.3	5.2	148.2	-8.8	5102.742	6242.427	70
5000.325	6273.493	81.9	-0.2	129.4	-4.0	5122.352	6253.401	65
5021.842	6284.956	98.7	-3.8	100.6	-6.6	5138.101	6262.975	40
5041.954	6298.340	109.1	0.4	111.5	-9.7	5156.307	6273.493	48
5057.251	6307.882	78.0	-0.8	133.9	-10.4	5173.009	6282.090	0
5074.003	6317.911	76.5	-2.7	124.0	-12.5	4936.729	6162.611	90
5090.704	6328.430	54.5	-0.9	144.5	-11.8	4953.430	6173.129	68
5111.769	6339.437	62.0	-3.0	58.9	0.8	4972.088	6184.136	95
4907.990	6240.505	113.9		107.4		4992.652	6192.487	70
4921.381	6249.591	115.4		106.2		5003.686	6205.140	8
4938.083	6259.621	93.3		125.5		5020.889	6215.659	62
4954.383	6269.651	93.2		143.9		5037.139	6226.177	55
4974.947	6283.035	92.0	2.8	154.5	-10.8	5057.702	6237.151	60
4990.244	6292.609	85.5	-1.9	134.5	-10.6	5075.909	6248.646	81
5007.447	6303.095	98.8	-1.8	125.3	-11.8	5093.613	6260.565	120
5024.199	6313.157	79.4	-1.6	123.5	-9.4	5112.271	6271.084	95
5044.311	6324.620	78.9	-1.9	132.9	-8.5	5127.067	6279.681	73
5062.467	6333.705	102.3	2.3	117.0	-10.3	5145.273	6290.199	55
5078.266	6343.735	95.8	-5.8	113.0	-11.2	5163.429	6298.796	20
5099.281	6356.142	62.9	0.9	58.0	-0.8	4923.337	6182.215	95
4897.457	6257.699	168.0		169.6		4940.541	6192.245	89
4910.849	6267.273	148.9		163.1		4957.292	6203.251	92
4927.601	6277.303	133.9		136.5		4977.856	6214.714	69
4943.851	6287.333	117.0		135.1		4990.294	6223.311	70
4960.603	6296.907	30.5	9.2	160.3	-12.9	5005.591	6232.853	78
4978.759	6305.960	66.8	2.2	154.8	-13.2	5022.795	6243.371	50
4999.322	6317.456	90.4	-0.4	137.1	-12.6	5039.045	6253.401	75
5018.481	6329.863	62.0	0.0	157.0	-11.6	5059.658	6265.352	82
5025.946	6334.854	60.0	2.8	160.9	-13.6	5081.175	6276.359	72
5032.826	6338.460	82.3	1.1	152.0	-12.3	5097.877	6286.389	90
5050.029	6349.922	102.7	-7.5	105.2	-10.7	5118.942	6297.363	65
5066.780	6360.441	53.1	-0.2	129.7	-12.5	5135.693	6307.426	60
5087.344	6371.448	53.3	-2.3	40.8	1.9	5152.896	6315.534	20
4890.285	6270.139	140.7		143.6		4914.209	6196.055	135
4906.034	6281.602	157.6		167.9		4931.914	6206.573	128
4922.786	6292.609	143.4		155.2		4948.164	6216.603	115
4939.537	6302.150	82.6		171.4		4969.229	6228.098	110
4955.326	6313.157	79.5	4.5	163.6	-9.2	4984.526	6240.017	98
4971.586	6323.187	78.2	-0.8	159.9	-11.2	5000.325	6249.591	78
4987.837	6333.217	64.9	-0.9	184.0	-11.2	5017.077	6260.109	70
5006.043	6346.112	22.2	4.2	181.8	-14.9	5033.829	6270.139	100
5015.280	6350.768	47.9	3.7	159.0	-12.9	5054.392	6281.602	98
5020.387	6355.686	72.7	-0.5	128.0	-11.0	5068.737	6292.609	98
5038.092	6367.149	71.8	-3.6	118.9	-12.5	5086.441	6302.150	59

JUNE 1994						DECEMBER 1994		
		SURVEY DIPOLE MODE						Vertical Dipole
		Horizontal		Vertical				
Northing	Easting	conductivity (mS/m)	inphase (ppt)	conductivity (mS/m)	inphase (ppt)	Northing	Easting	conductivity (mS/m)
5054.342	6376.691	45.5	1.4	99.4	-13.0	5106.052	6312.669	65
5075.859	6387.209	37.9	-5.1	31.7	4.6	5123.255	6324.620	60
4878.298	6279.713	40.9		63.4		5139.505	6331.295	28
4896.505	6294.042	71.4		57.6		4900.366	6212.793	140
4918.472	6307.882	169.9		144.4		4920.428	6223.800	150
4931.760	6316.434	153.2		136.9		4935.274	6231.908	108
4931.864	6316.511	38.9	3.2	180.0	-12.7	4955.838	6244.348	105
4961.023	6338.918	50.4	0.2	180.0	-11.9	4966.370	6252.945	111
4977.304	6350.411	32.8	2.4	168.9	-13.8	4983.122	6262.975	88
4985.776	6355.484	67.5	-3.0	136.9	-10.5	5000.325	6273.493	92
4993.604	6362.362	40.5	4.3	145.0	-13.1	5021.842	6284.956	105
5008.400	6372.392	65.7	-2.7	123.8	-12.3	5041.954	6298.340	110
5017.095	6378.617	35.6	0.4	135.0	-13.8	5057.251	6307.882	68
5025.653	6383.887	43.0	-0.7	127.5	-12.4	5074.003	6317.911	60
5044.311	6394.373	25.6	1.2	76.0	-11.0	5090.704	6328.430	55
5062.969	6405.380	22.3	-11.3	30.6	11.0	5111.769	6339.437	60
4867.314	6298.829	79.7		166.4		5127.067	6348.034	58
4884.066	6310.291	108.1		100.3		4894.599	6229.531	198
4900.316	6322.243	107.7		107.2		4907.990	6240.505	185
4941.293	6350.179	37.3	0.2	163.8	-12.2	4921.381	6249.591	132
4949.117	6355.198	29.6	4.3	179.5	-13.5	4938.083	6259.621	132
4965.869	6366.607	72.2	0.8	151.0	-10.3	4954.383	6269.651	60
4984.025	6378.612	45.8	-3.2	135.9	-10.1	4974.947	6283.035	62
4997.918	6388.642	58.9	-4.3	126.0	-11.0	4990.244	6292.609	81
5015.572	6399.160	33.7	0.7	117.5	-12.4	5007.447	6303.095	100
5032.324	6411.111	42.3	-1.2	59.2	-10.3	5024.199	6313.157	75
5050.982	6421.630	-3.9		34.5	15.8	5044.311	6324.620	90
4852.970	6316.023	101.5		158.2		5062.467	6333.705	108
4869.722	6327.977	118.6		101.9		5078.266	6343.735	93
4885.972	6339.925	111.0		83.6		5099.281	6356.142	61
4927.675	6366.830	66.0	-0.8	137.3	-14.9	5114.127	6362.851	22
4936.679	6371.936	42.1	-0.3	146.9	-15.5	4878.298	6242.883	82
4952.477	6384.343	74.0	-0.5	133.4	-15.8	4897.457	6257.699	149
4970.132	6393.917	77.8	-5.1	123.5	-14.0	4910.849	6267.273	190
4986.884	6404.893	83.5	-7.3	94.8	-10.6	4927.601	6277.303	100
5004.137	6415.410	28.2	0.2	82.0	-10.9	4943.851	6287.333	89
5020.836	6427.361	45.5	-2.3	31.2	-5.6	4960.603	6296.907	25
5038.543	6435.958	10.7	-7.3	33.5	10.0	4978.759	6305.960	65
4943.441	6331.788	67.9		131.1		4999.322	6317.456	90
4860.192	6343.735	107.3		93.9		5018.481	6329.863	60
4875.941	6354.254	126.5		109.3		5032.826	6338.460	70
4892.241	6364.740	130.0	0.6	127.7	-12.7	5050.029	6349.922	108
4909.444	6375.258	84.6	0.0	128.8	-15.3	5066.780	6360.441	55
4925.243	6387.209	55.0	1.7	123.6	-14.9	5087.344	6371.448	51
4941.945	6398.672	78.9	-4.0	120.9	-14.4	5098.829	6377.179	22
4959.650	6409.679	60.3	-3.9	116.6	-13.7	4870.173	6259.621	80

JUNE 1994						DECEMBER 1994		
		SURVEY DIPOLE MODE						Vertical Dipole
		Horizontal		Vertical				
Northing	Easting	conductivity (mS/m)	inphase (ppt)	conductivity (mS/m)	inphase (ppt)	Northing	Easting	conductivity (mS/m)
4975.950	6420.653	49.1	-3.5	83.5	-11.3	4890.285	6270.139	56
4993.153	6429.738	38.8	-4.8	37.0	-9.0	4906.034	6281.602	180
5009.905	6443.122	36.3	-7.2	34.3	0.2	4922.786	6292.609	80
5028.061	6452.208	3.8	-5.5	41.5	12.6	4939.537	6302.150	100
4848.241	6361.967	115.7		103.5		4955.326	6313.157	60
4863.901	6372.430	83.5		157.2		4971.586	6323.187	80
4880.696	6382.450	121.1	-1.0	131.7	14.5	4987.837	6333.217	55
4897.036	6392.470	68.2	4.3	139.8	-19.0	5006.043	6346.112	10
4913.831	6403.964	58.3	-3.6	142.0	-14.9	5020.387	6355.686	10
4930.626	6415.016	65.5	-3.3	121.5	-11.5	5038.092	6367.149	68
4946.966	6426.510	60.6	-4.9	81.3	-10.4	5054.342	6376.691	35
4963.761	6437.561	42.5	-6.3	43.5	-8.1	5075.859	6387.209	42
4981.463	6445.371	39.8	-6.0	31.8	-7.8	5085.438	6391.019	40
4997.804	6460.107	26.2	12.2	60.2	-6.0	4862.550	6270.139	115
5016.187	6468.948	18.3	11.4	36.5	4.1	4878.298	6279.713	105
4853.915	6388.786	116.6		109.5		4896.505	6294.042	110
4886.143	6409.122	75.5	2.6	153.3	-15.8	4918.472	6307.882	125
4902.937	6420.173	58.1	0.3	146.4	-15.9	4931.864	6316.511	20
4919.051	6431.667	65.9	-2.5	99.2	-11.4	4961.023	6338.918	42
4936.980	6442.277	35.5	-3.2	40.8	-8.1	4977.304	6350.411	10
4956.186	6455.392	42.8	-5.9	29.4	-7.2	4993.604	6362.362	31
4970.570	6463.202	18.3	0.5	81.7	-14.2	5008.400	6372.392	50
4985.776	6475.285	25.4	15.3	75.7	-6.0	5025.653	6383.887	40
5004.613	6484.779	7.1	8.2	38.9	5.4	5044.311	6394.373	12
4826.681	6391.881	120.2		118.9		5062.969	6405.380	20
4843.475	6403.375	102.7		128.5		5071.564	6411.774	18
4859.362	6414.426	25.3	5.4	192.5	-17.2	4850.563	6292.609	132
4875.476	6423.415	90.5	-2.6	144.9	-13.2	4867.314	6298.829	132
4891.816	6435.351	40.7	-6.3	121.9	-9.8	4884.066	6310.291	118
4907.476	6447.434	47.4	-3.3	48.0	-6.7	4900.316	6322.243	110
4924.271	6459.518	47.2	-5.8	31.4	-6.4	4932.867	6344.224	50
4941.066	6469.980	8.5	2.3	97.0	-14.2	4949.117	6355.198	5
4956.952	6482.063	40.8	-1.9	77.2	-13.3	4965.869	6366.607	50
4975.336	6492.084	51.5	6.0	45.1	1.3	4984.025	6378.612	32
4989.406	6501.956	25.2	4.0	25.1	-0.2	4997.918	6388.642	50
4814.198	6409.122	118.3		100.2		5015.572	6399.160	20
4830.993	6421.205	120.8		135.1		5032.324	6411.111	49
4847.106	6432.846	99.2	0.9	161.2	-12.4	5050.982	6421.630	0
4857.773	6441.687	31.0	1.2	137.9	-12.2	4852.970	6316.023	140
4879.788	6452.739	57.0	-3.7	50.6	-8.0	4869.722	6327.977	122
4895.902	6464.233	51.2	-4.6	37.1	-7.5	4885.972	6339.925	120
4912.696	6475.727	20.9	-1.3	85.5	-11.5	4902.222	6349.495	108
4929.037	6487.368	32.6	2.6	90.4	-13.9	4918.472	6360.473	100
4945.378	6498.273	41.3	-3.2	62.3	-12.3	4936.679	6371.936	38
4962.172	6508.882	30.0	-10.2	47.4	9.3	4952.477	6384.343	62
4975.790	6517.134	40.5	5.3	27.9	-3.5	4970.132	6393.917	65

JUNE 1994						DECEMBER 1994		
		SURVEY DIPOLE MODE						Vertical Dipole
		Horizontal		Vertical				
Northing	Easting	conductivity (mS/m)	inphase (ppt)	conductivity (mS/m)	inphase (ppt)	Northing	Easting	conductivity (mS/m)
4803.077	6427.541	122.0		105.5		4986.884	6404.893	80
4818.964	6438.004	141.3		132.5		5004.137	6415.410	25
4835.078	6448.466	77.8		120.5		5020.836	6427.361	43
4848.695	6456.865	49.2	2.6	61.2	-9.5	5038.543	6435.958	5
4865.490	6469.980	40.7	-1.9	39.5	-6.6	4943.441	6331.788	98
4885.008	6481.032	18.0	0.3	98.8	-13.8	4860.192	6343.735	122
4900.668	6492.526	26.7	-1.2	96.0	-12.0	4875.941	6354.254	130
4917.462	6503.577	17.9	0.4	104.7	-15.6	4892.241	6364.740	120
4934.257	6514.629	40.9	0.3	60.5	-11.2	4909.444	6375.258	80
4947.420	6523.029	3.4		44.9	13.7	4925.243	6387.209	45
4953.775	6525.534	2.0	6.0	41.0	15.5	4941.945	6398.672	75
4807.843	6452.887	102.7		108.7		4959.650	6409.679	55
4824.184	6464.380	55.3		71.7		4975.950	6420.653	45
4840.979	6475.874	38.2	-0.3	31.0	-8.9	4993.153	6429.738	40
4857.319	6486.926	42.5	-1.3	52.1	-10.4	5009.905	6443.122	30
4873.433	6496.799	68.9	-3.0	74.5	-12.1	5028.061	6452.208	0
4889.320	6508.882	54.2	-4.2	77.2	-11.5	4831.901	6349.884	105
4906.568	6519.345	27.5	0.8	90.5	-12.3	4848.241	6361.967	125
4922.909	6530.396	35.4	1.8	62.5	-11.3	4863.901	6372.430	80
4939.023	6540.417	-22.0		38.0	17.5	4880.696	6382.450	118
4947.032	6546.061	8.3	9.0	35.0	12.5	4897.036	6392.470	61
4797.403	6469.096	26.6		49.7		4913.831	6403.964	45
4813.063	6481.621	37.2		35.4		4930.626	6415.016	62
4829.404	6493.115	54.0	-4.2	59.9	-8.4	4946.966	6426.510	49
4845.745	6503.135	53.4	-4.9	57.6	-11.0	4963.761	6437.561	40
4862.539	6514.187	61.7	-3.9	60.5	-11.1	4981.463	6445.371	42
4877.745	6525.239	48.9	-2.7	72.5	-12.1	4997.804	6460.107	35
4894.994	6536.143	45.9	0.2	66.2	-12.9	5016.187	6468.948	20
4911.335	6546.606	42.9	-0.1	42.5	-5.5	4820.326	6364.620	125
4927.675	6557.657	-46.6		33.8	19.0	4837.120	6376.703	122
4936.980	6563.994	-15.2	10.2	43.3	12.3	4853.915	6388.786	115
4785.829	6485.895	39.4		39.4		4870.256	6398.659	71
4801.035	6496.799	47.6		66.3		4886.143	6409.122	70
4817.829	6508.882	53.6		69.9		4902.937	6420.173	68
4834.170	6519.345	42.2	-16.3	65.1	-10.8	4919.051	6431.667	64
4851.419	6529.954	59.5	-4.8	61.4	-10.0	4936.980	6442.277	32
4865.717	6541.890	28.6	-2.0	63.9	-12.8	4956.186	6455.392	45
4883.419	6552.942	38.6	-1.1	73.5	-13.4	4970.570	6463.202	10
4900.214	6563.994	43.9	4.2	42.7	-4.2	4985.776	6475.285	22
4916.554	6574.456	-24.9		41.9		5004.613	6484.779	8
4822.595	6535.701	60.0	0.4	81.0	-13.0	4809.886	6379.798	150
4840.525	6546.606	58.8	-1.5	66.5	-11.1	4826.681	6391.881	130
4854.596	6558.247	56.0	-2.1	67.7	-12.2	4843.475	6403.375	80
4871.844	6569.151	48.1	-2.2	76.9	-12.2	4859.362	6414.426	20
4888.639	6580.203	44.9	8.5	41.9	-1.5	4875.476	6423.415	81
4904.980	6590.223	-8.1	11.9	41.5	19.4	4891.816	6435.351	42

JUNE 1994						DECEMBER 1994		
		SURVEY DIPOLE MODE						Vertical Dipole
		Horizontal		Vertical				
Northing	Easting	conductivity (mS/m)	inphase (ppt)	conductivity (mS/m)	inphase (ppt)	Northing	Easting	conductivity (mS/m)
4860.951	6585.950	64.3	-1.4	73.4	-10.4	4907.476	6447.434	50
4877.291	6597.002	48.1	6.9	45.5	9.0	4924.271	6459.518	45
4894.086	6607.022	-8.1	5.6	41.5	12.6	4941.066	6469.980	0
4824.982	6584.763	62.5		83.9	7.1	4956.952	6482.063	35
4832.581	6591.255	70.0	-3.8	67.0	-9.1	4975.336	6492.084	51
4849.376	6602.749	64.4	-2.8	50.0	-7.8	4989.406	6501.956	21
4866.851	6612.622	25.1	-7.2	33.5	8.8	6798.311	6379.628	120
4820.553	6607.464	68.9	-1.5	60.5	-8.9	4814.198	6409.122	132
4838.482	6617.337	41.4	1.0	35.8	-8.4	4830.993	6421.205	150
4854.142	6630.010	0.4		23.0	15.2	4847.106	6432.846	100
4818.519	6629.985	42.1	-2.6	35.2	-5.6	4857.773	6441.687	30
4826.454	6635.167	33.0	-0.5	25.7	-5.0	4879.788	6452.739	55
4842.567	6647.840	-38.5		20.0	17.0	4895.902	6464.233	50
4807.389	6648.871	8.9		41.5	-4.5	4912.696	6475.727	10
4815.333	6653.587	31.4	1.1	21.5	-2.7	4929.037	6487.368	32
4831.674	6661.986	-12.5		26.6	18.4	4945.378	6498.273	38
4803.758	6667.144	32.5	4.0	19.9	-0.5	4962.172	6508.882	20
4820.099	6677.164	-12.0		25.4	18.2	4975.790	6517.134	40
						4795.134	6412.794	100
						4803.077	6427.541	100
						4818.964	6438.004	122
						4835.078	6448.466	70
						4848.695	6456.865	50
						4865.490	6469.980	40
						4885.008	6481.032	15
						4900.668	6492.526	21
						4917.462	6503.577	18
						4934.257	6514.629	35
						4947.420	6523.029	0
						4953.775	6525.534	0
						4775.389	6429.752	65
						4791.049	6442.277	45
						4807.843	6452.887	40
						4824.184	6464.380	48
						4840.979	6475.874	62
						4857.319	6486.926	90
						4873.433	6496.799	65
						4889.320	6508.882	50
						4906.568	6519.345	28
						4922.909	6530.396	28
						4939.023	6540.417	0
						4764.268	6445.519	60
						4780.609	6457.013	55
						4797.403	6469.096	30
						4813.063	6481.621	40
						4829.404	6493.115	60

JUNE 1994						DECEMBER 1994		
		SURVEY DIPOLE MODE						Vertical
		Horizontal		Vertical				Dipole
Northing	Easting	conductivity (mS/m)	inphase (ppt)	conductivity (mS/m)	inphase (ppt)	Northing	Easting	conductivity (mS/m)
						4845.745	6503.135	58
						4862.539	6514.187	61
						4877.745	6525.239	45
						4894.994	6536.143	40
						4911.335	6546.606	38
						4927.675	6557.657	0
						4936.980	6563.994	0
						4785.829	6485.895	60
						4801.035	6496.799	20
						4817.829	6508.882	60
						4834.170	6519.345	50
						4851.419	6529.954	60
						4865.717	6541.890	45
						4883.419	6552.942	35
						4900.214	6563.994	40
						4916.554	6574.456	0
						4822.595	6535.701	62
						4840.525	6546.606	60
						4854.596	6558.247	56
						4871.844	6569.151	48
						4888.639	6580.203	41
						4904.980	6590.223	0
						4845.291	6574.456	80
						4860.951	6585.950	62
						4877.291	6597.002	40
						4894.086	6607.022	0
						4817.375	6579.172	46
						4832.581	6591.255	75
						4849.376	6602.749	62
						4866.851	6612.622	20
						4820.553	6607.464	68
						4838.482	6617.337	49
						4854.142	6630.010	0
						4809.659	6624.263	40
						4826.454	6635.167	30
						4842.567	6647.840	0
						4807.389	6648.871	20
						4815.333	6653.587	30
						4831.674	6661.986	0
						4803.758	6667.144	30
						4820.099	6677.164	0

Appendix B

Magnetic Survey Data

Station Location		Averaged Magnetic Value (nT)
Northing (ft)*	Easting (ft)*	
5068.586	6101.9428	56821
5089.3501	6113.5684	56972
5110.0641	6125.0637	56719
5126.1137	6139.1968	57355
5144.6209	6149.1941	56706
5161.0717	6161.1453	56863
5179.9801	6172.0219	56514
5195.5281	6180.4561	55738
5213.2829	6191.4304	55891
5229.8842	6199.343	55872
5025.7035	6097.1233	56680
5040.5494	6106.6973	56292
5060.6114	6121.5142	56568
5079.269	6131.5441	56621
5095.5693	6143.0068	57036
5115.6313	6155.4465	57444
5134.2889	6164.9879	56593
5150.5391	6177.4276	56606
5169.6983	6187.9134	56730
5185.447	6196.999	55923
5202.7003	6207.0289	55973
5219.452	6215.6259	56385
4997.0149	6103.3431	56619
5014.2181	6114.8059	56815
5029.5153	6124.8358	56549
5046.2671	6134.8982	56651
5063.0188	6145.384	57343
5083.5823	6156.8793	57062
5103.1929	6171.6637	56441
5121.8505	6181.7261	56437
5138.1007	6193.6448	56384
5156.7583	6204.6516	56727
5172.5571	6213.2487	55960
5190.7132	6223.7671	56154
5207.0136	6231.8775	57290
4988.8898	6122.947	56614
5003.2341	6131.0556	56499

Station Location		Averaged Magnetic Value
Northing (ft)*	Easting (ft)*	(nT)
5023.7977	6142.5184	56613
5035.7345	6151.1154	56780
5052.0349	6161.6338	56756
5072.5984	6172.6406	56230
5092.209	6187.9134	56564
5110.365	6198.4318	55918
5126.1638	6209.8945	56441
5145.2729	6220.4129	56810
5161.0717	6229.9869	55930
5178.7764	6240.9612	55901
5195.0265	6249.1023	57753
4976.9028	6139.6852	58030
4995.5604	6149.7151	56714
5011.3091	6159.2566	56679
5023.7475	6167.8862	56378
5040.4992	6177.9161	56709
5061.0628	6189.3788	56925
5081.1749	6204.1957	56499
5099.331	6215.6585	56415
5115.5812	6227.1212	56778
5134.2388	6232.6396	56932
5150.0376	6246.7251	56073
5168.1937	6257.2435	55537
5184.494	6265.3521	55213
4950.5715	6143.9838	56642
4967.8248	6154.0137	56796
4985.0279	6165.9649	55970
4999.8738	6175.5063	56723
5012.8137	6184.1034	56648
5029.5153	6194.6217	56923
5050.0788	6206.0845	57110
5069.7396	6221.3899	56807
5087.3941	6231.4198	56194
5102.7415	6242.4266	56446
5122.3521	6253.4009	57057
5138.1007	6262.9749	56530
5156.307	6273.4932	55471

Station Location		Averaged Magnetic Value (nT)
Northing (ft)*	Easting (ft)*	
5173.0085	6282.0903	55491
4936.7287	6162.6107	57237
4953.4303	6173.1291	56170
4972.0879	6184.1359	55237
4992.6515	6192.4874	56731
5003.6855	6205.1401	56834
5020.8887	6215.6585	56913
5037.1389	6226.1768	57139
5057.7024	6237.1511	56787
5075.9086	6248.6464	56736
5093.6133	6260.5651	57032
5112.2709	6271.0835	57300
5127.0666	6279.6805	56551
5145.2729	6290.1989	54399
5163.4289	6298.7959	54790
4923.3374	6182.2146	57797
4940.5405	6192.2445	57451
4957.2922	6203.2514	55633
4977.8558	6214.7141	55947
4990.2942	6223.3112	56407
5005.5914	6232.8526	56664
5022.7946	6243.371	56406
5039.0448	6253.4009	56362
5059.6584	6265.3521	56686
5081.1749	6276.3589	57189
5097.8765	6286.3888	57431
5118.9415	6297.3631	57169
5135.6933	6307.4256	55636
5152.8964	6315.5342	54855
4914.2092	6196.0546	56851
4931.9138	6206.573	56641
4948.164	6216.6029	56760
4969.2291	6228.0982	56166
4984.5264	6240.0168	56476
5000.3252	6249.5908	56668
5017.0769	6260.1092	56200
5033.8286	6270.1391	56253

Station Location		Averaged Magnetic Value (nT)
Northing (ft)*	Easting (ft)*	
5054.3922	6281.6018	56711
5068.7365	6292.6087	56878
5086.4411	6302.1501	57533
5106.0517	6312.6685	57321
5123.2549	6324.6197	58590
5139.5051	6331.2954	59098
4900.3664	6212.7928	56419
4920.4284	6223.7996	56185
4935.2742	6231.9082	56405
4955.8377	6244.3479	56445
4966.3703	6252.945	56797
4983.122	6262.9749	56457
5000.3252	6273.4932	56146
5021.8416	6284.956	56441
5041.9537	6298.34	56887
5057.251	6307.8815	56960
5074.0027	6317.9114	56915
5090.7043	6328.4297	57056
5111.7694	6339.4366	57039
5127.0666	6348.0336	57246
4894.5986	6229.531	56410
4907.9899	6240.5053	56578
4921.3813	6249.5908	56866
4938.0829	6259.6207	56302
4954.3832	6269.6506	56843
4974.9468	6283.0347	57040
4990.244	6292.6087	56997
5007.4472	6303.0945	56786
5024.1989	6313.1569	56849
5044.311	6324.6197	56519
5062.4671	6333.7052	56183
5078.2659	6343.7351	56740
5099.2808	6356.1422	54871
5114.1267	6362.8505	54861
4878.2982	6242.8825	56633
4897.4574	6257.6994	56814
4910.8488	6267.2734	56816

Station Location		Averaged Magnetic Value (nT)
Northing (ft)*	Easting (ft)*	
4927.6005	6277.3033	56605
4943.8507	6287.3332	56758
4960.6025	6296.9072	57277
4978.7585	6305.9602	57030
4999.3221	6317.4555	56678
5018.4812	6329.8626	57076
5032.8255	6338.4596	56425
5050.0287	6349.9224	56457
5066.7804	6360.4408	56232
5087.3439	6371.4476	54674
5098.8294	6377.179	55302
4870.1731	6259.6207	56433
4890.2853	6270.1391	56652
4906.0339	6281.6018	56811
4922.7857	6292.6087	57043
4939.5374	6302.1501	57170
4955.3262	6313.1569	57616
4971.5864	6323.1868	57502
4987.8366	6333.2167	57342
5006.0428	6346.1123	56762
5020.3871	6355.6863	55992
5038.0918	6367.1491	56295
5054.342	6376.6905	55335
5075.8585	6387.2089	54143
5085.4381	6391.0189	55025
4862.5496	6270.1391	56168
4878.2982	6279.7131	56259
4896.5045	6294.0415	56451
4918.4723	6307.8815	56731
4931.8637	6316.5111	57603
4961.0229	6338.9182	57081
4977.304	6350.4109	56594
4993.6044	6362.3621	56595
5008.4001	6372.392	56706
5025.6534	6383.8873	56098
5044.311	6394.3731	54877
5062.9686	6405.3799	54319

Station Location		Averaged Magnetic Value (nT)
Northing (ft)*	Easting (ft)*	
5071.5642	6411.7739	55432
4850.5626	6292.6087	58505
4867.3143	6298.8285	56096
4884.0661	6310.2912	55993
4900.3162	6322.2425	56243
4932.8668	6344.2236	57707
4949.117	6355.1979	56993
4965.8687	6366.6066	57037
4984.0248	6378.6118	56889
4997.9177	6388.6417	55987
5015.5722	6399.1601	55779
5032.324	6411.1113	54701
5050.9816	6421.6297	56895
4852.97	6316.0226	56041
4869.7217	6327.9768	56268
4885.9719	6339.925	56387
4902.2221	6349.4949	56948
4918.4723	6360.4733	57049
4936.6786	6371.9361	56811
4952.4774	6384.3432	56599
4970.1319	6393.9172	56009
4986.8836	6404.8925	55447
5004.1369	6415.4098	54439
5020.8358	6427.361	55357
5038.5432	6435.9581	55479
4943.4406	6331.7879	56128
4860.1923	6343.7351	56406
4875.941	6354.2535	56512
4892.2413	6364.7399	56751
4909.4444	6375.2577	57255
4925.2432	6387.2089	56869
4941.9448	6398.6716	56832
4959.6495	6409.6785	55190
4975.9499	6420.6527	54127
4993.153	6429.7383	55400
5009.9047	6443.1223	57721
5028.0608	6452.2078	55674

Station Location		Averaged Magnetic Value (nT)
Northing (ft)*	Easting (ft)*	
4831.9005	6349.884	56216
4848.2412	6361.9673	56577
4863.901	6372.4296	57222
4880.6957	6382.4499	56831
4897.0364	6392.4702	57548
4913.831	6403.964	57434
4930.6256	6415.0158	56614
4946.9663	6426.5096	55047
4963.7609	6437.5614	55855
4981.4634	6445.3713	59528
4997.8041	6460.107	57481
5016.1874	6468.9484	56547
4820.3258	6364.6197	56493
4837.1204	6376.703	56642
4853.915	6388.7862	56599
4870.2558	6398.6592	57912
4886.1426	6409.1215	57658
4902.9372	6420.1733	58019
4919.0509	6431.6671	57870
4936.9803	6442.2768	55843
4956.1863	6455.3916	59570
4970.5696	6463.2015	59084
4985.7755	6475.2848	56816
5004.6127	6484.7786	59266
4809.8859	6379.7975	56575
4826.6805	6391.8807	56698
4843.4751	6403.3746	56714
4859.362	6414.4264	57510
4875.4757	6423.4151	57490
4891.8164	6435.351	57414
4907.4763	6447.4343	56062
4924.2709	6459.5176	55360
4941.0655	6469.9799	58836
4956.9523	6482.0632	55779
4975.3356	6492.0835	56110
4989.4063	6501.9564	56179
6798.3112	6379.6277	56396

Station Location		Averaged Magnetic Value (nT)
Northing (ft)*	Easting (ft)*	
4814.198	6409.1215	56498
4830.9927	6421.2048	56485
4847.1064	6432.846	57095
4857.7733	6441.6874	56843
4879.7878	6452.7392	55757
4895.9016	6464.233	55121
4912.6962	6475.7269	55273
4929.0369	6487.3681	56423
4945.3776	6498.2725	56042
4962.1722	6508.8822	56374
4975.7895	6517.1342	55725
4795.1339	6421.7942	56319
4803.0773	6427.5411	56555
4818.9641	6438.0035	56406
4835.0778	6448.4658	56218
4848.6951	6456.8652	55916
4865.4897	6469.9799	56221
4885.0078	6481.0317	56549
4900.6676	6492.5256	56501
4917.4623	6503.5773	57082
4934.2569	6514.6291	56753
4947.4202	6523.0285	56369
4953.7749	6525.5335	55984
4775.3889	6429.7515	56290
4791.0487	6442.2768	56536
4807.8433	6452.8865	56217
4824.184	6464.3804	55768
4840.9787	6475.8742	56243
4857.3194	6486.926	56679
4873.4331	6496.7989	56506
4889.3199	6508.8822	56365
4906.5684	6519.3445	56340
4922.9092	6530.3963	56300
4939.0229	6540.4166	54974
4764.2681	6445.5187	56290
4780.6088	6457.0125	56354
4797.4034	6469.0958	55912

Station Location		Averaged Magnetic Value (nT)
Northing (ft)*	Easting (ft)*	
4813.0633	6481.6212	56284
4829.404	6493.115	56574
4845.7447	6503.1353	56519
4862.5393	6514.1871	56331
4877.7452	6525.2388	56397
4894.9938	6536.1432	56299
4911.3345	6546.6056	56238
4927.6752	6557.6574	56008
4936.9803	6563.9937	56138
4785.8288	6485.8945	56340
4801.0347	6496.7989	56592
4817.8293	6508.8822	56420
4834.17	6519.3445	56345
4851.4185	6529.9543	56260
4865.7167	6541.8902	56555
4883.4191	6552.9419	56810
4900.2137	6563.9937	56811
4916.5544	6574.4561	58210
4822.5954	6535.7012	56387
4840.5247	6546.6056	56254
4854.5959	6558.2468	56418
4871.8444	6569.1512	56618
4888.6391	6580.203	56591
4904.9798	6590.2233	57090
4845.2908	6574.4561	56159
4860.9506	6585.9499	56322
4877.2913	6597.0017	56347
4894.086	6607.022	55737
4817.3754	6579.1715	55997
4832.5813	6591.2548	56276
4849.376	6602.7486	56348
4866.8514	6612.6215	56558
4820.5528	6607.464	55744
4838.4822	6617.337	56207
4854.142	6630.0097	56792
4809.659	6624.2627	55424
4826.4536	6635.1672	55897

Station Location		Averaged Magnetic Value (nT)
Northing (ft)*	Easting (ft)*	
4842.5673	6647.8399	56776
4807.3894	6648.8714	55717
4815.3328	6653.5868	55845
4831.6735	6661.9861	55462
4803.7581	6667.1436	55981
4820.0989	6677.1639	56724

* Distance is based on the coordinates used by Canonie Environmental, (1989)

Appendix C

Well Construction Data

Well Id.	Ground Elevation (m)	TOC* Elevation (m)	Screen Depth (cm)	Screen Legnth (cm)
W 1A	249.174	250.107	142.59	76
W 1B	249.137	250.091	71.46	6.3
W 1C	249.180	249.796	259.78	6.3
W 2A	249.079	249.442	109.72	76
W 2B	249.073	249.460	123.06	6.3
W 2C	249.046	249.808	245.33	6.3
W 3A	249.095	249.445	112.26	76
W 3B	249.076	249.527	118.62	6.3
W 3C	249.049	249.741	252.48	6.3
W 4A	248.741	249.662	143.07	76
W 4B	248.735	249.280	110.84	6.3
W 4C	248.744	249.701	219.29	6.3
W 5A	247.506	247.851	235.33	76
W 5B	247.515	248.168	150.53	6.3
W 5C	247.512	248.186	254.07	6.3
W 6A	247.329	247.357	210.87	76
W 6B	247.241	247.982	181.66	6.3
W 6C	247.332	247.982	258.51	6.3
W7A	248.479	249.652	115.28	76
W 7B	248.491	249.229	92.73	6.3
W 7C	248.460	249.082	260.89	6.3
E 8A	246.570	247.567	117.82	76
E 8B	246.570	247.256	95.27	6.3
E 8C	246.591	247.741	248.35	6.3
W 9A	247.747	248.686	140.37	76
W 9B	247.753	248.338	112.11	6.3
W 9C	247.753	248.409	195.47	6.3
E 10A	247.198	247.707	201.35	76
E 10B	247.180	248.241	216.91	6.3
E 10C	247.186	247.643	279.00	6.3
W 11A	249.021	249.948	137.83	76
W 11B	249.015	249.500	113.06	6.3
W 11C	249.009	250.274	194.68	6.3
W 12A	248.899	249.692	154.66	76
E 13A	247.125	247.668	118.14	76
W 14A	248.027	248.570	232.47	76
W 15A	249.485	250.424	144.50	76
DC 1	-	247.046	63.20	76
DC 2	-	247.043	120.68	6.3
DC 3	-	247.473	69.87	6.3

TOC* = Top of Casing.

Appendix D

Water Elevation Data

DATE	Water Elevation (m)											
	W1A	W2A	W3A	W4A	W5A	W6A	W7A	E8A	W9A	E10A	W11A	W12A
8/26/94	249.049	249.018	249.070	249.098	246.445	246.345	248.427	246.201	247.226			
8/29/94	249.012	249.021	249.052	249.082	246.402	246.335	248.396	246.168	247.162			
8/30/94	249.015	249.021	249.067	249.098	246.399	246.338	248.384	246.165	247.457			
8/31/94	249.021	249.034	249.049	249.073	246.390	246.329	248.424	246.171	247.168			
9/2/94	248.991	249.006	249.061	249.082	246.393	246.345	248.375	246.152	247.131			
9/7/94	249.064	249.064	249.061	249.088	246.387	246.378	248.448	246.302	247.146			
9/9/94	248.976	248.997	249.030	249.064	246.381	246.348	248.348	246.134	247.082			
9/14/94	248.963	248.976	249.006	249.027	246.378	246.351	248.348	246.143	247.067			
9/20/94	248.939	248.954	248.988	249.015	246.354	246.354	248.384	246.137	247.076			
9/26/94	248.997	248.985	248.994	249.012	246.369	246.338	248.442	246.143	247.137			
9/27/94	249.037	248.994	248.994	249.009	246.393	246.360	248.448	246.186	247.155			
9/28/94	249.088	249.009	248.994	249.006	246.399	246.369	248.448	246.451	247.223			
9/29/94	249.012	248.988	248.973	248.991	246.485	246.338	248.442	246.177	247.421			
9/30/94	248.966	248.985	248.988	248.997	246.521	246.357	248.439	246.137	247.302	246.358		
10/1/94	249.012	248.988	248.979	249.000	246.655	246.332	248.448	246.159	247.354	246.402		
10/2/94	248.982	248.970	248.988	248.994	246.640	246.341	248.442	246.146	247.335	246.477		
10/3/94	248.951	248.948	248.970	248.979	246.643	246.332	248.439	246.140	247.177	246.508		
10/5/94	248.954	248.957	248.982	249.003	246.652	246.329	248.436	246.152	247.204	246.542		248.918
10/6/94	248.948	248.957	248.979	248.997	246.652	246.335	248.433	246.140	247.177	246.539	248.918	248.915
10/7/94	248.948	248.945	248.985	249.000	246.643	246.338	248.436	246.137	247.171	246.555	248.933	248.927
10/8/94	248.936	248.945	248.970	248.982	246.652	246.332	248.421	246.149	247.152	246.548	248.915	248.905
10/9/94	249.037	249.000	248.970	248.982	246.649	246.360	248.448	246.314	247.482	246.611	248.912	248.909
10/10/94	248.973	248.951	248.948	248.960	246.610	246.332	248.430	246.162	247.354	246.558	248.884	248.893
10/12/94	248.966	248.954	248.982	249.009	246.591	246.335	248.427	246.152	247.256	246.555	248.930	248.924
10/13/94	248.954	248.957	248.976	248.985	246.607	246.329	248.430	246.165	247.238	246.567	248.921	248.912
10/14/94	248.960	248.951	248.973	248.985	246.619	246.338	248.436	246.165	247.226	246.558	248.921	248.918
10/15/94	248.939	248.942	248.954	248.963	246.591	246.323	248.463	246.177	247.213	246.558	248.899	248.896
10/17/94	248.957	248.954	248.976	248.994	246.613	246.351	248.439	246.220	247.235	246.586	248.933	248.918
10/18/94	248.963	248.966	248.982	248.997	246.649	246.357	248.448	246.274	247.259	246.620	248.933	248.918
10/19/94	249.040	248.991	248.973	248.988	246.668	246.366	248.454	246.354	247.540	246.676	248.924	248.909
10/20/94	249.000	248.976	248.960	248.966	246.662	246.335	248.454	246.259	247.448	246.576	248.915	248.905
10/22/94	248.994	248.966	248.966	248.985	246.637	246.335	248.445	246.250	247.363	246.586	248.942	248.912
10/23/94	248.979	248.960	248.954	248.957	246.637	246.332	248.448	246.265	247.335	246.605	248.896	248.896
10/24/94	248.979	248.951	248.960	248.973	246.607	246.341	248.448	246.253	247.317	246.614	248.909	248.902
10/25/94	248.960	248.945	248.945	248.948	246.613	246.329	248.436	246.256	247.296	246.614	248.881	248.884
10/26/94	248.948	248.930	248.936	248.948	246.619	246.335	248.442	246.259	247.284	246.589	248.878	248.881
10/28/94	248.973	248.951	248.973	248.988	246.637	246.332	248.442	246.265	247.296	246.471	248.930	248.915
10/29/94	248.957	248.948	248.951	248.954	246.619	246.317	248.442	246.259	247.287	246.436	248.893	248.887
10/30/94	248.954	248.933	248.954	248.960	246.628	246.320	248.442	246.262	247.277	246.439	248.899	248.890
11/1/94	249.101	249.061	248.994	249.000	246.790	246.445	248.442	246.570	247.735	246.751	248.954	248.918
11/3/94	249.058	249.012	248.994	249.012	246.680	246.348	248.445	246.372	247.418	246.539	248.966	248.936
11/4/94	249.085	249.015	249.006	249.024	246.710	246.384	248.454	246.497	247.555	246.673	248.976	248.933
11/5/94	249.082	249.034	248.994	249.009	246.747	246.381	248.448	246.454	247.598	246.648	248.957	248.927
11/6/94	249.110	249.061	249.009	249.024	246.774	246.415	248.451	246.540	247.598	246.738	248.957	248.915
11/7/94	249.107	249.058	249.067	249.104	246.729	246.390	248.451	246.476	247.460	246.645	249.046	248.982
11/9/94	249.116	249.061	249.049	249.076	246.756	246.402	248.460	246.524	247.652	246.698	249.012	248.957
11/10/94	249.101	249.040	249.040	249.064	246.713	246.366	248.448	246.445	247.479	246.620	249.012	248.954
11/11/94	249.104	249.055	249.061	249.098	246.704	246.369	248.451	246.418	247.415	246.598	249.046	248.979
11/13/94	249.098	249.049	249.058	249.095	246.701	246.360	248.463	246.390	247.427	246.558	249.040	248.976
11/14/94	249.110	249.049	249.043	249.076	246.744	246.387	248.460	246.460	247.591	246.629	249.012	248.960
11/15/94	249.085	249.034	249.037	249.064	246.698	246.354	248.457	246.384	247.433	246.542	249.003	248.957
11/16/94	249.085	249.043	249.061	249.088	246.665	246.354	248.457	246.363	247.396	246.517	249.037	248.976
11/17/94	249.095	249.046	249.070	249.104	246.640	246.341	248.454	246.335	247.412	246.492	249.037	248.973
11/20/94	249.088	249.046	249.073	249.101	246.625	246.335	248.451	246.277	247.384	246.439	249.046	248.982

DATE	Water Elevation (m)											
	W1A	W2A	W3A	W4A	W5A	W6A	W7A	E8A	W9A	E10A	W11A	W12A
11/21/94	249.082	249.046	249.046	249.061	246.707	246.351	248.460	246.393	247.561	246.564	249.006	248.945
11/22/94	249.049	249.000	249.009	249.027	246.625	246.308	248.442	246.253	247.405	246.408	248.954	248.924
11/24/94	249.082	249.043	249.079	249.107	246.604	246.317	248.451	246.235	247.372	246.399	249.049	248.982
11/25/94	249.058	249.018	249.034	249.055	246.613	246.280	248.457	246.226	247.415	246.383	248.985	248.945
11/29/94	249.095	249.052	249.052	249.073	246.698	246.338	248.466	246.433	247.527	246.576	249.006	248.948
12/1/94	249.088	249.037	249.076	249.101	246.607	246.296	248.485	246.274	247.466	246.421	249.040	248.976
12/3/94	249.101	249.046	249.061	249.082	246.689	246.354	248.482	246.442	247.649	246.601	249.018	248.963
12/4/94	249.088	249.037	249.052	249.073	246.640	246.284	248.463	246.305	247.515	246.461	249.003	248.957
12/5/94	249.091	249.046	249.061	249.079	246.646	246.290	248.466	246.311	247.491	246.461	249.012	248.963
12/6/94	249.088	249.043	249.055	249.082	246.619	246.290	248.470	246.277	247.460	246.443	249.012	248.963
12/7/94	249.091	249.037	249.034	249.052	246.686	246.317	248.451	246.387	247.567	246.561	248.985	248.948
12/12/94	249.101	249.052	249.085		246.643	246.280	248.457	246.320	247.457	246.480	249.015	248.976
12/16/94	249.101	249.052	249.085	249.122	246.640	246.284	248.494	246.287	247.524	246.446	249.037	248.979
12/19/94	249.104	249.079	249.110	249.143	246.665	246.317	248.460	246.405	247.540	246.589	249.058	248.985
12/20/94	249.107	249.073	249.104	249.137	246.646	246.302	248.457	246.375	247.506	246.548	249.049	248.985
12/23/94	249.104	249.064	249.098	249.125	246.640	246.284	248.470	246.326	247.546	246.492	249.046	248.982
12/28/94	249.116	249.070	249.116	249.152	246.628	246.335	248.476	246.250	247.509	246.427	249.073	249.000
12/30/94	249.091	249.049	249.095		246.561	246.274		246.223	247.402	246.399	249.040	
12/31/94	249.107	249.052	249.095	249.134	246.595	246.274	248.470	246.229	247.485	246.393	249.040	
1/4/95	249.098		249.079		246.558	246.268		246.216	247.430	246.393	249.024	
4/8/95	249.125	249.061	249.064	249.113	246.595	246.351	248.457	246.354	247.652	246.570	249.034	248.991
5/1/95	249.140	249.076	249.119	249.183	246.573	246.338	248.470	246.210	247.500	246.467	249.091	249.018
5/2/95	249.131	249.070	249.101	249.159	246.567	246.311	248.460	246.192	247.466	246.449	249.064	249.009
5/3/95	249.128	249.070	249.101	249.159	246.561	246.320	248.460	246.210	247.427	246.443	249.058	249.006
5/4/95	249.146	249.073	249.101	249.155	246.588	246.320	248.463	246.250	247.598	246.489	249.064	249.006
5/8/95	249.128	249.064	249.095	249.146	246.561	246.314	248.457	246.177	247.396	246.446	249.055	249.003
5/9/95	249.149	249.091	249.119	249.183	246.616	246.338	248.466	246.345	247.631	246.595	249.091	249.018
5/10/95	249.143	249.088	249.125	249.186	246.591	246.253	248.476	246.229	247.537	246.492	249.088	249.018
5/11/95	249.159	249.088	249.155	249.235	246.628	246.351	248.460	246.479	247.726	246.701	249.116	249.034
5/12/95	249.155	249.088	249.146	249.216	246.613	246.287	248.460	246.396	247.680	246.617	249.113	249.030
5/13/95	249.149	249.088	249.149	249.216	246.616	246.253	248.470	246.329	247.567	246.548	249.113	249.027
5/14/95	249.140	249.076	249.119	249.171	246.607	246.229	248.463	246.299	247.540	246.524	249.073	249.000
5/15/95	249.131	249.076	249.119	249.180	246.585	246.244	248.460	246.265	247.454	246.486	249.095	249.021
5/16/95	249.140	249.082	249.143	249.220	246.585	246.244	248.457	246.238	247.405	246.471	249.119	249.027
5/17/95	249.128	249.061	249.107	249.168	246.579	246.213	248.457	246.232	247.460	246.467	249.064	249.003
5/18/95	249.131	249.067	249.098	249.174	246.585	246.226	248.466	246.226	247.418	246.464	249.070	249.018
5/19/95	249.125	249.061	249.113	249.180	246.573	246.226	248.463	246.226	247.402	246.458	249.076	249.012
5/20/95	249.122	249.055	249.125	249.186	246.561	246.226	248.457	246.201	247.384	246.452	249.079	249.009
5/21/95	249.113	249.049	249.113	249.165	246.549	246.220	248.445	246.186	247.338	246.446	249.061	248.997
5/22/95	249.107	249.043	249.091	249.140	246.540	246.207	248.436	246.183	247.305	246.439	249.046	248.991
5/26/95	249.140	249.088	249.143	249.213	246.582	246.241	248.466	246.259	247.543	246.508	249.098	249.021
5/27/95	249.137	249.070	249.140	249.201	246.585	246.229	248.463	246.247	247.454	246.483	249.095	249.018
5/28/95	249.149	249.085	249.146	249.220	246.628	246.296	248.479	246.332	247.704	246.617	249.101	249.037
5/29/95	249.128	249.073	249.122	249.171	246.585	246.204	248.470	246.247	247.521	246.489	249.058	249.000
5/30/95	249.119	249.070	249.140	249.192	246.585	246.207	248.470	246.216	247.518	246.477	249.076	249.015
5/31/95	249.122	249.064	249.128	249.189	246.585	246.210	248.466	246.204	247.448	246.474	249.073	249.015
6/1/95	249.122	249.061	249.122	249.186	246.582	246.213	248.466	246.192	247.375	246.471	249.070	249.015
6/2/95	249.113	249.061	249.119	249.186	246.579	246.213	248.463	246.180	247.369	246.467	249.070	249.015
6/3/95	249.104	249.061	249.119	249.186	246.573	246.213	248.460	246.174	247.372	246.464	249.070	249.015
6/4/95	249.098	249.064	249.122	249.186	246.564	246.213	248.457	246.165	247.390	246.458	249.070	249.018
6/5/95	249.091	249.058	249.122	249.186	246.558	246.213	248.457	246.162	247.375	246.452	249.070	249.018
6/6/95	249.113	249.055	249.113	249.171	246.561	246.204	248.457	246.159	247.326	246.464	249.064	249.009
6/7/95	249.091	249.049	249.098	249.155	246.546	246.210	248.463	246.149	247.284	246.467	249.037	249.003
6/8/95	249.104	249.037	249.067	249.116	246.561	246.204	248.463	246.186	247.500	246.446	249.006	248.979

DATE	Water Elevation (m)											
	W1A	W2A	W3A	W4A	W5A	W6A	W7A	E8A	W9A	E10A	W11A	W12A
6/9/95	249.101	249.049	249.082	249.137	246.552	246.189	248.454	246.165	247.396	246.446	249.034	248.994
6/10/95	249.134	249.055	249.113	249.165	246.570	246.210	248.476	246.204	247.424	246.467	249.064	249.003
6/11/95	249.110	249.049	249.085	249.140	246.564	246.192	248.457	246.162	247.433	246.458	249.046	248.997
6/12/95	249.076	249.037	249.088	249.149	246.546	246.192	248.445	246.140	247.357	246.430	249.052	249.000
6/13/95	249.055	249.037	249.082	249.143	246.527	246.195	248.436	246.128	247.329	246.443	249.040	248.997
6/18/95	249.024	249.018	249.055	249.113	246.506	246.201	248.351	246.110	247.177	246.443	249.003	248.985
6/20/95	248.979	249.003	249.040	249.101	246.503	246.207	248.268	246.095	247.125	246.439	249.003	248.976
6/22/95	248.963	248.985	249.015	249.067	246.491	246.204	248.271	246.101	247.119	246.480	248.988	248.954
7/8/95	248.963	248.994	248.994	249.040	246.527	246.201	248.378	246.134	247.280	246.545	248.960	248.936
7/9/95	248.973	248.985	248.991	249.043	246.521	246.195	248.390	246.119	247.244	246.539	248.957	248.945
7/10/95	248.945	248.963	248.994	249.058	246.497	246.195	248.326	246.095	247.165	246.555	248.945	248.951
7/11/95	248.942	248.970	248.979	249.015	246.494	246.183	248.320	246.104	247.159	246.558	248.936	248.933
7/12/95	248.927	248.960	248.982	249.021	246.497	246.189	248.277	246.098	247.134	246.552	248.939	248.936
7/13/95	248.909	248.951	248.985	249.024	246.500	246.195	248.235	246.095	247.104	246.545	248.939	248.939
7/14/95	248.905	248.939	248.979	249.009	246.497	246.198	248.220	246.095	247.098	246.539	248.924	248.933
7/15/95	248.905	248.927	248.966	249.000	246.491	246.201	248.204	246.091	247.088	246.530	248.912	248.927
8/24/95	248.887	248.896	248.921	248.957	246.494	246.220	248.308	246.110	247.122	246.592	248.878	248.875
8/25/95	248.878	248.912	248.921	248.960	246.497	246.213	248.293	246.113	247.104	246.605	248.866	248.872
8/26/95	248.872	248.893	248.924	248.960	246.500	246.210	248.284	246.113	247.088	246.611	248.860	248.872
8/27/95	248.860	248.890	248.918	248.951	246.497	246.213	248.299	246.113	247.082	246.611	248.848	248.866
8/28/95	248.851	248.887	248.912	248.945	246.497	246.213	248.305	246.113	247.079	246.611	248.835	248.860
8/29/95	248.845	248.887	248.905	248.939	246.488	246.213	248.296	246.104	247.067	246.595	248.835	248.854
8/30/95	248.838	248.884	248.899	248.933	246.482	246.213	248.287	246.095	247.052	246.580	248.835	248.848
8/31/95	248.835	248.884	248.893	248.927	246.476	246.213	248.277	246.085	247.040	246.561	248.835	248.845
9/1/95	248.829	248.878	248.884	248.921	246.470	246.213	248.265	246.085	247.027	246.555	248.832	248.838
9/2/95	248.823	248.857	248.878	248.915	246.463	246.213	248.253	246.085	247.015	246.548	248.826	248.829
9/3/95	248.817	248.841	248.875	248.912	246.460	246.210	248.244	246.082	247.003	246.542	248.820	248.826
9/4/95	248.811	248.826	248.869	248.909	246.482	246.210	248.241	246.079	246.991	246.629	248.814	248.823
9/6/95	248.811	248.848	248.893	248.930	246.479	246.207	248.204	246.070	247.003	246.552	248.841	248.848
9/7/95	248.814	248.838	248.872	248.915	246.494	246.220	248.357	246.180	246.960	246.586	248.808	248.817
9/8/95	248.896	248.881	248.896	248.930	246.494	246.232	248.393	246.204	247.030	246.611	248.854	248.857
9/9/95	248.875	248.887	248.896	248.915	246.491	246.198	248.366	246.149	247.052	246.608	248.835	248.838
9/10/95	248.835	248.845	248.884	248.905	246.485	246.204	248.293	246.098	247.024	246.592	248.820	248.829
9/11/95	248.845	248.854	248.899	248.936	246.494	246.204	248.277	246.095	247.018	246.586	248.841	248.826
9/12/95	248.848	248.863	248.905	248.936	246.494	246.201	248.296	246.095	247.030	246.605	248.851	248.845
9/13/95	248.841	248.860	248.893	248.912	246.494	246.195	248.280	246.104	247.012	246.611	248.829	248.838
9/14/95	248.802	248.820	248.845	248.869	246.482	246.198	248.250	246.079	246.988	246.589	248.768	248.784
9/15/95	248.777	248.805	248.838	248.823	246.485	246.192	248.204	246.101	246.963	246.586	248.753	248.765
9/16/95	248.811	248.845	248.905	248.921	246.488	246.216	248.226	246.098	246.957	246.598	248.835	248.841
9/17/95	248.805	248.826	248.851	248.866	246.479	246.204	248.308	246.098	246.936	246.592	248.780	248.787
9/18/95	248.787	248.802	248.848	248.979	246.479	246.198	248.247	246.088	246.933	246.564	248.780	248.796
9/19/95	248.790	248.817	248.863	248.881	246.485	246.192	248.262	246.091	246.927	246.589	248.793	248.808
9/20/95	248.793	248.823	248.869	248.881	246.491	246.189	248.280	246.091	246.921	246.586	248.796	248.805
9/21/95	248.863	248.863	248.881	248.921	246.530	246.213	248.378	246.149	247.046	246.601	248.820	248.829
9/22/95	248.845	248.854	248.878	248.896	246.479	246.204	248.372	246.107	246.991	246.592	248.811	248.820
9/23/95	248.823	248.820	248.854	248.872	246.485	246.180	248.338	246.104	246.991	246.586	248.774	248.790
9/24/95	248.826	248.835	248.884	248.909	246.488	246.189	248.317	246.098	246.991	246.595	248.820	248.829
9/25/95	248.838	248.863	248.890	248.918	246.479	246.186	248.335	246.095	246.997	246.570	248.829	248.838
9/26/95	248.826	248.848	248.881	248.796	246.479	246.195	248.326	246.088	246.979	246.564	248.811	248.826
9/27/95	248.802	248.820	248.841	248.869	246.479	246.180	248.290	246.098	246.957	246.561	248.774	248.820
9/28/95	248.790	248.811	248.841	248.866	246.479	246.174	248.280	246.095	246.942	246.558	248.762	248.808
9/29/95	248.777	248.802	248.841	248.863	246.476	246.195	248.265	246.088	246.954	246.564	248.768	248.799
9/30/95	248.765	248.793	248.841	248.863	246.476	246.198	248.250	246.085	246.893	246.564	248.771	248.784
10/1/95	248.759	248.787	248.832	248.857	246.479	246.201	248.207	246.088	246.881	246.561	248.759	248.771

DATE	Water Elevation (m)											
	W1A	W2A	W3A	W4A	W5A	W6A	W7A	E8A	W9A	E10A	W11A	W12A
10/2/95	248.750	248.774	248.823	248.851	246.479	246.207	248.183	246.091	246.875	246.558	248.744	248.756
10/3/95	248.780	248.811	248.848	248.878	246.479	246.168	248.326	246.128	246.985	246.583	248.796	248.808
10/10/95	248.784	248.787	248.820	248.835	246.488	246.192	248.326	246.104	246.982	246.558	248.756	248.762
10/11/95	248.780	248.787	248.820	248.838	246.491	246.198	248.323	246.101	246.985	246.555	248.759	248.768
10/12/95	248.774	248.787	248.823	248.845	246.491	246.201	248.317	246.101	246.991	246.548	248.759	248.771
10/16/95	248.774	248.790	248.784	248.805	246.485	246.177	248.332	246.107	246.982	246.576	248.720	248.744
10/21/95	248.909	248.878	248.866	248.884	246.491	246.213	248.415	246.235	247.070	246.611	248.820	248.823
10/22/95	248.884	248.851	248.832	248.848	246.491	246.186	248.405	246.195	247.070	246.564	248.774	248.784
10/23/95	248.875	248.845	248.866	248.893	246.497	246.192	248.393	246.143	247.082	246.570	248.814	248.823
10/24/95	248.860	248.841	248.835	248.860	246.488	246.177	248.390	246.131	247.073	246.567	248.784	248.793
10/25/95	248.857	248.838	248.832	248.857	246.488	246.174	248.384	246.128	247.064	246.564	248.777	248.784
10/26/95	248.863	248.848	248.878	248.896	246.494	246.250	248.402	246.128	247.088	246.583	248.823	248.826
10/27/95	249.000	248.939	248.945	248.970	246.530	246.372	248.463	246.430	247.180	246.760	248.905	248.890
10/28/95	248.982	248.918	248.869	248.878	246.558	246.229	248.442	246.335	247.558	246.664	248.814	248.832
10/29/95	248.896	248.832	248.826	248.832	246.491	246.168	248.412	246.180	247.345	246.545	248.759	248.765
10/30/95	248.881	248.814	248.823	248.832	246.485	246.171	248.421	246.177	247.293	246.536	248.756	248.765
11/1/95	248.963	248.893	248.899	248.915	246.500	246.186	248.433	246.186	247.470	246.558	248.848	248.851
11/7/95	248.963	248.918	248.902	248.924	246.497	246.159	248.430	246.177	247.375	246.483	248.857	248.854
11/14/95	249.104	249.000	249.018	249.046	246.524	246.235	248.445	246.381	247.427	246.573	248.979	248.930
11/22/95	249.101	249.000	249.021	249.061	246.530	246.216	248.442	246.357	247.448	246.570	248.991	248.945
11/30/95	249.119	249.018	249.070		246.534	246.220	248.454	246.338	247.747	246.564	249.052	248.979
12/4/95	249.073	248.991	249.012	249.040	246.515	246.174	248.448	246.296	247.393	246.508	248.960	248.933
12/14/95	249.104	249.009	249.009		246.506	246.326		246.186	247.393	246.710	248.970	248.930
12/23/95	249.070	249.000	248.994		246.491	246.168		246.207	247.424	246.427	248.960	248.933
12/30/95	249.046	248.991			246.463	246.168		246.162	247.354	246.408	248.960	
1/6/96	248.966	248.899			246.500	246.143		246.110	247.253	246.386	248.896	
1/22/96	249.082	248.985			246.454	246.192		246.168	247.399	246.436		
3/16/96	249.085	248.960	249.018		246.412	246.180	248.415	246.116	247.460	246.418	248.970	
3/23/96	249.058		248.991		246.369	246.174		246.076	247.357	246.377		
3/28/96	249.088	248.960	249.034	249.076	246.418	246.189		246.079	247.747	246.393	248.979	
4/2/96	249.073	248.954	249.037	249.088	246.409	246.168	248.436	246.070	247.491	246.383	248.976	248.948
4/5/96	249.043	248.927	249.003	249.040	246.384	246.174	248.427	246.058	247.436	246.374	248.927	
5/31/96	249.037	248.966	249.046	249.110	246.433	246.250	248.436	246.067	247.302	246.424	248.973	248.960
6/1/96	249.018	248.933	249.037	249.104	246.448	246.259	248.427	246.088	247.302	246.449	248.966	248.957

DATE	Water Elevation (m)											
	E13A	W14A	W15A	W1B	W2B	W3B	W4B	W5B	W6B	W7B	E8B	W9B
8/26/94				249.043	249.055	249.064	248.491	246.290	246.588		246.189	247.213
8/29/94				249.006	249.055	249.052	248.476	246.262	246.579		246.159	247.216
8/30/94				249.006	249.046	249.067	248.494	246.253	246.573		246.155	247.192
8/31/94				249.015	249.061	249.046	248.466	246.268	246.567		246.159	247.216
9/2/94				248.982	249.037	249.055	248.479	246.262	246.564		246.146	247.180
9/7/94				249.055	249.049	249.058	248.482	246.366	246.585		246.280	247.183
9/9/94				248.966	249.030	249.030	248.454	246.256	246.588		246.128	247.149
9/14/94				248.957	249.012	249.003	248.421	246.262	246.591		246.128	247.119
9/20/94				248.933	248.982	248.988	248.412	246.250	246.576	248.470	246.128	247.116
9/26/94				248.988	248.994	248.988	248.405	246.268	246.570	248.476	246.131	247.134
9/27/94				249.024	248.991	248.988	248.402	246.284	246.576	248.476	246.162	247.143
9/28/94				249.021	248.994	248.991	248.409	246.290	246.601	248.488	246.433	247.162
9/29/94				249.000	248.982	248.970	248.375	246.296	246.561	248.491	246.149	247.220
9/30/94				248.966	248.976	248.979	248.390	246.271	246.576	248.488	246.131	247.256
10/1/94				249.003	248.991	248.976	248.396	246.284	246.561	248.485	246.143	247.271
10/2/94				248.976	248.970	248.973	248.387	246.305	246.564	248.476	246.131	247.293
10/3/94				248.948	248.963	248.963	248.372	246.305	246.555	248.466	246.131	247.293
10/5/94				248.945	248.973	248.976	248.387	246.311	246.558	248.479	246.134	247.265
10/6/94				248.942	248.976	248.976	248.387	246.308	246.555	248.470	246.131	247.247
10/7/94				248.942	248.973	248.979	248.393	246.308	246.558	248.457	246.134	247.238
10/8/94				248.930	248.957	248.960	248.372	246.311	246.561	248.445	246.131	247.223
10/9/94				248.921	248.988	248.963	248.375	246.430	246.585	248.476	246.262	247.271
10/10/94				248.966	248.930	248.939	248.351	246.311	246.561	248.473	246.140	247.305
10/12/94				248.963	248.970	248.976	248.393	246.308	246.558	248.463	246.137	247.305
10/13/94				248.951	248.970	248.966	248.384	246.335	246.555	248.460	246.143	247.293
10/14/94				248.951	248.960	248.966	248.378	246.345	246.558	248.466	246.159	247.287
10/15/94				248.936	248.948	248.948	248.357	246.341	246.549	248.457	246.155	247.271
10/17/94				248.948	248.970	248.970	248.378	246.369	246.573	248.451	246.201	247.256
10/18/94				248.966	248.979	248.976	248.390	246.418	246.579	248.457	246.247	247.262
10/19/94				249.000	248.988	248.970	248.384	246.509	246.595	248.476	246.335	247.280
10/20/94				249.000	248.966	248.954	248.360	246.409	246.564	248.479	246.226	247.335
10/22/94				248.982	248.976	248.960	248.372	246.390	246.567	248.470	246.226	247.357
10/23/94				248.979	248.957	248.948	248.357	246.399	246.564	248.482	246.241	247.360
10/24/94				248.970	248.954	248.957	248.360	246.387	246.570	248.476	246.232	247.351
10/25/94				248.948	248.948	248.939	248.341	246.393	246.558	248.470	246.235	247.348
10/26/94				248.939	248.927	248.933	248.338	246.393	246.558	248.463	246.241	247.335
10/28/94				248.970	248.966	248.966	248.384	246.399	246.558	248.466	246.244	247.326
10/29/94				248.948	248.954	248.945	248.351	246.369	246.546	248.470	246.247	247.320
10/30/94				248.945	248.942	248.948	248.357	246.390	246.549	248.460	246.244	247.311
11/1/94				249.098	249.030	248.991	248.396	246.710	246.677	248.485	246.564	247.360
11/3/94				249.052	249.012	248.988	248.402	246.515	246.573	248.488	246.354	247.396
11/4/94				249.076	249.012	249.006	248.427	246.506	246.616	248.485	246.494	247.399
11/5/94				249.079	249.012	248.991	248.409	246.518	246.604	248.488	246.448	247.433
11/6/94				249.101	249.030	249.006	248.418	246.704	246.643	248.491	246.530	247.476
11/7/94				249.101	249.064	249.067	248.497	246.613	246.619	248.485	246.463	247.482
11/9/94				249.110	249.055	249.046	248.470	246.640	246.634	248.488	246.518	247.485
11/10/94				249.088	249.046	249.040	248.463	246.561	246.595	248.482	246.433	247.500
11/11/94				249.091	249.064	249.058	248.494	246.521	246.598	248.485	246.405	247.488
11/13/94				249.088	249.064	249.061	248.482	246.497	246.585	248.497	246.369	247.466
11/14/94				249.101	249.055	249.049	248.476	246.558	246.604	248.497	246.448	247.470
11/15/94				249.079	249.034	249.043	248.463	246.497	246.576	248.488	246.372	247.473
11/16/94				249.079	249.052	249.058	248.482	246.476	246.573	248.485	246.348	247.463
11/17/94				249.082	249.061	249.067	248.494	246.387	246.561	248.457	246.326	246.997
11/20/94				249.079	249.058	249.073	248.497	246.335	246.546	248.482	246.256	247.213

DATE	Water Elevation (m)										
	E13A	W14A	W15A	W1B	W2B	W3B	W4B	W5B	W6B	W7B	E8B	W9B
11/21/94				249.076	249.058	249.046	248.466	246.470	246.570	248.500	246.381	247.262
11/22/94				249.037	248.997	249.009	248.421	246.326	246.530	248.470	246.229	247.299
11/24/94				249.076	249.064	249.082	248.503	246.299	246.537	248.473	246.207	247.320
11/25/94				249.049	249.021	249.034	248.448	246.305	246.509	248.470	246.204	247.335
11/29/94				249.085	249.049	249.049	248.466	246.482	246.561	248.512	246.415	247.409
12/1/94				249.079	249.055	249.070	248.482	246.341	246.512	248.491	246.247	247.418
12/3/94				249.088	249.058	249.058	248.482	246.515	246.570	248.497	246.433	247.448
12/4/94				249.076	249.043	249.049	248.466	246.396	246.503	248.491	246.274	247.470
12/5/94				249.079	249.058	249.058	248.476	246.399	246.506	248.509	246.262	246.985
12/6/94				249.079	249.055	249.055	248.479	246.363	246.503	248.500	246.247	247.110
12/7/94				249.085	249.046	249.037	248.451	246.463	246.537	248.500	246.369	247.238
12/12/94				249.088	249.064	249.079		246.494	246.509	248.488	246.284	247.457
12/16/94				249.091	249.067	249.082	248.479	246.421	246.500	248.506	246.250	247.457
12/19/94				249.095	249.101	249.110	248.540	246.485	246.537	248.500	246.378	247.527
12/20/94				249.095	249.085	249.098	248.518	246.457	246.521	248.500	246.345	247.521
12/23/94				249.098	249.079	249.095	248.524	246.460	246.503	248.506	246.302	247.521
12/28/94				249.107	249.095	249.113	248.549	246.439	246.491	248.503	246.229	247.509
12/30/94				249.082	249.067	249.095		246.363	246.491	248.482	246.192	247.479
12/31/94				249.095	249.073	249.091	248.463	246.415	246.494	248.494	246.195	247.470
1/4/95				249.085	249.052	249.079		246.375	246.485		246.189	247.466
4/8/95				249.101	249.058	249.064	248.500	246.503	246.561	248.503	246.348	247.476
5/1/95				249.116	249.091	249.119	248.567	246.439	246.546	248.515	246.189	247.497
5/2/95				249.107	249.079	249.101	248.540	246.436	246.537	248.546	246.171	247.479
5/3/95				249.101	249.073	249.098	248.540	246.430	246.540	248.534	246.162	247.448
5/4/95				249.122	249.079	249.101	248.540	246.488	246.543	248.543	246.216	247.521
5/8/95				249.101	249.073	249.101	248.534	246.427	246.540	248.506	246.162	247.430
5/9/95				249.128	249.098	249.122	248.585	246.524	246.540	248.534	246.338	247.473
5/10/95				249.122	249.104	249.125	248.601	246.457	246.488	248.567	246.201	247.506
5/11/95				249.134	249.134	249.162	248.622	246.573	246.576	248.561	246.473	247.610
5/12/95				249.122	249.116	249.146	248.613	246.512	246.494	248.552	246.381	247.622
5/13/95				249.128	249.116	249.146	248.604	246.476	246.476	248.540	246.317	247.591
5/14/95				249.119	249.095	249.122	248.558	246.457	246.454	248.543	246.290	247.558
5/15/95				249.116	249.088	249.119	248.570	246.433	246.457	248.546	246.250	247.509
5/16/95				249.110	249.110	249.143	248.570	246.427	246.460	248.552	246.220	247.470
5/17/95				249.104	249.076	249.113	248.549	246.439	246.442	248.555	246.213	247.448
5/18/95				249.110	249.079	249.113	248.558	246.445	246.445	248.543	246.201	247.436
5/19/95				249.104	249.082	249.119	248.564	246.424	246.445	248.518	246.189	247.424
5/20/95				249.101	249.085	249.125	248.573	246.402	246.445	248.521	246.177	247.415
5/21/95				249.085	249.070	249.107	248.552	246.387	246.442	248.500	246.168	247.387
5/22/95				249.073	249.052	249.088	248.527	246.378	246.439	248.482	246.162	247.366
5/26/95				249.119	249.113	249.146	248.604	246.482	246.470	248.555	246.238	247.558
5/27/95				249.113	249.104	249.140	248.601	246.494	246.454	248.515	246.207	247.521
5/28/95				249.128	249.119	249.146	248.619	246.527	246.494	248.555	246.323	247.537
5/29/95				249.107	249.095	249.119	248.564	246.482	246.427	248.549	246.213	247.530
5/30/95				249.098	249.088	249.125	248.588	246.448	246.430	248.521	246.192	247.521
5/31/95				249.098	249.091	249.122	248.585	246.454	246.433	248.512	246.183	247.485
6/1/95				249.098	249.095	249.119	248.585	246.457	246.436	248.506	246.174	247.451
6/2/95				249.088	249.098	249.116	248.585	246.454	246.436	248.503	246.165	247.439
6/3/95				249.082	249.098	249.116	248.585	246.442	246.433	248.503	246.159	247.427
6/4/95				249.076	249.095	249.119	248.585	246.430	246.436	248.521	246.152	247.424
6/5/95				249.070	249.091	249.119	248.582	246.418	246.436	248.524	246.149	247.415
6/6/95				249.079	249.079	249.113	248.573	246.421	246.445	248.549	246.149	247.393
6/7/95				249.076	249.064	249.095	248.549	246.412	246.424	248.534	246.140	247.354
6/8/95				249.085	249.037	249.067	248.512	246.430	246.430	248.515	246.152	247.390

DATE	Water Elevation (m)										
	E13A	W14A	W15A	W1B	W2B	W3B	W4B	W5B	W6B	W7B	E8B	W9B
6/9/95				249.079	249.052	249.082	248.537	246.387	246.418	248.524	246.140	247.409
6/10/95				249.113	249.076	249.110	248.564	246.427	246.433	248.530	246.183	247.405
6/11/95				249.091	249.058	249.085	248.540	246.424	246.424	248.534	246.137	247.427
6/12/95				249.061	249.018	249.088	248.549	246.360	246.424	248.500	246.125	247.280
6/13/95				249.040	249.061	249.079	248.546	246.335	246.424	248.506	246.122	247.317
6/18/95				249.003	249.034	249.061	248.515	246.305	246.430	248.405	246.101	247.232
6/20/95				248.960	249.018	249.049	248.500	246.277	246.430	248.357	246.095	247.204
6/22/95				248.945	248.997	249.021	248.460	246.293	246.427	248.293	246.098	247.152
7/8/95				248.951	248.988	249.000	248.442	246.332	246.415	248.473	246.104	247.326
7/9/95				248.954	248.985	248.994	248.439	246.345	246.421	248.460	246.101	247.302
7/10/95				248.918	248.988	248.997	248.451	246.326	246.415	248.415	246.098	247.247
7/11/95				248.921	248.966	248.979	248.424	246.326	246.399	248.390	246.098	247.229
7/12/95				248.909	248.960	248.976	248.427	246.323	246.409	248.341	246.091	247.119
7/13/95				248.893	248.954	248.973	248.430	246.317	246.415	248.284	246.082	246.979
7/14/95				248.890	248.945	248.966	248.421	246.314	246.418	248.262	246.088	247.012
7/15/95				248.884	248.936	248.960	248.409	246.308	246.421	248.238	246.091	247.034
8/24/95				248.869	248.899	248.918	248.360	246.320	246.442	248.354	246.107	247.207
8/25/95				248.857	248.893	248.918	248.357	246.317	246.445	248.329	246.104	247.180
8/26/95				248.841	248.890	248.918	248.354	246.314	246.445	248.311	246.104	247.155
8/27/95				248.838	248.881	248.912	248.345	246.314	246.448	248.326	246.104	247.140
8/28/95				248.835	248.872	248.905	248.335	246.314	246.448	248.341	246.104	247.128
8/29/95				248.829	248.872	248.902	248.335	246.302	246.439	248.326	246.101	247.116
8/30/95				248.823	248.872	248.899	248.335	246.296	246.433	248.302	246.095	247.107
8/31/95				248.820	248.872	248.899	248.335	246.284	246.427	248.287	246.091	247.101
9/1/95				248.814	248.860	248.890	248.326	246.284	246.427	248.277	246.088	247.085
9/2/95				248.802	248.848	248.881	248.320	246.280	246.427	248.271	246.085	247.067
9/3/95				248.793	248.841	248.875	248.314	246.280	246.427	248.268	246.082	247.058
9/4/95				248.787	248.835	248.866	248.311	246.280	246.433	248.277	246.079	247.049
9/6/95				248.787	248.860	248.896	248.338	246.265	246.433	248.204	246.067	247.046
9/7/95				248.802	248.845	248.872	248.296	246.293	246.451	248.277	246.177	247.034
9/8/95				248.881	248.881	248.896	248.329	246.335	246.451	248.421	246.146	247.055
9/9/95				248.860	248.881	248.893	248.323	246.314	246.424	248.421	246.119	247.064
9/10/95				248.820	248.851	248.878	248.305	246.290	246.424	248.341	246.088	247.058
9/11/95				248.817	248.857	248.893	248.332	246.290	246.415	248.296	246.082	247.058
9/12/95				248.832	248.869	248.902	248.341	246.299	246.412	248.308	246.085	247.058
9/13/95				248.829	248.866	248.884	248.320	246.305	246.424	248.314	246.091	247.058
9/14/95				248.780	248.811	248.841	248.271	246.290	246.427	248.265	246.082	247.046
9/15/95				248.759	248.799	248.832	248.259	246.287	246.421	248.213	246.091	247.040
9/16/95				248.787	248.851	248.838	248.320	246.293	246.430	248.253	246.095	247.024
9/17/95				248.780	248.817	248.841	248.271	246.287	246.430	248.308	246.098	247.021
9/18/95				248.765	248.802	248.841	248.277	246.284	246.427	248.265	246.085	247.009
9/19/95				248.765	248.820	248.857	248.287	246.287	246.421	248.265	246.088	246.976
9/20/95				248.765	248.835	248.863	248.290	246.293	246.418	248.284	246.088	246.970
9/21/95				248.835	248.860	248.875	248.317	246.323	246.436	248.421	246.143	247.043
9/22/95				248.826	248.851	248.872	248.302	246.308	246.430	248.402	246.104	247.024
9/23/95				248.796	248.814	248.848	248.274	246.296	246.409	248.384	246.098	247.024
9/24/95				248.802	248.838	248.881	248.314	246.299	246.412	248.345	246.088	247.021
9/25/95				248.820	248.866	248.890	248.320	246.296	246.415	248.354	246.091	247.027
9/26/95				248.805	248.845	248.872	248.305	246.280	246.427	248.335	246.079	247.021
9/27/95				248.784	248.811	248.845	248.268	246.268	246.418	248.302	246.091	247.018
9/28/95				248.771	248.805	248.841	248.268	246.262	246.415	248.293	246.085	247.003
9/29/95				248.759	248.802	248.838	248.265	246.293	246.427	248.311	246.082	246.985
9/30/95				248.747	248.799	248.838	248.265	246.308	246.421	248.540	246.079	246.982
10/1/95				248.750	248.793	248.823	248.256	246.287	246.427	248.485	246.079	246.973

DATE	Water Elevation (m)										
	E13A	W14A	W15A	W1B	W2B	W3B	W4B	W5B	W6B	W7B	E8B	W9B
10/2/95				248.750	248.787	248.814	248.247	246.268	246.427	248.424	246.082	246.963
10/3/95				248.756	248.808	248.841	248.290	246.277	246.424	248.512	246.122	247.024
10/10/95				248.765	248.793	248.811	248.244	246.323	246.427	248.323	246.101	246.945
10/11/95				248.762	248.796	248.817	248.244	246.326	246.430	248.305	246.098	246.951
10/12/95				248.759	248.799	248.820	248.247	246.326	246.430	248.287	246.095	246.966
10/16/95				248.753	248.774	248.780	248.210	246.329	246.402	248.338	246.067	247.000
10/21/95				248.884	248.866	248.860	248.290	246.375	246.439	248.387	246.177	247.046
10/22/95				248.860	248.826	248.826	248.253	246.335	246.412	248.405	246.143	247.067
10/23/95				248.857	248.841	248.872	248.299	246.326	246.421	248.412	246.119	247.070
10/24/95				248.838	248.829	248.838	248.265	246.323	246.405	248.418	246.116	247.079
10/25/95				248.835	248.832	248.835	248.262	246.317	246.402	248.412	246.116	247.067
10/26/95				248.841	248.854	248.872	248.305	246.277	246.412	248.412	246.116	247.082
10/27/95				248.979	248.939	248.939	248.369	246.543	246.598	248.427	246.424	247.107
10/28/95				248.960	248.881	248.863	248.287	246.405	246.457	248.448	246.296	247.171
10/29/95				248.872	248.811	248.817	248.238	246.314	246.393	248.433	246.143	247.271
10/30/95				248.860	248.799	248.814	248.241	246.302	246.396	248.424	246.146	247.274
11/1/95				248.933	248.881	248.893	248.320	246.323	246.412	248.445	246.149	247.335
11/7/95				248.945	248.905	248.899	248.329	246.320	246.387	248.439	246.159	247.329
11/14/95				249.079	248.994	249.018	248.448	246.451	246.457	248.448	246.375	247.460
11/22/95				249.085	249.003	249.021	248.454	246.491	246.436	248.451	246.345	247.460
11/30/95	246.479		249.354	249.095	249.040	249.067		246.451	246.439	248.466	246.326	247.302
12/4/95	246.448	247.107	249.256	249.055	248.988	249.015	248.442	246.421	246.396	248.473	246.277	247.399
12/14/95	246.564	247.091	249.256	249.076	249.000	249.006		246.430	246.372		246.186	247.399
12/23/95	246.424	247.128	249.204	249.043	248.997	249.012		246.375	246.387		246.186	247.399
12/30/95	246.415	247.094	249.140	249.021	248.988			246.360	246.384		246.149	247.332
1/6/96	246.397	247.036	249.058	248.939	248.927			246.332	246.360		246.110	247.241
1/22/96	246.439	247.146	249.293	249.049	249.460			246.351	246.418		246.143	247.348
3/16/96	246.436	247.192			248.985	249.024		246.369	246.399		246.104	247.460
3/23/96		247.094		249.018				246.351	246.390		246.073	247.348
3/28/96	246.424	247.110	249.217	249.052	248.988	249.037	248.485	246.381	246.415		246.082	247.235
4/2/96	246.421	247.116	249.223	249.040	248.982	249.043	248.488	246.384	246.399	248.430	246.070	247.448
4/5/96	246.406	247.079	249.174	249.003	248.957	249.009	248.442	246.363	246.390	248.424	246.061	247.415
5/31/96	246.433	247.070	249.192	248.988	249.003	249.055	248.506	246.381	246.360	248.445	246.058	247.317
6/1/96	246.455	247.161	249.314	248.979	248.991	249.030	248.439	246.293	246.488	248.451	246.116	247.396

DATE	Water Elevation (m)											
	E10B	W11B	W1C	W2C	W3C	W4C	W5C	W6C	W7C	E8C	W9C	E10C
8/26/94			246.820	249.043		249.027	247.220	247.512		247.741	247.290	
8/29/94			246.960	249.030		249.012	247.189	247.488		247.741	247.259	
8/30/94			247.003	249.024		249.030	247.186	247.488		247.741	247.265	
8/31/94			247.046	249.034		249.005	247.168	247.457		247.741	247.250	
9/2/94			247.107	249.015		249.018	247.171	247.488		247.741	247.262	
9/7/94			246.881	249.034		249.024	247.265	247.552		247.741	247.290	
9/9/94			247.012	249.015		248.997	247.149	247.460		247.741	247.220	
9/14/94			247.192	248.991		248.966	247.171	247.439	246.046	247.741	247.204	
9/20/94			247.348	248.997		248.948	247.125	247.433	246.845	247.314	247.204	
9/26/94			247.527	248.970	248.866	248.945	247.119	247.436	247.107	247.329	247.213	
9/27/94			247.555	248.966	248.872	248.945	247.152	247.451	247.223	247.375	247.226	
9/28/94			247.573	248.970	248.881	248.942	247.177	247.491	247.308	247.405	247.256	
9/29/94			247.598	248.957	248.884	248.915	247.113	247.405	247.387	247.390	247.210	
9/30/94	247.006		247.625	248.960	248.884	248.927	247.085	247.430	247.491	247.381	247.259	247.323
10/1/94	247.034		247.640	248.963	248.887	248.936	247.091	247.436	247.552	247.381	247.226	247.387
10/2/94	247.046		247.043	248.957	248.890	248.933	247.027	247.433	247.631	247.378	247.229	247.384
10/3/94	247.046		247.055	248.948	248.890	248.915	247.034	247.418	247.698	247.381	247.277	247.384
10/5/94	247.055		247.521	248.948	248.899	248.927	247.027	247.430	247.799	247.381	247.210	247.390
10/6/94	247.052	248.933	247.723	248.948	248.902	248.933	247.037	247.424	247.866	247.378	247.204	247.393
10/7/94	247.052	248.939	247.860	248.951	248.896	248.939	247.037	247.415	247.909	247.381	247.204	247.387
10/8/94	247.061	248.927	247.951	248.902	248.896	248.912	247.043	247.424	247.942	247.378	247.195	247.396
10/9/94	247.128	248.921	248.061	248.945	248.899	248.915	247.113	247.494	247.982	247.378	247.284	247.485
10/10/94	247.052	248.905	248.149	248.902	248.896	248.893	247.043	247.424	248.018	247.381	247.216	247.396
10/12/94	247.049	248.945	248.305	248.945	248.905	248.933	247.030	247.418	248.073	247.381	247.226	247.390
10/13/94	247.058	248.927	248.366	248.942	248.909	248.918	247.037	247.424	248.098	247.381	247.213	247.393
10/14/94	247.058	248.936	248.418	248.936	248.902	248.915	247.043	247.433	248.131	247.384	247.216	247.396
10/15/94	247.058	248.905	248.454	248.918	248.905	248.893	247.027	247.424	248.143	247.399	247.192	247.393
10/17/94	247.070	248.939	248.543	248.942	248.905	248.918	247.055	247.457	248.183	247.430	247.238	247.405
10/18/94	247.107	248.942	248.582	248.948	248.912	248.927	247.088	247.485	248.207	247.466	247.256	247.451
10/19/94	247.152	248.933	248.610	248.945	248.912	248.924	247.119	247.515	248.226	247.463	247.305	247.485
10/20/94	247.076	248.921	248.643	248.933	248.912	248.896	247.070	247.457	248.247	247.442	247.259	247.421
10/22/94	247.082	248.927	248.683	248.942	248.912	248.912	247.052	247.463	248.271	247.442	247.250	247.418
10/23/94	247.098	248.902	248.713	248.918	248.918	248.890	247.055	247.466	248.293	247.460	247.241	247.427
10/24/94	247.098	248.921	248.726	248.927	248.918	248.902	247.061	247.463	248.296	247.445	247.247	247.424
10/25/94	247.091	248.893	248.732	248.918	248.912	248.884	247.055	247.454	248.305	247.442	247.229	247.418
10/26/94	247.070	248.893	248.747	248.890	248.912	248.881	247.052	247.442	248.314	247.436	247.229	247.402
10/28/94	247.058	248.939	248.774	248.933	248.912	248.921	247.067	247.466	248.326	247.442	247.253	247.393
10/29/94	247.043	248.899	248.780	248.921	248.912	248.887	247.049	247.466	248.335	247.460	247.268	247.329
10/30/94	247.049	248.909	248.787	248.905	248.915	248.896	247.043	247.470	248.348	247.497	247.271	247.384
11/1/94	247.284	248.960	248.817	248.976	248.915	248.936	247.277	247.668	248.360	247.375	247.354	247.546
11/3/94	247.125	248.970	248.829	248.976	248.915	248.942	247.122	247.540	248.375	247.500	247.363	247.460
11/4/94	247.171	248.988	248.835	248.973	248.899	248.957	247.192	247.607	248.384	247.558	247.418	247.491
11/5/94	247.195	248.966	248.848	248.970	248.909	248.942	247.195	247.604	248.238	247.598	247.427	247.524
11/6/94	247.265	248.963	248.866	248.976	248.915	248.951	247.253	247.643	248.402	247.671	247.436	247.604
11/7/94	247.192	249.049	248.872	249.030	248.915	249.030	247.198	247.631	248.399	247.610	247.451	247.537
11/9/94	247.229	249.021	248.899	249.018	248.915	249.003	247.235	247.649	248.424	247.634	247.476	247.561
11/10/94	247.177	249.018	248.909	249.009	248.921	248.997	247.159	247.604	248.430	247.595	247.424	247.524
11/11/94	247.159	249.049	248.918	249.027	248.921	249.030	247.146	247.598	248.430	247.579	247.427	247.503
11/13/94	247.134	249.046	248.942	249.030	248.927	249.021	247.143	247.585	248.454	247.564	247.412	247.485
11/14/94	247.186	249.027	248.942	249.021	248.924	249.006	247.186	247.619	248.457	247.588	247.442	247.518
11/15/94	247.116	249.018	248.948	248.997	248.930	248.997	247.122	247.564	248.460	247.552	247.393	247.466
11/16/94	247.104	249.024	248.957	249.021	248.930	249.021	247.101	247.555	248.463	247.540	247.399	247.457
11/17/94	247.091	249.052	248.960	249.034	248.933	249.030	247.095	247.549	248.470	247.530	247.402	247.451
11/20/94	247.046	249.055	248.973	249.021	248.936	249.034	247.046	247.509	248.479	247.488	247.366	247.405

DATE	Water Elevation (m)											
	E10B	W11B	W1C	W2C	W3C	W4C	W5C	W6C	W7C	E8C	W9C	E10C
11/21/94	247.134	249.009	248.985	249.024	248.933	248.997	247.137	247.567	248.482	247.552	247.402	247.433
11/22/94	247.006	248.963	248.979	248.960	248.933	248.960	247.024	247.463	248.485	247.454	247.296	247.375
11/24/94	247.003	249.055	248.985	249.030	248.939	249.040	247.018	247.476	248.491	247.451	247.338	247.372
11/25/94	246.988	248.997	248.994	249.000	248.942	248.988	247.018	247.454	248.494	247.445	247.293	247.360
11/29/94	247.131	249.006	249.015	249.021	248.945	249.003	247.125	247.570	248.509	247.582	247.393	247.491
12/1/94	247.006	249.043	249.006	249.027	248.948	249.030	247.009	247.491	248.497	247.470	247.348	247.375
12/3/94	247.122	249.027	249.018	249.030	248.948	249.015	247.113	247.582	248.497	247.537	247.421	247.448
12/4/94	247.021	249.012	249.012	249.015	248.948	249.009	247.012	247.491	248.500	247.485	247.341	247.390
12/5/94	247.012	249.027	247.198	249.021	248.933	249.009	247.037	247.503	246.256	247.491	247.351	247.384
12/6/94	247.000	249.021	247.433	249.021	249.034	249.015	247.009	247.491	246.439	247.500	247.335	247.372
12/7/94	247.070	248.997	247.613	249.003	249.052	248.985	247.076	247.540	246.610	247.497	247.363	247.433
12/12/94	247.024	249.046	248.256	249.037	249.076		246.997	247.509	247.305		247.363	247.396
12/16/94	246.994	249.052	248.527	249.040	249.076	249.049	246.973	247.491	247.652	247.497	247.363	247.399
12/19/94	247.091	249.070	248.683	249.064	249.101	249.076	247.034	247.570	247.875	247.555	247.421	247.454
12/20/94	247.061	249.061	247.110	249.040	248.973	249.064	247.021	247.552	246.256	247.543	247.399	247.387
12/23/94	247.024	249.058	247.640	249.052	249.095	249.055	247.006	247.534	246.558	247.503	247.390	247.402
12/28/94	246.979	249.076	248.210	249.070	249.107	249.085	246.973	247.500	247.155	247.466	247.381	247.357
12/30/94	246.948	249.043	248.433	249.046	249.085		246.915	247.463	247.463		247.323	247.329
12/31/94	246.948	249.049	248.503	249.052	249.095	249.049	246.930	247.463	247.558	247.442	247.329	247.326
1/4/95	246.936	249.040	248.698	249.024	249.082		246.912	247.448	247.854		247.305	247.311
4/8/95	247.027	249.034	249.012	249.055	249.070	249.040	247.034	247.552	248.466	247.451	247.424	247.351
5/1/95	246.939	249.088	249.107	249.098	249.095	249.113	246.954	247.503	248.549	247.470	247.405	247.287
5/2/95	246.933	249.061	249.113	249.082	249.095	249.088	246.939	247.485	248.555	247.466	247.378	247.308
5/3/95	246.915	249.058	249.110	249.070	249.095	249.088	246.930	247.482	248.552	247.454	247.366	247.296
5/4/95	246.973	249.061	249.110	249.076	249.088	249.085	246.979	247.506	248.549	247.497	247.396	247.354
5/8/95	246.918	249.049	249.116	249.070	249.091	249.079	246.933	247.479	248.558	247.454	247.357	247.299
5/9/95	247.064	249.088	249.125	249.095	249.095	249.110	247.058	247.595	248.564	247.527	247.485	247.412
5/10/95	246.979	249.085	249.134	249.098	249.098	249.116	246.982	247.509	248.573	247.497	247.412	247.348
5/11/95	247.134	249.113	249.131	249.140	249.098	249.165	247.098	247.665	248.579	247.652	247.512	247.503
5/12/95	247.076	249.107	249.131	249.122	249.101	249.149	247.067	247.622	248.579	247.634	247.491	247.451
5/13/95	247.024	249.107	249.137	249.116	249.095	249.143	247.034	247.591	248.582	247.591	247.476	247.415
5/14/95	247.009	249.067	249.146	249.091	249.098	249.101	247.018	247.573	248.582	247.576	247.430	247.402
5/15/95	246.973	249.082	249.140	249.085	249.101	249.113	246.991	247.555	248.576	247.543	247.418	247.366
5/16/95	246.966	249.113	249.146	249.122	249.101	249.149	246.982	247.549	248.579	247.534	247.433	247.366
5/17/95	246.960	249.058	249.149	249.079	249.098	249.095	246.979	247.524	248.585	247.524	247.387	247.363
5/18/95	246.951	249.073	249.143	249.082	249.095	249.101	246.973	247.518	248.585	247.506	247.390	247.351
5/19/95	246.948	249.073	249.143	249.088	249.095	249.107	246.960	247.518	248.585	247.500	247.390	247.345
5/20/95	246.942	249.073	249.143	249.091	249.095	249.113	246.948	247.515	248.585	247.494	247.390	247.335
5/21/95	246.930	249.046	249.137	249.073	249.098	249.088	246.930	247.497	248.582	247.482	247.360	247.308
5/22/95	246.924	249.027	249.131	249.055	249.098	249.067	246.918	247.485	248.576	247.473	247.338	247.284
5/26/95	247.024	249.091	249.131	249.113	249.107	249.143	247.024	247.537	248.576	247.546	247.418	247.402
5/27/95	246.994	249.091	249.125	249.104	249.095	249.134	247.049	247.524	248.567	247.518	247.409	247.381
5/28/95	247.101	249.110	249.140	249.122	249.098	249.152	247.128	247.619	248.582	247.591	247.558	247.470
5/29/95	246.994	249.058	249.137	249.085	249.091	249.098	247.046	247.521	248.585	247.518	247.409	247.387
5/30/95	246.979	249.076	249.131	249.091	249.098	249.116	247.037	247.524	248.585	247.512	247.402	247.372
5/31/95	246.970	249.073	249.137	249.091	249.098	249.110	247.040	247.518	248.585	247.506	247.387	247.363
6/1/95	246.963	249.070	249.140	249.091	249.095	249.107	247.043	247.512	248.585	247.500	247.378	247.357
6/2/95	246.960	249.067	249.143	249.091	249.095	249.107	247.037	247.509	248.588	247.497	247.369	247.351
6/3/95	246.957	249.067	249.143	249.091	249.095	249.107	247.024	247.509	248.591	247.494	247.366	247.345
6/4/95	246.954	249.070	249.137	249.091	249.095	249.107	247.015	247.509	248.595	247.491	247.396	247.345
6/5/95	246.951	249.073	249.137	249.091	249.098	249.107	247.003	247.509	248.591	247.488	247.387	247.345
6/6/95	246.945	249.061	249.140	249.082	249.101	249.101	247.006	247.479	248.598	247.476	247.363	247.335
6/7/95	246.945	249.040	249.140	249.070	249.110	249.079	246.991	247.482	248.604	247.460	247.341	247.323
6/8/95	246.942	248.997	249.131	249.027	249.110	249.043	246.991	247.473	248.591	247.470	247.335	247.332

DATE	Water Elevation (m)											
	E10B	W11B	W1C	W2C	W3C	W4C	W5C	W6C	W7C	E8C	W9C	E10C
6/9/95	246.939	249.027	249.119	249.046	249.101	249.061	246.985	247.494	248.579	247.466	247.341	247.323
6/10/95	246.954	249.058	249.119	249.070	249.101	249.095	247.006	247.518	248.579	247.476	247.366	247.332
6/11/95	246.948	249.034	249.125	249.055	249.104	249.070	246.988	247.494	248.585	247.466	247.348	247.329
6/12/95	246.936	249.043	247.216	249.058	249.107	249.073	247.000	247.497	248.585	247.405	247.345	247.308
6/13/95	246.930	249.034	247.515	249.055	249.104	249.070	247.000	247.488	248.579	247.399	247.329	247.326
6/18/95	246.924	249.006	248.277	249.037	249.098	249.034	246.976	247.457	246.869	247.390	247.299	247.302
6/20/95	246.915	248.985	248.460	249.021	249.064	249.024	246.954	247.424	247.140	247.405	247.290	247.284
6/22/95	246.869	248.957	248.634	248.988	249.037	248.994	246.905	247.351	247.482	247.393	247.256	247.192
7/8/95	246.945	248.942	248.912	248.985	249.037	248.960	246.960	247.427	248.131	247.415	247.280	247.302
7/9/95	246.942	248.945	248.912	248.970	249.027	248.963	246.985	247.424	248.146	247.409	247.277	247.296
7/10/95	246.933	248.942	248.930	248.979	249.009	248.970	246.979	247.421	248.189	247.399	247.271	247.290
7/11/95	246.930	248.921	248.936	248.960	249.003	248.954	246.973	247.412	248.210	247.396	247.256	247.290
7/12/95	246.927	248.930	246.948	248.960	248.997	248.957	246.970	247.412	248.232	247.396	247.256	247.290
7/13/95	246.921	248.936	247.610	248.960	248.991	248.963	246.963	247.412	246.476	247.393	247.253	247.287
7/14/95	246.909	248.924	247.774	248.951	248.985	248.942	246.948	247.390	246.909	247.390	247.244	247.253
7/15/95	246.896	248.905	247.942	248.939	248.976	248.918	246.936	247.366	246.729	247.387	247.229	247.216
8/24/95	246.954	248.860	248.912	248.902	249.006	248.881	246.973	247.387	248.299	247.375	247.207	247.284
8/25/95	246.957	248.857	248.912	248.896	249.006	248.899	246.970	247.384	248.311	247.372	247.201	247.274
8/26/95	246.957	248.854	248.912	248.893	249.006	248.915	246.966	247.381	248.314	247.369	247.198	247.268
8/27/95	246.954	248.841	248.912	248.884	249.003	248.902	246.960	247.372	248.317	247.363	247.183	247.265
8/28/95	246.951	248.835	248.912	248.878	249.003	248.893	246.954	247.366	248.317	247.360	247.174	247.262
8/29/95	246.939	248.832	248.909	248.878	249.000	248.881	246.951	247.363	248.317	247.357	247.171	247.259
8/30/95	246.927	248.826	248.909	248.878	249.000	248.872	246.951	247.363	248.317	247.357	247.171	247.256
8/31/95	246.912	248.823	248.905	248.878	248.997	248.863	246.948	247.360	248.317	247.354	247.168	247.253
9/1/95	246.909	248.820	248.899	248.863	248.994	248.851	246.948	247.357	248.314	247.351	247.155	247.250
9/2/95	246.905	248.817	248.893	248.854	248.985	248.845	246.945	247.354	248.311	247.348	247.134	247.247
9/3/95	246.902	248.811	248.884	248.845	248.979	248.832	246.945	247.351	248.308	247.345	247.122	247.244
9/4/95	246.899	248.805	248.878	248.838	248.973	248.826	246.945	247.348	248.280	247.338	247.143	247.232
9/6/95	246.893	248.829	248.881	248.860	248.976	248.854	246.951	247.357	248.284	247.338	247.152	247.229
9/7/95	246.927	248.793	248.878	248.841	248.973	248.823	246.982	247.372	248.284	247.360	247.134	247.238
9/8/95	246.942	248.838	248.872	248.869	248.963	248.854	246.973	247.375	248.274	247.369	247.186	247.268
9/9/95	246.942	248.835	248.884	248.869	248.963	248.841	246.957	247.357	248.280	247.354	247.168	247.262
9/10/95	246.915	248.814	248.869	248.835	248.966	248.841	246.945	247.338	248.284	247.332	247.162	247.235
9/11/95	246.927	248.832	248.869	248.857	248.966	248.857	246.957	247.360	248.287	247.345	247.168	247.244
9/12/95	246.930	248.845	248.875	248.881	248.966	248.863	246.966	247.354	248.290	247.345	247.171	247.250
9/13/95	246.936	248.826	248.881	248.860	248.963	248.845	246.954	247.348	248.293	247.341	247.149	247.247
9/14/95	246.905	248.762	248.872	248.802	248.963	248.796	246.945	247.335	248.290	247.326	247.113	247.232
9/15/95	246.921	248.753	248.869	248.787	248.960	248.780	246.945	247.332	248.284	247.329	247.098	247.229
9/16/95	246.927	248.826	248.866	248.851	248.960	248.848	246.951	247.351	248.284	247.338	247.143	247.235
9/17/95	246.902	248.768	248.863	248.811	248.954	248.796	246.942	247.323	248.280	247.317	247.104	247.229
9/18/95	246.887	248.774	248.854	248.793	248.957	248.915	246.945	247.338	248.274	247.320	247.113	247.216
9/19/95	246.912	248.774	248.857	248.814	248.951	248.814	246.948	247.338	248.271	247.323	247.110	247.223
9/20/95	246.905	248.777	248.857	248.823	248.954	248.811	246.951	247.338	248.271	247.326	247.107	247.229
9/21/95	246.924	248.814	248.857	248.848	248.951	248.838	246.966	247.338	248.268	247.329	247.159	247.247
9/22/95	246.918	248.805	248.857	248.841	248.951	248.823	246.957	247.338	248.268	247.332	247.131	247.244
9/23/95	246.884	248.771	248.851	248.814	248.948	248.799	246.954	247.326	248.265	247.323	247.107	247.229
9/24/95	246.921	248.814	248.851	248.838	248.948	248.841	246.960	247.335	248.265	247.329	247.137	247.226
9/25/95	246.893	248.826	248.857	248.863	248.948	248.845	246.933	247.305	248.271	247.290	247.122	247.198
9/26/95	246.890	248.808	248.860	248.838	248.948	248.832	246.942	247.311	248.277	247.302	247.116	247.201
9/27/95	246.890	248.768	248.860	248.814	248.942	248.799	246.936	247.293	248.280	247.290	247.088	247.195
9/28/95	246.887	248.762	248.851	248.811	248.939	248.796	246.933	247.287	248.274	247.280	247.073	247.192
9/29/95	246.893	248.765	248.845	248.808	248.936	248.793	246.942	247.311	248.262	247.296	247.082	247.195
9/30/95	246.890	248.768	248.838	248.805	248.936	248.793	246.945	247.314	248.265	247.308	247.079	247.198
10/1/95	246.878	248.756	248.838	248.784	248.939	248.784	246.942	247.323	248.265	247.311	247.076	247.195

DATE	Water Elevation (m)											
	E10B	W11B	W1C	W2C	W3C	W4C	W5C	W6C	W7C	E8C	W9C	E10C
10/2/95	246.869	248.741	248.838	248.768	248.939	248.777	246.942	247.329	248.262	247.314	247.076	247.195
10/3/95	246.899	248.820	248.832	248.811	248.939	248.808	246.966	247.326	248.256	247.314	247.085	247.201
10/10/95	246.902	248.750	248.180	248.774	248.838	248.765	246.945	247.332	247.079	247.308	247.079	247.213
10/11/95	246.896	248.756	248.552	248.784	248.835	248.771	246.945	247.332	247.171	247.305	247.079	247.210
10/12/95	246.890	248.759	248.314	248.787	248.832	248.774	246.945	247.332	247.259	247.305	247.079	247.201
10/16/95	246.887	248.710	248.506	248.753	248.832	248.732	246.942	247.314	247.546	247.299	247.055	247.201
10/21/95	246.933	248.811	248.640	248.841	248.866	248.811	246.988	247.366	247.790	247.363	247.159	247.265
10/22/95	246.896	248.765	248.668	248.802	248.835	248.774	246.954	247.341	247.835	247.329	247.122	247.220
10/23/95	246.893	248.811	248.680	248.823	248.841	248.820	246.973	247.348	247.869	247.326	247.155	247.207
10/24/95	246.896	248.777	248.692	248.820	248.835	248.787	246.942	247.332	247.905	247.320	247.116	247.210
10/25/95	246.890	248.771	248.704	248.817	248.835	248.780	246.942	247.335	247.893	247.320	247.104	247.207
10/26/95	246.912	248.820	248.716	248.841	248.841	248.823	246.954	247.341	247.957	247.326	247.134	247.213
10/27/95	247.073	248.899	248.738	248.905	248.835	248.893	247.110	247.530	247.991	247.479	247.320	247.326
10/28/95	246.997	248.805	248.753	248.851	248.835	248.808	247.046	247.427	248.021	247.424	247.259	247.293
10/29/95	246.899	248.750	248.744	248.784	248.835	248.762	246.927	247.329	248.049	247.323	247.149	247.207
10/30/95	246.893	248.753	248.747	248.780	248.835	248.762	246.927	247.335	248.055	247.323	247.143	247.201
11/1/95	246.930	248.841	248.765	248.863	248.851	248.841	246.927	247.366	248.095	247.357	247.216	247.235
11/7/95	246.912	248.857	248.835	248.881	248.838	248.851	246.945	247.366	248.210	247.366	247.210	247.235
11/14/95	247.012	248.973	248.896	248.982	248.848	248.973	247.037	247.500	248.299	247.500	247.335	247.338
11/22/95	246.994	248.982	248.973	248.985	248.869	248.988	247.021	247.494	248.372	247.485	247.335	247.323
11/30/95	246.988	249.046	248.991	249.034	248.881		247.003	247.512	248.418		247.125	247.320
12/4/95	246.939	248.957	248.997	248.970	248.896	248.966	246.951	247.448	248.436	247.439	247.296	247.277
12/14/95	247.052	248.957	249.006	248.985	248.902		246.960	247.500	248.451		247.369	247.332
12/23/95	246.875		248.701	248.982	248.915		246.857	247.387	248.460		247.256	247.220
12/30/95	246.854		249.003	248.979	248.912		246.820	247.363			247.220	247.201
1/6/96	246.823		248.976	248.927	248.918		246.777	247.326			247.168	
1/22/96	246.854		248.985	249.015	248.933		246.832	247.366			247.241	
3/16/96	246.805	248.936	249.055	249.009	248.982		246.881	247.348			247.268	247.162
3/23/96	246.756		249.052	248.979	248.979		246.841	247.341			247.238	247.125
3/28/96	246.753	248.963	249.030	249.021	248.994		246.890	247.360			247.192	247.125
4/2/96	246.765	248.966	249.040	249.021	248.985	249.027	246.875	247.366	248.445	247.314	247.323	247.122
4/5/96	246.747	248.918	249.027	248.982	248.985	248.985	246.845	247.341	248.442	247.302	247.284	247.104
5/31/96	246.796	248.954	249.076	249.030	249.015	249.046	246.893	247.372	248.512	247.345	247.320	247.155
6/1/96	246.841	248.966	249.070	249.030	249.030	249.043	246.930	247.396	248.524	247.375	247.317	247.213

DATE	Water Elevation (m)								
	W11C	S4	S1	S2	S3	D CRK	DC1	DC2	DC3
8/26/94		248.951	248.918	248.936	248.723		246.183	246.213	
8/29/94		248.948	248.905	248.930	248.716		246.165	246.195	
8/30/94		248.948	248.909	248.933	248.716		246.162	246.189	
8/31/94		248.951	248.918	248.936	248.713		246.162	246.223	
9/2/94		248.942	248.905	248.936	248.707		246.155	246.216	
9/7/94		248.954	248.918	248.942	248.723		246.241	246.317	
9/9/94		248.942	248.905	248.933	248.716		246.143	246.210	
9/14/94		248.933	248.890	248.918	248.701		246.137	246.192	
9/20/94		248.924	248.893	248.924	248.701		246.119	246.189	
9/26/94		248.945	248.905	248.930	248.695		246.125	246.186	
9/27/94		248.948	248.912	248.933	248.701		246.146	246.226	
9/28/94		248.954	248.918	248.942	248.707		246.262	246.332	
9/29/94		248.948	248.915	248.927	248.707		246.122	246.195	
9/30/94		248.930	248.905	248.924	248.704		246.128	246.192	
10/1/94		248.945	248.912	248.927	248.701		246.131	246.207	
10/2/94		248.936	248.905	248.927	248.707		246.128	246.189	
10/3/94		248.927	248.902	248.921	248.701		246.128	246.186	
10/5/94		248.924	248.896	248.915	248.707		246.125	246.186	
10/6/94	248.854	248.924	248.887	248.921	248.710	246.128	246.125	246.189	
10/7/94	248.936	248.921	248.884	248.918	248.707	246.119	246.122	246.189	
10/8/94	248.912	248.924	248.881	248.915	248.707	246.125	246.125	246.186	
10/9/94	248.918	248.921	248.909	248.930	248.707	246.210	246.207	246.277	
10/10/94	248.893	248.924	248.902	248.912	248.698	246.131	246.131	246.186	
10/12/94	248.942	248.921	248.899	248.915	248.707	246.125	246.134	246.192	
10/13/94	248.927	248.921	248.896	248.912	248.710	246.134	246.140	246.192	
10/14/94	248.927	248.924	248.890	248.918	248.710	246.140	246.146	246.201	
10/15/94	248.896	248.921	248.887	248.912	248.713	246.149	246.155	246.207	
10/17/94	248.936	248.918	248.887	248.915	248.707	246.201	246.204	246.271	
10/18/94	248.945	248.927	248.887	248.921	248.720	246.229	246.229	246.293	
10/19/94	248.933	248.945	248.905	248.924	248.707	246.314	246.311	246.363	
10/20/94	248.918	248.942	248.909	248.921	248.710	246.201	246.201	246.223	
10/22/94	248.921	248.939	248.905	248.921	248.707	246.210	246.213	246.259	
10/23/94	248.905	248.930	248.905	248.918	248.710	246.223	246.226	246.271	
10/24/94	248.918	248.921	248.905	248.909	248.716	246.226	246.229	246.290	
10/25/94	248.896	248.918	248.899	248.909	248.710	246.232	246.232	246.290	
10/26/94	248.884	248.912	248.896	248.902	248.704	246.232	246.235	246.274	
10/28/94	248.933	248.915	248.890	248.909	248.710	246.229	246.232	246.293	
10/29/94	248.893	248.915	248.890	248.912	248.704	246.235	246.235	246.280	
10/30/94	248.909	248.912	248.881	248.902	248.701	246.232	246.232	246.284	
11/1/94	248.966	248.951	248.918	248.939	248.713	246.564	246.564	246.631	
11/3/94	248.973	248.942	248.915	248.924	248.720	246.341	246.341	246.396	
11/4/94	248.979	248.948	248.912	248.924	248.707	246.509	246.503	246.573	
11/5/94	248.963	248.948	248.915	248.927	248.716	246.442	246.445	246.494	
11/6/94	248.954	248.954	248.924	248.933	248.710	246.534	246.534	246.591	
11/7/94	249.040	248.951	248.921	248.936	248.720	246.470	246.470	246.530	
11/9/94	249.018	248.957	248.930	248.933	248.716	246.521	246.524	246.576	
11/10/94	249.012	248.954	248.927	248.933	248.723	246.427	246.430	246.476	
11/11/94	249.043	248.954	248.921	248.936	248.723	246.405	246.405	246.463	
11/13/94	249.043	248.954	248.924	248.936	248.716	246.372	246.372	246.427	
11/14/94	249.018	248.954	248.924	248.936	248.713	246.451	246.451	246.509	
11/15/94	249.009	248.954	248.924	248.930	248.723	246.366	246.369	246.421	
11/16/94	249.037	248.954	248.921	248.936	248.720	246.338	246.345	246.393	
11/17/94	249.049	248.954	248.921	248.933	248.729	246.317	246.323	246.357	

DATE	Water Elevation (m)								
	W11C	S4	S1	S2	S3	D CRK	DC1	DC2	DC3
11/20/94	249.049	248.954	248.924	248.930	248.729	246.253	246.256	246.299	
11/21/94	249.009	248.954	248.918	248.933	248.716	246.372	246.372	246.427	
11/22/94	248.966	248.945	248.912	248.918	248.716	246.210	246.216	246.262	
11/24/94	249.052	248.951	248.924	248.936	248.729	246.192	246.198	246.241	
11/25/94	248.991	248.951	248.921	248.933	248.726	246.186	246.192	246.213	
11/29/94	249.006	248.954	248.921	248.936	248.726	246.399	246.396	246.457	
12/1/94	249.040	248.954	248.921	248.936	248.735	246.235	246.238	246.274	
12/3/94	249.021	248.954	248.924	248.936	248.726	246.427	246.421	246.497	
12/4/94	249.012	248.954	248.921	248.936	248.723	246.253	246.256	246.302	
12/5/94	249.021	248.957	248.924	248.939	248.723	246.241	246.241	246.284	
12/6/94	249.024	248.957	248.924	248.936	248.729	246.235	246.238	246.271	
12/7/94	249.000	248.948	248.921	248.936	248.723	246.375	246.372	246.421	
12/12/94	249.046		248.924	248.942	248.729	246.268	246.271	246.299	
12/16/94	249.049			248.939	248.729	246.229	246.232	246.262	
12/19/94	249.067	248.945	248.921	248.936	248.726	246.369	246.375	246.412	
12/20/94	249.058		248.921	248.936	248.726	246.332	246.338	246.360	
12/23/94	249.055		248.924	248.936	248.716	246.290	246.287	246.320	
12/28/94	249.079				248.726	246.220	246.216	246.256	
12/30/94	249.043				248.729	246.180	246.174	246.213	
12/31/94	249.049				248.716	246.174	246.177	246.207	
1/4/95	249.037					246.180	246.177	246.207	
4/8/95	249.049	248.966	248.930	248.942	248.707	246.335	246.338	246.402	
5/1/95	249.110	248.954	248.939	248.960	248.707	246.171	246.174	246.213	
5/2/95	249.085	248.957	248.939	248.963	248.707	246.177	246.174	246.204	
5/3/95	249.076	248.957	248.936	248.957	248.710	246.174	246.171	246.198	
5/4/95	249.076	248.957	248.942	248.960	248.704	246.186	246.189	246.247	
5/8/95	249.070	248.954	248.939	248.960	248.710	246.168	246.165	246.210	
5/9/95	249.104	248.963	248.942	248.960	248.710	246.329	246.326	246.393	
5/10/95	249.104	248.954	248.939	248.960	248.707	246.192	246.192	246.229	
5/11/95	249.131	248.960	248.939	248.966	248.713	246.479	246.482	246.534	
5/12/95	249.128	248.960	248.942	248.966	248.707	246.390	246.384	246.424	
5/13/95	249.125	248.957	248.942	248.966	248.707	246.308	246.311	246.345	
5/14/95	249.085	248.957	248.936	248.957	248.707	246.287	246.280	246.323	
5/15/95	249.098	248.954	248.933	248.960	248.707	246.241	246.241	246.274	
5/16/95	249.131	248.957	248.942	248.957	248.713	246.207	246.210	246.241	
5/17/95	249.076	248.951	248.936	248.951	248.698	246.204	246.198	246.238	
5/18/95	249.091	248.960	248.939	248.954	248.704	246.192	246.192	246.223	
5/19/95	249.088	248.960	248.936	248.957	248.704	246.192	246.186	246.216	
5/20/95	249.085	248.954	248.936	248.960	248.704	246.180	246.180	246.207	
5/21/95	249.058	248.954	248.933	248.954	248.704	246.177	246.174	246.201	
5/22/95	249.043	248.954	248.930	248.948	248.701	246.168	246.168	246.195	
5/26/95	249.113	248.963	248.942	248.963	248.713	246.216	246.220	246.265	
5/27/95	249.107	248.960	248.939	248.957	248.710	246.195	246.195	246.229	
5/28/95	249.122	248.960	248.945	248.960	248.713	246.308	246.308	246.372	
5/29/95	249.076	248.960	248.936	248.963	248.704	246.192	246.192	246.229	
5/30/95	249.098	248.960	248.933	248.963	248.704	246.186	246.186	246.223	
5/31/95	249.091	248.960	248.936	248.957	248.707	246.177	246.177	246.210	
6/1/95	249.088	248.960	248.939	248.954	248.707	246.174	246.171	246.201	
6/2/95	249.088	248.960	248.936	248.954	248.707	246.168	246.168	246.198	
6/3/95	249.088	248.960	248.933	248.951	248.707	246.165	246.165	246.195	
6/4/95	249.085	248.957	248.936	248.954	248.713	246.162	246.162	246.195	
6/5/95	249.088	248.957	248.933	248.957	248.716	246.162	246.162	246.195	
6/6/95	249.079	248.957	248.933	248.963	248.716	246.155	246.155	246.195	

DATE	Water Elevation (m)								
	W11C	S4	S1	S2	S3	D CRK	DC1	DC2	DC3
6/7/95	249.055	248.954	248.921	248.960	248.720	246.152	246.152	246.186	
6/8/95	249.024	248.948	248.933	248.951	248.710	246.149	246.149	246.204	
6/9/95	249.052	248.951	248.933	248.951	248.713	246.149	246.149	246.210	
6/10/95	249.073	248.957	248.939	248.957	248.710	246.189	246.189	246.235	
6/11/95	249.049	248.954	248.933	248.954	248.710	246.146	246.146	246.180	
6/12/95	249.049	248.951	248.933	248.951	248.713	246.143	246.143	246.180	
6/13/95	249.055	248.948	248.927	248.951	248.710	246.140	246.140	246.183	
6/18/95	249.018	248.948	248.912	248.948	248.716	246.131	246.131	246.171	
6/20/95	248.997	248.933	248.902	248.945	248.713	246.128	246.128	246.171	
6/22/95	248.994	248.924	248.878	248.939	248.710	246.122	246.122	246.159	
7/8/95	248.960	248.951	248.912	248.951	248.701	246.128	246.128	246.165	
7/9/95	248.963	248.948	248.887	248.933	248.704	246.119	246.119	246.165	
7/10/95	248.963	248.921	248.887	248.939	248.704	246.125	246.125	246.171	
7/11/95	248.936	248.918	248.881	248.951	248.704	246.125	246.125	246.168	
7/12/95	248.939	248.905	248.872	248.948	248.701	246.122	246.122	246.165	
7/13/95	248.942	248.896	248.860	248.942	248.701	246.119	246.119	246.162	
7/14/95	248.939	248.893	248.845	248.924	248.701	246.119	246.119	246.162	
7/15/95	248.933	248.890	248.826	248.915	248.701	246.116	246.116	246.159	
8/24/95	248.875	248.857	248.863	248.893	248.668	246.125	246.122	246.155	
8/25/95	248.872	248.848	248.848	248.884	248.680	246.128	246.125	246.152	
8/26/95	248.872	248.845	248.829	248.878	248.686	246.128	246.128	246.152	
8/27/95	248.857	248.841	248.808	248.878	248.683	246.134	246.134	246.177	
8/28/95	248.848	248.838	248.793	248.869	248.683	246.137	246.137	246.174	
8/29/95	248.848	248.829	248.777	248.863	248.674	246.128	246.128	246.174	
8/30/95	248.848	248.820	248.762	248.857	248.665	246.122	246.122	246.174	
8/31/95	248.848	248.841	248.747	248.854	248.655	246.119	246.119	246.174	
9/1/95	248.845	248.799	248.723	248.841	248.646	246.116	246.116	246.174	
9/2/95	248.835	248.784	248.695	248.829	248.640	246.113	246.113	246.174	
9/3/95	248.829	248.771	248.686	248.820	248.634	246.110	246.113	246.171	
9/4/95	248.817	248.756	248.677	248.820	248.625	246.110	246.110	246.168	
9/6/95	248.841	248.729	248.668	248.811	248.649	246.110	246.110	246.162	
9/7/95	248.817	248.896	248.796	248.851	248.674	246.213	246.213	246.280	
9/8/95	248.851	248.890	248.845	248.893	248.649	246.128	246.128	246.189	
9/9/95	248.848	248.878	248.838	248.884	248.649	246.119	246.119	246.174	
9/10/95	248.832	248.814	248.802	248.845	248.637	246.113	246.113	246.171	
9/11/95	248.857	248.796	248.784	248.838	248.640	246.113	246.113	246.168	
9/12/95	248.857	248.805	248.771	248.848	248.662	246.107	246.107	246.168	
9/13/95	248.851	248.790	248.768	248.848	248.655	246.113	246.113	246.171	
9/14/95	248.787	248.774	248.723	248.817	248.628	246.110	246.110	246.168	
9/15/95	248.771	248.753	248.689	248.796	248.616	246.107	246.107	246.165	
9/16/95	248.845	248.756	248.732	248.832	248.655	246.110	246.110	246.171	
9/17/95	248.793	248.802	248.716	248.811	248.619	246.113	246.113	246.177	
9/18/95	248.796	248.747	248.665	248.787	248.613	246.113	246.113	246.168	
9/19/95	248.799	248.750	248.674	248.796	248.631	246.110	246.110	246.165	
9/20/95	248.799	248.744	248.671	248.790	248.619	246.113	246.113	246.168	
9/21/95	248.832	248.866	248.796	248.869	248.649	246.198	246.198	246.259	
9/22/95	248.817	248.854	248.784	248.860	248.640	246.116	246.116	246.183	
9/23/95	248.787	248.826	248.756	248.848	248.631	246.116	246.116	246.171	
9/24/95	248.832	248.802	248.738	248.829	248.643	246.113	246.113	246.168	
9/25/95	248.838	248.811	248.738	248.832	248.655	246.113	246.113	246.165	
9/26/95	248.823	248.793	248.732	248.829	248.637	246.110	246.110	246.165	
9/27/95	248.793	248.790	248.707	248.817	248.649	246.107	246.107	246.177	
9/28/95	248.787	248.774	248.689	248.808	248.637	246.107	246.107	246.174	

DATE	Water Elevation (m)								
	W11C	S4	S1	S2	S3	D CRK	DC1	DC2	DC3
9/29/95	248.793	248.762	248.674	248.796	248.628	246.107	246.107	246.174	
9/30/95	248.784	248.750	248.659	248.787	248.616	246.101	246.101	246.155	
10/1/95	248.780	248.726	248.674	248.777	248.607	246.113	246.113	246.168	
10/2/95	248.765	248.701	248.689	248.771	248.595	246.110	246.110	246.195	
10/3/95	248.808	248.851	248.710	248.802	248.640	246.149	246.149	246.177	
10/10/95	248.774	248.774	248.713	248.793	248.604	246.119	246.119	246.168	
10/11/95	248.771	248.765	248.713	248.790	248.610	246.119	246.119	246.168	
10/12/95	248.768	248.759	248.720	248.780	248.613	246.119	246.119	246.171	
10/16/95	248.729	248.774	248.716	248.777	248.579	246.116	246.122	246.165	
10/21/95	248.832	248.881	248.854	248.872	248.637	246.159	246.159	246.216	
10/22/95	248.777	248.869	248.768	248.860	248.625	246.143	246.143	246.195	
10/23/95	248.832	248.841	248.848	248.854	248.631	246.143	246.140	246.189	
10/24/95	248.796	248.832	248.838	248.841	248.619	246.128	246.131	246.183	
10/25/95	248.787	248.826	248.832	248.835	248.613	246.125	246.128	246.183	
10/26/95	248.835	248.817	248.826	248.820	248.631	246.134	246.134	246.183	
10/27/95	248.912	248.918	248.878	248.890	248.677	246.436	246.436	246.497	
10/28/95	248.823	248.912	248.881	248.887	248.652	246.284	246.290	246.354	
10/29/95	248.762	248.841	248.869	248.832	248.604	246.143	246.137	246.192	
10/30/95	248.762	248.829	248.857	248.823	248.601	246.146	246.146	246.192	
11/1/95	248.845	248.872	248.869	248.869	248.643	246.152	246.152	246.204	
11/7/95	248.875	248.887	248.875	248.884	248.659	246.171	246.174	246.220	
11/14/95	248.988	248.921	248.896	248.902	248.698	246.393	246.393	246.421	
11/22/95	248.994	248.924	248.905	248.915	248.695	246.369	246.363	246.393	
11/30/95	249.058			248.924	248.707	246.348	246.345	246.402	246.388
12/4/95	248.970	248.921	248.902	248.921	248.707	246.302	246.296	246.329	246.360
12/14/95	248.970			248.927		246.210	246.207	246.274	246.375
12/23/95	248.976			248.924		246.204	246.204	246.223	246.321
12/30/95	248.973					246.159	246.162	246.216	246.308
1/6/96						246.134	246.134	246.183	246.296
1/22/96	249.021					246.152	246.155	246.201	246.318
3/16/96	249.009				248.692	246.125	246.125	246.174	246.314
3/23/96						246.101	246.107	246.122	246.302
3/28/96	249.027		248.890	248.905	248.698	246.131	246.134	246.110	246.311
4/2/96	249.030	249.138	248.878	248.909	248.707	246.107	246.107	246.122	246.296
4/5/96	248.982	248.887	248.875	248.899	248.692	246.095	246.095	246.116	246.293
5/31/96	249.021	248.915	248.875	248.951	248.692	246.122	246.122	246.174	246.314
6/1/96	249.009	248.887	248.875	248.899	248.686	246.134	246.140	246.174	246.330

Appendix E

Discharge Data for Runoff From the Study Area

DATE	DISCHARGE (liters per minute) SP	SS	SN
5/9/95	33.3	30.0	23.1
5/10/95	34.3	24.1	20.9
5/11/95	37.4	51.3	59.8
5/12/95	36.9	33.2	43.2
5/13/95	33.3	31.0	32.7
5/14/95	35.8	23.9	28.9
5/15/95	35.8	19.7	22.9
5/16/95	37.0	26.5	26.6
5/17/95	34.8	17.7	19.8
5/18/95	37.1	20.8	23.2
5/19/95	36.0	19.9	23.0
5/20/95	34.2	19.5	21.8
5/21/95	34.3	16.2	20.8
5/22/95	34.4	14.0	19.8
5/23/95	35.6	31.8	23.4
5/24/95	35.8	54.0	47.4
5/25/95	36.1	62.2	51.3
5/26/95	36.6	18.3	24.4
5/27/95	33.9	23.4	31.2
5/28/95	34.9	36.2	36.8
5/29/95	36.1	22.0	32.1
5/30/95	35.2	16.8	22.7
5/31/95	35.0	17.3	24.8
6/1/95	34.8	18.0	25.7
6/2/95	34.7	17.6	22.5
6/3/95	35.3	17.3	20.2
6/4/95	36.1	17.7	19.9
6/5/95	36.7	16.8	19.5
6/6/95	38.8	18.1	21.9
6/7/95	36.1	15.9	21.1
6/8/95	34.8	11.3	17.4
6/9/95	34.7	13.7	18.7
6/10/95	34.7	28.3	43.2
6/11/95	36.3	16.4	18.6
6/12/95	34.1	12.4	14.2
6/13/95	33.8	10.0	13.1
6/18/95	33.4	7.4	11.3
6/20/95	33.5	5.2	5.9
6/22/95	33.1	4.5	7.6
7/8/95	34.1	3.4	5.4
7/9/95	32.9	3.5	6.9
7/10/95	33.7	2.5	4.6
7/11/95	31.4	1.2	5.5
7/12/95	31.5	1.3	5.0
7/13/95	31.6	1.3	3.7
7/14/95	31.3	1.4	4.4
7/15/95	31.0	1.6	4.6
8/24/95	31.7	0.6	2.0
8/25/95	30.2	0.6	2.1
8/26/95	28.8	0.6	2.3
8/27/95	28.8	0.5	2.1

DATE	DISCHARGE (liters per minute) SP	SS	SN
8/28/95	28.9	0.5	1.9
8/29/95	29.3	0.5	1.2
8/30/95	29.6	0.4	0.8
8/31/95	29.7	0.4	1.0
9/1/95	29.5	0.4	0.8
9/2/95	29.3	0.4	0.8
9/3/95	28.1	0.4	0.7
9/4/95	31.0	0.5	0.3
9/6/95	31.1	0.5	0.2
9/7/95	30.1	0.9	1.9
9/8/95	31.5	0.8	0.5
9/9/95	31.8	0.8	1.5
9/10/95	30.2	0.5	0.4
9/11/95	30.1	0.5	0.3
9/12/95	28.1	0.5	0.3
9/13/95	29.9	0.5	0.5
9/14/95	27.9	0.4	0.3
9/15/95	28.3	0.5	0.4
9/16/95	28.0	0.5	0.3
9/17/95	28.0	0.5	0.1
9/18/95	28.4	0.5	0.0
9/19/95	29.3	0.6	0.1
9/20/95	29.4	0.6	0.1
9/21/95	29.0	1.0	0.7
9/22/95	29.5	1.6	0.7
9/23/95	28.7	0.7	0.7
9/24/95	28.7	0.6	0.7
9/25/95	30.7	0.6	0.2
9/26/95	29.0	0.7	0.4
9/27/95	31.5	0.5	0.3
9/28/95	31.0	0.5	0.3
9/29/95	28.8	0.6	0.3
9/30/95	29.9	0.5	0.2
10/1/95	29.6	0.4	0.2
10/2/95	28.8	0.4	0.1
10/3/95	28.5	0.4	0.3
10/10/95	27.4	0.3	0.3
10/11/95	30.0	0.2	0.2
10/12/95	28.6	0.4	0.2
10/16/95	27.8	0.4	0.2
10/21/95	32.3	1.0	1.6
10/22/95	27.8	0.8	1.0
10/23/95	28.9	0.6	1.0
10/24/95	28.6	0.5	0.6
10/25/95	29.1	0.6	0.5
10/26/95	29.2	0.6	0.8
10/27/95	32.2	7.3	4.5
10/28/95	30.6	2.6	2.2
10/29/95	30.7	0.6	0.6
10/30/95	30.0	0.6	1.1
11/1/95	30.6	1.1	2.0

DATE	DISCHARGE (liters per minute) SP	SS	SN
11/7/95	31.4	2.0	3.0
11/14/95	32.8	14.5	11.9
11/22/95	31.5	12.9	11.4
11/30/95	35.6	23.3	22.7
12/4/95	31.8	6.6	8.5
12/14/95	32.3	18.3	13.2
12/23/95	32.0	6.4	6.3
12/30/95	32.5	8.3	6.6
1/6/96	31.0	1.4	1.0

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