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Wisconsin Groundwater Management Practice Monitoring Project No. 48

GROUNDWATER
Wisconsin's buried treasure

Wisconsin Department of Natural Resources

Sept 21, 1989

Final Report

Evaluation of The Effect of Stormwater Disposal on Groundwater Quality

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ABSTRACT

Four sites in Stevens Point, Wisconsin, were examined to determine the impact of subsurface disposal of stormwater on groundwater quality in a shallow sand aquifer. Other research has shown that urban runoff can negatively impact surface waters by contaminating them with heavy metals, hydrocarbons, and high levels of inorganic contaminants. On the four study sites, runoff samples were collected and monitoring wells were installed and sampled to evaluate the impact of the stormwater on the groundwater quality. Disposal systems studied included dry wells and perforated tile lines connecting dry or wet wells. Study areas included commercial, industrial, and residential areas.

Results of chemical analyses of the groundwater and runoff samples showed that the groundwater was being impacted to varying degrees by the subsurface disposal of stormwater. High concentrations of sodium and chloride were found in the runoff and groundwater samples. While seasonal variability was high, concentrations of chloride over 100 mg/l were common, with a high of 4700 mg/l found in groundwater. Sodium concentrations of 25 to 100 mg/l were common, with a high value of 1020 mg/l.

Copper and chromium were generally very low in runoff and groundwater. Cadmium showed maximum runoff values of 0.03 mg/l and maximum groundwater concentration of 0.03 mg/l. Most groundwater samples were less than 0.002 mg/l. Lead and zinc values were more variable in both runoff and groundwater. Zinc concentration in runoff and groundwater commonly were 0.3 to 1.0 mg/l and 0.1 to 0.5 mg/l respectively. Lead concentrations in runoff were all less than 1 mg/l with 0.2 mg/l the maximum found in groundwater. Most groundwater samples had less than 0.02 mg/l lead.

Organic contamination of groundwater was apparent at most sites. Chemical oxygen demand values of 20 to 100 were common in downgradient groundwater. The occurrence of VOCs was generally low, but in several samples exceeded Wisconsin groundwater standards. Benzene; tolulene; 1,1 dichloroethylene; 1,1,1 trichloroethane; tran 1,3, dichloropropene; diesel fuel; tetrachloroethylene; and C-1,3 dichloropropene were all found in groundwater associated with storm drains. Poly nuclear aromatics were also found downgradient of most storm drains. Concentrations were generally less than 1 ug/l. Their significance is difficult to assess as groundwater standards are not yet developed.

One site where the parking lot was swept regularly showed the lowest concentrations of metals and COD in runoff and groundwater, but did have some occurrence of trace organics.

It can be concluded from this data that stormwater drainage wells do remove many contaminants from stormwater runoff. However, elevated levels of highly soluble inorganic chemicals and occasional occurrence of VOC, PNA, and trace metals indicate that these systems pose a threat to groundwater close to the drainage system. Use of this type of stormwater disposal should not be encouraged in areas where the aquifer is used for drinking water. Tradeoffs between groundwater and surface water contamination need to be considered in deciding on which route of stormwater disposal is most environmentally sound in a given area.

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INTRODUCTION

The question of how to efficiently dispose of urban runoff has been answered in many different ways. One of the most common techniques in use today includes some system of curb and gutter connecting to a closed or open drain system. A closed drain system does not disperse any of the water that enters the system but merely channels it to a disposal area, usually a surface body of water. An open system may be similar to a closed system except that it is designed to disperse, into the soil, some or all of the water that enters the system. An open system may make use of drains with open bottoms called drywells and perforated pipe to connect the drains in series. Drywells are classified by the U.S. Environmental Protection Agency as Class V Injection Wells. A Class V injection well is, roughly, any device deeper than it is wide for the purpose of transmitting surface water to the subsurface that does not fit within Classes I, II, III, and IV. There is currently some concern about how Class V wells affect aquifers when they are used to dispose of urban runoff - this study is designed to examine those effects.

OBJECTIVES

The objectives of this study were as follows:

1. To chemically characterize the runoff at four sites with different land uses.

2. To evaluate the impact of stormwater disposal on groundwater quality at these four sites.

3. To determine the effectiveness of drywells and perforated tile lines as a method of stormwater disposal.

LITERATURE REVIEW

Leopold (1968) said, "Of all land-use changes affecting the hydrology of an area, urbanization is by far the most forceful." It is obvious that by drastically altering the landscape we are going to have some effect on the water that flows over that landscape. Urban runoff is modified by the paved surfaces and the stormdrains (Thomas and Schneider, 1970). In the average city, about one third of the land is covered by impervious surface (Daniel and Forrest, 1979), thus a large portion of the land surface of an urban environment may be adversely impacting runoff quality and quantity.

Stormwater runoff has been recognized as an important source of water pollution (Colyer and Yen, 1986) by many agencies and researchers. Salo (1968) states that "Urban runoff contains significant levels of many contaminants, including most heavy metals and some organic compounds." The chemical oxygen demand of urban runoff can range from a few to 1,000 mg/l (Daniel et.al., 1978). The Federal Water Pollution Control Act, P.L. 92-500, provided examination of two sources of pollution, point and nonpoint (Bauman 1980). Urban runoff falls into the classification of nonpoint pollution. Some studies have determined that groundwater is not being presently threatened By urban runoff but warn of the potential for unlawful disosal of hazardous materials in recharge structures (Heaney, 1986).

While most State Health Departments prohibit disposing of storm water runoff by injecting it into the groundwater (USDOT, 1980), it is a common practice in central Wisconsin. The

components of the runoff disposal system that are susceptible to contamination are the precipitation, runoff, basin soils, soil water, and groundwater or receiving surface water (Salo, 1986). Studies in Wisconsin have shown that the concentration of pollutants in runoff is directly proportional to the volume and intensity of the runoff event and vary in concentration throughout the event(Bauman 1980).

Four groups of contaminants have generated the greatest interest in urban runoff research: nutrients, heavy metals, salts and hydrocarbons. Nutrients, especially phosphorous, are of concern because of the potential for eutrophacation in receiving bodies of water. The average amount of phosphorous in the runoff from an acre of urban land is likely to be twice that in the runoff from an acre of rural land (Bauman 1980). An urban watershed will yield about 0.8 lbs/acre/year of phosphorous while agricultural land may yield 0.2 to 0.5 lbs/acre/year (Daniel et.al., 1978).

The toxics that have received the most attention in recent studies have been the heavy metals, especially lead, mercury, cadmium, chromium, copper, nickel, and zinc (Bauman 1980). In one study, copper, lead, nickel and zinc were present in every component of the runoff system. Arsenic was detected in every component except rainfall (Salo, 1986). Copper, zinc, and lead will commonly make up 85 percent of the toxic metal load in urban runoff (Daniel et.al., 1978). Ionic lead will precipitate in the soil as lead sulfate and will remain immobile because of relatively low solubility (USDOT, 1980). Most metals in runoff seem to adsorb to soil particles (Metzler and Jarvis, 1985) and a

study in Fresno, California has shown that soils with a high cation exchange capacity are more effective at attenuating migrating contaminants than soils with a low cation exchange capacity (Salo, 1986).

"Approximately nine million tons of deicing salts were used in the U.S. in 1970 alone, and one study estimates that the amount used doubles every five years." (McConnel and Lewis, 1972) If this trend has continued, in 1990 we will use 72 million tons of deicing salts. The two salts most commonly used for deicing are calcium chloride and sodium chloride. In addition to the environmental impact of the salts there are several common additives to deicing salts including ferric ferrocyanade, sodium ferrocyanide, sodium hexametaphosphate, and chromate salts (McConnel and Lewis, 1972). The problem develops when these salts and additives reach the groundwater. One study estimates that anywhere from 25 to 50 percent of the salt used on roadways infiltrates to the groundwater (McConnel and Lewis, 1972). The American Heart Association recommends a limit of 22 parts per million (ppm) sodium (59 ppm chloride) in drinking water for patients whose diets are restricted to less than one gram of sodium per day (with the normal adult intake estimated at four grams sodium per day)." (McConnel and Lewis, 1972) "The U.S. Public Health Service recommends the rejection of water supplies for public consumption that have 250 mg/l or more chloride, with 25 ppm the desirable level." (McConnel and Lewis, 1972) Chloride associated with urban runoff has not been demonstrated to be a problem in Wisconsin (Bauman 1980).

Motor oil, diesel fuel, and plant waxes have all been

identified as sources of hydrocarbons in urban runoff (Fam et.al., 1987). A major source of hydrocarbons on comercial parking lots is crank-case oil drippings (Hoffman et.al., 1982). Like heavy metals, hydrocarbons are more closely associated with the small sized particle fraction than the soluble fraction of runoff (Fam et.al., 1987) (Hoffman et.al., 1982). The majority of solids transported by urban runoff are sand sized with only less than ten percent silt and clay sized particles (Daniel et.al., 1978).

Volatile organic compounds have been found in detention basin soils (Salo, 1986). The polynuclear aromatic hydrocarbons (PNAs)found most frequently in one study were anthracene, fluoranthene, indenol pyrene, and benzo-perylene (Fam et.al., 1987). PNAs, unlike volatile organic compounds, can accumulate in the food chain (Fam et.al., 1987). PNAs have been found in greater concentrations in industrial areas than in residential areas but it seems that any amount of urbanization will contribute some PNAs to runoff (Fam et.al., 1987).

SITE DESCRIPTIONS

The four study sites for this project are located in the city of Stevens Point, Wisconsin (see Fig. 1). Stevens Point is located in central Wisconsin 30 miles south of Wausau, Wisconsin and 110 miles north of Madison, Wisconsin. The city of Stevens Point is in an area of glacial outwash, the soils are generally sandy in texture with low relief. Groundwater in this area is commonly within 30 feet of the surface, making this an ideal area to study the impacts of subsurface disposal of runoff on groundwater quality.

SITE 1

Site 1 is a 2.5 acre asphalt parking lot located southwest of the intersection of US Highway 10 and IGA Avenue. This parking lot and associated paved drainage areas serve Eastside IGA grocery store, Schierl Tire Center, and a small carwash. Figure 2 shows the runoff drainage system for this parking area. Since no accurate drawings were made of the drainage system during construction, it was necessary to estimate the location of some sections of perforated pipe. The majority of the runoff from Schierl Tire Center and the carwash drain into a separate drainage system and only a small portion enters the system under study. This parking area is served by six storm drains. Upon inspection, the drains appeared to be in good condition and free of debris.

A total of four monitoring wells have been installed on this site over the course of the study (see Fig. 2). The upgradient well (1A) is a single-depth monitoring well located near the

Location of the Study Sites for the Stormwater/Groundwater Project

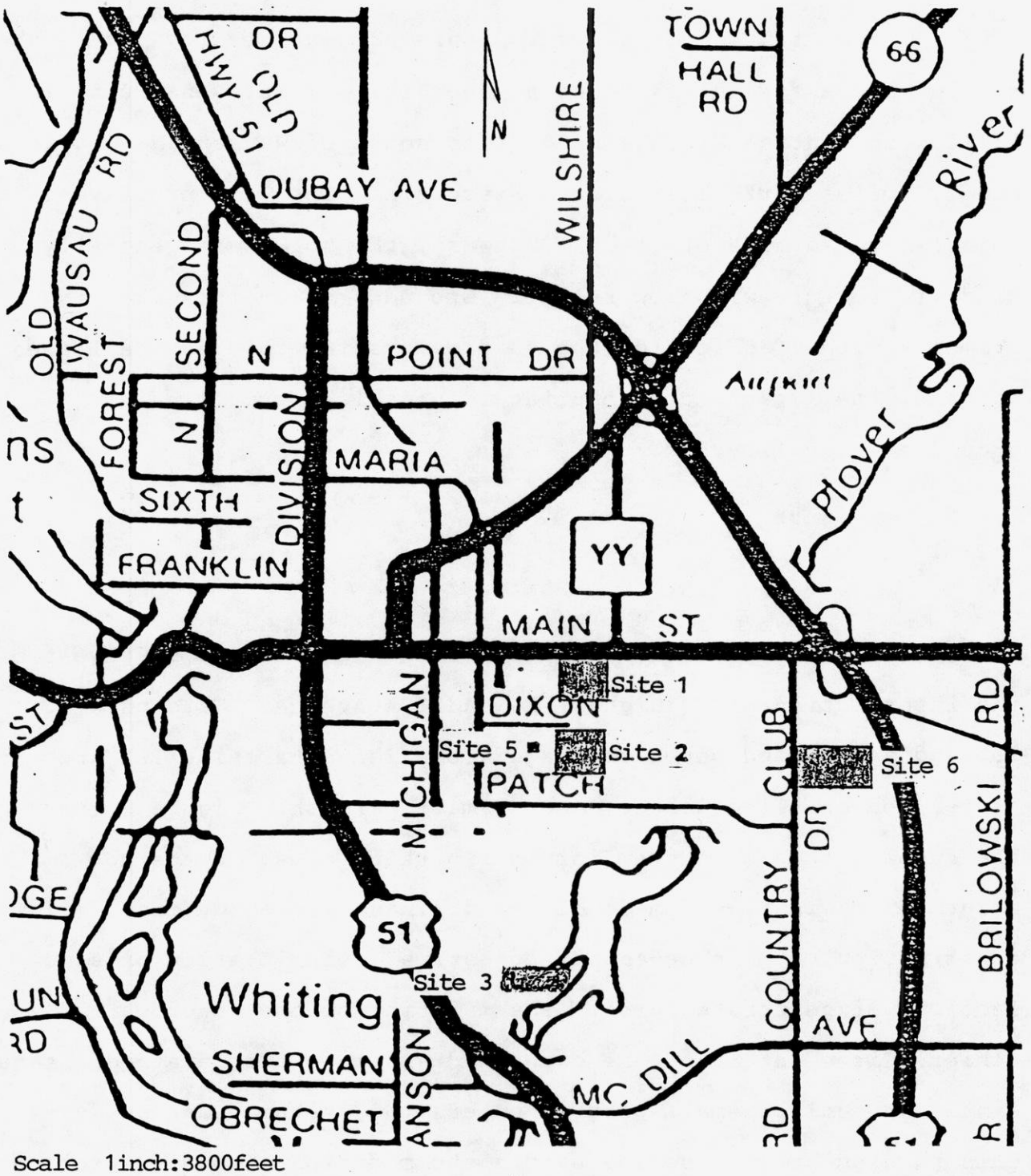

Figure 1. Map of the city of Stevens Point showing the location of sites 1, 2, 3, 5, and 6.

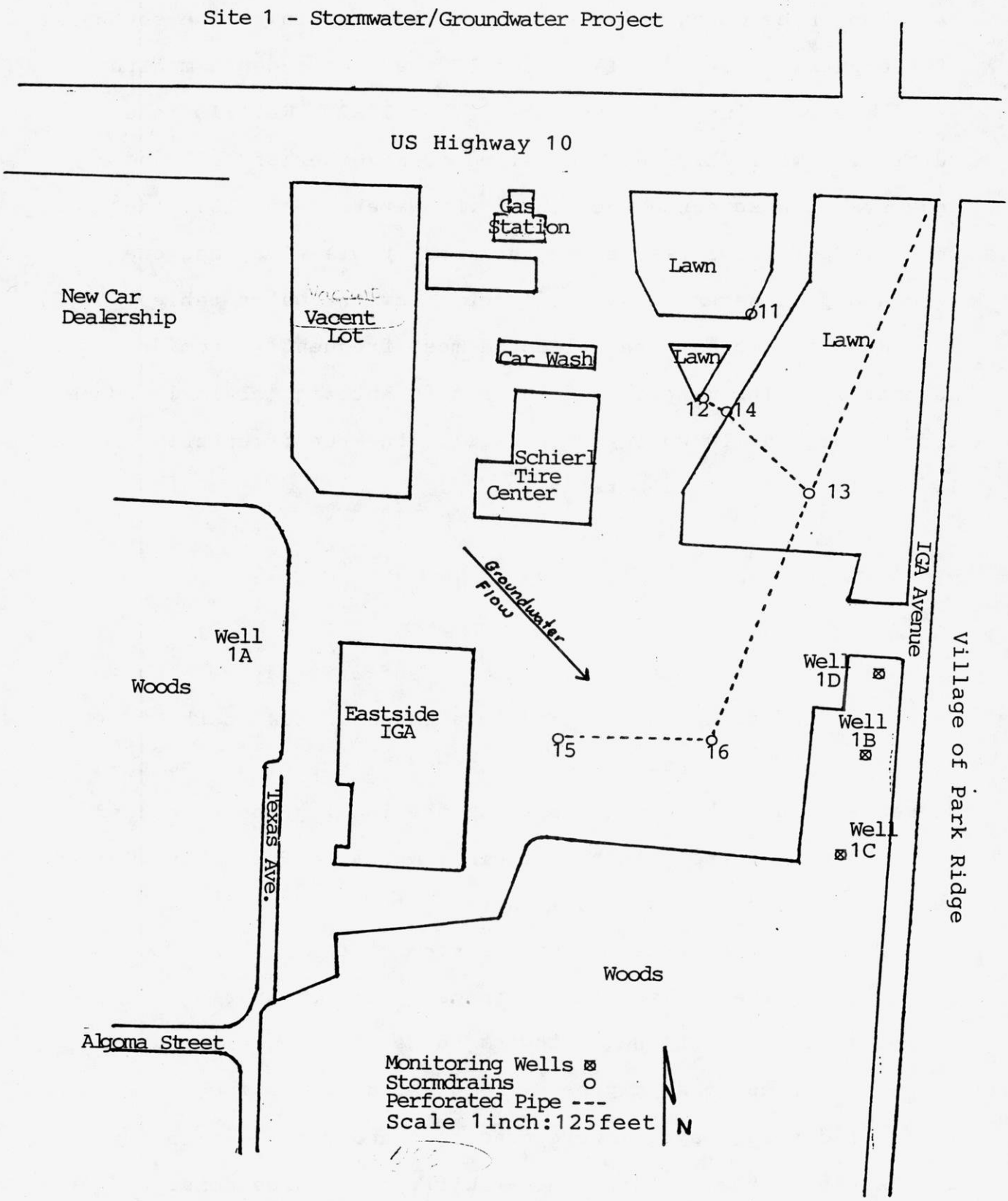

Figure 2. Map of site 1 showing drain system and monitoring well locations.

northwest corner of the parking lot and was installed in the fall of 1987.

The three downgradient wells are located in a line southeast of the parking lot. Wells 1B and 1C are single-depth monitoring wells and were installed in the fall of 1987. Well 1D is a multilevel well which was installed in November of 1988 and consists of a screened section at the water table (1D), one screened port five feet below the water table (1D5) and one screened port seven and a half feet below the water table (1D7.5).

Runoff samples were collected most frequently from drains 11, 15, and 16. The majority of the runoff entering drain 11 comes from US Highway 10 while almost all of the runoff entering drains 15 and 16 is from the parking lot.

SITE 2

Site 2 is a 1.5 acre parking lot and driveway serving the Worzalla Publishing Company and located one block south of site 1 (see fig. 3). The parking area is used by employees and the driveway is used by trucks to reach the loading docks located at the southwest corner of the building. Worzalla Publishing Company is a printing and binding company.

Figure 3 shows the drainage system of the parking lot and driveway. The parking lot drainage system consisted of three drywells, located at the southwest corner of the building, connected by perforated pipe. The parking lot drainage system and the roof drainage system were connected and ran to an infiltration area south of the building. The infiltration area consisted of

Site 2 - Stormwater/groundwater Project

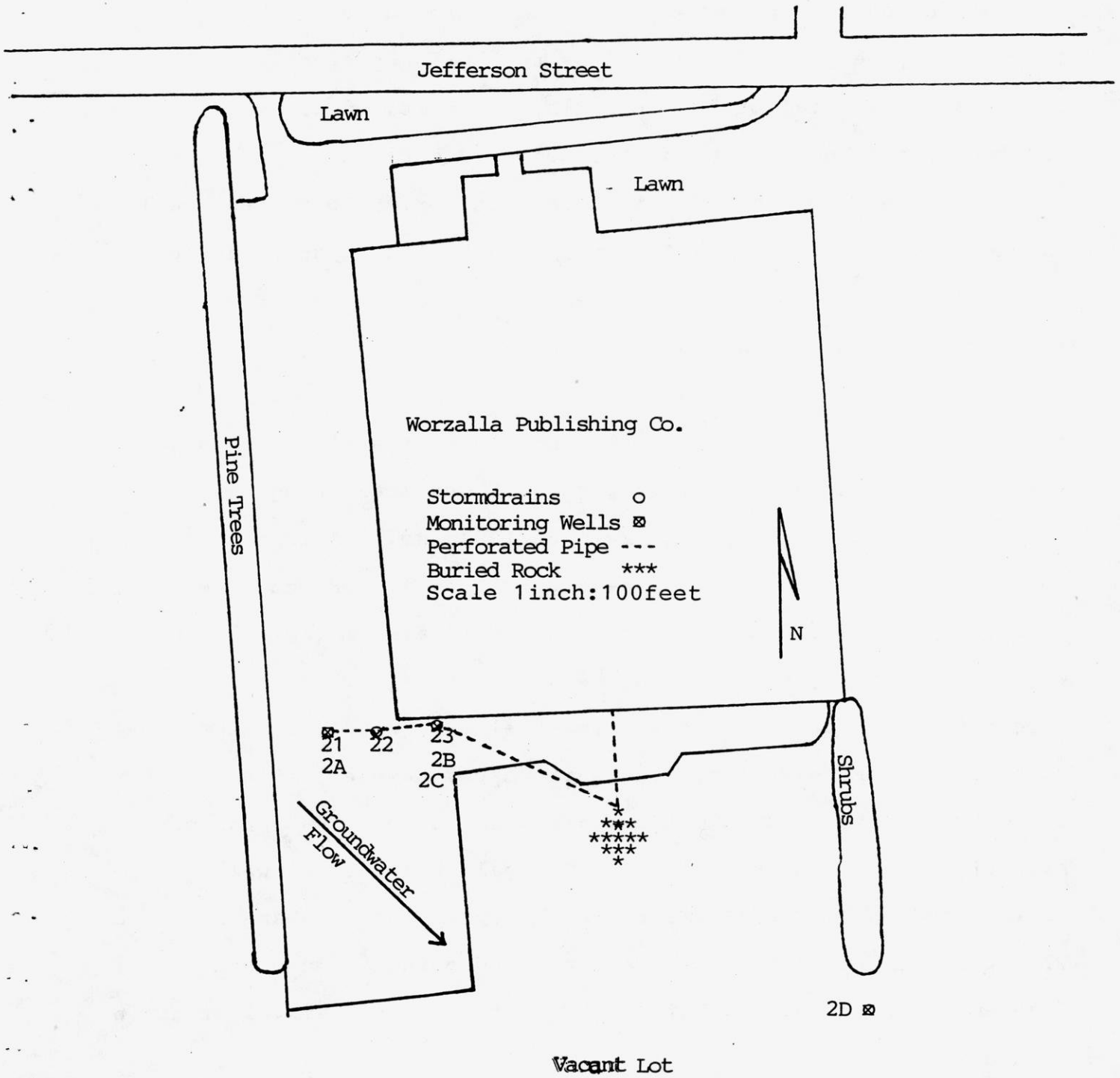

Figure 3. Map showing the drainage system and monitoring well locations at site 2.

buried six inch diameter rock used to disperse the water underground. The southern end of the parking lot was frequently flooded during the spring snowmelt and during heavy rains. This flooding may be partially caused by the build up of silt in the drywells; in several of the drywells, the silt had almost completely blocked off the perforated pipe outlet.

Since there was no suitable location for an upgradient well on the Worzalla Publishing Company property, the upgradient well is located on a residential lot designated site 5 (see Fig. 4). The upgradient well (5A) is a single-depth monitoring well and was installed in the Fall of 1987.

A total of four downgradient wells have been installed on the Worzalla Publishing Company property. Three monitoring wells were installed in drywells in the Fall of 1987, well 2A in drain 21, wells 2B and 2C in drain 23 (see Fig. 3). Wells 2B and 2C were placed in the same drain because well 2C is a skimming well and well 2B is set eight feet into the water table. These three wells were originally driven, galvanized steel pipe with stainless steel screens. After several samples were taken, however, it was determined that the zinc oxide coating on the pipe was producing high zinc levels in the samples. The galvanized steel well casings and points were removed in the spring of 1988 and replaced with polyvinal chloride (PVC) casings and points. In March of 1989 an expansion of the building resulted in the removal of drain 23 and wells 2B and 2C.

Multilevel well 2D was installed about 200 feet south of the building in December of 1988. This well consists of a screened section at the water table (2D) and a screened port five feet

Sites 1, 2, and 5 - Stormwater/Groundwater Project

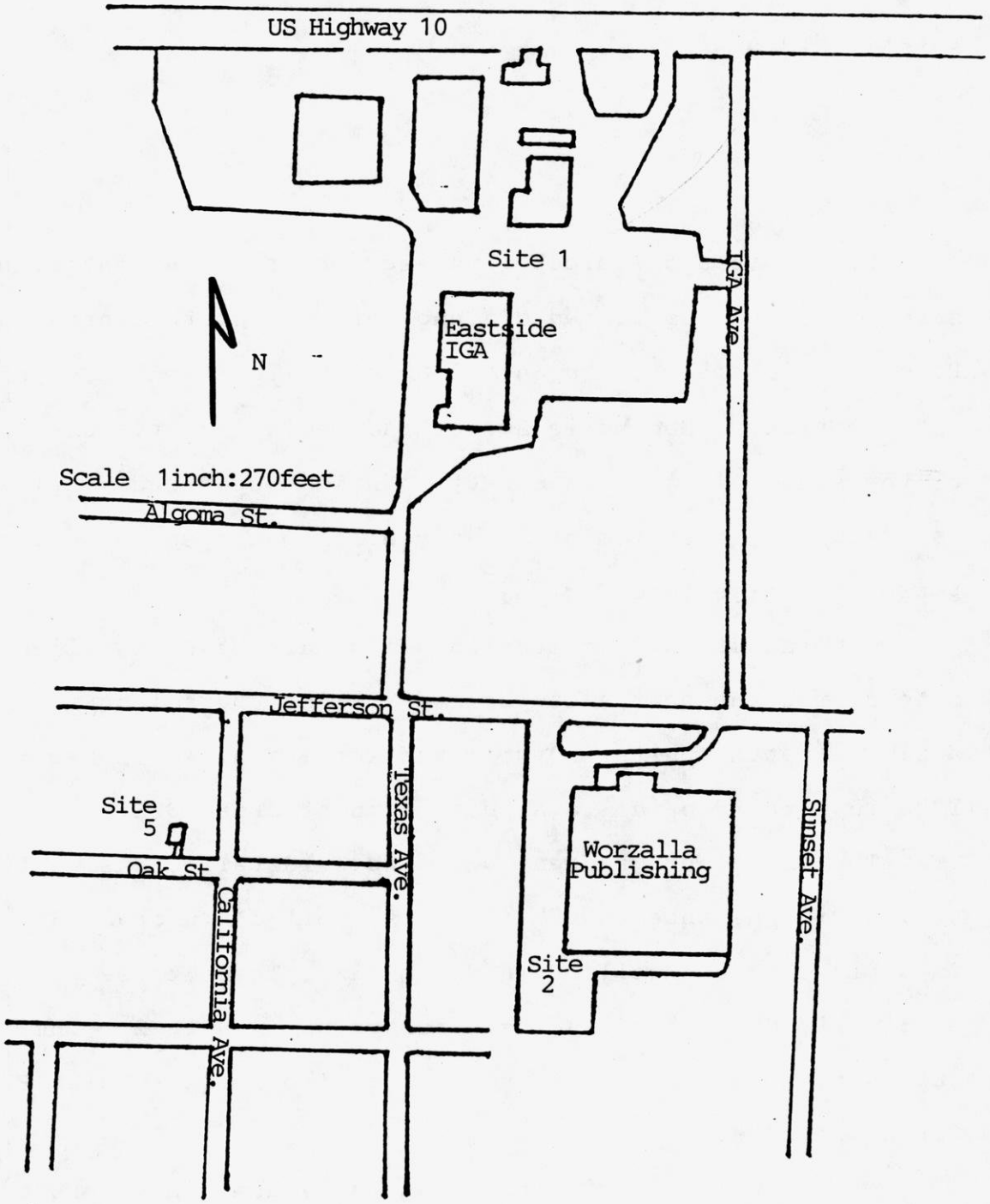

Figure 4. Map showing the location of site 5 in relation to sites 1 and 2.

below the water table (2D5).

Runoff samples were collected most frequently at drains 21 and 23. Because of the crown on the driveway, very little water entered drain 22.

SITE 3

Site 3 is a one block long section of a residential city street and its associated drainage area in south central Stevens Point. This site is the one block of Della Street east of the intersection of Soo Marie Avenue and Della Street. One block east of the study site, Della Street ends in a dead end. Della Street is drained by a system of six drywells connected in series with perforated pipe (see Fig. 5).

A total of four monitoring wells have been installed on this site during the course of the study. The upgradient well (3D) is a single-depth monitoring well and was installed in December of 1988 in a residential lawn just south of drain 32S.

The three downgradient wells were installed during the Fall of 1987 in the three north drywells; well 3A in drain 31N, well 3B in drain 32N, and well 3C in drain 33N. These three wells were originally driven, galvanized casings as in site 2. The galvanized casings at this site were also replaced with PVC in the Spring of 1988.

The drywells at site three actually drain a watershed that is larger than the study area (see Fig. 5). The watershed is 2.7 acres in size and extends outside the study area approximately one half block west on Della Street and one block north on Soo Marie

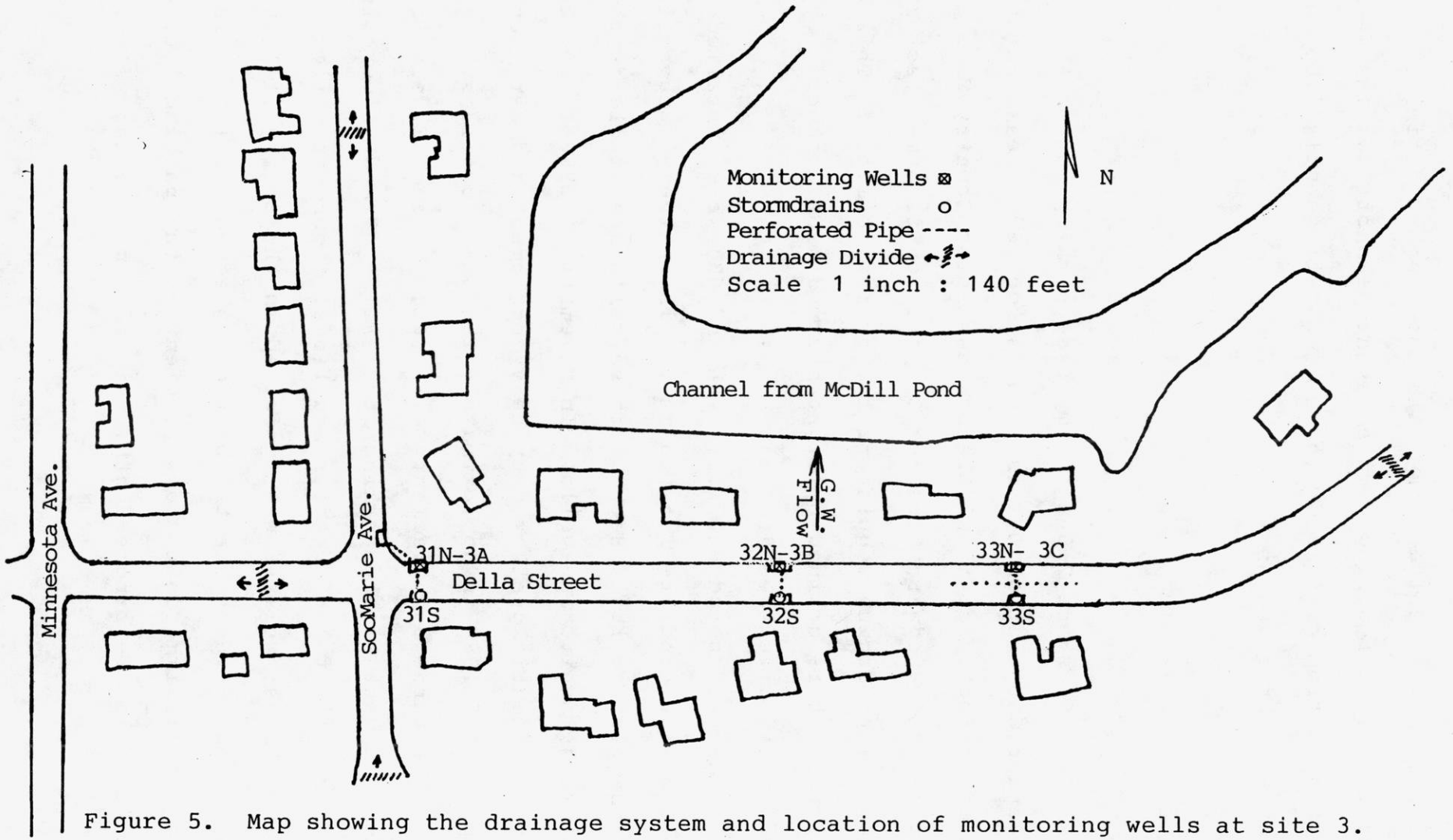

Figure 5. Map showing the drainage system and location of monitoring wells at site 3.

Avenue. As a result of the site topography, drain 32N receives the most runoff during a given event. Runoff samples were collected from all six drains but most frequently from the northern three drains.

SITE 6

Site 6 is the 2.3 acre employee parking lot of the Woodward Governor Corporation. This site is located in eastern Stevens Point, directly south of the Stevens Point Country Club golf course. The Woodward Governor Corporation is a manufacturing facility producing regulators for primary drivers. This concrete parking lot is drained by eight storm drains connected by perforated pipe (see Fig. 6).

The two upgradient wells (6A and 6B) were installed in the fall of 1987 and are located in the intensively managed lawn east of the parking lot. Both of these wells are single-depth, skimming, monitoring wells. In November of 1988 these two wells were accidently destroyed by heavy equipment and were replaced in December of 1988 in approximately the same locations.

The three downgradient wells (6C, 6D, and 6E) are located in the lawn west of the parking lot. Wells 6C and 6D were installed in the Fall of 1987. After additional groundwater flow direction calculations, well 6E was installed in the Spring of 1988. Well 6E is considered to be the best downgradient well at this site since it is immediately downgradient of the parking lot. All three wells are single-depth, skimming, monitoring wells.

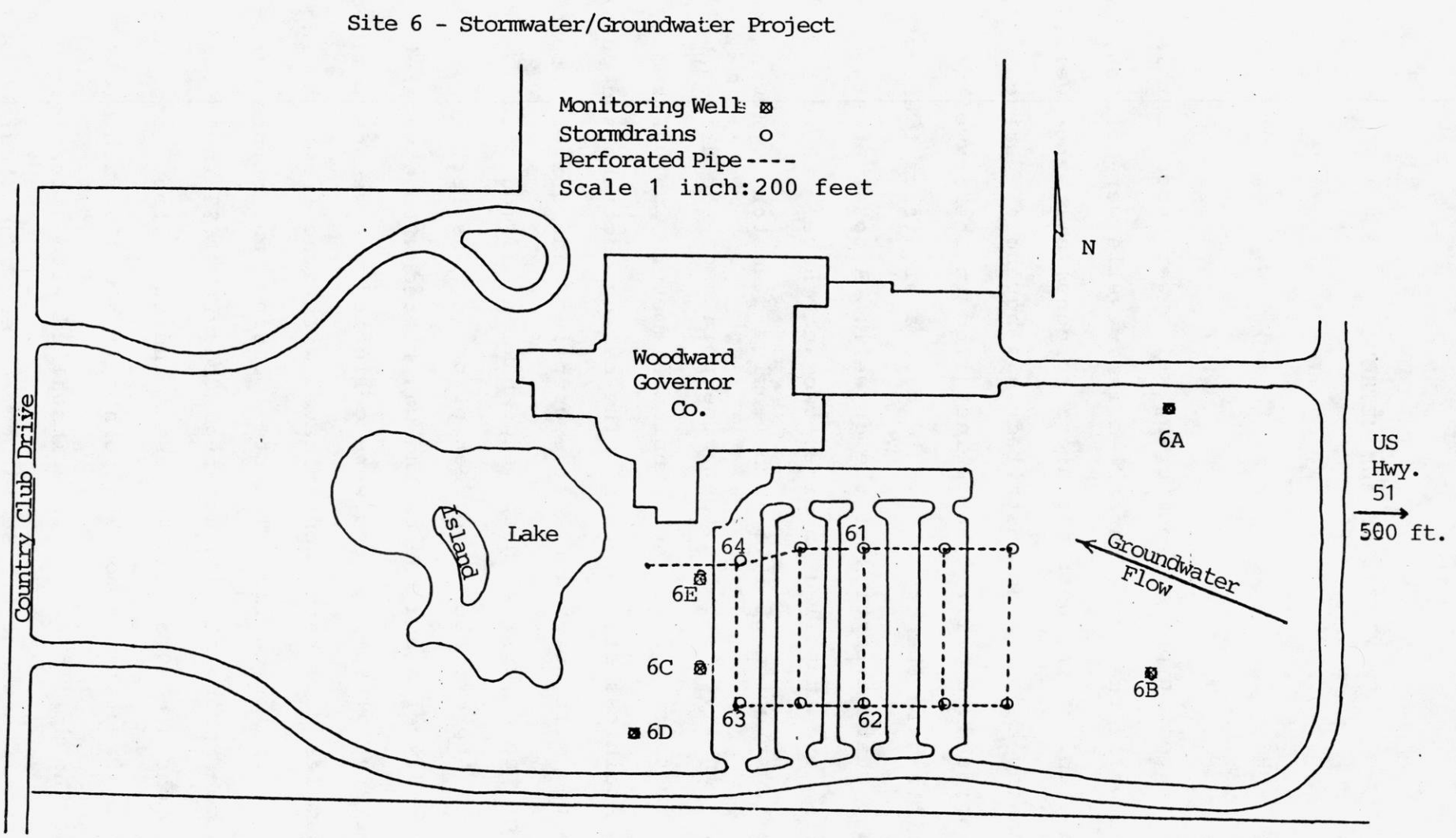

Figure 6. Map showing the drainage system and location of monitoring wells at site 6.

MATERIALS AND METHODS

MONITORING WELLS

Two different types of monitoring wells were used in this study. The wells that were installed in drywells were driven, galvanized steel casing with stainless screens; all other wells were PVC casing and screens installed in a borehole. Driven wells, as opposed to drilled, were installed in the drywells because drilling in the drywell would have a significant effect on the drainage characteristics of the drywell. A total of six driven wells were installed on sites two and three. The driven wells were constructed of 1.25 inch (inside diameter), galvanized steel casing in five foot lengths. The points of the driven wells were three foot long, 1.25 inch (inside diameter), galvanized steel with stainless steel screen. The casing sections and point were connected with heavy duty drive couplings and driven through the floor of the drywell with a sledge hammer and modified post-driver. Approximately two feet of casing was left above the floor of the drywells and the casing was fitted with a water-tight cap. After several sample sets were collected, it was determined that the samples were being contaminated with zinc from the zinc oxide coating on the casing. The steel casings and points were removed in the Spring of 1988 and replaced with 1.25 inch (inside diameter), Schedule 40 or 80 PVC casing and three foot long 1.25 inch (inside diameter), Timco PVC points with 0.010 inch slots.

All of the drilled wells were installed with a trailer-mounted, four inch diameter, solid-stem auger. The single-depth

wells were constructed of 1.25 inch (inside diameter), Schedule 40 or 80 PVC casing. All points were Timco three foot long 1.25 inch (inside diameter), PVC with 0.010 inch slots. Points and casing were either male/female flush-threaded or male/male National Pipe Threaded (NPT). The NPT casing and points were connected with Schedule 40 or 80 female/female couplings.

The multiport wells were constructed of a PVC spine with polypropelene tubing attached to the outside (see Fig. 7). The spine of these wells was 1.25 inch (inside diameter), Schedule 80 flush-threaded PVC casing with a six foot, 0.010 inch wide slot, screen. The screen was placed in the middle of the casing to skim the water table and the blind section of the casing below the screen was used only to support the additional ports. The ports were constructed of polypropelene tubing screened at one end with a tight-woven nylon fabric. The screened end of the tubing was attached with strapping tape to the blind section of casing at the desired distance below the middle of the screen. Once the screened end was attached, the length of tubing was secured to the spine at one foot intervals with strapping tape.

Once the casing and point was installed in a bore-hole, the hole was back-filled with cuttings to within two feet of the surface and firmly tamped. The bore-hole was then sealed with a six inch layer of powdered Bentonite. A six inch diameter galvanized steel culvert was then installed over the well and the casing cut to fit the culvert. The wells were capped with a PVC slip-joint cap and the culvert capped with a fitted galvanized steel cap. In areas where vandalism was anticipated to be a problem, a hasp and padlock were installed on the culvert. When

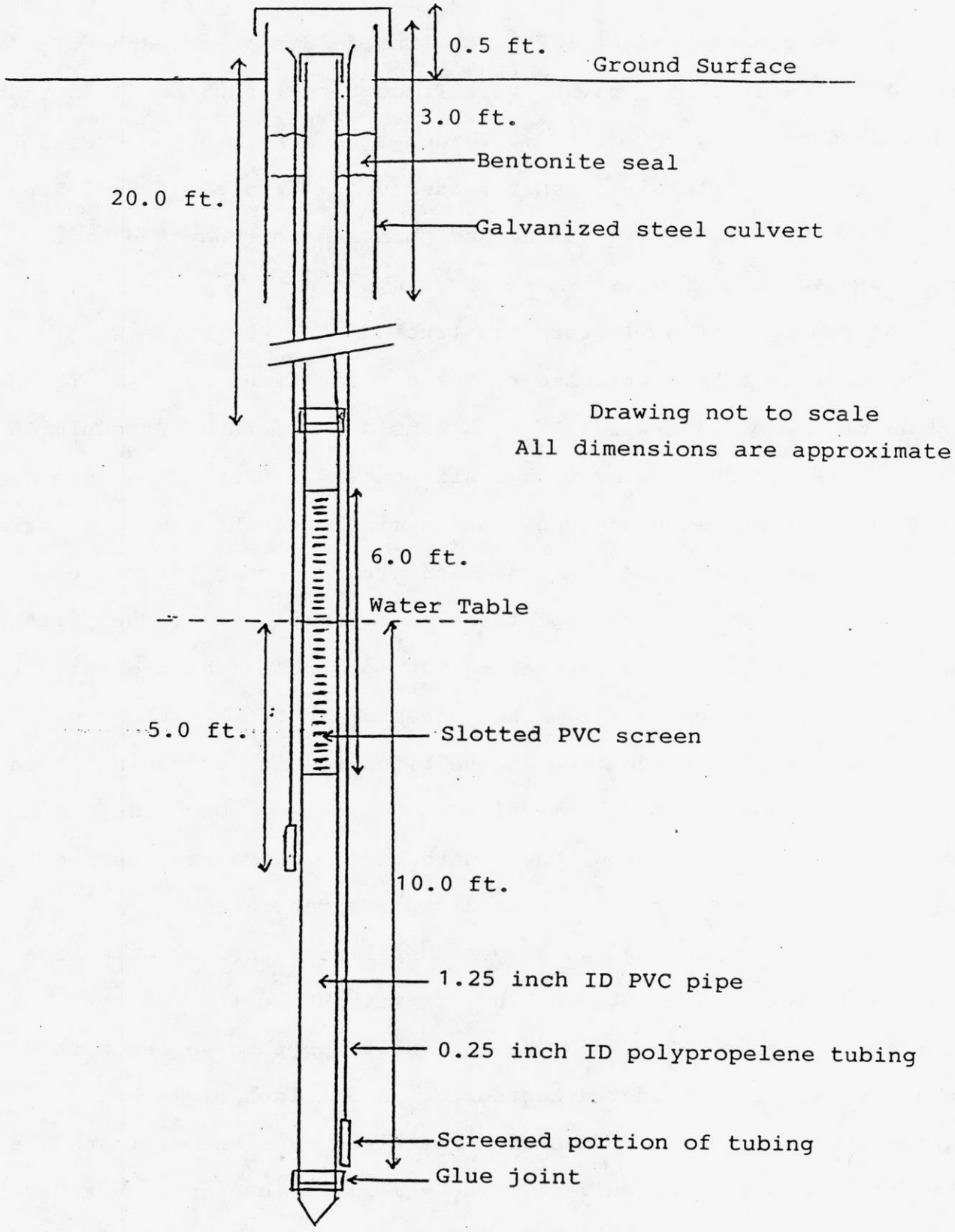

Figure 7. Diagram of a multilevel well.

wells were installed in a maintained lawn, the culvert was set low enough to mow over. The wells at site six have plastic culverts protecting them, provided by Woodward Governor Company, instead of galvanized steel.

Once the well and culvert were installed, the well was developed with a gasoline powered centripetal pump when possible. The well was pumped until the water ran clear. If the well was too deep to use the centripetal pump, a bailer and rope were used and the well was bailed until the water was clear.

When a well was to be abandoned, the casing and point were pulled with a winch or set of hydraulic jacks. Once the casing and point were removed, the hole was filled with clean sand to within three feet of the surface and a two foot thick seal of powdered Bentonite was added. The culvert was then removed and topsoil added to fill the last foot of the hole.

RUNOFF COLLECTION

Runoff samples were collected in plastic five gallon pails suspended from the storm drain grates. The buckets were sampled and then emptied. In the Spring of 1988 all buckets were removed, washed and replaced.

SAMPLING

Monitoring well samples were collected quarterly beginning with the last quarter of 1987 and concluding with the second quarter of 1989. Additional sample sets were collected as time allowed to help better define the chemical characteristics of the

sites. Runoff samples were collected during selected major runoff events, beginning in October of 1987 until August of 1988. After August of 1988, samples were collected less frequently and from only two sites.

Before a sample was taken from a well the water level was recorded and the well was purged. Water levels were taken with fiberglass tape and brass popper. Wells were purged by removing approximately three times the volume of standing water in the well from the well. When it was less than 26 feet to water, a peristaltic pump and Tygon tubing were used to collect inorganic and metals samples. If it was greater than 26 feet to water, a PVC bailer was used to collect inorganic and metals samples. A Teflon bailer was used to collect all samples to be analyzed for organic contaminants. Samples to be analyzed for metals were filtered (0.45 micron filter) in the field and preserved with nitric acid (5 ml acid/liter of sample). Inorganic and metal samples were placed in 250 ml Nalgene bottles, samples for organic analysis were placed in appropriate amber glass bottles with Teflon seals. Once samples were sealed in bottles, they were transported to the laboratory, in a cooler, on ice.

All analyses were performed by the Environmental Task Force laboratory of the University of Wisconsin-Stevens Point (Lab State ID No. 750040280). Analysis performed according to the methods listed in Table 1. Quality control data was collected for each test method used and was generated for ten percent of the samples analyzed. The methods of quality control include duplicate analysis for measuring precision, and check standards and spikes for measuring accuracy.

Table 1. Analytical methods and method detection limits for alalysis.

Test	Method	Method Detection Limit (Conc. in mg/l unless noted)
Alkalinity	SM Sec. 304	2
Conductivity	SM Sec. 205	0.1 umho/cm
Cadmium	SM Sec. 303A	0.005
Chloride	SM Sec. 407D	0.34
Chromium	SM Sec. 303A	0.02
Copper	SM Sec. 303A	0.01
Lead-Low Range	SM Sec. 304	0.002
Zinc	SM Sec. 303A	0.01
Sodium	SM Sec. 325B	0.1
Hardness-Total	SM Sec. 314B	0.89
Ammonia Nitrogen	TIM - B	0.01
Nitrate/Nitrite Nitrogen	TIM - A	0.07
Kjeldahl Nitrogen	TIM - B	0.17
Chemical Oxygen Demand	HH - 8000	2
pH	SM Sec. 423	+/- 0.1 Std. Units
Reactive Phosphate	SM Sec. 424G	0.0011
Total Phosphate	SM Sec. 424G	0.0042
VOC	EP Meth. 601, 602	Appendix A
PNAs	EP Meth. 610	Appendix B

SM "Standard Methods For The Examination of Water and Wastewater", 15th Ed.

TIM "Technicon Industrial Methods"
- A Method No. 158-71W/A Nitrate and Nitrite in Water and Seawater
- B Method No. 329-74W/B Determination of Nitrogen (ammonia) in water and acid digest

HH "Hach Handbook of Water Analysis", 1979

EP "Code of Federal Regulations, Title 40", Pt.136, App.A, Rev. July 1, 1986.

Table is adapted from "Environmental Task Force Laboratory Manual", R. Stephens et.al., 1989.

RESULTS AND DISCUSSION

Tables listing the results of all samples are located in Appendix C. Table 2 lists the Wisconsin Unique Well number for each monitoring well. On almost every site, the most outstanding chemical characteristic of the runoff and the groundwater was the chloride and sodium concentration. The most obvious source of the sodium and chloride is road salt and deicing compounds.

SITE 1

The stormdrain-perforated pipe system at site one seems to be very effective at dispersing the runoff from the parking lot. The impact of stormwater on groundwater at this site and site two is especially significant because the residential neighborhood located immediately downgradient from both sites is on private water supply. Most of these private wells are shallow, driven sandpoints and are especially vulnerable to contamination from the parking lots.

The levels of chloride and sodium in the runoff at this site were the second highest found during the study with the spring runoff showing the highest concentrations (see Fig. 8). Road salt used on US Highway 10 and on the parking lot is probably the primary source of the sodium and chloride since the highest concentrations correspond to the spring snowmelt. Conductivity of runoff samples were high and corresponded to high levels of sodium and chloride. Several exceptionally high levels of chemical oxygen demand were found in the fall of 1987 and 1988 (see Fig. 9). With the exception of one sample, the concentrations of

Table 2. Wisconsin Unique Well Identification Numbers assigned to monitoring wells.

Monitoring Well	Wisconsin Unique Well Identification Number
1A	AN001
1B	AN002
1C	AN003
1D	AN004
1D5	AN005
1D7.5	AN006
2A	AN007
2B	AN008
2C	AN009
2D	AN010
2D5	AN011
3A	AN012
3B	AN013
3C	AN014
3D	AN015
5A	AN016
6A	AN017
6B	AN018
6C	AN019
6D	AN020
6E	AN021
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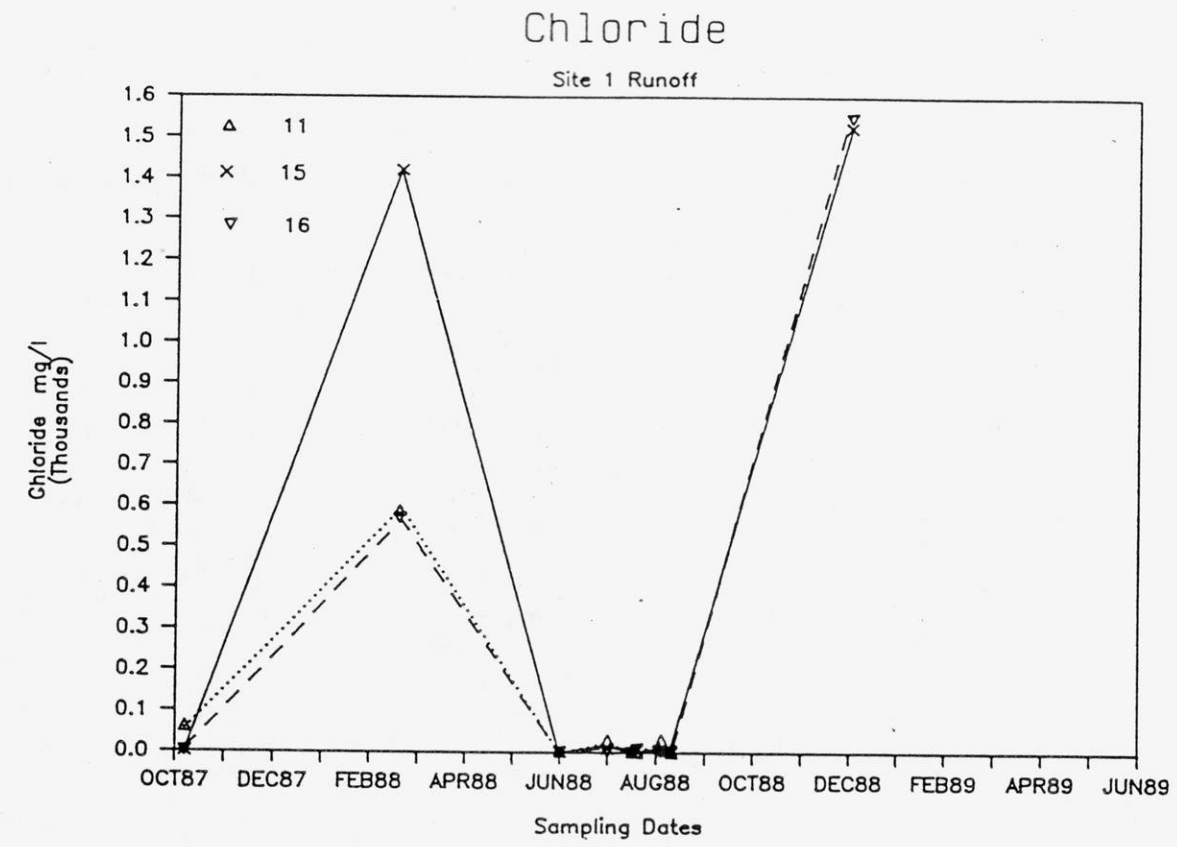
7A1	AN023
7B	AN024
7C0	AN025
7C1.5	AN026
7C3	AN027
7D	AN028



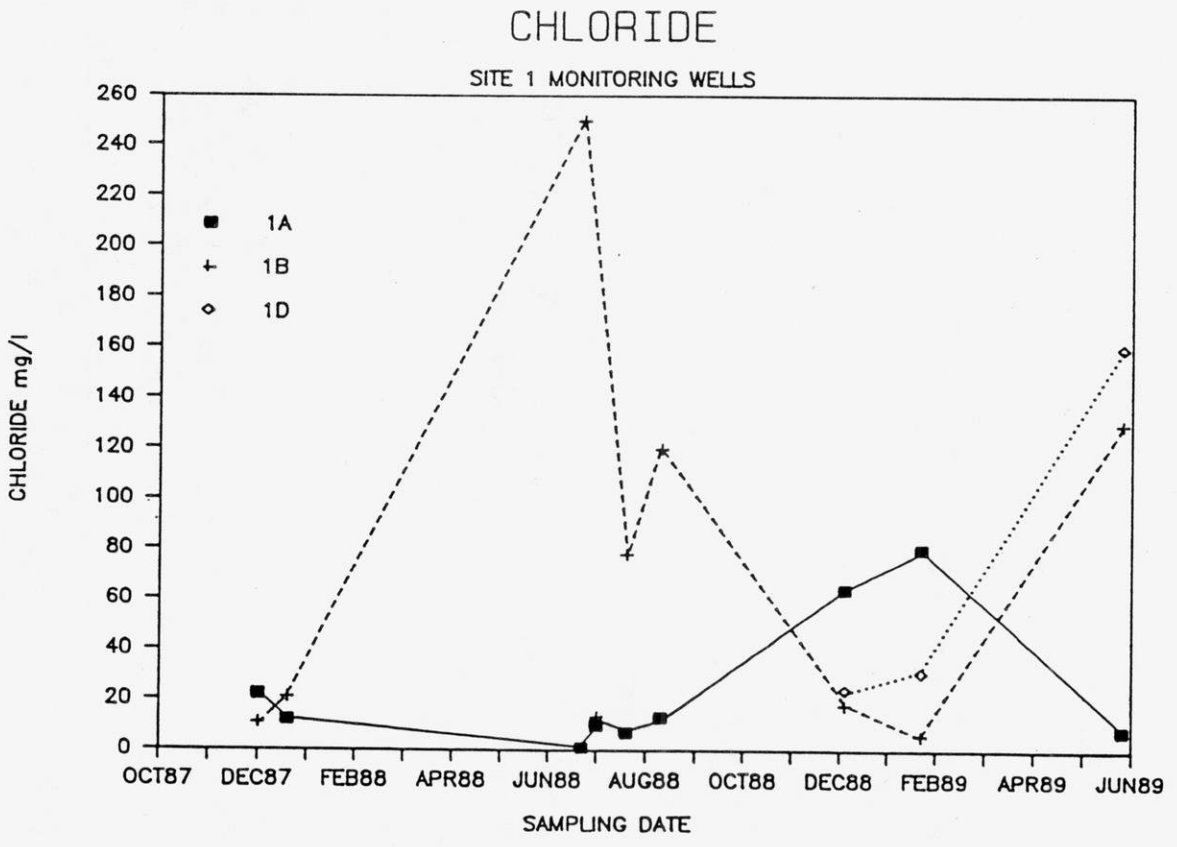
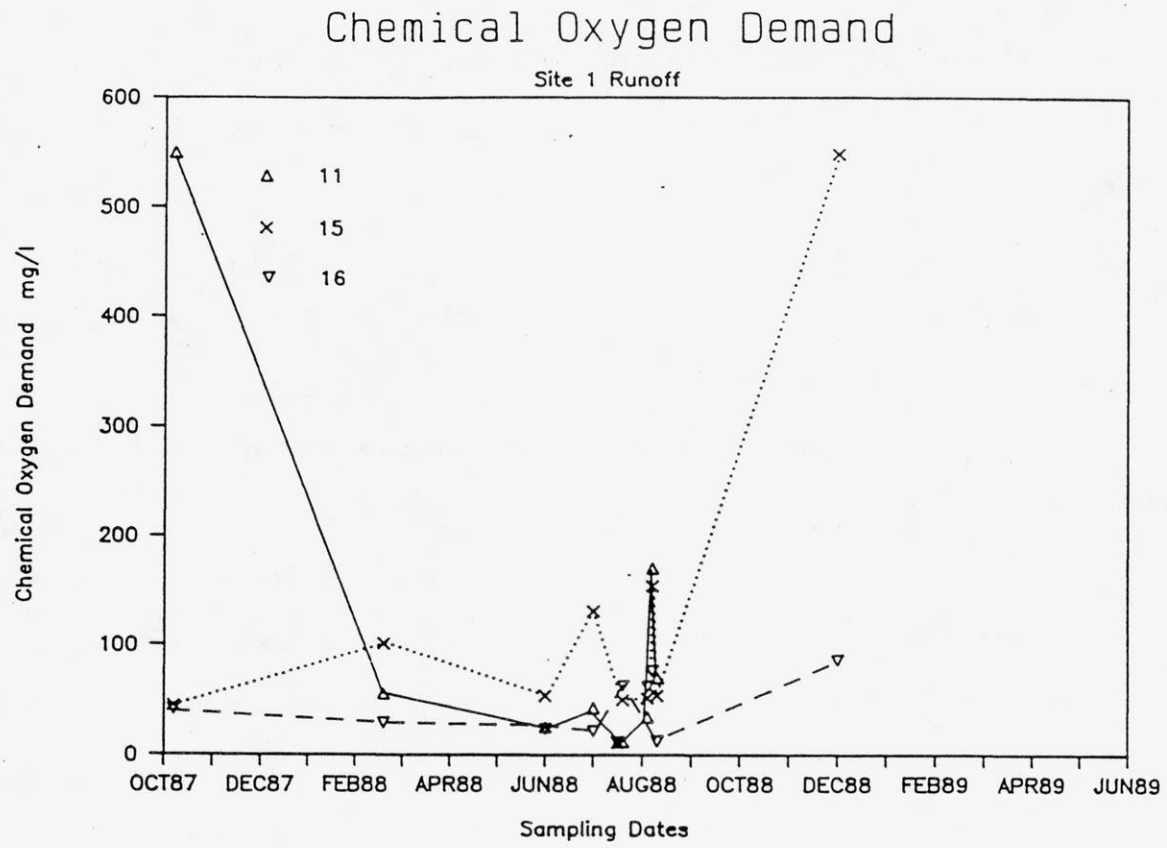


Figure 8. Chloride concentration site 1 runoff and monitoring well samples.

ammonium and nitrate nitrogen were very low in the runoff samples at this site. Cadmium, copper, and zinc were found occasionally in runoff samples in low concentrations. Significant amounts of lead were found in the runoff samples taken in August and December of 1988. Six of these samples exceeded the State drinking water standard of 0.050 mg/l.

The chloride and sodium levels in the downgradient monitoring wells were high. The highest levels of chloride in the monitoring well samples occurred in the early summer, several months after the highest concentrations appeared in the runoff (see Fig. 8). The chemical oxygen demand of the downgradient groundwater ranged from very 2.3mg/l to 25.19mg/l. The highest downgradient chemical oxygen demand values were found in the late spring and early summer, several months after the highest values were found in the runoff samples (see Fig. 9). Levels of ammonium and nitrate nitrogen were low in groundwater samples. The values for nitrate nitrogen increased slightly in June of 1988, probably from lawn fertilizer being used in the area. Small amounts of zinc and copper were found in the groundwater samples. Very little lead was detected in the groundwater despite the relatively high concentrations in the runoff. It is possible that the lead is tied up in the subsoil in an insoluble form and unable to migrate.

VOCs were found in relativly high concentrations in several runoff samples (see Table 3.) but monitoring well samples showed only occasional low concentrations (see Table 4.). PNAs were detected in every sample collected for PNA analysis (see Table 5.). The concentration of PNAs in the monitoring well samples was relativly low, below 0.5 ppb in all but one case.



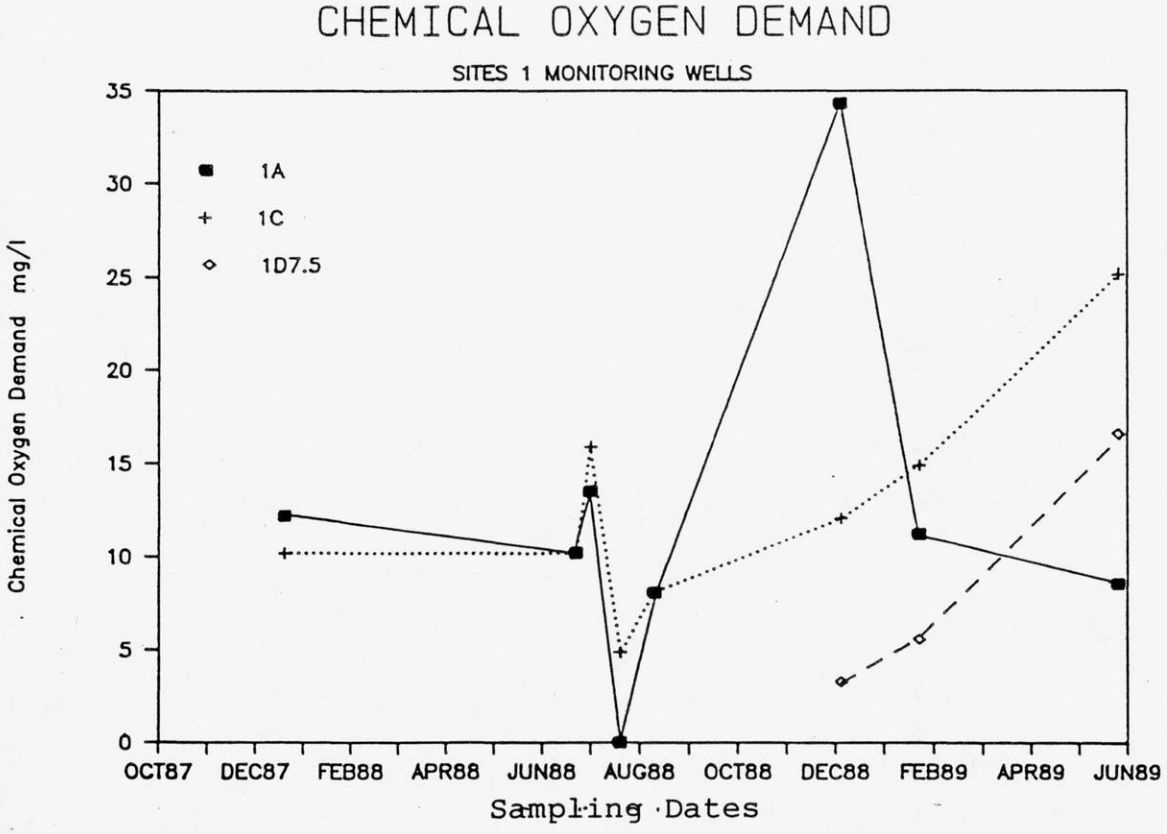


Figure 9. Chemical oxygen demand of site 1 runoff and monitoring well samples.

Table 3. Volatile organic compound concentration of runoff samples collected at site 1.

SAMPLE LOCATION/DATE	COMPOUND NAME	CONCENTRATION ppb
IGA DRAIN 11 880219	t-1,2-Dichloroethylene	8.2
11 880602	--------	ND
11 880719	--------	ND
IGA DRAIN 12 880219	t-1,2-Dichloroethylene	16.4
IGA DRAIN 15 880602	Benzene	0.4
	Tetrachlotoethylene	0.6
IGA DRAIN 16 880602	Tetrachlotoethylene	0.8
16 880719	trans-1,3-Dichloralpropene	<0.4

Table 4. Volatile organic compound concentration of monitoring well samples taken from site 1.

SAMPLE LOCATION/DATE	COMPOUND NAME	CONCENTRATION ppb
IGA UPGRADIENT		
1A 880317	--------	ND
1A 880622	--------	ND
1A 880719	--------	ND
1A 890524	--------	ND
IGA DOWNGRADIENT		
1B 880317	--------	ND
1B 880622	Tetrachloroethylene	1.5
1B 880719	trans-1,3-Dichloralpropene	0.8
	Toluene	<0.3
	Trichloralethene	1.0
1B 890524	--------	ND
IGA DOWNGRADIENT		
1C 880317	--------	ND
1C 880622	c-1,3-Dichloropropene	1.7
1C 890524	--------	ND
IGA DOWNGRADIENT		
1D 890524	--------	ND

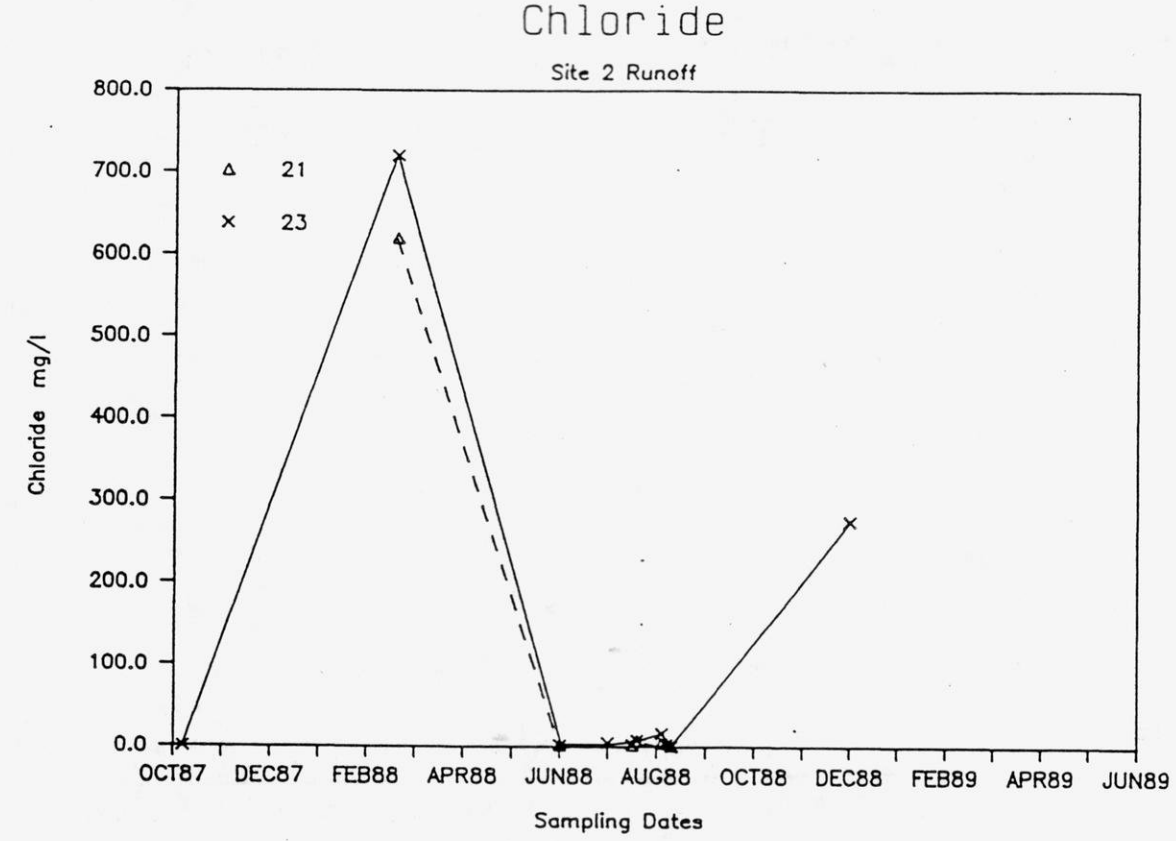
Table 5. Polynuclear aromatic hydrocarbon concentration of samples taken at site 1.

SAMPLE LOCATION/DATE	COMPOUND NAME	CONCENTRATION ppb
IGA DRAIN		
11 890123	Acenapthalene	1.16
	Fluorene	0.18
	Phenanthrene	0.25
	Anthracene	<0.01
	Fluoranthrene	1.06
	Pyrene	0.19
	Benzo(a)anthracene	0.05
	Benzo(k)fluoranthene	0.02
	Benzo(ghi)perylene	0.11
IGA DOWNGRADIENT		
1D 890612	Fluorene	0.02
	Fluoranthrene	<0.01
1D5 890123	Acenapthalene	0.48
	Fluorene	0.28
	Phenanthrene	0.31
	Fluoranthrene	0.21
	Chrysene	0.02
	Benzo(b)fluoranthene	0.04
	Benzo(a)pyrene	0.15
1D7.5 890123	Acenapthalene	<0.10
	Fluorene	0.10
	Phenanthrene	0.06
	Fluoranthrene	<0.01
	Pyrene	0.04
	Chrysene	0.02
	Benzo(b)fluoranthene	0.29
	Benzo(a)pyrene	0.04

SITE 2

As with site one, the highest chloride and sodium concentrations in the runoff were seen in the early winter and late spring (see Fig. 10). Chloride levels were lower at this site than at site one; this may be due to less street runoff entering the system or the fact that this is an employee parking lot and does not have as many cars entering and leaving to bring in more salt. The highest chemical oxygen demand values for the runoff were found in the fall of 1987 and 1988 (see Fig. 11). The high chemical oxygen demand of the fall runoff samples indicates that there is some large input of organic material into the runoff water. Volatile organic compounds were not detected in the runoff so the organic material may be a natural source. Ammonia and nitrate nitrogen levels were very low at this site. Small amounts of copper, zinc and lead were found in the runoff. Lead concentration in some of the fall and winter, 1988 samples approached the State drinking water standard but did not exceed it.

Since well 2C is was installed directly in the floor of the drywell, we would except to see a very short lag-time between a peak in runoff and a peak in the ground water. This is the case for the early winter of 1988 chloride concentration (see Fig. 10). Unfortunately, well 2C was not sampled in February of 1988 because the entire drain was filled with water but we would expect that the spring runoff peak in chloride concentration would match the groundwater concentration. The chemical oxygen demand of the groundwater samples from well 2C does not follow the same pattern



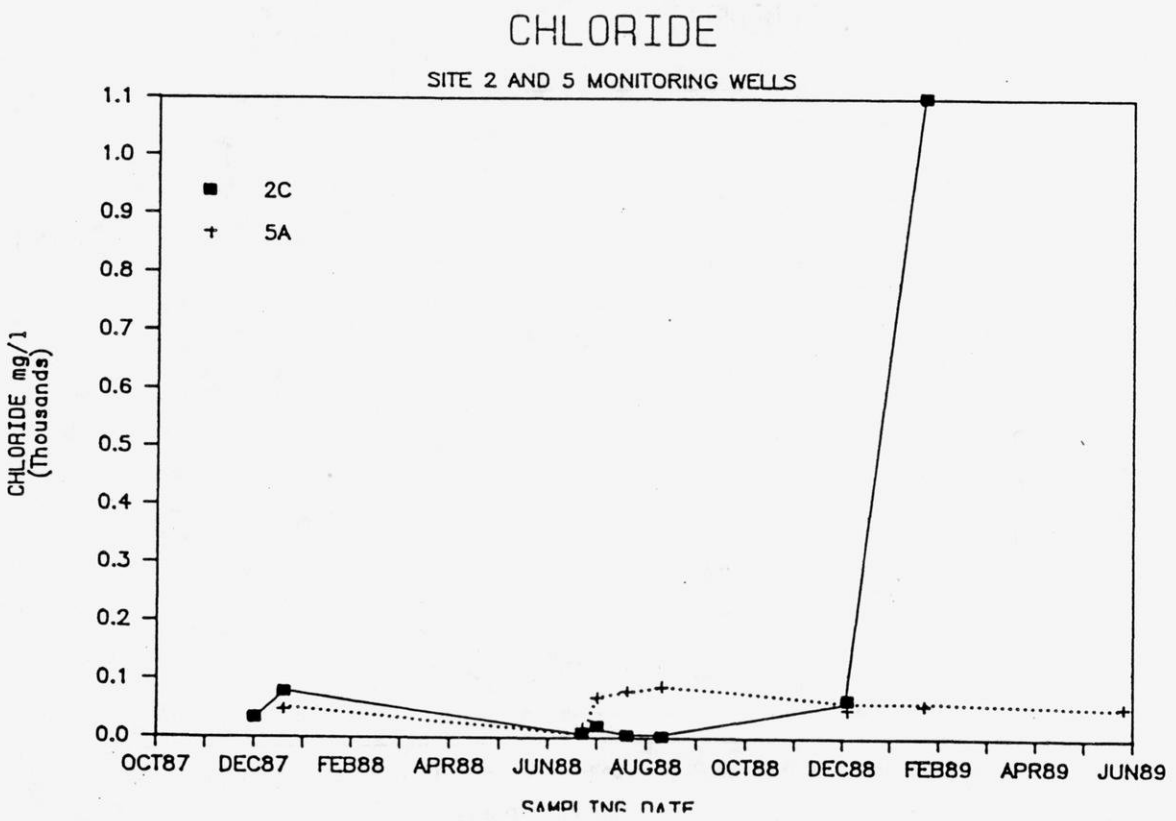
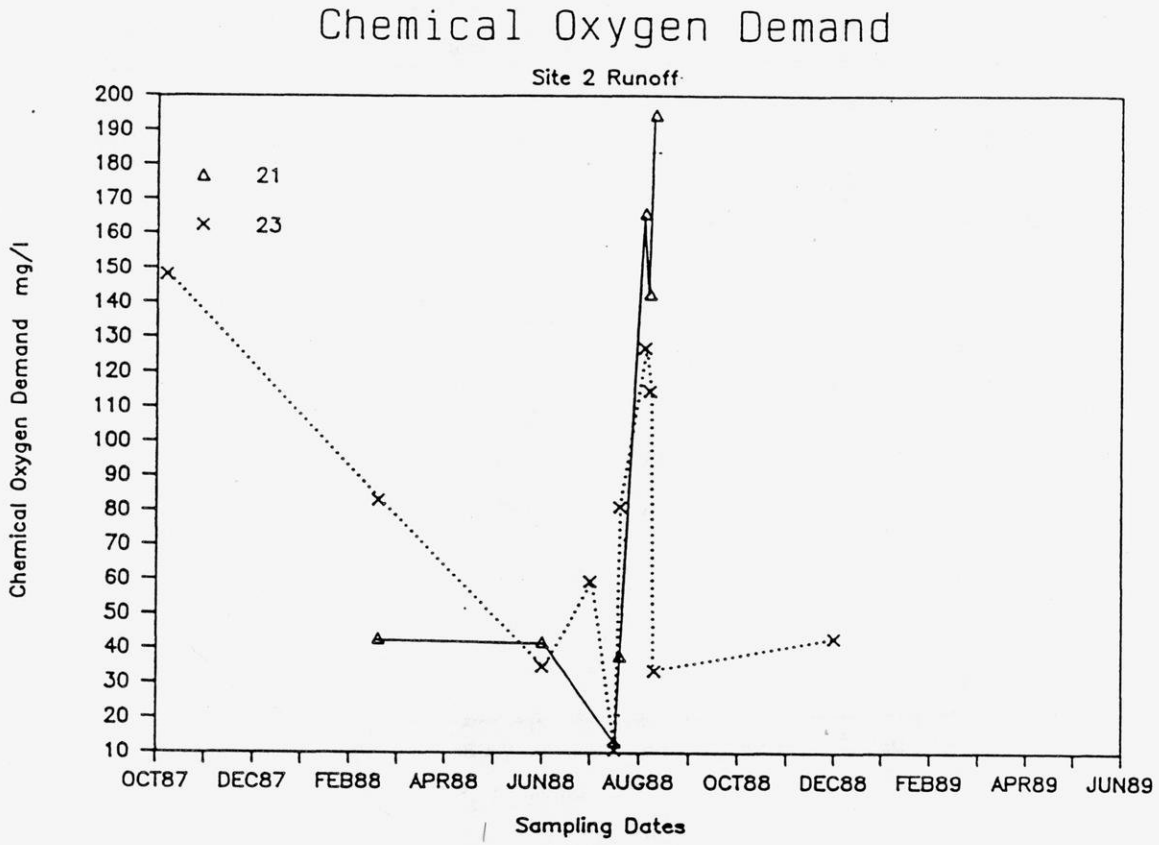


Figure 10. Chloride concentration of runoff and monitoring well samples at sites 2 and 5.



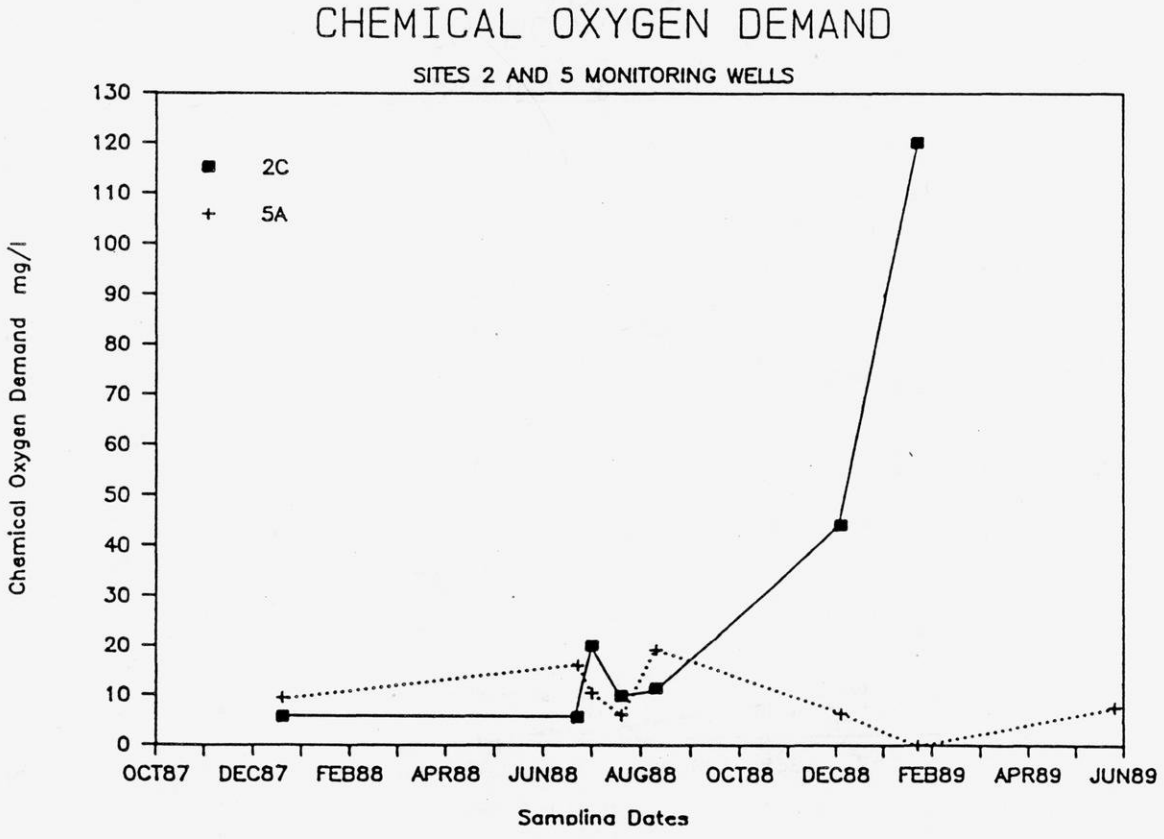


Figure 11. Chemical oxygen demand of runoff and monitoring well samples at sites 2 and 5.

as the runoff (see Fig. 11). This may indicate that the organic compound causing the high chemical oxygen demand in the runoff is not reaching the water table. The amount of nitrate nitrogen in groundwater samples was significantly higher than in the runoff for this site. This is probably from residential use of lawn fertilizers upgradient. Copper, lead, and zinc were all found in relatively small amount in groundwater samples. Some of the first metals samples taken in the fall of 1987 showed high concentration of zinc but this dropped drastically when the galvanized casings and points were replaced with PVC. One sample, taken in December of 1988, had a lead concentration in excess of the State drinking water standard.

VOCs were found in all but one of the runoff samples analyzed with a maximum concentration of 13.2 ppb in one sample (see Table 6.). However, only one monitoring well sample contained VOCs and only in very concentrations (0.9 ppb) (see Table 7.). PNAs were found in one of the three monitoring well samples analyzed (see Table 8.). A sample of sediment from the drywell floor was also analyzed for PNAs and showed the presence of two compounds.

SITE 3

Site three is the residential neighborhood located in south-central Stevens Point and is drained by a system of drywells and perforated pipe. The chloride concentrations in the runoff at this site were the highest found during the study. As shown in Figure 12, the highest concentrations of chloride in the runoff were found in the spring of 1988 and 1989. The primary source of the sodium and chloride in the runoff is almost certainly deicing

Table 6. Volatile organic compound concentration of runoff samples collected at site 2.

SAMPLE LOCATION/DATE	COMPOUND NAME	CONCENTRATION ppb
WORZALLA DRAIN		
21 880602	t-1,3-Dichloropropene	1.3
	c-1,3-Dichloropropene	1.9
WORZALLA DRAIN		
22 880219	t-1,2-Dichloroethylene	13.2
WORZALLA DRAIN		
23 880602	c-1,3-Dichloropropene	2.2
	Ethylbenzene	0.3
23 880719	--------	ND

Table 7. Volatile organic compound concentration of monitoring well samples taken from sites 2 and 5.

SAMPLE LOCATION/DATE	COMPOUND NAME	CONCENTRATION ppb
WORZALLA UPGRADIENT		
5A 880317	--------	ND
5A 880622	--------	ND
5A 890524	--------	ND
WORZALLA IN DRAIN		
2A 880622	--------	ND
2A 880719	trans-1,3-Dichloralpropene	0.9
	Toluene	<0.3
WORZALLA IN DRAIN		
2B 880317	--------	ND
2B 880622	--------	ND
WORZALLA IN DRAIN		
2C 880317	--------	ND
2C 880622	--------	ND
2C 880719	--------	ND
WORZALLA DOWNGRADIENT		
2D 890524	--------	ND

Table 8. Polynuclear aromatic hydrocarbon concentration of samples taken at site 2.

SAMPLE LOCATION/DATE	COMPOUND NAME	CONCENTRATION ppb
WORZALLA IN DRAIN		
2C 890123	----------	ND
WORZALLA DRAIN SEDIMENT		
2C-SED 890123	Acenapthalene	0.78
	Acenapthene	2.25
WORZALLA DOWNGRADIENT		
2D5 890612	Acenapthalene	1.32
	Fluorene	0.02
	Fluoranthrene	0.12
IGA FAR DOWNGRADIENT		
321 SUNRISE	----------	ND

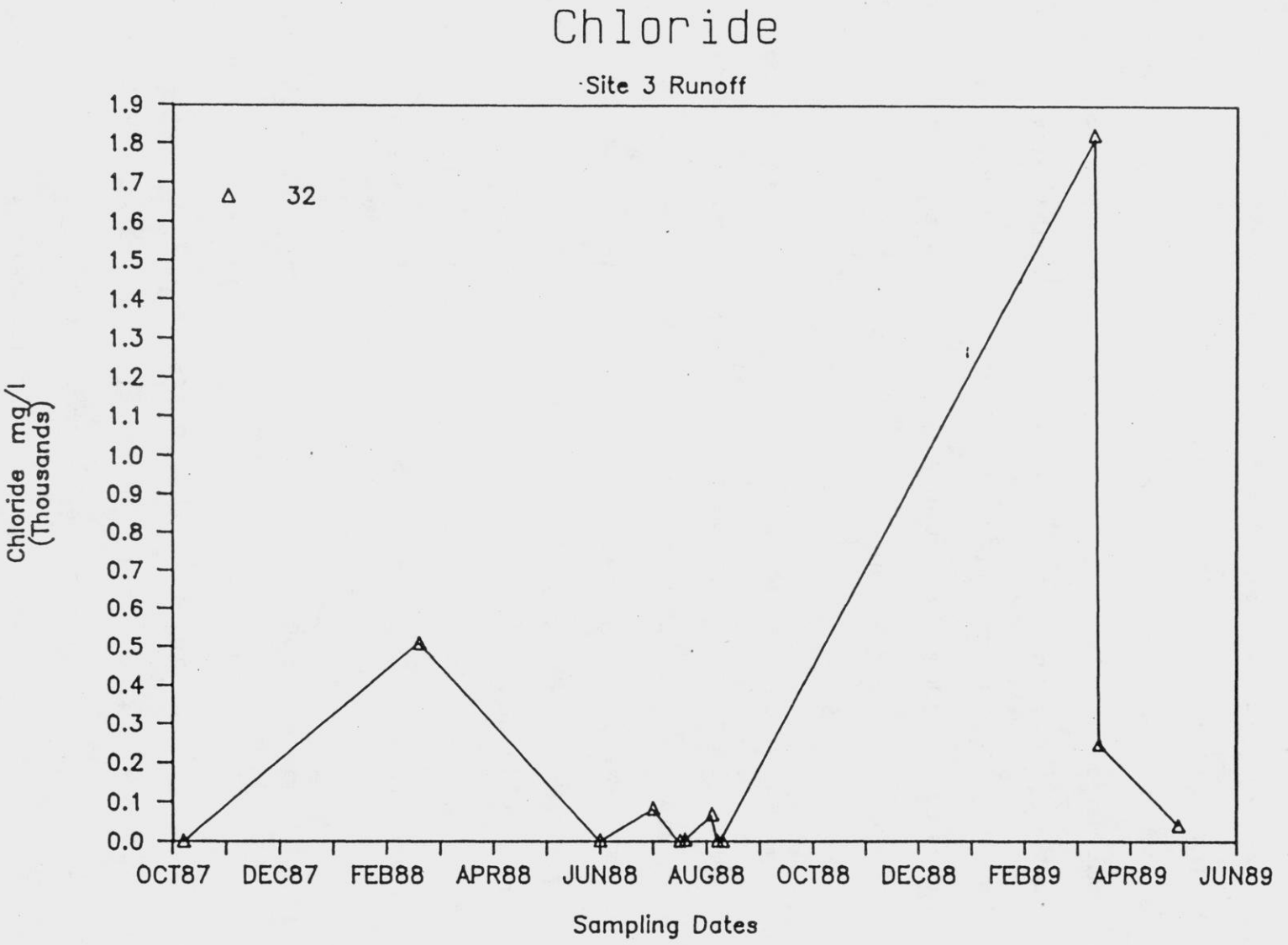
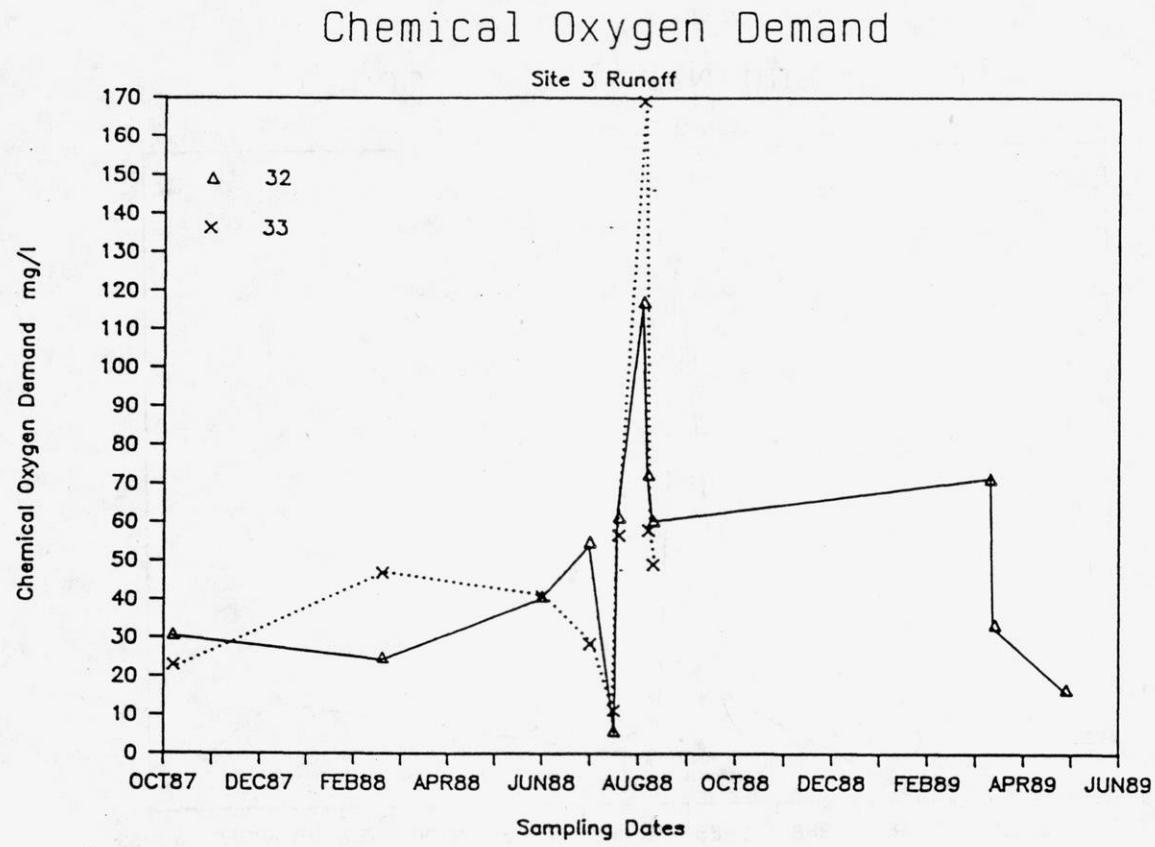


Figure 12. Chloride concentration of site 3 runoff.

salts. The chemical oxygen demand of runoff samples follows a pattern similar to the runoff at site two (see Figs. 13 and 11), in that the highest levels were found in the early fall of 1988. The levels of chemical oxygen demand in the site three runoff samples indicate that there is a significant amount of organic matter in the runoff. The high values in the early fall are very likely from dead leaves and other vegetation which were frequently found in the runoff collection bucket. No volatile organic compounds were found in the runoff or groundwater at this site. Nitrate nitrogen levels in the runoff, although below the State drinking water standard of 10 mg/l, did peak noticeably in the summer of 1988 (see Fig. 14). The peak in nitrate nitrogen is probably due to the use of fertilizers on the residential lawns bordering the site. Cadmium, copper and chromium were all found in low concentrations in the runoff. Several samples taken in the fall of 1988 and the spring of 1989 had significant concentrations of lead and zinc. Two samples contained lead in excess of the State drinking water standard and one sample contained 0.42 mg/l zinc.

As with site two, the downgradient wells at this site are located in the drywells. The peak in chloride and sodium values for the downgradient monitoring well samples occurred at approximately the same time as for the runoff. In March of 1989, the sample from well 3B contained 7300 mg of sodium per liter. The peak in chemical oxygen demand for the monitoring well samples occurred in the spring of 1989 (see Fig. 13). It is interesting to note that the material causing the chemical oxygen demand seems to be moving from the surface to the groundwater, unlike site two.



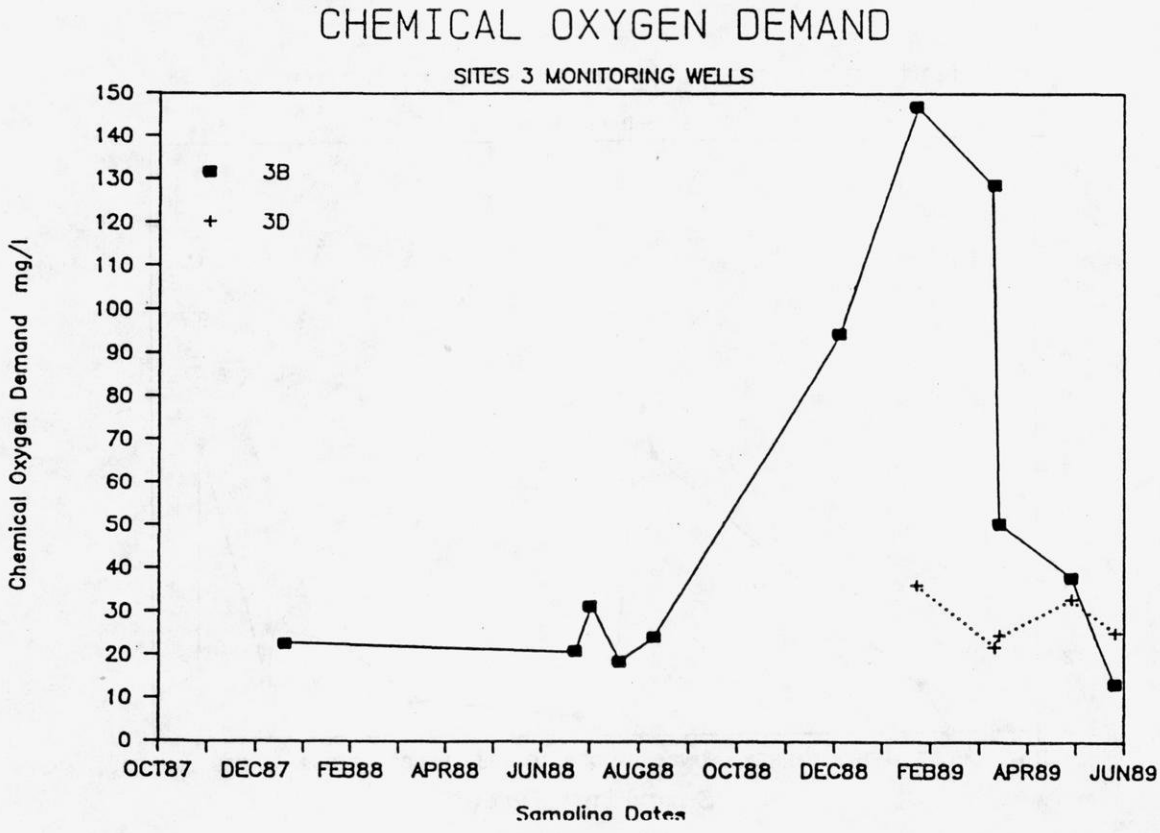
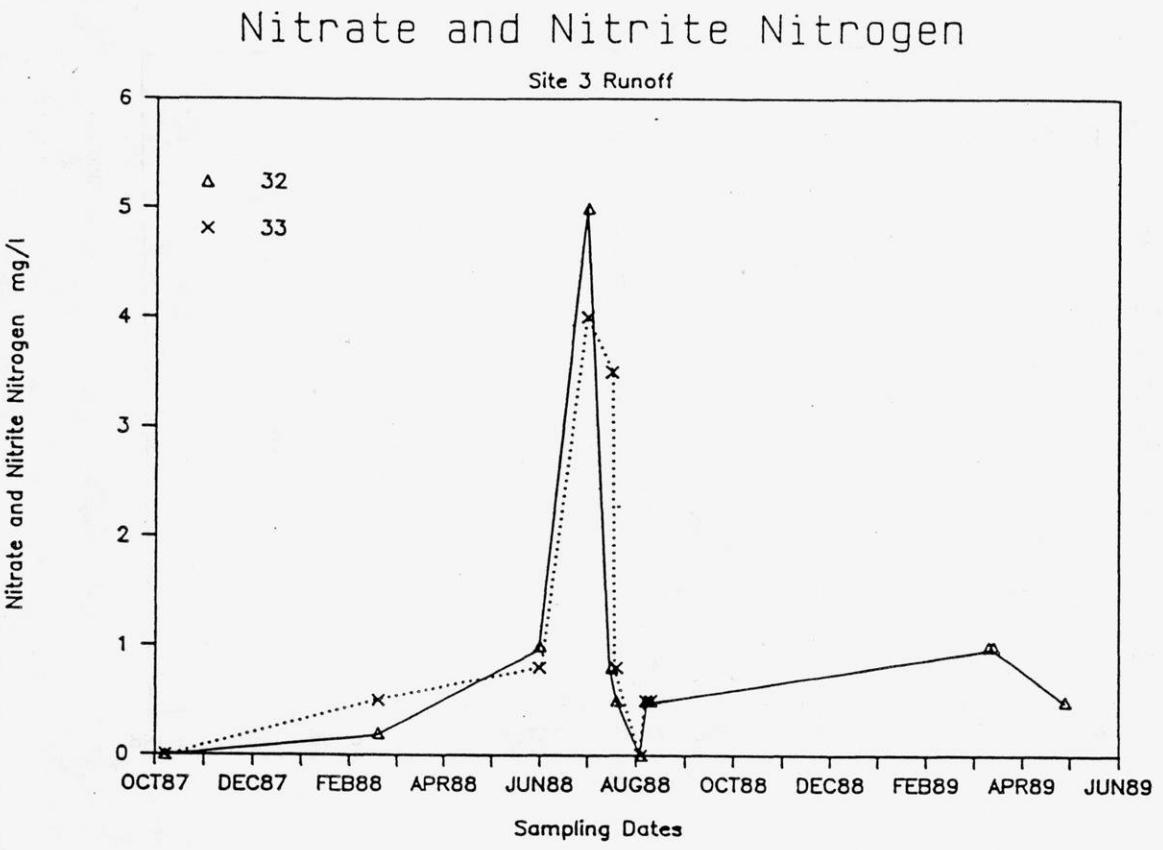


Figure 13. Chemical oxygen demand of site 3 runoff and monitoring well samples.



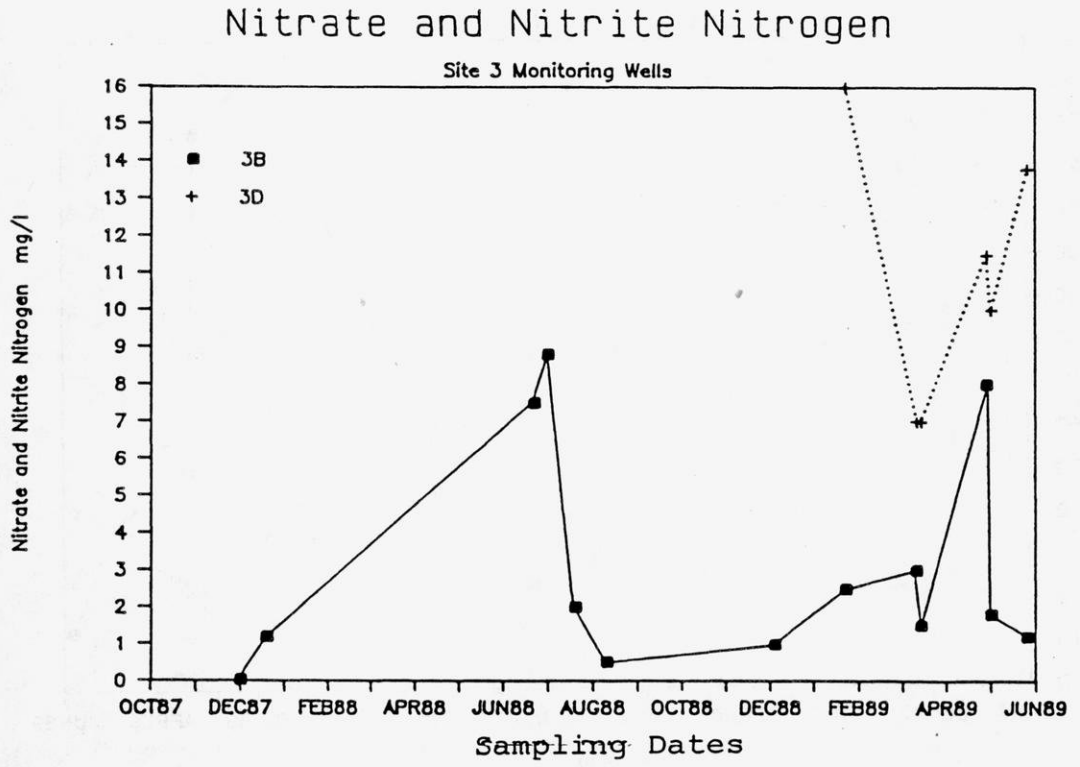


Figure 14. Nitrate and nitrite nitrogen concentration of site 3 runoff and monitoring well samples.

Table 9. Volatile organic compound concentration of runoff samples collected at site 3.

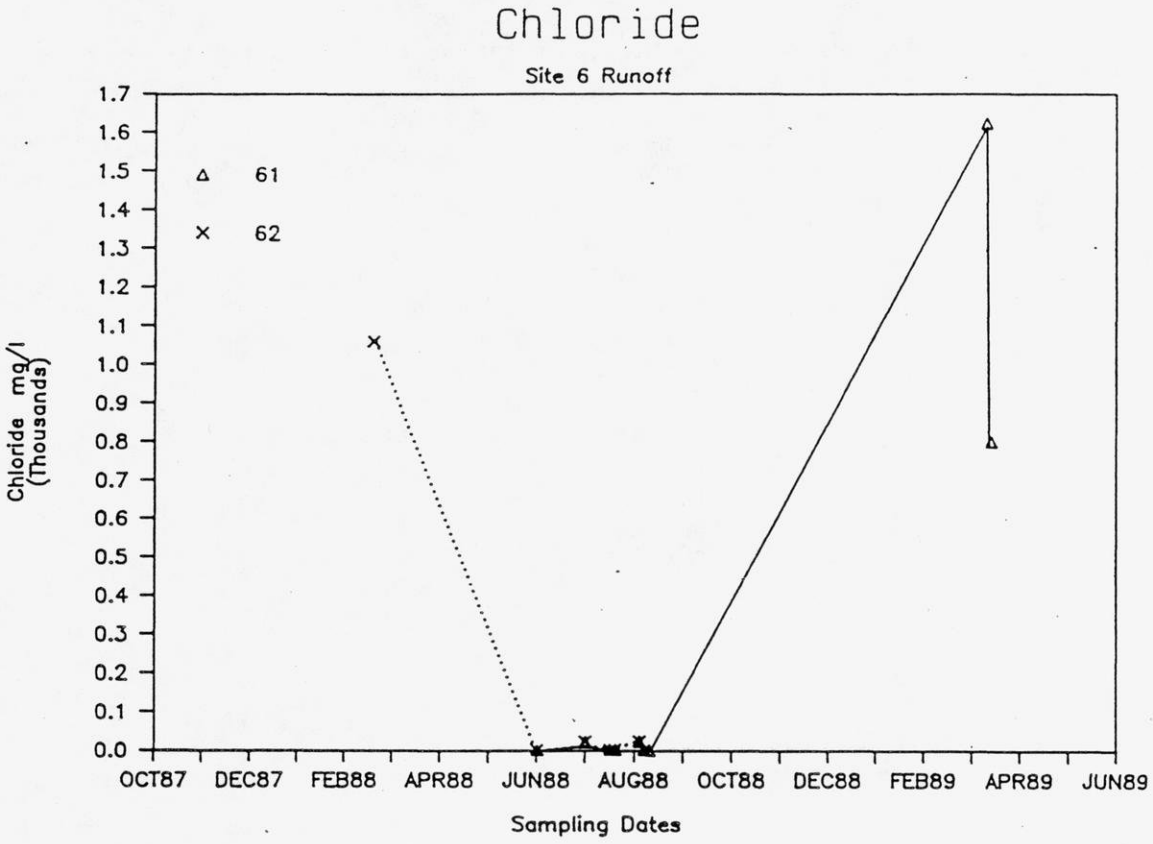
SAMPLE LOCATION/DATE	COMPOUND NAME	CONCENTRATION ppb
DELLA DRAIN 31 880602	t-1,3-Dichloropropene	4.8
DELLA DRAIN 32 880219	--------	ND
32 880602	t-1,3-Dichloropropene	1.3
32 890310	DIESEL	<.5 ppm
32 890311	DIESEL	<.5 ppm
32 890428	--------	ND
32 890428	--------	ND
DELLA DRAIN 33 880602	--------	ND

Table 10. Volatile organic compound concentration of monitoring well samples taken from site 3.

SAMPLE LOCATION/DATE	COMPOUND NAME	CONCENTRATION ppb
DELLA IN DRAIN		
3A 880317	--------	ND
3A 880622	--------	ND
3A 890524	--------	ND
DELLA IN DRAIN		
3B 880317	--------	ND
3B 880622	--------	ND
3B 890310	--------	ND
3B 890311	--------	ND
3B 890428	--------	ND
3B 890429	--------	ND
3B 890524	--------	ND
DELLA IN DRAIN		
3C 880317	--------	ND
3C 880622	--------	ND
3C 890524	--------	ND
DELLA UPGRADIENT		
3D 890310	--------	ND
3D 890311	--------	ND
3D 890428	--------	ND
3D 890429	--------	ND
3D 890524	--------	ND

Table 11. Polynuclear aromatic hydrocarbon concentration of samples taken at site 3.

SAMPLE LOCATION/DATE	COMPOUND NAME	CONCENTRATION ppb
DELLA IN DRAIN		
3B 890123	Acenapthalene	0.55
	Fluorene	0.25
	Phenanthrene	0.16
	Fluoranthrene	0.02
	Benzo(k)fluoranthene	<0.01
	Benzo(ghi)perylene	0.05
3B 890613	Napthalene	0.23
	Acenapthene	0.43
	Pyrene	0.17



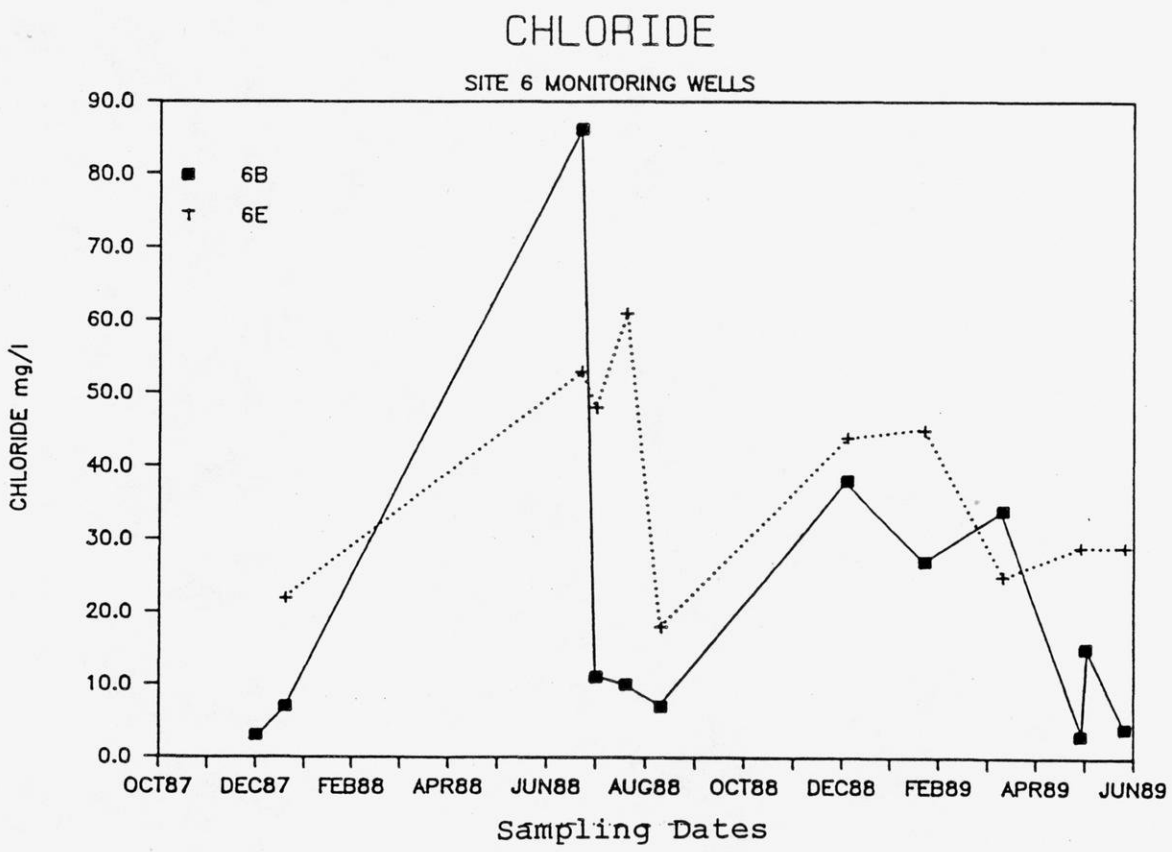
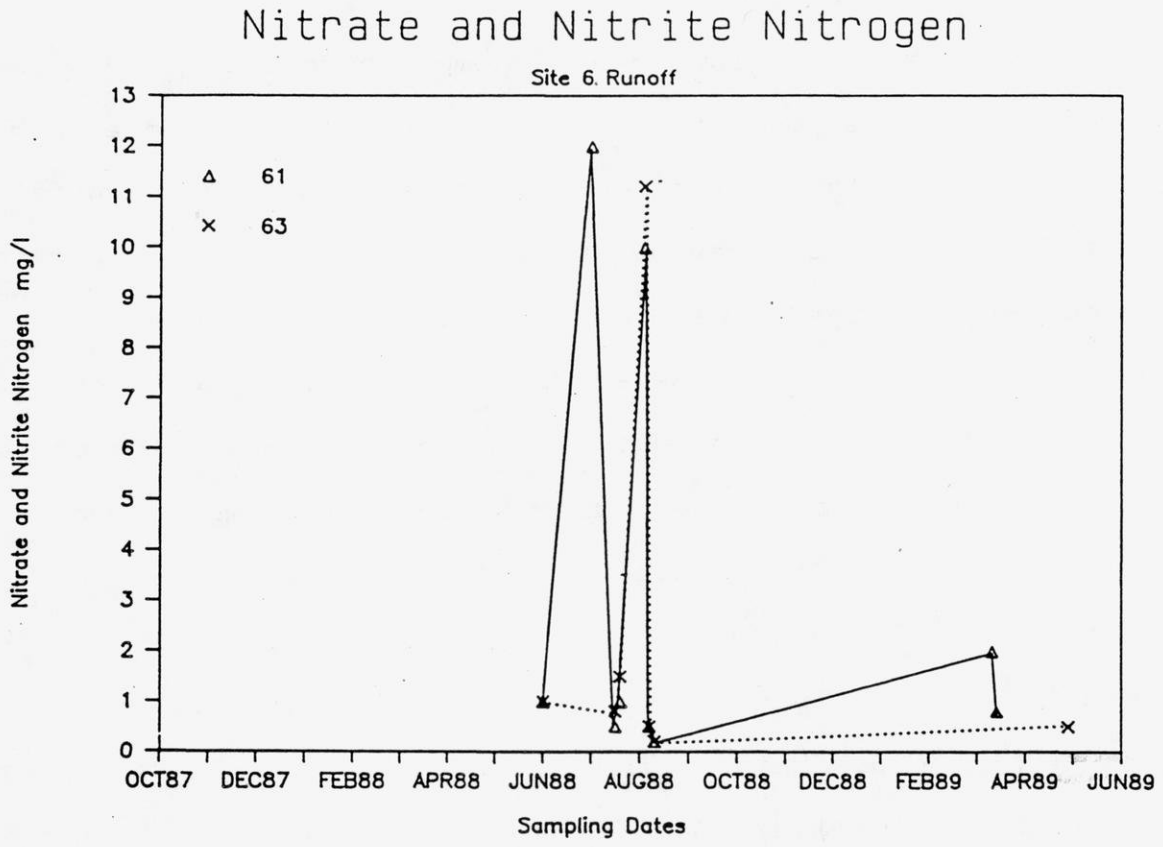


Figure 15. Chloride concentration of site 6 runoff and monitoring well samples.



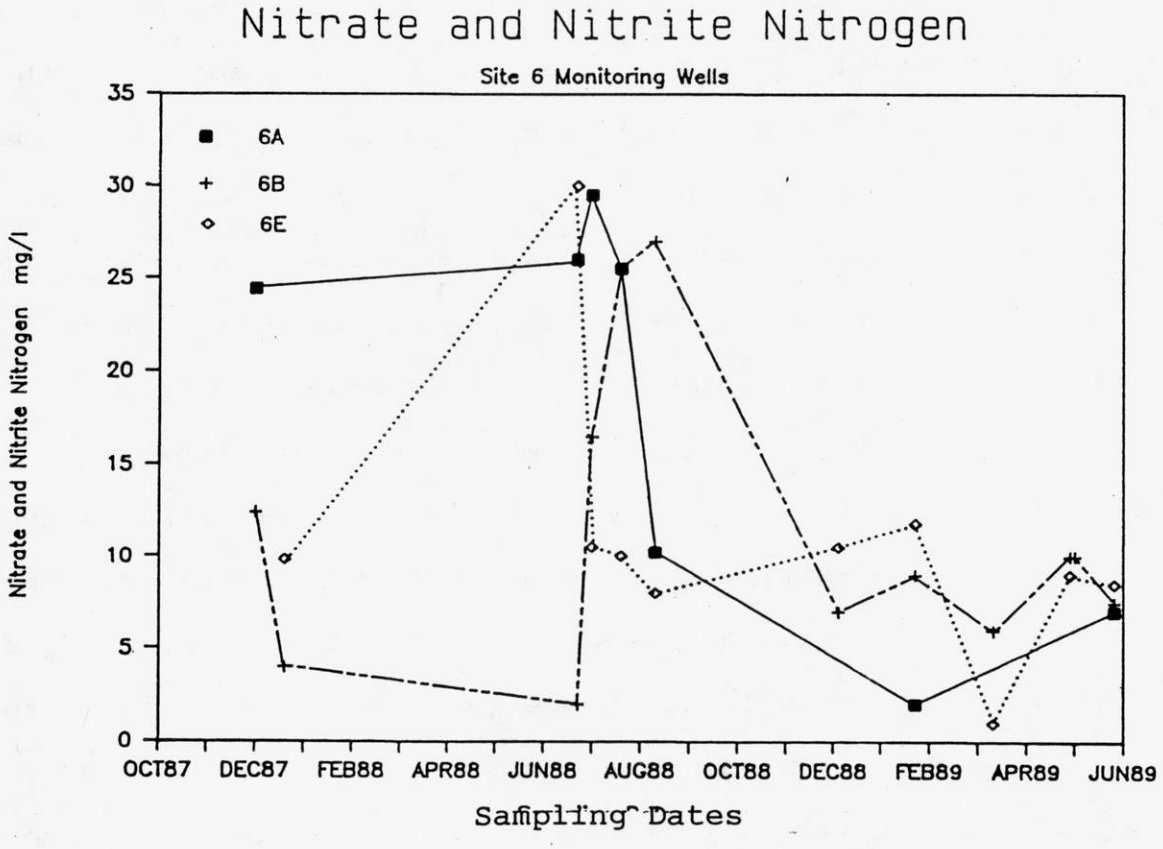


Figure 16. Nitrate and nitrite nitrogen concentration of site 6 runoff and monitoring well samples.

the runoff peaks in mid summer. Compared to the other sites, the level of chemical oxygen demand for the runoff at this site is relatively low, averaging about 20 mg/l. This low chemical oxygen demand in the runoff may be due to the fact that this parking lot is concrete instead of asphalt or the fact that this lot is swept daily, by hand, during the summer. No chromium and very little copper and zinc were found in the runoff. Two samples collected in March of 1989 contained approximately 0.060 mg/l lead.

The peaks in the concentrations of sodium and chloride in the monitoring well samples roughly followed the peaks in the runoff (see Fig. 15). Since the downgradient well (6E) is located 50 feet form the perforated pipe, some lag time would be expected. The upgradient wells (6A and 6B) also showed high concentrations of chloride and sodium, occasionally exceeding the levels in the downgradient well. The source of chloride and sodium in the upgradient wells is probably deicing salts used on US Highway 51 which borders the site on the upgradient edge (see Fig. 6). The peak in nitrate nitrogen concentration of the monitoring well samples peaked in mid summer (see Fig. 16). Nitrate nitrogen levels in the upgradient wells often exceeded the levels in the downgradient well. The lawn in which the upgradient wells are located is fertilized at a rate of one pound of nitrogen per one thousand square feet; this rate of fertilization may account for the high nitrate nitrogen levels in the groundwater. No cadmium or chromium and very little copper and lead were found in the monitoring well samples. The spring, 1988 metals samples contained about 1.3 mg/l of zinc. Other than this one sample set, zinc levels were low in the groundwater.

VOCs, especialy gasoline components, were detected several times in runoff samples from this site (see Table 12.). Only one sample from wells 6C or 6D showed a detectable concentration of a VOC (see table 13.). This one monitoring well sample that contained benzene was collected twenty days after a runoff sample that contained benzene. Downgradient well 6E, the well in the groundwater flow path downgradient of most of the parking lot, yielded several samples containing detectable levels of VOCs. Of the two samples collected from well 6E for PNA analysis only one showed the presence of any PNAs (see Table 14). This one sample contained less than 0.5ppb of all compounds except one; this one compound, Benzo(b)fluoranthene, was present at 0.84ppb (see Table 14.)

Table 12. Volatile organic compound concentration of runoff samples collected at site 6.

SAMPLE LOCATION/DATE	COMPOUND NAME	CONCENTRATION ppb
WOODWARD DRAIN		
61 880602	--------	ND
61 890311	--------	ND
61 890311	DIESEL	<.5
WOODWARD DRAIN		
62 880602	Benzene	0.3
62 880719	--------	ND
WOODWARD DRAIN		
63 880602	--------	ND
63 890428	DIESEL	<.5 ppm
WOODWARD DRAIN		
64 880602	--------	ND
64 880719	--------	ND

Table 13. Volatile organic compound concentration of monitoring well samples taken from site 6.

SAMPLE LOCATION/DATE	COMPOUND NAME	CONCENTRATION ppb
WOODWARD UPGRADIENT		
6A 880622	--------	ND
6A 880719	--------	ND
6A 890524	--------	ND
WOODWARD UPGRADIENT		
6B 880317	--------	ND
6B 881202	--------	ND
6B 890311	--------	ND
6B 890428	--------	ND
6B 890429	--------	ND
6B 890429	--------	ND
6B 890524	--------	ND
WOODWARD DOWNGRADIENT		
6C 880317	--------	ND
6C 880622	Benzene	1.1
6C 881202	--------	ND
6C 890122	--------	ND
6C 890524	--------	ND
WOODWARD DOWNGRADIENT		
6D 880317	--------	ND
6D 880622	--------	ND
6D 881202	--------	ND
6D 890122	--------	ND
6D 890524	--------	ND

Table 13 continued. Volatile organic compound concentration of monitoring well samples taken from site 6.

SAMPLE LOCATION/DATE	COMPOUND NAME	CONCENTRATION ppb
WOODWARD DOWNGRADIENT		
6E 880317	Toluene	2.0
	1,1-Dichloroethylene	12.4
	1,1,1-Trichloroethane	10.4
6E 880622	--------	ND
6E 880719	--------	ND
6E 881202	Toluene	<0.5
6E 890122	--------	ND
6E 890310	trans-1,3-dichloropropene	.74 ppb
6E 890428	--------	ND
6E 890524	--------	ND

Table 14. Polynuclear aromatic hydrocarbon concentration of samples taken at site 6.

SAMPLE LOCATION/DATE	COMPOUND NAME	CONCENTRATION ppb
WOODWARD DOWNGRADIENT		
6E 890123	Fluorene	0.07
	Phenanthrene	0.09
	Fluoranthrene	0.36
	Chrysene	<0.01
	Benzo(b)fluoranthene	0.84
	Benzo(k)fluoranthene	<0.01
6E 890613	----------	ND

Table 15. Volatile organic compound concentration of runoff samples collected at site 7.

SAMPLE LOCATION/DATE	COMPOUND NAME	CONCENTRATION ppb
MOBIL RUNOFF 71 890310	DIESEL	<.5 ppm
71 890311	DIESEL	3.12 ppm
MOBIL RUNOFF 74 890428	DIESEL	<.5 PPM
7 SURFACE 890310 MOBIL POND IN LOT	DIESEL	.96 ppm

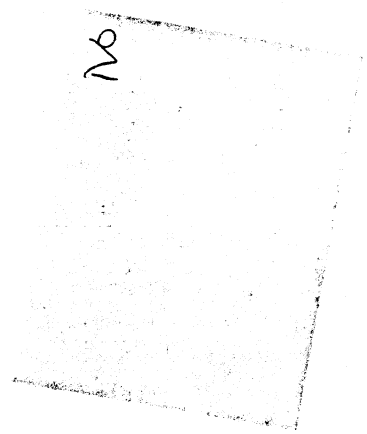


Table 16. Volatile organic compound concentration of monitoring well samples taken from site 7.

SAMPLE LOCATION/DATE	COMPOUND NAME	CONCENTRATION ppb
MOBIL UPGRADIENT		
7A 890122	--------	ND
7A 890310	--------	ND
7A 890311	--------	ND
7A 890428	--------	ND
7A 890429	--------	ND
7A 890524	--------	ND
MOBIL DRAIN		
7B 890310	DIESEL	.84 ppm
7B 890311	DIESEL	3.48 ppm
7B 890428	DIESEL	<.5 ppm
7B 890428	DIESEL	<.5 PPM
7B 890429	DIESEL	<.5 ppm
7B 890524	Benzene	14.0
	Toluene	13.2
	1,4-Xylene	0.8
	1,2-Xylene	0.7
MOBIL DOWNGRADIENT		
7C3 890122	Benzene	4.3
	Toluene	4.0
	Ethylbenzene	4.0
7C3 890428	DIESEL	<.5 PPM
7C3 890429	DIESEL	<.5 PPM
7C3 890524	Chlorobenzene	0.4
	1,2-Xylene	0.6
	Isopropylbenzene	0.5
	N-Propylbenzene	1.0
	2-Chlorotoluene	4.0
MOBILE BY DRAIN		
7D 890429	--------	ND
7D 890524	--------	ND

Figure 17. Polynuclear aromatic hydrocarbon concentration of samples taken at site 1.

SAMPLE LOCATION/DATE	COMPOUND NAME	CONCENTRATION ppb
MOBIL IN DRAIN		
7B 890123	Phenanthrene	2.30
	Fluoranthrene	2.20
7B 890613	Phenanthrene	0.90
	Pyrene	3.40
	Chrysene	2.40
	Benzo(k)fluoranthene	0.40
	Benzo(ghi)perylene	1.90
MOBIL DOWNGRADIENT		
7C0 890613	Acenapthene	0.54
	Anthracene	<0.01
	Fluoranthrene	0.02
	Pyrene	0.30
	Benzo(b)fluoranthene	0.06
	Benzo(a)pyrene	0.04
	Benzo(ghi)perylene	0.05
7C3 890123	Napthalene	4.09
	Acenapthalene	0.17
	Fluorene	0.03
	Phenanthrene	0.27
	Fluoranthrene	0.49
	Chrysene	0.06
	Benzo(k)fluoranthene	0.05
	Benzo(a)pyrene	0.13
7C3 890612	Fluorene	0.07
	Acenapthene	1.34
	Anthracene	0.09
	Fluoranthrene	2.45
	Pyrene	2.10
	Benzo(b)fluoranthene	2.34
	Benzo(ghi)perylene	1.28
MOBIL BY DRAIN		
7D 890612	Phenanthrene	0.30
	Chrysene	0.90
	Benzo(a)anthracene	0.10
	Benzo(ghi)perylene	1.20

CONCLUSIONS

Subsurface disposal of urban runoff has an impact on local groundwater; the severity of that impact is a function of the chemical characteristics of the runoff, the impervious surface, the drain type, the subsurface soil and the distance to groundwater. In this study, some of the most dramatic impacts were the increased sodium and chloride concentrations in the groundwater. Many samples from downgradient monitoring wells contained greater than 100 mg/l sodium. In the late winter and early spring, samples collected downgradient from site three ranged from 300 to 7300 mg/l sodium. The recommended safe dietary intake of sodium for adults is 1100-3300 mg/day (USDHHS, 1986). Many people with a history of hypertension or heart disease are on a sodium-restricted diet and are only allowed 1000 or 2000 mg sodium/day. Assuming a person consumed two liters of water per day, lived on the downgradient edge of site three, and was on a shallow private well, this person would receive 600-14,600 mg/day sodium in their drinking water. It is important that doctors and persons on sodium-restricted diets be informed of the potential sodium content of drinking water in high risk areas. Serious consideration should be given to reducing the amount of deicing salts and increasing the use of sand and cinders on ice-covered roads. There has been no statistical correlation between increased salt use and decreased number of automobile accidents (McConnell and Lewis, 1972).

In this study, heavy metals in runoff did not seem to be severely impacting groundwater. Some groundwater samples taken from wells located in the drywells had concentrations of lead that exceeded the State Drinking Water Standard of 0.050 mg/l, but no samples taken from wells downgradient of sites had lead levels that exceeded 0.010 mg/l lead. Since the heavy metals seem to

associate with small soil particles, regular pavement cleaning with a vacuum-type sweeper may reduce heavy metal loads in runoff.

Volatile organic compounds were regularly found in runoff samples and less frequently in monitoring well samples. If the source of the VOCs is gasoline or other petroleum products, many of the volatile components seem to be evaporating as the runoff flows over the pavement to the drain. It does appear, though, that some of the VOCs are reaching the drains and moving into the groundwater. PNAs were found in almost all samples analyzed. Most groundwater samples contained little more than a trace of any one PNA compound, but the combined effect of several compounds is unknown. Since PNAs were frequently found in monitoring well samples, it seems that PNAs are moving in the groundwater. Other organic contaminants associated with urban runoff need further evaluation; they are difficult to characterize and are of unknown toxicity. It is possible that the COD of a sample may be used as a relative indicator of the total organics concentration.

In an urban area that depends on groundwater for its water supply, a method of stormwater disposal other than underground injection may be preferred. In low-traffic areas and parking lots, porous or lattice block pavement may be used to disperse runoff quickly over a large area. Porous pavement can reduce runoff rate, provide some "treatment" by aerobic bacteria living in the pavement subbase, and can provide improved wet pavement skid resistance (USEPA, 1980).

It seems that the drain systems examined in this study, with the exception of site two, which was poorly maintained, disposed of runoff quickly and effectively. In most cases, the subsurface injection system was the most cost effective method of runoff disposal. The presence of drywells or storm

drains of any type does, however, provide a rapid conduit for groundwater contaminants if a spill or intentional disposal of hazardous material was to occur near a drain. While no such problem was detected in this study, the possibility does exist and should be considered, especially if the drains are used in areas where groundwater is used for drinking water supply.

It is difficult to directly compare monitoring results between drywells and perforated tile drainage systems. The data suggests drywells cause more contaminants; however, the nature of the monitoring system may account for these differences. Wells were installed through drywells and samples then taken immediately under the drains, while at perforated drain systems at sites one and six the wells were from 50 to 200 feet downgradient of the drain system, allowing for more contaminant attenuation. Dry wells by their nature would produce a smaller plume of contamination than drainage tile systems, so that total loading of contaminants to groundwater may be similar even though concentration in the plume would be higher downgradient of drywells.

Perforated tile systems do allow for more soil contact and are more likely to have aerated soil conditions, both of which should result in improved treatment.

The effect of age of the drainage system and potential treatment efficiency with age and buildup of organic matter and fine soil particles should be investigated.

LITERATURE CITED

Bauman, James, A. Domanik, and J. Konrad. 1980. Nonpoint source pollution in urban areas. In: Seminar on Water Quality Management Trade-Offs; Point Source vs. Diffuse Source. Environmental Protection Agency Report EPA-905/9-80-009.

Browne, F.X.. 1980. Water pollution: Nonpoint sources. J WPCF. 52:6.

Colyer, Peter J. and B.C. Yen. 1983. Current issues and future needs in urban storm drainage. Water Res. 17:9.

Daniel, Tom and M. Forrest. 1979. Nonpoint pollution: How Wisconsin's cities affect water quality. University of Wisconsin Extension publicatiion G2967.

Daniel, Tom, R.C. Wendt, and J.G. Konrad. 1978. Nonpoint pollution: Runoff in urban areas. University of Wisconsin Extension publication G2958.

Fam, Sami, M.K. Stenstrom, and G. Silverman. 1987. Journal of Environmental Engineering. 113:5.

Heaney, James P.. Reasearch needs in urban storm-water pollution. 1986. Journal of Water Resources Planning and Management. 112:1.

Hoffman, Eva J., J.S. Latimer, G.L. Mills, and J.G. Quinn. 1982. Petroleum hydrocarbons in urban runoff from a commercial land use area. J WPCF 54:11.

Leopold, L.B. 1968. Hydrogeology for urban land planning-a guide book on the hydrologic effects of urban land use. U.S. Geol. Survey Circular 167.

McConnell, H. Hugh and J. Lewis. 1972. Add salt to taste. Environment 14:9.

Metzler, Suzanne C., C. Jarvis. 1985. Effects of waste oil contamination. Environmental Progress 4:1.

Thomas, Harold E. and W.J. Schneider. 1970. Water as an urban resource and nuisance: Water in the urban environment. Geological Survey Circular 601-D.

U.S. Department of Transportation. 1980. Underground disposal of storm water runoff: Design guidelines manual. U.S. DOT Federal Highway Administration publication HDV-21.

U.S. Department of Health and Human Services. 1986. A word about low sodium diets. HHS Publication No. (FDA) 87-2179.

U.S. Environmental Protection Agency. 1980. Porous pavement: phase I design and operational criteria. Municipal Environmental Research Laboratory, Cincinnati, OH. EPA-600/2-80-135.

APPENDIX A

MDL for VOC Analysis

Table 1. Method Detection Limit (MDL) for volatile organic compound analysis.

COMPOUND	MDL ppb
Benzene	0.5
Chlorobenzene	0.3
1,1-Dichloroethane	0.7
trans-1,2-Dichloroethylene	0.5
cis-1,3-Dichloropropene	0.4
trans-1,3-Dichloropropene	0.4
Ethylbenzene	0.5
Tetrachloroethylene	0.5
Toluene	0.3
1,1,1-Trichloroethane	1.0
Trichloroethylene	0.6
1,4-Xylene	*
1,2-Xylene	*
Isopropylbenzene	*
2-Chlorotoluene	*
N-Propylbenzene	*

* MDL not available

APPENDIX B

MLDs for PNA Analysis

Table 1. Minimum Limit of Detection (MLD) for polunuclear aromatic hydrocarbon analysis.

COMPOUND	MLD* ppb
Napthalene	0.07
Acenapthalene	0.10
Fluorene	0.01
Acenapthene	0.15
Phenanthrene	0.01
Anthracene	0.01
Fluoranthrene	0.02
Pyrene	0.02
Chrysene	0.01
Benzo(a)anthracene	0.01
Benzo(b)fluoranthene	0.02
Benzo(k)fluoranthene	0.01
Benzo(a)pyrene	0.02
Benzo(ghi)perylene	0.02

* Minium Limit of Detection indicates the minimum theoretical concentration detectable by the instruments.

APPENDIX C

Inorganic Data Tables

Table 1. Alkalinity of monitoring well samples by sampling date. All values are mg/l.

WELL	871130	880317	880627	880701	880719	880809	881202	890127	890317	890313	890428	890429	890524	AVG	MIN	MAX
1A		20	8	12	12	20	12	20					8	14	8	20
1B		28	16	24	24	28	64	52					24	33	16	64
1C		24	14	28	30	16	44	60					16	29	14	60
1D							50	64					40	51	40	64
1D5							96	124					100	107	96	124
1D7.5							60	64					56	60	56	64
2A			20	20	16	16	20	64						26	16	64
2B		32	26	28	26	28	24	32						28	24	32
2C		40	28	32	22	16	24	92						36	16	92
2D								24					12	18	12	24
2D5								24					8	16	8	24
3A		68	116		68		36						84	74	36	116
3B		68	92	100	80	60	24	80	50	46	104	68	48	68	24	104
3C		112	128	120	100	72	76						60	95	60	128
3D								164	132	134	116	116	116	130	116	164
5A		36	12	20	16	20	20	36					16	22	12	36
6A			172	168	136	152		200					132	160	132	200
6B		68	50	68	80	88	204	228	92		132	128	96	112	50	228
6C		56	144	140	88	140	136	208					104	127	56	208
6D		88	130	132	124	116	160	108					24	110	24	160
6E		72	56	56	56	88	88	104	52		92		104	77	52	104

Table 2. Alkalinity of runoff samples by sampling date. All values are mg/l.

DRAIN	871007	880219	880607	880701	880715	880719	880803	880805	880809	881207	890317	890313	890428	AVG	MIN	MAX
11	100	20	16	128	16	22	156	16	12					54	12	156
12	100	24												62	24	100
13	36													36	36	36
14	84	48												66	48	84
15	18	40	24	32	16	24	20	20	28	20				24	16	40
16	16	12	12	28	4	32	36	12	16	24				19	4	36
21		12	12		16	30	152	12	16					36	12	152
22	10													10	10	10
23	14	28	16	24	20	40	80	20	20	26				29	14	80
31N	72	28	16	40	24	44	156	24	24					48	16	156
31S	28													28	28	28
32N	32	20	24	116	26	60	160	16	14		40	20	20	46	14	160
32S	28													28	28	28
33N	32	12	20	112	112	36	106	20	32					54	12	112
33S	26													26	26	26
41		48	172	84	192	172	208	268	160					163	48	268
61			44	140	28	44	132	40	28		64	44		63	28	140
62		36	32	144	36	40	152	20						66	20	152
63			44		48	60	150	44	40				52	63	40	150
64			36	148										92	36	148

Table 3. Chemical Oxygen Demand of monitoring well samples by sampling date. All values are mg/l.

WELL	871130	880317	880627	880701	880719	880809	881702	890122	890317	890313	890428	890429	890524	AVG	MIN	MAX
1A		12.2	10.2	13.5	8.7	8.1	34.3	11.2					8.58	14.01	8.10	34.30
1B		14.8	15.8	33.5	8.2	24.0	5.7	3.2					25.19	16.30	3.20	33.50
1C		10.2	10.2	15.9	4.9	8.1	12.1	14.9					25.19	12.69	4.90	25.19
1D							7.7	21.3					19.83	16.28	7.70	21.30
1D5							2.3	6.9					10.72	6.64	2.30	10.72
1D7.5							3.3	5.6					16.62	8.51	3.30	16.62
2A			6.9	8.6	6.1	12.4	14.7	26.6						12.55	6.10	26.60
2B		9.2	18.1	9.7	5.4	10.8	9.0	5.6						9.61	5.40	18.10
2C		5.6	5.5	20.0	9.8	11.3	44.1	120.2						30.93	5.50	120.20
2D								58.0					8.58	33.29	8.58	58.00
2D5								<3.0					10.18	10.18	10.18	10.18
3A		24.7	15.5		9.8		8.5						21.98	16.00	8.50	24.70
3B		22.6	21.0	31.3	18.5	24.3	94.3	146.8	128.6	50.4	37.9		13.40	53.55	13.40	146.80
3C		43.7	25.9	20.0	15.5	18.9	<3						2.16	20.94	2.16	43.20
3D								36.3	22.1	24.9	33.1		25.38	28.36	22.10	36.30
5A		9.5	16.0	10.4	6.0	19.2	6.3	<3.0					7.56	10.71	6.00	19.20
6A			25.4	<3	10.9	8.1		3.0					12.96	12.07	3.00	25.40
6B		14.4	14.4	18.6	6.3	16.2	<3	3.5	9.6		8.6		2.70	10.48	2.70	18.60
6C		9.8	18.8	<3		28.4	7.3	<3.0					16.20	16.10	7.30	28.40
6D		4.0	7.2	<3	6.5	11.3	6.2	<3.0					10.80	7.67	4.00	11.30
6E		10.8	5.5	41.9	9.3	17.3	27.6	<3.0	35.0		7.2		5.40	17.78	5.40	41.90

Table 4. Chemical oxygen demand of runoff samples by sampling date. All samples are mg/l.

DRAIN	871007	880719	880602	880701	880715	880719	880803	880805	880809	881202	890317	890313	890428	AVG	MIN	MAX
11	2870	56	25.4	43.2	11.2	12.0	34.6	170.7	70.2					365.9	11.2	2870.0
12	19	59												39.0	19.0	59.0
13	76													76.0	76.0	76.0
14	54	155												104.5	54.0	155.0
15	45	101	53.7	130.7	10.3	50.0	51.3	153.7	53.5	548				119.7	10.3	548.1
16	41	79	23.3	21.1	11.2	62.6	61.8	76.3	11.9	86				42.4	11.2	85.9
21		43	41.9		13.2	38.1	165.9	142.6	194.4					91.3	13.2	194.4
22	140													140.0	140.0	140.0
23	148	83	34.8	59.4	10.8	81.1	126.9	114.5	33.5	43				73.5	10.8	148.0
31N	6564	22	34.1	54.3	8.4	39.7	136.0	62.1	125.8					782.9	8.4	6564.0
31S	60													60.0	60.0	60.0
32N	31	25	41.1	55.1	6.0	61.5	117.2	72.5	60.5		71.5	33.6	16.8	49.3	6.0	117.2
32S	25													25.0	25.0	25.0
33N	23	47	40.9	28.5	11.2	56.6	169.0	57.9	49.1					53.7	11.2	169.0
33S	18													18.0	18.0	18.0
41		25	60.3	118.4	90.7	44.1	167.0	205.2	86.4					99.6	25.0	205.2
61			10.9	4.4	2.0	8.2	38.1	13.2	3.2		78.7	33.6		21.4	2.0	78.7
62		72	17.3	5.5	14.8	13.6	14.1	12.1						21.3	5.5	72.0
63			8.2		12.0	10.3	15.8	10.4	9.2				6.2	10.3	6.2	15.8
64			9.8	32.5										21.2	9.8	32.5

Table 5. Chloride concentration of monitoring well samples by sampling date. All values are mg/l.

WELL	871130	880317	880622	880701	880719	880809	881207	890127	890317	890313	890428	890429	890524	AVG	MIN	MAX
1A	22	12	1	10	7	13	64	80					8	24	1	80
1B	11	21	250	14	78	120	18	6					130	72	6	250
1C	2	5	125	68	16	7	1	21					56	33	1	125
1D							74	31					160	72	24	160
1D5							38	55					81	58	38	81
1D7.5							25	16					100	47	16	100
2A			9	5	2	1	2	207						38	1	207
2B	46	69	56	56	34	6	40	65						47	6	69
2C	33	77	6	19	4	2	65	1100						163	2	1100
2D								13					<1	13	13	13
2D5								2					<1	2	2	2
3A	7	30	68		5		1						7	18	1	68
3B	78	99	49	43	9	3	4700	3050	4600	950	30	16	3	1048	3	4700
3C	3	120	60	36	29	1	7						2	32	1	120
3D								38	26	23	26	30	33	29	23	38
5A	36	48	17	70	81	89	49	57					55	56	17	89
6A	10		10	16	14	11		4					160	32	4	160
6B	3	7	86	11	10	7	38	27	34		3	15	4	20	3	86
6C	14	16	22	61	120	90	25	5					140	55	5	140
6D	18	6	38	23	21	20	10	30					15	20	6	38
6E		22	53	48	61	18	44	45	25		29		29	37	18	61

Table 6. Concentration of chloride in runoff samples by sampling date. All samples are mg/l.

DRAIN	871007	880719	880602	880701	880715	880719	880803	880805	880809	881707	890317	890313	890428	AVG	MIN	MAX
11	63	590	3.0	32	1	1	33	7	<1					91	1	590
12	33	850												442	33	850
13	8													8	8	8
14	22	1360												691	22	1360
15	1	1420	3.0	11	3	6	1	4	5	1525				298	1	1525
16	<1	570	1.0	2	2	10	3	2	<1	1550				268	1	1550
21		620	2.0		2	8	4	4	1					92	1	620
22	1													1	1	1
23	<1	720	2.0	5	3	8	16	3	<1	275				129	2	720
31N	21	600	2.0	4	2	8	29	3	1					74	1	600
31S	1													1	1	1
32N	1	510	2.0	85	2	5	70	2	1		1825	250	42	233	1	1825
32S	<1													0	0	0
33N	<1	370	1.0	29	22	5	24	2	1					57	1	370
33S	<1													0	0	0
41		730	188.0	160	350	195	240	300	210					297	160	730
61			1.5	24	2	2	25	1	<1		1625	800		310	1	1625
62		1060	1.5	24	3	3	24	2						160	2	1060
63			1.0		4	3	26	3	1				5	6	1	26
64			1.0	24										13	1	24

Table 7. Conductivity of monitoring well samples by sampling date. All values are umhos/cm.

WELL	871130	880317	880622	880701	880719	880809	881202	890122	890317	890313	890428	890429	890524	AVG	MIN	MAX
1A	187	122	111.0	108.0	90.8	104.0	258	318.0					103.0	155.8	90.8	318.0
1B	168	166	908.0	575.0	362.0	543.0	201	121.0					620.0	407.1	121.0	908.0
1C	88	94	487.0	318.0	146.0	135.0	107	210.0					281.0	207.3	88.0	487.0
1D							227	259.0					724.0	403.3	227.0	724.0
1D5							344	457.0					519.0	440.0	344.0	519.0
1D7.5							252	194.0					511.0	319.0	194.0	511.0
2A			122.0	87.8	46.2	75.3	62	906.0						216.6	46.2	906.0
2B	203	337	290.0	294.0	234.0	90.9	213	301.0						245.4	90.9	337.0
2C	206	391	321.0	194.0	74.4	71.2	290	3640.0						648.5	71.2	3640.0
2D								120.0					64.8	92.4	64.8	120.0
2D5								40.1					82.7	61.4	40.1	82.7
3A	76	242	255.0		137.0		83						187.0	180.8	83.0	255.0
3B	416	490	438.0	434.0	212.0	141.0	12690	9000.0	12810	3090	465	222	125.0	3117.9	125.0	12810.0
3C	134	653	492.0	424.0	395.0	153.0	159						124.0	316.8	124.0	653.0
3D								522.0	410	410	442	394	466.0	440.7	394.0	522.0
5A	240	302	297.0	323.0	364.0	378.0	329	299.0					285.0	313.0	240.0	378.0
6A	564		630.0	610.0	521.0	429.0		357.0					853.0	566.3	357.0	853.0
6B	311	220	400.0	343.0	397.0	435.0	564	548.0	360		417	376	282.0	387.3	220.0	564.0
6C	386	396	567.0	477.0	637.0	646.0	440	320.0					757.0	514.0	320.0	757.0
6D	527	267	417.0	438.0	426.0	417.0	366	405.0					169.0	381.3	169.0	527.0
6E		331	350.0	376.0	410.0	26.2	407	393.0	268		375		390.0	332.6	26.2	410.0

Table 8. Conductivity of runoff samples by sampling date. All samples are umhos/cm.

DRAIN	87J007	880719	880607	880701	880715	880719	880803	880805	880809	881707	890317	890313	890428	AVG	MIN	MAX
11	680	1750	59.0	394.0	37.2	62.8	403.0	72.4	88.1					394.1	37.2	1750.0
12	331	2550												1440.5	331.0	2550.0
13	104													104.0	104.0	104.0
14	259	4420												2339.5	259.0	4420.0
15	46	4250	84.1	172.0	44.8	68.8	63.0	82.1	31.3	4470				931.2	31.3	4470.0
16	49	1710	42.0	61.8	39.0	104.0	96.0	47.7	34.2	4550				673.4	34.2	4550.0
21		1874	42.2		41.3	76.7	302.0	50.4	33.8					345.8	33.8	1874.0
22	40													40.0	40.0	40.0
23	35	2140	55.3	73.4	42.8	110.0	203.0	67.9	43.0	950				372.0	35.0	2140.0
31N	447	1770	82.1	108.0	50.3	113.0	444.0	67.5	54.4					348.5	50.3	1770.0
31S	79													79.0	79.0	79.0
32N	76	1440	70.3	603.0	66.5	143.0	594.0	38.8	34.2		5540	997	69	806.0	34.2	5540.0
32S	55													55.0	55.0	55.0
33N	62	1213	64.3	371.0	267.0	94.0	335.0	51.5	65.1					280.3	51.5	1213.0
33S	53													53.0	53.0	53.0
41		2420	975.0	682.0	465.0	949.0	1146.0	1449.0	1006.0					1136.5	465.0	2420.0
61			107.0	452.0	64.6	15.0	446.0	82.2	67.3		4930	1460		847.1	15.0	4930.0
62		3460	76.0	454.0	82.2	126.0	445.0	43.5						669.5	43.5	3460.0
63			98.6		107.0	149.0	454.0	97.1	84.4				121	158.7	84.4	454.0
64			87.8	466.0										276.9	87.8	466.0

Table 9. Sodium concentration of monitoring well samples by sampling date. All values are mg/l.

WELL	871130	880317	880622	880701	880719	880809	881702	890122	890317	890313	890428	890429	890524	AVG	MIN	MAX
1A	24.0	13.8	7.0	88.0	6.5	8.9	29.5	45.5						27.9	6.5	88.0
1B	31.0	23.0	70.0	87.5	45.5	72.5	44.7	37.5						51.4	23.0	87.5
1C	17.0	4.5	30.0	29.0	22.6	25.0	23.4	62.5						26.8	4.5	62.5
1D							29.0	37.5						33.3	29.0	37.5
1D5							44.0	50.0						47.0	44.0	50.0
1D7.5							35.5	37.5						36.5	35.5	37.5
2A			11.5	6.0	5.9	11.0	4.5	187.5						37.7	4.5	187.5
2B	25.0	22.2	33.0	31.5	28.0	8.3	30.5	35.0						26.7	8.3	35.0
2C	12.5	26.8	67.5	23.0	11.1	9.5	35.0	680.0						108.2	9.5	680.0
2D								13.0						13.0	13.0	13.0
2D5								1.8						1.8	1.8	1.8
3A	1.2	46.5	29.5		33.0		5.0							23.0	1.2	46.5
3B	38.5	82.5	21.5	18.0	9.1	6.2	2250.0	2125.0	7300.0	300.0	55.2	29.6		1019.6	6.2	7300.0
3C	2.1	117.5	37.5	17.0	12.8	2.8	5.4							27.9	2.1	117.5
3D								37.5	16.0	16.5	14.6	15.2		20.0	14.6	37.5
5A	19.0	36.5	5.5	42.5	40.0	45.2	30.9	25.0						30.6	5.5	45.2
6A	3.0		3.0	4.0	3.2	1.8		3.5						3.1	1.8	4.0
6B	1.3	2.4	57.5	3.0	2.1	2.2	8.5	12.5	24.0		3.2	3.6		10.9	1.3	57.5
6C	8.5	2.8	6.0	62.5	54.0	48.2	6.0	12.5						25.1	2.8	62.5
6D	4.8	4.0	19.5	6.5	5.3	5.7	11.5	12.5						8.7	4.0	19.5
6R		6.8	30.5	12.5	14.0	20.0	23.2	62.5	21.0		10.0			22.3	6.8	62.5

Table 10. Concentration of sodium in runoff samples by sampling date. All samples are mg/l.

DRAIN	871007	880219	880607	880701	880715	880719	880803	880805	880809	881202	890312	890313	890428	AVG	MIN	MAX
11	17.4	315	4	15.5	1.0	2.1	14.4	7.8	2.0					42.1	1.0	315.0
12	10.8	420												215.4	10.8	420.0
13	4.8													4.8	4.8	4.8
14	9.3	800												404.7	9.3	800.0
15	2.3	800	4	9.5	2.0	1.5	1.5	7.0	6.0	1100				193.4	1.5	1100.0
16	7.1	780	1	1.5	0.9	5.3	3.0	3.8	0.7	875				112.3	0.7	875.0
21		290	1		1.0	2.1	1.9	5.7	0.8					43.2	0.8	290.0
22	1.7													1.7	1.7	1.7
23	1.3	350	2	3.5	0.9	2.6	8.4	5.8	2.0	100				47.7	0.9	350.0
31N	16.4	320	3	3.5	1.3	4.8	15.7	3.7	1.8					41.1	1.3	320.0
31S	2.9													2.9	2.9	2.9
32N	3.6	335	4	57.5	1.7	5.3	41.0	3.0	1.5		487.5	87.5	6.1	86.1	1.5	487.5
32S	2.4													2.4	2.4	2.4
33N	2.6	215	2	14.0	9.7	3.2	13.2	3.5	2.6					29.5	2.0	215.0
33S	2.9													2.9	2.9	2.9
41		400	103	85.0	190.0	105.0	122.0	65.0	115.5					148.2	65.0	400.0
61			5	8.0	1.6	5.0	7.1	9.0	3.2		462.0	130.0		70.1	1.6	462.0
62		490	6	7.0	1.7	5.3	6.3	6.5						74.7	1.7	490.0
63			4		1.5	3.2	7.0	6.7	3.0				18.0	6.2	1.5	18.0
64			4	6.5										5.3	4.0	6.5

Table 11. Ammonium concentration of monitoring well samples by sampling date. All values are mg/l.

WELL	871130	880317	880622	880701	880719	880809	881202	890122	890317	890313	890428	890429	890524	AVG	MIN	MAX
1A	0.02	0.14	0.16	0.21	0.10	0.02	0.03	0.07						0.09	0.02	0.21
1B	<0.01	0.08	0.12	0.10	0.10	0.08	0.02	0.07						0.08	0.02	0.12
1C	<0.01	0.04	0.90	0.12	0.18	0.10	0.05	0.10						0.21	0.04	0.90
1D							0.02	0.03						0.03	0.02	0.03
1D5							0.01	0.01						0.01	0.01	0.01
1D7.5							<0.01	0.01						0.01	0.01	0.01
2A			0.14	0.16	0.25	0.02	0.12	0.30						0.17	0.02	0.30
2B	0.08	0.20	0.20	0.12	0.03	0.04	0.04	0.13						0.11	0.03	0.20
2C	0.11	0.10	0.15	0.06	0.07	0.02	0.44	1.36						0.29	0.02	1.36
2D								0.06						0.06	0.06	0.06
2D5								0.04						0.04	0.04	0.04
3A	<0.01	0.04	0.15		0.10		0.04							0.08	0.04	0.15
3B	2.20	0.56	0.26	0.34	0.14	0.08	0.65	0.13	0.60	0.20	0.02	<0.01		0.47	0.02	2.20
3C	0.05	0.06	0.12	0.06	0.12	0.02	0.06							0.07	0.02	0.12
3D								0.04	<0.02	<0.02	0.01	<0.01		0.03	0.01	0.04
5A	0.01	0.10	0.21	0.18	0.08	0.14	0.06	0.17						0.12	0.01	0.21
6A	<0.01		0.35	0.18	0.10	0.06		0.03						0.14	0.03	0.35
6B	<0.01	0.04	0.18	0.15	0.04	0.06	0.02	0.04	0.02		<0.01	<0.01		0.07	0.02	0.18
6C	<0.01	0.10	0.16	0.18	0.10	0.03	0.01	0.05						0.09	0.01	0.18
6D	0.01	0.08	0.18	0.06	0.06	0.03	0.02	0.04						0.06	0.01	0.18
6R		0.08	0.16	0.22	0.09	0.12	0.09	0.12	0.32		<0.01			0.15	0.08	0.32

Table 12. Concentration of ammonium nitrogen in runoff samples by sampling date. All samples are mg/l.

DRAIN	871007	880719	880607	880701	880715	880719	880803	880805	880809	881707	890317	890313	890478	AVG	MIN	MAX
11	0.50	0.6	0.58	0.33	0.24	0.20	0.76	0.33	0.04					0.40	0.04	0.76
12	0.05	0.6												0.33	0.05	0.60
13	0.02													0.02	0.02	0.02
14	<0.02	0.8												0.80	0.80	0.80
15	0.20	0.8	0.78	0.18	0.34	0.27	0.06	0.04	0.11	0.72				0.35	0.04	0.80
16	0.22	1.0	0.70	0.38	0.45	0.08	0.63	0.60	0.07	0.78				0.49	0.07	1.00
21		0.6	0.71		0.18	0.24	0.02	0.63	0.14					0.36	0.02	0.71
22	0.25													0.25	0.25	0.25
23	0.25	0.8	0.56	0.20	0.18	0.02	0.03	0.24	0.08	0.36				0.27	0.02	0.80
31N	0.62	0.4	0.78	0.75	0.27	0.22	9.60	0.24	0.10					1.44	0.10	9.60
31S	0.20													0.20	0.20	0.20
32N	0.05	0.4	0.66	0.32	0.21	0.24	4.20	0.42	0.04		0.50	0.60	0.37	0.67	0.04	4.20
32S	0.02													0.02	0.02	0.02
33N	<0.02	0.6	0.62	0.22	0.18	0.50	0.80	0.21	0.06					0.40	0.06	0.80
33S	0.06													0.06	0.06	0.06
41		0.6	0.83	1.62	2.00	0.78	0.96	1.98	1.04					1.23	0.60	2.00
61			0.12	0.09	0.17	<0.01	0.06	0.09	0.03		0.10	0.28		0.12	0.03	0.28
62		0.2	0.24	0.10	0.14	0.04	0.10	0.18						0.14	0.04	0.24
63			0.08		0.10	0.01	0.03	0.06	0.04				0.14	0.07	0.01	0.14
64			0.16	0.24										0.20	0.16	0.24

Table 13. Nitrate nitrogen concentration in monitoring well samples by sampling date. All values are mg/l.

WELL	871130	880317	880627	880701	880719	880809	881707	890127	890317	890313	890428	890429	890524	AVG	MIN	MAX
1A	2.75	2.0	2.5	2.8	1.2	2.0	1.0	2.2					3.2	2.2	1.0	3.2
1B	1.54	3.5	6.0	3.5	1.8	4.0	1.5	7.5					9.5	3.8	1.5	9.5
1C	1.02	3.2	4.0	1.8	1.8	2.5	0.8	4.0					5.0	2.7	0.8	5.0
1D							3.0	7.5					7.0	4.2	2.5	7.0
1D5							4.0	5.5					5.0	4.8	4.0	5.5
1D7.5							3.2	7.5					3.0	2.9	2.5	3.2
2A			4.0	2.0	0.8	3.5	1.2	0.2						2.0	0.2	4.0
2B	2.70	2.8	6.0	2.5	3.8	1.0	3.0	3.2						3.1	1.0	6.0
2C	1.90	3.2	2.8	5.0	1.5	3.0	3.2	<0.2						2.9	1.5	5.0
2D								1.0					<0.2	1.0	1.0	1.0
2D5								3.0					3.0	3.0	3.0	3.0
3A	0.60	0.8	1.5		1.8		0.8						1.2	1.1	0.6	1.8
3B	0.03	1.2	7.5	8.8	2.0	0.5	1.0	2.5	3.0	1.5	8.0	1.8	1.2	3.0	0.0	8.8
3C	0.88	2.0	5.2	5.8	11.5	0.5	0.5						0.2	3.3	0.2	11.5
3D								16.0	7.0	7.0	11.5	10.0	13.8	10.9	7.0	16.0
5A	0.77	3.5	30.0	4.0	2.2	3.0	7.5	3.8					4.8	6.6	0.8	30.0
6A	24.40		26.0	29.5	25.5	10.2		2.0					7.0	17.8	2.0	29.5
6B	12.40	4.0	2.0	16.5	25.5	27.0	7.0	9.0	6.0		10.0	10.0	7.5	11.4	2.0	27.0
6C	3.60	26.5	11.5	2.0	5.6	5.8	12.5	1.5					9.0	8.7	1.5	26.5
6D	19.60	7.8	10.0	11.0	12.8	10.5	3.5	14.2					0.2	10.0	0.2	19.6
6E		9.8	30.0	10.5	10.0	8.0	10.5	11.8	1.0		9.0		8.5	10.9	1.0	30.0

Table 34. Concentration of zinc in runoff samples by sampling date. All values are mg/l.

DRAIN	871007	880719	880602	880701	880715	880719	880803	880805	880809	881202	890312	890313	890428	AVG	MIN	MAX
11		0.11	0.06	0.14			0.04		0.28					0.13	0.04	0.28
12		0.26												0.26	0.26	0.26
13														0.00	0.00	0.00
14		0.39												0.39	0.39	0.39
15		0.18	0.15	0.16			0.01		0.11	0.57				0.20	0.01	0.57
16		0.12	0.03	0.12			0.08		0.02	0.77				0.19	0.02	0.77
21		0.33	0.38				0.32		0.50					0.38	0.32	0.50
22														0.00	0.00	0.00
23		0.10	0.04	0.73			0.09		0.04	0.22				0.20	0.04	0.73
31N		0.13	0.03	0.06			0.03		0.22					0.09	0.03	0.22
31S														0.00	0.00	0.00
32N		0.04	0.03	0.62			0.01		0.06		0.42	0.09	0.05	0.17	0.01	0.62
32S														0.00	0.00	0.00
33N		0.06	0.02	0.32			0.14		0.03					0.11	0.02	0.32
33S														0.00	0.00	0.00
41		0.38	0.06	0.10			1.07		0.11					0.34	0.06	1.07
61			0.02	0.04			0.14		<0.01		0.17	0.14		0.10	0.02	0.17
62		0.03	0.02	0.03			0.11							0.05	0.02	0.11
63			0.02				0.09		0.01				0.09	0.05	0.01	0.09
64			0.03	0.04										0.04	0.03	0.04

Table 14. Concentration of nitrate nitrogen in runoff samples by sampling date. All samples are mg/l.

DRAIN	871007	880219	880607	880701	880715	880719	880803	880805	880809	881207	890312	890313	890428	AVG	MIN	MAX
11	17.5	0.5	1.0	3.5	0.5	0.5	<0.2	1.0	<0.2					3.5	0.5	17.5
12	4.5	0.8												2.7	0.8	4.5
13	0.5													0.5	0.5	0.5
14	2.0	1.2												1.6	1.2	2.0
15	0.5	1.0	1.0	1.0	1.0	0.5	1.5	0.8	0.2	0.8				0.8	0.2	1.5
16	<0.2	1.0	0.5	0.5	0.8	0.2	0.5	1.0	<0.2	0.8				0.7	0.2	1.0
21		0.5	0.5		0.5	<0.2	<0.2	0.8	<0.2					0.6	0.5	0.8
22	0.2													0.2	0.2	0.2
23	<0.2	0.8	0.5	0.5	0.5	<0.2	<0.2	0.8	<0.2	0.5				0.6	0.5	0.8
31N	1.0	0.2	0.8	0.5	0.5	0.5	<0.2	0.5	0.5					0.6	0.2	1.0
31S	<0.2													0.0	0.0	0.0
32N	<0.2	0.2	1.0	5.0	0.8	0.5	<0.2	0.5	0.5		1.0	1.0	0.5	1.1	0.2	5.0
32S	<0.2													0.0	0.0	0.0
33N	<0.2	0.5	0.8	4.0	3.5	0.8	<0.2	0.5	0.5					1.5	0.5	4.0
33S	<0.2													0.0	0.0	0.0
41		0.6	0.5	<0.2	0.5	0.8	0.5	0.5	0.5					0.6	0.5	0.8
61			1.0	12.0	0.5	1.0	10.0	0.5	0.2		2.0	0.8		3.1	0.2	12.0
62		1.0	1.0	12.5	0.5	1.5	10.5	0.5						3.9	0.5	12.5
63			1.0		0.8	1.5	11.2	0.5	0.2				0.5	2.2	0.2	11.2
64			1.0	11.5										6.3	1.0	11.5

Table 15. Total Kjedahl Nitrogen concentration of monitoring well samples. All values are mg/l.

WELL	870130	880317	880622	880701	880719	880809	881202	890122	890317	890313	890428	890429	890524	AVG	MIN	MAX
1A			0.89											0.89	0.89	0.89
1B			0.42											0.42	0.42	0.42
1C			0.49											0.49	0.49	0.49
1D														0.00	0.00	0.00
1D5														0.00	0.00	0.00
1D7.5														0.00	0.00	0.00
2A			0.09											0.09	0.09	0.09
2B			0.54											0.54	0.54	0.54
2C			0.50											0.50	0.50	0.50
2D														0.00	0.00	0.00
2D5														0.00	0.00	0.00
3A														0.00	0.00	0.00
3B			0.89											0.89	0.89	0.89
3C			0.12											0.12	0.12	0.12
3D														0.00	0.00	0.00
5A			0.59											0.59	0.59	0.59
6A			0.69											0.69	0.69	0.69
6B			0.69											0.69	0.69	0.69
6C			0.68											0.68	0.68	0.68
6D			0.36											0.36	0.36	0.36
6R			1.78											1.78	1.78	1.78

Table 16. Concentration of total Kjeldahl nitrogen in runoff samples by sampling date. All

DRAIN	871007	880719	880607	880701	880715	880719	880803	880805	880809	881207	890317	890313	890428	AVG	MIN	MAX
11	90.00		0.96	1.48	0.68	0.32		2.95						16.07	0.32	90.00
12	0.97													0.97	0.97	0.97
13	1.78													1.78	1.78	1.78
14	5.30													5.30	5.30	5.30
15	2.00		1.26	1.38	0.66	0.62	1.78	2.70						1.49	0.62	2.70
16	1.46		0.90	0.52	1.07	0.71		2.10						1.13	0.52	2.10
21			1.58		0.72	0.80								1.03	0.72	1.58
22	2.02													2.02	2.02	2.02
23	1.48		2.00	0.80	0.50	0.60		5.30						1.78	0.50	5.30
31N	22.80		1.70	1.58	1.18	0.78								5.61	0.78	22.80
31S	4.00													4.00	4.00	4.00
32N	3.00		0.92	0.45	1.18	1.02		2.15						1.45	0.45	3.00
32S	1.07													1.07	1.07	1.07
33N	2.40		1.16	1.94	0.69	0.93		2.40						1.59	0.69	2.40
33S	1.10													1.10	1.10	1.10
41			1.64	5.70	3.50	1.64								3.12	1.64	5.70
61			0.26	0.38	0.54	0.24	0.72	0.10						0.37	0.10	0.72
62			0.56	0.40	0.28	0.36	0.74	0.50						0.47	0.28	0.74
63			0.08		1.09	0.30	0.70	0.10						0.45	0.08	1.09
64			0.24	1.84										1.04	0.24	1.84

Table 17. pH of monitoring well samples by sampling date. All values are standard pH units.

WELL	871130	880317	880622	880701	880719	880809	881207	890122	890312	890313	890428	890429	890524	AVG	MIN	MAX
1A	6.31	6.92	6.62	6.69	6.35	6.56	6.16	6.10					6.33	6.45	6.10	6.92
1B	6.18	7.00	6.31	6.42	6.28	6.17	6.68	6.45					5.93	6.38	5.93	7.00
1C	6.43	6.61	6.27	6.51	6.51	6.48	6.64	6.77					5.87	6.45	5.87	6.77
1D							6.71	6.58					6.26	6.52	6.26	6.71
1D5							7.90	8.02					7.89	7.94	7.89	8.02
1D7.5							6.92	7.08					6.68	6.89	6.68	7.08
2A			6.75	6.81	6.50	6.37	6.18	6.94						6.59	6.18	6.94
2B	6.63	7.07	7.26	7.30	6.26	6.60	6.22	6.26						6.69	6.22	7.30
2C	6.82	7.14	6.75	7.08	6.33	6.21	6.11	6.80						6.66	6.11	7.14
2D								6.53					6.59	6.56	6.53	6.59
2D5								6.52					6.41	6.47	6.41	6.52
3A	7.05	8.24	8.00		7.35		6.75						7.37	7.46	6.75	8.24
3B	6.79	7.78	7.40	7.34	7.30	6.94	6.41	6.77	7.14	7.27	7.38	7.11	7.30	7.15	6.41	7.78
3C	7.78	8.26	7.39	7.44	6.99	7.08	7.20						7.27	7.43	6.99	8.26
3D								6.42	6.38	6.36	6.42	6.40	6.37	6.39	6.36	6.42
5A	6.96	7.27	6.99	6.75	6.67	6.24	6.37	6.34					6.18	6.64	6.18	7.27
6A	6.90		7.44	7.36	7.05	7.09		7.30					7.18	7.19	6.90	7.44
6B	6.43	7.64	7.59	7.46	7.33	7.16	6.93	6.94	7.22		7.32	7.25	7.15	7.20	6.43	7.64
6C	7.36	7.36	7.96	7.98	7.57	7.19	6.86	7.32					7.11	7.41	6.86	7.98
6D	7.04	7.91	7.65	7.61	7.24	6.89	7.23	6.49					6.42	7.16	6.42	7.91
6E		7.23	7.38	6.80	6.67	7.02	6.69	6.53	6.95		6.72		6.70	6.87	6.53	7.38

Table 18. pH of runoff samples by sampling date. All values are standard pH units.

DRAIN	870107	880219	880607	880701	880715	880719	880803	880805	880809	881207	890312	890313	890428	AVG	MIN	MAX
11	5.65	7.23	6.72	7.54	6.97	7.16	7.41	7.06	6.88					6.96	5.65	7.54
12	7.74	7.32												7.53	7.32	7.74
13	7.25													7.25	7.25	7.25
14	7.13	7.53												7.33	7.13	7.53
15	7.05	7.55	7.15	6.92	6.79	6.92	7.09	6.78	7.07	6.73				7.01	6.73	7.55
16	7.27	7.24	6.87	7.14	7.04	6.88	7.32	6.74	6.51	6.21				6.92	6.21	7.32
21		7.10	6.14		6.67	6.73	6.94	6.61	6.48					6.67	6.14	7.10
22	6.51													6.51	6.51	6.51
23	6.84	7.38	6.60	7.03	6.90	6.49	7.03	6.73	6.67	6.78				6.85	6.49	7.38
31N	6.90	7.63	6.90	7.20	6.84	7.18	7.39	7.00	7.12					7.13	6.84	7.63
31S	6.76													6.76	6.76	6.76
32N	6.84	7.42	7.15	7.67	7.23	7.68	7.42	6.94	6.89		7.09	7.10	7.69	7.26	6.84	7.69
32S	6.86													6.86	6.86	6.86
33N	6.93	7.09	6.99	7.59	7.52	7.18	7.66	7.16	7.23					7.26	6.93	7.66
33S	7.26													7.26	7.26	7.26
41		7.30	7.09	7.06	6.80	7.08	7.06	6.98	6.77					7.02	6.77	7.30
61			8.02	8.07	8.22	7.71	8.07	7.86	7.68		8.31	8.27		8.02	7.68	8.31
62		7.45	7.87	8.15	7.64	7.87	8.01	7.51						7.79	7.45	8.15
63			7.79		7.58	7.59	8.00	8.03	7.76				8.81	7.94	7.58	8.81
64			7.94	7.92										7.93	7.92	7.94

ble 19. Reactive Phosphorus concentration of monitoring well samples by sampling dates. All values are mg/l.

WI	871130	880317	880622	880701	880719	880809	881207	890122	890317	890313	890428	890429	890524	AVG	MIN	MAX
1A	<0.002	<0.002	0.005	0.002	0.002	<0.002	<0.002	<0.002						0.003	0.002	0.005
1B	0.005	<0.002	<0.002	0.002	<0.002	<0.002	<0.002	<0.002						0.004	0.002	0.005
1C	<0.002	<0.002	0.002	0.002	<0.002	<0.002	<0.002	<0.002						0.002	0.002	0.002
1D							<0.002	<0.002						0.000	0.000	0.000
1D5							<0.002	<0.002						0.000	0.000	0.000
107.5							<0.002	<0.002						0.000	0.000	0.000
2A			0.005	0.005	0.010	<0.002	<0.002	<0.002						0.007	0.005	0.010
2B	<0.002	<0.002	<0.002	0.002	<0.002	<0.002	<0.002	<0.002						0.002	0.002	0.002
2C	<0.002	<0.002	0.008	0.002	<0.002	<0.002	<0.002	0.005						0.005	0.002	0.008
2D								<0.002						0.000	0.000	0.000
2D5								<0.002						0.000	0.000	0.000
3A	<0.002	0.370	0.222		0.275		0.032							0.225	0.032	0.370
3B	<0.002	0.010	0.110	0.085	0.145	0.155	0.026	<0.002	0.042	0.228	0.045	0.070		0.092	0.010	0.228
3C	<0.002	0.070	0.145	0.140	0.130	0.108	0.100							0.116	0.070	0.145
3D								<0.002	<0.002	<0.002	0.002	0.002		0.002	0.002	0.002
5A	<0.002	<0.002	0.012	0.010	0.005	<0.002	<0.002	<0.002						0.009	0.005	0.012
6A	<0.002		0.010	0.008	0.002	<0.002		<0.002						0.007	0.002	0.010
6B	<0.002	<0.002	0.005	0.005	0.002	<0.002	<0.002	<0.002	<0.002		0.002	<0.002		0.004	0.002	0.005
6C	<0.002	0.010	0.010	0.005	0.002	<0.002	<0.002	<0.002						0.007	0.002	0.010
6D	<0.002	<0.002	0.006	0.002	0.030	<0.002	<0.002	<0.002						0.013	0.002	0.030
6E		<0.002	0.008	0.002	0.002	<0.002	<0.002	<0.002	0.025		0.002			0.008	0.002	0.025

Table 20. Concentration of reactive phosphorous in runoff samples by sampling date. All values are mg/l.

DRAIN	871007	880219	880607	880701	880715	880719	880803	880805	880809	881207	890317	890313	890428	AVG	MIN	MAX
11	13.600	0.080	0.050	0.015	0.002	0.002	0.035	0.010	0.015					1.534	0.002	13.600
12	0.032	0.020												0.026	0.020	0.032
13	0.095													0.095	0.095	0.095
14	0.200	<0.002												0.200	0.200	0.200
15	0.055	<0.002	0.042	0.010	<0.002	0.060	0.015	0.005	0.012	0.006				0.026	0.005	0.060
16	0.046	<0.002	0.045	0.040	<0.002	0.002	0.025	0.020	0.008	0.008				0.024	0.002	0.046
21		<0.002	0.062		<0.002	0.005	0.012	0.002	0.005					0.017	0.002	0.062
22	0.040													0.040	0.040	0.040
23	0.026	0.120	0.088	0.040	0.015	0.005	0.005	0.002	0.002	0.005				0.031	0.002	0.120
31N	8.100		0.080	0.035	<0.002	<0.002	0.825	0.098	0.038					1.529	0.035	8.100
31S	0.452	0.020												0.236	0.020	0.452
32N	0.318		0.105	0.435	<0.002	0.055	0.400	0.040	0.008		0.002	0.150	0.050	0.156	0.002	0.435
32S	0.092	0.020												0.056	0.020	0.092
33N	0.105		0.025	0.070	<0.002	0.020	0.170	0.005	<0.002					0.066	0.005	0.170
33S	0.090	0.050												0.070	0.050	0.090
41			0.010	0.367	<0.002	0.002	0.005	0.002	<0.002					0.076	0.002	0.362
		<0.002														
61			0.020	0.020	<0.002	<0.002	0.058	0.010	<0.002		0.005	0.002		0.019	0.002	0.058
62			0.045	0.020	0.145	<0.002	0.075	0.015						0.060	0.015	0.145
63		<0.002	0.028		0.068	<0.002	0.060	0.035	0.018				0.040	0.042	0.018	0.068
64			0.030	0.110										0.070	0.030	0.110

Table 21. Total phosphorous concentration of monitoring well samples. All values are mg/l.

WELL	871130	880317	880622	880701	880719	880809	881202	890122	890312	890313	890428	890429	890524	AVG	MIN	MAX
1A			0.140	0.015	0.020	0.050	0.015	0.008						0.041	0.008	0.140
1B			0.055	0.010	0.010	0.048	0.015	0.010						0.025	0.010	0.055
1C			0.040	0.015	0.015	0.050	0.008	0.006						0.022	0.006	0.050
1D							0.005	0.008						0.007	0.005	0.008
1D5							0.002	0.010						0.006	0.002	0.010
1D7.5							0.005	0.005						0.005	0.005	0.005
2A			0.016	0.008	0.022	0.038	0.005	0.010						0.017	0.005	0.038
2B			<0.002	0.030	0.010	0.025	0.008	0.008						0.016	0.008	0.030
2C			0.008	0.010	0.005	0.025	0.012	0.025						0.014	0.005	0.025
2D								0.010						0.010	0.010	0.010
2D5								0.005						0.005	0.005	0.005
3A			0.225		0.290		0.035							0.183	0.035	0.290
3B			0.120	0.095	0.215	0.188	0.035	0.030	0.065	0.250				0.125	0.030	0.250
3C			0.450	0.145	0.135	0.150	0.105							0.197	0.105	0.450
3D								0.008	0.010	0.005				0.008	0.005	0.010
5A			0.070	0.070	0.010	0.038	0.018	0.005						0.019	0.005	0.038
6A			0.010	0.012	0.010	0.012		0.005						0.010	0.005	0.012
6B			0.075	0.010	0.010	0.075	0.018	0.005	0.005					0.014	0.005	0.025
6C			0.025	0.025		0.012	0.015	0.010						0.017	0.010	0.025
6D			0.010	0.015	0.045	0.038	0.042	0.010						0.027	0.010	0.045
6R			0.020	0.925	0.015	<0.002	0.042	0.010	0.140					0.192	0.010	0.925

Table 22. Concentration of total phosphorous in runoff samples by sampling date. All values are mg/l.

DRAIN	871007	880719	880602	880701	880715	880719	880803	880805	880809	881207	890317	890313	890428	AVG	MIN	MAX
11		0.135	0.050	0.212	0.005	0.010		0.350						0.127	0.005	0.350
12		0.070												0.020	0.020	0.020
13														0.000	0.000	0.000
14		0.028												0.028	0.028	0.028
15		0.042	0.042	0.075	<0.002	0.090	0.138	0.400		0.500				0.184	0.042	0.500
16		0.020	0.045	0.055	<0.007	0.015	0.180	0.068		0.025				0.058	0.015	0.180
21		0.008	0.080		0.005	0.018	0.385							0.099	0.005	0.385
22														0.000	0.000	0.000
23		0.075	0.090	0.107	0.015	0.020	0.220	0.675		0.010				0.152	0.010	0.675
31N		0.030	0.090	0.128	0.017	0.037								0.058	0.017	0.128
31S														0.000	0.000	0.000
32N		0.020	0.110	0.540	0.017	0.160		0.750			0.050	0.220		0.170	0.017	0.540
32S														0.000	0.000	0.000
33N		0.050	0.035	0.220	0.010	0.060	0.490	0.550						0.202	0.010	0.550
33S														0.000	0.000	0.000
41		0.015	0.010	0.478	0.010	0.008								0.104	0.008	0.478
61			0.020	0.040	0.005	0.010	0.105	0.050			0.056	0.030		0.040	0.005	0.105
62		0.032	0.045	0.035	0.160	0.018	0.120	0.038						0.064	0.018	0.160
63			0.030		0.078	0.025	0.098	0.050						0.056	0.025	0.098
64			0.030	0.202										0.116	0.030	0.202

Table 23. Total Hardness of monitoring well samples by sampling date. All values are mg/l.

WELL	871130	880317	880622	880701	880719	880809	881207	890122	890317	890313	890428	890429	890524	AVG	MIN	MAX
1A		12	32	24	20	32	42	48					32	30	12	48
1B		20	228	108	56	74	16	8					132	80	8	228
1C		28	144	72	20	16	8	12					100	50	8	144
1D							44	68					180	97	44	180
1D5							84	128					164	125	84	164
1D7.5							48	40					196	95	40	196
2A			30	20	8	10	20	36						21	8	36
2B		92	60	54	40	28	32	68						53	28	92
2C		104	66	32	8	12	36	116						53	8	116
2D								24					24	24	24	24
2D5								16					36	26	16	36
3A		<4	8		<4		32						8	16	8	32
3B		20	148	160	86	76	1134	100	272	20	100	44	44	184	20	1134
3C		24	19	166	168	70	76						72	85	19	168
3D								204	172	172	192	188	196	187	172	204
5A		40	40	48	60	68	80	92					76	63	40	92
6A			300	294	256	230		188					192	243	188	300
6B		100	184	158	192	208	288	268	128		208	208	140	189	100	288
6C		172	112	72	164	184	216	140					248	164	72	248
6D		108	202	204	208	190	169	184					72	167	72	208
6E		128	116	144	180	108	144	148	72		160		172	137	72	180

Table 24. Total hardness of runoff samples by sampling date. All values are mg/l.

DRAIN	871007	880719	880607	880701	880715	880719	880803	880805	880809	881202	890317	890313	890428	AVG	MIN	MAX
11	262	32	20	164	12	26	174	20	16					81	12	262
12	152	72												112	72	152
13	56													56	56	56
14	108	164												136	108	164
15	28	120	36	64	16	28	24	36	32	112				50	16	120
16	18	60	16	205	16	40	40	22	14	128				56	14	205
21		36	12		16	34	158	16	20					42	12	158
22	20													20	20	20
23	22	72	28	32	20	52	100	32	24	60				44	20	100
31N	196	36	28	40	24	44	156	44	28					66	24	196
31S	40													40	40	40
32N	36	20	32	160	26	60	188	20	16		116	40	20	61	16	188
32S	36													36	36	36
33N	34	28	28	150	112	36	140	30	28					65	28	150
33S	30													30	30	30
41		100	240	110	292	232	272	368	208					228	100	368
61			36	212	32	52	220	36	28		104	76		88	28	220
62		236	28	234	36	56	212	20						117	20	236
63			40		48	60	210	48	32				20	65	20	210
64			32	216										124	32	216

le 25. Cadmium concentration of monitoring well samples by sampling date. All values are mg/l.

]130	880317	880627	880701	880719	880809	881207	890127	890317	890313	890428	890429	890524	AVG	MIN	MAX
A	<0.005	<0.005	<0.005		0.004	0.005	<0.005					<0.005	0.005	0.004	0.005
B	<0.005	<0.005	<0.005		0.032	0.004	<0.005					<0.005	0.018	0.004	0.032
C	0.015	<0.005	<0.005		0.019	<0.002	<0.005					<0.005	0.019	0.019	0.019
D						<0.002	<0.005					<0.005	0.000	<0.000	0.000
D5						<0.002	<0.005					<0.005	0.000	<0.000	0.000
7.5						<0.002	<0.005					<0.005	0.000	<0.000	0.000
A		<0.005	<0.005		0.008	<0.002							0.008	0.008	0.008
B	<0.005	<0.005	<0.005		0.002	0.004							0.003	0.002	0.004
C	<0.005	<0.005	<0.005		<0.002	0.014							0.014	0.014	0.014
D							<0.005					<0.005	<0.000	<0.000	<0.000
D5							<0.005					<0.005	<0.000	<0.000	<0.000
A	<0.005	<0.005				0.006						<0.005	0.006	0.006	0.006
B	<0.005	<0.005	<0.005		<0.002	0.007	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.007	0.007	0.007
C	<0.005	<0.005	<0.005		<0.002	<0.002						<0.005	0.000	0.000	0.000
D							<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.000	0.000	0.000
A	<0.005	<0.005	<0.005		<0.002	0.004	<0.005					<0.005	0.004	0.004	0.004
A		<0.005	<0.005		<0.002		<0.005					<0.005	0.000	0.000	0.000
B	<0.005	<0.005	<0.005		<0.002	<0.002	<0.005	<0.005		<0.005	<0.005	<0.005	0.000	0.000	0.000
C	<0.005	<0.005	<0.005		<0.002	<0.002	<0.005					<0.005	0.000	0.000	0.000
D	<0.005	<0.005	<0.005		<0.002	<0.002						<0.005	0.000	0.000	0.000
R	<0.005	<0.005	<0.005		<0.002	<0.002	<0.005	<0.005		<0.005		<0.005	0.000	0.000	0.000

Table 26. Concentration of cadmium in runoff samples by sampling date. All samples are mg/l.

DRAIN	871007	880219	880602	880701	880715	880719	880803	880805	880809	881707	890312	890313	890428	AVG	MIN	MAX
11		<0.005	<0.005	<0.005			<0.002		<0.002					0.000	0.000	0.000
12		<0.005												0.000	0.000	0.000
13														0.000	0.000	0.000
14		<0.005												0.000	0.000	0.000
15		<0.005	<0.005	<0.005			<0.002		<0.002	0.008				0.008	0.008	0.008
16		<0.005	<0.005	<0.005			<0.002		0.008	0.010				0.009	0.008	0.010
21		<0.005	<0.005				<0.002		<0.002					0.000	0.000	0.000
22														0.000	0.000	0.000
23		<0.005	<0.005	<0.005			<0.002		<0.002	<0.002				0.000	0.000	0.000
31N		<0.005	<0.005	<0.005			<0.002		<0.002					0.000	0.000	0.000
31S														0.000	0.000	0.000
32N		<0.005	<0.005	<0.005			<0.002		<0.002		<0.005	<0.005	<0.005	0.000	0.000	0.000
32S														0.000	0.000	0.000
33N		<0.005	<0.005	<0.005			0.030		<0.002					0.030	0.030	0.030
33S														0.000	0.000	0.000
41		<0.005	<0.005	<0.005			0.060		<0.002					0.060	0.060	0.060
61			<0.005	<0.005			0.030		<0.002		<0.005	<0.005		0.030	0.030	0.030
62		<0.005	<0.005	<0.005			0.020							0.020	0.020	0.020
63			<0.005				0.020		<0.002				<0.005	0.020	0.020	0.020
64			<0.005	<0.005										0.000	0.000	0.000

Table 27. Chromium concentration of monitoring well samples by sampling date. All values are mg/l.

WELL	870130	880317	880622	880701	880719	880809	881707	890122	890313	890313	890428	890429	890524	AVG	MIN	MAX
1A	<0.02												<0.02	0.00	0.00	0.00
1B	<0.02												<0.02	0.00	0.00	0.00
1C	<0.02												<0.02	0.00	0.00	0.00
1D													<0.02	0.00	0.00	0.00
1D5													<0.02	0.00	0.00	0.00
1D7.5													<0.02	0.00	0.00	0.00
2A														0.00	0.00	0.00
2B	<0.02													0.00	0.00	0.00
2C	<0.02													0.00	0.00	0.00
2D													<0.02	0.00	0.00	0.00
2D5													<0.02	0.00	0.00	0.00
3A	<0.02												<0.02	0.00	0.00	0.00
3B	<0.02							<0.02	<0.02	<0.02	<0.02		<0.02	0.00	0.00	0.00
3C	<0.02												<0.02	0.00	0.00	0.00
3D								<0.02	<0.02	<0.02	<0.02		<0.02	0.00	0.00	0.00
5A	<0.02												<0.02	0.00	0.00	0.00
6A	<0.02												<0.02	0.00	0.00	0.00
6B	<0.02							<0.02			<0.02	<0.02	<0.02	0.00	0.00	0.00
6C	<0.02												<0.02	0.00	0.00	0.00
6D	<0.02												<0.02	0.00	0.00	0.00
6E								<0.02			<0.02		<0.02	0.00	0.00	0.00

Table 28. Concentration of chromium in runoff samples by sampling date. All samples are mg/l.

DRAIN	871007	880719	880607	880701	880715	880719	880803	880805	880809	881707	890317	890313	890428	AVG	MIN	MAX
11														0.00	0.00	0.00
12														0.00	0.00	0.00
13														0.00	0.00	0.00
14														0.00	0.00	0.00
15														0.00	0.00	0.00
16														0.00	0.00	0.00
21														0.00	0.00	0.00
22														0.00	0.00	0.00
23														0.00	0.00	0.00
31N														0.00	0.00	0.00
31S														0.00	0.00	0.00
32N											0.05	0.02	<0.02	0.04	0.02	0.05
32S														0.00	0.00	0.00
33N														0.00	0.00	0.00
33S														0.00	0.00	0.00
41														0.00	0.00	0.00
61											0.07	0.05		0.06	0.05	0.07
62														0.00	0.00	0.00
63													<0.02	0.00	0.00	0.00
64														0.00	0.00	0.00

Table 29. Copper concentration of monitoring well samples by sampling date. All values are mg/l.

WELL	871130	880317	880622	880701	880719	880809	881202	890122	890317	890313	890428	890429	890524	AVG	MIN	MAX
1A	0.03	<0.01	0.01	0.03		0.01	0.07	0.01					0.02	0.03	0.01	0.07
1B	0.03	0.02	0.05	0.05		0.02	0.03	<0.01					0.04	0.03	0.02	0.05
1C	0.03	0.02	0.04	0.05		0.02	0.03	0.01					0.03	0.03	0.01	0.05
1D							0.03	0.01					0.01	0.02	0.01	0.03
1D5							0.01	<0.01					0.02	0.02	0.01	0.02
1D7.5							<0.01	<0.01					0.03	0.03	0.03	0.03
2A			0.03	0.02		0.02	0.06							0.03	0.02	0.06
2B	0.16	<0.01	0.07	0.03		0.03	0.04							0.06	0.02	0.16
2C	0.04	<0.01	0.04	0.02		0.04	0.10							0.05	0.02	0.10
2D								<0.01					0.03	0.03	0.03	0.03
2D5								<0.01					0.02	0.02	0.02	0.02
3A	0.01	0.01	0.02				0.05						0.03	0.02	0.01	0.05
3B	0.04	<0.01	0.02	0.01		0.03	0.04	0.02	0.03	0.03	0.02	0.01	0.02	0.02	0.01	0.04
3C	0.03	<0.01	0.02	0.03		0.02	0.07						0.02	0.03	0.02	0.07
3D								<0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.02
5A	0.01	<0.01	0.04	0.04		0.03	0.06	<0.01					0.02	0.03	0.01	0.06
6A	0.02		0.03	0.03		0.03		<0.01					0.02	0.03	0.02	0.03
6B	<0.01	<0.01	0.02	0.03		0.04	<0.01	<0.01	0.02		0.01	0.01	0.02	0.02	0.01	0.04
6C	0.01	<0.01	0.03	0.01		0.03	0.04	0.02					0.02	0.02	0.01	0.04
6D	<0.01	<0.01	0.02	0.02		0.04	0.07						0.02	0.03	0.02	0.07
6E		<0.01	0.02	0.02		0.05	0.07	<0.01	0.03		0.01		0.02	0.03	0.01	0.07

Table 30. Concentration of copper in runoff samples by sampling date. All samples are mg/l.

DRAIN	871007	880219	880607	880701	880715	880719	880803	880805	880809	881202	890312	890313	890428	AVG	MIN	MAX
11		0.02	<0.01	0.04			0.06		0.09					0.05	0.02	0.09
12		0.02												0.02	0.02	0.02
13														0.00	0.00	0.00
14		0.05												0.05	0.05	0.05
15		0.03	0.01	0.07			0.07		0.06	0.12				0.06	0.01	0.12
16		0.06	<0.01	0.05			0.08		0.04	0.09				0.06	0.04	0.09
21		0.08	<0.01				0.08		0.07					0.08	0.07	0.08
22														0.00	0.00	0.00
23		0.01	<0.01	0.04			0.07		0.04	0.06				0.04	0.01	0.07
31N		0.02	<0.01	0.03			0.07		0.07					0.05	0.02	0.07
31S														0.00	0.00	0.00
32N		0.03	<0.01	0.01			0.06		0.05		0.08	0.02	0.01	0.04	0.01	0.08
32S														0.00	0.00	0.00
33N		0.04	<0.01	0.02			0.05		0.05					0.04	0.02	0.05
33S														0.00	0.00	0.00
41		0.42	<0.01	0.02			0.20		0.06					0.18	0.02	0.42
61			<0.01	0.01			0.04		0.04		0.07	0.03		0.04	0.01	0.07
62		0.02	<0.01	0.02			0.03							0.02	0.02	0.03
63			0.01				0.03		0.04				0.01	0.02	0.01	0.04
64			<0.01	0.02										0.02	0.02	0.02

Table 31. Lead concentration of monitoring well samples by sampling dates. All values are mg/l.

WELL	870130	880317	880622	880701	880719	880809	881707	890122	890317	890313	890428	890429	890524	AVG	MIN	MAX
1A	<0.05	<0.05	<0.005	<0.003		<0.005	0.004	<0.002					0.005	0.005	0.004	0.005
1B	<0.05	<0.05	<0.005	0.006		<0.005	0.010	<0.002					<.003	0.008	0.006	0.010
1C	<0.05	<0.05	<0.005	0.004		<0.005	<0.003	<0.002					0.004	0.004	0.004	0.004
1D							<0.003	<0.002					<.003	0.000	0.000	0.000
1D5							<0.003	<0.002					0.004	0.004	0.004	0.004
1D7.5							<0.003	<0.002					0.004	0.004	0.004	0.004
2A			<0.005	<0.003		<0.005	0.055							0.055	0.055	0.055
2B	0.20	<0.05	<0.005	<0.003		<0.005	0.009							0.105	0.009	0.200
2C	<0.05	<0.05	<0.005	<0.003		<0.005	0.095							0.095	0.095	0.095
2D								<0.002					<.003	0.000	0.000	0.000
2D5								<0.002					0.005	0.005	0.005	0.005
3A	<0.05	<0.05	<0.005				0.016						<.003	0.016	0.016	0.016
3B	<0.05	<0.05	<0.005	<0.003		<0.005	0.007	<0.002	<0.002	<0.002	<0.003	<0.002	0.004	0.006	0.004	0.007
3C	<0.05	<0.05	<0.005	<0.003		<0.005	0.032						0.004	0.018	0.004	0.032
3D								<0.002	0.003	0.004	<0.003	<0.002	<.003	0.004	0.003	0.004
5A	<0.05	<0.05	<0.005	<0.003		<0.005	0.007	<0.002					<.003	0.007	0.007	0.007
6A	<0.05		<0.005	<0.003		<0.005		<0.002					<.003	0.000	0.000	0.000
6B	<0.05	<0.05	<0.005	<0.003		<0.005	<0.01	<0.002	<0.002		<0.003	<0.002	<.003	0.000	0.000	0.000
6C	<0.05	<0.05	<0.005	<0.003		<0.005	0.006	<0.002					<.003	0.006	0.006	0.006
6D	<0.05	<0.05	<0.005	<0.003		<0.005	<0.003						0.004	0.004	0.004	0.004
6E		<0.05	<0.005	<0.003		<0.005	<0.003	0.002	<0.002		<0.003		<.003	0.002	0.002	0.002

Table 32. Concentration of lead in runoff samples by sampling date. All values are mg/l.

DRAIN	871007	880719	880607	880701	880715	880719	880803	880805	880809	881707	890317	890313	890428	AVG	MIN	MAX
11		<0.05	<0.005	<0.003			0.009		0.220					0.115	0.009	0.220
12		<0.05												0.000	0.000	0.000
13														0.000	0.000	0.000
14		<0.05												0.000	0.000	0.000
15		<0.05	<0.005	<0.003			0.040		0.210	0.780				0.343	0.040	0.780
16		<0.05	<0.005	<0.003			0.057		0.053	0.700				0.270	0.053	0.700
21		<0.05	<0.005				0.046		0.180					0.113	0.046	0.180
22														0.000	0.000	0.000
23		<0.05	<0.005	<0.003			0.017		0.014	0.049				0.027	0.014	0.049
31N		<0.05	<0.005	<0.003			0.005		0.053					0.029	0.005	0.053
31S														0.000	0.000	0.000
32N		<0.05	<0.005	<0.003			<0.005		0.014		0.062	0.014	0.007	0.024	0.007	0.062
32S														0.000	0.000	0.000
33N		<0.05	<0.005	<0.003			0.005		0.006					0.006	0.005	0.006
33S														0.000	0.000	0.000
41		<0.05	<0.005	<0.003			0.500		0.021					0.261	0.021	0.500
61			<0.005	<0.003			0.026		<0.005		0.060	0.062		0.049	0.026	0.062
62		<0.05	<0.005	<0.003			<0.005							0.000	0.000	0.000
63			<0.005				<0.005		0.006				0.036	0.021	0.006	0.036
64			<0.005	<0.003										0.000	0.000	0.000

Table 33. Concentration of Zinc in monitoring well samples by sampling date. All values are mg/l.

WELL	871130	880317	880622	880701	880719	880809	881207	890122	890317	890313	890428	890429	890524	AVG	MIN	MAX
1A	0.04	0.38	0.06	0.78		0.05	0.13	0.15					3.48	0.63	0.04	3.48
1B	0.03	0.35	0.10	0.46		0.07	0.14	0.11					0.83	0.26	0.03	0.83
1C	0.03	0.53	0.10	0.16		0.04	0.06	0.12					0.32	0.17	0.03	0.53
1D							0.06	0.12					0.12	0.10	0.06	0.12
1D5							0.01	0.07					0.07	0.05	0.01	0.07
1D7.5							0.01	0.09					0.06	0.05	0.01	0.09
2A			0.29	0.06		0.04	0.27							0.17	0.04	0.29
2B	16.70	9.30	1.90	0.12		0.06	0.12							4.70	0.06	16.70
2C	13.00	13.80	0.36	0.84		0.19	0.56							4.79	0.19	13.80
2D								.08					0.03	0.03	0.03	0.03
2D5								0.08					0.04	0.06	0.04	0.08
3A	2.48	0.50	0.12				0.54						0.05	0.74	0.05	2.48
3B	36.50	1.49	0.42	0.06		0.11	1.92	1.40	0.47	0.04	0.08	0.12	0.08	3.56	0.04	36.50
3C	2.20	0.07	0.15	0.14		0.06	1.30						0.04	0.57	0.04	2.20
3D								0.08	0.09	0.04	0.04	0.06	0.02	0.06	0.02	0.09
5A	0.08	4.27	0.16	0.10		0.02	0.10	0.09					0.02	0.61	0.02	4.27
6A	1.20		0.10	0.07		0.01		0.10					0.01	0.25	0.01	1.20
6B	0.07	1.29	0.03	0.06		0.02	0.23	0.10	0.09		0.03	0.12	0.02	0.19	0.02	1.29
6C	0.10	1.77	0.10	0.03		<0.1	0.14	0.12					0.02	0.33	0.02	1.77
6D	0.07	0.51	0.07	0.04		0.02	0.08						0.01	0.11	0.01	0.51
6E		1.39	0.80	0.06		0.01	0.12	0.15	0.10		0.06		0.02	0.30	0.01	1.39

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