EVALUATION OF THE EFFECT OF STORMWATER DISPOSAL ON GROUNDWATER QUALITY

by

JAMES ALLEN BERNDT

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APPROVED BY THE GRADUATE COMMITTEE OF:

Dr. Byron Shaw, Committee Chairman
Professor of Soil Science and of Water Science

Dr. Gerald Nienke
Associate Professor of Water Science

Dr. David Ozsvath
Assistant Professor of Hydrogeology

ABSTRACT

Six 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 trace metals, hydrocarbons and high levels of inorganic contaminants.

At the six study sites, runoff samples were collected and monitoring wells were installed and sampled to evaluate the impact of stormwater on the groundwater quality. Urban stormwater disposal systems studied included drywells 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 revealed that the groundwater was being impacted 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.

Sample analysis demonstrated that copper and chromium concentrations were generally below 0.42 mg/l and 0.09 mg/l, respectively, in runoff and groundwater. Cadmium was present at maximum runoff values of 0.03 mg/l and maximum groundwater concentration of 0.03 mg/l. Most groundwater samples contained less than 0.002 mg/l cadmium. 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 were all less than 1 mg/l in runoff with a maximum of 0.2 mg/l in groundwater.

Organic compounds in the groundwater were apparent in samples collected at most sites. Chemical oxygen demand values of 20 to 100 were common in downgradient groundwater. Volatile organic compounds (VOCs) were rarely detected in samples, but several samples exceeded Wisconsin groundwater standards. Benzene; toluene;

1,1 dichloroethylene; 1,1,1 trichloroethane; trans 1,3 dichloropropene; diesel fuel; tetrachloroethylene; and C-1,3 dichloropropene were all found in groundwater downgradient of storm drains. Poly nuclear aromatic hydrocarbons (PNAs) were also found associated with most storm drains in concentrations near the detection limit. The significance of these organic compounds in groundwater is difficult to assess since drinking water standards have not yet been developed. It has been suggested by other researchers that regular sweeping of parking areas may reduce the concentration of trace metals and some organic compounds in runoff.

One site where the parking lot was swept regularly, presented the lowest concentrations of metals and COD in both runoff and groundwater samples, but the runoff did contain some organic compounds.

These data seem to indicate that stormwater drainage wells do remove many contaminants from stormwater runoff before the runoff reaches the groundwater. However, elevated levels of highly soluble inorganic chemicals and occasional occurrence of VOC, PNA, and trace metals suggest 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. Additional research is needed to further define the impact of subsurface stormwater disposal on groundwater quality, especially in the area of organic compound transport.

ACKNOWLEDGEMENTS

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INTRODUCTION

The question of how to efficiently dispose of urban runoff has been addressed in many different ways. One of the most common techniques in use today includes a system of curbs and gutters connecting to a closed or open drain system. A closed drain system does not disperse any of the water that enters the system, but instead channels the water to a disposal area, usually a body of surface water. An open system may be similar to a closed system, except that this system 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 (drywells) and perforated pipe, which connects the drains in series. Figure I contains a cross-section of a typical drywell. Drywells are classified by the U.S. Environmental Protection Agency as Class V Injection Wells. A Class V injection well is, in simple terms, any device deeper than it is wide used with the purpose of transmitting surface water to the subsurface that does not fit within Classes I, II, III, or 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 some of those effects.

The objectives of this study were as follows:

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

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

3. To evaluate the effectiveness of drywells and perforated pipe line as a method of stormwater disposal at these six sites.

STANDARD DRYWELL

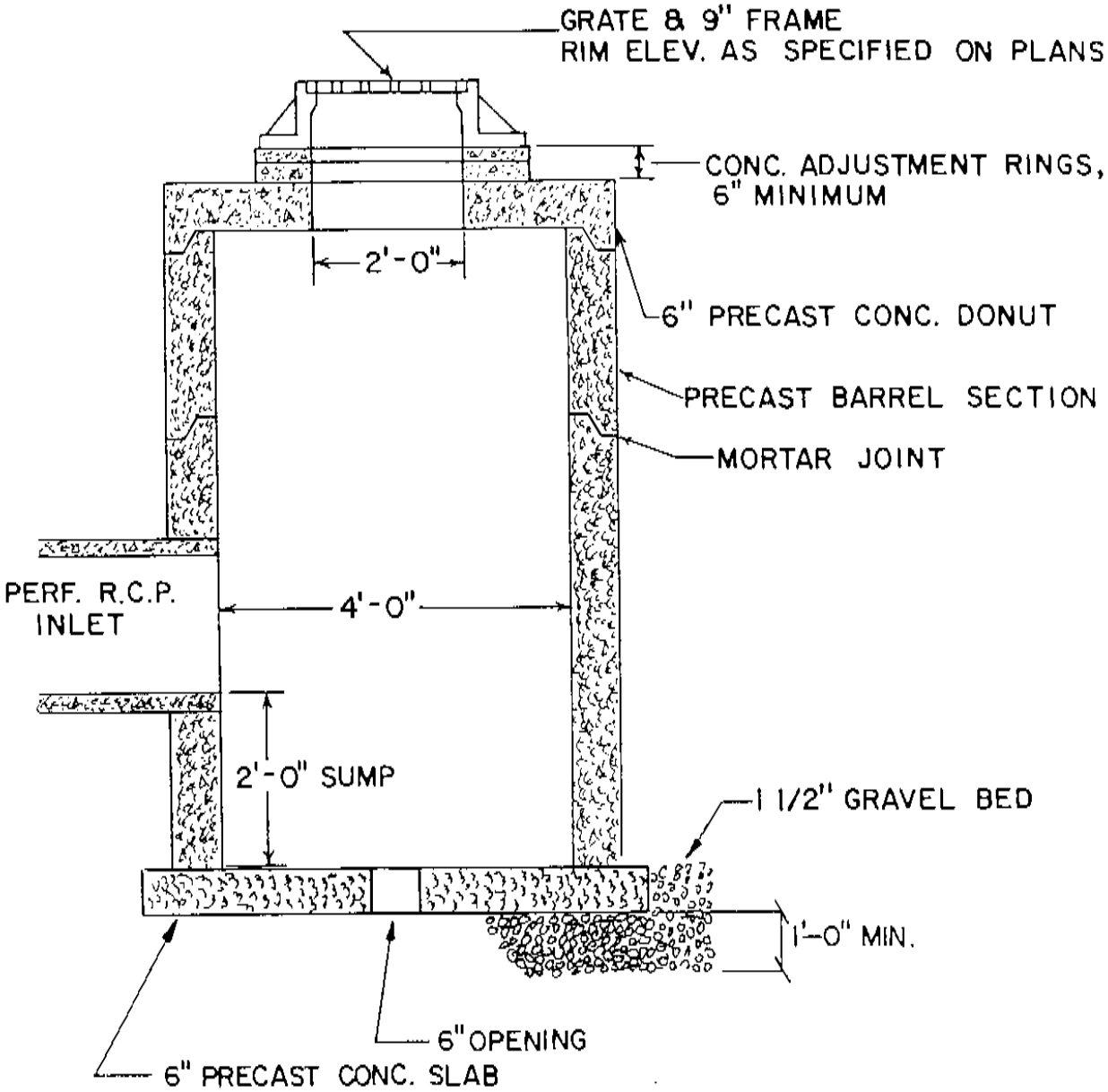

FIGURE 1 - TYPICAL DRYWELL CONSTRUCTION

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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 altering the landscape is going to effect the way water flows over that landscape. Paved surfaces and stormdrains will chemically modify and intensify the rate of urban runoff (Thomas and Schneider, 1970). In the average city, about one third of the land is covered by impervious surfaces (Daniel and Forrest, 1979), thus a large portion of the land surface of an urban environment may be adversely impacting runoff quality and quantity.

The Federal Water Pollution Control Act, P.L. 92-500, provided for the examination of point and nonpoint sources of pollution (Bauman 1980). Urban runoff falls into the category of nonpoint source pollution. 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 trace 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). Some studies have determined that groundwater is not presently threatened by urban runoff but warn of the potential for unlawful disposal of hazardous materials in recharge structures (Heaney, 1986).

Most State Health Departments prohibit the injection of urban runoff into the groundwater (USDOT, 1980), however, injection of urban runoff into the groundwater is a common practice in central Wisconsin. All components of the runoff system are susceptible to contamination including precipitation, runoff, basin soils, soilwater, 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 these concentrations vary throughout the event (Bauman 1980).

Four groups of contaminants have generated the greatest interest in urban runoff research: nutrients, trace metals, salts and hydrocarbons. Nutrients, especially phosphorous, are of concern because of the potential for increasing eutrophication in receiving bodies of water. It has been noted that the average amount of phosphorous in 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 toxins that have received the most attention in recent studies have been the trace 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 may precipitate in the soil as lead sulfate and remain immobile because of relatively low solubility (USDOT, 1980). Most metals in runoff seem to adsorb to soil particles (Metzler and Jarvis, 1985). 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 have used 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 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). Crank-case oil drippings are a

major source of hydrocarbons in parking areas (Hoffman et al., 1982). Like trace 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 (VOCs) 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

This project originally contained seven study sites. Early in the investigation one Site (Site 4) was removed from the project. The six study sites utilized for this project are located in the city of Stevens Point, Wisconsin. 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 located in an area of glacial outwash, the soils are generally sandy in texture with low relief. Shallow groundwater in this area is commonly unconfined and within 30 feet of the surface, making this an ideal area to study the impacts of subsurface disposal of runoff on groundwater quality. A detailed description of each Site follows:

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. The parking area contains six storm drains connected by perforated pipe. Since no as built drawings of the drainage system were available, it was necessary to estimate the location of some sections of perforated pipe. The positions of the perforated pipe shown in Figure 2 are an estimate by members of the Copps Corporation Engineering Department; Copps was the original developer of the property.

Upon inspection, the drains appeared to be in good condition and free of debris. Only a small portion of the runoff from the north end of the Site enters the system under study, the majority of the runoff from Schierl Tire Center and the carwash drain into a separate municipal sanitary sewer system.

A total of four monitoring wells were installed at this Site over the course of the study (see Figure 2). The upgradient well (1A) is a single-depth monitoring well, installed in the fall of 1987, located near the northwest corner of the parking lot.

The three downgradient wells (1B, 1C and 1D) are located in a line southeast of the parking lot. Wells 1B and 1C are single-depth monitoring wells which were installed in the fall of 1987. Well 1D is a multilevel well installed in November of 1988 and consists of a five foot 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).

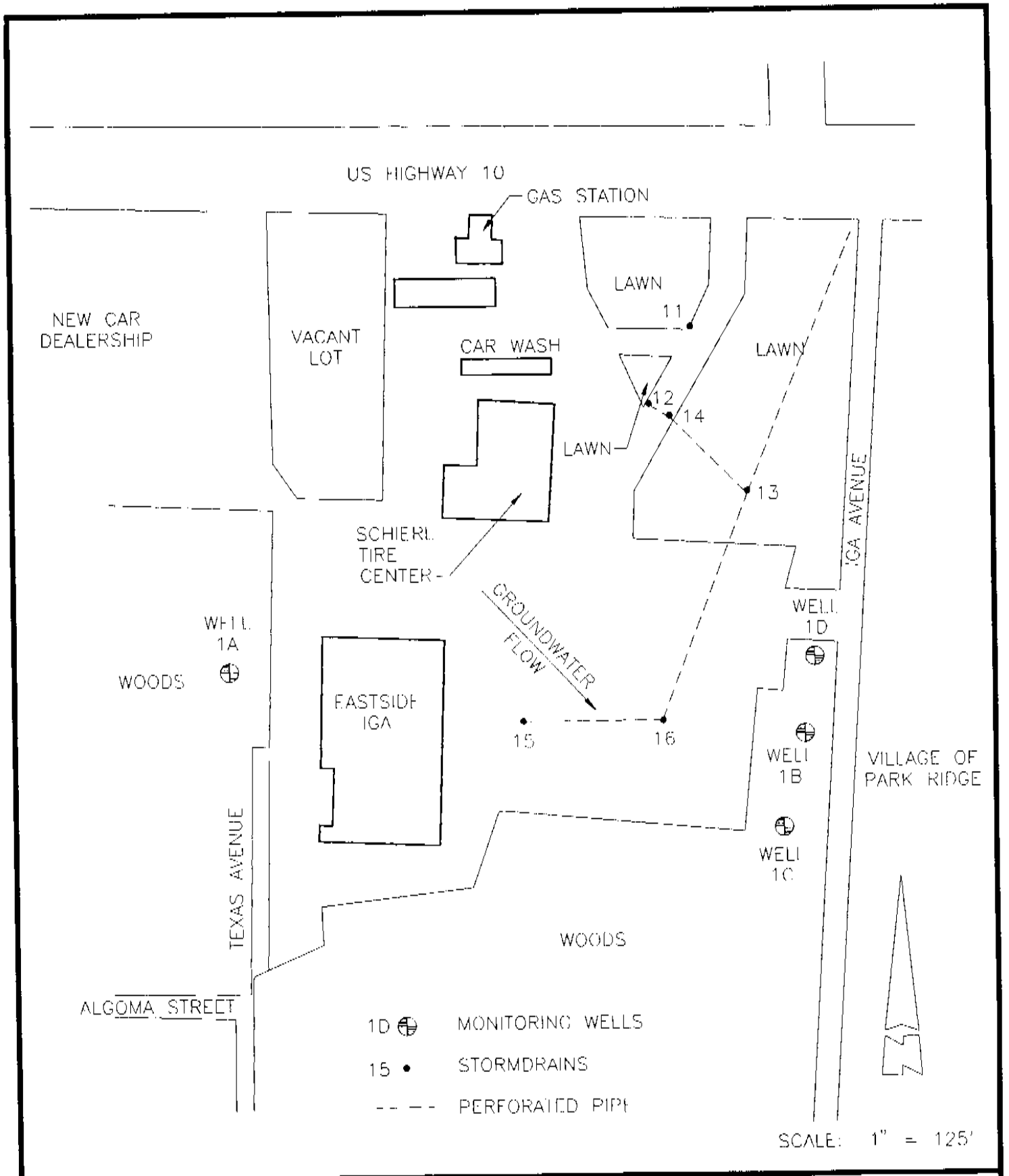

FIGURE 2 · MAP SHOWING DRAIN SYSTEM AND MONITORING WELL LOCATIONS AT SITE 1

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Runoff samples were collected regularly 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 (see Figure 3) which is located one block south of Site 1. Worzalla Publishing Company is a printing and binding company. 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.

Figure 3 shows the drainage system for the parking lot and driveway. The parking lot drainage system consists 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 are connected and drain into a subsurface infiltration area south of the building. The infiltration area contains buried six inch diameter rock used to store excess runoff prior to absorption by the surrounding soil.

The south end of the parking lot was frequently flooded during periods of snowmelt and during heavy rains. This flooding may be partially caused by the build up of silt and organic matter in the drywells; in several of the drywells silt and organic matter had almost completely blocked off the perforated pipe outlet.

Because 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. Site 5 is located approximately 0.5 miles west of Site 2. The upgradient well (5A) is a single-depth monitoring well which was installed in the Fall of 1987. A total of four downgradient wells were 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 Figure 3). The screen of well 2C intersects the water table (skimming well); the screen of well 2B is set eight feet into the water table. These wells were placed in the same drain to evaluate vertical differences in groundwater. These three wells were originally constructed of galvanized steel pipe with stainless steel screens. After several samples were taken, however, it was determined that the zinc oxide coating on the

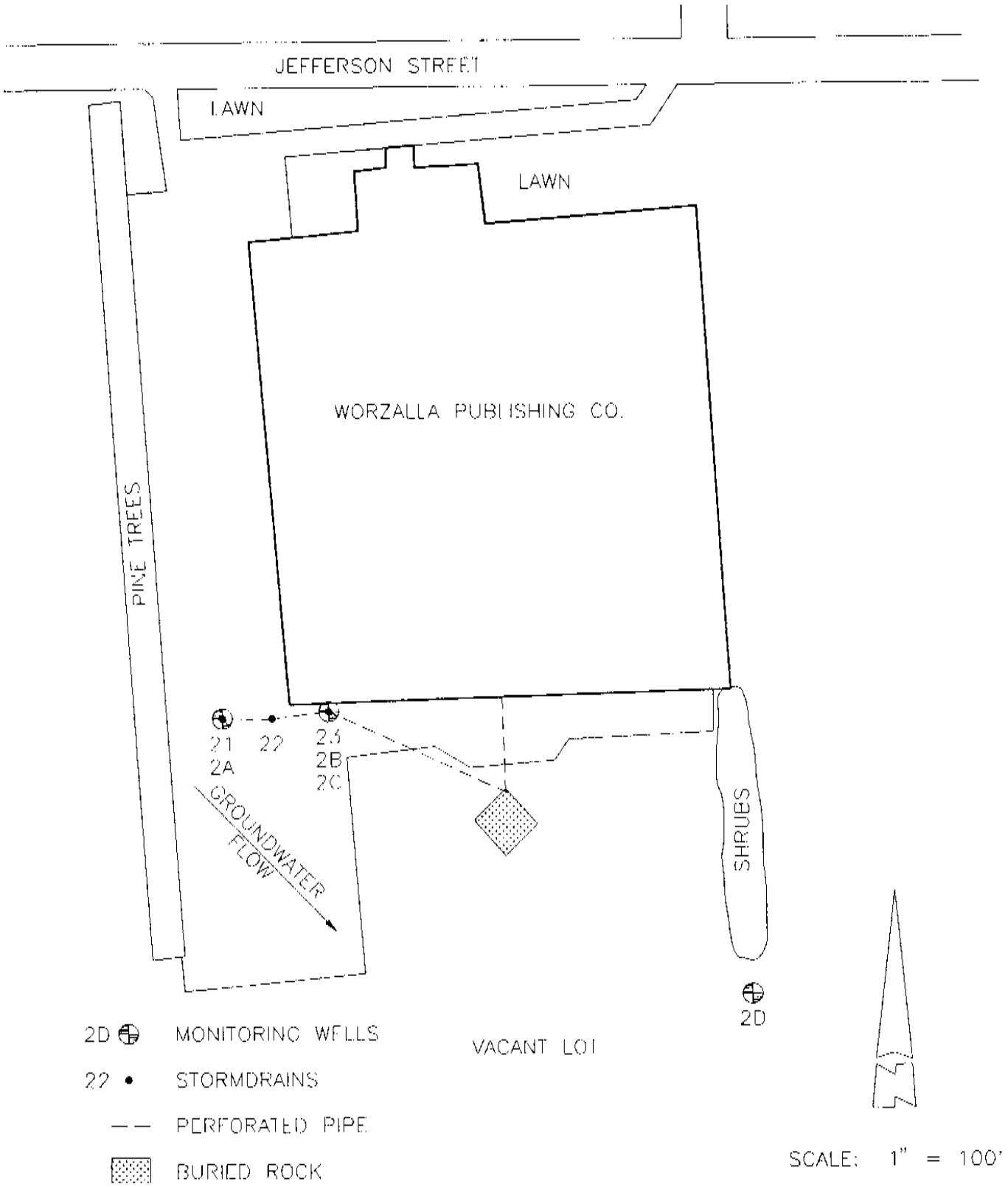

FIGURE 3 – MAP SHOWING THE DRAINAGE SYSTEM AND MONITORING WELL LOCATIONS AT SITE 2.

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pipe was producing high zinc levels in the samples. The galvanized steel well casings and stainless steel points were removed in the spring of 1988 and replaced with polyvinyl chloride (PVC) casings and points. In March of 1989 an expansion of the building resulted in the destruction of drain 23 and wells 2B and 2C.

Multilevel well 2D was installed approximately 200 feet south of the building along the east property line in December of 1988. This well consists of a screened section at the water table (2D) and a screened port five feet below the water table (2D5).

Runoff samples were collected regularly at drains 21 and 23. Because of the crown on the driveway, very little runoff 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 block of Della Street east of the intersection of Soo Marie Avenue and Della Street. Approximately one quarter mile east of the study Site, Della Street terminates in a dead end. Della Street is drained by a system of six drywells connected in series with perforated pipe (see Figure 4). 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 which 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 is in drain 31N, well 3B is in drain 32N, and well 3C is in drain 33N. These three wells were originally driven, galvanized casings as in Site 2. The galvanized casings and stainless steel screens at this Site were also replaced with PVC in the Spring of 1988.

The drywells at Site 3 actually drain an approximately 2.7 acre watershed that is larger than the study area (see Figure 4). The watershed extends outside the study area one half block west on Della Street and one block north on Soo Marie Avenue. As a result of the Site topography, drain 32N receives the most runoff during a given event. Runoff samples were collected most frequently from drains 31N, 32N and 33N.

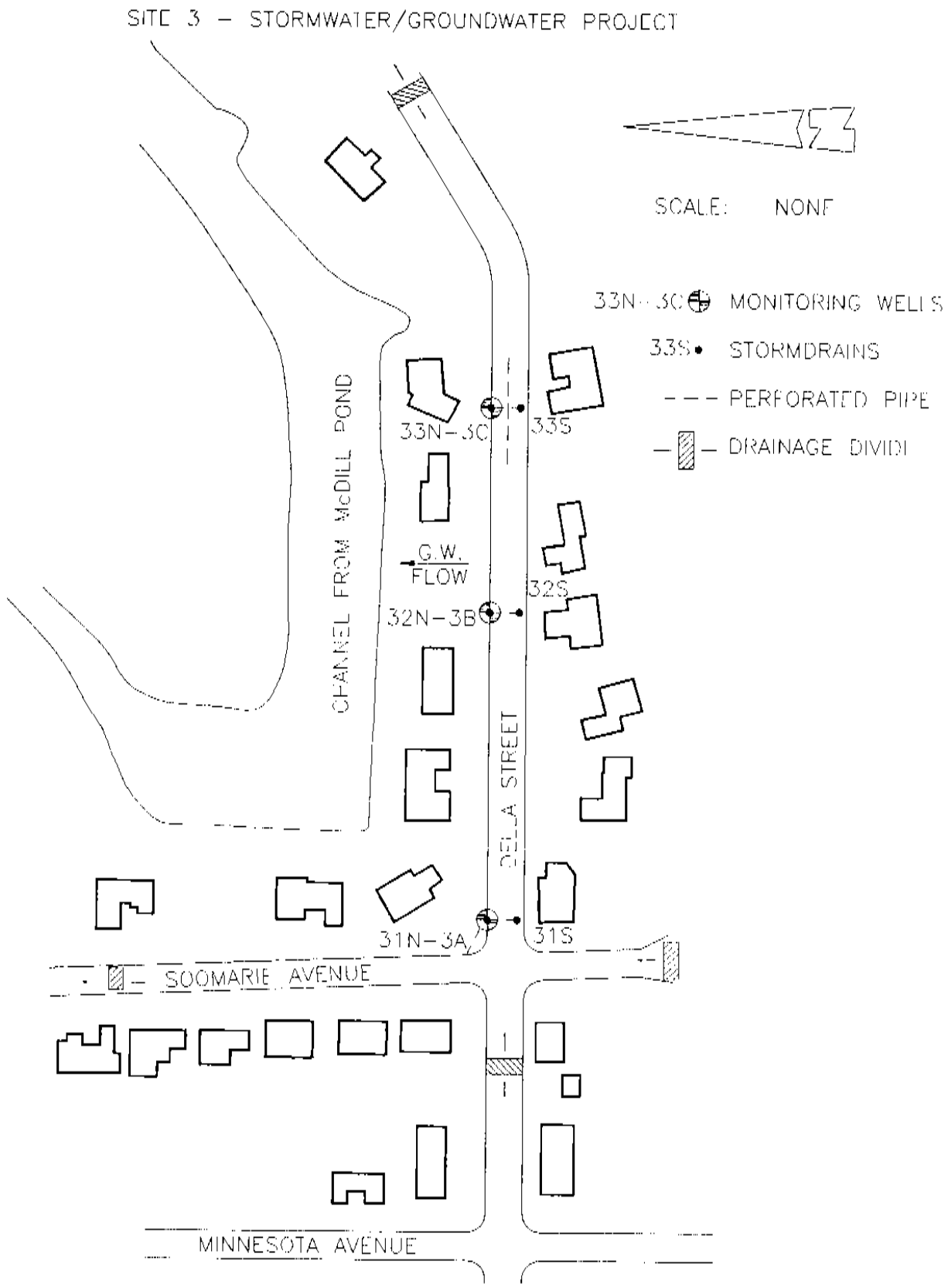

FIGURE 4 MAP SHOWING THE DRAINAGE SYSTEM AND LOCATION OF MONITORING WELLS AT SITE 3.

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Site 6

Site 6 is a 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 Figure 5).

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.

Site 7

Site 7 is a Mobil gasoline station and carwash located at the southwest corner of US Highway 66 (Stanley Street) and Minnesota Avenue. This Site contains three storm drains (drains 71, 72, and 73) connected by PVC pipe which empties into a drywell (drain 74) on the northeast corner of the Site (see Figure 6). Drain 74 also receives some runoff from Stanley Street and Minnesota Avenue.

Two multi-level monitoring wells were installed on residential properties adjacent to Site 7. Well 7A is located northwest (upgradient) of the Site and consists of one port at the water table (7A0) and three feet of screen one foot below the water table (7A1). Well 7C is located east (downgradient) of the Site and consists of one port at the water table (7C0), one port 1.5 feet below the water table (7C1.5) and three feet of screen beginning three feet below the water table (7C3).

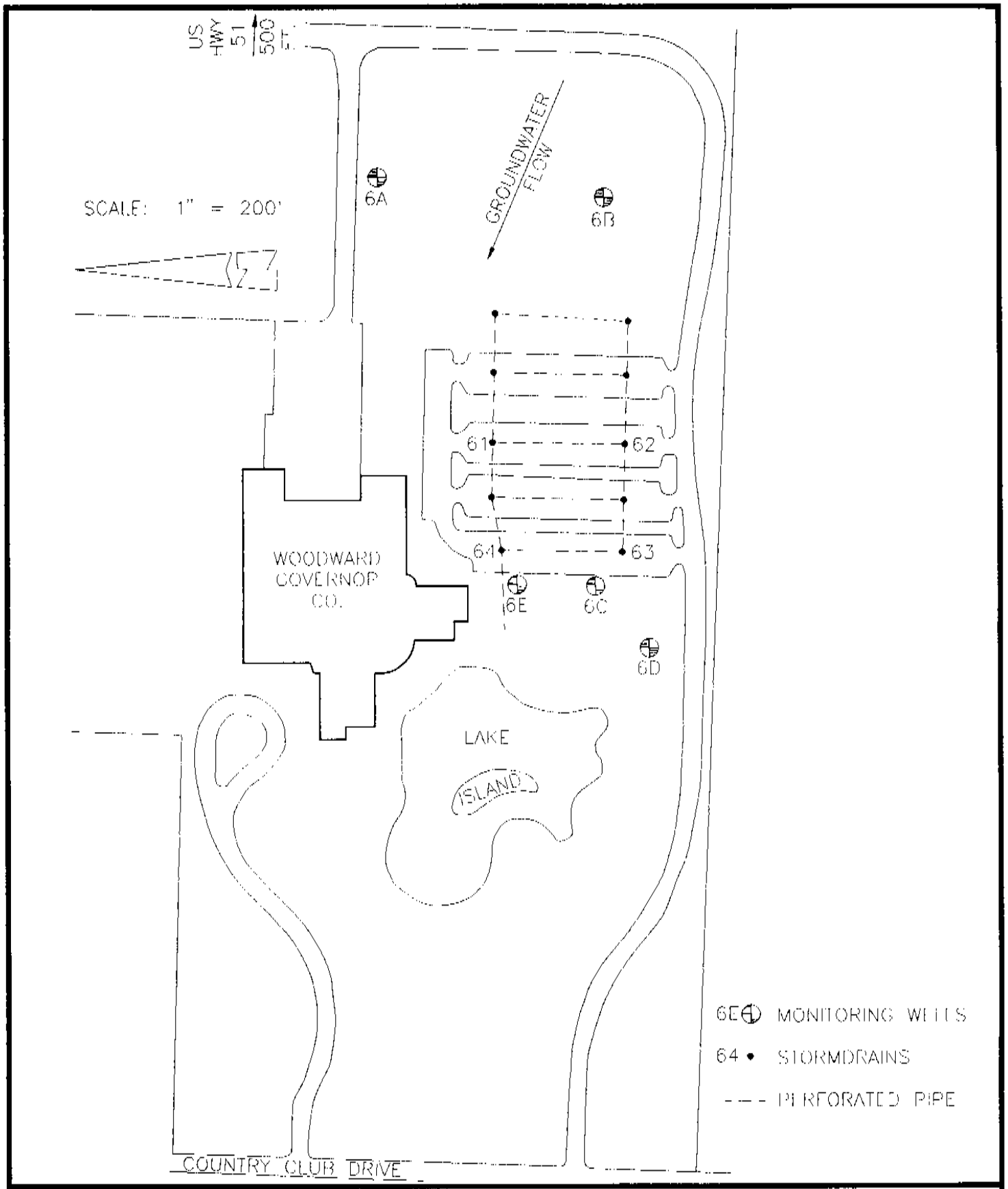

FIGURE 5 - MAP SHOWING THE DRAINAGE SYSTEM AND LOCATION OF MONITORING WELLS AT SITE 6.

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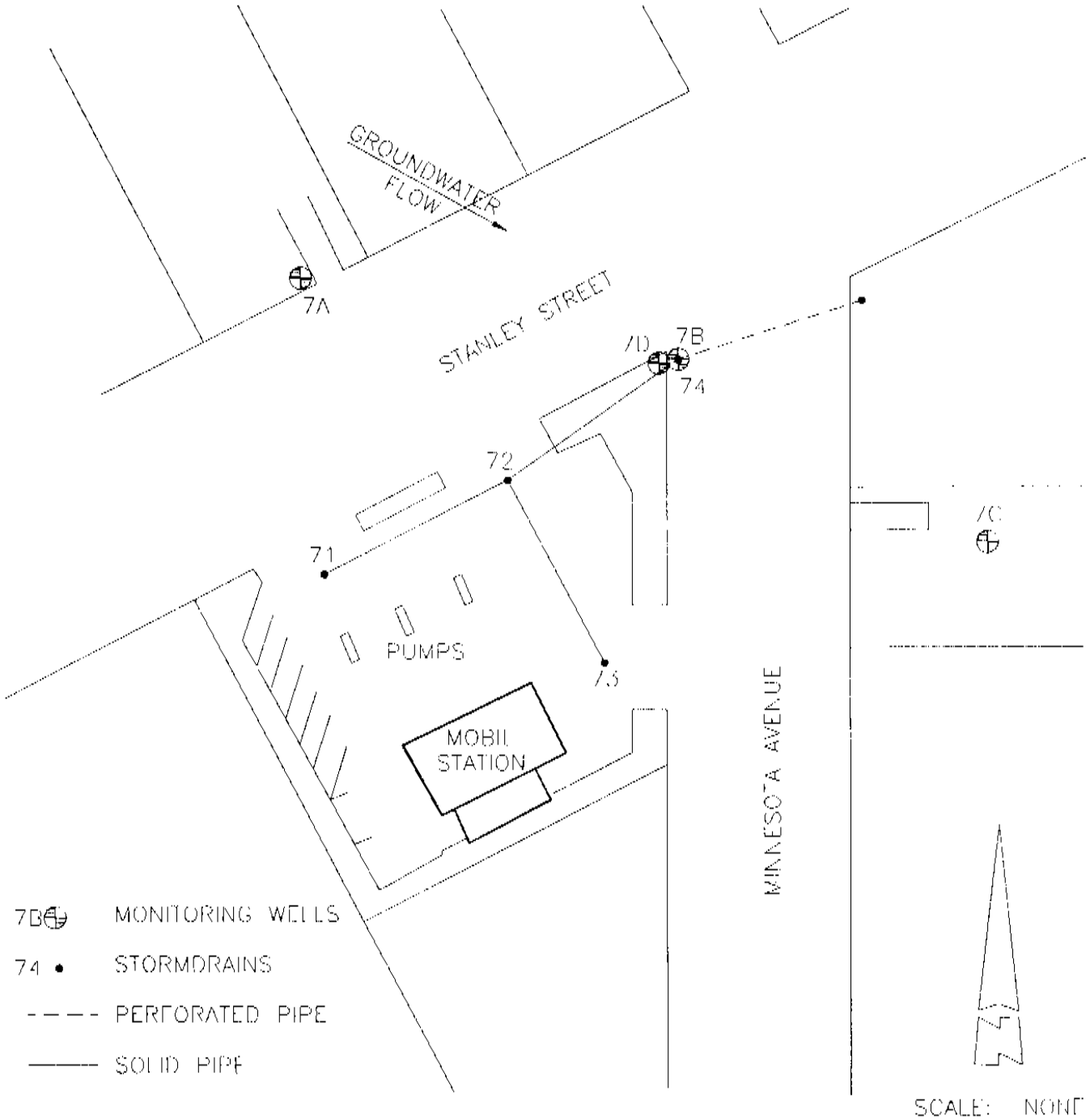

FIGURE 6 – MAP SHOWING THE DRAINAGE SYSTEM AND LOCATION OF MONITORING WELLS AT SITE 7.

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A single-depth PVC monitoring well (7B) was installed in drain 74. Water levels in this well were consistently above the levels observed in wells 7A and 7C indicating a perched water table under drain 74. In the Spring of 1989 an additional single-depth skimming monitoring well (7D) was installed adjacent to drain 74 to provide groundwater samples from the local water table in the vicinity of drain 74. The water levels observed in well 7D were consistent with the levels observed in wells 7A and 7C.

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 2 and 3. 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 groundwater 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 wide 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 wide 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 Figure 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

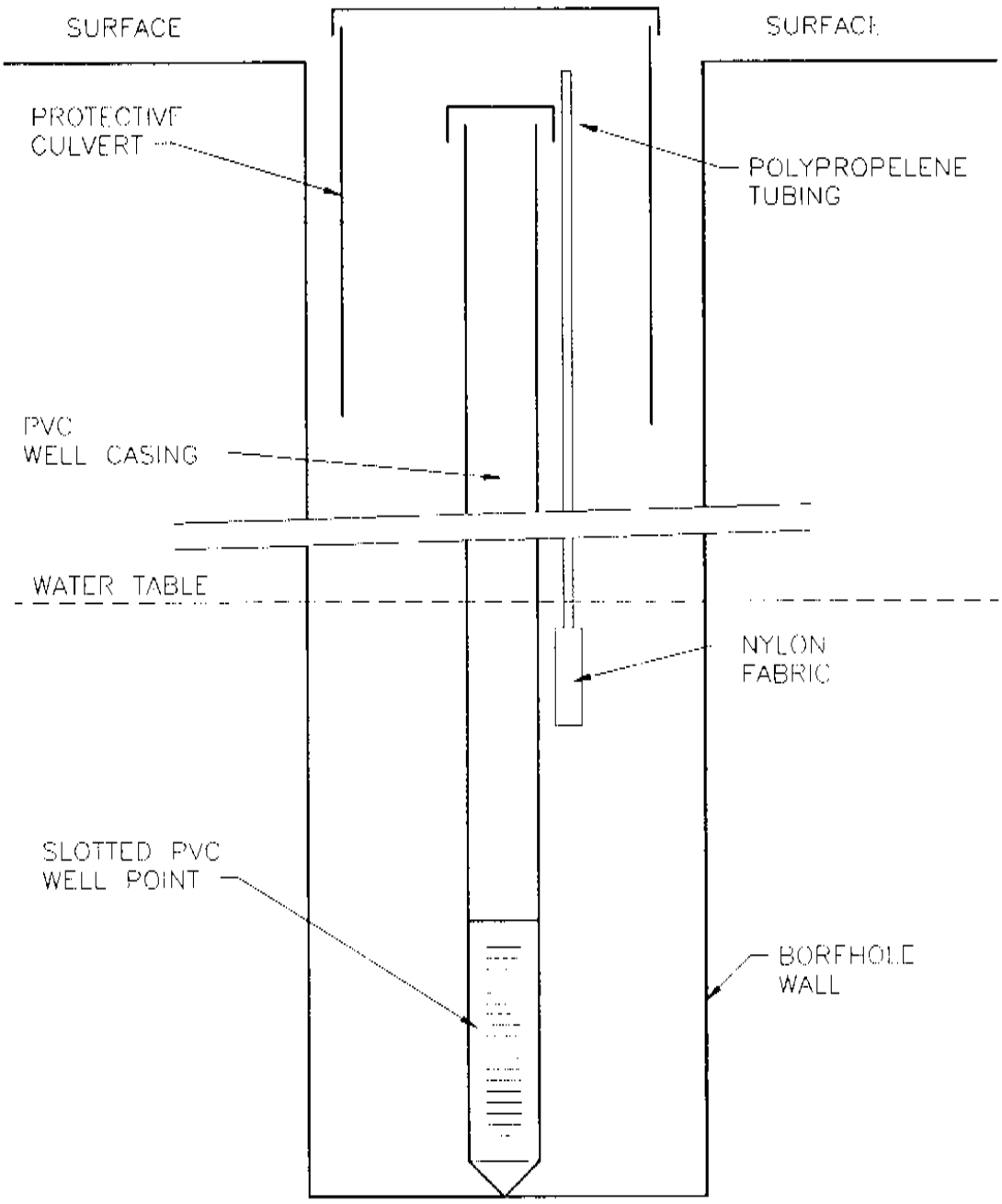

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FIGURE 7 – SCHEMATIC DIAGRAM OF A MULTIPORT WELL

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. After the screened end was attached, the length of tubing was secured to the spine at one foot intervals with strapping tape.

After the casing and point were installed in a bore-hole, the hole was back-filled with auger 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 wells were installed in a maintained lawn, the culvert was set low enough to mow over. The wells at Site 6 have plastic culverts protecting them, provided by Woodward Governor Company, instead of galvanized steel.

After the well and culvert were installed, the well was developed. If the water table was within 26 feet of the surface, the well was developed with a gasoline powered centripetal pump; if the water table was greater than 26 feet from the surface, a bailer was used to develop the well. The well was developed until the water ran clear.

When a well was to be abandoned, the casing and point were pulled with a winch or set of hydraulic jacks. After 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.

Monitoring Well 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 groundwater.

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 groundwater was less than 26 feet below

the surface, a peristaltic pump and Tygon tubing were used to collect inorganic and metals samples. If groundwater was greater than 26 feet below the surface, 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. All sampling equipment was decontaminated with a distilled water rinse between samples.

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.

Runoff Sampling

Runoff samples were collected quarterly beginning with the last quarter of 1987 and concluding with the second quarter of 1989. Plastic five gallon pails suspended from the storm drain and drywell grates were used to collect runoff samples. Runoff samples were collected in conjunction with monitoring well samples on a quarterly basis as close to a runoff event as possible. The buckets were sampled and then emptied. In the Spring of 1988 all buckets were removed, washed and replaced. Runoff samples were collected during selected major runoff events, beginning in October of 1987 until August of 1988 using the techniques described above in 'Monitoring Well Sampling'. After December of 1988, runoff samples were collected less frequently and only from Sites 3, 6 and 7.

Sample Analysis

All analyses were performed by the Environmental Task Force laboratory of the University of Wisconsin-Stevens Point (Wisconsin Lab ID No. 750040280). All analysis were 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 quality control methods utilized include duplicate analysis for measuring precision, and check standards and spikes for measuring accuracy.

It is important to note that the method used for polynuclear aromatic hydrocarbon analysis (PNA) did not generate quantitative data. Therefore, the PNA data collected during this research project have been reported qualitatively as compounds detected in each sample. Additional PNA samples were collected from Sites 3, 6 and 7 in August and October of 1989 after the completion of this

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.

research project. These additional samples were analyzed using a method that produced quantitative results. These quantitative results have been included in the PNA tables to give an indication of PNA concentrations in groundwater and runoff at the sites.

RESULTS AND DISCUSSION

Since the stormwater disposal system for each site is unique, the results and discussion will be broken down by site. The outstanding chemical characteristics of the runoff and groundwater will be described for each site along with the potential contaminant sources.

Table 2 lists the Wisconsin Unique Well number for each monitoring well; Appendix A contains the construction details for each monitoring well. Appendix B contains the method detection limits for the volatile organic compound analyses; tables listing the results of all inorganic sample analyses are located in Appendix C.

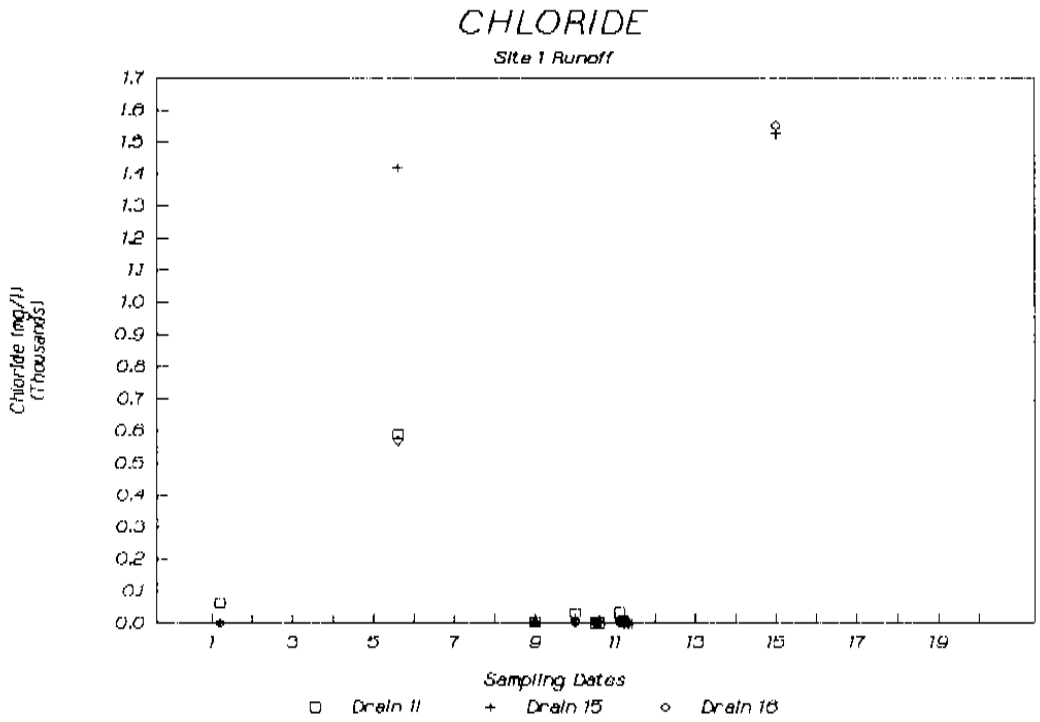
Site 1

The stormdrain-perforated pipe system at Site 1 seems to be very effective at dispersing the runoff from the parking lot. The impact of stormwater on groundwater at this Site and Site 2 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 third highest found during the study with the fall runoff showing concentrations greater than 1500 mg/l (see Figure 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 snowmelt events. Conductivity of runoff samples in the fall exceeded 4000 umhos/cm corresponding to high levels of sodium and chloride. Several samples from the fall of 1987 and 1988 contained greater than 500 mg/l chemical oxygen demand (see Figure 9). With the exception of one sample, the concentrations of ammonium and nitrate nitrogen were generally below 0.8 and 4.5 mg/l, respectively, in the runoff samples from this Site. Cadmium, copper, and zinc were found in runoff samples at levels less than or equal to 0.010, 0.07 and 0.78 mg/l, respectively. 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.

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

Monitoring Well	Well Description	Wisconsin Unique Well Identification Number
Site 1 - Eastside IGA		
1A	Upgradient 1 1/4" PVC	AN001
1B	Downgradient 1 1/4" PVC	AN002
1C	Downgradient 1 1/4" PVC	AN003
1D	Downgradient Screen at WT	AN004
1D5	1/4" port 5ft below WT	AN005
1D7.5	1/4" port 7.5ft below WT	AN006
Site 2 - Worzalla Publishing		
5A	Upgradient Site 2 1 1/4" PVC	AN016
2A	In drain 1 1/4" PVC	AN007
2B	In drain 1 1/4" PVC	AN008
2C	In drain 1 1/4" PVC	AN009
2D	1/4" port at WT	AN010
2D5	1 1/4" Downgrad. Screen 5ft below WT	AN011
Site 3 - Della St.		
3A	In drain 1 1/4" PVC	AN012
3B	In drain 1 1/4" PVC	AN013
3C	In drain 1 1/4" PVC	AN014
3D	Upgradient 1 1/4" PVC	AN015
Site 6 - Woodward Governor		
6A	Upgradient 1 1/4" PVC	AN017
6B	Upgradient 1 1/4" PVC	AN018
6C	Downgradient 1 1/4" PVC	AN019
6D	Downgradient 1 1/4" PVC	AN020
6E	Downgradient 1 1/4" PVC	AN021
Site 7 - Mobil Station		
7A0	1/4" port at WT	AN022
7A1	Upgradient screen 1ft below WT	AN023
7B	In drain 1 1/4" PVC	AN024
7C0	1/4" port at WT	AN025
7C1.5	1/4" port 1.5ft below WT	AN026
7C3	1 1/4" Downgrad. screen 3ft below WT	AN027
7D	Adjacent to drain 1 1/4" PVC	AN028



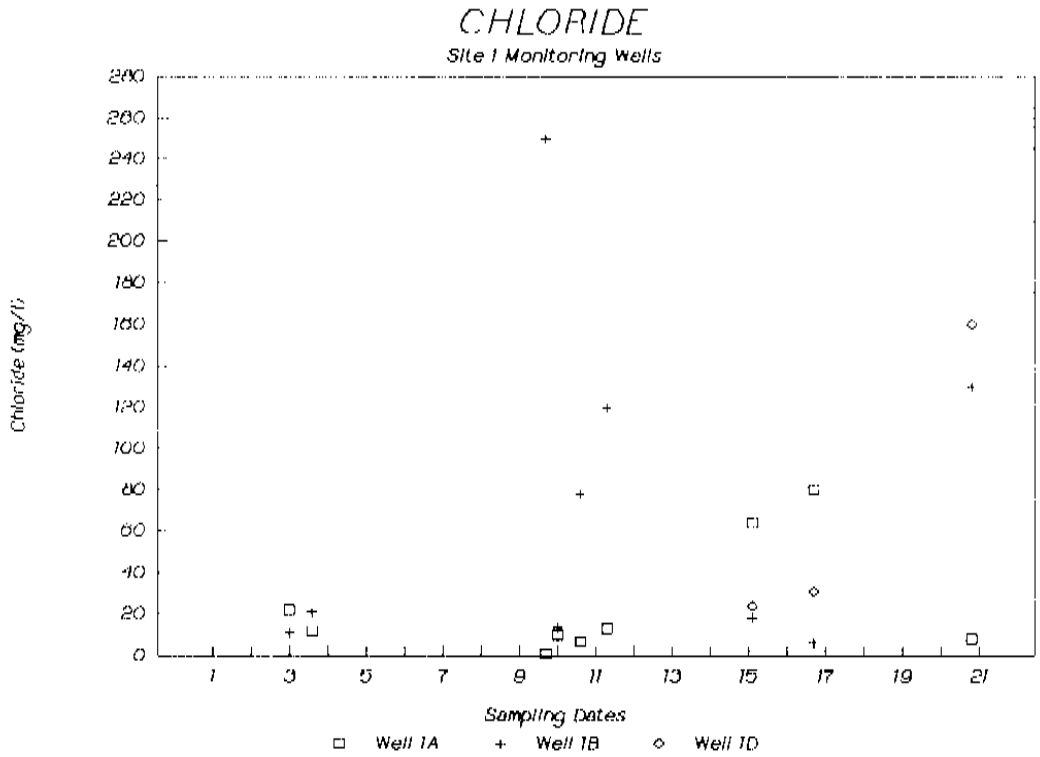
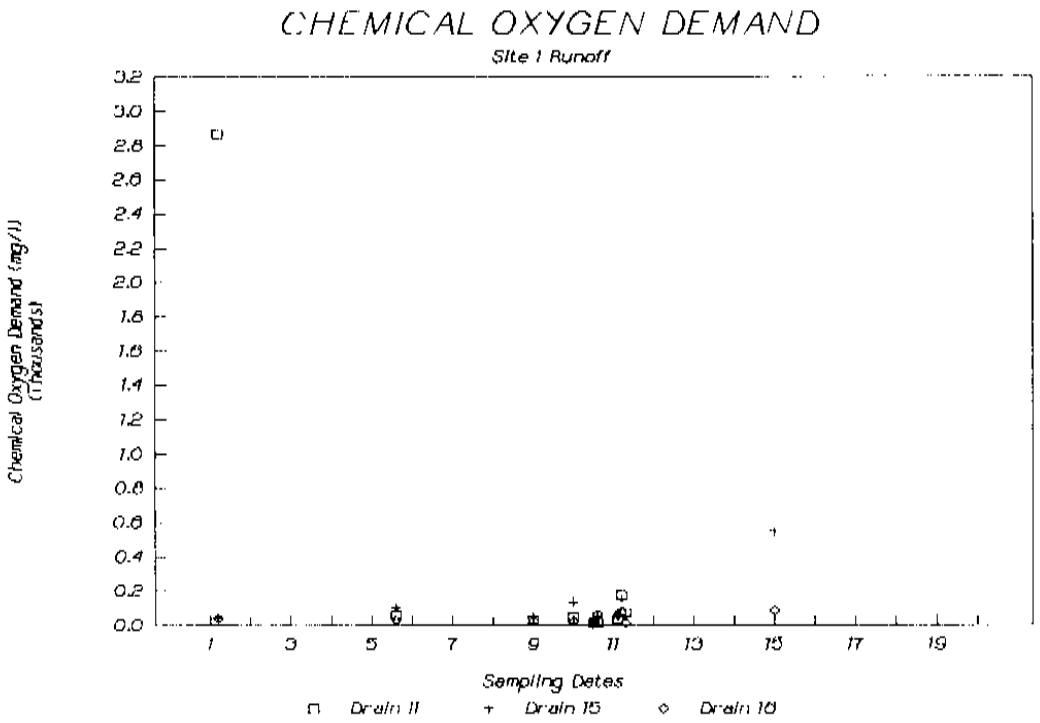


Figure 8. Chloride concentration of selected Site 1 runoff and monitoring well samples.



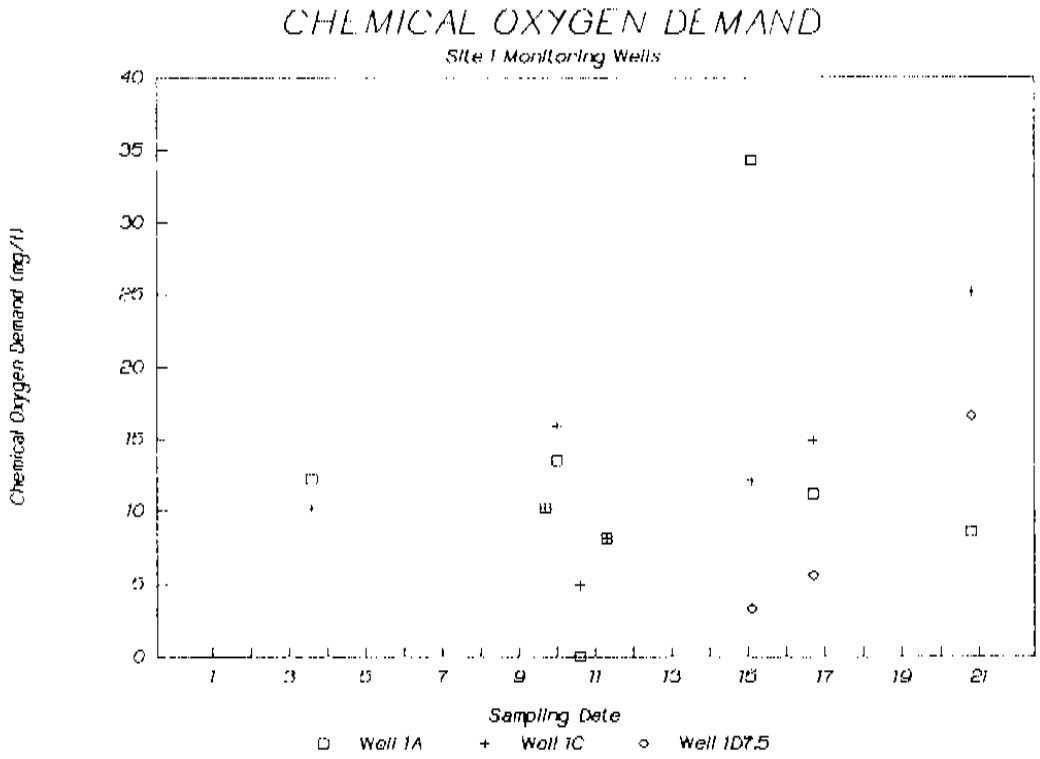


Figure 9. Chemical oxygen demand of selected Site 1 runoff and monitoring well samples.

The chloride and sodium levels in the downgradient monitoring wells were higher than levels in the upgradient well for most sampling events. 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 Figure 8). Chloride values peaked in the upgradient well in late fall, possibly indicating another chloride source farther upgradient.

The chemical oxygen demand of the downgradient groundwater ranged from 2.3 mg/l to 25.19 mg/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 Figure 9). Levels of ammonium and nitrate nitrogen in groundwater samples were less than or equal to 0.90 and 6.0 mg/l, respectively. The values for nitrate nitrogen increased slightly in June of 1988, possibly from lawn fertilizer being used in the area.

Small amounts of zinc and copper were found in the groundwater samples at levels less than or equal to 0.78 and 0.05 mg/l, respectively. The maximum concentration of lead detected in groundwater samples from this site was 0.010 mg/l despite several runoff samples in excess of 0.700 mg/l. It is possible that the lead is tied up in the subsoil in an insoluble form and did not migrate to the downgradient monitoring wells.

VOCs were found in relatively high concentrations in several runoff samples (see Table 3.) but monitoring well samples showed only occasional low concentrations (see Table 4.). PNAs were detected at levels near the detection limit in every sample collected for PNA analysis (see Table 5).

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

SAMPLE LOCATIDN/DATE	COMPOUND NAME	CONCENTRATION ppb
IGA DRAIN		
11 880219	t-1,2-Dichloroethylene	8.2
11 880602	None Detected	ND
11 880719	None Detected	ND
IGA DRAIN		
12 880219	t-1,2-Dichloroethylene	16.4
IGA DRAIN		
15 880602	Benzene	0.4
	Tetrachloroethylene	0.6
IGA DRAIN		
16 880602	Tetrachloroethylene	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	None Detected	ND
1A 880622	None Detected	ND
1A 880719	None Detected	ND
1A 890524	None Detected	ND
IGA DOWNGRADIENT		
1B 880317	None Detected	ND
1B 880622	Tetrachloroethylene	1.5
1B 880719	trans-1,3-Dichloralpropene	0.8
	Toluene	<0.3
	Trichloralethene	1.0
1B 890524	None Detected	ND
IGA DOWNGRADIENT		
1C 880317	None Detected	ND
1C 880622	c-1,3-Dichloropropene	1.7
1C 890524	None Detected	ND
IGA DOWNGRADIENT		
1D 890524	None Detected	ND

Table 5. Polynuclear aromatic hydrocarbons detected in samples collected at site 1.

SAMPLE LOCATION/DATE	COMPOND
IGA DRAIN	
11 890123	Acenapthalene
	Fluorene
	Phenanthrene
	Anthracene
	Fluoranthrene
	Pyrene
	Benzo(a)anthracene
	Benzo(k)fluoranthene
	Benzo(ghi)perylene
IGA DOWNGRADIENT	
1D 890612	Fluorene
	Fluoranthrene
1D5 890123	Acenapthalene
	Fluorene
	Phenanthrene
	Fluoranthrene
	Chrysene
	Benzo(b)fluoranthene
	Benzo(a)pyrene
1D7.5 890123	Acenapthalene
	Fluorene
	Phenanthrene
	Fluoranthrene
	Pyrene
	Chrysene
	Benzo(b)fluoranthene
	Benzo(a)pyrene

Site 2

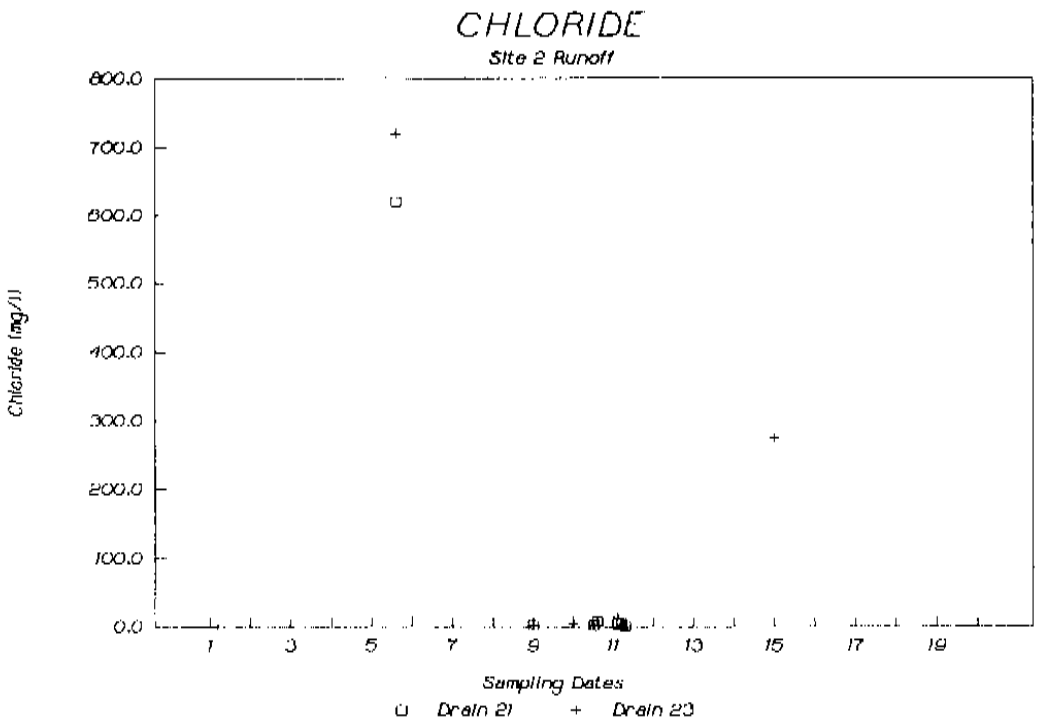
As with Site 1, the highest chloride concentration was seen in the early winter when it exceeded 700 mg/l as shown in Figure 10. Chloride levels were lower at this Site than at Site 1; this may be due to less street runoff entering the system or the fact that this is an employee parking lot and does not have as much traffic bringing in salt.

The highest chemical oxygen demand values for the runoff were found in the fall of 1987 and 1988 (see Figure 11). The high chemical oxygen demand of the fall runoff samples approached 200 mg/l and indicates 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 from a natural source. Ammonia and nitrate nitrogen concentrations in the runoff did not exceed 0.80 mg/l at this Site. Copper, zinc and lead were detected in runoff samples at levels below or equal to 0.08, 0.50 and 0.049 mg/l, respectively. Lead concentration in some of the fall and winter, 1988 samples approached but did not exceed the State drinking water standard of 0.050 mg/l.

Since well 2C was installed directly in the floor of the drywell, we would expect to see a very short lag-time between a contaminant concentration peak in runoff and a contaminant concentration peak in the ground water. This is the case for the early winter of 1988 chloride concentration (see Figure 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 as the runoff (see Figure 11). The highest chemical oxygen demand in the runoff occurred in the late fall, whereas the highest chemical oxygen demand in well 2C did not occur until early winter. This may indicate that the organic compound causing the high chemical oxygen demand in the runoff is being attenuated by the soils in the drywell.

The amount of nitrate nitrogen in groundwater samples was four to five times higher than in the runoff for this Site. This nitrate may be from residential use of lawn fertilizers upgradient from the Site. Copper, lead, and zinc were commonly detected in groundwater samples at or below 0.07, 0.055 and 0.30 mg/l,



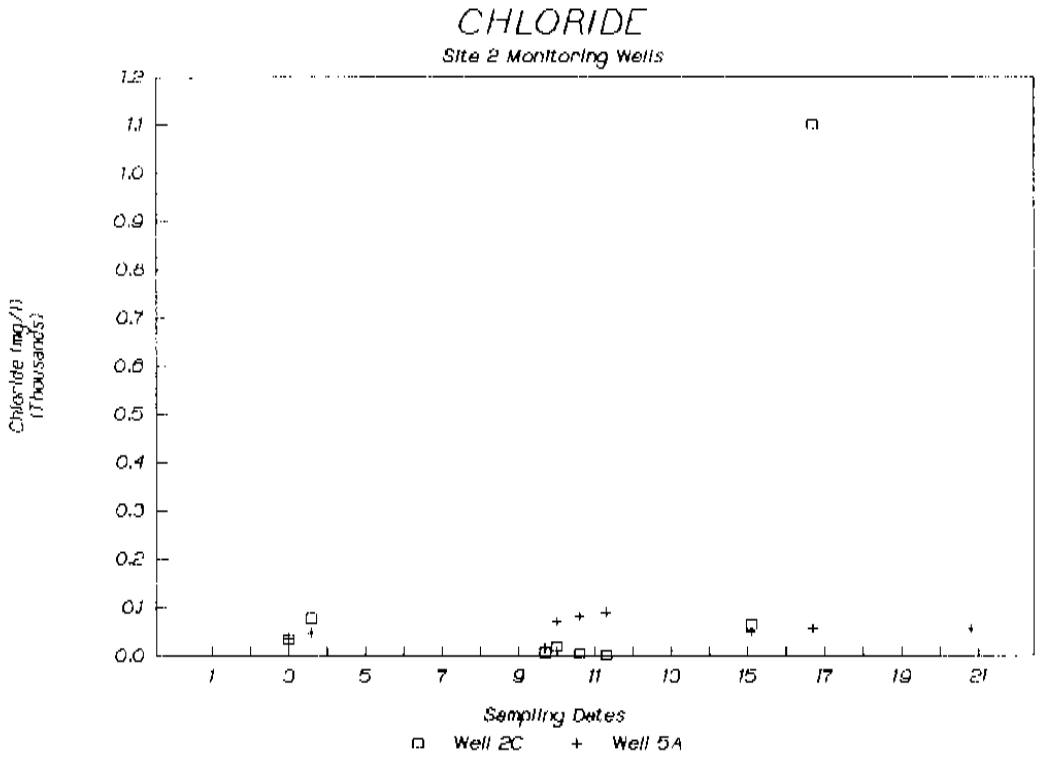
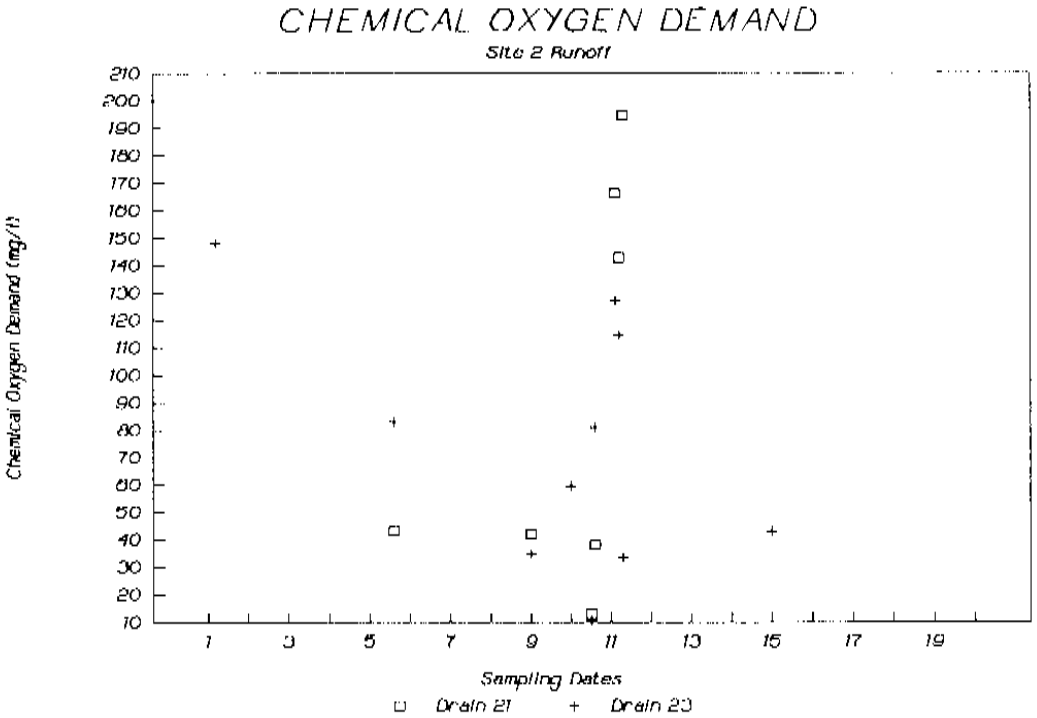


Figure 10. Chloride concentration of selected Sites 2 and 5 runoff and monitoring well samples.



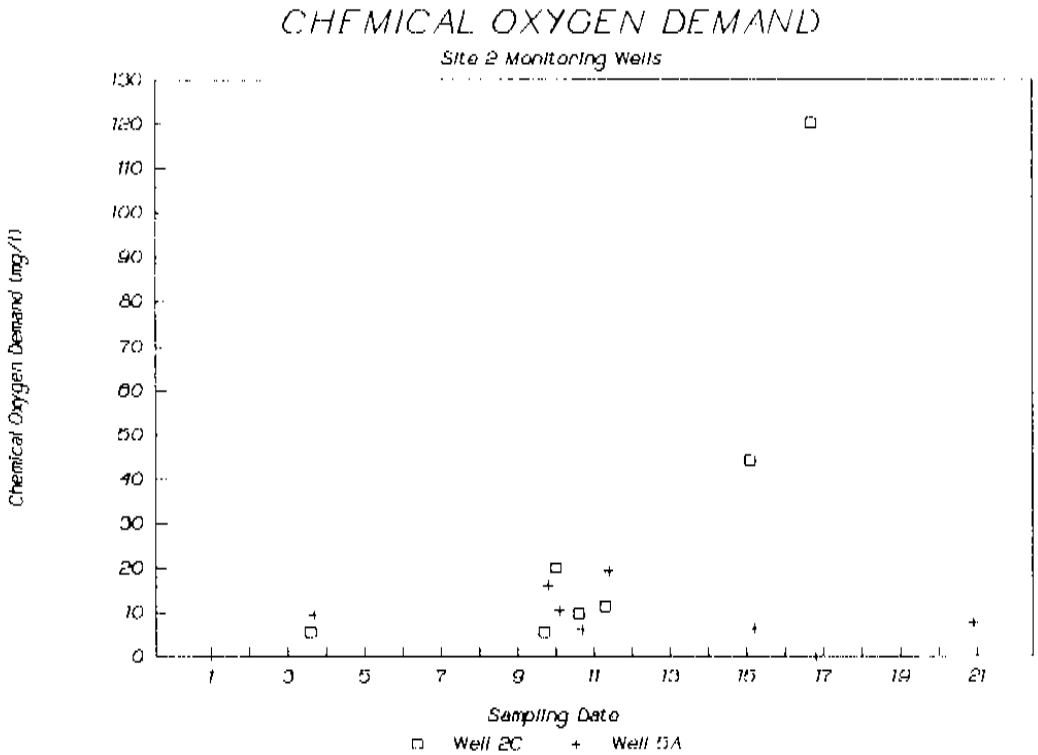


Figure 11. Chemical oxygen demand of selected Sites 2 and 5 runoff and monitoring well samples.

respectively. Some of the first metals samples collected in the fall of 1987 showed high concentrations of zinc but this dropped drastically when the galvanized casings and points were replaced with PVC. One ground water 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. The concentration of VOCs in this sample was approximately 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.

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	None Detected	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	None Detected	ND
5A 880622	None Detected	ND
5A 890524	None Detected	ND
WORZALLA IN DRAIN		
2A 880622	None Detected	ND
2A 880719	trans-1,3-Dichloralpropene	0.9
	Toluene	<0.3
WORZALLA IN DRAIN		
2B 880317	None Detected	ND
2B 880622	None Detected	ND
WORZALLA IN DRAIN		
2C 880317	None Detected	ND
2C 880622	None Detected	ND
2C 880719	None Detected	ND
WORZALLA IN DRAIN		
2D 890524	None Detected	ND

Table 8. Polynuclear aromatic hydrocarbons detected in samples collected at site 2.

SAMPLE LOCATION/DATE	COMPOND
WORZALLA IN DRAIN	
2C 890123	ND
WORZALLA DRAIN SEDIMENT	
2C-SED 890123	Acenapthalene
	Acenapthene
WORZALLA DOWNGRADIENT	
2D5 890612	Acenapthalene
	Fluorene
	Fluoranthrene
IGA FAR DOWNGRADIENT	
321 SUNRISE	ND

ND None Detected

Site 3

Site 3 is a one block long section of a city street in a residential neighborhood located in south-central Stevens Point. This Site is drained by a system of drywells and perforated pipe.

The chloride concentrations in the runoff at this Site were the second highest found during the study, peaking at 1825 mg/l. 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 salts.

The chemical oxygen demand of runoff samples follows a pattern similar to the runoff at Site 2 (see Figures 11 and 13), in that the highest levels were found in the early fall of 1988. The levels of chemical oxygen demand in the Site 3 runoff samples indicate that there is a significant amount of organic matter in the runoff. The high values in the early fall are possibly 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 Figure 14). The peak in nitrate nitrogen may be due to the use of fertilizers on the residential lawns bordering the Site.

Cadmium, copper and chromium were detected in runoff samples at concentrations less than or equal to 0.030, 0.08 and 0.05 mg/l, respectively. 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 of 0.050 mg/l and one sample contained 0.42 mg/l zinc.

As with Site 2, the downgradient wells at this Site are located in the drywells. The peak in chloride and sodium concentrations 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 Figure 13). It is interesting to note that the material causing the chemical oxygen demand seems to be attenuated in the drywell soils as noted at Site 2.

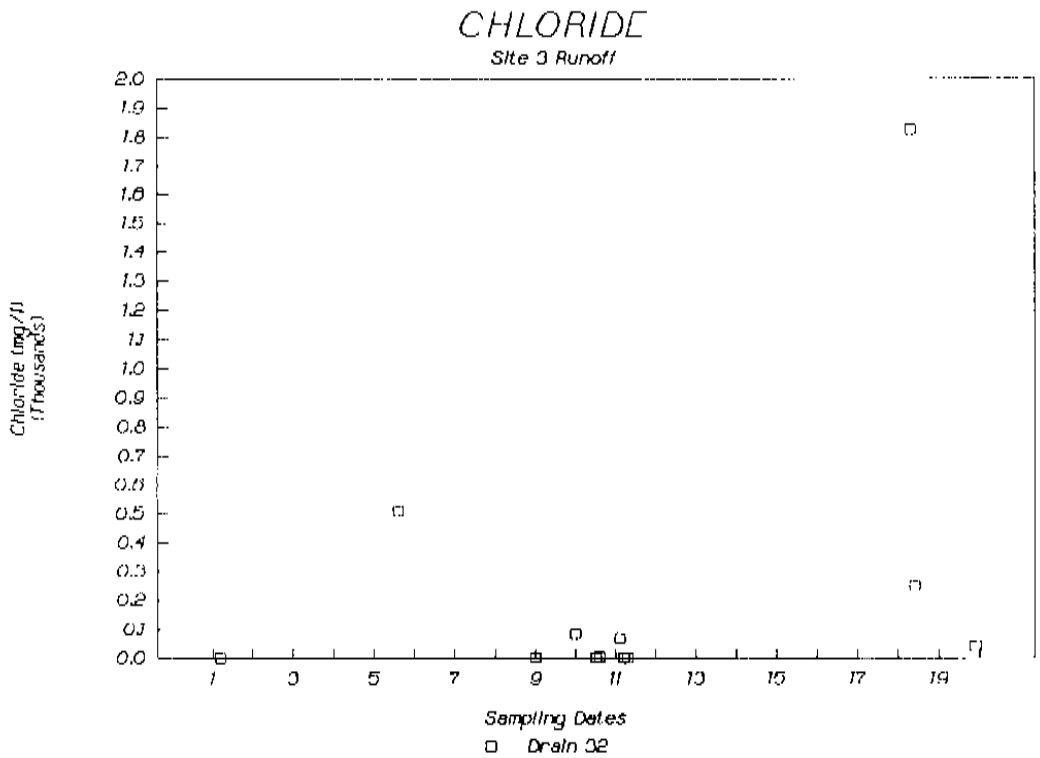
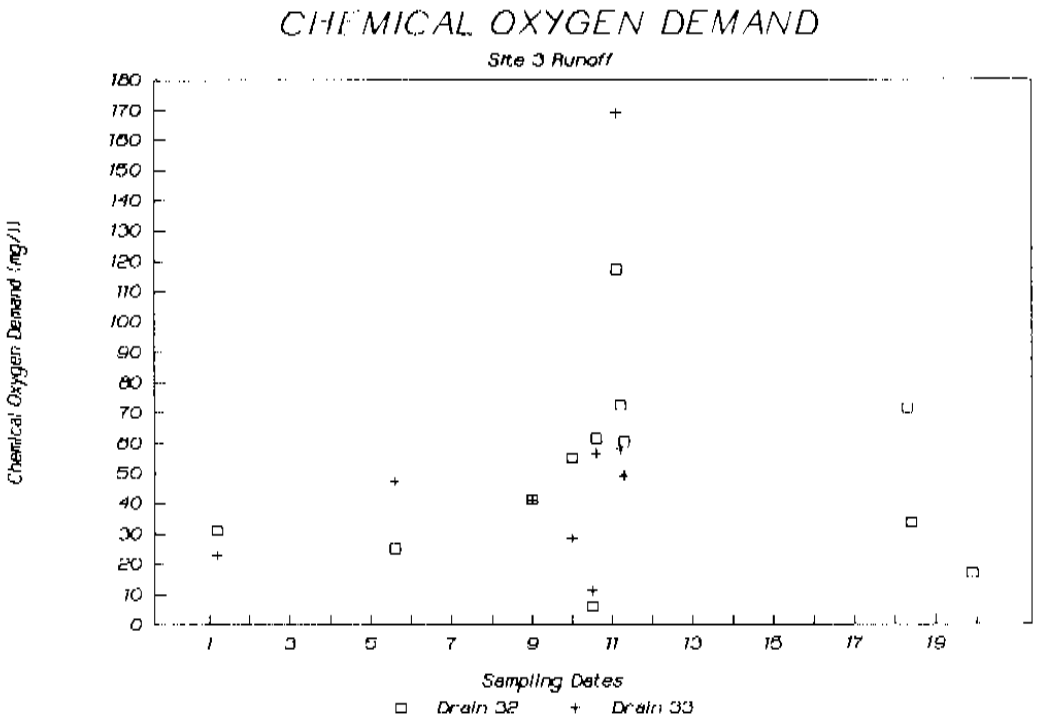


Figure 12. Chloride concentration of selected Site 3 runoff samples.



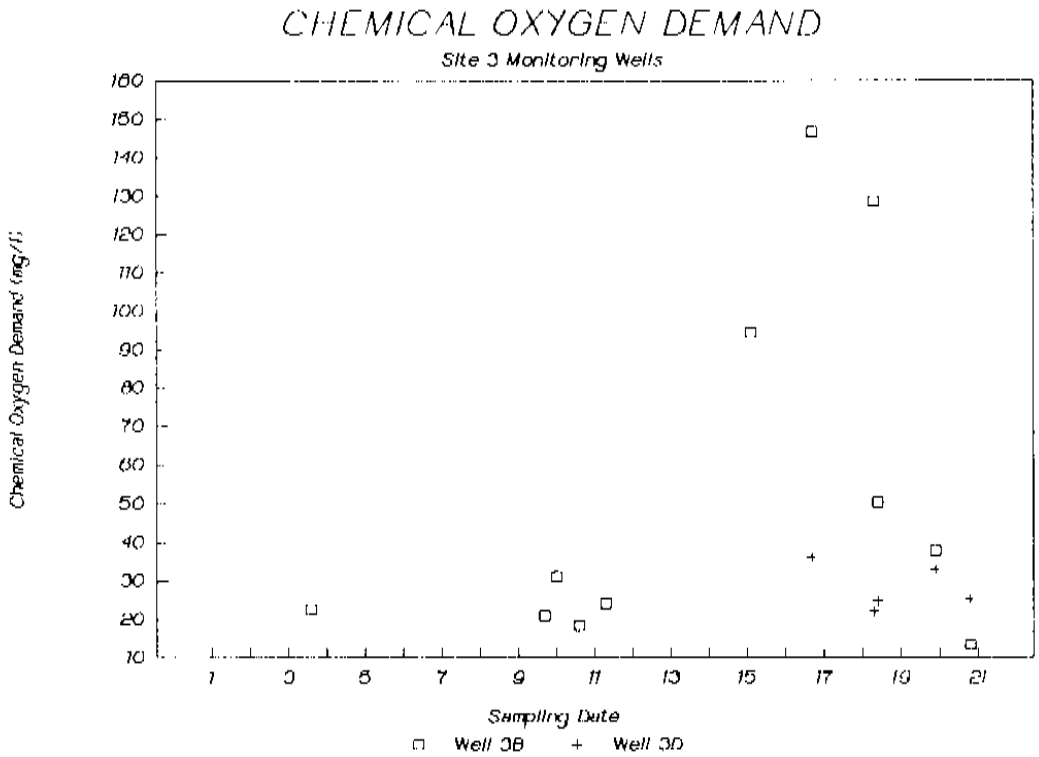
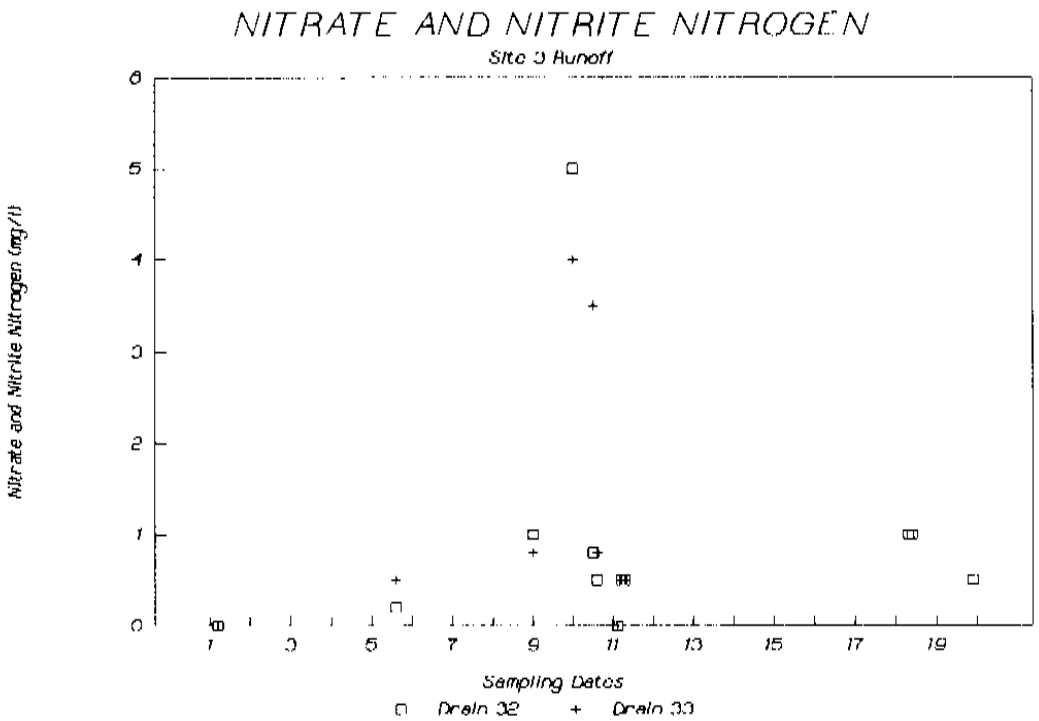


Figure 13. Chemical oxygen demand of selected Site 3 runoff and monitoring well samples.



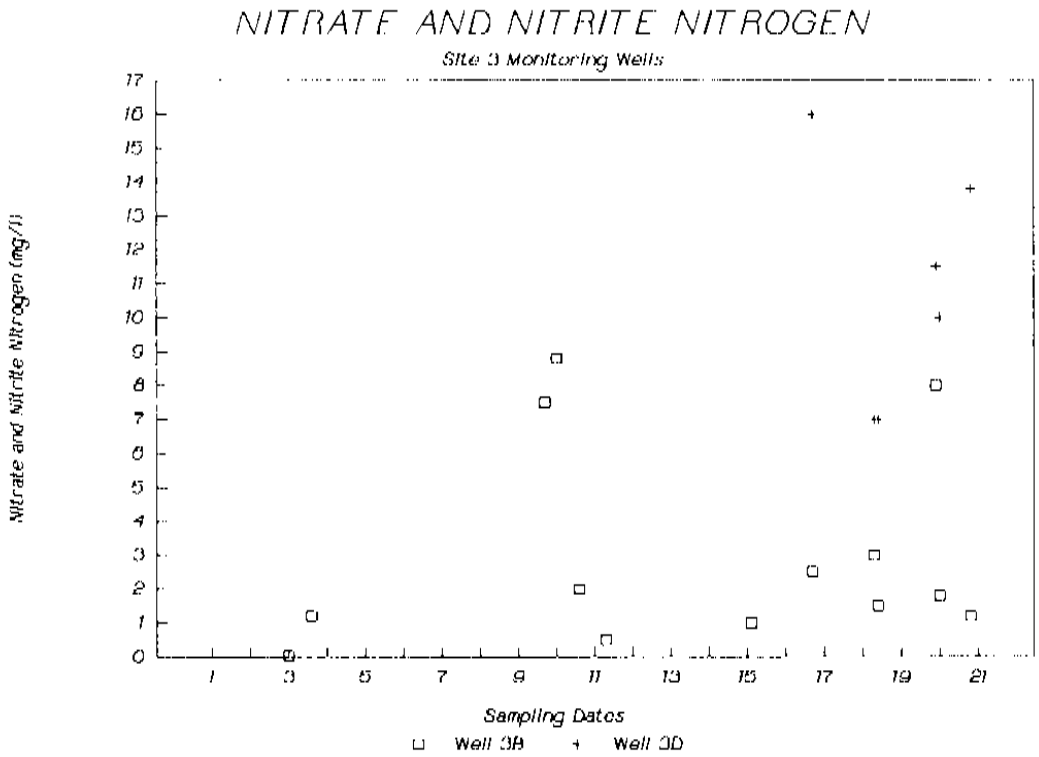


Figure 14. Nitrate and nitrite nitrogen concentration of selected Site 3 runoff and monitoring well samples.

The nitrate nitrogen in the runoff does not seem to be attenuated as it moves to the groundwater. The peak in nitrate nitrogen concentration for downgradient monitoring wells occurred at approximately the same time as the nitrate nitrogen peak in the runoff samples (see Figure 14). The upgradient monitoring well at this Site is located in a residential lawn which may account for the high nitrate nitrogen concentration in the upgradient groundwater samples.

No cadmium or chromium and copper were found in wells at this Site. Copper and lead were detected at levels less than or equal to 0.07 and 0.032 mg/l, respectively, in the monitoring well samples. The first metals samples taken in the fall of 1987 contained large amounts of zinc. The zinc levels dropped drastically once the galvanized casings and points were replaced with PVC. Several of the monitoring well metals samples collected in December of 1988 contained greater than 1 mg/l zinc.

VOCs were found in the runoff at this Site in low concentrations (see Table 9.); low concentrations would be expected since this is the least industrial of all the sites. No VOCs were found in any of the monitoring well samples analyzed (see Table 10). Only two monitoring well samples from this Site were analyzed for PNAs but both showed concentrations near the detection limit of several compounds (see Table 11.).

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	None Detected	ND
32 880602	t-1,3-Dichloropropene	1.3
32 890310	DIESEL	<.5 ppm
32 890311	DIESEL	<.5 ppm
32 890428	None Detected	ND
32 890428	None Detected	ND
DELLA DRAIN		
33 B80602	None Detected	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	None Detected	ND
3A 880622	None Detected	ND
3A 890524	None Detected	ND
DELLA IN DRAIN		
3B 880317	None Detected	ND
3B 880622	None Detected	ND
3B 890310	None Detected	ND
3B 890311	None Detected	ND
3B 890428	None Detected	ND
3B 890429	None Detected	ND
3B 890524	None Detected	ND
DELLA IN DRAIN		
3C 880317	None Detected	ND
3C 880622	None Detected	ND
3C 890524	None Detected	ND
DELLA UPGRADIENT		
3D 890310	None Detected	ND
3D 890311	None Detected	ND
3D 890428	None Detected	ND
3D 890429	None Detected	ND
3D 890524	None Detected	ND

Table 11. Polynuclear aromatic hydrocarbons detected in samples collected at site 3.

SAMPLE LOCATION/DATE	COMPOND	CONCENTRATION (ppb)
DELLA IN DRAIN		
3B 890123	Acenapthalene	
	Fluorene	
	Phenanthrene	
	Fluoranthrene	
	Benzo(k)fluoranthene	
	Benzo(ghi)perylene	
3B 890613	Napthalene	
	Acenapthene	
	Pyrene	
3B 890808*	ND	ND
3B 891005*	ND	ND

ND None Detected
* Supplemental data collected after the completion of this project.

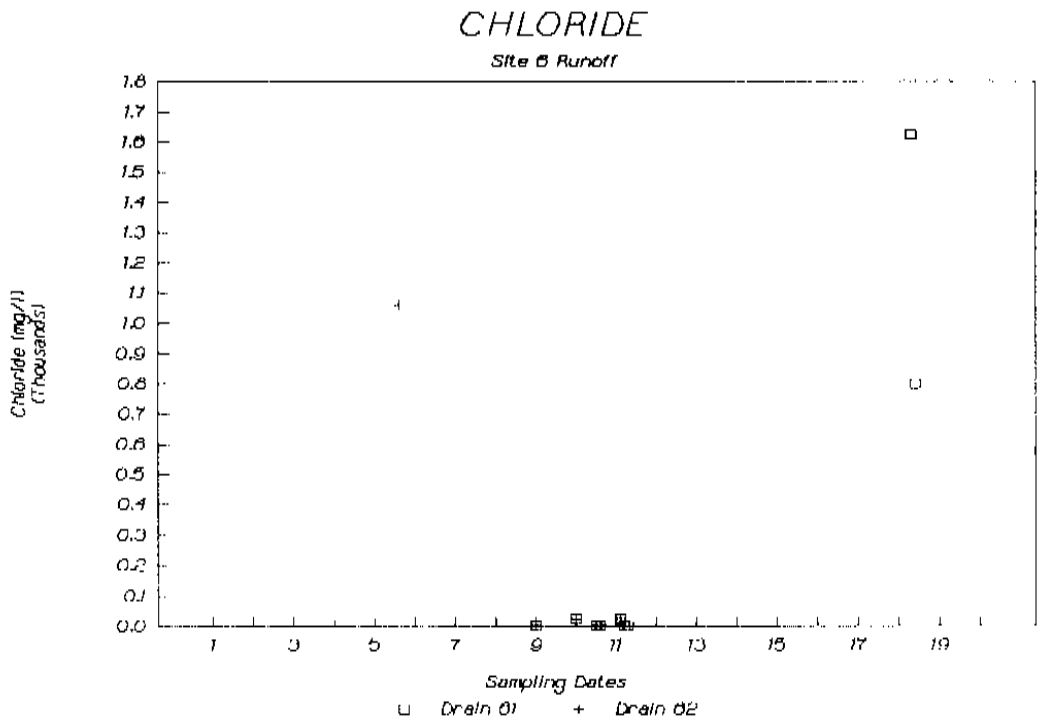
Site 6

Relatively few runoff samples were collected at Site 6, but from those that were collected we see the same pattern in chloride concentration, peaking in the spring (see Figure 15). Since no deicing salt is used on this parking lot, the source of deicing salt may be that which is brought into the Site on the underside of cars.

As seen in Figure 16, nitrate nitrogen concentration in 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 Figure 15). Since the downgradient well (6E) is located 50 feet downgradient of 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 may be deicing salts used on US Highway 51 which borders the Site on the upgradient edge (see Figure 6). The nitrate nitrogen concentration of the monitoring well samples peaked in mid summer (see Figure 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 (0.07 mg/l) and lead (0.006) 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 concentrations in groundwater samples were generally below 1.00 mg/l with most samples below 0.08 mg/l.



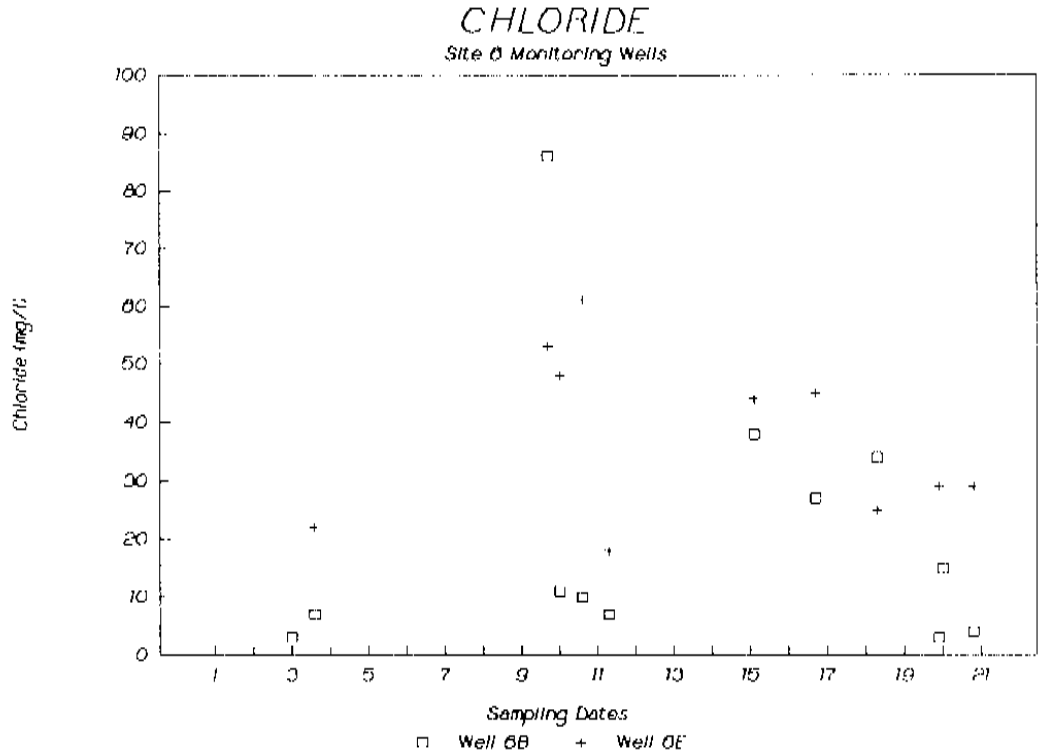
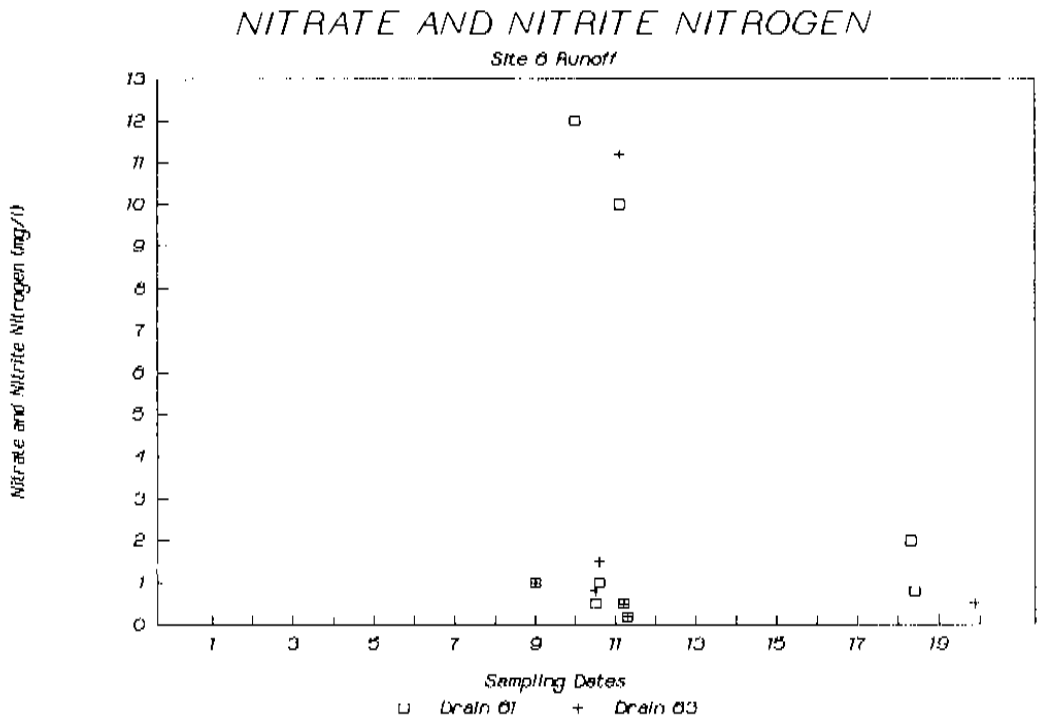


Figure 15. Chloride concentration of selected Site 6 runoff and monitoring well samples.



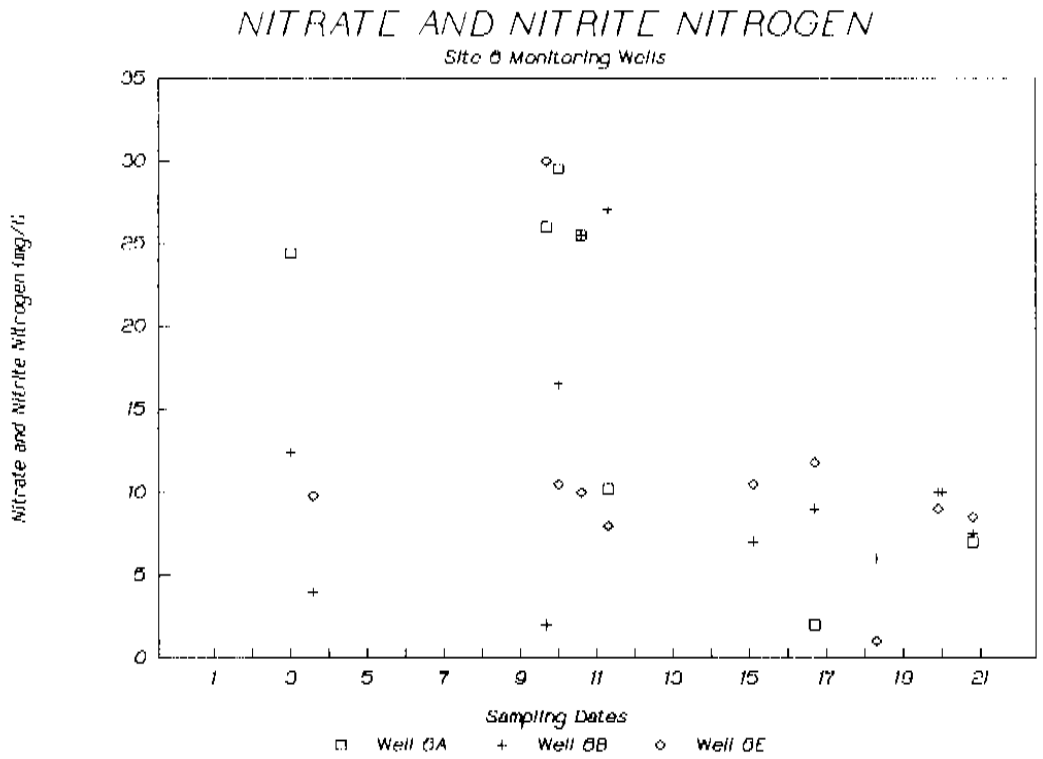


Figure 16. Nitrate and nitrite nitrogen concentration of selected Site 6 runoff and monitoring well samples.

VOCs, especially 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).

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

SAMPLE LOCATION/DATE	COMPOUND NAME	CONCENTRATION ppb
WOODWARD DRAIN		
61 880602	None Detected	ND
61 890311	None Detected	ND
61 890311	DIESEL	<.5
WOODWARD DRAIN		
62 880602	Benzene	0.3
62 880719	None Detected	ND
WOODWARD DRAIN		
63 880602	None Detected	ND
63 890428	DIESEL	<.5 ppm
WOODWARD DRAIN		
64 880602	None Detected	ND
64 880719	None Detected	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	None Detected	ND
6A 880719	None Detected	ND
6A 890524	None Detected	ND
WOODWARD UPGRADIENT		
6B 880317	None Detected	ND
6B 881202	None Detected	ND
6B 890311	None Detected	ND
6B 890428	None Detected	ND
6B 890429	None Detected	ND
6B 890429	None Detected	ND
6B 890524	None Detected	ND
WOODWARD DOWNGRADIENT		
6C 880317	None Detected	ND
6C 880622	Benzene	1.1
6C 881202	None Detected	ND
6C 890122	None Detected	ND
6C 890524	None Detected	ND
WOODWARD DOWNGRADIENT		
6D 880317	None Detected	ND
6D 880622	None Detected	ND
6D 881202	None Detected	ND
6D 890122	None Detected	ND
6D 890524	None Detected	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	None Detected	ND
6E 880719	None Detected	ND
6E 881202	Toluene	<0.5
6E 890122	None Detected	ND
6E 890310	trans-1,3-dichloropropene	.74 ppb
6E 890428	None Detected	ND
6E 890524	None Detected	ND

Table 14. Polynuclear aromatic hydrocarbons detected in samples collected at site 6.

SAMPLE LOCATION/DATE	COMPOND	CONCENTRATION (ppb)
WOODWARD DOWNGRADIENT		
6E 890123	Fluorene	
	Phenanthrene	
	Fluoranthrene	
	Chrysene	
	Benzo(b)fluoranthene	
	Benzo(k)fluoranthene	
6E 890613	ND	
6E 890810*	Pyrene	1.1
6E 891006*	ND	ND

ND None Detected
* Supplemental data collected after the completion of this project.

Site 7

Site 7 is a Mobil gasoline station and carwash which is drained by three storm drains emptying into a single drywell. Since sample collection at this Site did not begin until January of 1989 and ended in May 19B9, there is not enough inorganic chemistry data to generate meaningful graphs. Table 15 contains a summary of several inorganic parameters for the runoff and three wells at this Site.

Chloride values in the runoff and wells at this Site were similar in magnitude to the values at Site 3. Although a very high chloride level (10,200 ppm) was observed in well 7B in March, the downgradient values in well 7C1.5 showed no significant changes by May although two months may not be enough time to transport the chloride plume to the downgradient well. In April and May the upgradient well (7A1) actually had a higher chloride value than the downgradient wells. The high concentration in the upgradient well may be from a chloride plume originating farther upgradient.

Nitrate and nitrite nitrogen concentrations in runoff and monitoring well samples were low, typically between 1.0 and 5.0 ppm. Samples from well 7B had very high chemical oxygen demand peaking at 241.4 ppm in March. Chemical oxygen demand in samples from the downgradient well were much lower, averaging about 18 ppm. Once again, two months may not be enough time to transport the organic plume to the downgradient well. No chromium and small amounts (<1.0 ppm) of copper lead and zinc were found in the monitoring well and runoff samples.

Diesel fuel was detected in every runoff sample analyzed for VOCs as shown in Table 16. No VOCs were detected in the upgradient well at this Site (Table 17). Well 7B contained detectable VOCs in every sample analyzed. One sample from 7B contained 14.0 ppb benzene which is in excess of the State Drinking Water Standard of 5.0 ppb benzene. Every sample from the downgradient well 7C3 also contained VOCs with 4.3 ppb benzene in one sample. The VOCs detected in the samples collected from this Site are typical gasoline components. This gasoline may be spillage in the vicinity of the pumps at the Mobil station. All downgradient wells also contained many PNA compounds associated with gasoline (Table 18).

Table 15. Summary of inorganic analysis by sampling date for samples collected from three wells at Site 7.

CHLORIDE

WELL	890122	890312	890428	890524
7A1	65	42	650	520
7B	NS	10200	98	12
7C1.5	100	NS	100	170
RUNOFF				
71	NS	3550	NS	NS

CHEMICAL OXYGEN DEMAND

WELL	890122	890312	890428	890524
7A1	6.0	27.4	67.2	37.8
7B	NS	241.4	165.6	123.9
7C1.5	11.1	NS	26.9	16.3
RUNOFF				
71	NS	78.7	NS	NS

NITRATE AND NITRITE NITROGEN

WELL	890122	890312	890428	890524
7A1	0.5	5.0	1.8	1.2
7B	NS	1.0	0.2	0.2
7C1.5	4.0	NS	1.0	2.5
RUNOFF				
71	NS	0.5	NS	NS

NS - Not Sampled

Table 16. 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 17. Volatile organic compound concentration of monitoring well samples taken from Site 7.

SAMPLE LOCATION/DATE	COMPOUND NAME	CONCENTRATION ppb
MOBIL UPGRADIENT		
7A 890122	None Detected	ND
7A 890310	2 UNIDENTIFIED	
7A 890311	None Detected	ND
7A 890428	None Detected	ND
7A 890429	None Detected	ND
7A 890524	None Detected	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	None Detected	ND
7D 890524	None Detected	ND

Table 18. Polynuclear aromatic hydrocarbons detected in samples collected at site 7.

SAMPLE LOCATION/DATE	COMPOND	CONCENTRATION (ppb)
MOBIL IN DRAIN		
7B 890123	Phenanthrene	
	Fluoranthrene	
7B 890613	Phenanthrene	
	Pyrene	
	Chrysene	
	Benzo(k)fluoranthene	
	Benzo(ghi)perylene	
7B 890810*	Acenaphthylene	4.0
	Acenapthene	1.7
	Phenanthrene	2.0
	Fluoranthrene	7.6
	Pyrene	5.2
	Benzo(a)anthracene	1.4
	Chrysene/Benzo(b)fluoranthene	2.8
	Benzo(k)fluoranthene	7.3
	Benzo(a)pyrene	7.2
	Benzo(ah)anthrancene	5.2
	Benzo(ghi)perylene	5.4
7B 891006*	Acenaphthylene	4.8
	Acenapthene	3.6
	Phenanthrene	2.4
	Fluoranthrene	9.8
	Pyrene	6.B
	Benzo(a)anthracene	4.5
	Chrysene/Benzo(b)fluoranthene	4.0
	Benzo(k)fluoranthene	14.0
	Benzo(a)pyrene	13.3
	Benzo(ah)anthrancene	7.B
	Benzo(ghi)perylene	3.9
MOBIL DOWNGRADIENT		
7C0 890613	Acenapthene	
	Anthracene	
	Fluoranthrene	
	Pyrene	
	Benzo(b)fluoranthene	
	Benzo(a)pyrene	
	Benzo(ghi)perylene	
7C0 890808*	ND	ND
7C0 891006*	ND	ND

Table 18. cont. Polynuclear aromatic hydrocarbons detected in samples collected at site 7.

SAMPLE LOCATION/DATE	COMPOND	CONCENTRATION (ppb)
MOBIL DOWNGRADIENT (cont.)		
7C3 890123	Napthalene	
	Acenapthalene	
	Fluorene	
	Phenanthrene	
	Fluoranthrene	
	Chrysene	
	Benzo(k)fluoranthene	
	Benzo(a)pyrene	
7C3 890612	Fluorene	
	Acenapthene	
	Anthracene	
	Fluoranthrene	
	Pyrene	
	Benzo(b)fluoranthene	
	Benzo(ghi)perylene	
7C3 890810*	ND	ND
7C3 891006*	Napthalene	5.3
	Acenaphthylene	1.6
MOBIL BY DRAIN		
7D 890612	Phenanthrene	
	Chrysene	
	Benzo(a)anthracene	
	Benzo(ghi)perylene	
7D 891006*	Benzo(a)pyrene	1.6

ND None Detected
* Supplemental data collected after the completion of this project.

CONCLUSIONS

Subsurface disposal of urban runoff has a negative 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 characteristics 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 3 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. A sodium restriced diet may allow a person only 1000 to 2000 mg sodium/day. Assuming a person consumes two liters of water per day, lived on the downgradient edge of Site 3, and was obtained drinking water from 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 use of deicing salts and decreased number of automobile accidents (McConnell and Lewis, 1972).

In data collected during this study suggests trace metals in runoff do not migrate freely to 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 trace 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 groundwater 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. Organic contaminants associated with urban runoff other than VOCs need further evaluation. These contaminants, which include PNAs, 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 2 which was poorly maintained, disposed of runoff quickly and effectively. In most cases, the subsurface injection system was the most cost-effect 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 spills were detected in this study the possibility does exist and should be considered, especially if the drains are used in areas where groundwater is used as the drinking water supply.

It is difficult to directly compare monitoring results between drywells and perforated pipe drainage systems. The data suggests drywells allow higher concentrations of contaminants to reach the groundwater; however, the nature of the monitoring system may account for these differences. Wells were installed through drywells and samples taken immediately under the drains, while at perforated drain sites the wells were between 500 and 200 feet downgradient of the drain system, allowing increased contaminant attenuation and dilution. Dry wells by their nature would produce a smaller plume of contamination than perforated pipe systems. The total loading of contaminants to groundwater may be similar for the two system types even though plume concentrations would be

higher downgradient of drywells. Perforated pipe systems provide soil-water interaction over a larger area which may result in improved contaminant attenuation and dilution.

Additional research into the effect of age of the drainage system and potential contaminant reduction efficiency with age and buildup of organic matter would help to further define the effectiveness of drywells. Also, additional research on organic compound transport in drain systems would help define appropriate areas for subsurface disposal of urban runoff.

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APPENDIX A

Monitoring Well Construction Details

Table 1. Monitoring well construction details.

WELL	RISER TYPE	RISER LENGTH	SCREEN TYPE	SCREEN LENGTH	SCREEN POSITION RELATIVE TO WT	APPROX. DEPTH TO WT WHEN WELL INSTALLED (Below casing top)
1A	1.25 in dia PVC	24.8 ft	0.010 in slot PVC	3.0 ft	Skimming	29.3 ft
1B	1.25 in dia PVC	26.0 ft	0.010 in slot PVC	3.0 ft	Skimming	27.5 ft
1C	1.25 in dia PVC	25.1 ft	0.010 in slot PVC	3.0 ft	Skimming	26.6 ft
1D	1.25 in dia PVC	22.9 ft	0.010 in slot PVC	6.0 ft	Skimming	25.9 ft
1D5	0.25 in dia tube	30.0 ft	Nylon wrapped tube	0.5 ft	5.0 ft below WT	25.9 ft
1D7.5	0.25 in dia tube	33.9 ft	Nylon wrapped tube	0.5 ft	7.5 ft below WT	25.9 ft
5A	1.25 in dia PVC	23.2 ft	0.010 in slot PVC	3.0 ft	Skimming	24.7 ft
2A	1.25 in dia PVC	20.0 ft	0.010 in slot PVC	3.0 ft	Skimming	21.5 ft
2B	1.25 in dia PVC	27.0 ft	0.010 in slot PVC	3.0 ft	Skimming	28.5 ft
2C	1.25 in dia PVC	19.9 ft	0.010 in slot PVC	3.0 ft	Skimming	21.4 ft
2D	0.25 in dia tube	26.5 ft	Nylon wrapped tube	0.5 ft	Skimming	27.0 ft
2D5	1.25 in dia PVC	32.0 ft	0.010 in slot PVC	3.0 ft	5.0 ft below WT	27.0 ft
3A	1.25 in dia PVC	9.2 ft	0.010 in slot PVC	3.0 ft	Skimming	10.7 ft
3B	1.25 in dia PVC	2.8 ft	0.010 in slot PVC	3.0 ft	Skimming	4.3 ft
3C	1.25 in dia PVC	2.7 ft	0.010 in slot PVC	3.0 ft	Skimming	4.2 ft
3D	1.25 in dia PVC	6.7 ft	0.010 in slot PVC	3.0 ft	Skimming	8.2 ft
6A	1.25 in dia PVC	23.0 ft	0.010 in slot PVC	3.0 ft	Skimmimig	24.5 ft
6B	1.25 in dia PVC	22.2 ft	0.010 in slot PVC	3.0 ft	Skimmimig	23.7 ft
6C	1.25 in dia PVC	27.5 ft	0.010 in slot PVC	3.0 ft	Skimmimig	29.0 ft
6D	1.25 in dia PVC	24.7 ft	0.010 in slot PVC	3.0 ft	Skimmimig	23.2 ft
6E	1.25 in dia PVC	27.9 ft	0.010 in slot PVC	3.0 ft	Skimmimig	29.4 ft
7A0	0.25 in dia tube	18.5 ft	Nylon wrapped tube	0.5 ft	Skimmimg	18.5 ft
7A1	1.25 in dia PVC	20.0 ft	0.010 in slot PVC	3.0 ft	1.0 ft below WT	18.5 ft
7B	1.25 in dia PVC	1.3 ft	0.010 in slot PVC	3.0 ft	Skimmimg	2.8 ft
7C0	0.25 in dia tube	22.4 ft	Nylon wrapped tube	0.5 ft	Skimmimg	22.9 ft
7C1.5	0.25 in dia tube	23.9 ft	Nylon wrapped tube	0.5 ft	1.5 ft below WT	22.9 ft
7C3	1.25 in dia PVC	25.4 ft	0.010 in slot PVC	3.0 ft	3.0 ft below WT	22.9 ft
7D	1.25 in dia PVC	10.6 ft	0.010 in slot PVC	3.0 ft	Skimmimg	12.1 ft

WT Water Table

APPENDIX B

Method Detection Limits for
Volatile Organic Compound Analysis

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

COMPOUND	MDL ppb
Benzene	0.5
Chlorobenzene	0.3
1,1-Dichloroethane	0.7
trans-1,2-Dichloropropene	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 C

Inorganic Data Tables

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

WELL	871130	880317	880622	880701	880719	880809	881202	890122	890312	890313	890428	890429	890524
1A		20	8	12	12	20	12	20					8
1B		28	16	24	24	28	64	52					24
1C		24	14	28	30	16	44	60					16
1D							50	64					40
1D5							96	124					100
1D7.5							60	64					56
2A			20	20	16	16	20	64					
2B		32	26	28	26	28	24	32					
2C		40	28	32	22	16	24	92					
2D								24					12
2D5								24					8
3A		68	116		68		36						84
3B		68	92	100	80	60	24	80	50	46	104	68	48
3C		112	128	120	100	72	76						60
3D								164	132	134	116	116	116
5A		36	12	20	16	20	20	36					16
6A			172	168	136	152		200					132
6B		68	50	68	80	88	204	228	92		132	128	96
6C		56	144	140	88	140	136	208					104
6D		88	130	132	124	116	160	108					24
6E		72	56	56	56	88	88	104	52		92		104
7A0								72	56	60	56	56	36
7A1								80	56		32	32	84
7B									86	104	124	168	136
7C0													76
7C1.5								80			80	80	64
7C3								116			84	84	88
7D											40	44	84

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

DRAIN	871007	880219	880602	880701	880715	880719	880803	880805	880809	881202	890312	890313	890428
11	100	20	16	128	16	22	156	16	12				
12	100	24											
13	36												
14	84	48											
15	18	40	24	32	16	24	20	20	28	20			
16	16	12	12	28	4	32	36	12	16	24			
21		12	12		16	30	152	12	16				
22	10												
23	14	28	16	24	20	40	80	20	20	26			
31N	72	28	16	40	24	44	156	24	24				
31S	28												
32N	32	20	24	116	26	60	160	16	14		40	20	20
32S	28												
33N	32	12	20	112	112	36	106	20	32				
33S	26												
41		48	172	84	192	172	208	268	160				
61			44	140	28	44	132	40	28		64	44	
62		36	32	144	36	40	152	20					
63			44		48	60	150	44	40				52
64			36	148									
71											20	31	
74													20

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

WELL	871130	880317	880622	880701	880719	880809	881202	890122	890312	890313	890428	890429	890524
1A		12.2	10.2	13.5	8.7	8.1	34.3	11.2					8.58
1B		14.8	15.8	33.5	8.2	24.0	5.7	3.2					25.19
1C		10.2	10.2	15.9	4.9	8.1	12.1	14.9					25.19
1D							7.7	21.3					19.83
1D5							2.3	6.9					10.72
1D7.5							3.3	5.6					16.62
2A			6.9	8.6	6.1	12.4	14.7	26.6					
2B		9.2	18.1	9.2	5.4	10.8	9.0	5.6					
2C		5.6	5.5	20.0	9.8	11.3	44.1	120.2					
2D								58.0					8.58
2D5								<3.0					10.18
3A		24.2	15.5		9.8		8.5						21.98
3B		22.6	21.0	31.3	18.5	24.3	94.3	146.8	128.6	50.4	37.9		13.40
3C		43.2	25.9	20.0	15.5	18.9	<3.0						2.16
3D								36.3	22.1	24.9	33.1		25.38
5A		9.5	16.0	10.4	6.0	19.2	6.3	<3.0					7.56
6A			25.4	<3.0	10.9	8.1		3.0					12.96
6B		14.4	14.4	18.6	6.3	16.2	<3.0	3.5	9.6		8.6		2.70
6C		9.8	18.8	<3.0		28.4	7.3	<3.0					16.20
6D		4.0	7.2	<3.0	6.5	11.3	6.2	<3.0					10.80
6E		10.8	5.5	41.9	9.3	17.3	27.6	<3.0	35.0		7.2		5.40
7A0								18.6	24.0	31.2	24.0		46.98
7A1								6.0	27.4		67.2		37.80
7B									241.4	124.8	165.6		123.90
7C0													16.30
7C1.5								11.1			26.9		16.30
7C3								18.1			37.0		22.60
7D											4.2		

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

DRAIN	871007	880219	880602	880701	880715	880719	880803	880805	880809	881202	890312	890313	890428
11	2870	56	25.4	43.2	11.2	12.0	34.6	170.7	70.2				
12	19	59											
13	76												
14	54	155											
15	45	101	53.7	130.7	10.3	50.0	51.3	153.7	53.5	548			
16	41	29	23.3	21.1	11.2	62.6	61.8	76.3	11.9	86			
21		43	41.9		13.2	38.1	165.9	142.6	194.4				
22	140												
23	148	83	34.8	59.4	10.8	81.1	126.9	114.5	33.5	43			
31N	6564	22	34.1	54.3	8.4	39.7	136.0	62.1	125.8				
31S	60												
32N	31	25	41.1	55.1	6.0	61.5	117.2	72.5	60.5		71.5	33.6	16.8
32S	25												
33N	23	47	40.9	28.5	11.2	56.6	169.0	57.9	49.1				
33S	18												
41		25	60.3	118.4	90.7	44.1	167.0	205.2	86.4				
61			10.9	4.4	2.0	8.2	38.1	13.2	3.2		78.7	33.6	
62		72	17.3	5.5	14.8	13.6	14.1	12.1					
63			8.2		12.0	10.3	15.8	10.4	9.2				6.2
64			9.8	32.5									
71											78.7	78.7	
74													45.1

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

WELL	871130	880317	880622	880701	880719	880809	881202	890122	890312	890313	890428	890429	890524
1A	22	12	1	10	7	13	64	80					8
1B	11	21	250	14	78	120	18	6					130
1C	2	5	125	68	16	7	1	21					56
1D							24	31					160
1D5							38	55					81
1D7.5							25	16					100
2A			9	5	2	1	2	207					
2B	46	69	56	56	34	6	40	65					
2C	33	77	6	19	4	2	65	1100					
2D								13					<1
2D5								2					<1
3A	2	30	68		5		1						2
3B	78	99	49	43	9	3	4700	3050	4600	950	30	16	3
3C	3	120	60	36	29	1	7						2
3D								38	26	23	26	30	33
5A	36	48	17	70	81	89	49	57					55
6A	10		10	16	14	11		4					160
6B	3	7	86	11	10	7	38	27	34		3	15	4
6C	14	16	22	61	120	90	25	5					140
6D	18	6	38	23	21	20	10	30					15
6E		22	53	48	61	18	44	45	25		29		29
7A0								57	41	41	61	62	810
7A1								65	42		650	620	520
7B									10200	300	98	101	12
7C0													94
7C1.5								100			100	100	170
7C3								140			150	150	130
7D											41	31	99

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

DRAIN	871007	880219	880602	880701	880715	880719	880803	880805	880809	881202	890312	890313	890428
11	63	590	3.0	32	1	1	33	7	<1				
12	33	850											
13	8												
14	22	1360											
15	1	1420	3.0	11	3	6	1	4	5	1525			
16	<1	570	1.0	2	2	10	3	2	<1	1550			
21		620	2.0		2	8	4	4	1				
22	1												
23	<1	720	2.0	5	3	8	16	3	<1	275			
31N	21	600	2.0	4	2	8	29	3	1				
31S	1												
32N	1	510	2.0	85	2	5	70	2	1		1825	250	42
32S	<1												
33N	<1	370	1.0	29	22	5	24	2	1				
33S	<1												
41		730	188.0	160	350	195	240	300	210				
61			1.5	24	2	2	25	1	<1		1625	800	
62		1060	1.5	24	3	3	24	2					
63			1.0		4	3	26	3	1				5
64			1.0	24									
71											3550	1200	
74													27

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

WELL	871130	880317	880622	880701	880719	880809	881202	890122	890312	890313	890428	890429	890524
1A	187	122	111.0	108.0	90.8	104.0	258	318.0					103.0
1B	168	166	908.0	575.0	362.0	543.0	201	121.0					620.0
1C	88	94	487.0	318.0	146.0	135.0	107	210.0					281.0
1D							227	259.0					724.0
1D5							344	457.0					519.0
1D7.5							252	194.0					511.0
2A			122.0	87.8	46.2	75.3	62	906.0					
2B	203	337	290.0	294.0	234.0	90.9	213	301.0					
2C	206	391	321.0	194.0	74.4	71.2	290	3640.0					
2D								120.0					64.8
2D5								40.1					82.7
3A	76	242	255.0		137.0		83						187.0
3B	416	490	438.0	434.0	212.0	141.0	12690	9000.0	12810	3090	465	222	125.0
3C	134	653	492.0	424.0	395.0	153.0	159						124.0
3D								522.0	410	410	442	394	466.0
5A	240	302	297.0	323.0	364.0	378.0	329	299.0					285.0
6A	564		630.0	610.0	521.0	429.0		357.0					853.0
6B	311	220	400.0	343.0	397.0	435.0	564	548.0	360		412	376	282.0
6C	386	396	567.0	477.0	637.0	646.0	440	320.0					757.0
6D	527	267	417.0	438.0	426.0	417.0	366	405.0					169.0
6E		331	350.0	376.0	410.0	26.2	407	393.0	268		375		390.0
7A0								387.0	333	337	384	359	2710.0
7A1								323.0	338		2120	2000	1820.0
7B									26700	20700	684	709	325.0
7C0													490.0
7C1.5								557.0			540	497	761.0
7C3								704.0			714	665	674.0
7D											297	231	534.0

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

DRAIN	871007	880219	880602	880701	880715	880719	880803	880805	880809	881202	890312	890313	890428
11	680	1750	59.0	394.0	37.2	62.8	403.0	72.4	88.1				
12	331	2550											
13	104												
14	259	4420											
15	46	4250	84.1	172.0	44.8	68.8	63.0	82.1	31.3	4470			
16	49	1710	42.0	61.8	39.0	104.0	96.0	47.7	34.2	4550			
21		1874	42.2		41.3	76.7	302.0	50.4	33.8				
22	40												
23	35	2140	55.3	73.4	42.8	110.0	203.0	67.9	43.0	950			
31N	447	1770	82.1	108.0	50.3	113.0	444.0	67.5	54.4				
31S	79												
32N	76	1440	70.3	603.0	66.5	143.0	594.0	38.8	34.2		5540	997	69
32S	55												
33N	62	1213	64.3	371.0	267.0	94.0	335.0	51.5	65.1				
33S	53												
41		2420	975.0	682.0	465.0	949.0	1146.0	1449.0	1006.0				
61			107.0	452.0	64.6	15.0	446.0	82.2	67.3		4930	1460	
62		3460	76.0	454.0	82.2	126.0	445.0	43.5					
63			98.6		107.0	149.0	454.0	97.1	84.4				121
64			87.8	466.0									
71											992	3850	
74													168

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

WELL	871130	880317	880622	880701	880719	880809	881202	890122	890312	890313	890428	890429	890524
1A	24.0	13.8	7.0	88.0	6.5	8.9	29.5	45.5					
1B	31.0	23.0	70.0	87.5	45.5	72.5	44.2	37.5					
1C	17.0	4.5	30.0	29.0	22.6	25.0	23.4	62.5					
1D							29.0	37.5					
1D5							44.0	50.0					
1D7.5							35.5	37.5					
2A			11.5	6.0	5.9	11.0	4.5	187.5					
2B	25.0	22.2	33.0	31.5	28.0	8.3	30.5	35.0					
2C	12.5	26.8	67.5	23.0	11.1	9.5	35.0	680.0					
2D								13.0					
2D5								1.8					
3A	1.2	46.5	29.5		33.0		5.0						
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	
3C	2.1	117.5	37.5	17.0	12.8	2.8	5.4						
3D								37.5	16.0	16.5	14.6	15.2	
5A	19.0	36.5	5.5	42.5	40.0	45.2	30.9	25.0					
6A	3.0		3.0	4.0	3.2	1.8		3.5					
6B	1.3	2.4	57.5	3.0	2.1	2.2	8.5	12.5	24.0		3.2	3.6	
6C	8.5	2.8	6.0	62.5	54.0	48.2	6.0	12.5					
6D	4.8	4.0	19.5	6.5	5.3	5.7	11.5	12.5					
6E		6.8	30.5	12.5	14.0	20.0	23.2	62.5	21.0		10.0		
7A0								37.5	33.0	33.0	28.0	30.0	
7A1								62.5	33.0		294.0	324.0	
7B									3038.0	2062.0	108.0	124.0	
7C0													
7C1.5								75.0			62.4	66.4	
7C3								125.0			82.0	82.4	
7D											34.0	25.0	

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

DRAIN	871007	880219	880602	880701	880715	880719	880803	880805	880809	881202	890312	890313	890428
11	17.4	315	4	15.5	1.0	2.1	14.4	7.8	2.0				
12	10.8	420											
13	4.8												
14	9.3	800											
15	2.3	800	4	9.5	2.0	1.5	1.5	7.0	6.0	1100			
16	2.1	280	1	1.5	0.9	5.3	3.0	3.8	0.7	825			
21		290	1		1.0	2.1	1.9	5.7	0.8				
22	1.7												
23	1.3	350	2	3.5	0.9	2.6	8.4	5.8	2.0	100			
31N	16.4	320	3	3.5	1.3	4.8	15.7	3.7	1.8				
31S	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
32S	2.4												
33N	2.6	215	2	14.0	9.7	3.2	13.2	3.5	2.6				
33S	2.9												
41		400	103	85.0	190.0	105.0	122.0	65.0	115.5				
61			5	8.0	1.6	5.0	7.1	9.0	3.2		462.0	130.0	
62		490	6	7.0	1.7	5.3	6.3	6.5					
63			4		1.5	3.2	7.0	6.7	3.0				18.0
64			4	6.5									
71											988.0	338.0	
74													24.0

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	890312	890313	890428	890429	890524
1A	0.02	0.14	0.16	0.21	0.10	0.02	0.03	0.07					
1B	<0.01	0.08	0.12	0.10	0.10	0.08	0.02	0.07					
1C	<0.01	0.04	0.90	0.12	0.18	0.10	0.05	0.10					
1D							0.02	0.03					
1D5							0.01	0.01					
1D7.5							<0.01	0.01					
2A			0.14	0.16	0.25	0.02	0.12	0.30					
2B	0.08	0.20	0.20	0.12	0.03	0.04	0.04	0.13					
2C	0.11	0.10	0.15	0.06	0.07	0.02	0.44	1.36					
2D								0.06					
2D5								0.04					
3A	<0.01	0.04	0.15		0.10		0.04						
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	
3C	0.05	0.06	0.12	0.06	0.12	0.02	0.06						
3D								0.04	<0.02	<0.02	0.01	<0.01	
5A	0.01	0.10	0.21	0.18	0.08	0.14	0.06	0.17					
6A	<0.01		0.35	0.18	0.10	0.06		0.03					
6B	<0.01	0.04	0.18	0.15	0.04	0.06	0.02	0.04	0.02		<0.01	<0.01	
6C	<0.01	0.10	0.16	0.18	0.10	0.03	0.01	0.05					
6D	0.01	0.08	0.18	0.06	0.06	0.03	0.02	0.04					
6E		0.08	0.16	0.22	0.09	0.12	0.09	0.12	0.32		<0.01		
7A0								0.02	<0.02	<0.02	0.03	<0.01	
7A1								0.01	<0.02		0.02	<0.01	
7B									1.98	1.75	0.97	1.14	
7C0													
7C1.5								0.03			<0.01	<0.01	
7C3								0.04			<0.01	<0.01	
7D											<0.01	<0.01	

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

DRAIN	871007	880219	880602	880701	880715	880719	880803	880805	880809	881202	890312	890313	890428
11	0.50	0.6	0.58	0.33	0.24	0.20	0.76	0.33	0.04				
12	0.05	0.6											
13	0.02												
14	<0.02	0.8											
15	0.20	0.8	0.78	0.18	0.34	0.27	0.06	0.04	0.11	0.72			
16	0.22	1.0	0.70	0.38	0.45	0.08	0.63	0.60	0.07	0.78			
21		0.6	0.71		0.18	0.24	0.02	0.63	0.14				
22	0.25												
23	0.25	0.8	0.56	0.20	0.18	0.02	0.03	0.24	0.08	0.36			
31N	0.62	0.4	0.78	0.75	0.27	0.22	9.60	0.24	0.10				
31S	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
32S	0.02												
33N	<0.02	0.6	0.62	0.22	0.18	0.50	0.80	0.21	0.06				
33S	0.06												
41		0.6	0.83	1.62	2.00	0.78	0.96	1.98	1.04				
61			0.12	0.09	0.17	<0.01	0.06	0.09	0.03		0.10	0.28	
62		0.2	0.24	0.10	0.14	0.04	0.10	0.18					
63			0.08		0.10	0.01	0.03	0.06	0.04				0.14
64			0.16	0.24									
71											0.62	0.40	
74													0.44

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

WELL	871130	880317	880622	880701	880719	880809	881202	890122	890312	890313	890428	890429	890524
1A	2.75	2.0	2.5	2.8	1.2	2.0	1.0	2.2					3.2
1B	1.54	3.5	6.0	3.5	1.8	4.0	1.5	2.5					9.5
1C	1.02	3.2	4.0	1.8	1.8	2.5	0.8	4.0					5.0
1D							3.0	2.5					7.0
1D5							4.0	5.5					5.0
1D7.5							3.2	2.5					3.0
2A			4.0	2.0	0.8	3.5	1.2	0.2					
2B	2.70	2.8	6.0	2.5	3.8	1.0	3.0	3.2					
2C	1.90	3.2	2.8	5.0	1.5	3.0	3.2	<0.2					
2D								1.0					<0.2
2D5								3.0					3.0
3A	0.60	0.8	1.5		1.8		0.8						1.2
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
3C	0.88	2.0	5.2	5.8	11.5	0.5	0.5						0.2
3D								16.0	7.0	7.0	11.5	10.0	13.8
5A	0.77	3.5	30.0	4.0	2.2	3.0	7.5	3.8					4.8
6A	24.40		26.0	29.5	25.5	10.2		2.0					7.0
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
6C	3.60	26.5	11.5	2.0	5.6	5.8	12.5	1.5					9.0
6D	19.60	7.8	10.0	11.0	12.8	10.5	3.5	14.2					0.2
6E		9.8	30.0	10.5	10.0	8.0	10.5	11.8	1.0		9.0		8.5
7A0								6.0	5.2	5.0	4.2	4.5	2.0
7A1								0.5	5.0		1.8	1.8	1.2
7B									1.0	0.5	0.2	<0.2	0.2
7C0													4.0
7C1.5								4.0			1.0	1.0	2.5
7C3								2.0			0.8	1.0	1.0
7D											5.0	4.5	2.0

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

DRAIN	871007	880219	880602	880701	880715	880719	880803	880805	880809	881202	890312	890313	890428
11	17.5	0.5	1.0	3.5	0.5	0.5	<0.2	1.0	<0.2				
12	4.5	0.8											
13	0.5												
14	2.0	1.2											
15	0.5	1.0	1.0	1.0	1.0	0.5	1.5	0.8	0.2	0.8			
16	<0.2	1.0	0.5	0.5	0.8	0.2	0.5	1.0	<0.2	0.8			
21		0.5	0.5		0.5	<0.2	<0.2	0.8	<0.2				
22	0.2												
23	<0.2	0.8	0.5	0.5	0.5	<0.2	<0.2	0.8	<0.2	0.5			
31N	1.0	0.2	0.8	0.5	0.5	0.5	<0.2	0.5	0.5				
31S	<0.2												
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
32S	<0.2												
33N	<0.2	0.5	0.8	4.0	3.5	0.8	<0.2	0.5	0.5				
33S	<0.2												
41		0.6	0.5	<0.2	0.5	0.8	0.5	0.5	0.5				
61			1.0	12.0	0.5	1.0	10.0	0.5	0.2		2.0	0.8	
62		1.0	1.0	12.5	0.5	1.5	10.5	0.5					
63			1.0		0.8	1.5	11.2	0.5	0.2				0.5
64			1.0	11.5									
71											0.5	0.5	
74													0.5

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

WELL	871130	880317	880622	880701	880719	880809	881202	890122	890312	890313	890428	890429	890524
1A				0.89									
1B				0.42									
1C				0.49									
1D													
1D5													
1D7.5													
2A				0.09									
2B				0.54									
2C				0.50									
2D													
2D5													
3A													
3B				0.89									
3C				0.12									
3D													
5A				0.59									
6A				0.69									
6B				0.69									
6C				0.68									
6D				0.36									
6E				1.78									
7A0													
7A1													
7B													
7C0													
7C1.5													
7C3													
7D													

Table 16. Concentration of total Kjeldahl nitrogen in runoff samples by sampling date. All values are mg/l.

DRAIN	871007	880219	880602	880701	880715	880719	880803	880805	880809	881202	890312	890313	890428
11	90.00		0.96	1.48	0.68	0.32		2.95					
12	0.97												
13	1.78												
14	5.30												
15	2.00		1.26	1.38	0.66	0.62	1.78	2.70					
16	1.46		0.90	0.52	1.07	0.71		2.10					
21			1.58		0.72	0.80							
22	2.02												
23	1.48		2.00	0.80	0.50	0.60		5.30					
31N	22.80		1.70	1.58	1.18	0.78							
31S	4.00												
32N	3.00		0.92	0.45	1.18	1.02		2.15					
32S	1.07												
33N	2.40		1.16	1.94	0.69	0.93		2.40					
33S	1.10												
41			1.64	5.70	3.50	1.64							
61			0.26	0.38	0.54	0.24	0.72	0.10					
62			0.56	0.40	0.28	0.36	0.74	0.50					
63			0.08		1.09	0.30	0.70	0.10					
64			0.24	1.84									
71													
74													

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

WELL	871130	880317	880622	880701	880719	880809	881202	890122	890312	890313	890428	890429	890524
1A	6.31	6.92	6.62	6.69	6.35	6.56	6.16	6.10					6.33
1B	6.18	7.00	6.31	6.42	6.28	6.17	6.68	6.45					5.93
1C	6.43	6.61	6.27	6.51	6.51	6.48	6.64	6.77					5.87
1D							6.71	6.58					6.26
1D5							7.90	8.02					7.89
1D7.5							6.92	7.08					6.68
2A			6.75	6.81	6.50	6.37	6.18	6.94					
2B	6.63	7.02	7.26	7.30	6.26	6.60	6.22	6.26					
2C	6.82	7.14	6.75	7.08	6.33	6.21	6.11	6.80					
2D								6.53					6.59
2D5								6.52					6.41
3A	7.05	8.24	8.00		7.35		6.75						7.37
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
3C	7.78	8.26	7.39	7.44	6.99	7.08	7.20						7.27
3D								6.42	6.38	6.36	6.42	6.40	6.37
5A	6.96	7.27	6.99	6.75	6.67	6.24	6.37	6.34					6.18
6A	6.90		7.44	7.36	7.05	7.09		7.30					7.18
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
6C	7.36	7.36	7.96	7.98	7.57	7.19	6.86	7.32					7.11
6D	7.04	7.91	7.65	7.61	7.24	6.89	7.23	6.49					6.42
6E		7.23	7.38	6.80	6.67	7.02	6.69	6.53	6.95		6.72		6.70
7A0								6.49	6.51	6.48	6.39	6.43	6.11
7A1								6.49	6.48		6.00	6.05	6.39
7B									6.65	6.76	6.96	6.99	6.82
7C0													6.47
7C1.5								6.19			6.32	6.27	6.19
7C3								6.25			6.28	6.29	6.28
7D											6.46	6.37	6.66

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

DRAIN	871007	880219	880602	880701	880715	880719	880803	880805	880809	881202	890312	890313	890428
11	5.65	7.23	6.72	7.54	6.97	7.16	7.41	7.06	6.88				
12	7.74	7.32											
13	7.25												
14	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			
16	7.27	7.24	6.82	7.14	7.04	6.88	7.32	6.74	6.51	6.21			
21		7.10	6.14		6.67	6.73	6.94	6.61	6.48				
22	6.51												
23	6.84	7.38	6.60	7.03	6.90	6.49	7.03	6.73	6.67	6.78			
31N	6.90	7.63	6.90	7.20	6.84	7.18	7.39	7.00	7.12				
31S	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
32S	6.86												
33N	6.93	7.09	6.99	7.59	7.52	7.18	7.66	7.16	7.23				
33S	7.26												
41		7.30	7.09	7.06	6.80	7.08	7.06	6.98	6.77				
61			8.02	8.07	8.22	7.71	8.07	7.86	7.68		8.31	8.27	
62		7.45	7.87	8.15	7.64	7.87	8.01	7.51					
63			7.79		7.58	7.59	8.00	8.03	7.76				8.81
64			7.94	7.92									
71											7.35	7.43	
74													7.27

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

WELL	871130	880317	880622	880701	880719	880809	881202	890122	890312	890313	890428	890429	890524
1A	<0.002	<0.002	0.005	0.002	0.002	<0.002	<0.002	<0.002					
1B	0.005	<0.002	<0.002	0.002	<0.002	<0.002	<0.002	<0.002					
1C	<0.002	<0.002	0.002	0.002	<0.002	<0.002	<0.002	<0.002					
1D							<0.002	<0.002					
1D5							<0.002	<0.002					
1D7.5							<0.002	<0.002					
2A			0.005	0.005	0.010	<0.002	<0.002	<0.002					
2B	<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					
2D								<0.002					
2D5								<0.002					
3A	<0.002	0.370	0.222		0.275		0.032						
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	
3C	<0.002	0.070	0.145	0.140	0.130	0.108	0.100						
3D								<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					
6A	<0.002		0.010	0.008	0.002	<0.002		<0.002					
6B	<0.002	<0.002	0.005	0.005	0.002	<0.002	<0.002	<0.002	<0.002		0.002	<0.002	
6C	<0.002	0.010	0.010	0.005	0.002	<0.002	<0.002	<0.002					
6D	<0.002	<0.002	0.006	0.002	0.030	<0.002	<0.002	<0.002					
6E		<0.002	0.008	0.002	0.002	<0.002	<0.002	<0.002	0.025		0.002		
7A0								<0.002	<0.002	<0.002	<0.002	<0.002	
7A1								<0.002	<0.002		<0.002	<0.002	
7B									0.005	0.005	0.085	0.150	
7C0													
7C1.5								<0.002			<0.002	<0.002	
7C3								<0.002			<0.002	<0.002	
7D											<0.002	0.005	

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

DRAIN	871007	880219	880602	880701	880715	880719	880803	880805	880809	881202	890312	890313	890428
11	13.600	0.080	0.050	0.015	0.002	0.002	0.035	0.010	0.015				
12	0.032	0.020											
13	0.095												
14	0.200	<0.002											
15	0.055	<0.002	0.042	0.010	<0.002	0.060	0.015	0.005	0.012	0.006			
16	0.046	<0.002	0.045	0.040	<0.002	0.002	0.025	0.020	0.008	0.008			
21		<0.002	0.062		<0.002	0.005	0.012	0.002	0.005				
22	0.040												
23	0.026	0.120	0.088	0.040	0.015	0.005	0.005	0.002	0.002	0.005			
31N	8.100		0.080	0.035	<0.002	<0.002	0.825	0.098	0.038				
31S	0.452	0.020											
32N	0.318		0.105	0.435	<0.002	0.055	0.400	0.040	0.008		0.002	0.150	0.050
32S	0.092	0.020											
33N	0.105		0.025	0.070	<0.002	0.020	0.170	0.005	<0.002				
33S	0.090	0.050											
41			0.010	0.362	<0.002	0.002	0.005	0.002	<0.002				
61		<0.002	0.020	0.020	<0.002	<0.002	0.058	0.010	<0.002		0.005	0.002	
62			0.045	0.020	0.145	<0.002	0.075	0.015					
63		<0.002	0.028		0.068	<0.002	0.060	0.035	0.018				0.040
64			0.030	0.110									
71											0.002	0.015	
74													0.055

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
1A			0.140	0.015	0.020	0.050	0.015	0.008					
1B			0.055	0.010	0.010	0.048	0.015	0.010					
1C			0.040	0.015	0.015	0.050	0.008	0.006					
1D							0.005	0.008					
1D5							0.002	0.010					
1D7.5							0.005	0.005					
2A			0.016	0.008	0.022	0.038	0.005	0.010					
2B			<0.002	0.030	0.010	0.025	0.008	0.008					
2C			0.008	0.010	0.005	0.025	0.012	0.025					
2D								0.010					
2D5								0.005					
3A			0.225		0.290		0.035						
3B			0.120	0.095	0.215	0.188	0.035	0.030	0.065	0.250			
3C			0.450	0.145	0.135	0.150	0.105						
3D								0.008	0.010	0.005			
5A			0.020	0.020	0.010	0.038	0.018	0.005					
6A			0.010	0.012	0.010	0.012		0.005					
6B			0.025	0.010	0.010	0.025	0.018	0.005	0.005				
6C			0.025	0.025		0.012	0.015	0.010					
6D			0.010	0.015	0.045	0.038	0.042	0.010					
6E			0.020	0.925	0.015	<0.002	0.042	0.010	0.140				
7A0								0.005	0.005	0.005			
7A1								0.022	0.008				
7B									0.025	0.030			
7C0													
7C1.5								0.005					
7C3								0.008					
7D													

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

DRAIN	871007	880219	880602	880701	880715	880719	880803	880805	880809	881202	890312	890313	890428
11		0.135	0.050	0.212	0.005	0.010		0.350					
12		0.020											
13													
14		0.028											
15		0.042	0.042	0.075	<0.002	0.090	0.138	0.400		0.500			
16		0.020	0.045	0.055	<0.002	0.015	0.180	0.068		0.025			
21		0.008	0.080		0.005	0.018	0.385						
22													
23		0.075	0.090	0.107	0.015	0.020	0.220	0.675		0.010			
31N		0.030	0.090	0.128	0.012	0.032							
31S													
32N		0.020	0.110	0.540	0.012	0.160		0.250			0.050	0.220	
32S													
33N		0.050	0.035	0.220	0.010	0.060	0.490	0.550					
33S													
41		0.015	0.010	0.478	0.010	0.008							
61			0.020	0.040	0.005	0.010	0.105	0.050			0.056	0.030	
62		0.032	0.045	0.035	0.160	0.018	0.120	0.038					
63			0.030		0.078	0.025	0.098	0.050					
64			0.030	0.202									
71											0.025	0.015	
74													

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

WELL	871130	880317	880622	880701	880719	880809	881202	890122	890312	890313	890428	890429	890524
1A		12	32	24	20	32	42	48					32
1B		20	228	108	56	74	16	8					132
1C		28	144	72	20	16	8	12					100
1D							44	68					180
1D5							84	128					164
1D7.5							48	40					196
2A			30	20	8	10	20	36					
2B		92	60	54	40	28	32	68					
2C		104	66	32	8	12	36	116					
2D								24					24
2D5								16					36
3A		<4	8		<4		32						8
3B		20	148	160	86	76	1134	100	272	20	100	44	44
3C		24	19	166	168	70	76						72
3D								204	172	172	192	188	196
5A		40	40	48	60	68	80	92					76
6A			300	294	256	230		188					192
6B		100	184	158	192	208	288	268	128		208	208	140
6C		172	112	72	164	184	216	140					248
6D		108	202	204	208	190	169	184					72
6E		128	116	144	180	108	144	148	72		160		172
7A0								80	80	84	112	112	328
7A1								36	84		248	252	136
7B									392	280	80	88	108
7C0													108
7C1.5								116			100	100	152
7C3								100			132	136	108
7D											60	60	76

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

DRAIN	871007	880219	880602	880701	880715	880719	880803	880805	880809	881202	890312	890313	890428
11	262	32	20	164	12	26	174	20	16				
12	152	72											
13	56												
14	108	164											
15	28	120	36	64	16	28	24	36	32	112			
16	18	60	16	205	16	40	40	22	14	128			
21		36	12		16	34	158	16	20				
22	20												
23	22	72	28	32	20	52	100	32	24	60			
31N	196	36	28	40	24	44	156	44	28				
31S	40												
32N	36	20	32	160	26	60	188	20	16		116	40	20
32S	36												
33N	34	28	28	150	112	36	140	30	28				
33S	30												
41		100	240	110	292	232	272	368	208				
61			36	212	32	52	220	36	28		104	76	
62		236	28	234	36	56	212	20					
63			40		48	60	210	48	32				20
64			32	216									
71											168	116	
74													20

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

WELL	871130	880317	880622	880701	880719	880809	881202	890122	890312	890313	890428	890429	890524
1A		<0.005	<0.005	<0.005		0.004	0.005	<0.005					<0.005
1B		<0.005	<0.005	<0.005		0.032	0.004	<0.005					<0.005
1C		0.015	<0.005	<0.005		0.019	<0.002	<0.005					<0.005
1D							<0.002	<0.005					<0.005
1D5							<0.002	<0.005					<0.005
1D7.5							<0.002	<0.005					<0.005
2A			<0.005	<0.005		0.008	<0.002						
2B		<0.005	<0.005	<0.005		0.002	0.004						
2C		<0.005	<0.005	<0.005		<0.002	0.014						
2D								<0.005					<0.005
2D5								<0.005					<0.005
3A		<0.005	<0.005				0.006						<0.005
3B		<0.005	<0.005	<0.005		<0.002	0.007	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
3C		<0.005	<0.005	<0.005		<0.002	<0.002						<0.005
3D								<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
5A		<0.005	<0.005	<0.005		<0.002	0.004	<0.005					<0.005
6A			<0.005	<0.005		<0.002		<0.005					<0.005
6B		<0.005	<0.005	<0.005		<0.002	<0.002	<0.005	<0.005		<0.005	<0.005	<0.005
6C		<0.005	<0.005	<0.005		<0.002	<0.002	<0.005					<0.005
6D		<0.005	<0.005	<0.005		<0.002	<0.002						<0.005
6E		<0.005	<0.005	<0.005		<0.002	<0.002	<0.005	<0.005		<0.005		<0.005
7A0								<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
7A1								<0.005	<0.005		<0.005	<0.005	<0.005
7B								0.010	<0.005	<0.005	<0.005	<0.005	<0.005
7C0													<0.005
7C1.5								<0.005			<0.005	<0.005	<0.005
7C3								<0.005			<0.005	<0.005	<0.005
7D											<0.005	<0.005	<0.005

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	881202	890312	890313	890428
11		<0.005	<0.005	<0.005			<0.002		<0.002				
12		<0.005											
13													
14		<0.005											
15		<0.005	<0.005	<0.005			<0.002		<0.002	0.008			
16		<0.005	<0.005	<0.005			<0.002		0.008	0.010			
21		<0.005	<0.005				<0.002		<0.002				
22													
23		<0.005	<0.005	<0.005			<0.002		<0.002	<0.002			
31N		<0.005	<0.005	<0.005			<0.002		<0.002				
31S													
32N		<0.005	<0.005	<0.005			<0.002		<0.002		<0.005	<0.005	<0.005
32S													
33N		<0.005	<0.005	<0.005			0.030		<0.002				
33S													
41		<0.005	<0.005	<0.005			0.060		<0.002				
61			<0.005	<0.005			0.030		<0.002		<0.005	<0.005	
62		<0.005	<0.005	<0.005			0.020						
63			<0.005				0.020		<0.002				<0.005
64			<0.005	<0.005									
71											0.008	<0.005	
74													<0.005

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

WELL	871130	880317	880622	880701	880719	880809	881202	890122	890312	890313	890428	890429	890524
1A	<0.02												<0.02
1B	<0.02												<0.02
1C	<0.02												<0.02
1D													<0.02
1D5													<0.02
1D7.5													<0.02
2A													
2B	<0.02												
2C	<0.02												
2D													<0.02
2D5													<0.02
3A	<0.02												<0.02
3B	<0.02								<0.02	<0.02	<0.02	<0.02	<0.02
3C	<0.02												<0.02
3D									<0.02	<0.02	<0.02	<0.02	<0.02
5A	<0.02												<0.02
6A	<0.02												<0.02
6B	<0.02								<0.02		<0.02	<0.02	<0.02
6C	<0.02												<0.02
6D	<0.02												<0.02
6E									<0.02		<0.02		<0.02
7A0									<0.02	<0.02	<0.02	<0.02	<0.02
7A1									<0.02		<0.02	<0.02	<0.02
7B									<0.02	<0.02	<0.02	<0.02	<0.02
7C0													<0.02
7C1.5											<0.02	<0.02	<0.02
7C3											<0.02	<0.02	<0.02
7D											<0.02	<0.02	<0.02

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

DRAIN	871007	880219	880602	880701	880715	880719	880803	880805	880809	881202	890312	890313	890428
11													
12													
13													
14													
15													
16													
21													
22													
23													
31N													
31S													
32N											0.05	0.02	<0.02
32S													
33N													
33S													
41													
61											0.07	0.05	
62													
63													<0.02
64													
71											0.05	0.09	
74													<0.02

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	890312	890313	890428	890429	890524
1A	0.03	<0.01	0.01	0.03		0.01	0.07	0.01					0.02
1B	0.03	0.02	0.05	0.05		0.02	0.03	<0.01					0.04
1C	0.03	0.02	0.04	0.05		0.02	0.03	0.01					0.03
1D							0.03	0.01					0.01
1D5							0.01	<0.01					0.02
1D7.5							<0.01	<0.01					0.03
2A			0.03	0.02		0.02	0.06						
2B	0.16	<0.01	0.02	0.03		0.03	0.04						
2C	0.04	<0.01	0.04	0.02		0.04	0.10						
2D								<0.01					0.03
2D5								<0.01					0.02
3A	0.01	0.01	0.02				0.05						0.03
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
3C	0.03	<0.01	0.02	0.03		0.02	0.07						0.02
3D								<0.01	0.02	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
6A	0.02		0.03	0.03		0.03		<0.01					0.02
6B	<0.01	<0.01	0.02	0.03		0.04	<0.01	<0.01	0.02		0.01	0.01	0.02
6C	0.01	<0.01	0.03	0.01		0.03	0.04	0.02					0.02
6D	<0.01	<0.01	0.02	0.02		0.04	0.07						0.02
6E		<0.01	0.02	0.02		0.05	0.07	<0.01	0.03		0.01		0.02
7A0								<0.01	0.04	0.02	0.02	0.01	0.02
7A1								<0.01	0.03		0.01	0.01	0.03
7B								.02	0.06	0.03	0.02	0.02	0.01
7C0													0.09
7C1.5								<0.01			0.02	0.01	0.01
7C3								<0.01			0.01	0.01	0.02
7D											0.02	0.01	0.03

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

DRAIN	871007	880219	880602	880701	880715	880719	880803	880805	880809	881202	890312	890313	890428
11		0.02	<0.01	0.04			0.06		0.09				
12		0.02											
13													
14		0.05											
15		0.03	0.01	0.07			0.07		0.06	0.12			
16		0.06	<0.01	0.05			0.08		0.04	0.09			
21		0.08	<0.01				0.08		0.07				
22													
23		0.01	<0.01	0.04			0.07		0.04	0.06			
31N		0.02	<0.01	0.03			0.07		0.07				
31S													
32N		0.03	<0.01	0.01			0.06		0.05		0.08	0.02	0.01
32S													
33N		0.04	<0.01	0.02			0.05		0.05				
33S													
41		0.42	<0.01	0.02			0.20		0.06				
61			<0.01	0.01			0.04		0.04		0.07	0.03	
62		0.02	<0.01	0.02			0.03						
63			0.01				0.03		0.04				0.01
64			<0.01	0.02									
71											0.10	0.16	
74													0.07

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

WELL	871130	880317	880622	880701	880719	880809	881202	890122	890312	890313	890428	890429	890524
1A	<0.05	<0.05	<0.005	<0.003		<0.005	0.004	<0.002					0.005
1B	<0.05	<0.05	<0.005	0.006		<0.005	0.010	<0.002					<.003
1C	<0.05	<0.05	<0.005	0.004		<0.005	<0.003	<0.002					0.004
1D							<0.003	<0.002					<.003
1D5							<0.003	<0.002					0.004
1D7.5							<0.003	<0.002					0.004
2A			<0.005	<0.003		<0.005	0.055						
2B	0.20	<0.05	<0.005	<0.003		<0.005	0.009						
2C	<0.05	<0.05	<0.005	<0.003		<0.005	0.095						
2D								<0.002					<.003
2D5								<0.002					0.005
3A	<0.05	<0.05	<0.005				0.016						<.003
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
3C	<0.05	<0.05	<0.005	<0.003		<0.005	0.032						0.004
3D								<0.002	0.003	0.004	<0.003	<0.002	<.003
5A	<0.05	<0.05	<0.005	<0.003		<0.005	0.007	<0.002					<.003
6A	<0.05		<0.005	<0.003		<0.005		<0.002					<.003
6B	<0.05	<0.05	<0.005	<0.003		<0.005	<0.01	<0.002	<0.002		<0.003	<0.002	<.003
6C	<0.05	<0.05	<0.005	<0.003		<0.005	0.006	<0.002					<.003
6D	<0.05	<0.05	<0.005	<0.003		<0.005	<0.003						0.004
6E		<0.05	<0.005	<0.003		<0.005	<0.003	0.002	<0.002		<0.003		<.003
7A0								0.002	0.014	<0.002	<0.003	<0.002	0.003
7A1								0.002	<0.002		<0.003	<0.002	<.003
7B								<0.002	<0.002	<0.002	0.003	0.004	0.006
7C0													0.004
7C1.5								0.003			<0.003	<0.002	<.003
7C3								0.002			<0.003	<0.002	<.003
7D											<0.003	<0.002	0.004

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

DRAIN	871007	880219	880602	880701	880715	880719	880803	880805	880809	881202	890312	890313	890428
11		<0.05	<0.005	<0.003			0.009		0.220				
12		<0.05											
13													
14		<0.05											
15		<0.05	<0.005	<0.003			0.040		0.210	0.780			
16		<0.05	<0.005	<0.003			0.057		0.053	0.700			
21		<0.05	<0.005				0.046		0.180				
22													
23		<0.05	<0.005	<0.003			0.017		0.014	0.049			
31N		<0.05	<0.005	<0.003			0.005		0.053				
31S													
32N		<0.05	<0.005	<0.003			<0.005		0.014		0.062	0.014	0.007
32S													
33N		<0.05	<0.005	<0.003			0.005		0.006				
33S													
41		<0.05	<0.005	<0.003			0.500		0.021				
61			<0.005	<0.003			0.026		<0.005		0.060	0.062	
62		<0.05	<0.005	<0.003			<0.005						
63			<0.005				<0.005		0.006				0.036
64			<0.005	<0.003									
71											0.055	0.340	
74													0.130

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

WELL	871130	880317	880622	880701	880719	880809	881202	890122	890312	890313	890428	890429	890524
1A	0.04	0.38	0.06	0.78		0.05	0.13	0.15					3.48
1B	0.03	0.35	0.10	0.46		0.07	0.14	0.11					0.83
1C	0.03	0.53	0.10	0.16		0.04	0.06	0.12					0.32
1D							0.06	0.12					0.12
1D5							0.01	0.07					0.07
1D7.5							0.01	0.09					0.06
2A			0.29	0.06		0.04	0.27						
2B	[16.70]	[9.30]	1.90	0.12		0.06	0.12						
2C	[13.00]	[13.80]	0.36	0.84		0.19	0.56						
2D								.08					0.03
2D5								0.08					0.04
3A	[2.48]	[0.50]	0.12				0.54						0.05
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
3C	[2.20]	[0.07]	0.15	0.14		0.06	1.30						0.04
3D								0.08	0.09	0.04	0.04	0.06	0.02
5A	0.08	4.27	0.16	0.10		0.02	0.10	0.09					0.02
6A	1.20		0.10	0.07		0.01		0.10					0.01
6B	0.07	1.29	0.03	0.06		0.02	0.23	0.10	0.09		0.03	0.12	0.02
6C	0.10	1.77	0.10	0.03		<0.1	0.14	0.12					0.02
6D	0.07	0.51	0.07	0.04		0.02	0.08						0.01
6E		1.39	0.80	0.06		0.01	0.12	0.15	0.10		0.06		0.02
7A0								0.10	0.10	0.12	0.11	0.09	0.01
7A1								0.10	0.13		0.06	0.09	0.01
7B								0.31	0.45	0.33	0.09	0.08	0.02
7C0													
7C1.5								0.09			0.06	0.08	0.03
7C3								0.08			0.04	0.08	0.03
7D											0.05	0.18	0.02

[] Sample contained artifically high Zn concentration due to Zn coated well casing

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

DRAIN	871007	880219	880602	880701	880715	880719	880803	880805	880809	881202	890312	890313	890428
11		0.11	0.06	0.14			0.04		0.28				
12		0.26											
13													
14		0.39											
15		0.18	0.15	0.16			0.01		0.11	0.57			
16		0.12	0.03	0.12			0.08		0.02	0.77			
21		0.33	0.38				0.32		0.50				
22													
23		0.10	0.04	0.73			0.09		0.04	0.22			
31N		0.13	0.03	0.06			0.03		0.22				
31S													
32N		0.04	0.03	0.62			0.01		0.06		0.42	0.09	0.05
32S													
33N		0.06	0.02	0.32			0.14		0.03				
33S													
41		0.38	0.06	0.10			1.07		0.11				
61			0.02	0.04			0.14		<0.01		0.17	0.14	
62		0.03	0.02	0.03			0.11						
63			0.02				0.09		0.01				0.09
64			0.03	0.04									
71											0.66	1.27	
74													0.48