THE GROUND-WATER POLLUTION POTENTIAL OF DRY WELLS IN PIMA COUNTY, ARIZONA

A REPORT SUBMITTED TO

TUCSON WATER
THE CITY OF TUCSON

AND

PIMA COUNTY DEPARTMENT OF TRANSPORTATION AND FLOOD CONTROL DISTRICT

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PREFACE

Tucson Water, the City of Tucson, funded two phases of a project to evaluate the potential of dry wells in the Tucson area to pollute ground water. The first phase entailed inventorying existing dry wells in the area and assessing pollutants in settling chamber sediment in candidate wells from the three major classes of wells, industrial, commercial, and residential. The second phase of the study involved detailed investigations at "worst case" industrial and commercial sites. Similar studies at a residential (apartment complex) site were funded by Pima County Department of Transportation and Flood Control District. This document reports the results of the second phase studies.

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EXECUTIVE SUMMARY

Developers and others in Arizona use dry wells to dispose of urban runoff in compliance with local detention/retention ordinances. Two possible consequences of dry well drainage are augmentation of local ground-water resources and pollution of the same supply. Concern for ground-water quality in the vicinity of drinking-water wells prompted Tucson Water and Pima County to support a project to evaluate the pollution potential of industrial, commercial, and residential dry wells. Concurrently, both the City of Tucson and Pima County issued dry-well ordinances prescribing limits on the construction of these wells. The ordinances prohibited further construction of dry wells in industrial areas.

The first phase of this study inventoried existing dry wells (there were 149 in 1986) and sampled dry-well sediment in candidate wells in each category (industrial, commercial, and residential) for analyses of the EPA priority pollutants. Results of this study demonstrated the presence of pollutants in dry-well sediment. A "worst case" candidate well was selected from each category for detailed studies during the second phase.

We were unable to sample the vadose zone at the primary residential site because the driller inadvertently ruptured a main water line (not delineated during the "blue-staking" operation). This flooded the dry well, compromising the program at the site. Accordingly, a backup residential site was chosen for detailed studies.

This report summarizes the results of the second phase studies.

<u>Objectives</u>

The objectives of the second phase were to determine if ground-water recharge occurs during dry-well drainage, and to determine the subsurface disposition of pollutants in runoff during recharge from dry wells in industrial, commercial, and residential locations.

<u>Procedure</u>

Preliminary activities at the industrial, commercial, and two residential sites included sampling runoff water (when possible) and dry-well sediment for laboratory characterization of priority pollutants. These data were correlated with data from the vadose-zone sampling program.

The procedure for determining the pollution potential of the industrial, commercial, and backup residential dry well consisted of drilling (using the hollow-stem auger method) in the vadose zone immediately next to each well, collecting vadose-zone

samples (using a ring sampler), storing and shipping samples to an EPA certified laboratory for analyses of priority pollutants (using EPA approved methods), and interpreting results. The sampling program employed a quality-assurance protocol. Laboratory analyses on subsets of vadose-zone samples included particle size and water content. A geologic log, maintained during drilling, aided in interpreting the vadose-zone lithology and in speculating on the hydraulic properties. When possible, the driller obtained ground-water samples from each borehole.

<u>Recharge Potential of Dry Wells</u>

There is evidence that dry well drainage has created a transmission zone in the vadose zone at the three sites studied during this project, facilitating recharge. For example, the water content of the extensive clay layer in the vadose zone underlying the industrial well is at field capacity, thus ensuring a transmission zone for percolating water. However, the clay layer promotes lateral water movement in more permeable materials overlying the clays, causing recharge to occur over a larger surface area of the water table than if flow were predominately vertical. (Such spreading is also effective in attenuating pollutants.)

The evidence for recharge at the commercial and residential sites is even more solid. These profiles are coarser grained than the profile at the industrial site so that deep percolation is essentially vertical.

<u>Results of the Sampling Program</u>

- <u>Pollutant Loading</u>

The laboratory analyses of runoff samples into the industrial, commercial, and primary residential dry wells defined the potential pollutants entering the dry wells. Also included as a source of pollutants is the dry-well sediment.

  - Runoff Samples

    - Organics

Volatile organics were essentially absent from the runoff water samples at each site, except for methylene chloride in a sample collected at the commercial dry-well site. Apparently, volatiles are readily dissipated by volatilization and possibly by photodecay. In contrast, each runoff sample contained several semivolatile organics, including:

- fluoranthene
- benzo(b)fluoranthene
- benzo(k)fluoranthene

- o phenanthrene
- o anthracene
- o benzo(a)anthracene
- o pyrene
- o benzo(a)pyrene
- o chrysene
- o 2-chlorophenol
- o 2,4-dichlorophenol
- o 4,6-dinitro-o-cresol
- o 4-nitrophenol

These organics appear to be ubiquitous in urban runoff, having been detected in runoff samples from Fresno and Phoenix. Benzo(a)pyrene is highly carcinogenic (Groenegen and Stolp, 1981) while anthracene and benzo(b)fluoranthene and other polycyclic aromatic hydrocarbons in the list are suspected human carcinogens (Kafura, 1988).

The organophosphorous pesticide dioxathion was detected in the runoff sample from the residential site. Fertilizers and pesticides were not detected in the runoff samples at the other sites.

o Metals

Metals detected in runoff samples at the three sites included:

- o cadmium
- o chromium
- o mercury
- o nickel
- o thallium
- o zinc

Chromium and lead concentrations exceeded drinking water standards in a runoff sample from the residential site.

o Dry-Well Sediment

o Organics

The dry well sediments at the industrial site contained the following volatile organics:

- o ethylbenzene
- o xylenes
- o 1,3-dichlorobenzene

The following volatiles were detected in dry well sediment from the commercial site:

- o ethylbenzene

o toluene

Methylene chloride, a volatile organic, was detected in dry-well sediment from the residential well.

Twenty-one semi-volatile organic compounds were detected in the sediment samples from the three wells:

- o naphthalene
- o acenaphthalene
- o acenaphthene
- o fluorene
- o phenanthrene
- o fluoranthene
- o anthracene
- o di-n-butylphthalate
- o fluoranthene
- o pyrene
- o benzo(a)anthracene
- o bis-(2-ethylhexyl)phthalate
- o chrysene
- o di-n-octylphthalate
- o benzo(b)fluoranthne
- o benzo(k)fluoranthne
- o benzo(a)pyrene
- o indeno(1,2,3-cd)pyrene
- o dibenzo(a,h)anthracene
- o benzo(ghi)perylene
- o dibenzofuron

These are classified as polycyclic aromatic hydrocarbons (PAHs) and phthalate esters. All 21 semivolatiles were detected in dry-well sediment at the primary residential site. Eight semivolatile organics were detected (at trace levels) in dry-well sediment from the backup residential site. The industrial well contained 18 and the commercial well contained 14 semivolatiles.

No pesticides were detected in the sediment sample from the industrial dry well. The commercial dry well contained the following pesticides/insecticides:

- o chloropyrifos
- o 2,4-DB

The primary residential dry well contained the following organophosphorous pesticides:

- o ethyl-parathion
- o stirphos

The organochlorine pesticide 4,4'-DDT was detected in sediment from the primary residential dry well. Sediment from the backup dry well contained chlordane.

All sediments contained oils and grease in varying concentrations, ranging from 1,100 mg/kg at the industrial site to 13,000 mg/kg at the primary residential site.

o Metals

The most prevalent metals (detected as total metals) in dry well sediment included:

- o cadmium
- o chromium
- o copper
- o lead
- o nickel
- o zinc

When analyzed in deionized water extracts, i.e., as mobile metals, the metals were all below detectable concentrations.

Analyses of Vadose-Zone Sediments

o Organics

None of the volatile and semivolatile organic pollutants identified in runoff and sediment samples were detected in any of the vadose-zone samples at the concentration limit of the analytical instrumentation, i.e., in the mg/kg range. Similarly, the samples were free of pesticides and insecticides.

The loss of the volatiles between the dry-well sediment samples and the vadose-zone samples is attributable mainly to volatilization and biodegradation. The absence of semivolatiles in the vadose-zone samples appears to be related to attenuation processes such as biodegradation and sorption onto organics. Specifically, it appears that the oils and grease present in the runoff and dry-well sediment sequester the hydrophobic organic constituents, limiting their mobility, and allowing biodegradation to occur. This action probably also occurs in sediment containing oils and greases that is washed through the dry-well overflow pipe into the lower, gravel-packed chamber of the wells. Thus, the semivolatiles are retained within the dry-well unit.

o Metals

Concentrations of extractable lead and cadmium were present at levels slightly above the limits of analytical instrumentation in vadose-zone samples at the industrial well site. Concentrations of nickel, copper, and silver were present at slightly higher levels. The transport of these metals to the water table is unlikely because of their low concentrations, their low solubilities, and because of the extensive sorptive capacity of the massive clay unit in the vadose zone at the site. This clay zone promotes lateral flow in the more permeable materials of the overlying vadose zone, thus increasing the surface area (and attenuation capacity) of clay exposed to the percolating water.

At the commercial site, the concentrations of some metals (copper, lead, nickel, chromium, and zinc) were fairly high in samples from 15 to 25 ft below land surface. The concentrations then diminished in the profile until the region from 60 to 76 ft below land surface, where concentrations of arsenic, chromium, nickel, and zinc reached fairly high values. The source of the high chromium and nickel concentrations may have been the drill bit. The mobility metals is limited by attenuation processes including sorption onto clays and hydrous oxides, and precipitation.

Metals detected in concentrations at or above analytical detection limits in the vadose-zone samples at the backup residential site included chromium, copper, and zinc.

<u>Analyses of Perched Ground-Water Samples</u>

Laboratory analyses of a perched ground-water sample from the backup residential site showed the presence of two volatile organics, toluene and xylenes, and two semivolatiles, phenol and benzylalcohol. The volatile organics were present at concentrations well below state action levels. Phenol concentrations were above EPA limits. The source of phenol, a disinfectant, may be from an adjoining property housing animal pens.

Metals detected in the perched ground-water sample included copper, iron, manganese, nickel, and zinc. Only managanese was present in concentrations above recommended drinking water standards.

<u>Analyses of Ground-Water Samples</u>

- Organics

We were unable to obtain a water table-sample from the borehole at the industrial site. However, a sample of ground water from a nearby (350 ft) Tucson Water well was free of volatile and semivolatile organics. However, the sample contained Total Organic Halides (TOX), suggesting the presence of chlorinated compounds. Additional sampling and analyses for the TOX components is warranted.

The following three volatile organics were detected in water table samples at the commercial dry-well site:

- o styrene
- o ethylbenzene
- o toluene

The principal laboratory detected styrene in a single sample. Styrene was not detected by the backup laboratory in a duplicate sample, and this organic compound was undetected in subsequent water-table samples.

Both ethylbenzene and toluene were present above analytical detection limits in water table samples bailed from a separate borehole. However, toluene was present in greater concentrations (28 micrograms/l toluene, cf. 2 micrograms/l, ethylbenzene). The detected concentrations are well below state action levels. However, inasmuch as both toluene and ethylbenzene were detected in dry-well sediment samples, we conclude that dry-well drainage is a possible source of these volatiles. However, a gasoline tank at a convenience store about 1/4 mile from the dry well is a potential source. Volatiles were undetected in a ground-water sample from the nearby (150 ft) Tucson Water well.

Toluene was detected in the ground-water sample from the backup residential site at a lower concentration than detected in the perched ground-water sample. The level was well below the state action level.

None of the semivolatiles were detected in water-table samples from the commercial and backup residential site. In addition, the pesticides detected in dry-well sediment were not present in the water-table samples.

o Metals

Heavy metals were below the limits prescribed by the National Primary and Secondary Drinking Water Regulations in ground-water samples pumped from the Tucson Water wells near the three dry wells. Similarly, heavy metals were either at or below detection limits in water-table samples at the commercial dry-well site. Manganese was present in the ground-water sample at the backup residential site at a concentration above EPA drinking water standards.

Conclusions

o There is evidence that drainage from the dry wells at the industrial, commercial, and residential sites has created transmission zones, facilitating recharge to the underlying water table.

o Volatile organics may be virtually absent in runoff samples draining into dry wells.

o Semivolatile organics are ubiquitous in runoff into dry wells, originating from automobile emissions, and pavement asphalt. The polycyclic aromatic hydrocarbons (PAHs), and phenolic compounds predominate.

o Pesticides in runoff appear to be site specific, being related to land-use practices (e.g. turfgrass irrigation) in the drainage areas.

o Volatile organics (e.g, ethylbenzene, toluene, and xylenes) occur in dry-well sediment. Being soluble, these organics may percolate through the vadose zone.

o A large variety of semivolatile organics occur in dry well sediment, including PAHs, phthalate esters, and phenolic compounds.

o Assuming that the data from the industrial and commercial sites represent worst-case conditions, there is no evidence for the accumulation of volatile and semivolatile organics, and pesticides, in the vadose zone at dry-well sites. Oils and grease entrained with the dry-well sediment appear to sequester the semivolatiles, limiting their movement into the vadose zone. Biodegradation is a possible mechanism limiting the movement of some of the more soluble PAH's among the semivolatiles.

o The evidence of phenol in perched ground water from the backup residential site shows that anaerobic conditions retard microbial decay of this compound. The possible source of phenol is disinfectants used on animals in an adjoining property.

o The water table at the commercial site appears to be contaminated with ethylbenzene and toluene, although concentrations are well below state action levels. Similarly, the concentration of toluene in ground water at the backup residential site is below state action levels. The source of these compounds appears to be mainly from automobiles.

o Local ground water, pumped from Tucson Water wells near the commercial and residential dry wells has not been contaminated by organics, including pesticides. The presence of TOX in the Tucson Water well near the industrial site warrants additional sampling and possibly an analysis for volatiles.

o Heavy metals, notably lead and chromium, may occur in runoff at concentrations exceeding drinking water standards. The concentrations of extractable (mobile) metals in dry-well sediment samples and vadose-zone samples are low, although nickel, chromium, and zinc concentrations may be high in local regions of the vadose zone.

o Except for the presence of manganese at levels above drinking water standards in ground water at the backup residential site, there is no evidence that dry-well drainage contributes heavy metals to ground water.

o The study shows that industrial, commercial, and residential dry wells are not a major source of ground-water pollution in Pima County, at least for the short time that the study wells have been in place.

o The potential for ground-water pollution is basically site specific, depending on land usage, drainage area, depth to ground water, and the vadose-zone lithology.

Recommendations

o Recommended Dry-Well Policies for Pima County

o Prohibit dry wells in industrial areas (already a requirement in Pima County and the City of Tucson)

o Prohibit or control activities in contributing draiange areas that are likely to introduce pollutants into dry wells

o Outdoor chemical storage in dry well drainage area (including pesticides and fertilizers)

o Livestock confinement in dry-well drainage area

o Locate trash bins outside of contributing area to dry wells

o Minimize drainage of irrigation runoff from grassed areas

o Dry-Well Design, Management, and Operational Practices

o Limit the drainage area contributing to each well or increase the number of wells

o Design dry wells with feature that promote volatilization of volatile organics and sorption of semivolatile organics

o Remove settling chamber sediment at routine intervals o The current restrictions on thickness of vadose zone between the dry well invert and the water table (75 ft for wells in commercial areas and 125 ft for wells in residential areas) should be continued.

o The restriction of 300 ft between dry wells and cased water supply wells, and 500 ft between dry wells and uncased water supply wells should be continued.

o Related Practices

o Prohibit parking directly over dry wells

o Encourage car owners to minimize crankcase and gasoline leaks

o Encourage disposal of crankcase oil at waste oil collection sites

o Further Research

o General

o Conduct long-term ground-water sampling at commercial and residential sites, monitoring for the presence of heavy metals, trace organics, and microorganisms.

o Conduct controlled laboratory studies on the potential for oils and grease to sequester runoff pollutants. Identify the microorganisms responsible for degradation.

o Determine the temporal changes in the trace organic content of settling-chamber sediment receiving runoff from newly paved areas.

o Specific Sites: C-1

o Evaluate leakage of volatiles from the gasoline tank at the convenience store near the commercial dry well to determine if tank leakage is a source of toluene and ethylbenzene at the water table.

o Specific Sites: R-2

o Determine the source of phenols in perched ground water.

THE GROUND-WATER POLLUTION POTENTIAL OF DRY WELLS IN PIMA COUNTY, ARIZONA

SECTION 1 INTRODUCTION:

Increased urbanization in the City of Tucson and Pima County has increased the rates and volume of urban runoff. Dry wells are used to dispose of urban runoff in the vadose zone to comply with local detention/retention ordinances. Figure 1 depicts the design of a commercially-available dry well in Arizona. As shown, this type of well includes two principal chambers: a concrete-lined settling chamber and a gravel-packed shaft. Overflow from the settling chamber drains into the shaft via an overflow pipe.

The Safe Drinking Water Act of 1974 classifies dry wells as storm water and industrial drainage wells within the general category of Class V wells. As a result of their inventory of Class V wells, the US Environmental Protection Agency (1987) estimates that there are about 90,000 dry wells in 38 states. The number of dry wells in the Phoenix area is greater than 11,000 (Kafura, and others, 1988). Drilling contractors are installing about 200 wells a month in the Phoenix area (Haney, Leach, and Sobchak, 1988). Currently, there are more than 150 dry wells in Pima County (Olson, 1987).

Figure 1 shows that dry wells terminate in permeable alluvium, above the water table. [However, there are some "dry" wells in Maricopa County terminating within water-bearing formations (e.g., Schmidt, 1985).] In addition to accommodating the requirements of detention/retention ordinances, water draining from dry wells may recharge underlying aquifers. There is concern, however, that pollutants in stormwater runoff may contaminate ground water during such events. During their inventory of Class V wells, the US Environmental Protection Agency (1987) determined that the contaminants in storm water runoff include herbicides, pesticides, fertilizers, de-icing salts, asphaltic sediments, gasoline, grease, rubber, tar and residues from roofs and paving, liquid wastes and industrial solvents, and asbestos. The US Environmental Protection Agency (1987) rates both storm water and industrial drainage wells as moderate threats to ground water, although industrial wells pose the greatest threat.

In 1985, responding to public concern over potential ground-water contamination from dry wells, the City of Tucson and Pima County notified engineers and architects to discontinue the use of dry

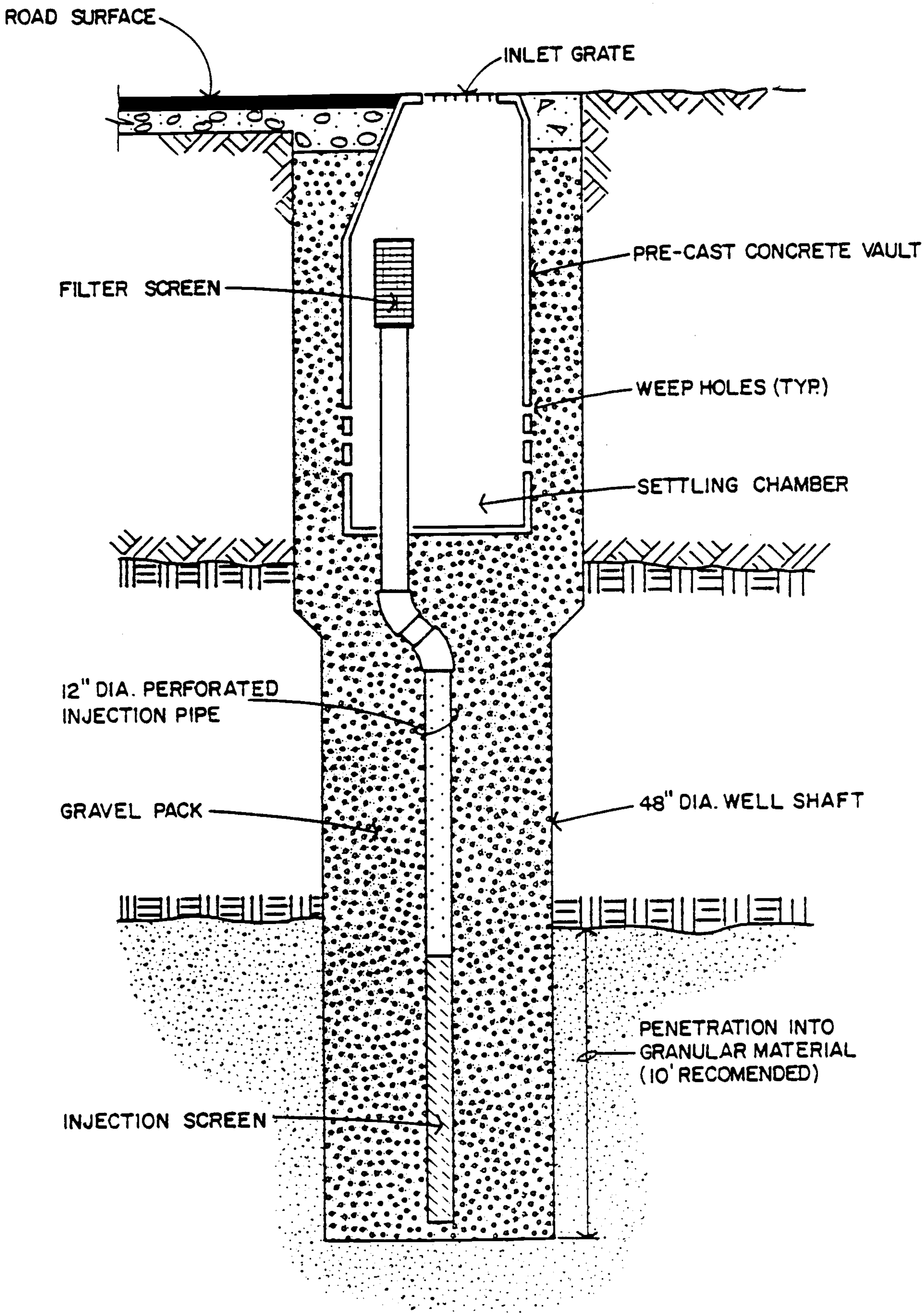

FIGURE 1. TYPICAL DRY WELL DESIGN IN TUCSON, ARIZONA, THE MAXWELL III, DESIGNED BY McGUCKIN DRILLING, INC.

wells as a solution to their flood control and drainage problems. About the same time, Tucson Water funded a study through the University of Arizona to quantify the pollution potential of the three classes of dry wells: industrial, commercial, and residential. This study, designated Phase I, resulted in a report by the Water Resources Research Center (1987) and a Master's thesis by Olson (1987). Phase II of the study was funded in 1987 to sample the vadose zone and ground water in the vicinity of one well in each class. The objective was to determine the fate of pollutants during deep percolation in the vadose zone and during recharge. This report reviews the findings of the Phase II study.

1.1 Previous Studies

The National Urban Runoff Program (NURP) determined that the most prevalent pollutant found in urban runoff is heavy metals, especially copper, lead, and zinc (US Environmental Protection Agency, 1987). Organic priority pollutants were detected less frequently than heavy metals, and at lower concentrations. Coliform bacteria are also detected at high concentrations in urban runoff. Runoff into industrial dry wells is generally of poorer quality than urban runoff, and accidental spills of organic wastes into dry wells have been reported (US Environmental Protection Agency, 1987). Dissolution of native salts in the vadose zone also adds to the mass flux of pollutants to the water table (Woessner and Wogsland, 1987).

Studies conducted for the Fresno National Urban Runoff Program (NURP) identified the presence of both inorganic and organic priority pollutants in urban runoff (Brown and Caldwell, 1984). In fact, 33 of the 129 organic pollutants in the EPA's list of priority pollutants were detected in runoff samples in the Fresno area (Table 1).

Kafura and others (1988) analyzed stormwater runoff from three industrial and two commercial areas in Phoenix. Table 2 shows the results of the organic analyses on these samples. According to Kafura and others (1988) most of the detected chemicals are on the RCRA and Arizona Department of Environmental Quality (ADEQ) hazardous substance list. Benzo(a)anthracene, benzo(b)fluoroanthene, and dibenzo(a,h)anthracene and other polycyclic aromatic hydrocarbons in Table 2 are suspected carcinogens (Kafura and others, 1988). They appear to be common in urban runoff from paved areas.

In his dry well studies for the Maricopa Association of Governments, Schmidt (1985) found lead, iron, and manganese, as well as low levels of two commonly used landscaping pesticides, Diazinon and Dachal, in stormwater entering a dry well. Resnick, DeCook and Phillips (1983) reported the presence of excessively high concentrations of total coliform, fecal coliform, fecal streptococci and suspended sediment in runoff in the Tucson area.

TABLE 1

Priority Metals and Organics Detected in Fresno NURP Project

Metals	Organics	Organics
Antimony	Aldrin	Di-n-octyl phthalate
Arsenic	Anthracene	Endosulfan
Cadmium	Benzo(a)pyrene	Endrin
Chromium	Benzo(b)fluoranthene	Fluoranthene
Copper	alpha-BHC	Heptachlor
Cyanide	gamma-BHC (lindane)	Heptachlor epoxide
Lead	Butylbenzylphthalate	4-nitrophenol
Mercury	Chlordane	Total PCB
Nickel	Chrysene	Pentachlorophenol
Zinc	DDE	Phenol
	DDT	Pyrene
	Dieldrin	

Brown and Caldwell (1984, pp. 4-7)

TABLE 2

COMPILATION OF STORMWATER RUNOFF ANALYSES FROM THREE INDUSTRIAL AND ONE COMMERCIAL AREA IN THE METROPOLITAN PHOENIX AREA
(After Kafura and others, 1988)

Chemical	Concentration Range (ppb)	Hazardous Substance
acenapthene	1	yes
anthracene	2-9	yes
benzo(a)anthracene	2-5	yes
benzo(b)fluoranthene	3-12	yes
benzo(k)fluoranthene	2-8	yes
benzo(g,h,i)perylene	2-7	yes
benzoic acid	33-960	yes
benzyl alcohol	10	no
butyl benzyl pthalate	1-3	yes
bis(2ethyl-hexyl)phthalate	6-44	yes
chrysene	2-44	yes
dibenzo(a,h)anthracene	3	yes
diethyl phthalate	2-3	yes
dimethyl phthalate	10	yes
2,4-dimethyl phthalate	14-20	no
di-n-butyl phthalate	1-2	yes
indeno (1,2,3-cd) perylene	8	yes
2-methyl phenol	71-85	no
4-methyl phenol	21-29	no
phenanthrene	8-12	yes
phenol	10	yes
pyrene	2-12	yes

* Indicates range of concentrations for samples in which the chemical was detected

** Indicates chemical is RCRA and/or the ADEQ hazardous substance list

A few studies have identified the extent that pollutants in stormwater runoff have migrated in the subsurface following disposal in retention facilities. Schmidt's (1985) study monitored subsurface pollutant migration as stormwater from a commercial parking lot drained through a dry well. This particular dry well terminated within shallow ground water underlying the site. Three monitor wells were drilled about 20 feet from the dry well to permit sampling the shallow ground water. None of the pollutants detected in the surface runoff were detected in the monitor wells. In fact, Schmidt (1985) found that storm runoff improved the inorganic quality of ground water at the monitor well immediately down gradient from the dry well.

Wilson and others (1985) conducted five injection tests on an experimental dry well at Tucson, Arizona to determine the attenuation of urban runoff pollutant analogs during lateral flow of ground water in the vadose zone and during mixing with native ground water. The test results showed significant, but certainly not complete, attenuation of pollutant analogs, especially when concentrated slugs of pollutants were injected.

Bandeen (1987) simulated drainage from a dry well using the saturated-unsaturated flow model UNSAT 2 . He examined three possible cases in the Tucson Basin: (1) 100 ft of uniform gravelly sand, (2) 30 ft of sandy-gravelly loam overlying 70 ft of sandy clay loam, and (3) 30 ft of gravelly sandy loam overlying 70 ft of sandy clay loam. The primary goals of his study were to estimate the extent of lateral flow and the surface area of vadose-zone sediment available for pollutant attenuation during deep percolation. For the first case, the simulated flow was essentially vertical. In the second and third cases, the layering between coarse and fine materials promoted lateral flow at the interface. The ratios of specific surface areas contacted during deep percolation for the three respective cases were 1 : 16.2 : 5.6. Such lateral spreading also increases the area of the water table contacted during recharge, thereby improving the opportunity for dilution of pollutants (Woessner and Wogsland, 1987). Thus, greater attenuation and dilution are expected when dry wells drain into fine-textured materials.

1.2 Institutional Regulation of Dry Wells

Concern over the potential effect of dry wells on water quality has resulted in federal, state and local regulations on their use.

1.2.1 Federal Regulations

Federal regulations addressing dry wells include the Safe Drinking Water Act (PL-523, Part C) and the Clean Water Act. The Safe Drinking Water Act established rules for five classes of injection wells. Stormwater injection wells represent one of over 30 different types of Class V injection wells. The rules also called for the development of regulations at the state level for underground injection control (UIC) programs. In Arizona, this program is currently implemented by the Environmental Protection Agency (EPA).

The EPA is currently finalizing the requirements for stormwater permits mandated by the Clean Water Act Amendments of 1987. An outcome of this exercise will be NPDES permits for stormwater discharges to waters of the United States. Structural approaches such as detention/retention techniques (ostensibly including dry wells) are suggested for reducing water quality problems in municipal storm sewer discharges (Federal Register, Wednesday, December 7, 1988, p 49458).

1.2.2 Arizona State Regulations

Arizona intends to seek primacy for the UIC program (which includes dry wells as Class V wells) from EPA in the early 1990's. This program will complement the State's Aquifer Protection Program, mandated by the Environmental Quality Act (EQA) of 1986, and comply with federal requirements.

Dry wells are regulated through the provisions of the Dry Well Act of 1986 and the Environmental Quality Act of 1986. The Dry Well Act was passed to control dry well construction in the state and to provide a mechanism for recording new and existing dry wells. The Act requires registration, establishing licensing and standards, coordination and integration with the EQA, and reporting.

Arizona Revised Statutes Title 49, Chapter 2, Article 8 of the Environmental Quality Act authorizes the Arizona Department of Environmental Quality (DEQ) to establish rules for regulating dry wells. Sections 49-331 through 49-336 of Article 8 contain specific statutory requirements for dry wells. Section 49-331 defines dry wells. Section 49-332 discusses the requirements for registering dry wells. Section 49-333 allows the Director of DEQ to adopt rules establishing standards for new and existing dry wells relative to their performance, operation, construction, design, closure, location, and inspection, and also addresses drilling requirements. Section 49-334 discusses enforcement and penalties. Section 49-335 requires the director of DEQ to adopt rules for implementing and regulating the dry well program. DEQ expects to adopt these rules in 1989. Finally, Section 49-336 exempts golf courses from the requirements of Article 8.

The EQA considers dry wells as discharging facilities requiring individual or general aquifer protection permits (Kafura, and others, 1988). In October, 1988, DEQ issued a concept paper which outlines a proposed strategy for developing the permitting program, describes the proposed program, and presents a tentative rule making calendar. A copy of this concept paper is included as Appendix 1.

1.2.3 Pima County and City of Tucson Regulations

The Interim Dry Well Policy, adopted by the Pima County Board of Supervisors on March 11, 1986, regulates dry well use in Pima County. The City of Tucson adopted the same policy for dry well use within the City on April 2, 1986. This policy is included as Appendix 2. The dry well policy includes requirements for siting, operation and maintenance of new dry wells. It prohibits new dry wells in industrial and landscaped areas, requires 75 feet and 125 feet of vertical separation between the dry well invert and the water table in residential and commercial areas, respectively, and requires 300 feet and 500 feet of horizontal separation from cased and non-cased water supply wells, respectively. Design and operation requirements call for an upstream sediment trap in or near each well to remove suspended sediment and time requirements for drainage (for mosquito control). The policy also requires annual maintenance, including removing the accumulated sediment, and detailed record keeping by the owners.

SECTION 2 SUMMARY OF PHASE I STUDIES

Olson, Osborn and Wilson (1986) and Olson (1987) reported the results of the Phase I activities in detail. This section summarizes the Phase I activities.

The objectives of the Phase I project included (1) inventorying existing dry wells in the Tucson vicinity, (2) identifying potential sources of pollution in dry well drainage areas, (3) determining the concentrations of organic and inorganic pollutants in dry-well sediment, (4) sampling pumping wells in the vicinity of selected dry wells, and (5) recommending additional studies.

2.1 Inventory of Dry Wells and Identification of Pollutants

Olson (1987) reported that there were 149 dry wells operating in the Tucson area in 1986, including 17 in industrial areas, 55 in commercial areas, and 77 in residential areas. The location of the dry wells are shown on Plate 1. Identified pollution sources included oil, gasoline and metals from automobiles; metals from various sources; and pesticides and fertilizers from landscaped areas and commercial garden centers.

The vertical separation between dry well inverts and ground water ranged from 50 to 280 ft (see Plate 1). The horizontal distance from dry wells to production wells ranged from 150 to 6,000 ft.

2.2 Sediment Sampling

Eight "worst case" dry wells were selected for sediment collection and analyses, including two residential wells, three commercial wells, and two industrial wells. The basis for selecting these wells included representativeness of the drainage area, closeness of production wells, depth to ground water, and the presence of sediment in the settling chamber. These factors were qualitatively assessed to identify sites with the greatest perceived threat to ground-water quality. The EPA certified commercial laboratory receiving the samples determined the type and degree of pollutants present at each site, including EPA priority pollutants and organophosphorus pesticides.

Tables 3, 4, and 5 summarize the pollutants detected in the dry-well settling chambers of the eight wells for residential, commercial and industrial sites, respectively. (See Olson, 1987, for details on laboratory QA/QC procedures.) A comparison of the data in Table 3 for the two residential sites at apartment complexes, R-1 and R-2, shows a significant difference in the organic pollutant load at each site. No organic pollutants were detected at R-2, but high concentrations of many polyaromatic

TABLE 3

Pollutants in Settling Chamber Sediments at Residential Sites

Compound	R-1 7/22/86	R-1 9/23/86	R-2 7/22/86	R-3 6/19/87
BASE/NEUTRALS AND ACIDS				
naphthalene	2.4	3.4	ND	ND
acenaphthylene	0.4	3.7	ND	ND
acenaphthene	21	27	ND	ND
fluorene	18	32	ND	ND
phenanthrene	120	180	ND	ND
anthracene	26	28	ND	ND
di-n-butylphthalate	ND	0.9	ND	ND
fluoranthene	190	360	ND	ND
pyrene	190	360	ND	ND
benzo(a)anthracene	94	170	ND	ND
bis-(2-ethylhexyl)phthalate	1.7	3.5	ND	ND
chrysene	102	200	ND	ND
di-n-octylphthalate	ND	0.3	ND	ND
benzo(b)fluoranthene	180	220	ND	ND
benzo(k)fluoranthene	ND	130	ND	ND
benzo(a)pyrene	91	160	ND	ND
indeno(1,2,3-cd)pyrene	70	80	ND	ND
dibenzo(a,h)anthracene	26	11	ND	ND
benzo(ghi)perylene	45	57	ND	ND
ORGANOPHOSPHOROUS INSECTICIDES				
Diazinon	ND	ND	ND	0.02
ethyl-parathion	0.6	ND	ND	ND
stirophos	6.2	ND	ND	ND
ORGANOCHLORINE PESTICIDES				
4,4'-DDT	ND	0.09	ND	ND
Oil and Grease	6600	13000	1300	790

Units: mg/kg (wet weight)
ND = Not detected

TABLE 4

Pollutants in Settling Chamber Sediments at Commercial Sites

Compound	C-1 7/22/86	C-1 9/23/86	C-2 7/22/86	C-3 7/22/86
PURGEABLE ORGANICS				
toluene	2.1	1.0	ND	ND
BASE/NUETRALS AND ACIDS				
pentachlorophenol	0.6	ND	ND	ND
naphthalene	0.2	ND	ND	ND
phenanthrene	0.34	ND	ND	ND
di-n-butylphthalate	37	1.5	ND	ND
fluoranthene	0.58	ND	ND	ND
pyrene	0.6	ND	ND	ND
benzylbutylphthalate	ND	17	ND	ND
bis(2-ethylhexyl)phthalate	31	4.9	260	ND
chrysene	ND	ND	3.2	ND
di-n-octylphthalate	38	6.2	4.2	ND
ORGANOPHOSPHOROUS INSECTICIDES				
chloropyrifos	0.38	ND	ND	ND
ethyl-parathion	ND	ND	ND	0.01
Oil and Grease	5800	3200	41000	8300

Units: mg/Kg (wet weight)
ND = not detected
NS = not sampled

TABLE 5

Pollutants in Settling Chamber Sediments at Industrial Sites

Compound	I-1 7/22/86	I-1 9/23/86	I-1 9/23/86 *	I-2 7/22/86	I-2 9/23/86
PURGEABLE ORGANICS					
chloromethane	ND	0.1	(ND)	ND	ND
1,3-dichlorobenzene	ND	ND	(3)	ND	ND
ethyl benzene	9.2	ND	(ND)	ND	ND
xylenes	172	ND	(21.5)	ND	ND
BASE/NEUTRALS AND ACIDS					
phenol	ND	ND	(ND)	ND	0.2
naphthalene	0.74	0.36	(0.26)	ND	ND
acenaphthylene	2.1	0.22	(0.17)	0.54	0.2
acenaphthene	ND	0.55	(0.66)	ND	0.4
fluorene	2.5	0.83	(0.85)	0.92	0.6
phenanthrene	23	7.4	(8.3)	18	11
anthracene	5	1.6	(1.4)	2.8	0.8
di-n-butylpthalate	ND	ND	(0.41)	ND	0.3
fluoranthene	33	16	(18)	32	29
pyrene	35	16	(19)	27	20
benzylbutylphthalate	ND	ND	(ND)	1.5	0.6
benzo(a)anthracene	16	12	(10)	16	9.8
bis(2-ethylhexyl)phthalate	3.2	2.7	(16)	42	9.5
chrysene	15	16	(15)	19	14
di-n-octylphthalate	1.4	ND	(6.9)	4.8	12
benzo(b)fluoranthene	42	12	(12)	49	12
benzo(k)fluoranthene	ND	10	(8.4)	4.0	9.7
benzo(a)pyrene	12	11	(9.3)	16	7.6
indeno(1,2,3-cd)pyrene	9.4	7.1	(7.1)	10	4.8
dibenzo(a,h)anthracene	2.6	1.3	(1.4)	3.1	0.6
benzo(ghi)perylene	6.0	5.2	(5.4)	6.2	3.8
ORGANOPHOSPHOROUS INSECTICIDES					
diazinon	ND	ND	(ND)	0.07	ND
chloropyrifos	ND	ND	(ND)	0.2	ND
Oil and Grease	8300	6600		8300	7400

Units: mg/Kg (wet weight)
ND = None Detected
*duplicate for 9/23/86 sample is shown in parentheses

hydrocarbons as well as two insecticides were detected at R-1. Both of these dry wells are situated in parking lot/driveway areas with comparable drainage areas. The major difference between the sites is the length of time each has been in operation. The dry well at R-1 has been in operation since May, 1984; at R-2 since June, 1985. In addition, the dry well at R-1 was installed in an existing parking lot, in which pollutants had been accumulating prior to installation of the dry well. The degree of oil spotting in parking areas from leaky crankcases was considerably more noticeable at R-1 than at R-2. The dry well at R-2 was installed in a new development.

This comparison suggests that pollutants in the source area and settling chamber sediment will accumulate over time. Inasmuch as the average dry-well life expectancy is 20 to 30 years (personal communication, D. McGuckin, 1987), and the dry wells at R-2 and R-1 had operated approximately one and two years, respectively, at the time of sampling, it cannot be assumed that the measured pollutant concentrations are representative of settling chamber sediment which has aged. Thus, in time pollutant levels in the dry-well settling chambers may increase, at least for the first few years, as shown by the samples taken at R-1 and R-2.

The data in Table 4, for commercial sites, show a situation similar to that found at the residential sites. That is, a number of organic pollutants were detected at one site, C-1, with markedly fewer pollutants detected at C-2 and C-3. The dry well at C-1 has been in service longer than C-2 and C-3; however, the physical layout of the drainage areas at the three commercial sites are not comparable as they were for the residential areas. The drainage area at C-2 is fairly small and the dry well at C-3 is in a grassed retention basin.

Dry-well sediments at both industrial sites, I-1 and I-2, contained a large number of measurable pollutant concentrations. In addition to the polyaromatic hydrocarbons and phthalates, detected in samples from residential and commercial areas, the dry well at I-1 contained high concentrations of volatile compounds.

The tables do not include data for metals. The laboratory analyzed the sediment for total metals, including sorbed, mobile, and metals within particulate crystalline structure. Inasmuch as the natural mineralogical component of trace metals and immobile metals sorbed to sediment surfaces overwhelm the dissolved or mobile fraction, the metals detected in these samples cannot be interpreted to be contaminants.

2.3 Well Water Samples

Tucson Water collected water samples from four pumping wells in the vicinity of the dry wells I-1, I-2, R-1, and C-1 for analyses by a commercial laboratory. Total Organic Halide (TOX) and Total Organic Carbon (TOC) were highest in the wells near I-1 and I-2. Thus, the TOX concentrations in the wells near I-1 and I-2 were 70 micrograms/l and 92 micrograms/l, respectively.

2.4 Final Site Selection

Based on the pollutant concentrations in the settling chamber sediments we selected one site from each land-use catagory for detailed analysis of the distribution of pollutants in the vicinity of the dry well. The selected sites were I-1, C-1, and R-1. Presumably, these sites have the greatest potential for causing ground-water quality problems within their particular land-use category. As it turned out, we were unable to complete the studies at R-1 because the driller inadvertantly struck a water main that was not marked during blue staking, flooding the dry well. Accordingly, R-2 was selected as the back up residential site.

SECTION 3: OBJECTIVES OF THE PHASE II STUDIES

The general objectives of the Phase II studies were twofold: (1) to determine if ground-water recharge occurs during dry-well drainage, and (2) to determine the presence or absence of pollutants (organics and metals) in stormwater runoff and dry-well sediment, and the disposition of detected pollutants in the vadose zone and underlying ground water at an industrial, commercial, and residential dry-well site.

3.1 Specific Objectives

The specific objectives of the field program included:

1. Collecting and analyzing stormwater runoff and/or sediment-chamber samples from each of the three dry wells identified during Phase I.

2. Determining pollutant concentrations, water content profiles, and distribution of grain sizes in vadose zone sediments contiguous to the three dry wells selected during Phase I.

3. Determining pollutant concentrations in ground-water samples beneath each of the three identified dry wells.

4. Correlating the results of pollutant analyses for the sediment samples, vadose-zone samples, and ground-water samples.

5. Preparing a report, including an assessment of the pollution potential of each class of dry wells (industrial, commercial, and residential) and recommending future use of dry wells in Pima County (including the City of Tucson).

SECTION 4. DESCRIPTION OF SELECTED DRY-WELL SITES

Based on the results of the Phase I studies, three dry-well sites (I-1, C-1, and R-1) were chosen for detailed studies during Phase II. This section describes these sites, together with the backup site R-2, chosen when we were unable to complete the studies at site R-1.

4.1 Industrial (Manufacturer) Dry Well, I-1

This establishment (see Figure 2) manufactures hard discs for computers. The dry-well drainage area for this site consists of the parking lot, the roof of the building and minor amounts of landscaping along the north and east edge of the parking area. Minor amounts of drainage from the vacant lot to the east and public street to the north also enter the dry well. The northernmost loading dock (shown on Figure 2) is drained via a sump pump into the parking lot within the dry-well drainage area.

The dry well was installed in June, 1985. The upper sediment chamber is about 20 ft deep. Total depth of the lower, gravel packed shaft is 35 ft. Table 6 is the manufacturer's log of this well. As shown, the upper 11 ft consist of tight clays, overlying 13 ft of coarser material. The region from 24 ft to 35 ft depth includes sand, gravel and cobbles. This unit was dry at the time of construction.

Depth to ground water in the production well 350 feet east of the dry well was estimated at about 130 feet in 1987. The driller's log (see Table 7) for the production well shows a low permeability zone at a depth of about 100 feet. Well cuttings analyses for this well (unpublished data from Tucson Water) list silt and clay percentages ranging from 50 to 90 percent, taken at 10 foot intervals between 90 and 500 feet. The massive low-permeability zone underlying the entire area extends for several miles to the south and west (Babcock et al., 1985).

4.2 Commercial Site (Retail Building and Home Supplies), C-1

Seven dry wells on this property drain the parking area, lumber yard and garden center associated with the store. Figure 3 shows the on-site dry wells and drainage areas. The dry well selected for the study is immediately south of the store's outdoor garden supply center and has been in operation since 1984. It receives drainage from the irrigation of potted plants in the garden center and from the adjacent parking lot. In addition, all of the other dry wells are connected by buried pipe

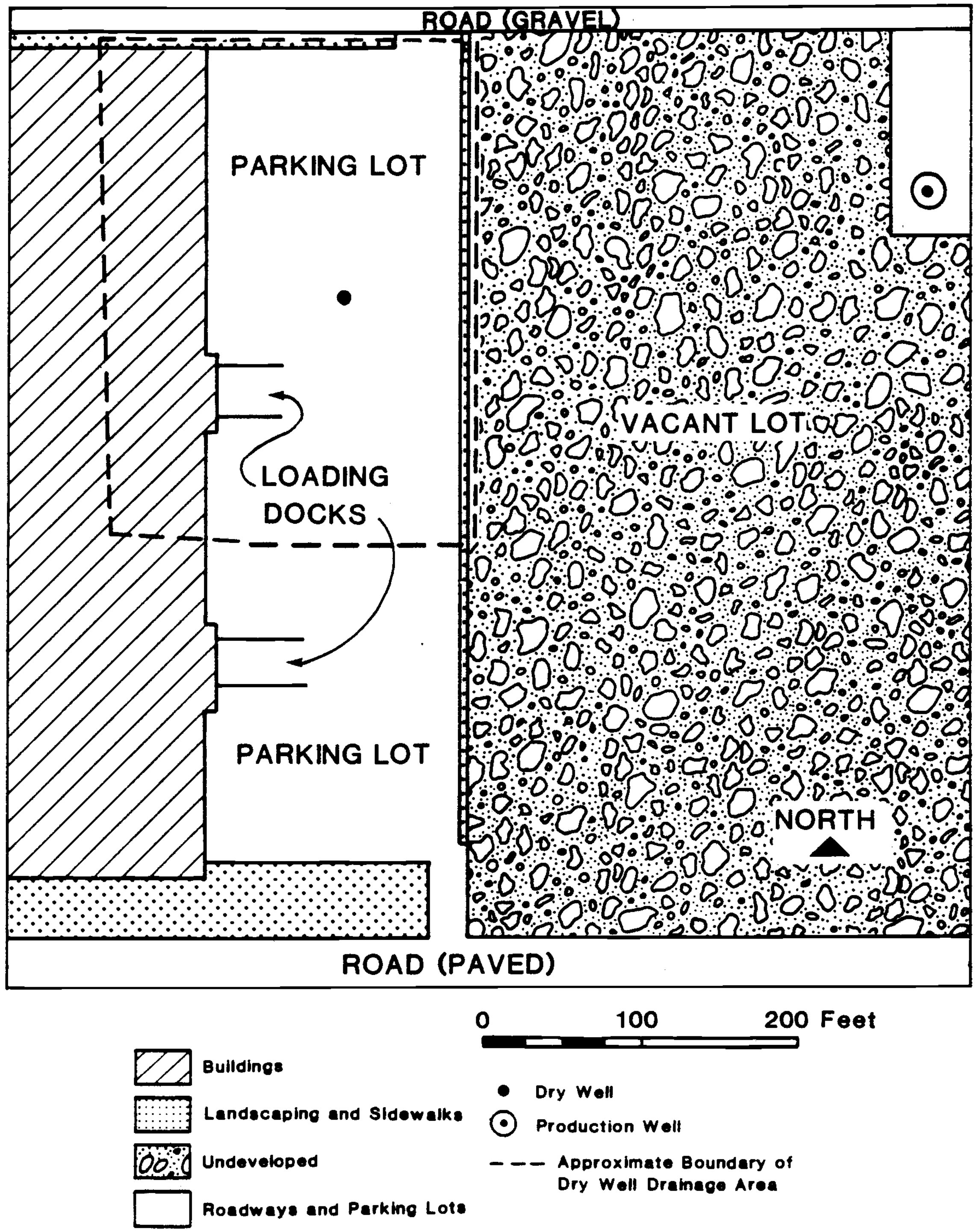

FIGURE 2. MAP SHOWING THE LOCATION OF THE DRY WELL AND DRAINAGE AREA AT SITE I-1

TABLE 6

Driller's Log for the Dry Well at I-1

Depth (ft)	Description
0-11	Tight clay
11-24	Decomposed granite
24-35	Sand, gravel and cobbles, dry

Source: McGuckin Drilling, Inc.

TABLE 7

Log for production well 350 feet east of I-1

Depth (ft)	Description
0-30	Cemented clay, sand and gravel
30-90	Sand and gravel
90-100	Cemented clay, sand and gravel
100-220	Sand, gravel and clay
220-230	Cemented clay, sand and gravel
230-350	Sand, gravel and clay
350-360	Cemented clay, sand and gravel
360-500	Sand, gravel and clay
500-530	Yellow sticky clay
530-700	Red clay, sticky, some gravel

Source: Tucson Water

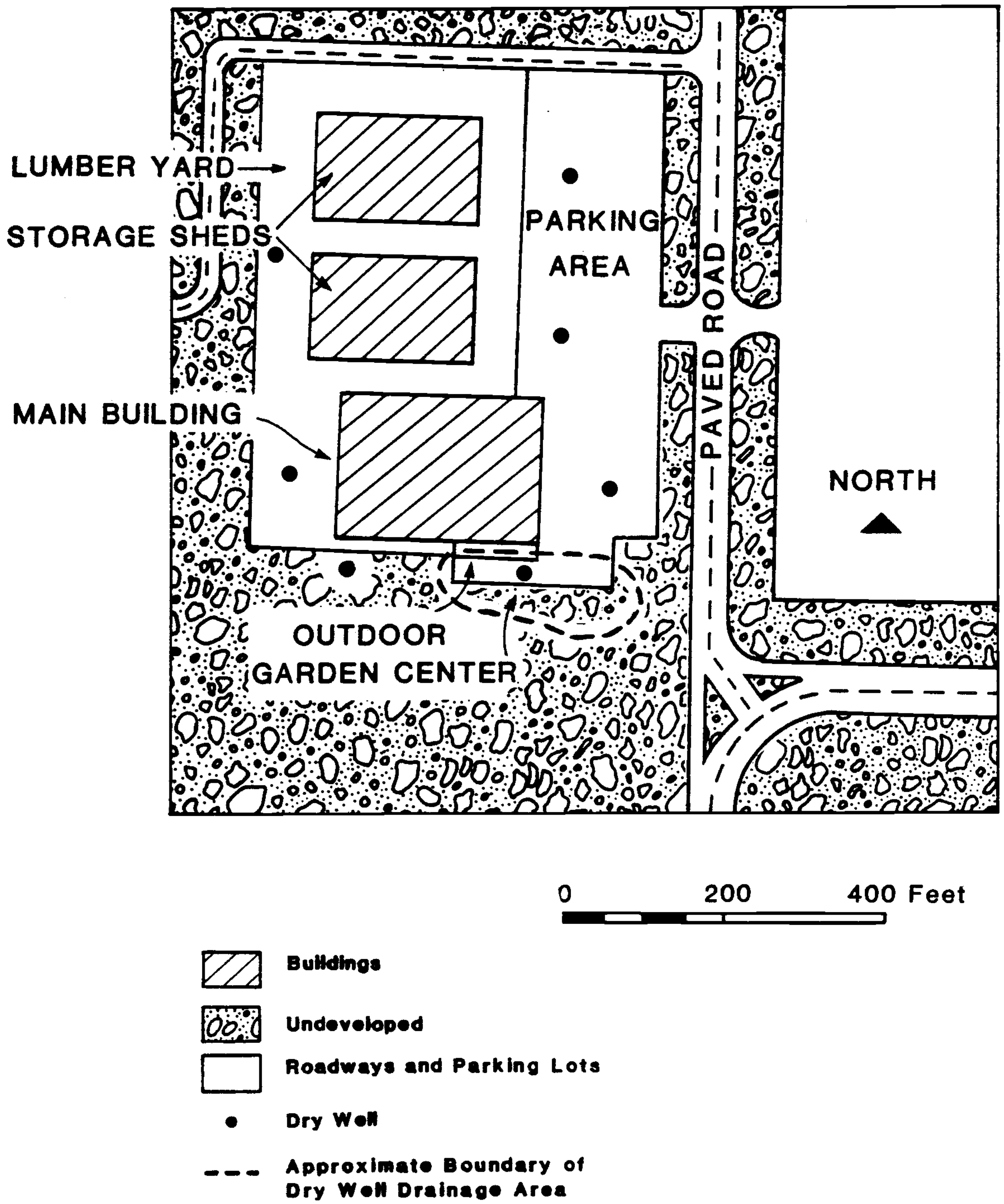

FIGURE 3. MAP SHOWING THE LOCATION OF THE DRY WELL AND DRAINAGE AREA AT SITE C-1

line to this dry well. Accordingly, this well received overflow runoff from the other six wells. Potential sources of pollution identified during the site visits include various soil enhancing agents stored in the garden center, and constituents from gasoline and oil spills in the parking lot. In the past, the garden store housed plastic jugs of Dursban (chloropyrifos) and paper bags of Diazinon, both pesticides, and paper bags of ammonium phosphate and sulfate. (The pesticides have since been moved inside the store.) A few of the ammonium sulfate bags were broken with the dry product exposed on the shelf. At the time of the visits, runoff from the watering of plants in the garden center was entering the dry well. Although the dry well is in a parking area, the area is sufficiently far from the store's main entrance that it is not usually used for customer parking.

The settling chambers of the dry wells are about 20 ft deep. Total depths of the seven wells range from 22 ft below land surface to 33 ft below land surface. The settling chamber of the dry well selected for detailed studies was back-filled by in-washed sediment to within about 10 ft of land surface.

Logs prepared by the dry-well contractor are included as Table 8. Local stratigraphic information is provided by the driller's log (Table 9) for Tucson Water's production well, 150 ft from the dry well. Both logs suggest an upper clay to silty clay zone that terminates at a depth of 17 ft, according to the dry well log, or at 25 ft according to the production well log. The dry well log describes a sand, gravel and cobble layer immediately below this zone at a depth of 22 ft. The production well log indicates fine sand to sand from a depth of 25 ft to 105 ft. Static water level in the production well is about 110 ft below land surface (Tucson Water, 1987).

4.3 Residential (Apartment Complex) Site, R-1

The dry well at this site is in an asphalt parking area which receives drainage from extensive grassed and landscaped areas and from rooftops in the complex (Figure 4). A trash receptacle is in the parking lot within the drainage area. Runoff from irrigated lawns at the complex was observed entering the dry well during two of three site visits. The dry well was installed in May, 1984, to correct a drainage problem at the site. The apartment complex was built in 1980.

The settling chamber of the dry well extends to about 20 ft below land surface. The dry well is completed at 25 ft. Table 10 is the driller's log for the well.

Depth to water at the site is approximately 250 ft and the nearest production well is 700 to 800 ft west of the dry well. Table 11 is the driller's log of the production well. The driller's log of the production well shows that the silt and clay

TABLE 8

Driller's Logs for the Dry Wells at C-1

Soil Description	Hole Number 1	2	3	4	5	6	7
	Depth Intervals (feet)						
Silty clay	0-17	0-25	0-28	0-9	0-18	0-16	0-16
Sugar sand	none	none	none	9-15	none	none	none
Silty clay	none	none	none	15-17	none	none	none
Sand, gravel and cobbles	17-22	25-30	28-33	17-22	18-23	16-22	16-22

Source: McGuckin Drilling, Inc.

TABLE 9

Log for Production Well 150 feet east of the Dry Well at C-1

Depth (feet)	Description
0-25	Clay soil, 70-75 % fines
25-105	Sand - fine sand
105-163	Fine sands, some clay and gravel
163-190	Sand and gravel. Mostly gravel at the top then mostly coarse, medium sand below 170', no clay
190-220	Less gravel, mostly medium sand
220-295	Sand and gravel. Mostly coarse sand and fine gravel
295-300	Large subangular gravel
300-333	Coarse sand and subangular gravel
333-339	Subangular large gravels and boulders
339-350	Sandy clay lenses in the gravel
350-400	Subangular coarse gravel, little sand. Sandy clay lenses present from 333', increase at 373'

Source: Tucson Water

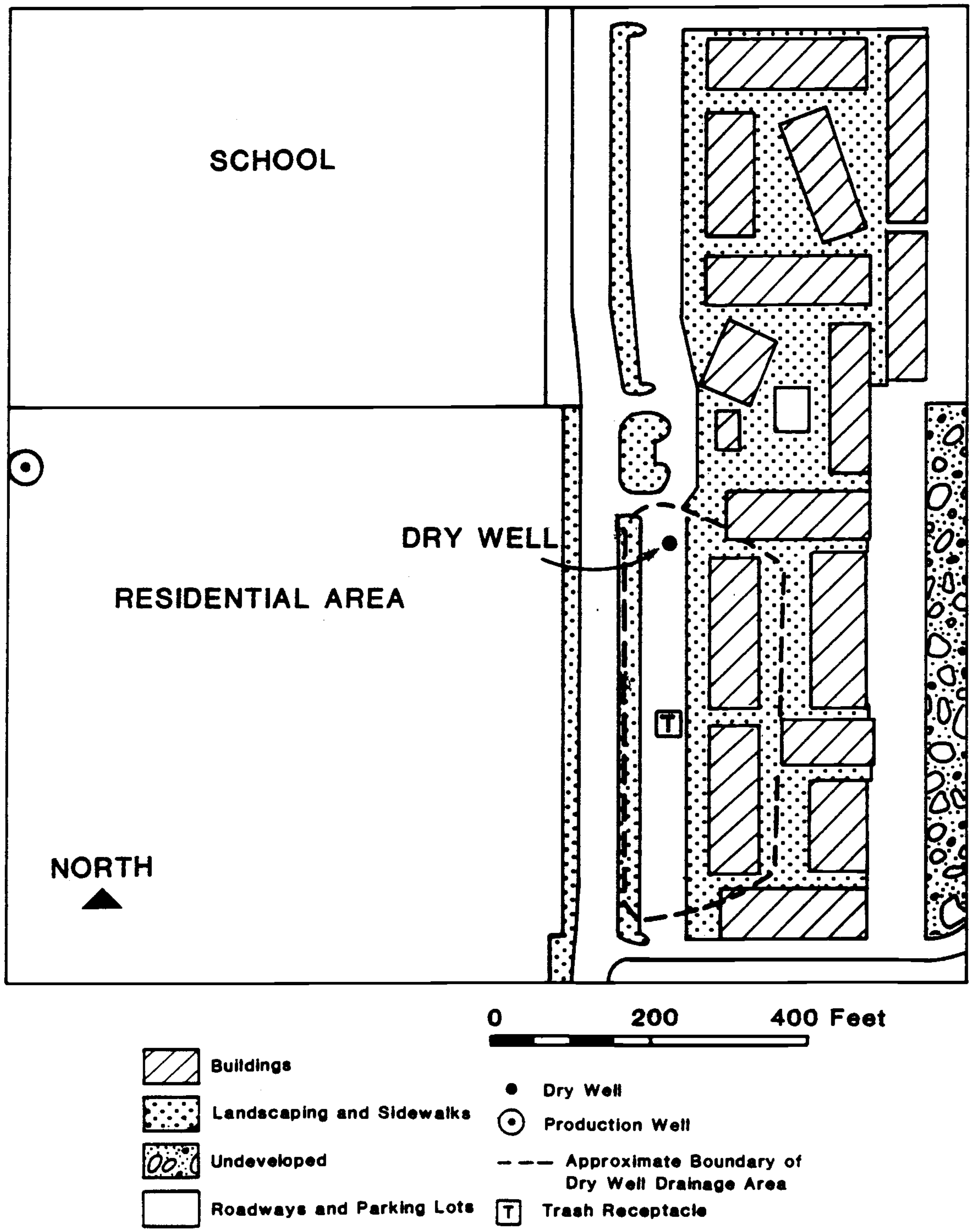

FIGURE 4. MAP SHOWING THE LOCATION OF THE DRY WELL AND DRAINAGE AREA AT SITE R-1.

TABLE 10

Driller's Log for Dry Well at Site R-1

Depth (ft)	Descriptior
0-4	Clay
4-10	Caliche
10-25	Sand-hard

Source: McGuckin Drilling, Inc.

TABLE 11

Log of Production Well West of Dry Well at R-1.

Depth (ft)	Description
0-3	Brown clay
3-7	Caliche
7-12	Brown clay and some rock
12-20	Sandy clay and gravel
20-60	Sand, clay, gravel, some boulders
60-70	Sand and gravel
70-170	Sand, gravel, rock and some clay
170-220	Sand, gravel and clay
220-240	Sand and gravel
240-245	Sand, gravel and clay
245-265	Sand, gravel and some clay
265-270	Clay, some rock
270-290	Sand, gravel and some clay
290-302	Sand and gravel
302-310	Clay, some gravel
310-325	Hard sand and gravel, little clay
325-330	Sand and gravel
330-355	Hard sand and gravel, little clay
355-370	Sand, gravel, little clay
370-410	Hard sand and gravel, little clay
410-425	Cemented sand and gravel
425-430	Sand and gravel
430-455	Cemented sand and gravel
455-470	Hard sand and gravel, little clay
470-495	Cemented sand, gravel, little clay
495-520	Sand, gravel, some clay
520-550	Hard sand, gravel, clay
550-595	Cemented sand, clay, some gravel
595-610	Cemented sand, gravel, clay
610-640	Cemented sand, gravel, some clay
640-650	Sand, gravel, rock - hard
650-725	Hard sand, gravel, clay
725-740	Cemented sand, gravel, clay
740-750	Cemented sand, clay, rock
750-765	Hard sand, gravel, rock, little clay
765-800	Conglomerate - Hard

Source: Tucson Water

percentages in the vadose zone strata are fairly uniform at 10 to 20 percent. The strata are primarily sand and gravel layers, with a possible layer of conglomerate between 130 ft and 150 ft.

4.4 Residential (Apartment Complex) Site, R-2

The dry well at site R-2 is within an asphalt-paved drive way (Figure 5) near the northeast corner of the apartment complex. Oily and gaseous emanations from vehicular traffic contribute to the pollutant loading of the dry well. Runoff of car-wash water may also contribute oils, greases, and gasoline byproducts. Other potential sources of pollutants include runoff from a small, adjoining grassed area. The grassed area is fertilized with ammonium phosphate fertilizer. Daily irrigation appears to maintain a high water content in the dry-well sediments. A trash receptacle is located immediately upgradient of the dry well. The dry well was installed, as one of three, in the apartment complex in 1985. The apartment complex was also constructed in 1986.

The settling chamber of the dry well terminates at about 20 ft below land surface. The lower, gravel-packed shaft extends to about 50 ft below land surface. Table 12 is the driller's log for the dry well.

Depth to water is about 135 ft below land surface. The closest production well is approximately 3000 ft south of the dry well. Table 13 is the log of this production well.

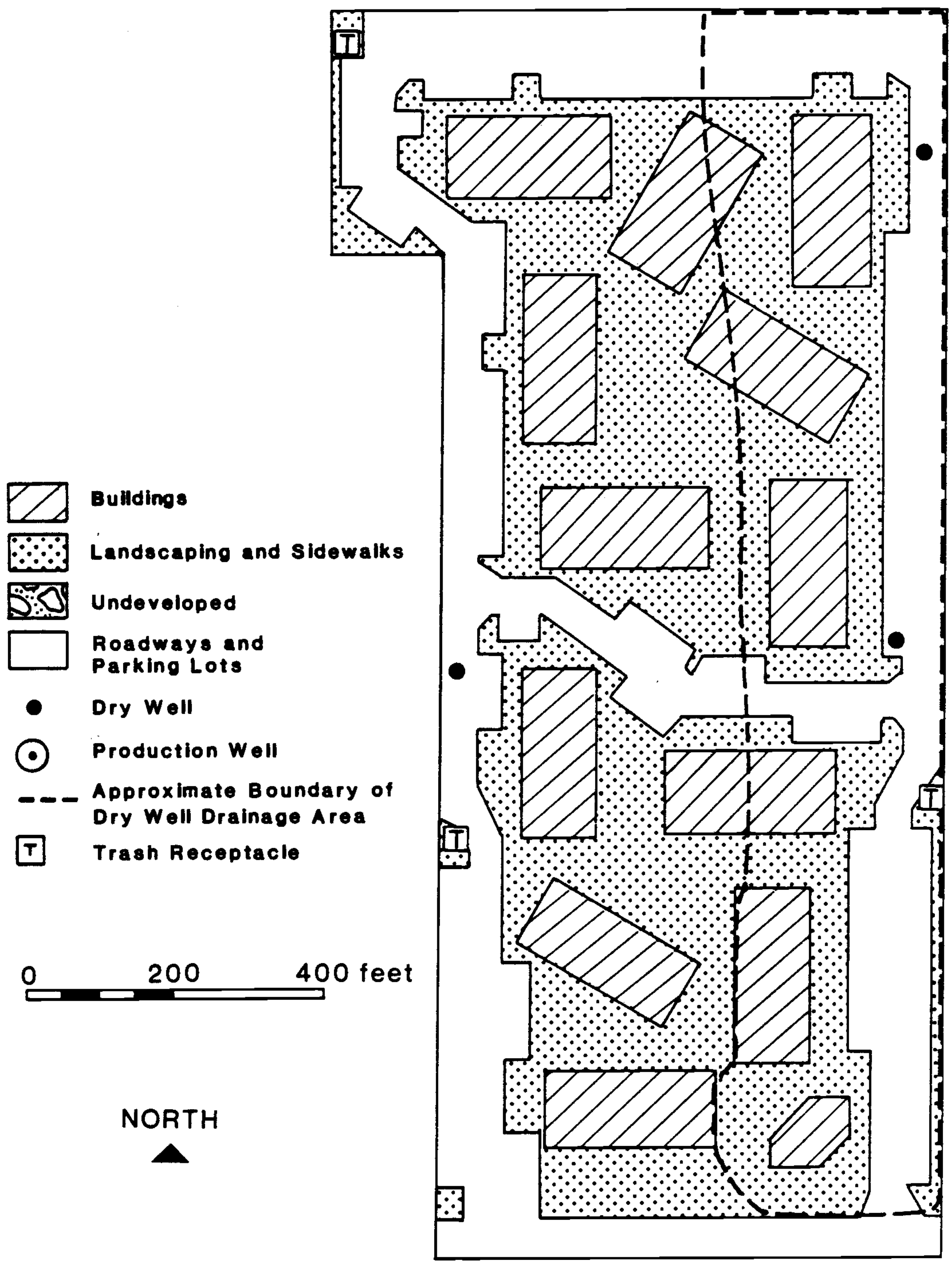

FIGURE 5. MAP SHOWING THE LOCATION OF DRY WELLS AND DRAINAGE AREA AT SITE R-2.

TABLE 12

Driller's Log for Dry Well at Site R-2

Depth (ft)	Description
0-13	Silty clay
13-18	Tight granite boulders
18-45	Decomposed granite

Source: McGuckin Drilling, Inc.

TABLE 13

Log of the Production Well Approximately 3000 ft South of R-2

Depth (ft)	Description
0-20	Top soil, fine sand and gravels
20-25	Sand gravel (this interval appeared to be channel deposits)
25-35	Gravelly sand
35-40	Gravel
40-50	Gravelly sand
50-130	Sandy gravel
130-135	Gravelly sand
135-140	Sandy gravel
140-145	Gravelly sand
145-155	Sandy gravel
155-160	Gravelly sand
160-235	Sandy gravel
235-255	Gravelly sand
	BREAK- Based upon color change of samples, lowered percentage of rhyolite and arkose.
255-335	Mostly sandy gravel to gravelly sands with some calcareous mudstones between 295 and 335 ft.
255-275	Sandy gravel
275-280	Gravelly sand
280-305	Sandy gravel
305-310	Gravel
310-335	Sandy gravel
	BREAK- Primarily based upon analyses of samples and mineralogy.
335-350	Sandy gravel to gravelly sand with an increased percentage of volcanics and darker minerals.
335-345	Sandy gravel
345-350	Gravelly sand

Source: Tucson Water

SECTION 5: METHODOLOGY

As indicated in Section 4, the basic purposes of the sampling program at each of the selected dry wells were: (1) to determine if water draining from the wells had reached the water table and (2) to determine if pollutants in runoff and dry-well sediment were present in vadose-zone soil samples and ground water.

The basic sampling process at the selected dry wells included the following steps:

1. Negotiating access
2. Preparing the site
3. Sampling stormwater runoff and/or dry well sediment
4. Drilling and sampling the vadose-zone
5. Observing and characterizing the lithology
6. Shipping and analyzing subsamples for chemical constituents
7. Analyzing subsamples for water content and grain-size analyses
8. Sampling perched ground water (when present) and the water table
9. Renovating the site after removing the drilling equipment
10. Interpreting the results

5.1 Negotiating Access

The owner of each of the three dry wells was formally requested, by personal contact and by mail, for permission to enter their property and undertake the sampling program. The owner of the industrial well complied with this request after receiving liability assurances. In contrast, access to the commercial and primary residential wells required more formal action.

5.2 Site Preparation

Prior to entering the property at each dry-well site, representatives from the electrical, water, gas, and telephone utilities "blue staked" the area in the immediate vicinity of each well. The purpose was to locate buried utilities which could be ruptured during drilling. The study team also photographed each site prior to drilling to document the initial conditions.

5.3 Stormwater and Dry-Well Sediment Sampling

Runoff samples were collected for laboratory analyses during stormwater runoff in the summer of 1987 at R-1 and I-1 and from standing water in the dry-well settling chamber at C-1. Dry well sediment samples were collected at drilling time. Procedures for sample collection were developed prior to entering the field to ensure a standardized method, to prevent cross-contamination of the samples, and to ensure compliance with EPA quality control and chain of custody requirements. The procedures for dry-well sediment sampling also included safety precautions relevant to entering confined spaces. Sampling procedures were modified in the field, as necessary, to handle specific situations.

Access to the settling chamber was accomplished by removing the inlet grate and lowering a ladder to the bottom of the chamber. Protective disposable coverings on the ladder feet and on the feet of personnel collecting the samples minimized carry-over of sediment from one chamber to the next. In addition, an untouched sample area was chosen to minimize the possibility of collecting contaminants introduced during the collection process.

Samples were composited from the upper four inches of accumulated sediment in the dry well settling chamber. Normally, the samples were collected by scooping sediment with clean glass beakers and filling laboratory supplied wide-mouth, glass jars equipped with teflon-lined plastic caps. The caps were sealed with electricians tape. The ladder was visually inspected following sampling at each site and, when necessary, steam cleaned using ordinary tap water. Attempts to minimize sample disturbance were generally unsuccessful due to the sandy texture of most of the sediments.

The field team refrigerated the samples immediately following collection and during temporary storage and shipment to a commercial analytical laboratory. The analytical laboratory received the samples within 48 hours of collection.

5.4 Drilling and Sampling the Vadose Zone

A drilling contractor was hired to obtain depth-wise vadose zone samples at the dry well sites for chemical analyses, water content determination, grain-size analyses, and geological profiling. The principal technique employed was ring sampling via a hollow-stem auger. This method is well-suited for obtaining relatively undisturbed samples in unconsolidated alluvium. The driller was also required to obtain split-spoon samples at specified intervals. Dry drilling was required to minimize cross contamination. The bore holes were located as close as possible to the dry well without intersecting the gravel pack.

Field personnel used great care during the drilling and sampling process to minimize contamination of the samples with foreign substances. The driller steam cleaned his rig and augers prior to entering each site. In addition, the driller brought a steam cleaner on site for cleaning the ring samplers, brass rings, and water-sample bailer prior to use.

The contract with the driller specified ring sampling at depths that would bracket the dry well settling chamber and at greater depths in the vadose zone. For example, sampling depths at site I-1 were 15 ft, 20ft, 25 ft, 27.5 ft, 30 ft, 32.5 ft, 35 ft, 37.5 ft, 40 ft, 45 ft, 50 ft, 60 ft, 80 ft, and 100 ft. The driller was required to obtain split-spoon samples at specified five foot intervals where ring samples were not taken. These samples further characterized the stratigraphy, grain-size variation, and moisture content in the vertical profile. The predetermined ring sample and split-spoon sample depths were varied when formation changes and perched ground water were observed.

The ring sampler used during the studies was a modified Dames and Moore sampler. This sampler accommodates three six inch long, 2.5 inch diameter, new brass sleeves for core sampling. At each sampling depth, the sampler was driven into undisturbed sediments ahead of the auger's cutting tip. Following removal of the sampler from the hollow-stem auger, the brass sleeves were extracted from the sampler, separated, and sealed at each end with a teflon liner and plastic cap. Subsequently, the caps were sealed in place with electrical tape to minimize loss of moisture and soil gas. The middle sleeve, considered to be the least disrupted, was reserved for chemical analysis. The two remaining segments were used for analyses of moisture content and grain-size.

5.5 Ground-Water Sampling

The drilling contractor was required, when possible, to obtain samples of perched ground water and ground water beneath the principal water table. Sampling entailed bailing using a teflon bailer, and emptying the bailed samples into bottles provided by the laboratories, and immediate capping and labelling. The sample bottles intended for analyses of volatile organics were filled to capacity to avoid loss of these substances to sample head space.

5.6 Field Observations

Field personnel maintained a field log book to record the on-site procedures and activities. The observations included drilling times, sampling times, and the number of blows required to drive the sampler into the formation being sampled. In addition, on-site geological logs of the profiles were constructed based on grab samples of the sediments collected at various depths.

5.7 Shipping and Chain of Custody

During sample collection, the soil and water samples were stored in coolers containing "blue ice". Subsequently, the samples intended for chemical analyses were stored in coolers provided by the commercial laboratories and shipped by overnight express service. Personnel from the University of Arizona and the commercial laboratories maintained the requisite chain of custody documentation.

5.8 Laboratory Analyses

A commercial laboratory analyzed the dry-well sediment, vadose zone soil samples, perched water, and water-table samples for priority organic and inorganic constituents. A back-up laboratory analyzed selected soil and water samples as a quality-control procedure. The laboratories used the methods listed in Table 14 for extraction and analyses of soils and analyses of water samples from all sites except site R-2. These methods are approved by the EPA and described in Test Methods for Evaluating Solid Waste: Physical/Chemical Methods, Second Edition (SW-846) (U.S. Environmental Protection Agency, 1982). Analyses conducted after November 1986 used the third edition of the same reference. Appendix 3 lists the specific parameters and the minimum detectable concentration for each parameter. The laboratories were also requested to determine the full suite of major inorganics, pH, specific electrical conductance, and cation exchange capacity for the soil samples. The laboratories were required to maintain a chain of custody for the handling of samples to ensure that holding times for the various constituents were not exceeded. Similarly, the laboratory was expected to employ the appropriate quality assurance/quality control procedures during the analytical process.

For the samples from site R-2, the laboratory analyzed VOCs in the soil and water samples using EPA Methods 8010 and 8020. These methods employ gas chromotography with specific detectors for analyzing the halogenated/aromatic compounds listed in Appendix 3. These methods allow greater sensitivity in detecting the compounds of interest than the methods based on GC/MS. Appendix 3 also lists the related detection limits of the VOCs analyzed by Methods 8010/8020.

5.8.1 Analyzing Subsamples for Water Content and Grain-Size Distribution

The percentage of water, on both a gravimetric and volumetric basis, was determined for the vadose-zone samples. The associated procedures are specified in Methods of Soils Analyses (Klute, 1986). Basically, gravimetric analyses involves weighing the soil sample at the field water content, oven drying the sample at 105 degrees C, reweighing, calculating the difference in weight and the weight percentage of water. The gravimetric moisture content is converted into volumetric water content using an estimate of the sample's bulk density. For the ring samples, the bulk density was calculated by dividing the net weight of the oven dry sample by the known volume of the brass sleeve. For split spoon samples, the approximate bulk density was estimated by averaging the bulk densities of ring-collected samples immediately above and below the split spoon samples.

TABLE 14

EPA Approved Methods of Analysis for Sediment and Water Samples

	Sediment Extraction Method	Sediment Analytical Method	Water
Volatile Organic Compounds	5030 (1)	8240 (1)	624
Base/Neutral and Acid Compounds	3550 (1)	8270 (1)	625
Chlorinated Pesticides and PCB's	3550 (1)	8080 (1)	608
Organophosphorous Pesticides	3550 (1)	8140 (1)	614
Chorophenoxy Herbicides	3550 (1)	8150 (1)	615
Priority Metals	3050 (1)	7000 (1)	7000
Oil and Grease		413.2 (2)	--

(1) EPA, 1982 (2) Federal Register, 44:233

Particle-size analyses at the industrial well site included determining the gravel, sand, and silt plus clay fraction by wet sieving. This fraction consists of the particles passing a 0.061 mm screen. This method was refined for the samples from the commercial dry-well site to include determining the silt percentage and the clay percentage in the fines fraction. The procedure included dry sieving to separate out the gravel fraction; adding a dispersive agent to the sand, silt, and clay mixture to deflocculate the clays; and wet sieving to separate the sand from the fines. The pipette method was used to separate the silt and clay fraction.

5.9 Renovating the Drill Sites

Site renovation included back filling each bore hole with grout and patching the surface in the vicinity of the bore hole. Surplus vadose zone sediments, collected during the drilling operation, were collected and transported off site.

SECTION 6 RESULTS AND DISCUSSION

6.1 Results of Studies at Site I-1

The borehole at this site was augered and sampled on 6/27/87. Total depth of the borehole was 140 ft below land surface. Although the borehole was completed to the water table, we were unable to obtain a water sample. A storm occurred in the area as the driller was approaching the final depth. We were concerned that the dry well and bore hole would be flooded by runoff. If this had occurred, runoff (and pollutants) would have been short-circuited through the borehole to the water table. Accordingly, drilling was stopped immediately, the auger was removed from the borehole, and the hole was backfilled with grout.

Possible sources of error arising during the field sampling program are summarized in Appendix 4.

6.1.1 Vadose Zone Stratigraphy and Water Content Distribution

The field team collected vadose-zone soil samples at five-foot intervals to describe the vadose-zone stratigraphy. Moisture content was determined for each depth at which samples for chemical analyses were collected. Volumetric moisture content was determined from the gravimetric moisture content, the bulk density determined at four depths representing different lithologies (see Table 15), and the density of water, using the procedure described in the previous section. Figure 6 shows the percentage of silt and clay for each five-foot interval and the volumetric moisture content at various depths.

The vadose zone in the borehole near I-1 is comprised of interbedded sands and silt and clay layers. Three relatively thin beds of fine-grained (i.e., silt plus clay) material occur in the upper 50 feet: one at five ft, a second at 35, and the third at about 45 feet below land surface (see Figure 6). The dry well is completed at 35 feet, just above the first fine-grained layer. Fine-grained materials predominate from about 70 ft to the total depth of the borehole.

6.1.2 Recharge Potential

The finer-grained regions appear to limit the vertical movement of water injected through the dry well, accounting for the higher water content values at these depths. In addition to the two perched ground-water layers in the upper 60 ft, there appeared to be a mound overlying the water table, within the lower fine-grained unit. Water content values within these three regions approached 40% by volume, equivalent to field capacity values for

TABLE 15

Bulk Densities for Four Vadose Zone Sediments at I-1

Depth (ft)	Lithology	Bulk Density
25	Well-sorted fine-sand	1.50
32.5	Medium to coarse sand	1.64
40	Fine to coarse sand	1.59
140	Silt and clay	1.51

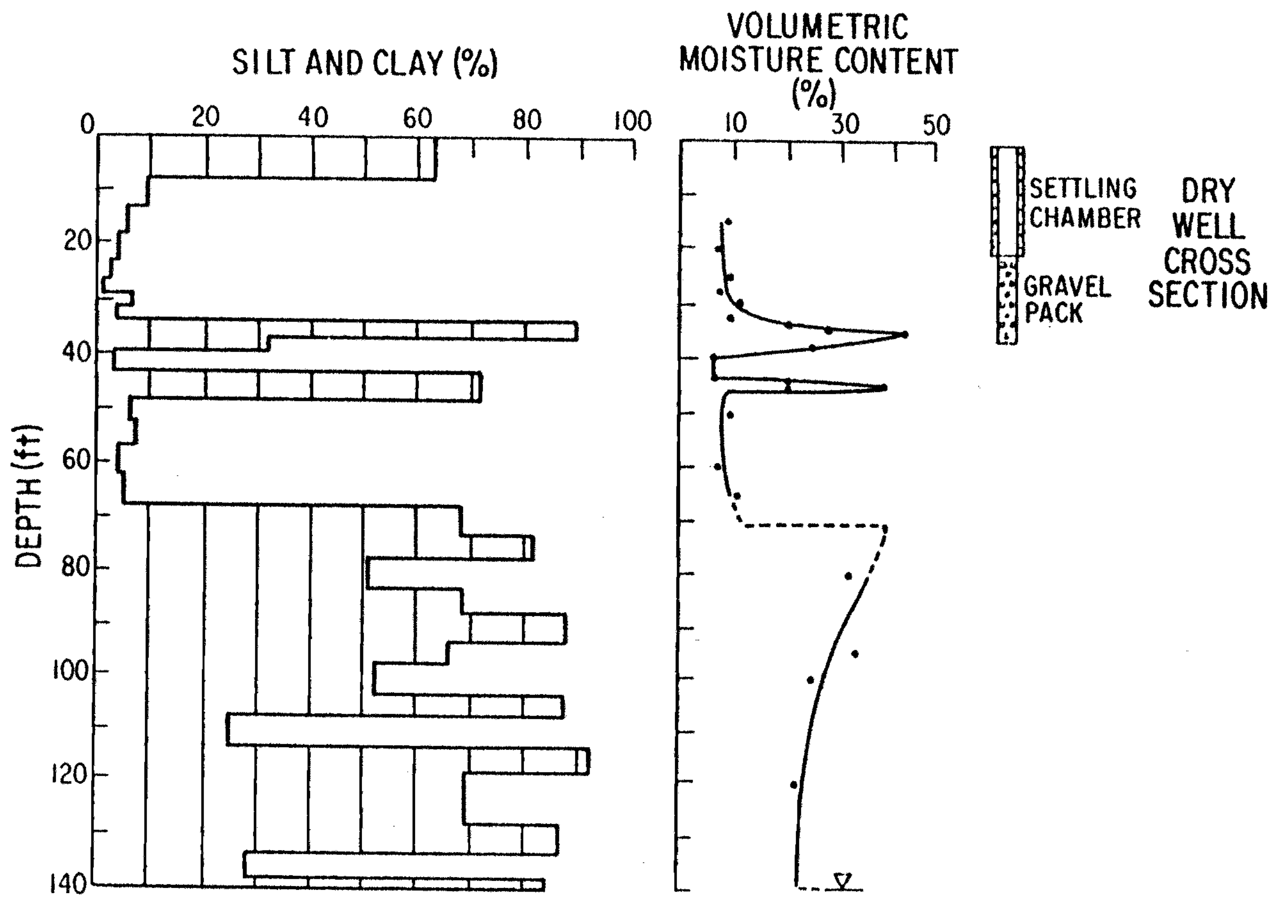

FIGURE 6. PERCENT VOLUMETRIC MOISTURE CONTENT AND THE DISTRIBUTION OF SILT AND CLAY IN VADOSE ZONE, SITE I-1

heavy clay soils (Hillel, 1980). According to the driller, the water content at this site is noticeably higher than normally expected in the Tucson basin. Thus it appears that dry-well drainage has created a transmission zone throughout the profile, facilitating recharge. However, the three flow-impeding layers cause water percolating through the vadose zone to flow laterally as well as vertically.

6.1.3 Pollutant Distribution

6.1.3.1 Organics

Table 16 lists the organic pollutants in runoff samples and dry-well sediment samples at site I-1, together with the results of corresponding analyses of vadose-zone samples and local ground water.

6.1.3.1.1 Runoff Samples

Runoff samples contained two non-volatile organics, fluoranthene and pyrene. Both of these compounds are present in tail gases of gasoline engines (Verschueren, 1977). The presence of these compounds in runoff is not surprising, given that the dry well is located within a parking lot.

Insecticides and pesticides were absent in the runoff samples.

6.1.3.1.2 Dry-Well Sediment

Table 16 lists the organic compounds detected in samples of dry-well sediment collected in 1986 and 1987. The 1986 samples contained the following volatile organics:

- o ethylbenzene
- o xylenes (m-xylene and 0-,p-xylene)
- o 1,3-dichlorobenzene
- o chloromethane.

Xylenes and ethylbenzene are components of asphalt. 1,3-dichlorobenzene is used as a fumigant and insecticide (Sax, 1986). Methylchloride is also used as a fumigant and insecticide and in the manufacture of organic chemicals, refrigerants, and synthetic rubber (Verschueren, 1977).

Volatiles were completely absent from the 1987 sediment sample.

Base/neutral and acid compounds comprise 19 of the 23 organic compounds detected in the settling-chamber sediments collected in 1986. Specifically, dry-well sediment contained the following non-volatile compounds:

- o naphthalene

TABLE 16
(Section I)

Organic Pollutants in Runoff and Dry Well Sediment, and Associated Levels in Vadose Zone Samples and Ground Water

Site I-1

	Runoff	Dry Well Sediment		
	8/02/87	7/22/86	9/23/86	9/23/86 (dup)
PURGEABLE ORGANICS				
ethyl benzene	ND	9.2	ND	ND
xylenes	ND	172.0	21.5	ND
chloromenthane	ND	0.1	0.1	ND
1,3-dichlorobenzene	ND	ND	ND	0.3
BASE NEUTRALS AND ACIDS				
fluoranthene	2.0	33.0	16.0	18.0
pyrene	1.0	35.0	16.0	19.0
naphthalene	ND	0.74	0.36	0.26
acenaphthalene	ND	2.1	0.22	0.17
acenaphthene	ND	ND	0.55	0.66
fluorene	ND	2.5	0.83	0.85
phenathrene	ND	23.0	7.4	8.3
anthracene	ND	5.0	1.6	1.4
benzo(a)anthracene	ND	16.0	12.0	10.0
bis(2-ethylhexyl)phthalate	ND	3.2	2.7	16.0
chrysene	ND	15.0	16.0	15.0
di-n-octylphthalate	ND	1.4	ND	6.9
benzo(b)fluoranthene	ND	42.0	12.0	12.0
benzo(k)fluoranthene	ND	ND	10.0	8.4
benzo(a)pyrene	ND	12.0	11.0	9.3
indeno(1,2,3-cd)pyrene	ND	9.4	7.1	7.1
dibenzo(a,h)anthracene	ND	2.6	1.3	1.4
benzo(ghi)perylene	ND	6.0	5.2	5.4
OILS AND GREASE		8,300	6,600	-

Units: Runoff, ppb
Sediment, mg/kg
ND: Not Detected

TABLE 16
(Section II)

Organic Pollutants in Runoff and Dry Well Sediment, and Associated Levels in Vadose Zone Samples and Ground Water

Site I-1

	Dry-Well Sediment 6/19/87	Vadose Zone 6/25/87	Ground Water 10/10/86
PURGEABLE ORGANICS			
ethyl benzene	ND	ND	ND
xylenes	ND	ND	ND
chloromenthane	ND	ND	ND
1,3-dichlorobenzene	ND	ND	ND
BASE NEUTRALS AND ACIDS			
fluoranthene	ND	ND	ND
pyrene	ND	ND	ND
naphthalene	ND	ND	ND
acenaphthalene	ND	ND	ND
acenaphthene	ND	ND	ND
fluorene	ND	ND	ND
phenathrene	ND	ND	ND
anthracene	ND	ND	ND
benzo(a)anthracene	ND	ND	ND
bis(2-ethylhexyl)phthalate	ND	ND	ND
chrysene	ND	ND	ND
di-n-octylphthalate	ND	ND	ND
benzo(b)fluoranthene	ND	ND	ND
benzo(k)fluoranthene	ND	ND	ND
benzo(a)pyrene	ND	ND	ND
indeno(1,2,3-cd)pyrene	ND	ND	ND
dibenzo(a,h)anthracene	ND	ND	ND
benzo(ghi)perylene	ND	ND	ND
OILS AND GREASE	1,100		

Units: Runoff, ppb
Sediment, mg/kg
ND: Not Detected

- o acenaphthalene
- o aceneaphthene
- o fluorene
- o phenanthrene
- o anthracene
- o di-n-butylphthalate
- o fluoranthene
- o pyrene
- o benzo(a)anthracene
- o bis(2-ethylhexyl)phthalate
- o chrysene, di-n-octylphthalate
- o benzo(b)fluoranthene
- o benzo(k)fluoranthene
- o benzo(a)pyrene
- o indeno(1,2,3-cd)pyrene
- o dibenzo(a,h)anthracene
- o benzo(ghi)perylene.

Again, these compounds are found in many sources including motor fuels, asphalt, plastics manufacture, and insecticide manufacture. Thus, their presence in dry-well sediment could have originated in runoff from both the parking lot and the plant complex.

The only semi-volatile compound detected in the 1987 sediment sample was pyrene, present at a concentration of 0.80 mg/kg. However, a duplicate analyses failed to detect pyrene. Thus, given that a concentration of 0.80 mg/kg pyrene is close to the detection limit (0.50 mg/kg), we conclude that the 1987 sediment sample was virtually free of pyrene and other semivolatiles.

Insecticides and pesticides were undetected in the sediment samples.

Oil and grease concentrations in the sediment samples decreased from a high of 8,300 mg/kg in the 7/22/86 sample to 1,100 mg/kg in the sample of 6/19/87.

As indicated, the concentrations of organics decreased in the 1987 sediment sample. Possible reasons for the decrease in organics, including oils and greases, include: (1) the dry well sediment was cleaned out between sampling dates, (2) the organic constituents were attenuated by volatilization, biodegradation or other processes, (3) runoff events washed the organic constituents from the sediment chamber into the gravel-packed portion of the dry well and into the vadose zone, and (4) concentrations are spatially variable in the sediment.

6.1.3.1.3 <u>Vadose-Zone Samples</u>

Table 17 lists the analyses conducted on depth-wise samples from the vadose zone. Volatile organics, acid and base/neutral

TABLE 17

Analyses Conducted on Vadose-Zone Soil Samples at I-1

	-----------------EPA Method Numbers----------------						
Depth (ft)	8240	8270	7000	8080	8140	8150	413.2
15	YES	YES	YES	NO	NO	NO	YES
20	YES	YES	YES	YES	YES	YES	NO
25	YES	YES	YES	NO	NO	NO	YES
27.5	YES	YES	YES	NO	NO	NO	NO
30	YES	YES	YES	YES	YES	YES	NO
32.5	YES	YES	YES	NO	NO	NO	NO
35	YES	YES	YES	NO	NO	NO	YES
37.5	YES	YES	YES	NO	NO	NO	NO
40	YES	YES	YES	YES	YES	YES	NO
45	YES	YES	YES	NO	NO	NO	YES
50	YES	YES	YES	NO	NO	NO	YES
60	YES	YES	YES	NO	NO	NO	YES
65	YES	YES	YES	NO	NO	NO	NO
80	YES	YES	YES	NO	NO	NO	YES
100	YES	YES	YES	NO	NO	NO	YES
120	YES	YES	YES	NO	NO	NO	YES
140	YES	YES	YES	NO	NO	NO	YES

Note:

Method 8240 = Volatile organic compounds
Method 8270 = Base/neutral and acid compounds (semi-volatiles)
Method 7000 = Priority metals
Method 8080 = Chlorinated pesticides and PCB's
Method 8140 = Organophosphorus pesticides
Method 8150 = Chlorophenoxy herbicides
Method 413.2 = Oil and grease

organics were determined for each vadose-zone soil sample because these parameters were detected in the settling chamber sediment. The laboratory completed a complete suite of analyses at 20, 30 and 40 feet, i.e., in the vicinity of the injection screen, to detect pollutants which may not have been retained in the settling chamber sediment. The analyses for the other depths all included the volatiles, semi-volatiles, priority metal pollutants, and oil and grease but not the pesticides and herbicides.

As Table 16 indicates, no organic pollutants were detected in the vadose-zone samples. The absence of detectable levels of organic pollutants in the vadose-zone sediments, compared to the settling-chamber sediment, is probably related to the following factors:

o There was a time lag between detecting volatiles in the sediment samples and drilling for vadose-zone samples. The four volatiles chloromethane, dichlorobenzene, ethyl benzene and xylenes were not detected in the 1987 vadose-zone samples at the detection limits of the analyses (i.e., in mg/kg or ppm) before drilling in 1987. However, the vadose zone was sampled approximately one year after collection of the initial settling chamber sediment samples, in which the high xylene concentrations were detected. Given the high vapor-pressure densities of these compounds, they were probably removed by volatilization in the interval between sampling the settling-chamber sediment and the vadose zone.

o The base neutral and acid compounds detected in the settling chamber sediment and storm runoff may be attenuated by biodegradation and immobilization in oils and greases. According to Groenewegen and Stolp (1981), polynuclear aromatic substances which are easily degraded are relatively soluble in water. Anthracene, and phenanthrene are include among this category. However, higher condensed polycyclic aromatic hydrocarbons (PAHs), such as chrysene, benzo(a)anthracene, and dibenzo(a,h)anthracene, are considerably less soluble (Groenewegen and Stolp, 1981). Such PAH's are fairly immobile due to their low solubilities and high octanol/water partition coefficients. According to Short (1988), oils serve as a sink for such hydrophobic pollutants. Thus, oils and grease collecting in the dry-well sediment and upper vadose zone may sequester the hydrophobic semivolatiles. Subsequent biodegradation reduces these compounds to carbon dioxide, water, and residual chlorides.

o It is possible that many of the polyaromatic hydrocarbons detected in the base/neutral and acid analysis of the settling chamber sediment came from tar-coated pieces of eroded asphalt. If this is true, the mobility of these compounds would be restricted simply by filtration of the particles in the gravel pack and vadose-zone sediments.

6.1.3.1.4 Ground Water

The driller was unable to obtain a water table sample from the borehole. Accordingly, we cannot specify the presence or absence of dry-well pollutants at the water table underlying the well.

Analyses of a sample of ground water taken from the nearby Tucson Water well on 10/01/86 was virtually free of volatile and semivolatile organics. However, the sample contained 70 micrograms/l Total Organic Halogens (TOX).

6.1.3.2 Heavy Metals

6.1.3.2.1 Runoff Samples/Dry-Well Settling Chamber Samples

Zinc and mercury were detected in runoff entering the dry well (see Table 18). However, the mercury concentration was close to the detection limit of 0.0010 mg/l.

Arsenic, cadmium, chromium, copper, lead, nickel, zinc and mercury were detected in the 7/21/86 sample of settling chamber sediment at I-1 (see Table 18). However, the analyses of this sample included total metals and as such does not necessarily represent mobile, or soluble metals. In contrast, the data for the 6/19/87 sample are for "extractable" metals. They were determined by agitating an anaerobic, 1:10 sediment:demineralized water mixture for 48 hours and analyzing the filtered extract. In this sample, the metals were present below detectable limits.

6.1.3.2.2 Vadose-Zone Samples

Table 19 shows the extractable metals detected in vadose-zone samples. As shown, minor amounts of cadmium, lead, nickel, copper and/or silver were detected at each of the fine-grained layers and at 65 feet at concentrations slightly above the minimum detectable concentrations. These metals may have been injected through the dry well; however, they may also occur naturally in the vadose zone. The observed concentrations do not pose a threat to ground-water quality. Moreover, it is unlikely that these metals could migrate to the water table at this site.

The fine-grained layers at 35 and 45 feet at this site, and the massive fine-grained layer below 70 feet may be particularly effective in sorbing the cationic metals, limiting their movement to the water table. In addition, the presence of fine-grained layers in the profile enhances lateral flow, thus increasing the surface area contacted by metals (and other pollutants) during movement through the profile. Lateral spreading also increases the surface area of the water table contacted by recharging water. Thus, if percolating water containing these concentrations reached the water table, dilution would probably

TABLE 18

Heavy Metals in Runoff and Dry-Well Sediment at Site I-1

Metal	Runoff 8/2/87	Dry-Well Sediment 7/21/86	Dry-Well Sediment 6/19/87
Arsenic	ND	0.54	<1.0
Antimony	ND	<10	<1.0
Beryllium	ND	<0.25	<1.0
Cadmium	ND	<0.29	<1.0
Chromium	ND	<5.0	<0.5
Copper	ND	9.6	<0.5
Lead	ND	21	<0.5
Nickel	ND	18	<0.5
Selenium	ND	<0.005	<0.1
Silver	ND	<0.5	<0.1
Thallium	ND	<5.0	<0.1
Zinc	0.067	120	<0.5
Mercury	0.0014	0.14	<0.01

Note: The metals in the 7/21/86 samples are total metals, whereas the metals in the 6/19/87 sample were detected in deionized water extracts, and hence represent mobile metals.

Units: Runoff, mg/l
Sediment, mg/kg
ND: Not Detected

TABLE 19

Metals Detected in Vadose Zone Sediments at I-1

Depth (ft)	Cadmium	Lead	Nickel	Copper	Silver
35	0.13	0.56	0.69	<0.50	<0.10
45	<0.10	0.58	<0.50	<0.50	<0.10
65	<0.10	<0.50	<0.50	0.74	<0.10
80	<0.10	<0.50	<0.50	0.77	<0.10
120	<0.10	<0.50	<0.50	0.86	0.21
140	<0.10	<0.50	0.90	0.56	0.24

Units: Mg/l

reduce the concentrations to levels below the safe drinking water limits established by the EPA. [Bandeen (1987) discusses the effect of lateral spreading on pollutant migration, attenuation, and dilution in detail.]

6.1.3.2.4 Ground-Water Samples

Heavy metals in ground-water samples from the nearby Tucson Water well were all within the limits prescribed by National Primary and Secondary Drinking Water Regulations.

6.1.4 Conclusions

o Ground-Water Recharge

Water content profiles suggest that ground-water recharge occurs during dry-well drainage at this site. However, the presence of the massive clay layer below 70 ft impedes free drainage. In addition, the clay layer causes water to spread laterally above this depth, forcing water to move vertically through a larger volume of the vadose zone, compared to profiles consisting of sands and gravels. Thus, more water is invested in developing a transmission zone to the water table.

o Fate of Pollutants in the Settling Chamber

The grease and oil content of the sediment, together with organics, diminished between the 1986 and 1987 samples. Volatile compounds are dissipated by volatilization. Apparently, the oils and grease in the dry-well sediment provide a large reservoir of organic carbon for sorption of the organics, particularly the hydrophobic semivolatiles. The more soluble semivolatiles may be biodegraded.

o Pollutant Transport in the Vadose Zone

None of the organics detected in the dry-well sediment were present in vadose-zone samples.

Undoubtedly, some of the semivolatiles and oils and greases are not retained in the settling chamber and wash through the overflow pipe, together with particulate matter, into the lower, gravel-packed chamber. The same processes may govern the fate of the semivolatiles in this chamber as occur in the settling chamber, i.e., retention within the oils and greases and biodegradation.

Heavy metals are probably sorbed onto the clays and hydrous oxides in the profile, limiting the movement of these pollutants. The extensive clay layer probably causes percolating water and entrained metals to migrate laterally. This increases the contact area for sorption. Concomitantly, the area of the water table contacted by percolating water is increased, enhancing dilution.

- Ground-Water Pollution Potential

Without analyses of ground-water samples from directly beneath the dry well, the extent of ground-water pollution, if any, is uncertain. The presence of high TOX values in a ground-water sample from the nearby Tucson Water well warrants additional sampling for TOX and volatile organics.

6.2 Results of Studies at Site C-1

The drilling contractor augered three boreholes (designated boreholes I, II, and III) within three ft of the dry well at site C-1. Soil samples from the first borehole were used for a grain-size analysis of the profile, while soil samples from boreholes I and II were used to determine the chemical analyses and water content distribution of the vadose-zone profile. Commercial laboratories analyzed ground-water samples from boreholes I and III and the nearby Tucson Water well for their chemical composition.

6.2.1 Stratigraphy of the Vadose Zone

Information on the geological properties of the vadose zone profile provides clues on the recharge potential from dry well drainage and on the transport of pollutants.

Table 20 summarizes the profile stratigraphy of borehole 1, based on the field geological log. Table 21 lists the particle-size distribution in borehole 1. In general, the high silt and clay contents in the upper 5 ft of the profile change to increasing amounts of sand to a depth of approximately 30 ft. Between 30 and 35 ft, the gravel fractions increase in significance. Below a depth of 37.5 ft, gravelly sediments, containing varying amounts of sand, silt and clay, predominate. The only noticeable break in the sequence of gravelly sediments is a narrow zone at a depth of 65 ft, where the gravel content suddenly decreases and sand and silt increase. Sorting is good to moderate in the upper 30 ft, and becomes poor to very poor from 30 ft to the bottom depth of 115 ft.

6.2.2 Recharge Potential

6.2.2.1 Stratigraphic Relationships Relating to Flow

Based on the particle size analysis and the field geologic log for borehole I, vadose-zone sediments below a depth of approximately 10 to 15 ft are probably fairly permeable. Two narrow intervals, one centered at 20 ft and another centered approximately at 65 ft, show noticeable increases in fines with corresponding decreases in sand and/or gravel content. A decrease in permeability may be expected in these zones. Figure 7 shows a clear correlation between moisture content and percent fines with depth, indicating that as the percent of silt and clay increase so does the amount of water in storage.

Field data on drilling times suggest that the region near 60 ft is compacted, correlating with a depth at which a facies change was observed. Acid reaction on the oven dried sample from a depth

TABLE 20

Description of Profile Stratigraphy, Borehole I

Site C-1

DEPTH INTERVAL [FT]	DESCRIPTION
0 - 5	Well sorted sandy, clayey silt.
5 - 10	Well sorted silty, clayey sand.
10 - 30	Moderately well sorted sand, with varying amounts of gravel and fines. Minor subrounded gravel.
30 - 55	Poorly sorted gravelly sand grading into sandy gravel. Decreasing fines with depth. Subrounded gravel.
55 - 65	Very poorly sorted gravelly, silty sand. Salmon-colored silt/clay matrix beginning at 60 ft. Subrounded gravel.
65 - 115	Sandy gravel, with varying amounts of fines. Salmon-colored silt/clay matrix. Subangular gravel.

TABLE 21
(SECTION I)

Summary of Grain Size Analysis Results, Borehole I, Site C-1

DEPTH % [FT]	GRAVEL % (>4mm)	GRAVEL % (2-4mm)	SAND % (50u-2mm)	SILT % (2-50u)	CLAY % (<2u)	TOTAL
5	0.0	0.0	21.1	54.9	19.5	95.5
10	7.0	0.0	42.2	29.0	18.6	96.8
15	0.1	0.3	87.6	9.8	4.5	102.3
20	8.0	11.5	51.0	22.9	6.6	100.1
25	2.1	6.0	78.5	8.0	4.2	98.8
27	0.9	3.6	89.2	3.8	1.5	99.0
30	6.5	8.4	80.5	2.3	1.1	98.8
32.5	33.7	13.9	42.2	6.9	1.8	98.5
35	24.6	17.7	9.0	4.8	1.6	97.7
37.5	45.5	16.2	32.8	4.0	0.9	99.4
45	66.3	10.7	19.9	1.8	0.9	99.6
50	64.0	13.0	20.4	1.7	0.9	100.0
55	54.7	12.5	1.8	6.2	3.6	98.7
65	6.8	15.0	53.1	18.5	4.3	97.7
70	36.8	18.0	37.9	3.3	3.6	99.6
75	36.2	21.8	32.6	4.7	3.9	99.1
85	31.8	16.8	41.3	5.9	3.6	99.4

TABLE 21
(SECTION II)

Summary of Grain Size Analysis Results, Borehole I, Site C-1

DEPTH % [FT]	GRAVEL % (>4mm)	GRAVEL % (2-4mm)	SAND % (50u-2mm)	SILT % (2-50u)	CLAY % (<2u)	TOTAL
90	52.3	22.0	18.3	3.2	3.6	99.4
95	40.6	21.4	24.7	7.3	5.1	99.1
100	42.8	22.9	23.5	6.6	2.8	98.6
105	37.1	16.8	29.5	9.6	6.0	99.0
115	47.5	16.7	18.1	10.2	6.1	98.6

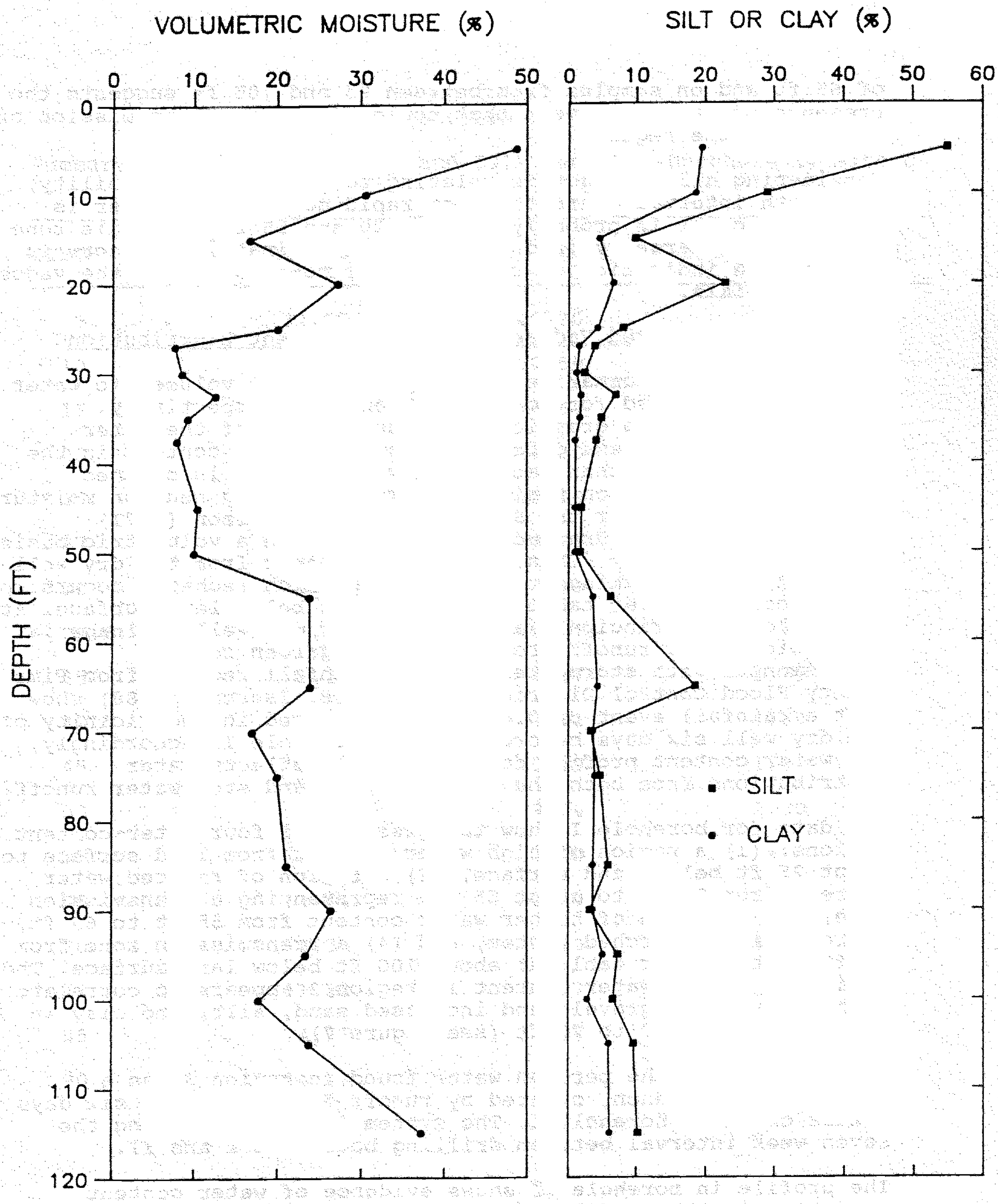

FIGURE 7. PERCENT VOLUMETRIC MOISTURE CONTENT AND THE DISTRIBUTION OF SILT AND CLAY IN THE VADOSE ZONE, SITE C-1

of 65 ft and on samples from between 95 and 105 ft suggests the presence of calcite cement that could impede the transmission of water in these regions.

Considering all the factors relating to sediment permeability, the depth interval where the most rapid movement of water is likely to occur is probably between 20 and 55 ft. In this zone not only do coarse-grained sediments predominate, but there is also little indication of compaction or cementation of the vadose zone materials.

6.2.2.2 Observed Vadose-Zone Water Content Distribution

Tables 22 and 23 summarize the gravimetric and volumetric water contents determined for boreholes I and II, respectively. Figures 8 and 9 are graphical representations of the water content results. These data show that the water content in the profile is greater than background values found in drained profiles in the Tucson Basin. For example, using neutron moisture logs in profiles near the Santa Cruz River, Wilson (1971) determined that the drained water content, on a volumetric basis, is about 10 percent. Thus, drainage of water from the dry well has created a transmission zone through which recharge occurs to the underlying water table at about 93 ft below land surface. At this site, the principal water source for dry-well drainage is irrigation water runoff from the nearby garden center, supplemented with stormwater runoff. Rainfall records from Pima County Flood Control District (Courtesy B. Iserman, 1988) show that a rainfall event of 0.41 inches occurred in the vicinity of the dry well six days before drilling borehole I. Accordingly, the water content profile for borehole I reflects water contributions from both the garden center and stormwater runoff.

The data for borehole I show the presence of four water-content regions: (1) a region of high water content from land surface to about 25 ft below land surface, (2) a region of reduced water content from 25 ft to about 55 ft, representing a transmission zone, (3) a region of higher water content from 55 ft to 65 ft, representing a perched system, and (4) a transmission zone from 65 ft to the water table at about 100 ft below land surface. The region of higher water content in region 3 appears to correlate with the reduced gravels and increased sand, silt, and clay in the region from 50 to 70 ft (see Figure 7).

It appears that the perched water found in region 3 was a temporary phenomenon, created by runoff from the storm six days before drilling borehole I. The system dissipated during the seven week interval between drilling boreholes I and II.

The profile in borehole II shows evidence of water content accretion in the profile at 25 ft and the dissipation of the perched system from 55 ft to 65 ft below land surface. By

TABLE 22
(SECTION I)

Summary of Moisture Content and Bulk Density, Borehole I, Site C-1.

DEPTH [FT]	% GRAV MOIST	% VOL MOIST	BULK DENS [G/CC]
5	32.25	48.70	*
10	20.20	30.50	*
15	11.04	16.67	1.51
20	16.90	27.20	1.61
25	12.18	20.00	1.64
27	4.81	7.60	1.58
30	5.36	8.46	1.58
32.5	7.09	12.57	1.77
35	5.13	9.17	1.79
37.5	4.14	7.81	1.89
45	5.34	10.39	1.94
50	4.96	9.94	2.00
55	12.59	23.80	*
65	12.64	23.89	*
70	9.54	16.99	1.78
75	11.22	19.97	*
85	11.77	21.07	*
90	14.73	26.37	1.79

TABLE 22
(SECTION II)

Summary of Moisture Content and Bulk Density, Borehole I, Site C-1.

DEPTH [FT]	% GRAV MOIST	% VOL MOIST	BULK DENS [G/CC]
95	14.30	23.31	*
100	10.89	17.75	*
105	14.56	23.73	*
115	25.06	37.21	1.48

* No bulk density for split spoon samples. Used an average.

TABLE 23

Summary of Moisture Content and Bulk Density, Borehole II, Site C-1.

DEPTH [FT] %	GRAV MOIST %	VOL MOIST	BULK DENS [G/CC]
15	12.25	19.48	1.59
20	6.18	10.33	1.67
25	33.73	46.51	1.38
27.5	7.69	12.25	1.59
30	5.78	9.52	1.65
32.5	9.30	14.93	1.61
35	5.65	8.64	1.53
37.5	6.28	9.98	1.59
40	4.83	8.50	1.76
45	4.08	7.10	1.74
50	7.66	14.05	1.83
60	8.38	15.12	1.80
76	8.40	16.18	1.93

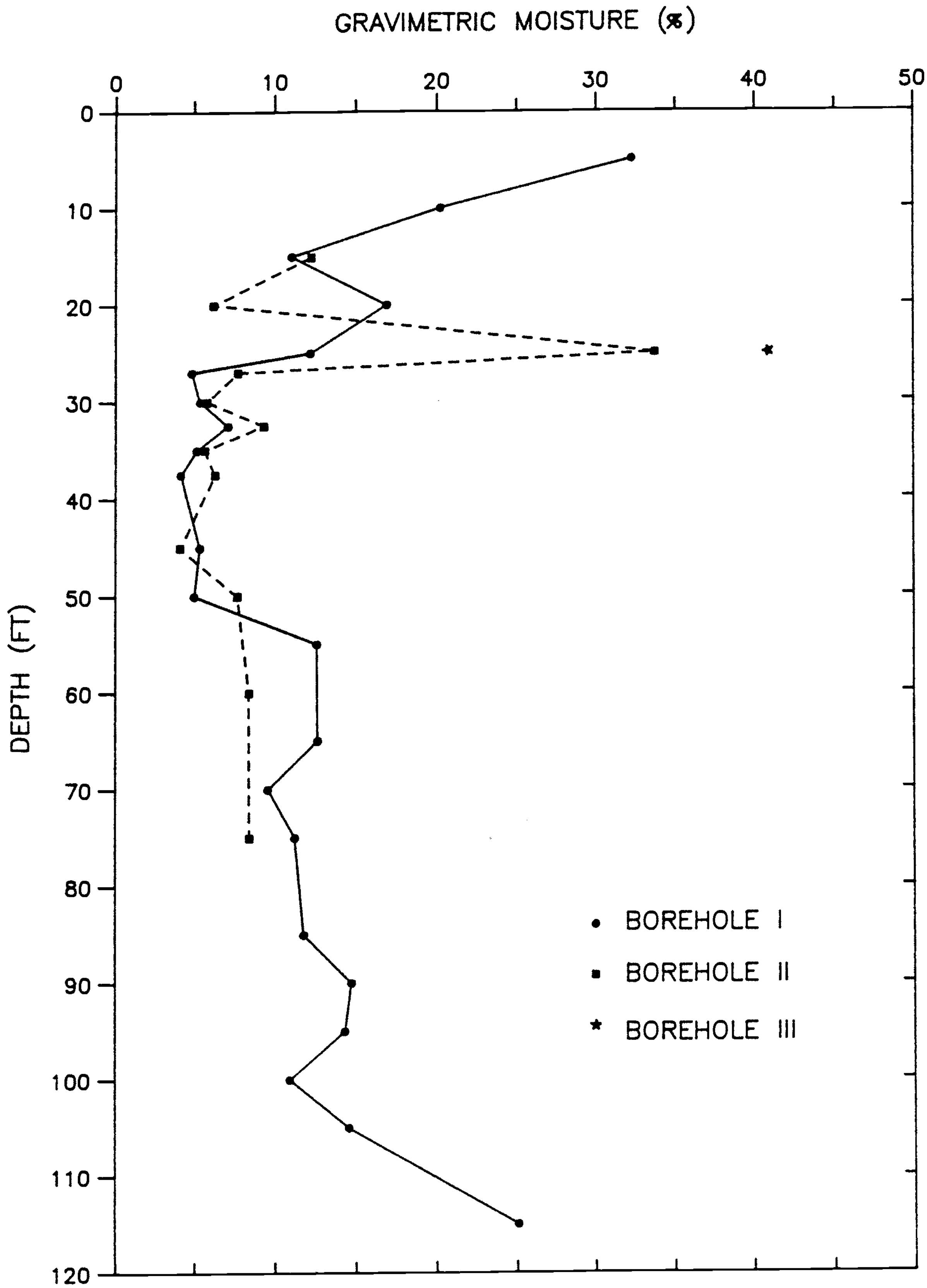

FIGURE 8. GRAVIMETRIC MOISTURE CONTENT OF THE VADOSE ZONE, BOREHOLES I AND II, SITE C-1

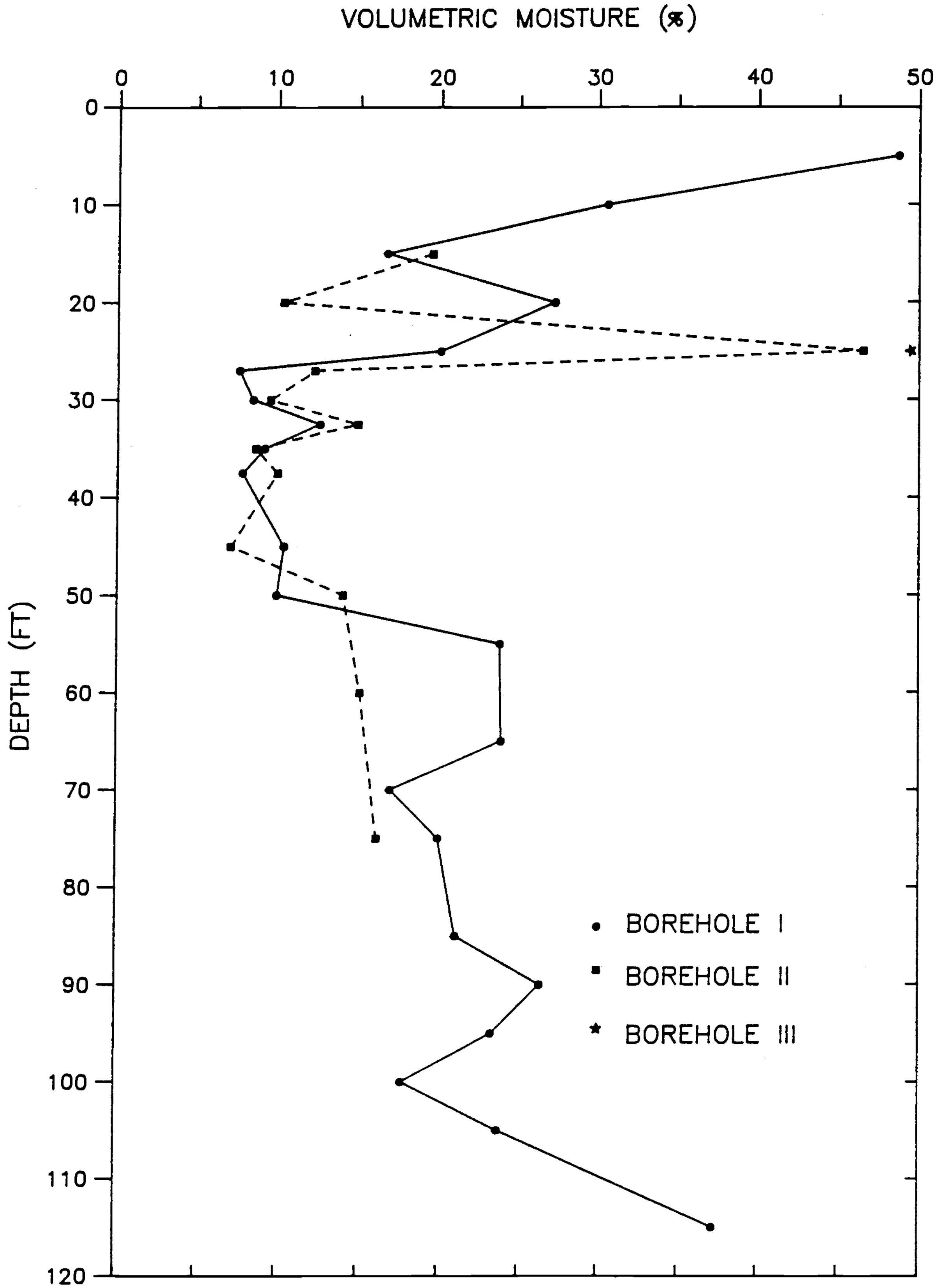

FIGURE 9. VOLUMETRIC MOISTURE CONTENT OF THE VADOSE ZONE, BOREHOLES I, AND II, SITE C-1

accretion in the profile at 25 ft and the dissipation of the perched system from 55 ft to 65 ft below land surface. By numerically integrating these curves, the volumetric water contents in the 15 to 75 ft interval for Boreholes I and II were 9.9 ft and 9.1 ft, respectively. Differences in water contents of the two profiles is attributable to drainage that occurred over the 7 week interval between drilling the two boreholes and to the spatial variability inherent in the vadose zone. The total moisture content in borehole I, from the surface to the final depth of 115 ft, was estimated to be 24.6 ft.

6.2.3 Pollutant Distribution

6.2.3.1 Organics

Table 24 lists the organic pollutants detected at site C-1 in surface runoff, dry-well sediment, vadose-zone soil samples, and ground water. These samples were not necessarily collected and analyzed in the same time frame. For example, the surface runoff samples were collected on 7/26/87 and the dry-well sediment samples were collected on 2/10/88 and 5/23/88.

6.2.3.1.1 Surface Runoff Samples

Analyses of the runoff and the sediment samples reflect the potential pollutants draining into the vadose zone during dry well drainage. The pollutants detected in the samples can be classified into the following groups: aromatic hydrocarbons, chlorinated herbicides, organophosphorous pesticides, phenols, and phthalate esters. The runoff samples included the volatile organic compounds methylene chloride, and the following semi-volatiles:

- 2-chlorophenol
- 2,4-dichlorophenol
- 4,6-dinitro-o-cresol
- and 4-nitrophenol

6.2.3.1.2 Dry-Well Sediment Samples

The dry-well sediment samples contained two volatile organics:

- toluene
- ethylbenzene

Toluene is a soluble [535 mg/l (Calabrese, Kostecki, and Leonard, 1988)], monocyclic aromatic hydrocarbon. The primary uses for toluene are as an additive to gasoline, as a solvent, and as a precursor for benzene.

Ethylbenzene is also a soluble, monocyclic aromatic compound which may be used, indirectly, as a gasoline additive. Ethylbenzene is a constituent in asphalt, and is used as a solvent and in the

TABLE 24
(Section I)

Organic Pollutants Detected in Runoff, Dry Well Sediment, Vadose Zone Samples, and Ground Water at Site C-1.

Compound	Runoff (1)	Dry Well Sediment Sample #1 (1)	Dry Well Sediment Sample #2 (2)
	7/27/87	7/22/86	9/23/86
PURGEABLE ORGANICS			
ethylbenzene	ND	ND	ND
methylene chloride	2.4	ND	ND
styrene	ND	ND	ND
toluene	ND	2.1	1.0
BASE NEUTRALS AND ACIDS			
pentachlorophenol	ND	0.6	ND
naphthalene	ND	0.2	ND
phenanthrene	ND	0.34	ND
di-n-butylphthalate	ND	37	1.5
fluoranthene	ND	0.58	ND
pyrene	ND	0.6	ND
benzylbutylphthalate	ND	ND	17
bis(2-ethylhexyl)phthalate	ND	31	4.9
di-n-octylphthalate	ND	38	6.2
2-chlorophenol	1.1	ND	ND
2, 4-dichlorophenol	2.3	ND	ND
4, 6-dinitro-o-cresol	21	ND	ND
4-nitrophenol	1.8	ND	ND
4-methylphenol	ND	ND	ND
PESTICIDES AND INSECTICIDES			
chlorophyrifos	ND	0.38	ND
2, 4-DB	ND	ND	ND
OIL AND GREASE	ND	5800	3200

(1) Reported by Olson (1987)
(2) Laboratory #1
(3) Laboratory #2
(4) See Table 23

Units: Runoff ug/l
Sediment, mg/kg
ND: Not Detected

TABLE 24
(Section II)

Organic Pollutants Detected in Runoff, Dry Well Sediment, Vadose Zone Samples, and Ground Water at Site C-1.

Compound	Dry Well Sediment Sample #2 (3) 9/23/86	Vadose Zone 2/10/88
PURGEABLE ORGANICS		
ethylbenzene	0.07	ND
methylene chloride	ND	ND
styrene	ND	ND
toluene	ND	ND
BASE NEUTRALS AND ACIDS		
pentachlorophenol	ND	ND
naphthalene	ND	ND
phenanthrene	ND	ND
di-n-butylphthalate	ND	ND
fluoranthene	ND	ND
pyrene	ND	ND
benzylbutylphthalate	ND	ND
bis(2-ethylhexyl)phthalate	ND	ND
di-n-octylphthalate	ND	ND
2-chlorophenol	ND	ND
2, 4-dichlorophenol	ND	ND
4, 6-dinitro-o-cresol	ND	ND
4-nitrophenol	ND	ND
4-methylphenol	2.0	ND
PESTICIDES AND INSECTICIDES		
chlorophyrifos	ND	ND
2, 4-DB	0.61	ND
OIL AND GREASE	4300	(4)

(1) Reported by Olson (1987)
(2) Laboratory #1
(3) Laboratory #2
(4) See Table 23
Units: mg/kg

TABLE 24
(Section III)

Organic Pollutants Detected in Runoff, Dry Well Sediment, Vadose Zone Samples, and Ground Water at Site C-1.

Compound	Water Table Sample #1 (2) 4/8/88	Water Table Sample #2 (3) 4/8/88
PURGEABLE ORGANICS		
ethylbenzene	ND	2
methylene chloride	ND	
styrene	ND	2
toluene	15	28
BASE NEUTRALS AND ACIDS		
pentachlorophenol	ND	ND
naphthalene	ND	ND
phenanthrene	ND	ND
di-n-butylphthalate	ND	ND
fluoranthene	ND	ND
pyrene	ND	ND
benzylbutylphthalate	ND	ND
bis(2-ethylhexyl)phthalate	ND	ND
di-n-octylphthalate	ND	ND
2-chlorophenol	ND	ND
2, 4-dichlorophenol	ND	ND
4, 6-dinitro-o-cresol	ND	ND
4-nitrophenol	ND	ND
4-methylphenol	ND	ND
PESTICIDES AND INSECTICIDES		
chlorophyrifos	ND	ND
2, 4-DB	ND	ND
OIL AND GREASE	0.09	ND

(1) Reported by Olson (1987)
(2) Laboratory #1
(3) Laboratory #2
(4) See Table 23

Units: mg/kg

production of styrene, which is then used in the manufacturing of plastics and synthetic rubbers (Callahan, 1979).
At first glance, the most likely source of toluene in the dry well is from the emissions of cars in the parking lot surrounding the dry well. However, approximately 99% of the toluene in auto emissions remains in the gaseous phase (Hyde, 1988), and therefore is not available for transport by surface runoff. Ethylbenzene behaves similarly, preferring the gaseous state after combustion. Consequently, automobile emissions are not likely to be a significant contributor of aromatic hydrocarbons to the dry-well environment. Leaking automobile gas tanks, although isolated in occurrence, could provide an alternative source of toluene. In addition, excessively rich fuel/air mixtures could allow for uncombusted gasoline to be emitted in tailpipe exhaust. Once again, this is isolated in occurrence. Leaching of the asphalt pavement is most likely the predominant source of ethylbenzene in the dry-well sediment.
The following semivolatiles were detected in the sediment:

- o pentachlorophenol
- o naphthalene
- o phenanthrene
- o di-n-butylphthalate
- o pyrene
- o 4-methylphenol

The sediment samples contained two pesticides chlorpyrifos and 2,4-DB.

6.2.3.1.3 <u>Fate of Volatile Organics in the Vadose Zone</u>

Toluene and ethylbenzene were undetected in vadose-zone samples. Processes that are effective in limiting the movement of toluene and ethylbenzene in the vadose-zone include volatilization, oxidation, biodegradation, and sorption. Volatilization is the principle mechanism governing the actual levels of toluene and ethylbenzene incorporated into the soil/water environment. Once volatilized, these compounds degrade in the atmosphere through a series of photochemical reactions. Volatilization occurs during the surface transport of these contaminants and during residence in the dry well sediments and standing water, when it is present. Wilson et al. (1985) conducted column experiments to determine the effect that movement through soil has on the fate and transport of selected organic pollutants. They discovered that, compared to volatilization from water, sediments inhibited volatilization by an order of magnitude.

Toluene and ethylbenzene entering the vadose zone via the dry well will migrate towards the water table in solution. The air space in the sediments will allow these compounds to continue to volatilize while infiltrating. Once in the gaseous phase, they will migrate away from their source.

Both toluene and ethylbenzene readily oxidize in the liquid phase when molecular oxygen is present. However, this detoxifying reaction is inhibited by the presence of water.

The high oil and grease levels, and concomitant total organic carbon (TOC) concentrations, in the dry well sediment and vadose zone region near the dry well (see Table 25) suggest that sorption onto organics may be a factor in attenuating toluene and ethylbenezene.

Some species of soil bacteria may use both toluene and ethylbenzene as sole sources of organic carbon (Callahan, 1979). Barker and Patrick (1985) determined in field injection tests in an unconfined sand aquifer, that 90% of the injected mass of toluene was lost to biodegradation within 73 days. They found dissolved oxygen to exert a major control on the reaction rates and consequently on the contaminant persistence.

During column studies, Wilson et al. (1981) found that 2 to 13% of toluene applied to the surface of a sandy soil with low organic content eluted out the bottom of the column. The retardation factor, which is the velocity of the water through the soil divided by the apparent velocity of a given compound, was less than 2. Volatilization and biodegradation were the mechanisms responsible for the observed reduction in mass. These authors also found that toluene degraded at relatively higher concentrations, but not at lower concentrations, unless in the presence of trichlorobenzene.

To summarize, volatilization appears to subordinate all other fate processes in reducing the concentrations of toluene and ethylbenzene detected in the samples of runoff and dry well sediment. Biodegradation and adsorption probably play lesser, although still significant roles in the attenuation of these hydrocarbons, particularly in the dry well and shallow vadose zone where organic content is high.

6.2.3.1.4 Fate of Semivolatiles and Other Organics in the Vadose Zone

Table 25 shows the distribution of oils and grease and TOC in dry-well sediment and the vadose zone. The dry-well sediment contained oil and grease concentrations in excess of 2,700 mg/kg. Similarly, the vadose-zone sample at 15 ft contained an oil and grease concentration of 15 mg/kg, greater than the background concentrations of between 2 and 6 mg/kg, found at greater depths in the vadose zone. The maximum TOC level in the sediment was about 10%. Vadose-zone samples from 15 to 25 ft also contained higher TOC levels than elsewhere in the profile. The background

TABLE 25

Total Organic Carbon Levels and Oil and Grease in Sediment Samples and Vadose Zone Samples, Site C-1.

Sample Depth	TOC BOREHOLE 1	TOC BOREHOLE 2	OIL AND GREASE BOREHOLE 2
Sediment#1	0.65	5.44	3,100
Sediment#2	1.5	9.95	2,700
Sediment#3	2.3	7.72	4,300
15	<0.04	0.38	15
20	0.08	0.03	6
25	0.073	0.12	5
27	<.04	ND	-
27.5	ND	0.02	2
30	0.89	0.02	<1
32.5	<0.04	0.02	3
35	<0.04	0.02	2
37.5	<0.04	0.01	2
40	0.04	<0.01	<1
45	<0.04	0.01	4
50	<0.04	0.01	5
60	<0.04	<0.01	3
65	<0.04	ND	-
70	<0.04	ND	-
76	ND	<0.01	5
80	<0.04		
90	<0.04		
115	<0.04		

Units: TOC, %
Oil and Grease, mg/kg

TOC appears to be about 0.01 to 0.02 %.

None of the semivolatile organics detected in the runoff and dry-well sediment samples were found in ground water beneath the dry well and in the Tucson Water well. As indicated in the section discussing the fate of PAH's in the industrial well, possible loss mechanisms include biodegradation and adsorption. Given the high oil and grease levels, and associated high TOC concentrations (table 23), in the sediment and vadose zone near the dry well, it appears that sorption into oils and greases is the prime mechanism for removal, particularly for hydrophobic organics. The more soluble constituents may be easily biodegraded (Groenewegen and Stolp, 1981).

The fate of hydrophobic organics in sediment that is transported through the overflow pipe into the lower, gravel-packed portion of the dry well is uncertain. However, it is speculated that the oils and grease carried over with the sediment act as a sink for these organics, and that biodegradation occurs as it does in the sediment left behind in the settling chamber.

6.2.3.1.5 Ground water

Styrene, not detected in runoff and dry-well sediment samples, was detected in a ground-water sample. Styrene is used in the manufacture of synthetic rubber and ABS plastics (Verschueren, 1977). This commercial polymer is moderately soluble and volatile. Given that styrene was not detected in the surface sources, we cannot state that the dry well is the source of this pollutant.

Both toluene and ethylbenzene were detected in water table samples bailed from the boreholes. In fact, of all the organics detected in surface sources, only these two pollutants were not completely attenuated (by the processes discussed in section 6.2.3.1.3) during flow in the vadose zone. This shows that the vadose zone at site C-1 appears capable of transmitting toxic organic compounds from the dry well to the ground water, even though they are undetected in vadose-zone samples.

We cannot categorically conclude that the dry well is the source of ethylbenzene and toluene in the water table samples. Leakage from a gasoline tank at a convenience store within a quarter mile of the dry well is also possible. However, none of the volatile organics, including styrene, toluene and ethylbenzene, were found in samples from the Tucson Water well which lies between the dry well and the convenience store.

Semivolatiles were undetected in water table samples and ground-water samples. The absence of semivolatile organics in ground water corresponds to the results of studies during the National Urban Runoff Program (NURP) in Fresno. Thus, Nightingale (1987a) concluded that none of semivolatile organics were present in ground water underlying detention/recharge basins receiving urban runoff.

No pesticides, including those found in the runoff sample, were detected in ground-water samples.

6.2.3.2 Heavy Metals

The most likely source of metals at this site is emanations from automobiles, both as gaseous emissions and as minute chips of paint and chrome from the finished surfaces of cars.

Olson (1987) reported the results of metals analyses for a runoff sample into the dry well on 7/26/87. Table 26 itemizes the concentrations of metals detected in dry-well sediment and vadose-zone samples from borehole II, together with the corresponding results for these metals in ground water bailed from the water table in borehole III, and well water from the nearby Tucson Water well. Figures 10 through 15 show the profile distributions of arsenic, chromium, copper, lead, nickel, and zinc.

6.2.3.2.1 Surface Runoff

The only metal detected in runoff samples was chromium, present at a concentration of 0.027 mg/l (Olson, 1987), about one half the National Primary Drinking Water Standard of 0.05 mg/l.

6.2.3.2.2 Dry-Well Sediment and the Vadose Zone

Metals reported for the solids samples were analyzed as total metals and concentrations are higher than for extractable metals. The concentrations of some metals were higher in the sediment samples and in vadose-zone samples from 15 ft to 25 ft than elsewhere in the profile (e.g. copper, lead, and zinc). Chromium and nickel concentrations were also high, although not as high as in the 76 ft sample. According to Dowdy and Volk ((1983), the mobility of heavy metals in soils is affected by (1) the presence of ion exchange sites, (2) incorporation into or on the surface of crystalline and noncrystalline inorganic precipitates, and (3) incorporation into organic compounds. Generally, heavy metals are sparingly soluble, occurring mainly in the sorbed state or as a component of insoluble inorganic or organic compounds. Thus, "Because of their low solubility, movement of heavy metals has generally been considered to be minimal" (Dowdy and Volk, 1983). Apparently, the accumulation of metals in the dry-well sediment and vadose-zone soils at 15 ft may be related to the higher cation exchange capacities of these sediment samples (see Table 27) and the higher organic matter content present in oils and grease. Undoubtedly, the crystalline structure of the solids is

TABLE 26
(Section I)

Heavy Metals Analyses (as Total Metals) for Dry Well Sediment and Vadose Zone Soil Samples (Both Collected 3/29/88), Water Table Sample (Collected 4/6/88), and Ground Water (Collected 4/4/88) from a Nearby Tucson Water Well, Site C-1.

Parameter	Dry Well Sediment #1	Dry Well Sediment #2	Dry Well Sediment #3	Vadose Zone Depth (ft) 15	20	25
Silver	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
Arsenic	2.8	2.6	3.1	10	<1.0	3.6
Beryllium	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Cadium	0.21	0.3	0.22	<0.2	<0.2	<0.2
Chromium	17.8	15.0	20.5	6.8	1.0	2.7
Copper	43.3	48.1	33.7	25.4	6.7	8.5
Mercury	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25
Nickel	13.7	10.2	20.8	8.3	1.0	2.9
Lead	18.2	18.0	18.3	1.3	1.9	4.9
Antimony	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Selenium	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Thallium	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Zinc	134.0	133.0	140	57.2	28.5	30.5

TABLE 26
(Section II)

Parameter	Vadose Zone Depth (ft) 27.5	30	32.5	35	37.5	40
Silver	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
Arsenic	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Beryllium	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Cadium	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Chromium	0.7	0.7	0.5	1.1	<0.5	<0.5
Copper	11.9	7.1	3.4	4.8	6.2	11.0
Mercury	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25
Nickel	<1.0	<1.0	<1.0	<1.0	<1.0	1.9
Lead	2.3	2.1	1.9	2.5	1.4	2.2
Antimony	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Selenium	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Thallium	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Zinc	25.9	22.0	15.6	15.7	13.6	20.5

TABLE 26

Heavy Metals Analyses (as Total Metals) for Dry Well Sediment and Vadose Zone Soil Samples (Both Collected 3/29/88), Water Table Sample (Collected 4/6/88), and Ground Water (Collected 4/4/88) from a Nearby Tucson Water Well, Site C-1.

(Section III)

Parameter	Vadose Zone Depth (ft) 45	50	60	76	Water Table	Ground Water
Silver	<0.25	<0.25	<0.25	<0.25	<0.05	<0.05
Arsenic	<1.0	1.4	2.6	2.0	<0.002	<0.002
Beryllium	<0.5	<0.5	<0.5	<0.5	<0.01	<0.01
Cadium	<0.2	<0.2	<0.2	<0.2	<0.0004	0.0014
Chromium	7.1	<0.5	<0.5	72.5	<0.01	<0.01
Copper	17.4	18.0	18.0	15.2	<0.02	0.05
Mercury	<0.25	<0.25	<0.25	<0.25	0.0007	<0.0005
Nickel	3.6	<0.5	2.5	29.6	<0.02	0.03
Lead	1.8	3.3	3.4	4.9	<0.002	0.005
Antimony	<1.0	<1.0	<1.0	<1.0	<0.002	<0.002
Selenium	<1.0	<1.0	<1.0	<1.0	<0.002	<0.002
Thallium	<1.0	<1.0	<1.0	<1.0	<0.002	<0.002
Zinc	26	32.1	29.7	24.6	<0.01	0.17

Units: Sediment, mg/kg
Water, mg/l

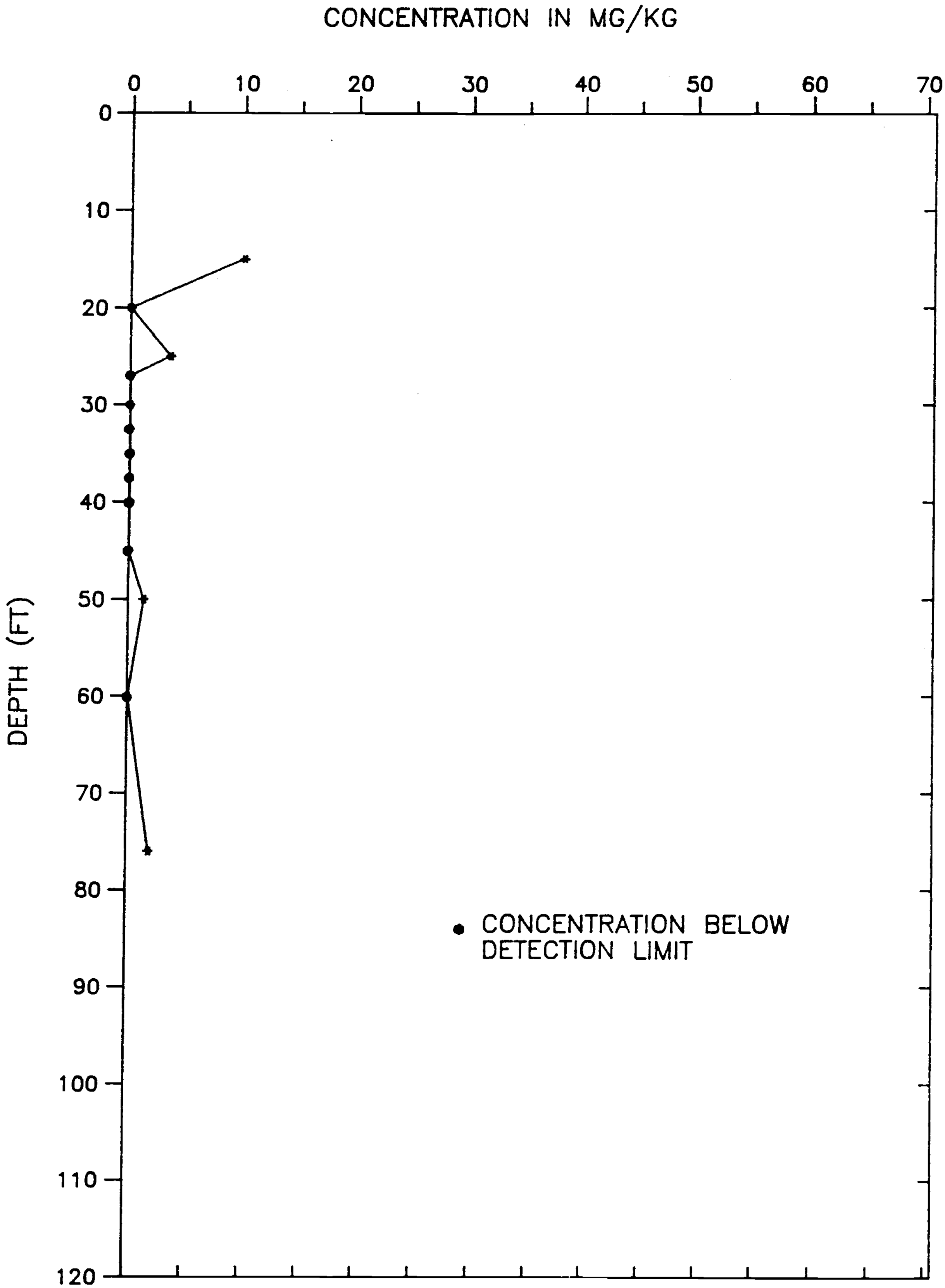

FIGURE 10. DISTRIBUTION OF ARSENIC IN THE VADOSE ZONE, SITE C-1

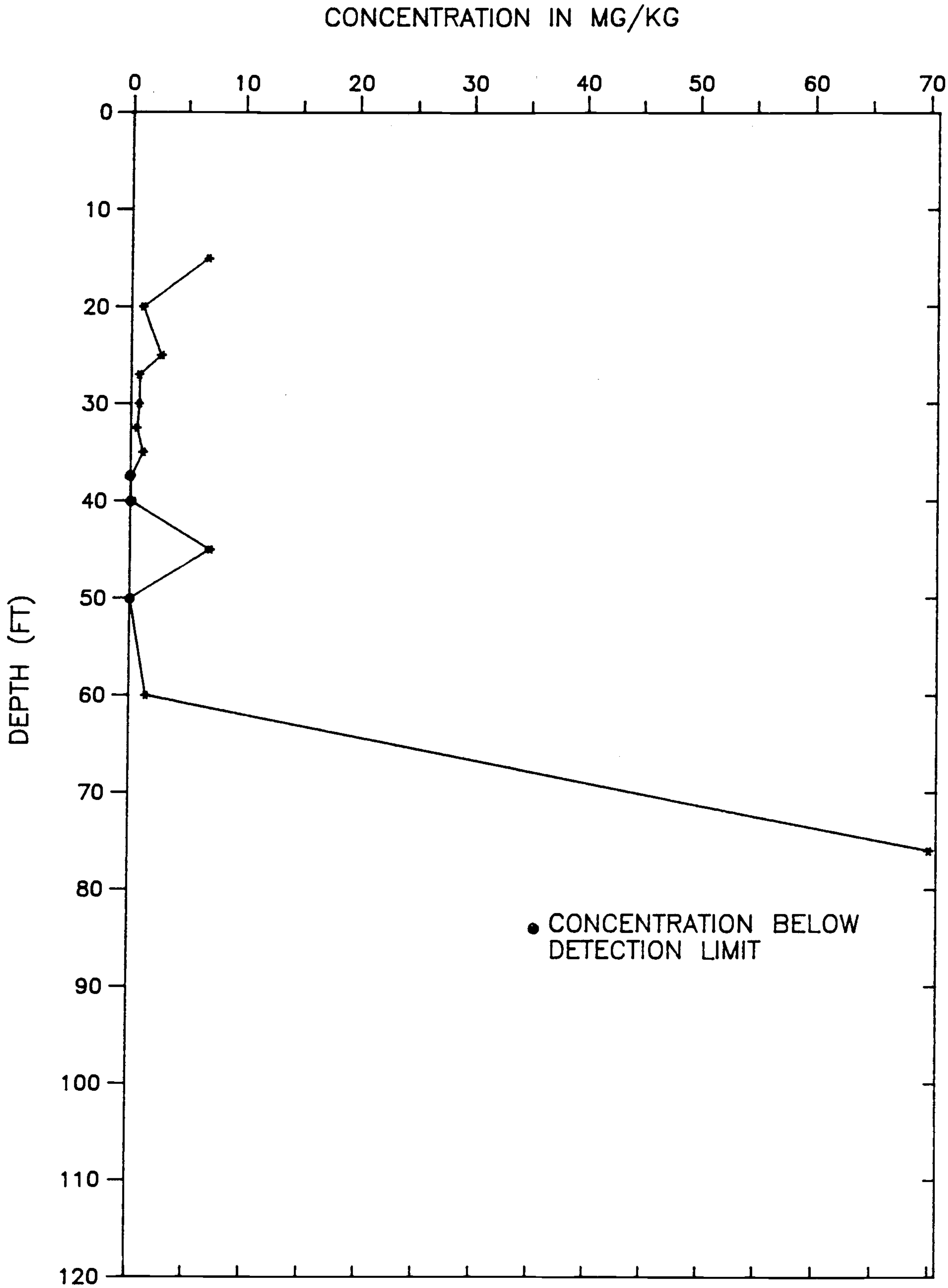

FIGURE 11. DISTRIBUTION OF CHROMIUM IN THE VADOSE ZONE, SITE C-1

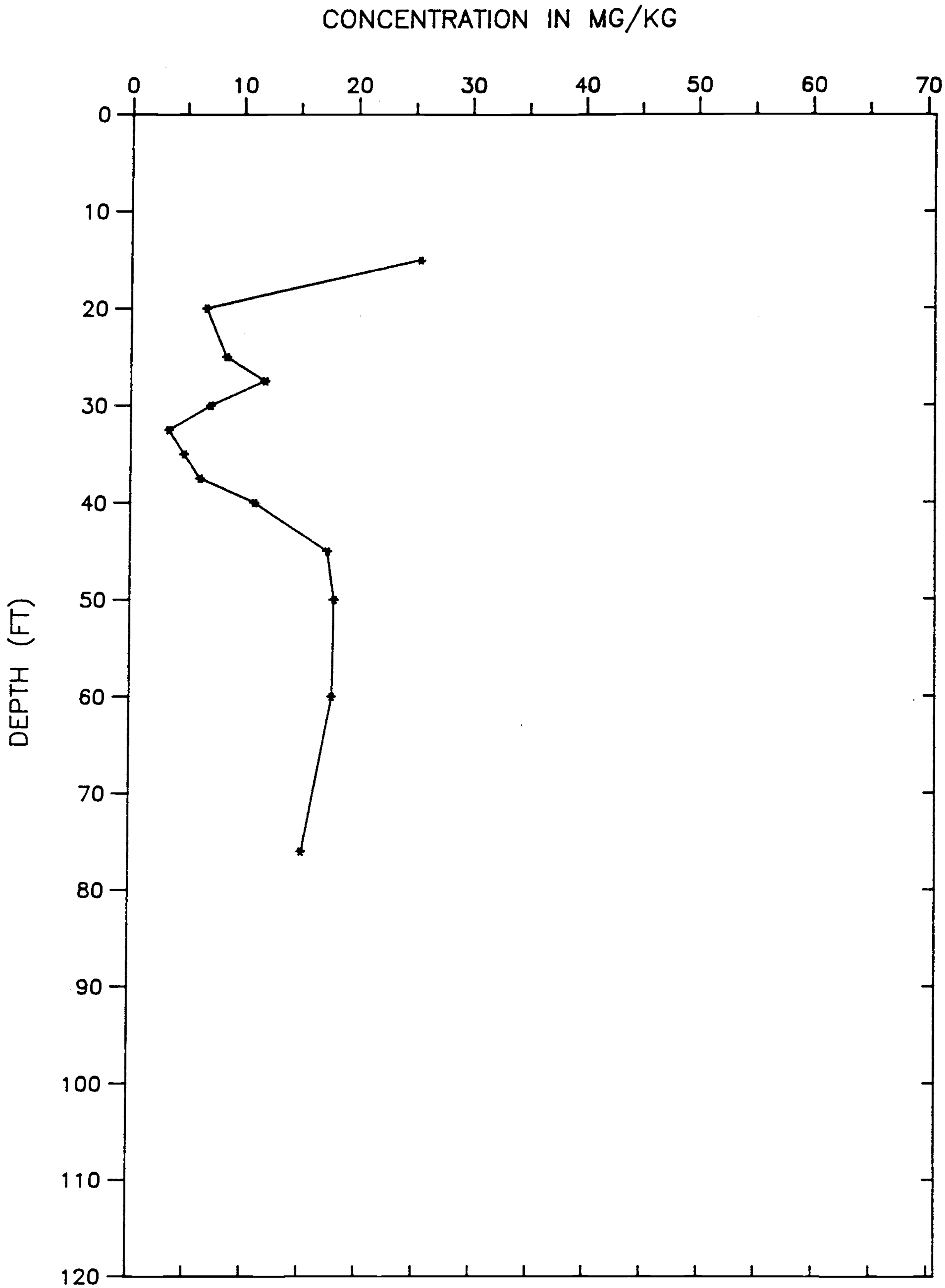

FIGURE 12. DISTRIBUTION OF COPPER IN THE VADOSE ZONE, SITE C-1

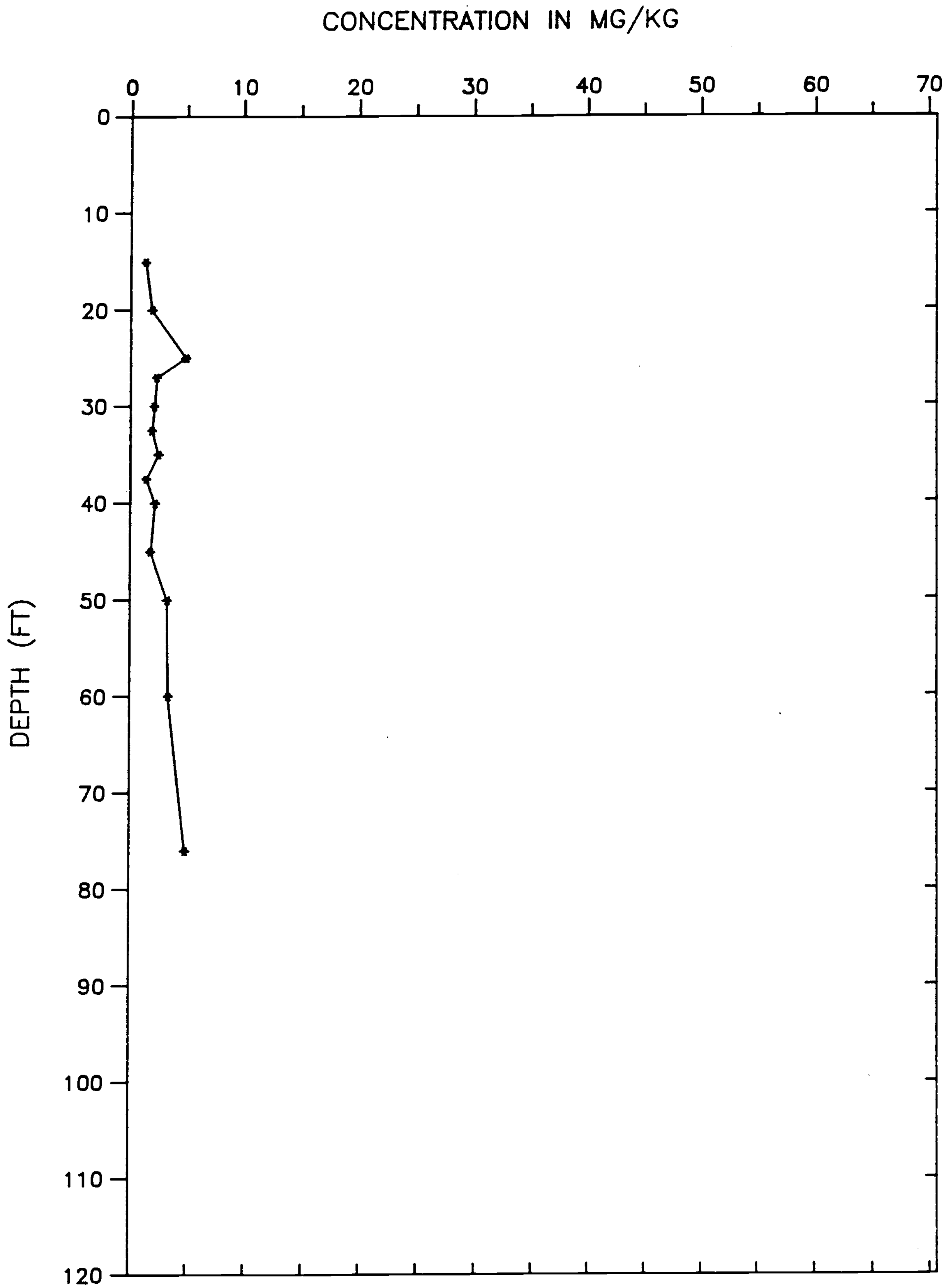

FIGURE 13. DISTRIBUTION OF LEAD IN THE VADOSE ZONE, SITE C-1

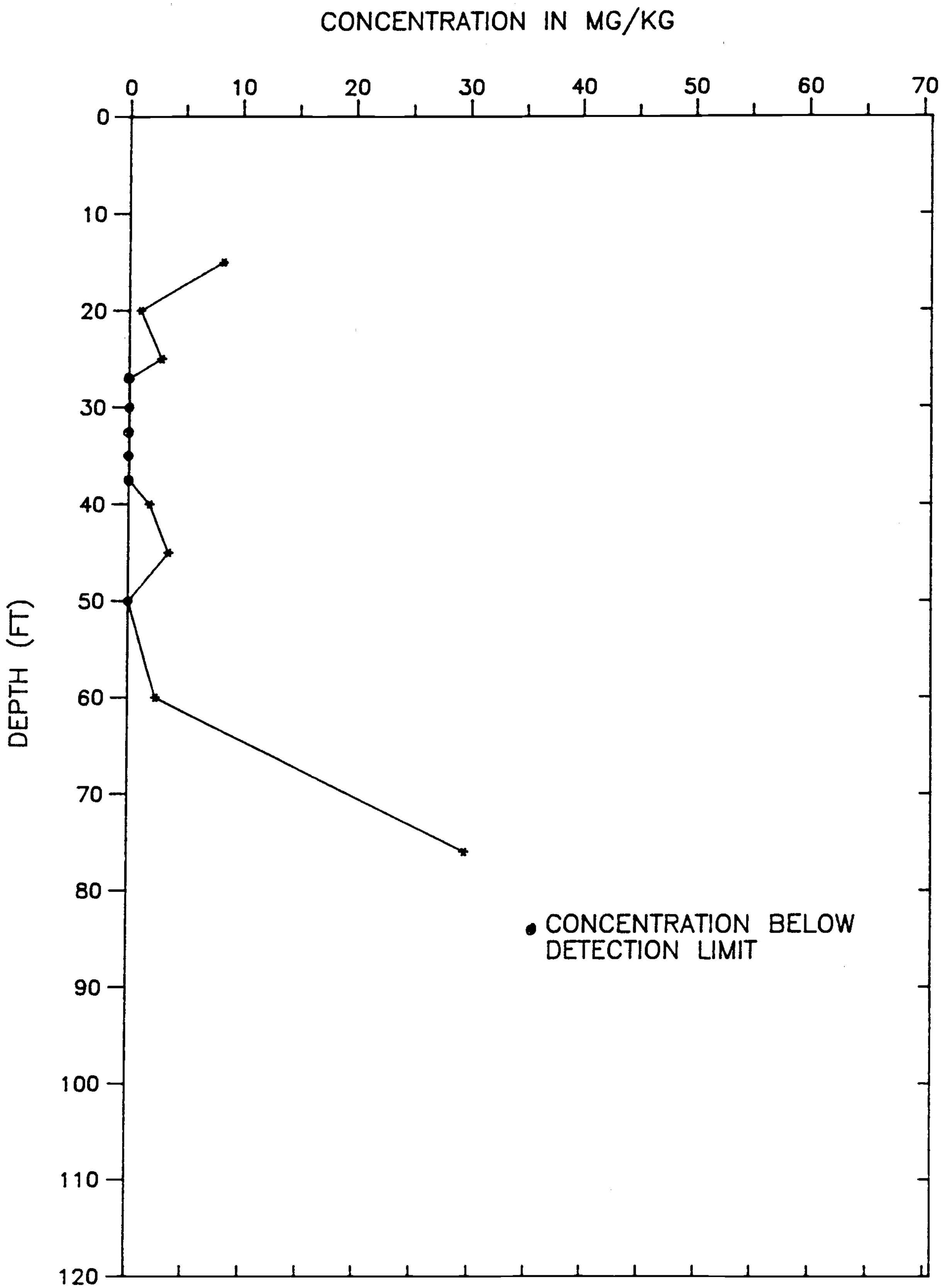

FIGURE 14. DISTRIBUTION OF NICKEL IN THE VADOSE ZONE, SITE C-1

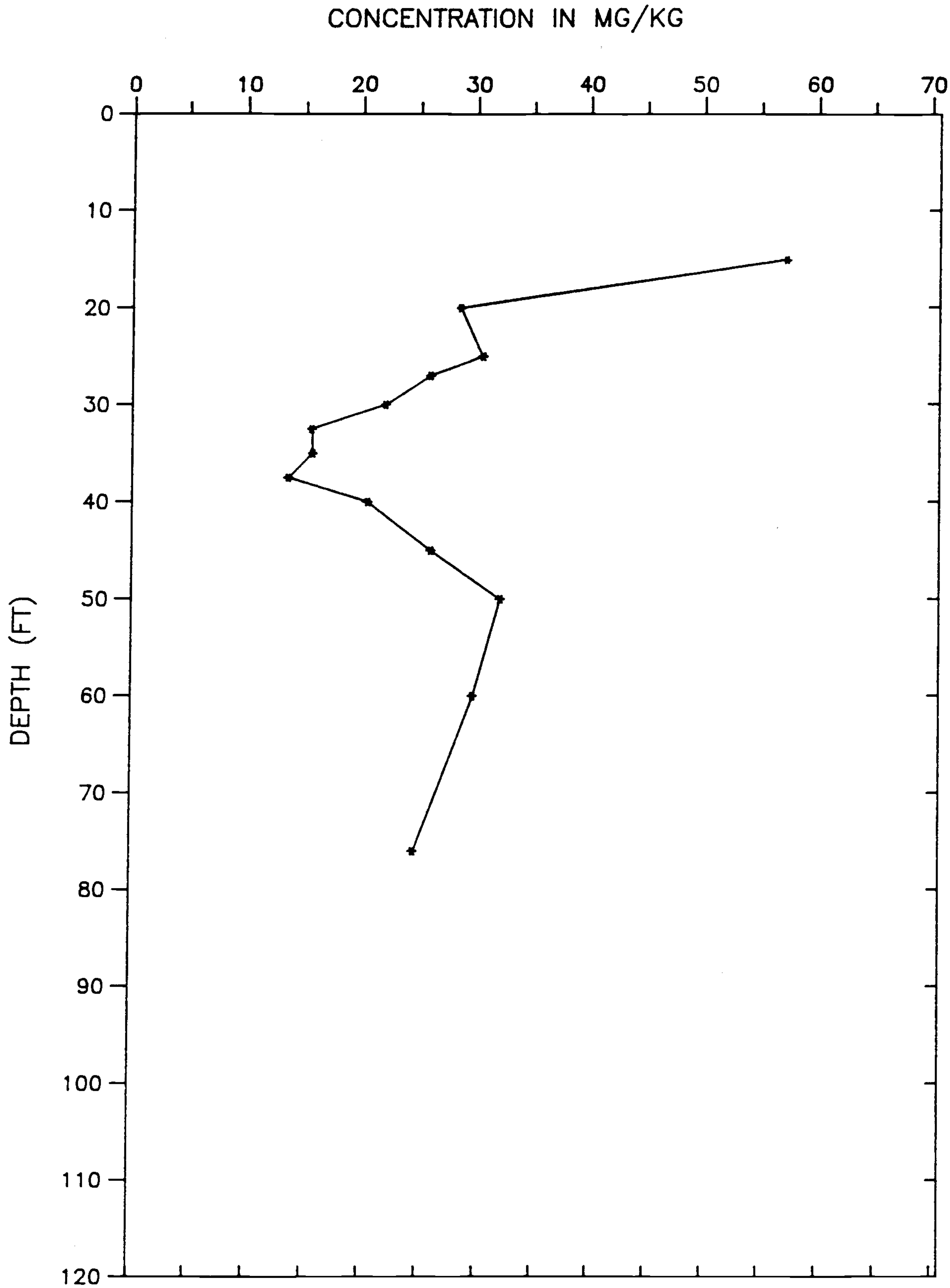

FIGURE 15. DISTRIBUTION OF ZINC IN THE VADOSE ZONE, SITE C-1

TABLE 27

Cation Exchange Capacity (CEC) for Soil Samples from Site C-1.

Sample Depth	CEC LAB#1	CEC LAB#2
Sediment#1	25.0	13.7
Sediment#2	18.0	26.8
Sediment#3	22.0	18.7
15	12.0	15.0
20	12.0	2.1
25	22.0	11.7
27	5.3	ND
27.5	ND	1.8
30	6.4	2.2
32.5	6.6	2.3
35	3.9	2.7
37.5	7.7	1.8
40	3.3	2.0
45	4.9	2.0
50	4.5	2.2
60	11.0	8.8
65	8.3	ND
70	6.1	ND
76	ND	6.6
80	14.0	
90	16.0	
115	16.0	

Note: The relationship between soil texture and cation exchange capacity is as follows (Donahue, Miller, and Shickluna, 1977):

Soil Texture	Cation Exchange Capacity (meq/100 soil)
Sands	1-5
Fine sandy loams	5-10
Loams and silt loams	5-15
Clay loams	15-30
Clays	over 30

Units: meq/100 gm

also a major contributor of metals. The concentrations of some metals were lower throughout the vadose zone below 15 ft but then increased toward the base of the borehole (e.g. arsenic, chromium, and nickel). It is possible that the drill bit is the source of these anomalous values. For example, the composition of the bit includes 9% chromium. These metals may concentrate in soils from 60 ft to 76 ft because of the higher cation exchange capacity of soils in this region (see Table 27).

Zinc was consistently present in high concentrations throughout the profile. This observation may be consistent with the observation of Dowdy and Volk (1983) that zinc is the element which consistently has the potential to move in soils. Exact mechanisms for zinc movement are unknown, but it appears that this metal moves in the anionic form and in organic chelates.

6.2.3.2.3 Ground Water

The concentrations of metals in ground water bailed from the water table at borehole III and pumped from the nearby pumping Tucson Water well are all within the limits prescribed for National Primary and Secondary Drinking Water Standards.

To summarize, metals originating in the dry-well sediment have essentially been retained by the sediment and shallow vadose zone and have not polluted ground water. This corresponds to the results of Nightingale's (1987) studies on metals movement beneath retention/recharge basins in Fresno, california, i.e., "Apparently, even though trace metals are present in the urban runoff, there is insignificant leaching of these elements to degrade the ground-water beneath the basins."

6.2.4 Conclusions

o Recharge Potential

The water-content profiles show that drainage from this commercial dry well has created a transmission zone, facilitating ground-water recharge. Given the coarse-grained nature of the vadose-zone sediments the predominant flow direction is probably vertical. However, one of the profiles showed the presence of a perching layer, suggesting that some lateral flow also occurs. Inasmuch as the profile receives daily runoff from the garden center, the water content of the profile probably remains near field capacity. Thus, stormwater drains to the water table with a minimum of storage in the vadose zone.

o Fate of Pollutants in the Settling Chamber

The majority of the organic pollutants detected in runoff and dry-well sediment samples are attenuated, apparently by volatilization, biodegradation, and sorption on oils and greases.

Thus, the oils and greases accumulating in the dry-well sediment and upper vadose zone appear to operate as a sink, primarily for the semivolatile organics and metals.

- Fate of Pollutants in the Vadose Zone

None of the organics detected in runoff and in the settling chamber were detected in the vadose zone. Volatilization is probably the principal loss mechanism for the volatile organics. As indicated, the oils and grease transported into the lower dry well chamber and upper vadose zone serve as a sink for the hydrophobic organics. Biodegradation reduces the concentrations of the more soluble semivolatiles.

- Ground-Water Pollution Potential

Evidence of toluene and ethylbenzene in ground-water samples suggests that the vadose zone is not completely effective in attenuating volatiles. Thus, this dry well is a potential source of ground-water pollution by volatile organics. Contributions from the other possible source in the area, a gasoline tank at a nearby convenience store, should be determined.

Heavy metals are attenuated by the dry-well sediment and vadose zone and have not polluted the underlying ground-water system.

There is no evidence that pesticides and fertilizers from the garden center have penetrated the vadose zone.

6.3 Results of Studies at Site R-1

A borehole was not completed at this site because the driller inadvertently ruptured a water main that was not delineated during "blue-staking". Water entered that dry well and vadose zone, nullifying the purpose of the drilling program which was to obtain vadose-zone and ground-water samples that were affected solely by natural runoff. This section reviews the results of analyses on runoff and dry-well sediment samples.

6.3.1 Pollutant Distribution

6.3.1.1 Organics

6.3.1.1.1 Runoff samples

Table 28 lists the priority organic pollutants detected in a runoff sample entering the dry well at site R-1. The sample was collected during the first summer storm of 1986, thus representing the "first flush" of pollutants into the dry well. No volatile organics were detected in the runoff sample. Seven semi-volatile compounds were detected:

- phenanthrene
- anthracene
- benzo(a)anthracene
- chrysene
- benzo(b)fluoranthene
- benzo(k)fluoranthene
- benzo(a)pyrene

6.3.1.1.2 Dry-Well Sediment

Table 28 lists the priority organic compounds found in samples of dry-well sediment, collected on three occasions in 1986 and on one date in 1988. Methylene chloride was the only volatile organic compound detected in these samples, being present in a 1986 sample and in the 1988 sample. This compound is used as a solvent, as a refrigerant, and for paint stripping and solvent degreasing (Verschueren, 1977).

Twenty-one semi-volatile organic compounds were detected in the sediment samples:

- naphthalene
- aceneaphthalene
- acenaphthene
- fluorene
- phenanthrene

TABLE 28

Organics in Runoff Sample and in Three Dry-Well Sediment Samples at Dry-Well Site R-1

Compound	Runoff 6/25/86	Dry-Well Sediment 7/22/86	9/26/86	3/22/88
VOLATILE ORGANIC COMPOUNDS				
methylene chloride (b)	ND	2.4	ND	0.5
BASE/NEUTRAL AND ACID COMPOUNDS				
naphthalene		2.4	3.4	ND
acenaphthalene	ND	0.4	3.7	ND
acenaphthene	ND	21	27	ND
fluorene	ND	18	32	14
phenanthrene	28	120	180	190
fluoranthene	ND	ND	ND	200
anthracene	21	26	28	29
di-n-butylphthalate	ND	ND	0.9	ND
fluoranthene	ND	190	360	ND
pyrene	ND	190	360	69
benzo(a)anthracene	4	94	170	210
bis-(2-ethylhexyl)phthalate	ND	1.7	3.5	ND
chrysene	9	102	200	240
di-n-octylphthalate	ND	ND	0.3	ND
benzo(b)fluoranthene	310	180	220	300
benzo(k)fluoranthene	240	ND	130	ND
benzo(a)pyrene	220	91	160	200
indeno(1,2,3-cd)pyrene	ND	70	80	130
dibenzo(a,h)anthracene	ND	26	11	ND
benzo(ghi)perylene	ND	45	57	120
dibenzofuron	ND	ND	ND	7
ORGANOPHOSPHOROUS PESTICIDES				
ethyl-parathion	ND	0.6	ND	ND
stirophos	ND	6.2	ND	ND
dioxathion	7.6	ND	ND	ND
ORGANOCHLORINE PESTICIDES				
4,4'-DDT	ND	ND	0.09	ND
OIL AND GREASE (mg/kg)	6.0	6,600	13,000	6,000

Units: ug/L, except where noted
ND: Not Detected

- o fluoranthene
- o anthracene
- o di-n-butylphthalate
- o fluoranthene
- o pyrene
- o benzo(a)anthracene
- o bis-(2-ethylyhexyl)phthalate
- o chrysene
- o di-n-octylphthalate
- o benzo(b)fluoranthene
- o benzo(k)fluoranthene
- o benzo(a)pyrene
- o indeno(1,2,3-cd)pyrene
- o dibenzo(a,h)anthracene
- o benzo(ghi)perylene
- o dibenzofuron

This list includes the same compounds found in dry-well sediment samples at site I-1 and C-1, plus an additional three semi-volatiles over site I-1 and an additional seven over site C-1. The concentrations of semi-volatiles were also much greater. In fact some of these compounds were more than an order of magnitude larger in the R-1 samples than in the I-1 and C-1 samples. The concentrations of the following compounds were all greater than 100 ppb:

- o phenanthrene
- o fluoranthene
- o pyrene
- o chrysene
- o benzo(b)fluoranthene
- o benzo(k)fluoranthene
- o benzo(a)pyrene
- o benzo(ghi)perylene

The probable reason for the greater concentrations at site R-1 is that the parking lot and other contributory regions of the drainage area have been in place longer than at the other sites. The overall drainage area of this well also appears to be greater than that for sites I-1 and C-1.

The semi-volatile compounds detected at site R-1 (and at sites I-1 and C-1) are found in automobile exhaust and in asphalt.

Based on the results of vadose-zone samples from the other two sites, we can speculate somewhat on the possible fate of these compounds in the vadose zone. First, the large concentrations of oil and greases in the sediment samples (see Table 28) may sequester the hydrophobic semi-volatiles, thus limiting their movement into the vadose zone. Second, the water table at the site is about 250 ft below land surface (Olson, 1987). Accordingly, the opportunity for attenuation (e.g. by sorptive processes) in the vadose zone is greater than at sites with shallower water tables.

The following organophosphorus pesticides were detected at site R-1:

- o ethyl-parathion
- o stirophos
- o dioxathion

The source of these compounds may be irrigation water runoff from the adjoining grassed areas. These compounds tend to be biodegraded in the vadose zone.

The following organochlorine pesticide was detected: 4,4"-DDT. This pesticide is likely to be more persistent in the vadose zone than the organophosphorous pesticides.

None of the priority organics and pesticides were detected at levels exceeding drinking water standards in a ground-water sample from a City of Tucson well, located 750 ft west of the dry well.

6.3.1.2 Metals

Table 27 lists the priority metals detected in runoff and dry-well sediment samples from site R-1. The metals analyses represent total and not extractable metals. The chromium and lead concentrations in runoff exceeded drinking water standards. The source of chromium is probably metals in the parking lot. Lead originates in gasoline. All of the metals for the dry well sediments listed in the table were above detectable limits. Concentrations of copper lead, and zinc were particularly high. The movement of the these metals into the vadose zone will probably be limited because of sorption onto clays and organics within the sediment, and precipitation. Apparently, of the metals, zinc is expected to have the greatest potential for movement in the profile (Dowdy and Volk, 1983). However, given the great depth to ground water and the presence of fine grained materials in the vadose zone (see table 11), the mobility of zinc is likely to be restricted.

None of the priority pollutant metals were detected at levels exceeding drinking water standards in a ground-water sample from a City of Tucson well, located 750 ft west of the dry well.

TABLE 29

Priority Pollutant Metals Detected in Runoff and Dry-Well Sediment Samples at Site R-1.

Compound	Runoff 6/25/86	Dry-Well Sediment 3/22/88
Arsenic	ND	2.2
Cadmium	0.010	0.61
Chromium	4.2	4.7
Copper	ND	31.4
Mercury	0.003	0.85
Nickel	1.5	4.1
Lead	0.01	47.0
Zinc	0.18	108

Units: Runoff, ppb
Sediment, mg/kg

6.4 Results of Studies at Site R-2

The drilling contractor augered a borehole near the selected dry well at site R-2 on February 22, 23, and 24, 1989. A dry-well sediment sample and vadose-zone samples were collected for laboratory analyses using methods described in Section 5. A thin seam of perched ground water was encountered at about 75 ft below land surface. The seam yielded a water sample. The contractor completed the hole to 130 ft below land surface having encountered the main water table at about 122 ft below land surface. A water table sample was collected for laboratory analyses. Section 5 describes the methods used to grout the borehole and renovate the site.

6.4.1 Stratigraphy of the Vadose Zone

Table 30 summarizes the profile stratigraphy based on the field geological log. Table 31 lists the particle-size distribution of vadose-zone samples taken in five ft increments down to 130 ft below land surface. Fine sediments predominate in the upper 16 ft of the profile, with the highest silt plus clay content occurring in the 10ft sample. Gravels and sands increase abruptly in the 16 ft sample, with gravels accounting for the bulk of the sample. At 20 ft, the fines again predominate. There is a generally decreasing trend in fines between 35 ft and 80 ft. Silts and clays increase slightly at 85 ft, but remain fairly constant throughout the remaining profile. Except for the region from 25 to 30 ft, sands are the dominant grain size in the lower region of the borehole.

Table 32 shows the depth-wise distribution of the soil portion (i.e., sand, silt, and clay) of the collected samples. Using the USDA textural triangle for the basic soil textural classes (see Gee and Bauder,1986,p.386), the dominant textural class is loamy sand. The region at 10 ft is classified as a loam. The following depths are classified as sandy loams: 15 ft, 20 ft, 71.5 ft, 85 ft, and 130 ft.

6.4.2 Recharge Potential

6.4.2.1 Stratigraphic Relationships Relating to Flow

The relative permeability of sequential depths of the profile are related to the percentage of fines, degree of sorting, and cementing. Figure 16 depicts the distribution of fines (silt plus clay) in the profile at R-2. CH2M Hill, Montgomery, and Wilson (1987) define small percent fines as being 30 percent or less of the total grain-size distribution. They interpreted small percent fines in a profile as being favorable for surface recharge. Using this criterion, the profile at R-2 appears to generally favor

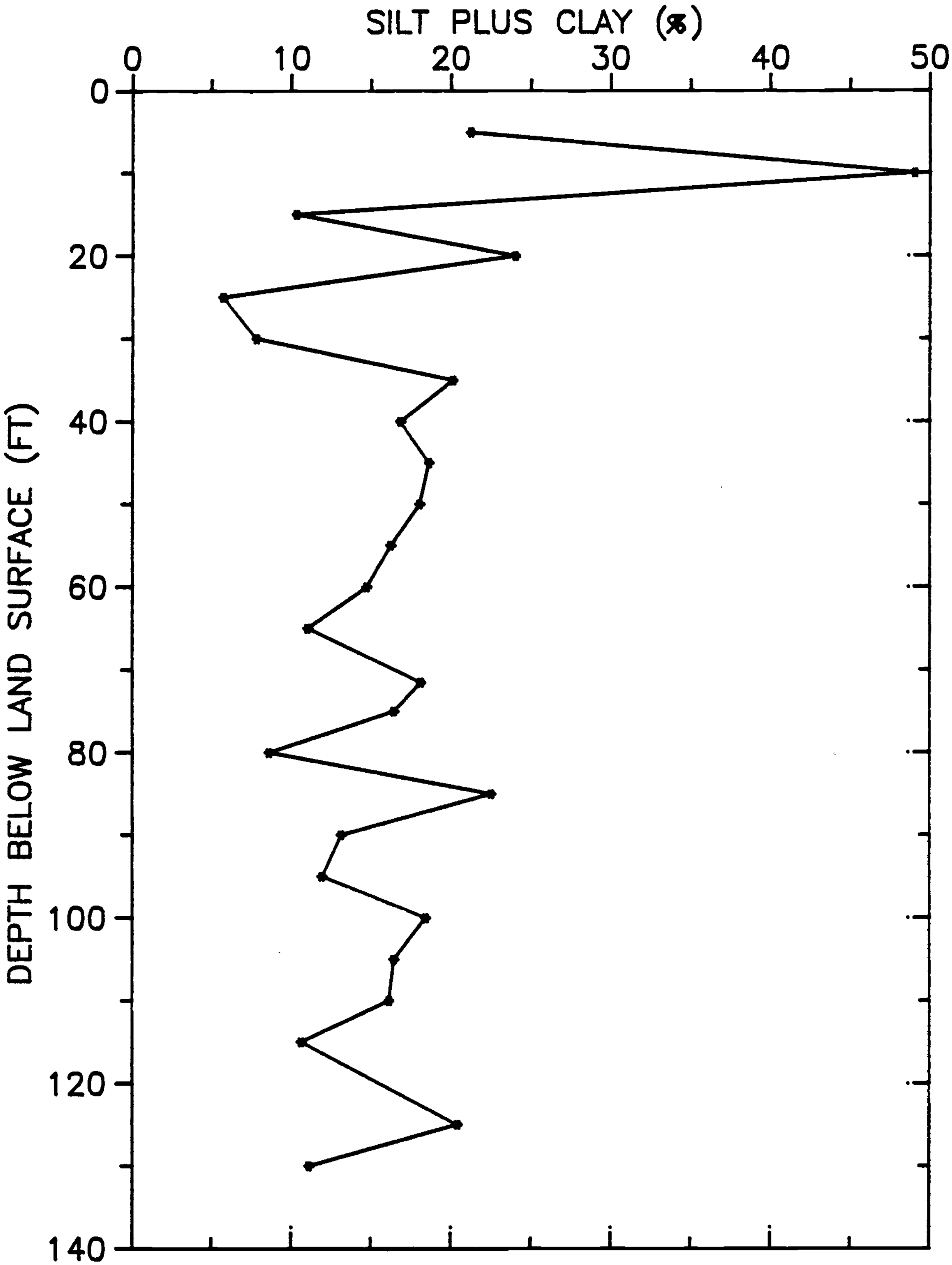

FIGURE 16. DISTRIBUTION OF THE SILT PLUS CLAY FRACTION IN THE VADOSE ZONE AT SITE R-2.

TABLE 30

Description of Profile Stratigraphy,
Residential Dry Well Site R-2

DEPTH INTERVAL [FT]	DESCRIPTION
0 - 16	Well sorted fine sand with increasing silt and clay content with depth.
16 - 17	Moderately well sorted clay loam with pebbles.
17 - 35	Very poorly sorted gravel to coarse sand, with varying amounts of fines. Some angular pieces of granite and some subrounded pebbles.
35 - 50	Poorly sorted silty gravel.
50 - 60	Poorly sorted silty sand with decreasing gravel.
60 - 71.5	Poorly sorted silty, gravelly sand, with increasing gravel.
71.5 - 105	Moderately well sorted to well sorted, medium to coarse sand, with subrounded to subangular pebbles.
105 - 130	Moderately well sorted to poorly sorted, medium to coarse sand, with a little to a lot of gravel and varying amounts of silt. Very weathered (breakable) pieces of gneiss.

TABLE 31
(Section I)

Summary of Grain Size Analysis, Residential Dry Well Site R-2

DEPTH	% GRAVEL (>4mm)	% GRAVEL (2-4mm)	% SAND (50u-2mm)	% SILT (2-50u)	% CLAY (<2u)	% SUM
5	1.5	4.0	73.8	18.5	2.7	100.4
10	1.4	1.8	44.5	33.3	15.7	96.7
16	48.4	15.3	26.3	6.2	4.1	100.2
20	17.7	13.2	41.4	15.6	8.4	96.3
25	47.3	16.2	30.1	3.4	2.3	99.3
30	38.3	20.0	32.2	5.0	2.8	98.3
35	9.0	7.9	59.4	18.3	1.8	96.5
40	15.7	12.5	52.7	15.2	1.6	97.7
45	13.0	8.7	58.6	15.8	2.8	98.9
50	6.8	10.1	63.66	14.5	3.5	98.5
55	1.2	5.6	73.7	13.4	2.8	96.7
60	13.7	10.7	58.0	13.6	1.1	97.1
65	16.1	16.1	54.9	10.2	0.8	98.1
71.5	24.9	15.8	41.4	13.2	4.9	100.1
75	8.6	16.9	57.3	13.7	2.7	99.1
80	9.7	11.6	66.6	8.5	1.1	97.5
85	9.6	12.9	53.0	15.5	7.0	97.9
90	2.2	10.8	71.3	11.7	1.4	97.3

TABLE 31.
(Section II)

Summary of Grain Size Analysis, Residential Dry Well Site R-2

DEPTH	% GRAVEL (>4mm)	% GRAVEL (2-4mm)	% SAND (50u-2mm)	% SILT (2-50u)	% CLAY (<2u)	% SUM
95	8.6	10.2	66.3	10.4	1.5	97.0
100	1.4	7.6	71.4	16.6	1.8	98.7
105	3.8	7.3	70.7	13.9	2.5	98.2
110	14.1	11.5	57.3	12.2	3.9	98.9
115	33.8	9.0	45.4	9.0	1.6	98.9
125	18.7	6.1	55.0	16.8	3.6	99.3
130	19.9	13.0	54.0	9.8	1.3	98.1

TABLE 32.
(Section I)

Summary of Grain Size Analysis Results, Soil Portion Only, Residential Dry Well Site R-2

DEPTH	% SAND (50u-2mm)	% SILT (2-50u)	% CLAY (<2u)	% SUM
5	78.0	19.6	2.8	100.4
10	46.0	34.4	16.2	96.6
15	72.2	17.0	11.0	100.6
20	59.9	22.6	12.2	94.7
25	82.4	9.4	6.2	97.9
30	77.2	12.0	6.8	96.0
35	71.6	22.0	2.2	95.8
40	73.4	21.2	2.2	96.8
45	74.8	20.2	3.6	98.6
50	76.6	17.4	4.2	98.2
55	79.0	14.4	3.0	96.4
60	76.7	18.0	1.4	96.1
65	81.0	15.0	1.2	97.2
71.5	69.8	22.2	8.2	100.2
75	76.8	18.4	3.6	98.8
80	84.6	10.8	1.4	96.8
85	68.3	20.0	9.0	97.3
90	81.9	13.4	1.6	96.9

TABLE 32.
(Section II)

Summary of Grain Size Analysis Results, Soil Portion Only, Residential Dry Well Site R-2

DEPTH	% SAND (50u-2mm)	% SILT (2-50u)	% CLAY (<2u)	% SUM
95	81.7	12.8	1.8	96.3
100	78.4	18.2	2.0	98.6
105	79.6	15.6	2.8	98.0
110	77.0	16.4	5.2	98.6
115	79.4	15.8	2.8	98.0
125	73.2	21.0	4.8	99.0
130	80.6	14.6	2.0	97.2

recharge during dry-well drainage. Thus, the only region with fines in excess of 30 percent is the 10 ft depth, where total fines equaled almost 50 percent.

There are six depths were the percentage of fines equal or exceeded 20 percent: 5 ft, 10 ft, 20 ft, 35 ft, 85 ft, and 125 ft. Flow may be somewhat impeded at these depths, particularly at a depth of 10 ft. These depths may also represent regions where water accumulates during deep percolation: Figure 17 shows the strong correlation between total silt plus clay and water content in the profile. Interestingly, we did not encounter perched water at any of these depths but at about 76 ft, where the silt plus clay percentage was only about 16.

Sorting is variable throughout the profile. The region from land surface to about 17 ft below land surface is well sorted to moderately poorly sorted. This may favor conduction of water despite the high degree of fines. From 17 ft to 71.5 ft, the samples are poorly sorted and flow conduction may be somewhat retarded despite the low percentage of fines. The region below 71.5 ft is moderately well sorted. Given the low percentage of fines throughout most of this lower zone, we anticipate favorable flow rates.

Except for the three uppermost samples, no acid reaction was observed on the oven-dried samples. Thus cementation is not a factor in retarding flow ad depths below about 15 ft.

To summarize, water is probably transmitted readily throughout the profile except in the upper 10 ft where the percentage of fines is high (greater than 30 percent) and cementation occurs.

6.4.2.2 <u>Evidence from the Observed Water Content Distribution in the Vadose Zone</u>

Table 33 lists the gravimetric and volumetric water contents of borehole samples from R-2. Figure 18 diagrams the volumetric water content profile. As indicated in the last section there is a close correspondence between the volumetric water content and percent fines. Maximum water contents occurred in the profile at 10 ft and 85 ft but free water samples were not available. In contrast, a perched water sample was obtained at 76 ft where the water content was only about 23 percent.

The average, volumetric water content throughout the profile was about 18 percent. This water content is slightly higher than field capacity values for sandy-textured soils, which are in the order of 10 to 15 percent. Thus, it appears that drainage from the dry well has created a transmission zone for percolating water, facilitating recharge. The total volume of water in storage within the transmission zone corresponds to a water depth

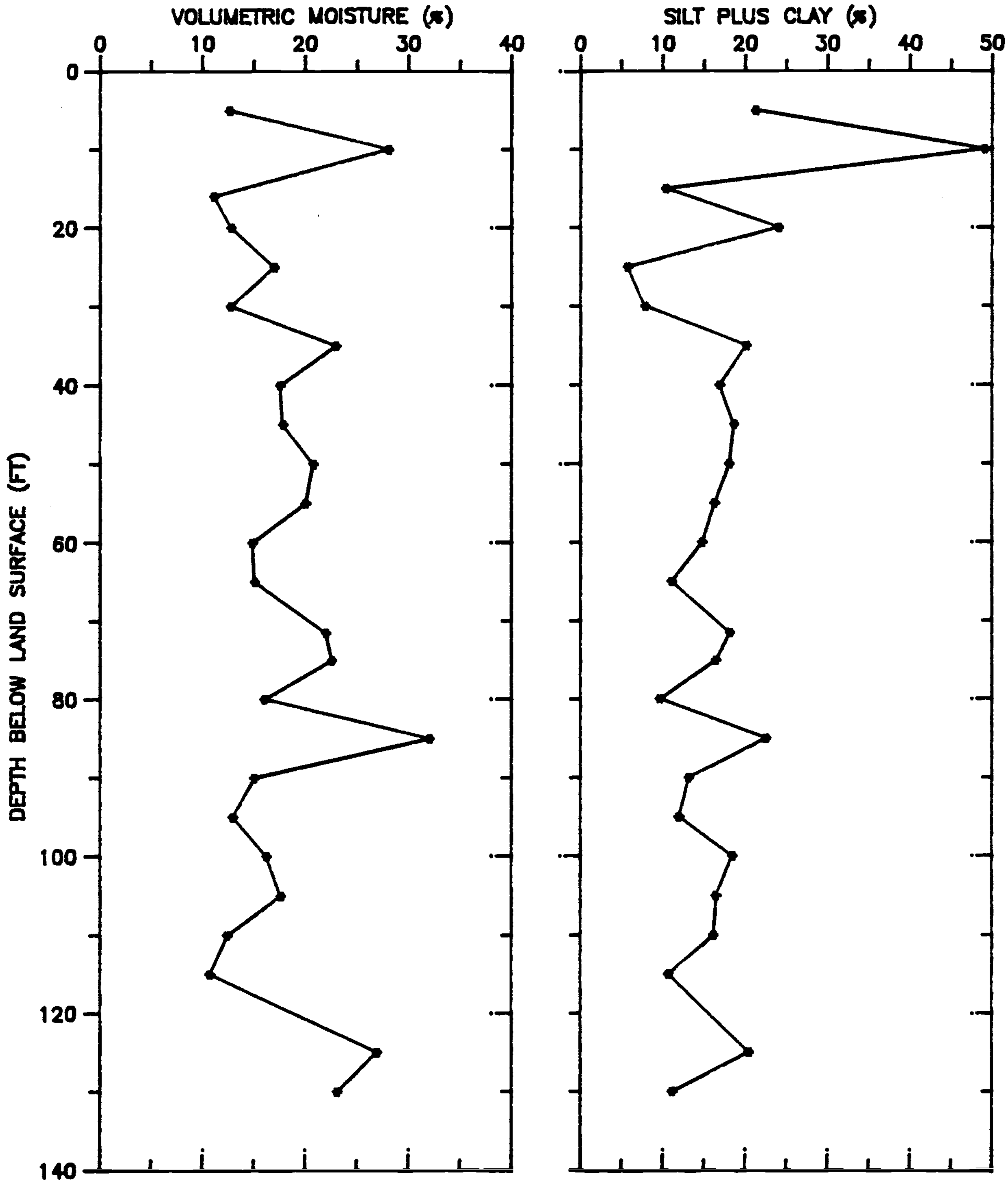

FIGURE 17. VOLUMETRIC MOISTURE CONTENT PROFILE AND THE DISTRIBUTION OF SILT PLUS CLAY IN THE VADOSE ZONE AT SITE R-2.

TABLE 33
(Section I)

Summary of Moisture Content and Bulk Density, Residential Dry Well Site R-1

DEPTH [FT]	% GRAV MOIST	% VOL MOIST	BULK DENSITY [G/CC]
5	9.88	12.60	1.28
10	18.00	28.01	1.56
16	5.88	11.08	1.88
20	9.65	12.78	1.32
25	8.63	16.98	1.97
30	8.10	12.69	1.57
35	11.68	22.93	1.96
40	10.48	17.51	1.67
45	9.05	17.81	1.97
50	11.16	20.75	1.86
55	10.76	19.98	1.86
60	8.22	14.81	1.80
65	7.70	15.08	1.96
71.5	11.33	21.99	1.94
75	12.07	22.57	1.87
80	8.78	16.01	1.82
85	19.57	32.01	1.64
90	8.45	14.99	1.77

TABLE 33
(Section II)

Summary of Moisture Content and Bulk Density, Residential Dry Well Site R-1

DEPTH [FT]	% GRAV MOIST	% VOL MOIST	BULK DENSITY [G/CC]
95	7.08	12.89	1.82
100	9.11	16.22	1.78
105	9.78	17.60	1.80
110	7.76	12.34	1.59
115	5.69	10.66	1.87
125	14.61	26.92	1.84
130	11.67	23.06	1.98

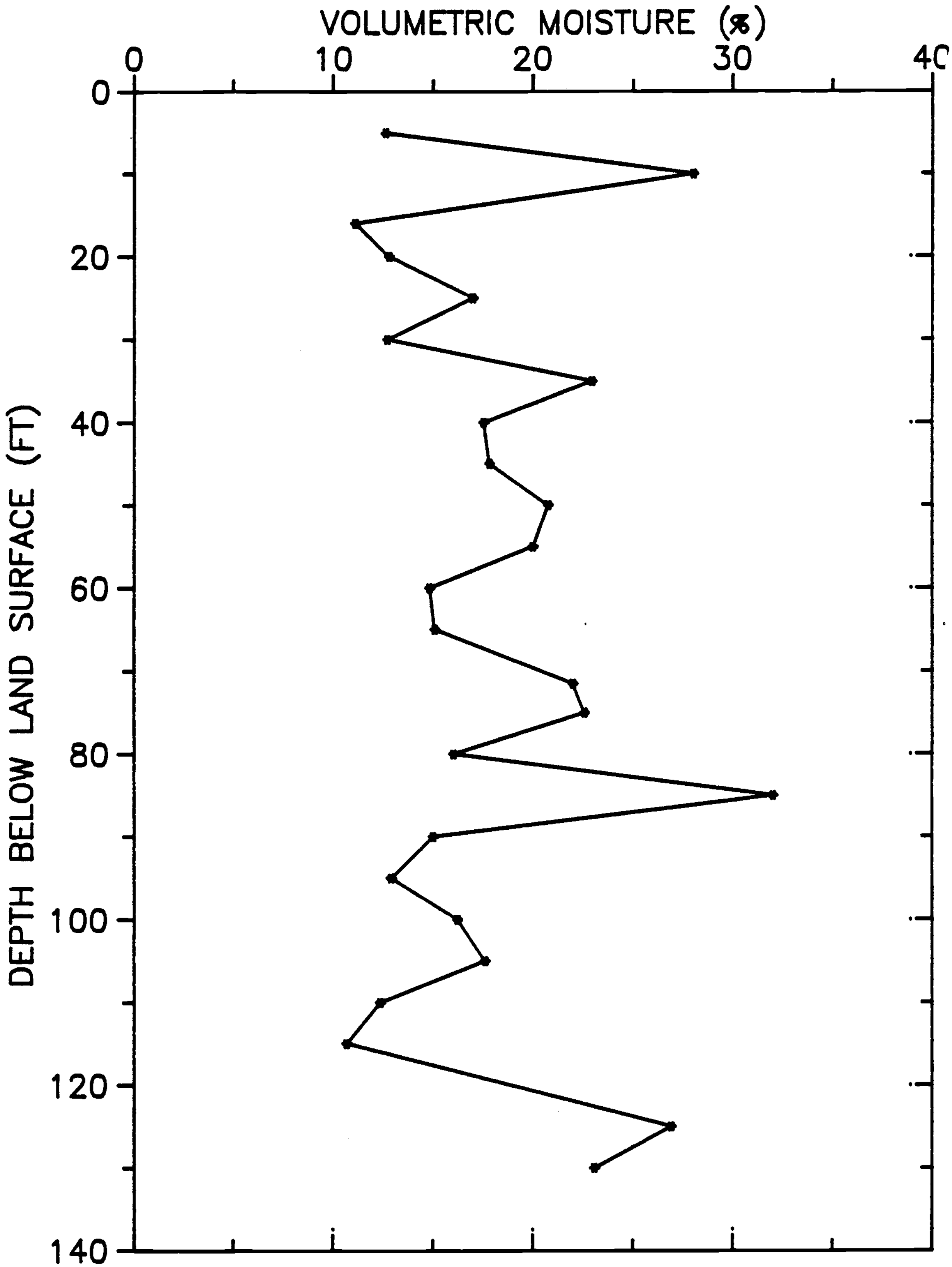

FIGURE 18. VOLUMETRIC MOISTURE CONTENT PROFILE, SITE R-2.

of about 23 ft.

6.4.3 Pollutant Distribution

6.4.3.1 General Chemistry

6.4.3.1.1 Dry Well Sediment

Values of inorganic chemical constituents (excluding heavy metals) in the dry-well sediment sample are as follows:

Alkalinity	138 mg/kg
Chloride	5.2 mg/kg
Nitrate (as N)	<0.05 mg/kg
Nitrite	25.6 mg/kg
Sulfate	20.4 mg/kg
pH	8.1

The most interesting feature of this analyses is the presence of nitrite. The major source of nitrogen is probably fertilizer (present as ammonium phosphate) occurring in runoff from the adjoining grassed area. Normally, nitrite occurs in transient small amounts during nitrification (Rowell, 1981). Thus, finding nitrite in the sediment samples in such large concentrations is unusual. A possible explanation is as follows: Inasmuch as the sediment in the dry well is nearly saturated (i.e., anoxic) because of the daily inflow of irrigation water, nitrification is inhibited. Accordingly, ammonium tends to be the dominant nitrogen species in the sediment. During sampling, we maintained the sample at a temperature close to freezing, inhibiting nitrification. The sample was also maintained near freezing during storage. Partial nitrification may have occurred before the sample was analyzed, however, converting ammonium to nitrite. Inasmuch as the microorganisms promoting conversion of nitrite to nitrate are inhibited by near-freezing temperatures, the process was held up at the nitrite stage.

6.4.3.1.2 Vadose Zone and Ground-Water Samples

Table 34 shows the major inorganic chemicals in samples of perched ground water, the water table, and ground water from the nearest Tucson Water well. Overall, the inorganic chemical quality of the three water samples is excellent, with low total salt levels and all of the major inorganics well below recommended standards.

Figure 19 is a Schoeller diagram of the three samples. This diagram shows that the chemical "fingerprints" of the three samples are very similar, although somewhat offset from one another. Thus, it appears that the origin of the waters is similar. Given the proximity of the dry well and the City well to

TABLE 34

General Chemistry of Perched Ground Water, Water Table, and Ground Water at Residential Site Site R-2

Constituent	Perched Ground water	Water Table	Ground Water*
Calcium	45.8	31.2	54.0
Magnesium	5.0	3.6	9.0
Manganese	1.0	0.2	<0.05
Sodium	21.8	14.0	40.0
Potassium	4.7	2.0	NA
Chloride	9.0	4.3	22.0
Sulfate	14.9	15.9	37.5
Nitrate (as nitrogen)	1.1	0.92	3.4
Carbonate (as CaCO3)	<5	<5	0.0
Bicarbonate (as CaCO3)	137	104	150
Hydroxide (as CaCO3)	<5	<5	NA
Conductivity (umhos/cm)	349	265	488
Total dissolved solids	255**	194	311
pH	8.22	7.6	7.6
Total organic carbon	16.4	8.3	NA

Units: mg/l, except conductivity (umhos/cm) and pH

* Source: Tucson Water. Sample analyzed on 2/12/76
** Estimated using the equation TDS = Conductivity * 0.73

NA = Not Available

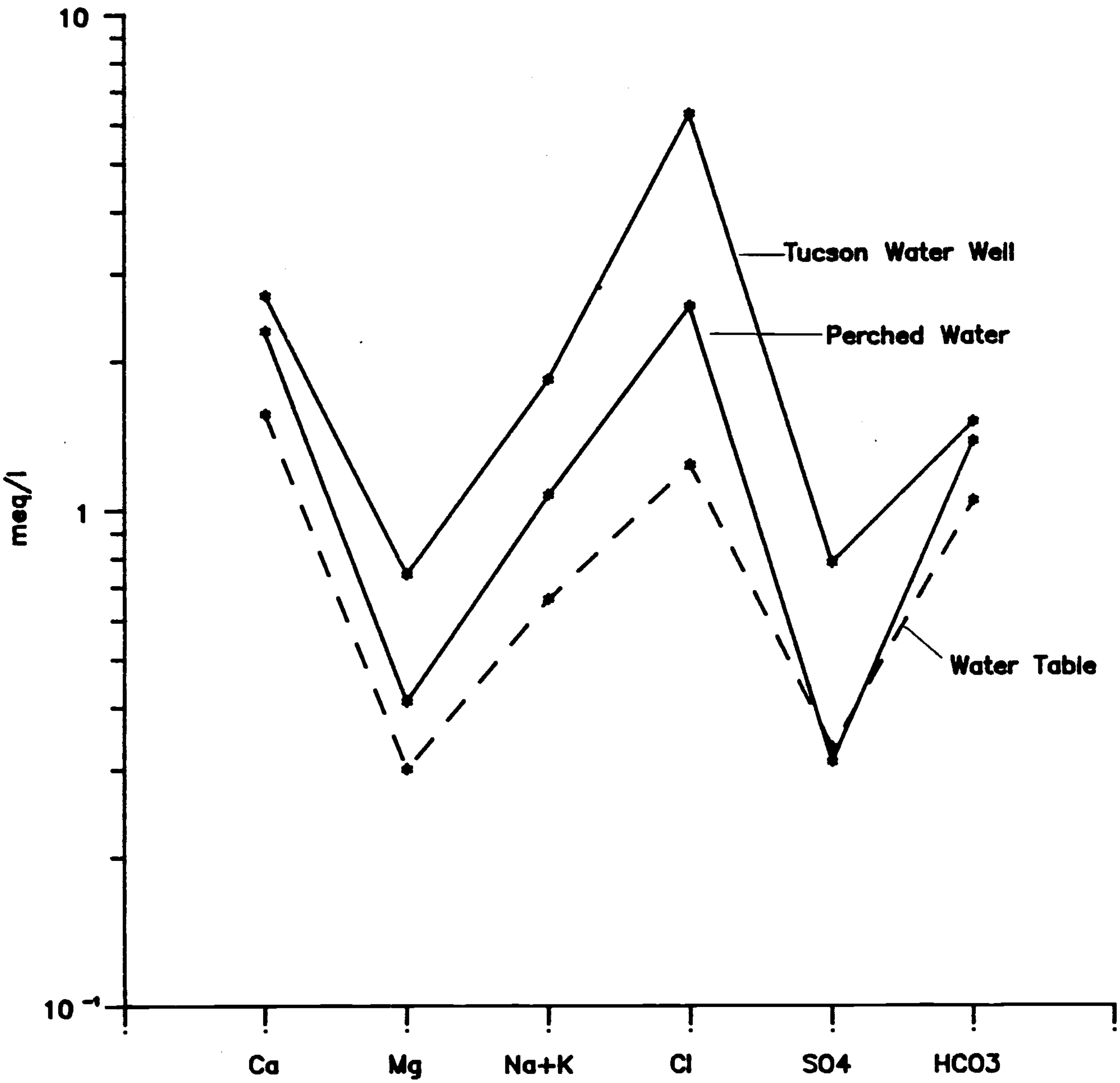

FIGURE 19. SCHOELLER DIAGRAM FOR PERCHED GROUND WATER AND A WATER TABLE SAMPLE AT SITE R-2, AND A GROUND WATER SAMPLE FROM A NEARBY TUCSON WATER WELL.

the Rillito River, river recharge is a likely source. However, it is also possible that water from the Tucson Water well, or a mixture from wells in the distribution system servicing the residential complex, is the source for the perched water and water table samples. As stated in Section 6.4.2.2, it appears that
a transmission zone exists throughout the profile. Surface water draining into the dry well from sources such as excess irrigation

water and car wash water, will then be transmitted downward through the profile.

6.4.3.2 Organics

Table 35 lists the trace organics and pesticides that were detected in the dry-well sediment, vadose zone, perched water, and the water table. The remaining pollutants in the list of halogenated/aromatic compounds for Method 8010/8020 (see Appendix 3) were undetected.

6.4.3.2.1 Dry-Well Sediment Samples

The two sediment samples from the dry well were free of volatile organics but contained traces of the following semivolatiles:

- phenanthrene
- pyrene
- chrysene
- benzo(k)fluoranthene
- benzo(a)pyrene
- indeno(1,2,3-cd)pyrene
- benzo(g,h,i)perylene

Sources for these compounds include motor fuels, asphalt, plastics manufacture, and insecticide manufacture.

As described elsewhere in this report, the fate of hydrophobic semivolatiles in the dry-well sediments seems to be related to the oil and grease content, and associated organic carbon percentage, of the sediment. Table 36 lists the oil and grease content and organic carbon percentage of sediment samples from R-2 and from the vadose zone. Both the organic carbon and the oil and grease concentrations in the sediment sample are several orders of magnitude greater than the background concentrations in the vadose zone. These organic accumulations apparently serve as a sink for the hydrophobic semivolatiles.

The more soluble PAH's among the semivolatiles may be biodegraded (Groenewegen and Stolp (1981).

The dry well sediment sample of 2/22/89 contained 0.061 mg/kg of chlordane. EPA has cancelled the registration of pesticides

TABLE 35
(Section I)

Organic Pollutants Detected in Dry Well Sediment, Vadose Zone Samples, and the Water Table at Site R-2

Compound	Dry Well 6/21/88	Sediment 2/22/89	Vadose Zone 2/23/89
HALOGENATED/AROMATIC VOLATILES			
toluene	ND	ND	ND
meta xylene	ND	ND	ND
ortho and para xylene			
SEMI-VOLATILES			
phenol	ND	ND	ND
benzyl alcohol	ND	ND	ND
phenanthrene	TR	ND	ND
fluoranthene	TR	ND	ND
pyrene	TR	TR	ND
chrysene	TR	ND	ND
benzo(k)fluoranthene	TR	TR	ND
benzo(a)pyrene	TR	ND	ND
indeno(1,2,3-cd)pyrene	TR	ND	ND
benzo(g,h,i)perylene	TR	TR	ND
ORGANOCHLORINE PESTICIDES AND PCB'S			
chlordane	ND	0.061	ND

Units: mg/kg
ND: Not Detected
TR: Trace

TABLE 35
(Section II)

Organic Pollutants Detected in Dry Well Sediment, Vadose Zone Samples, and the Water Table at Site R-2

Compound	Perched Ground Water 2/23/89	Water Table 2/24/89
HALOGENATED/AROMATIC VOLATILES		
toluene	54	3.7
meta xylene	1.1	ND
ortho and para xylene	1.5	ND
SEMI-VOLATILES		
phenol	22	ND
benzyl alcohol	TR	ND
phenanthrene	ND	ND
fluoranthene	ND	ND
pyrene	ND	ND
chrysene	ND	ND
benzo(k)fluoranthene	ND	ND
benzo(a)pyrene	ND	ND
indeno(1,2,3-cd)pyrene	ND	ND
benzo(g,h,i)perylene	ND	ND
ORGANOCHLORINE PESTICIDES AND PCB'S		
chlordane	ND	ND

Units: ug/l
ND: Not Detected
TR: Trace

TABLE 36

Organic Carbon Levels and Oil and Grease in Dry-Well Sediment, and Five Depths in the Vadose Zone, Residential Site R-2.

Sample Location	Organic Carbon (%)	Oil and Grease (mg/kg)
Sediment Chamber (7/22/86)	-	1,300
Sediment Chamber (6/21/88)	6.4	820
Sediment Chamber (2/22/89)	4.3	2,900
16 ft	0.023	<1
30 ft	0.025	2
45 ft	-	1
50 ft	0.017	<1
80 ft	0.007	<1

containing this compound except for ground insertion for termite control (Windholz et al., 1983). Conceivably, the small amount of chlordane in the dry-well sediment originated in foundation soils at the apartment complex.

6.4.3.2.2 <u>Vadose Zone Solids</u>

Table 35 shows that no volatile and semivolatile organics were detected in the vadose zone solids samples. The organic carbon concentrations in the vadose zone sediments above 50 ft were higher than in the background sample at 80 ft. Some oil and grease was detected in samples from 30ft and 45ft.

6.4.3.2.3 <u>Perched Ground Water</u>

The perched ground-water sample contained the following volatile organics:

- o toluene (present at 54 ug/l)
- o meta, ortho and para xylene.

The common source of these compounds is automotive emissions. Assuming that toluene and the xylenes were present in runoff from the pavement at the apartment complex, it appears that they were not completely attenuated during flow in the vadose zone. The observed concentrations were well below ADEQ Groundwater Action Levels of 2 ppm for toluene and 440 ug/l for xylenes.

Two semivolatiles were observed in the perched ground-water sample:

- o phenol
- o benzyl alcohol

Phenol was present at a concentration of 22 ug/l and benzyl alcohol was present only in trace concentrations. The phenol concentration was above the EPA limit of 1 ug/l for phenols as a class. Under aerobic conditions phenols decompose within two days in soil suspensions (Verschueren, 1977). However, phenols as a class (ostensibly including phenol) persist under anaerobic conditions and move readily through soils (Artiola-Fortuny and Fuller, 1982). Thus, the presence of phenol in the perched water sample suggests that the flow system is anaerobic.

Phenol is used as a general disinfectant for toilets, stables, cesspools, drains, and medical and industrial organic compounds and dyes. (Windholz, 1983). It is possible that phenol originated onsite at R-2. However, another possible source is disinfectant used on animals in an adjoining property containing animal pens for sheep and swine. This source area also contains a dry well. Thus, runoff from the animal pens could have contributed to dry well drainage, which in turn could have migrated in the perched water system toward the dry well at R-2.

Benzyl alcohol is a highly soluble organic compound with a specific gravity slightly greater than that of water. The common manmade source is gasoline exhaust (Verschueren, 1977). Thus, this compound could have originated in runoff from the driveway at R-2.

6.4.3.2.4 Water Table

The water table sample contained the following volatile organic:

- o toluene

This compound was present at a concentration of 3.7 ug/l, well below the state action level of 2 mg/l. Xylenes, phenol, and benzyl alcohol detected in the perched water sample, were absent in the water table sample.

6.4.3.3 Heavy Metals

Table 37 shows the concentrations of heavy metals in dry well sediment, vadose zone samples, perched ground water, and the water table at site R-2. The values are for extractable metals, thus reflecting metals that would be extracted during leaching of the solids by runoff water.

6.4.3.3.1 Dry Well Sediment

Table 37 shows that the following metals were present in greater than detection levels in the dry well sediment sample:

- o arsenic
- o cadmium
- o chromium
- o copper
- o nickel
- o lead
- o zinc

Concentrations of lead and zinc were present in the greatest abundance. The most likely source of the detected metals is automobiles.

Section 6.4.3.1.1 reported that anoxic conditions appear to exist in the dry well sediment at R-2, explaining the presence of nitrite in the sample. Such oxygen deficient soil environments favor the mobility of many heavy metals. As stated by Fuller (1977), "...trace concentrations of As, Be, Cr, Cu, Fe, Ni, Se, V, Zn, are much more mobile under anaerobic than aerobic conditions, all other factors the same". However, the high

TABLE 37

Heavy Metals (as Extractable) in Dry Well Sediment, Vadose Zone Samples, Perched Ground Water, and the Water table, Residential Site R-2.

Parameter	Dry Well Sediment	Vadose Zone Depth (ft)			
		16	30	50	80
Silver	<0.1	<0.1	<0.1	<0.1	<0.1
Arsenic	0.3	<0.3	<0.3	<0.3	<0.3
Beryllium	<0.05	<0.05	<0.05	<0.05	<0.05
Cadmium	0.05	<0.05	<0.05	<0.05	<0.05
Chromium	0.2	0.1	<0.1	<0.1	<0.1
Copper	0.9	1.2	0.3	2.1	0.1
Mercury	<0.005	<0.005	<0.005	<0.005	<0.005
Nickel	0.1	<0.1	<0.1	<0.1	<0.1
Lead	2.3	<0.3	<0.3	<0.3	<0.3
Antimony	<0.3	<0.3	<0.3	<0.3	<0.3
Selenium	<0.3	<0.3	<0.3	<0.3	<0.3
Thallium	<0.9	<0.9	<0.9	<0.9	<0.9
Zinc	56.6	0.6	0.4	1.7	0.5

Parameter	Perched Ground Water	Water Table
Silver	<0.010	<0.010
Arsenic	<0.002	<0.002
Beryllium	<0.005	<0.005
Cadmium	<0.005	<0.005
Chromium	<0.01	<0.01
Copper	0.03	<0.02
Mercury	<0.0005	<0.0005
Iron	0.10	0.02
Manganese	1.0	0.2
Nickel	0.03	<0.01
Lead	<0.003	<0.002
Antimony	<0.03	<0.03
Selenium	<0.002	<0.002
Thallium	<0.002	<0.002
Zinc	0.02	<0.01

Units: mg/l

organic concentrations in the sediment may tend to retain metals, counteracting the influence of the anaerobic conditions. Unfortunately, nothing dealing with movement of pollutants in the vadose zone is simple and Fuller (1977) notes that chelation of metals with organics also occurs, forming soluble and mobile compounds. Of course, other reactions also retard the movement of metals in soils, including precipitation, adsorption onto the exchange complex and adsorption reactions with hydrous oxides of iron, aluminum, and manganese (Fuller, 1977, Bloomfield, 1981).

6.4.3.3.2 Vadose-Zone

Metals present in concentrations at or above detection limits in the vadose-zone samples include:

- o chromium
- o copper
- o zinc.

Thus, except for these three metals, the metals detected in the dry well sediment did not move throughout the vadose zone in the vicinity of the dry well, suggesting that the immobilizing factors alluded to in the previous section were of greater importance than the mobilizing factors. Table 38 shows that the cation exchange capacities (CEC) of the dry well sediment and the vadose-zone sample at 16 ft were great enough to limit movement of the cationic metals through the profile. Precipitation is another mechanism effective in lowering metals concentrations. The slight increase in copper and zinc concentrations in the 50 ft sample may reflect the slight increase in CEC at that depth.

6.4.3.3.3 Perched Ground Water

Metals detected in perched ground water include the following:

- o copper
- o iron
- o manganese
- o nickel
- o zinc

The concentrations of these metals are below EPA drinking water standards except for manganese, present at 1.0 mg/l, compared with the EPA standard of 0.05 mg/l. Manganese is translocated readily under anaerobic conditions (Bloomfield, 1981). (This supports the earlier observation that phenol is present in the perched system because of the reduced oxygen status.) The toxicity of manganese is low and the main reason for the low limit is that laundry and bathroom fixtures are stained by very low concentrations of manganese (Manahan, 1975).

The reduced concentrations of copper, nickel, and zinc suggest

TABLE 38

Cation Exchange Capacity of Soil Samples, Residential Site R-2

Sample Location	Cation Exchange Capacity
Dry Well Sediment	9.8
16 ft	7.2
30 ft	3.3
50 ft	5.7
80 ft	5.4

Units: meq/100 gm

that the reactions favoring immobilization of these metals exceed the mobilization reactions, despite the prevalence of anaerobic conditions.

6.4.3.3.4 Water Table

The following two metals were detected in the water table sample:

- o iron
- o manganese

Only manganese was present above recommended standards.

Based on the results of the perched water and water table samples, it appears that metals analyzed for and detected in dry well sediment (and hence in runoff) are reduced below drinking water standards during percolation of runoff through the vadose zone. Iron and manganese were not determined in the sediment samples, but were detected in perched ground water and water table samples.

6.4.4 Conclusions

o Recharge Potential

The water content profile at this dry well appears to be close to field capacity throughout, indicating that a transmission zone is available for recharge during drainage from the unit. The vadose zone is comprised of predominantly coarse-grained deposits favoring vertical drainage. However, the relative degree of coarseness is variable and some lateral flow occurs. The presence of a perching layer at 76 ft below land surface shows that vertical flow can occur in the saturated state.

Samples of perched water, the water table, and ground water have similar Schoeller diagram fingerprints, suggesting a common recharge source. Thus, in addition to recharge from dry-well drainage, another possible recharge source is lateral subsurface flows from the Rillito River.

o Fate of Pollutants

Volatile organics entering the dry well appear to be mainly lost by volatilization. However, the presence of toluene and xylenes in the perched water sample and toluene in the water table sample shows that volatilization is not completely effective. The semivolatile organics appear to be mainly lost either by sorption onto oils and greases or by biodegradation. The detection of phenol in perched ground water suggests that the flow system is anaerobic, inhibiting the action of microorganisms in degrading some organic compounds.

Metals present in dry-well sediment are effectively attenuated during flow through the vadose zone. The increased mobility of manganese and iron under reduced oxygen conditions in the profile may account for their presence in perched water and at the water table.

o Ground-Water Pollution Potential

Except for the presence of manganese at a concentration exceeding drinking water standards, the ground water underlying the dry well has not been polluted by the dry well at R-2. However, the presence of toluene, xylenes, phenol, and benzyl alcohol in perched water and toluene in the water table show that the dry-well is a potential source of ground-water pollution by trace organics.

The possibility that the source of phenol in the perched ground-water sample is a dry well on an adjoining property deserves investigation.

There is no evidence that chlordane detected in the dry well sediment has moved into or through the vadose zone. There is also no evidence that fertilizers contributing to the high nitrite level found in the dry well sediment have caused nitrate pollution of the water table.

SECTION 7 CONCLUSIONS

o There is evidence that drainage from the dry wells at the industrial and commercial sites has created transmissions zones through their vadose zones, facilitating recharge to the underlying water table. These wells are comparatively shallow and additional studies are required to ascertain the recharge potential at sites with deeper water tables.

o Volatile organics may be virtually absent in runoff samples draining into dry wells. Apparently, volatilization is enhanced during runoff. However, the occurrence of volatile organics in dry-well sediment shows that removal is not complete.

o Semivolatile organics are ubiquitous in runoff into dry wells, originating from automobile emissions, and pavement asphalt. The polycyclic aromatic hydrocarbons (PAHs), and phenolic compounds predominate.

o Pesticides in runoff appear to be site specific, being related to land-use practices (e.g. turfgrass irrigation) in the drainage areas.

o Volatile organics (e.g, ethylbenzene, toluene, and xylenes) occur in dry-well sediment. Being soluble, these organics may percolate through the vadose zone.

o A large variety of semivolatile organics occur in dry well sediment, including PAHs, phthalate esters, and phenolic compounds. Greater numbers of these compounds occurred at the first-choice residential site in greater concentrations because of the larger contributing drainage area.

o Assuming that the data from the industrial, commercial, and residential sites represent worst-case conditions, there is no evidence for the accumulation of volatile and semivolatile organics, and pesticides, in the vadose zone at dry-well sites. Oils and grease entrained with the dry-well sediment appear to sequester the semivolatiles, limiting their movement into the vadose zone. Biodegradation also appears to be a mechanism limiting the movement of the less hydrophobic semivolatiles.

o Perched water at the backup residential site is contaminated with phenol. When encountered, perched ground water should be sampled as a harbinger of potential ground-water pollution.

o The water table at the commercial and backup residential sites appears to be contaminated with toluene. However, the concentrations are well below state action levels.

o Local ground water, pumped from Tucson Water wells near the commercial and residential dry wells has not been contaminated by organics, including pesticides. The presence of TOX in the Tucson Water well near the industrial site warrants additional sampling and possibly an analysis for volatiles.

o Heavy metals, notably lead and chromium, may occur in runoff at concentrations exceeding drinking water standards. The concentrations of extractable (mobile) metals in dry-well sediment samples and vadose-zone samples are low, although nickel, chromium, and zinc concentrations may be high in local regions of the vadose zone.

o There is no evidence that dry-well drainage contributes heavy metals to ground water.

o The study shows that industrial, commercial, and residential dry wells are not a major source of ground-water pollution, at least for the short time that the study wells have been in place.

o The potential for ground-water pollution is basically site specific, depending on land usage, drainage area, depth to ground water, and the vadose-zone lithology. For example, the industrial site investigated during this study is underlain by a massive clay formation, highly effective in retarding flow and attenuating pollutants. In contrast, two volatiles were present in the water table at the commercial site, where the vadose zone consists mainly of coarse-grained alluvium.

SECTION 8 RECOMMENDATIONS

o Dry Well Use

The following recommendations are suggested to reduce the threat of ground-water contamination from the use of dry wells:

o Industrial Areas.

The study did not demonstrate that the dry well at the industrial site has caused ground-water pollution. Nevertheless, the use of dry wells in industrial areas and areas receiving drainage from industrial areas should be prohibited. The dry well policies of Tucson and Pima County prohibit new installations in industrial areas. However, one of the industrial sites described in Phase I of this study is zoned commercial and receives drainage from an adjacent industrial area. Restrictions on dry-well use should address this problem.

o Commercial and Residential Areas.

Specific activities within dry-well drainage areas at commercial and residential sites should be prohibited. Activities identified during the Phase I survey that might adversely affect ground-water quality include livestock confinement and outdoor chemical storage. By restricting specific activities, rather than merely specifying siting requirements during planning stages, restrictions on land-use in the drainage area could be deeded to future owners.

o Dry-Well Maintenance

Sediment collected in the dry-well settling chamber should be cleaned out at routine intervals. This process will remove the pollutants sequestered by oils and grease and particulate matter. Regulations involving the disposal of hazardous wastes may require shipping the waste to an approved disposal facility.

o Dry-Well Design and Siting Restrictions

o The dry-well sediment collected from the settling chamber of the residential well contained greater numbers of semivolatiles at greater concentrations than the other wells. This seems to be related to the larger drainage area of the residential well. This suggests that a method for reducing the pollutant loading is to reduce the drainage area contributing to each dry well. Accordingly, the number of wells may need to be increased. Site specific studies will be required to select the balance between numbers of dry wells, pollution loading, and drainage areas.

o Dry-well contractors should be encouraged to design and incorporate features in their dry wells that increase volatilization (e.g., by promoting cascading) and sequestering of semivolatiles within the settling chamber.

o The current restrictions on thickness of vadose zone between the dry well invert and the water table (75 ft for wells in commercial areas and 125 ft for wells in residential areas) should be continued. Similarly, we recommend continuing the restriction of 300 ft between dry wells and cased water supply wells, and 500 ft between dry wells and uncased water supply wells.

o <u>Source Reduction</u>.

Inasmuch as most of the pollutants identified during this research are ubiquitous in the urban environment, the only practical method of reducing the threat of ground-water contamination from these pollutants is by reducing pollutant levels in source areas. Prohibiting the use of dry wells will, of course, eliminate the threat to ground-water from runoff injected through dry wells, but the problem of contaminated runoff will remain.

Following are methods for reducing the pollutant load entering dry wells and reducing the overall level of some pollutants in the environment:

o Waste oil and gasoline appear to be a major source of organic pollutants introduced into dry wells. Currently, emission testing is required to reduce the amount of pollutants emitted from automobiles to the atmosphere. A similar, simultaneous inspection could be done for oil and gasoline leaks from automobiles.

o A related problem is the indiscriminate dumping of used motor oil. Individuals who change the oil on their cars should take it to those service stations that provide a public service by accepting used oil. Some individuals, however, indiscriminately dump oil on the ground, or in the parking lot of their apartment complex. It is recommended that the city or county provide public waste-oil collection tanks, placed at conspicuous places throughout the city, which may reduce illegal dumping of waste oil. Of course these tanks should not be allowed in dry-well drainage areas.

o Periodic notices should be published in local media presenting acceptable methods for disposal of used waste oil and other common hazardous substances found in households. Common household chemicals may enter a dry well if they are inadvertently dumped into trash bins or otherwise disposed of within a dry-well drainage area. As the number of dry wells in the area increases, the possibility of pollution from this source will also increase.

o Parking should be prohibited directly over dry wells.

o Further Research

o General

o Conduct additional studies to determine the long-term effect of aging dry wells on ground-water recharge and pollution. This will require instrumenting the vadose zone and ground-water zone underlying a candidate dry well with appropriate devices to sample water for pollutant movement into the water table. Specific pollutants that should be determined include volatile organics, metals, and microorganisms. Collect data for a period of years.

o Conduct controlled laboratory studies on the potential for oils and grease to sequester runoff pollutants, particularly the semivolatiles and metals. Determine the potential for microorganisms to biodegrade the more soluble semivolatiles.

o Determine the temporal changes in the trace organic content of settling-chamber sediment receiving runoff from newly paved areas.

o Site-Specific Sites: I-1

o Extract additional ground-water samples from the Tucson Water well in the vicinity of the industrial well site and characterize the TOX according to apparent molecular weight.

o Specific Sites: C-1

o Evaluate leakage of volatiles from the gasoline tank at the convenience store near the commercial dry well to determine if tank leakage is a source of toluene and ethylbenzene at the water table.

o Specific Sites: R-2

o Determine the source of phenols and manganese in perched ground water.

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APPENDIX 1

ADEQ CONCEPT PAPER ON PROPOSED RULES FOR PERMITTING DRY WELLS

ARIZONA DEPARTMENT OF ENVIRONMENTAL QUALITY

ROSE MOFFORD, GOVERNOR
RONALD MILLER, ACTING DIRECTOR

October 11, 1988

TO: Interested Parties

FROM: William H. Shafer, P. E., Acting Assistant Director WHS
Office of Water Quality

RE: Transmittal of Concept Paper on Proposed Rules

Arizona Department of Environmental Quality is beginning the development of Drywell Rules, pursuant to legislative authority in Arizona Revised Statutes, Title 49, Chapter 2, Article 8 for drywells and State Environmental Quality Act provisions for Aquifer Protection Permits.

Attached is a copy of the concept paper which describes statutory requirements, strategy for program development, the proposed program, including standards, guidelines and enforcement, and the projected schedule for rule development. Public meetings on the draft rules are tentatively scheduled for February 1989.

The Department encourages your comments and suggestions on the Drywell Rules concept paper. Written comments may be submitted by November 14, 1988, to John Holt, 2005 North Central Avenue, Room 304, Phoenix, Arizona 85004.

For further information contact Lee Sobchak at 257-6827, or John Holt at 257-6872.

JH:bn

CONCEPT PAPER: DRY WELLS

The Legislature has authorized the Department of Environmental Quality (DEQ), to establish rules regarding dry wells, Arizona Revised Statutes Title 49, Chapter 2, Article 8. This concept paper will assist in the development of rules, and is meant to provide an initial opportunity for public involvement.

Dry wells are defined in A.R.S. § 49-331 as wells constructed and designed specifically for the disposal of storm water. Dry wells are installed at facilities without storm water sewers, and often because local governments require on-site retention and disposal of storm water runoff from precipitation events. Dry wells are used in several counties, primarily in Maricopa County, and may provide a conduit for contamination of groundwater in certain areas.

The statutory requirements of the law, DEQ's proposed strategy, and components of the proposed program are presented here to provide for public input prior to actual development of rules.

STATUTORY REQUIREMENTS

Section § 49-331 thru § 49-336 of the Arizona Revised Statutes contain the statutory requirements for dry well rules. A copy of these statutes is attached. Section 49-332 addresses registration requirements for dry wells. All dry wells not currently registered, should be registered with the Department to comply with the statute. Section 49-333 requires rules regarding the qualification and licensing of dry well drillers and provides discretionary authority to the Department for establishing standards for dry wells pertaining to their performance, operation, construction, design, closure, location and inspection. Section § 49-335 requires the Director to promulgate rules regarding administration and implementation of the dry well program. Section 49-334 provides enforcement and penalties for violation, and Section 49-336 exempts dry wells used in conjunction with golf course maintenance.

The Aquifer Protection Permit provisions under the Environmental Quality Act (ARS 49-241.B.) address dry wells as injection wells. The Department is required to develop a program whereby permits will be issued to dry wells under the Aquifer Protection Permit rules.

PROPOSED STRATEGY FOR PROGRAM DEVELOPMENT

- Continue the current registration process for dry wells.

- Conduct a literature survey to evaluate various dry well regulatory programs that are applicable to Arizona's climatic and geohydrologic setting.

- Develop dry well rules based on literature survey and field studies.

- Inform dry well drillers, local governments, and other interested parties of the rules regulating dry well installation. All local governments will be informed of the construction rules for dry wells, and of the need for a DEQ approval to construct dry wells.

- Revise the dry well program and amend rules, as necessary, to incorporate the findings from on-going or future hydrological studies.

DESCRIPTION OF PROPOSED PROGRAM

DEQ proposes that the dry well program be comprised of the following five major components (1) Registration of existing and new dry wells, (2) Licensing of dry well drillers, (3) Establishment of location, construction, design, maintenance, and closure standards, (4) Dry wells and the aquifer protection permit program, (5) Enforcement and penalty provisions.

1. Registration - A.R.S. § 49-332 establishes requirements for the registration of both existing and new dry wells. On August 13, 1986, DEQ adopted a form to register these dry wells and began their registration. The Department proposes that use of the current registration form (see example attached) be continued. Dry wells not registered may be subject to the enforcement provisions of A.R.S. 49-334.

2. Licensure - A.R.S. § 49-333 requires the Director to develop, by rule, qualifications for the licensing of dry well drillers. DEQ proposes that licensing requirements be satisfied by passing a written test pertaining to facility construction, design, location, operation, maintenance, and closure rules. Well drilling experience and obtaining the Department of Water Resources (DWR) license for augering and boring may also be required to obtain a license.

3. Standards - A.R.S § 49-333 provides discretionary authority to the Director to establish standards pertaining to performance, operation, construction, design, closure, location and inspection of dry wells. The Department proposes to establish location, design, closure and maintenance standards as rules, and may provide non-regulatory guidelines for general maintenance. The department will amend the dry well rules as ongoing hydrological studies are completed. General concepts include:

    a. Location - Setback requirements from underground storage tanks (USTs), chemical storage, loading or handling areas; vertical separation criteria from groundwater; and horizontal setback distances from domestic seepage pits, leach lines, water supply wells, and other dry wells.

    b. Design - Requirements that dry wells are designed to provide a method for removal of contaminants and sediments before direct discharge into the vadose zone. Operational rules may include measures to prevent siltation of the formation.

    c. Maintenance - Guidelines will be proposed ensuring the removal and proper disposal of sediments from settling chambers when sediment accumulates to a certain depth or at appropriate time intervals.

d. Closure - Requirements for closure, soil sampling, and notification.

4. Dry wells and the Aquifer Protection Permit Program - A.R.S. § 49-241 establishes an Aquifer Protection Permit system whereby injection wells are required to obtain either general or individual permits. As a part of this proposed permit program, dry wells situated in locations which drain areas where hazardous substances, are used, stored, loaded or treated will require an individual permit. When dry well rules are adopted, all other dry wells complying with the dry well rule requirements will be granted a general Aquifer Protection Permit pursuant to A.R.S § 49-245.

5. Enforcement

A.R.S. § 49-334 enables the Director to determine violations and to issue compliance orders for enforcement. Violations of permits issued for dry wells shall be enforced in accordance with the civil and criminal penalties that may be imposed for violations of all other Aquifer Protection Permits, A.R.S. § 49-261 et seq. A.R.S. § 49-333.D. enables the Director to revoke a well driller's license for good cause. Disposal of hazardous substances will also be prohibited in accordance with A.R.S. § 49-333.

TENTATIVE RULE MAKING CALENDAR

October, 1988	Concept paper distributed to public for 30 day comment
January, 1989	Draft rules distributed to public
February or March	Public meetings on draft rules
May, 1989	Submit rule package to Executive Budget Office
June, 1989	GRRC hearing
July, 1989	Publication in Administrative Register
August, 1989	Oral Proceedings
October, 1989	Adoption by Director
December, 1989	Certification by Attorney General's Office

P19/DW-Cal (10/4/88)

2. If an appeal is taken from the director's decision to grant, deny, modify or revoke a permit for a facility already subject to a permit, the facility may continue to operate as long as the operation complies with the conditions of the existing permit until final disposition of the appeal.

C. Decisions by the director shall be affirmed by the appeals board unless, considering the entire record before the board, it concludes that the director's decision is arbitrary, unreasonable, unlawful or based upon a technical judgment that is clearly invalid.

D. The director or any interested person who has appealed or intervened before the board may apply to the superior court for an order requiring cessation of discharge or conditions for continued discharge pending final disposition of the appeal as necessary to prevent an imminent and substantial endangerment to public health and the environment. The court shall determine the matter under the standards applicable for granting preliminary injunctions.

Added as § 36-3624 by Laws 1986, Ch. 368, § 21, eff. Aug. 13, 1986. Renumbered as § 49-324 by Laws 1986, Ch. 368, § 36, eff. July 1, 1987.

Historical Note

For effective date provision of Laws 1986, Ch. 368, see Historical Note preceding § 49-101.

ARTICLE 8. DRY WELLS

Article 8, consisting of §§ 49-331 to 49-336 (formerly in Title 36, Chapter 16 as Article 3, consisting of §§ 36-1891 to 36-1896, added by Laws 1986, Ch. 345, § 1, effective August 13, 1986), was transferred for placement here and renumbered by Laws 1987, Ch. 317, § 22, effective August 18, 1987, retroactively effective to July 1, 1987.

Laws 1987, Ch. 317, § 22 substituted "Dry Wells" for "Injection Well Regulation" as the heading of this article.

§ 49-331. Definitions

In this article, unless the context otherwise requires:

1. "Department" means the department of environmental quality.

2. "Director" means the director of the department of environmental quality.

3. "Dry well" means a well which is A bored, drilled or driven shaft or hole whose depth is greater than its width and is designed and constructed specifically for the disposal of storm water. Dry wells do not include class 1, class 2, class 3 or class 4 injection wells as defined by the Federal Underground Injection Control Program (P.L. 93-523, part C), as amended.[1]

4. "Owner" means a person who owns a dry well or a person who owned a dry well immediately before the discontinuation of its use.

Added as § 36-1891 by Laws 1986, Ch. 345, § 1. Renumbered as § 49-331 and amended by Laws 1987, Ch. 317, §§ 22, 23, eff. Aug. 18, 1987, retroactively effective to July 1, 1987.

[1] 42 U.S.C.A. § 300h.

Historical Note

Laws 1986, Ch. 345, § 2, as amended by Laws 1987, Ch. 317, § 46, effective August 18, 1987, retroactively effective to July 1, 1987, provides:

"Sec. 2. Report to the legislature

"The director of the department of environmental quality shall issue a report to the legislature on the current state of dry wells' use in Arizona, including precautions necessary to protect groundwater and the public health, within two years of the effective date of this act."

Laws 1987, Ch. 317, § 47, effective August 18, 1987, retroactively effective to July 1, 1987, provides:

"Sec. 47. Succession

"A. The department of environmental quality succeeds to the authority, powers, duties and responsibilities relating to those programs transferred to the department by this act.

"B. This act does not alter the effect of any actions or impair the obligations of the department of health services taken or incurred before the effective date of this act.

"C. Administrative rules and orders of the department of health services relating to the programs transferred to the department of environmental quality by this act continue in effect until superseded by administrative action by the department of environmental quality.

"D. all administrative matters, applications, contracts and judicial and quasi-judicial actions, whether completed, pending or in process, relating to the programs transferred to the department of environmental quality by this act, are transferred to and retain the same status with the department of environmental quality.

"E. All records, data and investigative findings, relating to the programs transferred to the department of environmental quality by this act, are transferred to the department of environmental quality."

Library References

Words and Phrases (Perm.Ed.)

§ 49-332. Registration

A. A person who owns an existing dry well which is or has been used for disposal shall register the well on a registration form provided by the director. This form shall be accompanied by a registration fee of ten dollars. Monies collected by the department shall be deposited in the state general fund. The registration form shall include information which the director determines is necessary to meet the purpose of this article.

B. The director shall assign a registration number to each dry well registered pursuant to this section and shall maintain a permanent record of the information contained on the registration form and the registration number.

C. An owner who brings a dry well into operation after August 13, 1986 shall register the well on a registration form provided by the director and pay the registration fee of ten dollars within thirty days of beginning operations.

D. A person who installs a dry well shall notify the owner of the registration requirements of subsection C.

E. This article shall not be construed to legalize any dry well existing on August 13, 1986 which is not in compliance with this chapter and chapter 5 of this title.[1]

Added as § 36-1892 by Laws 1986, Ch. 345, § 1. Renumbered as § 49-332 and amended by Laws 1987, Ch. 317, §§ 22, 24, eff. Aug. 18, 1987, retroactively effective to July 1, 1987.

[1] Section 49-901 et seq.

Historical Note

The 1987 amendment deleted transitional provisions, supplied the date in lieu of "the effective date of this section", and modified statutory references in subsec. E.

1986 Reviser's Note:

Prior to the 1987 renumbering and amendment, in subsections C and E the word "section" was substituted for "act" pursuant to authority of § 41-1304.02.

§ 49-333. Regulation of dry wells; license to drill

A. The director may adopt rules establishing standards for new and existing dry wells pertaining to their performance, operation, construction, design, closure, location and inspection.

B. Dry wells shall not be used for the disposal of hazardous substances as defined in the Comprehensive Environmental Response, Compensation, and Liability Act (P.L. 96-510), as amended,[1] or oil as defined in the Federal Water Pollution Control Act (P.L. 92-500), as amended.[2]

C. New dry well construction, including modifications of existing dry wells, shall be performed under the direct and personal supervision of a well driller who holds a dry well driller's license issued under this section. A person who intends to construct or modify one or more dry wells in this state shall file an application for a dry well driller's license with the director. The application shall include:

1. The name, mailing address and place of business of the applicant.
2. The applicant's experience and qualifications.
3. Such other information as the director may require.

D. The director shall, by rule, establish qualifications and a reasonable fee of not more than fifty dollars for licenses for dry well drillers and establish procedures for the evaluation and licensing of applicants. The rules shall establish qualifications for the protection of the public and shall include knowledge in the areas of location, design, construction, operation, maintenance and closure of dry wells. A nontransferable dry well driller's license shall be issued if the director finds that the applicant meets the qualifications established by the director. The director may revoke a well driller's license for good cause.

Added as § 36-1893 by Laws 1986, Ch. 345, § 1. Renumbered as § 49-333 by Laws 1987, Ch. 317, § 22, eff. Aug. 18, 1987, retroactively effective to July 1, 1987.

[1] 42 U.S.C.A. § 9601 et seq.

[2] 33 U.S.C.A. § 1251 et seq.

§ 49-334. Enforcement and penalties

A. If the director determines that a person is violating a provision of this article or any rule adopted pursuant to this article he may issue an order requiring compliance within a reasonable time. A compliance order becomes final thirty days after the order is served unless within thirty days of service the person named on the order requests a hearing. A hearing shall be conducted pursuant to title 41, chapter 6.[1] The director's decision may be appealed by any party to the superior court pursuant to title 12, chapter 7, article 6.[2]

B. The director may file an action in the superior court to enforce this article. The director may seek all appropriate relief including temporary and permanent injunctions.

Added as § 36-1894 by Laws 1986, Ch. 345, § 1. Renumbered as § 49-334 and amended by Laws 1987, Ch. 317, §§ 22, 25, eff. Aug. 18, 1987, retroactively effective to July 1, 1987.

[1] Section 41-1001 et seq.

[2] Section 12-901 et seq.

Historical Note

The 1987 amendment substituted "article" for "chapter" in the first sentence of subsec. B.

§ 49-335. Rules

The director shall adopt rules necessary to provide procedures for the administration of this article and to implement the program for the regulation of dry wells established by this article.

Added as § 36-1895 by Laws 1986, Ch. 345, § 1. Renumbered as § 49-335 and amended by Laws 1987, Ch. 317, §§ 22, 26, eff. Aug. 18, 1987, retroactively effective to July 1, 1987.

§ 49-336. Exemption; golf courses

Provisions of this article shall not apply to dry wells used in conjunction with golf course maintenance.

Added as § 38-1896 by Laws 1986, Ch. 345, § 1. Renumbered as § 36-1896. Renumbered as § 49-336 by Laws 1987, Ch. 317, § 22, effective Aug. 18, 1987, retroactively effective to July 1, 1987.

Historical Note

1986 Reviser's Note:

Pursuant to authority of § 41-1304.02, this section [former § 36-1896, renumbered as § 49-336] added by Laws 1986, Ch. 345, § 1 as § 38-1896, was renumbered as § 36-1896.

ARTICLE 9. POTABLE WATER SYSTEMS

Article 9, consisting of §§ 49-351 to 49-354 (formerly in Title 36, Chapter 16 as Article 2, consisting of §§ 36-1881 to 36-1884 added by Laws 1982, Ch. 287, § 4 effective May 3, 1982), was transferred for placement here and renumbered by Laws 1987, Ch. 317, § 27, effective August 18, 1987, retroactively effective to July 1, 1987.

Laws 1987, Ch. 317, § 27 substituted "Potable Water Systems" for "Water Quality Control" as the heading of this article.

INSTRUCTIONS FOR COMPLETING
DRY WELL REGISTRATION FORM

1. I.A. - Provide a name by which the facility may be referred to in all correspondence between involved entities. The location address should be a street address or descriptive in relation to major streets, e.g., 1/4 mile east of Major Street on Minor Road.

   If different from owner, the contact person should be a person of responsibility with which the Department can deal during and after the registration process. More than one person may be provided.

2. I.B. - Indicate the owner of the facility whenever possible. In any case, supply the party responsible for having the well(s) drilled.

3. I.C. - Give the location of the facility (not each dry well) in the township, range format. Break the section down to a 2.5 acre parcel if possible (1/4,1/4,1/4,1/4).

4. I.D. - Check all general categories which best describes the nature of the activity conducted at the facility.

5. I.E. - Indicate the type of chemicals, liquids, or solvents that are used, stored, or produced for businesses that apply.

6. I.F. - Obtain the most recent water table depth available. Give source of the data whether direct well measurement, driller's information, or an agency such as the Department of Water Resources (DWR). DWR is probably the best source in most cases. If the measurement is of a perched water table, so indicate. Include the date of the measurement when possible.

7. I.G. - Include water supply wells as described.

8. I.H. - Include a site plan of the facility as described.

9. I.I. - Indicate the drilling firm which drilled, or is intended to drill the dry well(s). If more than one firm is used, list all firms.

10. II.COLUMN B - If you have a special numbering system for the dry wells at the facility, list them here. The wells should be designated as such on the site plan.

11. II.COLUMN C - Indicate the status of each well. Active wells are those which are completed, and are ready to receive stormwater runoff. Newly completed wells which have been capped should be considered "UNDER CONSTRUCTION". "TEMPORARILY ABANDONED" wells would more appropriately apply to existing dry wells which have been temporarily taken out of service for some reason. "PERMANENTLY ABANDONED" means a well that has been destroyed by excavation or by backfilling with grout or other substances.

12. II.COLUMN D - Place either the actual depth drilled or the proposed depth (if filing this form prior to drilling) in this column.

13. II.COLUMN E - Place the actual or expected completion date for each well in this column.

14. II.COLUMN F - For each dry well, check appropriate area from which stormwater would drain into the dry well.

15. II.COLUMN G - If other liquids, such as air conditioning condensate, commonly drain into a dry well, please describe in this column. Also indicate liquids stored in such a manner that they might reach the dry well if spilled.

16. Sign and date the form in the space provided, include a check or money order for $10.00 for each set of ten dry wells payable to the Arizona Department of Environmental Quality and mail or deliver the form to:

    Arizona Department of Environmental Quality
    2005 N. Central Avenue
    Phoenix, Arizona 85004

17. III. - Please send the Drilling Log to the driller(s) listed on page 1 of this form. The dry well driller shall complete the form, and shall provide copies to the dry well owner and the Department at the following address within 30 days of completion of the dry well:

    Arizona Department of Environmental Quality
    Water Permits Unit, Room 300
    2005 N. Central Avenue
    Phoenix, Arizona 85004

18. Any questions concerning this form may be directed to the above address or to (602) 257-2270.

Office Use Only

Registration Number(s)

__ __ - __ __ __ __ __ __ - __ __

thru __ __ __ __ __ __

DATE:________ BY:______

ARIZONA DEPARTMENT OF ENVIRONMENTAL QUALITY
DRY WELL REGISTRATION

I. Facility Information

A. Facility/Project Name ______________________________

Location Address ______________________________

______________________ Zip Code ____________

Contact Person at Dry Well Location ________________ Title ____________

Telephone Number (   ) __________

B. Owner/Developer ______________________________

Mailing Address ______________________________

____

______________________ Zip Code ____________

Telephone Number (   ) ______________

C. Physical Location: Township ________, Range ________
Section ____, ___1/4, ___1/4, ___1/4, ___1/4

D. Nature of Business (Check all that apply)

__(00)Residential
__(01)Schools, churches & recreational fac.
__(02)Offices & Retail
__(03)Warehouse
__(04)Manufacturing
__(05)Ind/Ag Processing
__(06)Mining/Milling
__(07)Chem & Fuel Stor.
__(08)Vehicular Serv.
__(09)Other (explain) ____________

E. List any amount of liquids, solvents, or other chemicals that are produced used or stored at this facility ______________________________

____

F. Depth to Groundwater __________ Date of Measurement __________

Source of Data ______________________________
Give well locations if applicable)

G. Location of any water supply wells within 100 feet of the property boundry ______________________

H. Include site plan and vicinity map showing:
1) location of the dry wells
2) delineation of the drainage areas

I. Drilling Firm ______________________________

Address ______________________________

______________________ Zip Code ____________

II. DESCRIPTION OF INDIVIDUAL DRY WELLS

COLUMN A	COLUMN B	COLUMN C					COLUMN D	COLUMN E	COLUMN F											COLUMN G
DRY WELL NUMBER (Complete one line of table for each well)	DRY WELL NUMBER according to your own system, if applicable	WELL OPERATION STATUS Place "X" in one column for each well					TOTAL DEPTH of hole drilled for well in feet (or proposed)	DATE well was completed (or expected completion date)	DESCRIPTION OF AREAS DRAINED BY THE DRY WELL; Place "X" in all subcolumns which apply to the areas described											DESCRIBE FLUIDS OTHER THAN STORM WATER which are commonly received by the dry well.
		ACTIVE	TEMPORARILY ABANDONED	PERMANENTLY ABANDONED	UNDER CONSTRUCTION	PROPOSED ONLY			DRIVEWAYS & PARKING LOTS	ROOF TOPS	STREETS	LOADING DOCKS	LANDSCAPED AREAS	CHEMICAL STORAGE	VEHICULAR SERVICING	LIVESTOCK CONFINEMENT	AGRICULTURAL AREAS	GOLF COURSE	OTHER (EXPLAIN)	
WELL #1																				
WELL #2																				
WELL #3																				
WELL #4																				
WELL #5																				
WELL #6																				
WELL #7																				
WELL #8																				
WELL #9																				
WELL #10																				

III. CERTIFICATION

I certify under penalty of law that I have personally examined and am familiar with the information submitted in this and all attached documents, and that based on my inquiry of those individuals immediately responsible for obtaining the information, I believe that the submitted information is true, accurate, and complete.

Name and official title of owner/owner's authorized representative Address & Phone Number	Signature	Date Signed

PART III

DRILLING LOG
(To Be Completed By Driller)

Please describe materials encountered during drilling. Include color, grain size, and moisture content.		Draw a diagram of the dry well <u>as built</u>, indicating materials used, all diameters, and depths.
DEPTH	SOIL DESCRIPTION	

Special remarks:

I attest the above information is true and correct.

Driller's Signature_______________________ Date__________

Office Use Only
Registration Number(s)
__ __.__ __ __ __ __ __.__ __
thru __ __ __ __ __ __
Date:________ By:_____

APPENDIX 2

CITY OF TUCSON DRY-WELL POLICY

(28)

CITY OF TUCSON

The Sunshine City • P.O. BOX 27210
TUCSON, ARIZONA 85726-7210

DEPARTMENT OF TRANSPORTATION
ENGINEERING DIVISION
(602) 791-4251

March 31, 1986

TO: ENGINEERS AND ARCHITECTS

SUBJECT: DRY WELLS POLICY

On August 19, 1985, the City of Tucson issued a notice to all engineers and architects establishing a policy to discontinue use of dry wells as an alternative to flood control/drainage solutions. This came about as a result of community concern over a potential groundwater contamination problem, specifically expressed by Tucson Water.

On March 11, 1986, Pima County Board of Supervisors adopted a dry well policy which permits installation of dry wells in unincorporated Pima County on a restrictive basis. The restrictions set forth by the Pima County Engineer have been reviewed by both the City of Tucson Water and Transportation (City Engineer's Office) Departments.

This communication is a notification to the development community of Tucson that the City's Floodplain Management Section will approve dry wells in sites developed within the corporate limits of the City of Tucson on a limited basis. The restrictions approved by the Board of Supervisors will apply to all site development projects considering dry well installations. A copy of the restrictions is enclosed with this notice for your reference.

This notice lifts the the dry well moratorium in the City of Tucson on a limited basis, starting April 2, 1986.

Very truly yours,

Benny J. Young

Benny J. Young, P.E.
City Engineer

BJY/YDD/klb

Enclosure
dwpolicy.doc

INTERIM GUIDELINES GOVERNING THE DRY WELL POLICY: RESTRICTIONS

The following restrictions will apply to the proposed use of dry wells within the Corporate Limits of the City of Tucson:

1. DRY WELLS WILL NOT BE PERMITTED FOR INDUSTRIAL DEVELOPMENTS. Industrial subdivisions often contain building shells that are constructed prior to the finalization of the owner/user that is to occupy the structure. Dry wells are not acceptable in industrial developments due to the potential for a wide variety and magnitude of contaminants from industrial uses, and the potential for accidental or purposeful disposal of industrial waste within dry wells.

2. DRY WELLS SHALL NOT ADMIT RUNOFF FROM INTENSIVELY IRRIGATED LANDSCAPED AREAS. The use of pesticides and insecticides in landscaping in commercial and residential areas contribute a significant portion of the organic compounds that may adversely impact groundwater. Proper landscaping and berm design should be used to prevent landscape irrigation water from entering dry wells.

3. DRY WELLS IN RESIDENTIAL AREAS SHALL HAVE A MINIMUM VERTICAL SEPARATION OF SEVENTY FIVE (75) FEET FROM THE INVERT OF THE DRY WELL TO THE STATIC GROUNDWATER TABLE ELEVATION.

4. DRY WELLS IN COMMERCIAL OR BUSINESS ZONING AREAS SHALL HAVE A MINIMUM VERTICAL SEPARATION OF ONE HUNDRED TWENTY FIVE (125) FEET FROM THE DRY WELL INVERT TO THE STATIC GROUNDWATER TABLE ELEVATION.

5. ALL DRY WELLS SHALL HAVE A MINIMUM HORIZONTAL SEPARATION OF THREE HUNDRED FEET FROM A CASED WATER SUPPLY WELL.

6. ALL DRY WELLS SHALL HAVE A MINIMUM HORIZONTAL SEPARATION OF FIVE HUNDRED FEET FROM A NON-CASED WATER SUPPLY WELL.

7. ANNUAL INSPECTION AND MAINTENANCE SHALL BE PERFORMED BY THE OWNER. Sediment that is periodically removed from a dry well settling chamber is to be disposed of in a City or County-operated sanitary landfill.

8. RETENTION OF FLOODWATERS THROUGH THE USE OF DRY WELLS SHOULD ONLY BE USED FOR INCREASED ONSITE FLOODWATER RUNOFF. Offsite or through stream runoff shall not be captured and drained into a dry well.

9. RECORDS SHALL BE MAINTAINED BY THE INSTALLER AND SHALL INCLUDE A DETAILED DRILLER'S LOG OF THE GEOLOGICAL MATERIALS ENCOUNTERED AND AN AS-BUILT DETAIL OF THE CONSTRUCTED DRY WELL. These records shall be certified by the project engineers and provided to the County at project completion prior to final approval.

APPENDIX 3

ANALYTICAL METHODS, PARAMETERS AND MINIMUM DETECTABLE CONCENTRATIONS

VOLATILE ORGANIC COMPOUNDS

METHOD 8240

COMPOUND	MINIMUM DETECTABLE CONCENTRATION Soil (mg/Kg)	Water (ug/L)
chloromethane	0.20	1.00
bromomethane	0.10	1.00
vinyl chloride	0.10	1.00
chloroethane	0.20	1.00
methylene chloride	0.90	40.00
1,1 dichloroethene	0.10	1.00
1,1 dichloroethane	0.10	1.00
trans-1,2-dichloroethene	0.10	1.00
chloroform	0.10	1.00
1,2-dichloroethane	0.20	1.00
1,1,1-trichloroethane	0.10	1.00
carbon tetrachloride	0.10	1.00
bromodichloromethane	0.10	1.00
1,2-dichloropropane	0.20	3.00
trans-1,3-dichloropropene	0.20	1.00
trichloroethene	0.50	3.00
dibromochloromethane	0.20	1.00
1,1,2-trichloroethane	0.20	1.00
benzene	0.10	1.00
cis-1,3-dichloropropene	0.20	1.00
bromoform	0.20	1.00
tetrachloroethene	0.20	1.00
1,1,2,2-tetrachloroethane	0.30	3.00
toluene	0.10	1.00
chlorobenzene	0.10	1.00
ethylbenzene	0.30	2.00
total xylenes	0.60	6.00
1,3-dichlorobenzene	0.30	
1,4-dichlorobenzene	0.30	
1,2-dichlorobenzene	0.30	

SEMIVOLATILE ORGANIC COMPOUNDS
ACID AND BASE/NEUTRAL COMPOUNDS

METHOD 8270

COMPOUND	MINIMUM DETECTABLE CONCENTRATION Soil (mg/Kg)	Water (ug/L)
phenol	0.50	1.00
bis(2-chloroethyl)ether	0.50	1.00
2-chlorophenol	0.50	1.00
1,3-dichlorobenzene	0.50	1.00
1,4-dichlorobenzene	0.50	1.00
1,2-dichlorobenzene	0.50	1.00
bis(2-chloroisopropyl)ether	0.50	1.00
n-nitroso-di-n-propylamine	0.50	1.00
hexachloroethane	0.50	1.00
nitrobenzene	0.50	1.00
isophorone	0.50	1.00
2-nitrophenol	0.50	1.00
2,4-dimethylphenol	0.50	1.00
bis(2-chloroethoxy)methane	0.50	1.00
2,4-dichlorophenol	0.50	1.00
1,2,4-trichlorobenzene	1.00	1.00
naphthalene	0.50	1.00
hexachlorobutadiene	0.50	1.00
4-chloro-3-methylphenol	0.50	1.00
hexachlorocyclopentadiene	0.50	1.00
2,4,6-trichlorophenol	0.50	1.00
2-chloronaphthalene	0.50	1.00
dimethyl phthalate	4.00	8.00
acenaphthylene	0.50	1.00
acenaphthene	0.50	1.00
2,4-dinitrophenol	2.50	5.00
4-nitrophenol	1.00	1.00
2,4-dinitrotoluene	0.50	1.00
2,6-dinitrotoluene	0.50	1.00
diethylphthalate	0.50	1.00
4-chlorophenyl-phenylether	0.50	1.00
fluorene	0.50	1.00
4,6-dinitro-2-methylphenol	1.00	1.00
n-nitrosodiphenylamine	0.50	15.00
4-bromophenyl-phenylether	1.00	1.00
hexachlorobenzene	1.50	1.00
pentachlorophenol	2.50	1.00
phenanthrene	1.00	1.00
anthracene	1.00	1.00
di-n-butylphthalate	0.50	3.00
fluoranthene	0.50	2.00

SEMIVOLATILE ORGANIC COMPOUNDS
ACID AND BASE/NEUTRAL COMPOUNDS

METHOD 8270
(Continued)

COMPOUND	MINIMUM DETECTABLE CONCENTRATION Soil (mg/Kg)	Water (ug/L)
pyrene	0.50	1.00
butylbenzylphthalate	0.50	1.00
3,3'-dichlorobenzidine	19.00	38.00
benzo(a)anthracene	0.50	1.00
bis(2-ethylhexyl)phthalate	4.50	9.00
chrysene	1.00	2.00
di-n-octylphthalate	0.50	1.00
benzo(b)fluoranthene	1.00	2.00
benzo(k)fluoranthene	1.00	2.00
benzo(a)pyrene	0.50	1.00
indeno(1,2,3-cd)pyrene	0.50	1.00
dibenz(a,h)anthracene	0.50	1.00
benzo(g,h,i)perylene	0.50	1.00

CHLORINATED HERBICIDES

METHOD 8150

COMPOUND	MINIMUM DETECTABLE CONCENTRATION Soil (mg/Kg)	Water (ug/L)
dicamba	1.0	100
2,4-D	0.2	20
silvex	0.1	10
2,4,5-T	0.1	10
MCPA	30	3000
MCPP	40	4000

ORGANOCHLORINE PESTICIDES AND PCB'S

METHOD 8080

COMPOUND	MINIMUM DETECTABLE CONCENTRATION Soil (mg/Kg)	Water (ug/L)
alpha-BHC	0.07	0.50
gamma-BHC (Lindane)	0.06	0.50
beta-BHC	0.08	0.50
heptachlor	0.10	0.50
delta-BHC	0.07	0.50
aldrin	0.05	0.50
heptachlor epoxide	0.10	0.50
endosulfan I	0.10	0.50
4,4'-DDE	0.10	0.50
dieldrin	0.10	0.50
endrin	0.10	0.50
4,4'-DDD	0.10	0.50
endosulfan II	0.10	0.50
4,4'-DDT	0.10	0.50
endrin aldehyde	0.10	0.50
endosulfan sulfate	0.10	0.50
chlordane	1.0	5.0
toxaphene	5.0	25.
PCB-1016	1.0	5.0
PCB-1221	1.0	5.0
PCB-1232	1.0	5.0
PCB-1242	1.0	5.0
PCB-1248	1.0	5.0
PCB-1254	1.0	5.0
PCB-1260	1.0	5.0

ORGANOPHOSPHOROUS PESTICIDES

METHOD 8140

COMPOUND	MINIMUM DETECTABLE CONCENTRATION Soil (mg/Kg)	Water (ug/L)
diazinon	0.004	0.15
disulfoton	0.003	0.15
methyl-parathion	0.01	0.10
malathion	0.008	0.20
ethion	0.004	0.10
atrazine	0.12	0.10
dioxathion	0.06	2.5
DEF	0.02	0.15
CDEC	0.20	0.30
bolstar	0.02	0.15
chloropyrifos	0.01	0.15
EPN	0.06	0.10
Fensulfothion	0.29	3.5
fenthion	0.02	0.045
parathion	0.02	0.10
phorate	0.01	0.15
ronnel	0.03	0.20
iokuthion	0.02	0.15
TEPP	0.04	1.0
naled	1.9	0.10
dichlorvos	0.008	0.35
demeton	0.009	0.15
carbofuran	0.009	0.15
mevinphos		1.0
sulfotepp		0.10
merphos		0.20
tetrachlorovinphos		0.40
monocrotophos		0.50
coumaphos		0.50
simazine		0.15
ethoprop		0.03
DNBP		1.5
dimethoate		0.10
guthion		3.0

PRIORITY POLLUTANT METALS

WASTE EXTRACTION TEST

COMPOUND	MINIMUM DETECTABLE CONCENTRATION Soil (mg/Kg)	Water (mg/L)
antimony	1.0	0.20
arsenic	1.0	0.10
beryllium	0.10	0.0050
cadmium	0.10	0.010
chromium	0.50	0.010
copper	0.50	0.050
lead	0.50	0.10
mercury	0.010	0.0010
nickel	0.50	0.050
selenium	0.10	0.0050
silver	0.10	0.010
thallium	1.0	0.10
zinc	0.50	0.050

HALOGENATED/AROMATIC COMPOUNDS

METHOD 8010/8020

COMPOUND	DETECTION LIMIT (ug/l)
benzene	0.025
bromodichloromethane	0.010
bromoform	0.010
bromomethane	0.010
carbon tetrachloride	0.010
chlorobenzene	0.025
chloroethane	0.010
chloroform	0.010
chloromethane	0.010
dibromochloromethane	0.010
1,2-dichlorobenzene	0.025
1,3-dichlorobenzene	0.025
1,4-dichlorobenzene	0.025
dichlorodifluoromethane	0.010
1,1-dichlorethane	0.010
1,2-dichloroethane	0.010
1,1-dichloroethene	0.010
trans-1,2-dichloroethene	0.010
1,2-dichloropropane	0.010
cis-1,3-dichloropropene	0.010
trans-1,3-dichloropropene	0.010
ethylbenzene	0.025
methylene chloride	0.010
1,1,2,2-tetrachloroethane	0.010
tetrachloroethene	0.010
toluene	0.025
1,1,1-trichloroethane	0.010
1,1,2-trichloroethane	0.010
trichloroethene	0.010
trichlorofluoromethane	0.010
vinyl chloride	0.010
meta xylene	0.025
ortho & para xylene	0.025

APPENDIX 4

QUALITY CONTROL/SOURCES OF ERROR

QUALITY CONTROL/SOURCES OF ERROR

A. Industrial Well Site, I-1

o Laboratory Analyses

Twenty percent of the 17 sediment samples collected were split and analyzed for the same parameters by independent laboratories. The split consisted of sending the lower six-inch core to one laboratory and the middle six-inch core from the same sample interval to another laboratory. Samples selected for quality control were not selected at random. Rather, sample intervals expected to contain similar lithologic compositions were selected from the cores in which total sample recovery was achieved (i.e. no voids were present within the sample container). Despite this selection process, some spatial variation within the sediment is to be expected.

o Field Problems

During soil boring and sample collection, foreign material was introduced into the borehole. The sample results were not biased by these intrusions. However, hey serve to exemplify the variety of problems which are likely to occur during field investigations in general, and hollow-stem augering in particular. The specific intrusions were as follows:

o Gasket Material in Sample Slough.

Gasket material was used between auger flights to prevent borehole drift and wear on the joints. The material consisted of a stack of paper hand towels approximately one-eighth inch thick. A concern is that chemicals in the paper may be extracted with soil samples, introducing errors in the results. The slough was easily distinguished from the undisturbed sample and was readily removed. In addition, contaminants in the paper would have to penetrate six-inches of sediment in the top core to reach the middle core which was analyzed. Accordingly, it is unlikely that the paper affected the analytical results. In the future, prefabricated gasket material is recommended which does not extend into the hollow auger-stem.

o Leaf Debris in Sample Slough.

Lengths of hollow A-rods were used as extenders to lower the sampling device into the borehole. Most of the rods were disconnected in 20-foot lengths and suspended above the ground in front of the drill rig. When shorter lengths were used they were returned to a platform on the rig. Apparently some leaf debris entered one of the A-rods and fell to the top of the 45-foot sample during collection. This is not expected to have contaminated the middle core for the same reason stated above for the gasket material.

o Grease Spots on Top of Samples.

A problem similar to the leaf debris was encountered at 85 feet when grease spots were noted on the top of a split-spoon sample. After considerable investigation the source was determined to be drops of asphalt picked up when the A-rod was resting on the hot pavemement. No asphalt constituents were detected in the vadose-zone samples.

o Contaminants in Drilling Fluid.

Two and one-half gallons of demineralized water were added to the hole on three occasions. Because the driller had expected to need over 200 gallons of water for drilling fluid, the water was transported to the site in new, steam-cleaned, 55- gallon drums. Water was added to the borehole by dipping a five-gallon metal bucket, painted on the outside, into the drum containing demineralized water and then pouring the water down the outside of auger flights. A sample of the drilling fluid contained 42.0 ug/L of toluene and 1.0 ug/L of xylenes. The source of the contamination is unknown; however, the paint on the five-gallon bucket is suspected.

No toluene or xylenes were detected in the sediment samples and it is unlikely the drilling fluid reached the bottom of the hole because the fluid was added when silt and clay from the hole were sticking to the auger flights. Two and one-half gallons of water would be readily absorbed by the silt and clay on the auger flights before reaching the bottom of the hole. However, the uncertainty in interpreting the results, had xylenes or toluene been detected, might have jeopardized the validity of the results. Extreme caution is warranted when considering the use of drilling fluid, despite the likelihood of antagonizing the driller.

o Runoff in Dry Well During Drilling.

Approximately 150 gallons of condensate from the steam cleaner might have drained into the dry well during the first nine hours of drilling. The water entering the dry well did so in a small trickle over a long period of time. There is no evidence that this water penetrated the borehole.

B. Commercial Dry-Well Site, C-1

o Spatial Variability

A potential short-coming of the sediment sampling methodology used in this research project is the fact it provides discrete rather than continuous information on the geology of the profile. Both the field log and the laboratory particle size analysis are based on 6 inch cored samples, retrieved on the average, at 5 ft drilling intervals. Based on the known stratigraphic variability associated with fluvial depositional environments, this sampling methodology may not completely describe the stratigraphy of the borehole. It is possible that narrow horizons with anomalous variations in grain-size or moisture content may have been only partially sampled or completely missed. In spite of this potential source of error, it is assumed for the purpose of this research project that the sampling technique used here adequately represents the vadose zone stratigraphy at the dry well site.

Spatial variability is also manifested in the differences in grain size distribution that may occur over short distances both horizontally and vertically in the vadose zone. Because of this, particle size analysis, if performed on boreholes II and III, may have yielded results quite different than those obtained for borehole I. In order to characterize the general properties of the commercial dry well site, it is assumed that geologic information obtained from the profile in borehole I is roughly representative of the area.

o Temporal Variation

The time of sampling, particularly with respect to runoff events, can have a significant effect on both the moisture profile and the pollutants found in the vadose zone. Generally, the overall moisture content is greater during the rainy seasons than during the dry seasons, with a lag factor allowing for internal drainage. At this site, variations in the watering schedule for the outdoor garden center can have a similar effect on moisture content. The moisture content in turn affects the mobility, and hence, the concentration, of various pollutants. Temperature and evaporation rates are two parameters that vary throughout the year and directly affect the transport of contaminants.

The first flush, which is runoff generated at the start of a rainy season, typically contains significantly higher concentrations of pollutants which have accumulated over time.

o Differences in Analytical Detection Limits

There is an approximate three order of magnitude difference between the detection limit for organic constituents in soil samples and water samples. This difference in sensitivity makes comparison between potential contaminants in the vadose zone and ground water difficult. For example, an organic species may be detected in the ground water in parts per billion, but not appear in the dry well or soil samples due to the detection limit of the analytical procedure, which is in the parts per million range. The source of such a contaminant, is therefore difficult to determine, although it may indeed be from dry well drainage. This discrepancy in detection limits is a shortcoming of the analytical process as it currently exists.

In some cases, the detection limit can be improved by changing the analytical method. Volatile organics, which were originally analyzed on the GC/MS using method 8240, showed improved sensitivity when analyzed on the GC as halogenated volatiles and aromatic volatiles, methods 8010 and 8020, respectively. The acid and base neutral compounds, which were also analyzed using the GC/MS, can be analyzed on the GC in several subgroups such as phenols and phthalates. However, the sum of these analyses covers less than half of the compounds included in method 8270 on the GC/MS. Therefore, analysis of acid and base neutral compounds on the GC is not a viable alternative.

o <u>Moisture Content Determinations</u>

In general, gravimetric moisture should be considered more accurate than volumetric moisture as a measure of relative moisture in the soil profile. This is true because volumetric moisture calculations are based on bulk density estimates, whereas gravimetric moisture is simply computed as the ratio of the dry to the wet weight of the soil sample.

Inaccuracy in the determination of soil bulk density may have arisen from the approximation of the volume of the brass sleeve occupied by a given soil sample in cases where the sleeve was not completely filled. In addition, the sampling technique itself, which entailed pounding the soil material into the ring sampler, causes unnatural compaction of sediments which could result in consistently higher bulk density values. The degree of compaction of the sediments during sampling may also be inconsistent from one sample to another.

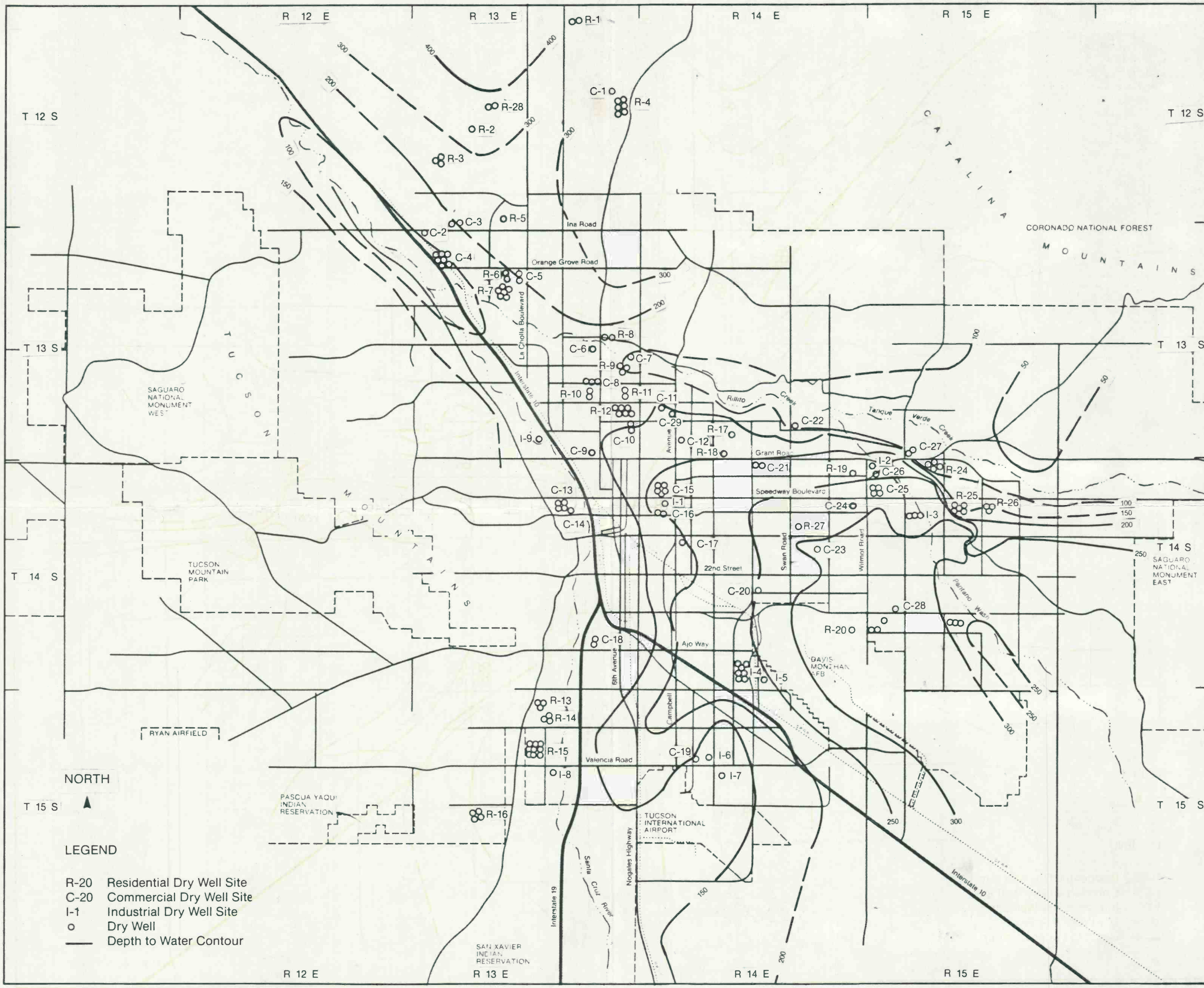

Plate 1. Known Dry Well Locations in the Tucson Basin with Depth to Water Contours.