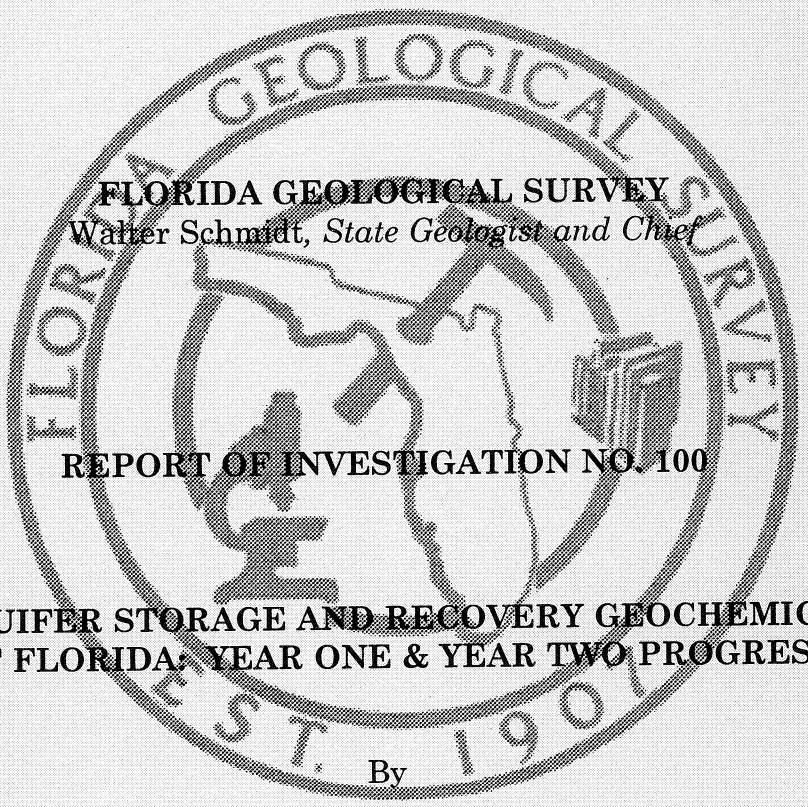
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FLORIDA GEOLOGICAL SURVEY
Walter Schmidt, *State Geologist and Chief*

REPORT OF INVESTIGATION NO. 100

FLORIDA AQUIFER STORAGE AND RECOVERY GEOCHEMICAL STUDY, SOUTHWEST FLORIDA: YEAR ONE & YEAR TWO PROGRESS REPORT

By

Holly Williams, James B. Cowart, and Jonathan D. Arthur

FLORIDA GEOLOGICAL SURVEY
Tallahassee

A final report of the draft submitted to the Underground Injection Control Program, Bureau of Water Facilities Regulation, Division of Water Rsource Management, Florida Department of Environmental Protection
2002

METRIC CONVERSION FACTORS

To eliminate duplication of parenthetical conversion of units in the text of reports, the Florida Geological Survey has adopted the practice of inserting a tabular listing of conversion factors. For readers who prefer U.S. units to the metric units used in this report, the following conversion factors are provided.

MULTIPLY	BY	TO OBTAIN
feet (ft)	30.48	centimeters (cm)
feet (ft)	0.3048	meters (m)
cubic feet (ft^3)	0.0283	cubic meters (m^3)
square feet (ft^2)	929	square centimeters (cm^2)
square feet (ft^2)	0.0929	square meters (m^2)
gallons (g)	3.785	liters (l)
gallons (g)	0.00378	cubic meters (m^3)
gallons (g)	0.1337	cubic feet (ft^3)
million gallons per day (mgd)	0.0438	cubic meters per second (m^3/s)
gallons per minute (gpm)	5.451	cubic meters per day (m^3/day)
feet per day	$3.53x10^{-4}$	centimeters per second (cm/sec)

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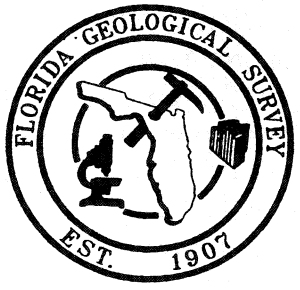
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PREFACE



This publication represents the results of continuing cooperation with our sister programs within the Department of Environmental Protection. The report summarizes the results of a cooperative project between the DEP Division of Water Resource Management, Underground Injection Control Program, and the Florida Geological Survey, Hydrogeology Research Program. It presents needed data on the geochemical processes related to design and permitting of Aquifer Storage and Recovery Facilities in Florida. Research such as this is critical to the understanding of our groundwater resources and the subsurface aquifers which contain this precious life sustaining natural resource. As Florida continues to develop and demand for freshwater continues to grow, understanding of our underground aquifers and the dynamics of water transport and associated geochemistry becomes ever more critical.

Walt Schmidt, Ph.D., PG.
State Geologist & Chief
Florida Geological Survey

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ABSTRACT

Uranium concentrations and $^{234}U/^{238}U$ activity ratios (AR) were determined for waters associated with two aquifer storage and recovery (ASR) facilities in southwest Florida. These ASR programs involve recharge of treated surficial water into carbonate aquifers, storage of waters in the aquifers, then recovery of the recharged water when needed. The storage zone in each case is the Suwannee Limestone. Uranium concentration of water recovered from the storage zone at the Hillsborough County site increased with time from 1.26 ug/L, to as high as 7.26 ug/L. Dilution of the recharged water also increased with time, having the reverse effect on uranium concentration of the final samples of recovered water. Activity ratios measured between 0.37 and 1.00 in recovered water, increasing with time. Uranium concentration in recovered water from the storage zone at the Charlotte County site increased with time from 0.06 ug/L to 5.79 ug/L. Dilution of the recharged water decreased the uranium concentration of recovered water with time to 2.28 ug/L. Activity ratios increased with time from .91 to 1.30. Uranium concentrations would be expected to increase with the introduction of oxygen-rich water due to its mobility in oxic conditions. Increasing AR at the Charlotte County site is affected by dilution with native water. At the Hillsborough County site, mobilization and leaching of uranium and dissolution of the aquifer rock matrix having a ^{234}U-deficient rind resulted in increasing activity ratios as interior, higher activity ration parts of the grain come in contact with the input water. Activity ratios below 0.5 are thought to be evidence of a ^{234}U-deficient ultra-thin coating of uranium on the aquifer rock surfaces. High activity ratios (>1.0) may be the result of enrichment of ^{234}U in the carbonate rock due to alpha recoil of ^{234}Th from an ultra-thin coating of uranium on the rock/grain surfaces. Uranium concentrations and the AR of recovered waters are also affected by the varying uranium isotope signature of the recharge water. Geochemical processes involving water-rock interaction clearly affect changes in water chemistry of recovered waters during ASR activities.

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By

Holly Williams, James B. Cowart, P.G. #385, and Jonathan D. Arthur, P.G. #1149

INTRODUCTION

Continued rapid urbanization, industrial growth, and agricultural demand are placing a burden on Florida's potable water supplies. Increasing population is detrimental to limited water sources, especially in coastal regions where encroaching saltwater can permanently damage fresh-water aquifer systems. Surface reservoirs such as water towers, rivers and lakes are limited in number and size by topography, real estate and capital. As the demand for water increases reserves in surface reservoirs and aquifers can become inadequate especially during dry seasons. Alternative storage methods are therefore being sought to increase the availability of water year round.

Aquifer storage and recovery is one alternative storage method that is quickly becoming widely used. Aquifer storage and recovery, or ASR, is a cyclic process which involves recharge of treated surficial water into an aquifer where it is stored for a period of time, and then recovered when needed. A recent concern with this method is the geochemical interaction between the recharged surface water and the native aquifer system.

The introduction of the oxygen-rich surficial water into a less oxygen-rich environment results in geochemical and isotopic changes within the environment of mixing. The interaction between environments includes the mixing of two or more waters and/or contact between water and rock or soil. In this situation, a geochemical change that may take place is the release, or mobilization, of uranium from the rock or soil into the surrounding water. In addition to uranium, other trace metals may be released to the water column by the water-rock interaction, and mixing between the native and recharge waters may change the geochemical signature of the water that will ultimately be recovered. The geochemical effect of introducing oxygen-rich water into an oxygen-poor environment on the native and recharge/recovery water and the chemical and possible physical changes in the aquifer rock is addressed in this investigation by the Florida Geological Survey (FGS) and the Florida State University (FSU) Department of Geology.

AQUIFER STORAGE AND RECOVERY (ASR)

A relatively new, cost-effective method to increase the volume of available water for use by the general public, industry and the agricultural community is called aquifer storage and recovery, or ASR. ASR is a cyclic process that begins with recharge, whereby large volumes of treated drinking water are pumped underground when an excess amount of water is available. The water is stored underground until it is removed, or recovered, to meet seasonal, long term, or

emergency demands.

ASR can be implemented as an efficient and cost-effective method of storing large volumes of water. Water storage in an aquifer is advantageous over surficial storage facilities for several reasons. An aquifer storage zone has a comparatively large storage capacity, minimal land requirements, and no loss of water due to evaporation. Johnson and Pyne (1995) state that operating costs are only slightly higher than those for conventional production wells but, ASR systems typically are able to increase water supply capacity at less than half the capital cost of other water supply alternatives.

ASR wells are Class V injection wells. In Florida, they are regulated by the FDEP's UIC Program. The first ASR facility was permitted in 1982 in Manatee County. In Florida, as of December, 1998, six ASR facilities have been permitted using water treated to drinking water standards. Seven potable water ASR facilities are undergoing operational testing, and three are in the cycle testing stage. Currently, there are plans to start the United States' first reclaimed ASR, or RASR, using treated waste water. One RASR facility is under design and construction in Hillsborough County, Florida, and five systems are in either the pre-application stage or the permitting stage.

The water sources for ASR programs include rivers, lakes and runoff. Source water is taken during wet seasons when there is an excess of available water, or during times of low demand. The water is stored in the aquifer until it is removed, or recovered, to meet seasonal, long-term or emergency demands. The water is stored in a section of an aquifer with suitable characteristics for recharge, storage and recovery. Three primary suitable aquifer characteristics are discussed in PEER Consultants, P.C. and CH2M Hill (1995). One characteristic is sufficient hydraulic conductivity. The storage zone in the aquifer may be required to have a productive capacity of 1 mgd or greater. A second characteristic is confinement. The zone should be confined vertically from both upper and lower units to prevent migration of relatively poorer-quality water from shallower and deeper zones, and to prevent loss of recharged water to these zones. A third characteristic of a suitable storage zone for ASR is the effect of chemical interaction between the sediments and the recharged water. The recharged water should meet the requirements of the Safe Drinking Water Act primary and secondary drinking water standards. This requirement is necessary to minimize impact on the aquifer rock in the storage zone and to prevent leaching of unacceptable levels of naturally occurring chemical constituents into the recharged water. Typically, the recovered water does not need retreatment other than disinfection (PEER Consultants, P.C. and CH2M Hill, 1995).

ASR storage zones include geologic settings such as sand, clayey sand, sandstone, limestone, dolostone, basalt and glacial drift aquifers (Johnson and Pyne, 1995). Suitable aquifers include confined and semi-confined and fresh, brackish and salt-water aquifers. Placement of the ASR well is also of importance. The well should be located a suitable distance from other wells open to the zone to prevent interaction with or adverse effects on those wells (Johnson and Pyne, 1995).

Twenty-seven ASR systems are operational in the United States as of December 1997. Internationally, ASR sites are in operation in London, England; three sites in Adelaide, Australia; two sites in Amsterdam, Netherlands; Kuwait City, Kuwait; Tel Aviv, Israel; and Kitchener/Waterloo, Canada (R. D. G. Pyne, oral communication, 1997). Principal applications for ASR in Florida include the previously mentioned seasonal, long-term and emergency storage

of water. In Florida, ASR sites in operation and in testing phases are located in coastal regions of central and southern peninsular Florida.

Environmental benefits of ASR exist as well. The increase in population in coastal cities has had detrimental effects on local ecosystems and the quality of water in aquifers. R.D.G. Pyne (oral communication, 1997) explains that these effects can be reduced or reversed by using ASR to maintain distribution system flow/pressure, restoring groundwater levels, controlling saltwater intrusion and contaminant plumes, reducing environmental effects of stream flow diversions, and help restore the Everglades and other wetland areas, and maintaining aquatic and terrestrial ecosystems during dry periods.

When implementing an ASR program, each facility undergoes numerous testing and construction phases. Investigations are conducted to evaluate the feasibility of using the ASR process in a specific locality and for a specific application; then, evaluations of the area's hydrogeology, water quality, local water use, and aquifer contamination potential are conducted. Availability of facilities to transport water from the source, to provide recovered water to the city, site constraints, environmental issues, permitting and economic considerations are investigated (PEER Consultants, P.C. and CH2M Hill, 1997). If favorable conditions exist, the next step is construction of wellhead facilities and the cycle testing program to evaluate hydrogeologic and chemical data for periods of recharge, storage and recovery. If, after ASR testing cycles, the storage zone is deemed favorable, the ASR facilities may be expanded to provide treated, recovered water to the region.

During the cycle testing program, treated water is recharged to the aquifer for a short time (up to three months) and then recovered. This process, with or without storage time, is repeated until the facility is deemed favorable or unfavorable for ASR activities. Selected water quality parameters are analyzed by the water departments during construction, testing and implementation of an ASR facility. Water quality analyses conducted on native water are listed in Table 1. Standard water quality analyses performed on all wells at the site during cycle testing are listed in Table 2. These parameters are selected for analysis based on an emphasis to evaluate/monitor human health concerns. Additional trace metal and water quality parameters, however, facilitate an understanding of ASR processes on recharge/recovery water and the aquifer storage zone environment.

HYDROGEOCHEMISTRY AND ASR

Water-rock interaction during the ASR process has not been investigated to a great extent and is therefore poorly understood. Analyses of uranium, strontium and trace metals are useful toward the interpretation and understanding of geochemical processes that occur during ASR activities. Background and importance of these parameters are discussed below.

The decay series arising from ^{238}U generally contains fifteen radioactive isotopes of eight different elements (see **Radioisotope Geochemistry** section for more detail). In a closed system, the parents and daughters of the series are not separated from each other, and the activity ratio of a daughter to its parent will be equal to one; this condition is known as secular equilibrium (Faure and Powell, 1972). In groundwater environments, a state of disequilibrium exists: there is an excess (in most cases) of ^{234}U (a radiogenic daughter of ^{238}U) to ^{238}U. This disequilibrium occurs in the course of natural geologic processes and is a function of two primary factors, radiological and chemical (Osmond and Cowart, 1976):

Table 1: Water quality analyses performed on native aquifer water (PEER Consultants, P.C. and CH2M Hill, 1995).

State Primary Drinking Water Standards		State Secondary Drinking Water Standards
Inorganics:	vinyl chloride	aluminum
antimony	1,1,1-trichloroethane	copper
arsenic	1,2-dichloroethane	color
asbestos	benzene	chloride
barium	cis-1,2-dichloroethene	foaming agents
beryllium	1,2-dichloropropane	iron
cadmium	ethylbenzene	manganese
chromium	monochlorobenzene	odor
cyanide	0-dichlorobenzene (1,2-dichlorobenzene)	pH (at collection point)
fluoride	styrene	silver
lead	toluene	sulfate
mercury	trans-1,2-dichloroethene	total dissolved solids
nickel	xylenes (total)	zinc
nitrate	dichloromethane (methylene chloride)	
nitrite	1,2,4-trichlorobenzene	
selenium	1,1,2- trichloroethane	
sodium	p-dichlorobenzene (1,4-dichlorobenzene)	
thallium	1,1-dichloroethylene	
	turbidity	
Organics:		
THMs (total)*	*Radionuclides:*	
trichloroethylene	gross alpha	
tetrachloroethylene		
carbon tetrachloride		
*trihalomethanes		

Table 2. Water quality analyses performed on ASR site-related wells during cycle testing (PEER Consultants, P.C. and CH2M Hill, 1997).

sulfate	total coliform
total dissolved solids	fecal coliform
pH	chlorine
total hardness	nitrate
non-carbonate hardness	iron
total alkalinity	calcium
turbidity	magnesium
conductivity	trihalomethanes
chloride	odor
fluoride	color
dissolved oxygen	

Radiological-disequilibrium is primarily the result of the decay of ^{238}U to ^{234}Th (which quickly decays to ^{234}U). One result of this decay is extensive damage to the crystal lattice causing the ^{234}U to be vulnerable to selective leaching by oxic waters. Another result of the decay of ^{238}U to ^{234}Th is the direct recoil of ^{234}Th into the surrounding water where the fate of the resultant ^{234}U would then be related to the redox condition of the water.

Chemical-uranium is mobile in the oxidized state and is immobile in reduced conditions. In a recent Florida Geological Survey investigation (Green et al., 1995), a core from the Suwannee Limestone in Hillsborough County, Florida was tested for uranium mobility. Leaching experiments demonstrated that up to 32% of the uranium in Floridan aquifer system rocks can be leached when exposed to oxidizing conditions in the laboratory. Their finding illustrates the potential for the ASR process, involving injection of oxygen-rich water into aquifers, to be capable of mobilizing uranium to the groundwater.

Another possible effect of ASR on aquifers is the potential to dissolve the aquifer rock, due to the aggressiveness of the injected oxygen-rich water. Dissolution of the aquifer rock will result in the introduction of more ions to the groundwater, including uranium, strontium, and other trace metals. Strontium is also examined in this study as a possible tool to quantify aquifer rock dissolution during ASR processes. Faure and Powell (1972) state that the isotopic composition of strontium ($^{87}Sr/^{86}Sr$) in oceans is the result of a mixture of isotopic varieties of strontium from different sources (see also **Radioisotope Geochemistry**). Due to the variations in the contribution of the strontium composition from each of the sources, the $^{87}Sr/^{86}Sr$ ratio in the oceans has varied in the past. Strontium is removed from the oceans primarily by co-precipitation with calcium carbonate. The isotopic composition of strontium in marine carbonates reflects the strontium compositions in the oceans during carbonate deposition. Thus, if surface waters (of known strontium composition) are aggressive and dissolve aquifer rock, the resultant strontium isotopic ratio in the water will be some mixture of the two strontium sources. Under favorable circumstances, it is possible that a reasonable estimate of the degree of rock dissolution can be calculated.

PURPOSE OF INVESTIGATION

The purpose of this investigation is to analyze the geochemical changes in native and recharge/recovery water, to estimate affects on the storage aquifer matrix, to increase the understanding of water-rock interactions due to ASR activities, and to provide the FDEP with additional scientific knowledge on which to base protective criteria for future ASR projects. This study primarily examines uranium concentrations and isotopic ratios ($^{234}U/^{238}U$) of native aquifer water (when available), recharge water, recovered water, and water in surrounding wells. This study also includes strontium isotope and trace metal analyses of these waters to investigate water-rock interaction as well as native-recharge water interaction.

Two ASR facilities in the project region (Southwest Florida Water Management District) were selected for this investigation. The Rome Avenue ASR site in Hillsborough County was already in the cycle testing phase and therefore provided sufficient time for data collection. Hence, the Rome Avenue ASR site is the primary site of this investigation. The Punta Gorda ASR site in Charlotte County began cycle testing late in the duration of this project and therefore only preliminary results are discussed in this report.

STUDY AREAS

ROME AVENUE ASR SITE

The Rome Avenue ASR site is located on the southwest corner of Rome and Sligh Avenues in the City of Tampa, Hillsborough County, Florida (Figure 1). The ASR site is located near the Hillsborough River, the source for the recharge water, and near the Tampa Water Department where river water is treated to drinking water standards before being transmitted to the site. The site lies within the Tampa Water Department's Northwest Service Area and the Southwest Florida Water Management District's (SWFWMD's) Northern Tampa Bay Water Use Caution Area. The site is near facilities favorable for ASR. Located on the grounds of the city's Rome Avenue Park, it consists of seven wells. Two wells (2-D and 2-S) existed prior to the construction of the ASR facilities. The wells were installed by the SWFWMD in order to monitor the shallow Floridan aquifer system (2-S) to 62 feet bls (below land surface), and to monitor for saltwater intrusion into the deeper Floridan aquifer system (2-D) between 717 and 771 feet bls (PEER Consultants, P.C. and CH2M Hill, 1997). As a part of the ASR facility construction, the wells SZOW-1, TPW-1, SMW-1, WTMW-1 and WTMW-2 were installed. SZOW-1 (Storage Zone Observation Well) was constructed first to obtain hydrogeologic data during construction, to evaluate the potential ASR storage zones at the site, and to act as a monitoring and testing well within the storage zone during ASR phases (PEER Consultants, P.C. and CH2M Hill, 1997). TPW-1 (Test Production Well) was then installed as the well responsible for recharge and recovery to the storage zone. SMW-1 (Shallow Floridan aquifer system Monitor Well), WTMW-1 and WTMW-2 (Water Table Monitor Wells) were then installed to monitor effects of ASR at various depths in the area. TPW-1 and SZOW-1 are the wells focused on in this study, with some interest in the 2-D and SMW-1 wells in the units above and below the storage zone.

Proposed expansion at the Rome Avenue ASR site includes ten more ASR wells. Estimated site capacity (total daily injection value) is close to 10 mgd. The wells will be constructed as close to the Rome Avenue ASR site as possible, while keeping sufficient distance between wells to minimize possible impacts that could result from over stressing the groundwater resources beneath the park (PEER Consultants, P.C. and CH2M Hill, 1997).

The ASR facility in Charlotte County is located on Washington Loop Road in the city of Punta Gorda, Florida (Figure 1). The site is located at the City of Punta Gorda Shell Creek Water Treatment Plant, near the Shell Creek Reservoir, the source for recharge water. The site consists of one well, presently in use, and two others, used temporarily. The two temporary wells were pad monitor wells drilled at the north and south edges of the drilling pad, installed before the production well, to monitor shallow water quality during well construction. Each of the two wells were drilled to a total depth of 12.5 feet bls.

PUNTA GORDA ASR SITE

The single well in use at the site was drilled to a total depth of 1043 feet. The well was utilized for hydraulic testing and then as the production well for the ASR site. In order to utilize an upper flow zone as the storage zone, the well was plugged with cement and gravel from 764 feet to total depth. The well is cased from the surface to 700 feet. The open interval in this well extends from 700 to 764 feet bls. No other wells are located on the site to monitor the

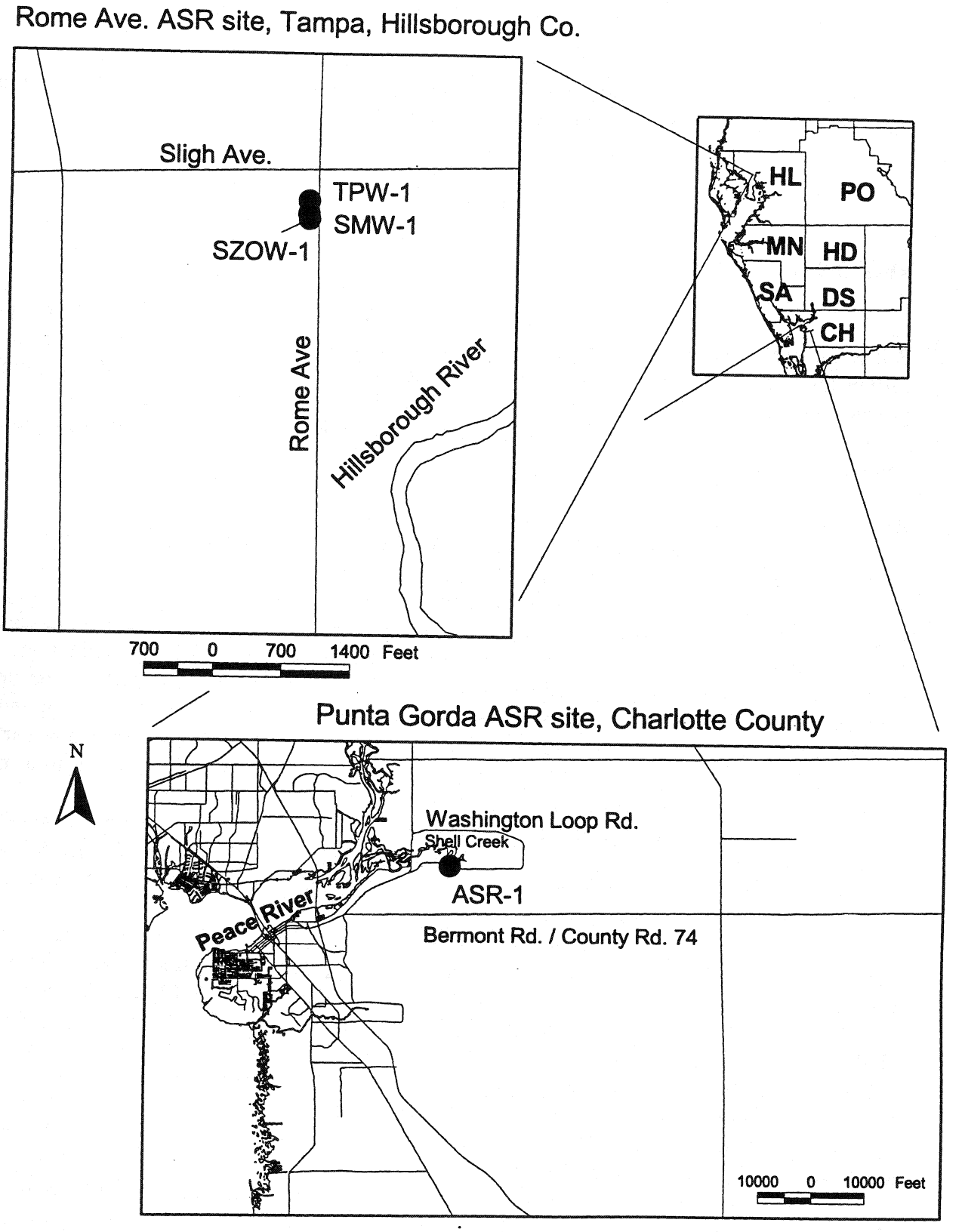


Figure 1. Location of ASR and monitor wells analyzed in this study. Cross section location line (See fig. 4) shown in Punta Gorda inset.

storage zone or zones above or below the storage zone. Thus, sampling included treated and untreated river water, and the production well at the ASR site.

GEOLOGY

REGIONAL

Lithologic units of interest to this study in west-central Florida range from upper Paleocene to Recent and are comprised of a sequence of sedimentary deposits including sands, carbonates, clays and evaporites. This sequence also serves as the extent of the potable groundwater resource in west-central Florida, and includes a complex aquifer system. The lithostratigraphy and hydrostratigraphy of west-central Florida is depicted in the stratigraphic column in Figure 2.

Avon Park Formation

The Middle Eocene (Miller, 1986) Avon Park Formation underlies all of west-central Florida. The lower Avon Park Formation is marked by bedded evaporites (Greenet al., 1995). These evaporites are identified by Ryder (1985) and Miller (1986) as the base of the upper Floridan aquifer system. Green et al. (1995) describe the unit as a light-orange to yellowish-gray calcarenitic limestone with variable amounts of organic-rich laminations and dolostone. Dolomite content in limestone increases with depth, and also exists at the upper boundary of the formation in places. Descriptions of the Avon Park Formation are based on drilling samples rather than outcrop samples. In Florida the Avon Park Formation surface exposures are limited to Citrus and Levy Counties. Middle Eocene rocks crop out to a much greater extent in southern Alabama and Georgia.

Porosity in the limestone sections of the Avon Park Formation is generally intergranular (Green et al., 1995) and averages about 15%. Fracture porosity in dolostone sections is common, as well as intercrystalline porosity in the sucrosic textures with vugular and moldic porosity to a lesser extent (Green et al., 1995).

Green et al. (1995) reports the top of the Avon Park Formation exists as high as -226 feet NGVD (National Geodetic Vertical Datum of 1929) in the study area. The Ocala Limestone overlies this unit. Miller (1986) reports the base of Middle Eocene rocks (approximately the base of the Avon Park Formation; Green et al., 1995), as deep as -2500 feet NGVD in the study area, with a thickness of up to 1500 feet. The formation dips to the southwest in the study area (Miller, 1986; Green et al., 1995). In Hillsborough County, the Avon Park Formation ranges in thickness from 1400 feet to approximately 1500 feet, thickening to the southwest, and in Charlotte County the formation thickens to the north from 900 feet to approximately 1250 feet (Miller, 1986).

The depositional environment of the Avon Park Formation, according to Miller (1986), was a shallow warm-water carbonate bank. The evaporites present at the base of the formation formed in a tidal flat or sabkha environment. Diagnostic fossils of the formation include the foraminifers *Dictyoconus americanus* and *Coskinolina floridana* throughout, and the echinoid *Neolaganum (Peronella) dalli* within the upper portion of the unit (Green et al., 1995).

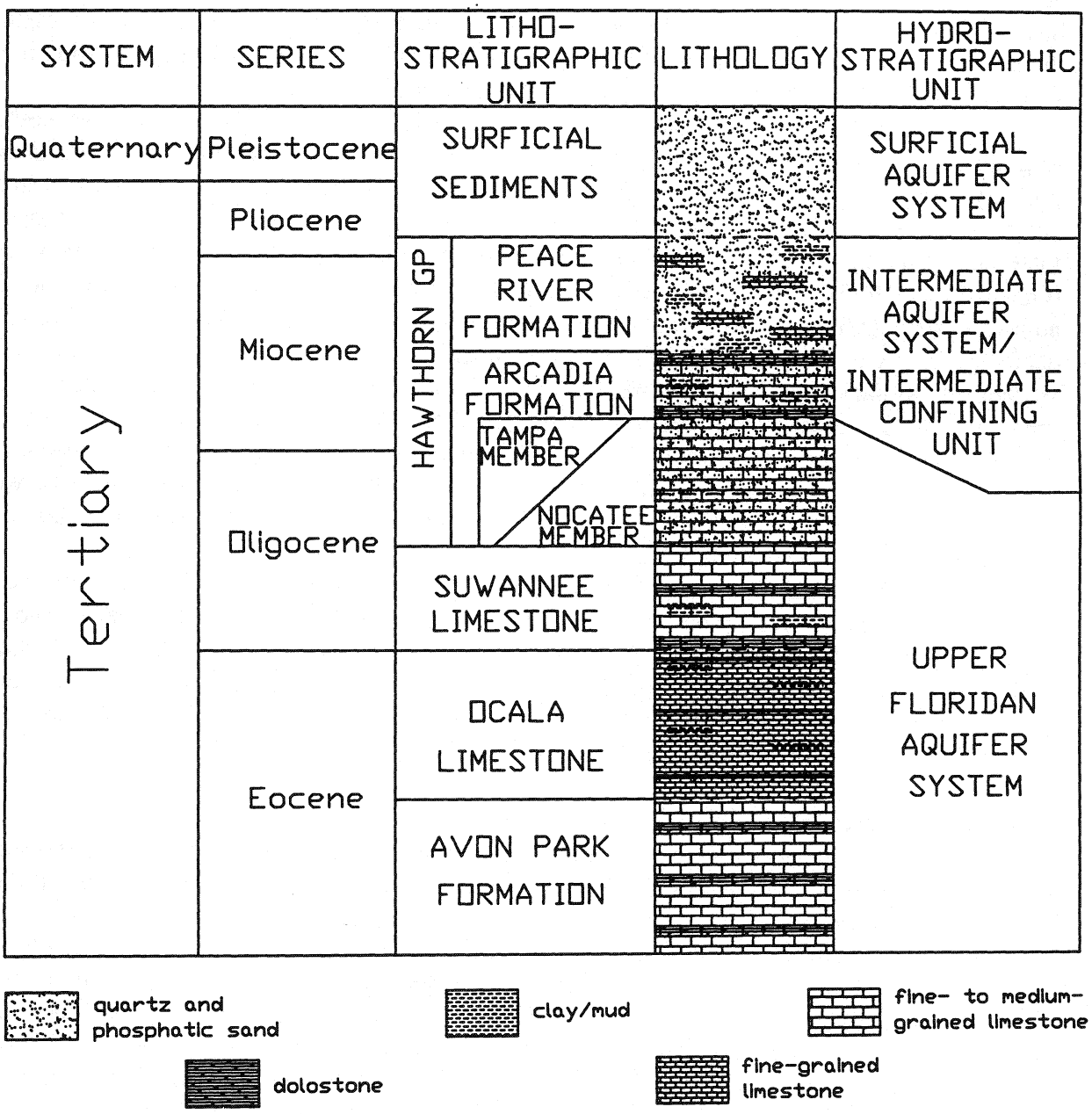


Figure 2. Stratigraphic column of lithostratigraphic and hydrostratigraphic units in west-central Florida (Modified from SEGS, 1986).

Ocala Limestone

The Upper Eocene Ocala Limestone is present throughout much of Florida and underlies much of southeastern Alabama and the Georgia coastal plain. The Ocala Limestone is absent in portions of central and northern peninsular Florida (north of the study area), where it has been eroded off of the Ocala Platform, and in southeast Florida. The formation is present at the surface to the west of the Ocala Platform, and also crops out in northern-most Florida in the vicinity of Marianna, and in southern Alabama and Georgia.

The Ocala Limestone consists of very pale orange to yellowish-gray wackestone to grainstone. The lower-most portions of the formation are dolomitized in places, with moldic porosity due to dissolution of Upper Eocene foraminifers. In non-dolomitized zones, as in the central portion of the unit, the lithology is packstone to grainstone consisting mainly of biogenic material including the foraminifers *Lepidocyclina* sp. and *Nummulites (Operculinoides)* spp. (Green et al., 1995). The formation is one of the most permeable rock units in the Floridan aquifer system (Miller, 1986), owing to some zones of the formation which are up to 100% coarse-grained grainstones. The upper portions of the Ocala Limestone range from a weathered wackestone to packstone with a variable amount of underlying Avon Park Formation, and with the overlying Oligocene strata are unconformable (Chen, 1965). calcilutite matrix with a chalky to clayey appearance (Green et al., 1995). The upper surface of the formation is marked by karstic features as a result of dissolution of the limestone (Miller, 1986). The contacts between the Ocala Limestone and the underlying Avon Park Formation, and with the overlying Oligocene strata are unconformable (Chen, 1965).

The Ocala Limestone thickens and dips to the southwest in Hillsborough County and thickens to the north and dips to the southwest in Charlotte County (Miller, 1986). The unit exists as high as -76 feet NGVD, deeper than -620 feet NGVD, and is over 300 feet in thickness in the study area (Green et al., 1995). The Ocala Limestone was deposited in a shallow, open to marginal marine environment, in warm, clear water on a carbonate bank probably similar to the modern Bahama Banks (Miller, 1986).

Suwannee Limestone

The Lower Oligocene Suwannee Limestone underlies much of west-central Florida. It is present at or near the surface in northern west-central Florida (Hernando and Pasco Counties). The lithology of the Suwannee Limestone varies from light gray to yellowish-gray wackestone to grainstone, variably moldic containing trace amounts of sand and clay within the upper portions, and some chert and organics throughout (Green et al., 1995). Miller (1986) discusses two rock types of the Suwannee Limestone, often locally and complexly interbedded. One rock type is highly vuggy limestone containing prominent gastropod and pelecypod casts and molds. The second rock type is fine pelletal limestone containing small foraminifers and pellets of micrite cemented with a micritic to finely crystalline limestone matrix. Green et al. (1995) also report a dolomitic limestone layer, 10 to 20 feet thick, existing within the lower one-third of the unit in Hillsborough and Pinellas Counties. The formation was deposited in a carbonate bank environment, similar to that of the underlying Ocala Limestone and Avon Park Formation (Miller, 1986).

Fossils in the Suwannee Limestone include gastropods, pelecypods, echinoids, miliolids and other benthic foraminifers including *Coskolina floridana* and *Dictyoconus cookei* (Green et al., 1995). Miller (1986) mentions that these latter two species are also found in the

Avon Park Formation. Miller (1986) believes that these are long-ranging species reestablished in the Suwannee Limestone due to a depositional environment similar to that of the Avon Park Formation.

The contact of the Suwannee Limestone varies from conformable to unconformable with the overlying Hawthorn Group (Green et al., 1995). In some cases, due to lack of a major facies change, the Suwannee Limestone appears to grade into the overlying Tampa Member of the Arcadia Formation, Hawthorn Group (a sandy wackestone unit with little to no phosphate).

The Suwannee Limestone in west-central Florida dips towards the south and west and thickens to the south in Hillsborough County and towards the middle of the county in Charlotte County (Miller, 1986). The top of the formation is located at approximately –100 feet NGVD in Hillsborough County and at –700 feet NGVD in Charlotte County. The lower boundary of the Suwannee limestone is found at –300 feet NGVD in Hillsborough County and at –1000 feet NGVD in Charlotte County (Miller, 1986). The formation dips approximately 0.1 degrees toward the southwest and the unit thickens from 100 to 356 feet in the study area, averaging approximately 219 feet (Green et al., 1995).

Hawthorn Group

The Hawthorn Group (Scott, 1988) is a complex Lower Oligocene to Lower Pliocene unit (Brewster-Wingard et al., 1997) overlying the Suwannee Limestone in the study area. The complexity lies in the wide range of lithologies, subtle facies changes and diagenesis.

The Hawthorn Group is comprised of two formations of the Lower Oligocene to Middle Miocene Arcadia Formation (Brewster-Wingard et al., 1997) and the Middle Miocene to Lower Pliocene Peace River Formation (Covington, 1993). Sediments of the Hawthorn Group were deposited in shallow to moderately deep marine waters (inner to middle shelf) in prodeltaic and shallow subtidal marine, to intertidal and supratidal conditions (Miller, 1986; Scott, 1988). Terrestrial sediments in the Hawthorn Group occur as paleosoils and weathered residuum (Scott, 1988).

The Arcadia Formation is a yellowish-gray to light olive-gray, clayey, fine-grained mudstone to wackestone with highly variable amounts of quartz sand, sand-size to gravel-size phosphate and dolomitized zones throughout. The clays within this unit range from very clean, with no accessory minerals, to very sandy with quartz and phosphatic sand. Some of the clay units are comprised of fine-grained dolostone with only minimal clay matrix (Green et al., 1995). The phosphates in this unit range in size from fine-grained up to gravel, and in color from dark gray, to green-gray, to yellow-orange, and white. The Hawthorn Group occurs from +100 to -106 feet NGVD and ranges in thickness from less than 10 up to 345 feet (Green et al., 1995).

Two members within the Arcadia Formation are the Tampa Member and the Nocatee Member. The Nocatee Member of the Arcadia Formation, also Upper Oligocene to Lower Miocene) is a gray clayey, carbonate mud-bearing sand with varying amounts of phosphate (Tihansky et al., 1996). The Nocatee Member lies within undifferentiated sections of the Arcadia Formation or subjacent to the base of the Tampa Member. The Nocatee Member is as thick as 200 feet and the top of the member is from 100 to 500 feet below mean sea level (Scott, 1988). Sediments of the Nocatee Member represent a high energy, open, near-shore environment on the edge of a carbonate bank (Scott, 1988).

The Tampa Member is Upper Oligocene (Brewster-Wingard et al., 1997) to Lower Miocene. The unit is a yellowish-gray with variable quartz sand content. The Tampa Member contains little to no phosphate, dolostone or chert, and porosity is intergranular and moldic (Green et al., 1995). The Tampa Member marks the top of the Arcadia Formation in much of Hillsborough County and it comprises the entirety of the formation in some places in the county. The Tampa member was deposited in warm, shallow, clear, open marine waters, and is a remnant of the carbonate bank environment characteristic of the study area throughout most of the Tertiary (Miller, 1986).

The Middle Miocene to Lower Pliocene (Covington, 1993) Peace River Formation is comprised of interbedded quartz sand, phosphatic sand and gravel, light to olive-gray clays and yellow to gray carbonates. The Peace River Formation is differentiated from the underlying Arcadia Formation by the dominance of siliciclastics (Scott, 1988) and phosphate content, and overall clay content of the Peace River Formation. The top of the formation is found as high as 175 feet above mean sea level in Polk County (northern part of the study area) to about mean sea level in the southern portion of the study area. The formation is very thin to missing (possibly due to erosion) in parts of Hillsborough County, and thickens to the south to 150 feet thick in Charlotte County.

Surficial Sediments

Overlying the Hawthorn Group are the Pliocene-Pleistocene sediments consisting of undifferentiated sands, clays, shells and organic material. These sediments are differentiated from the underlying Hawthorn Group by presence of shells, and lack of phosphatic material, carbonate, and lithified material. These surface sediments range in thickness from 5 to 85 feet (Green et al., 1995).

ROME AVENUE ASR SITE

The following is a brief description of representative lithology and stratigraphy at Rome Avenue based on samples from well 2-D (W-16574). A detailed description of these samples is provided in Appendix A. Figure 3 is a representative cross-section using wells in the area.

The Avon Park Formation extends from 1130 bls to 530 feet bls. The formation varies from limestone, to interbedded dolostone and limestone. The lower most section of the well consists of very fine to medium grained yellowish-gray dolomitized limestone. The zone exhibits an estimated 15% intergranular and vugular porosity and low to medium permeability. Limestone is present in the dolomitized zone from 5 to 45% and trace anhydrite and sparry calcite are present at the base of the well. A zone of limestone exists from 1035 to 880 feet bls. The limestone is very fine to medium grained yellowish-gray and is composed of biogenic and skeletal material with calcilutite matrix and cement. Porosity is estimated to be 10 to 15% and is intergranular and sometimes vugular and moldic; permeability is poor to medium. Fossils include echinoids, mollusks and fossil molds and casts. The overlying section (880-685 feet bls) is another dolomitized limestone zone. The non-altered limestone component of the dolostone ranges from 5 to 30%. Echinoids occur in the upper section of the dolomitized zone. Yellowish-gray wackestone to grainstone exists from 530 to 685 feet bls and is composed of biogenic and

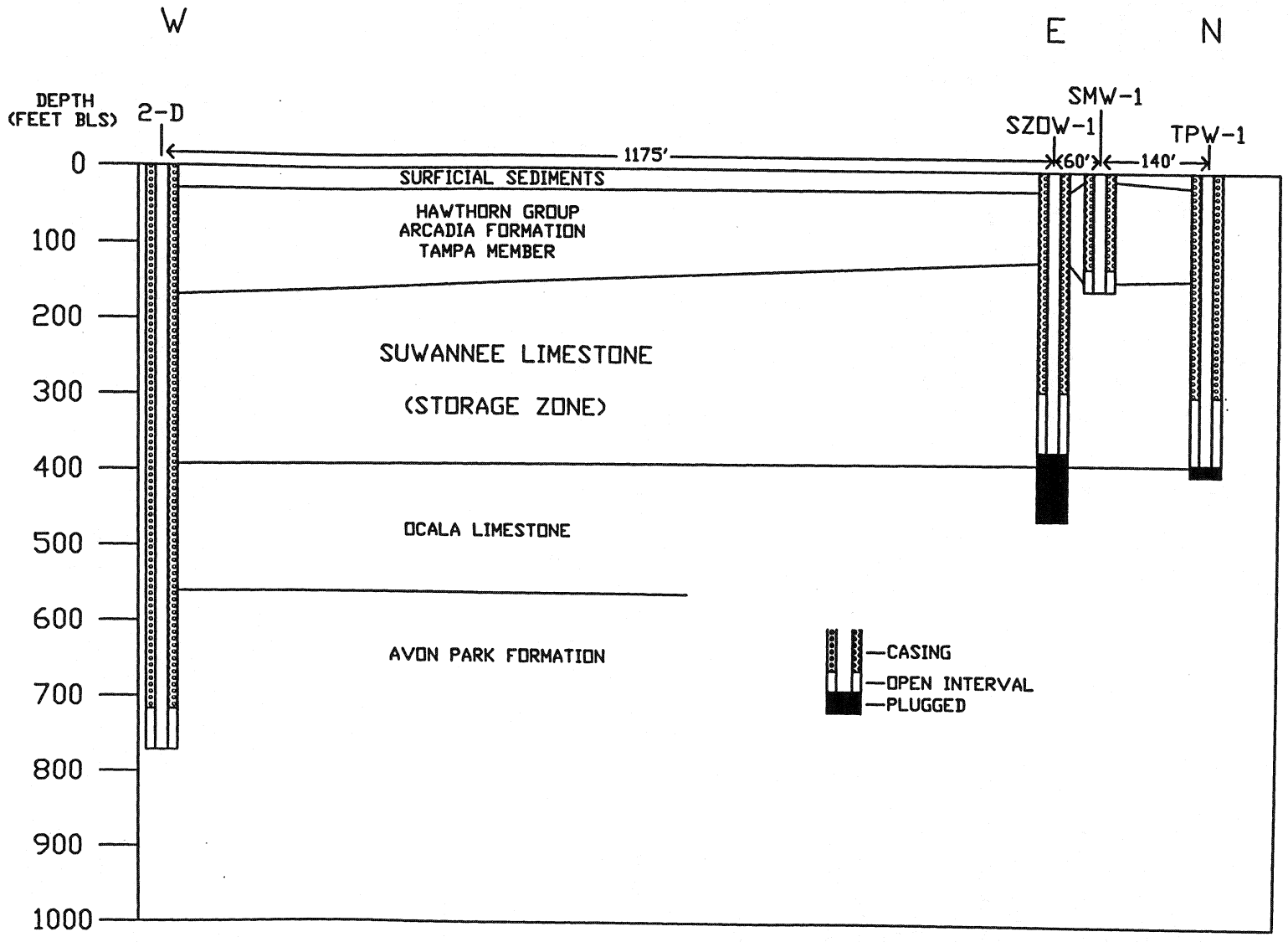


Figure 3. Cross-section of the Rome Avenue ASR site and wells located at the site. See Figure 1 for well locations.

skeletal grains and calcilutite matrix. Fossils include echinoids and *Dictyoconus americanus.* Samples from 530 to 425 feet bls are not available for inspection.

Ocala Limestone is present in the well from 425 to 385 feet bls and is a yellowish-gray packstone composed of biogenic and skeletal grains and calcilutite matrix. The limestone is moderately indurated. Grains range in size from very fine to very coarse. The limestone exhibits an estimated 20% intergranular porosity and poor to medium permeability. Accessory minerals include 1% quartz sand and 3% sparry calcite in the upper section of the formation. Fossils in the Ocala Limestone include echinoids, sponge spicules, mollusks and benthic foraminifera including lepidocyclina and nummulites species.

The Suwannee Limestone lies from 385 to 195 feet bls. The limestone is a yellowish-gray packstone to grainstone composed of biogenic and skeletal grains and calcilutite matrix and cement. The limestone is poorly to moderately indurated and grains range in size from very fine to coarse. The porosity is intergranular and estimated to be 20 to 25%. Limestone exhibits medium permeability. Accessory minerals include quartz sand (1-5%) and sparry calcite (1-5%). Fossils include the benthic foraminifera *Pararotalia* (*Rotalia*) sp. and *Dictyoconus cookei*, as well as echinoids, sponge spicules, mollusks and brachiopods. Samples from 180 to 195 feet bls are missing.

The Arcadia Formation extends from 30 to 180 feet bls, the entirety of which is composed of the Tampa Member. This limestone unit is a yellowish-gray wackestone composed of biogenic and skeletal grains and calcilutite matrix. The limestone is moderately indurated and grains range in size from cryptocrystalline to medium. Porosity is intergranular and is estimated to be 15%. Permeability is medium. Accessory minerals include quartz sand (3 to 10%), phosphatic sand (1%), and sparry calcite (1%). Fossils in this section include *Sorites* foraminifera, mollusks and echinoids.

Surficial sediments consisting of dark greenish-yellow, subangular to subrounded quartz sand extend from the land surface to 30 feet bls. The sand size ranges from fine to coarse with medium modal size. The sand is unconsolidated and exhibits an estimated 25% intergranular porosity and high permeability. Accessory minerals include phosphatic sand making up 2% of the matrix, and limestone increasing from zero to 5% of the sediment with depth.

PUNTA GORDA ASR SITE

The geology of the Punta Gorda ASR site is reviewed in the following description of the recharge/recovery well at the site, as reported in Montgomery Watson (1998). Figure 4 depicts a cross-section of the Punta Gorda ASR well and nearby wells.

The Ocala Limestone lies in the interval from 1043 feet bls (total depth of well) to 965 feet bls. The formation boundary between the Ocala Limestone and the overlying Suwannee Limestone was determined using geophysical logs. The limestone is composed of moderately soft, pelletal, white to very pale orange wackestone to packstone. The formation exhibits 15 to 40% intergranular porosity except locally where thin layers of very hard micrite with low porosity and permeability exist.

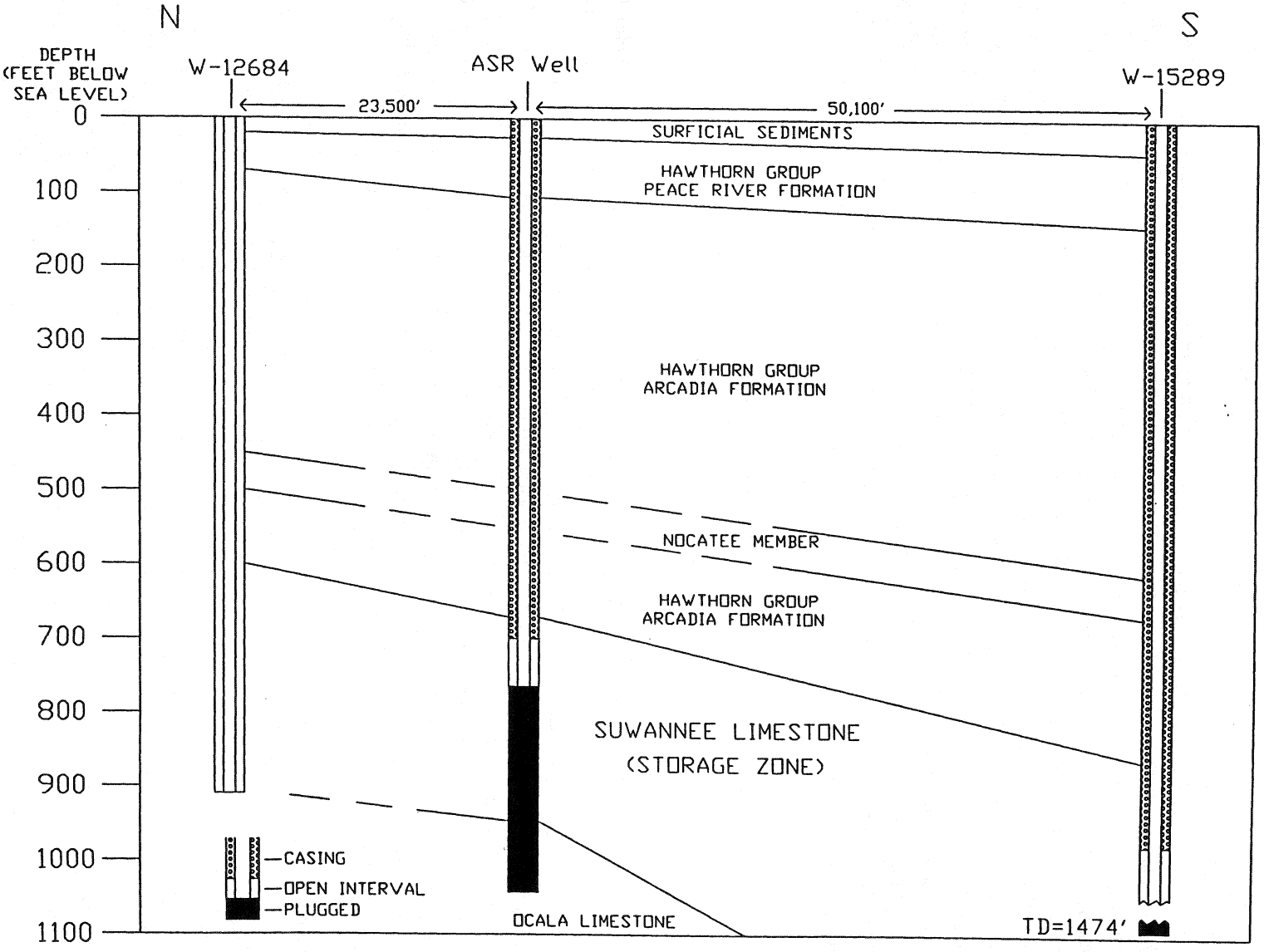


Figure 4. Cross-section of the Punta Gorda ASR site, ASR well and nearby wells (W-12684 and W-15289). Well construction information on W-12684 not available.

The Suwannee Limestone lies from 965 to 690 feet bls. The lithology is white to medium gray, well-indurated packstones and grainstones, variably recrystallized in part. The unit is highly fossiliferous. The limestone is highly porous and permeable where fossil moldic porosity has developed. Fossils include bryozoans, gastropods, pelecypods, corals, foraminifera, and plant fossils.

The overlying Hawthorn Group extends from approximately 45 to 690 feet bls. The Arcadia Formation within the Hawthorn Group exists from 125 to 690 feet bls. The formation is light gray to white, poor to moderately indurated mudstones and includes variable amounts of sand, clay and limestone. The Nocatee Member of the Arcadia Formation is present from 639 to 695 feet bls. The Peace River Formation within the Hawthorn Group exists from 45 to 125 feet bls based on gamma-ray activity and correlation with nearby wells (Figure 4). The limestone in the Peace River Formation is light gray to white, poor to moderately indurated mudstone. Sands in the formation are poorly cemented. Minor amounts of yellowish gray to olive clay is interbedded with the light olive gray limestone. The clay contains quartz and phosphatic sand, silt, a minor percentage of calcite, dolostone and fossils (pelecypods). Overlying the Hawthorn Group are surficial sediments: Plio-Pleistocene limestone, sand, sandstone, clay and variable amounts of whole and broken pelecypod and gastropod fragments.

HYDROGEOLOGY

REGIONAL

The hydrostratigraphy of west-central Florida consists of two major water-bearing units, the surficial aquifer system and the Floridan aquifer system. The two aquifer systems are separated by a low permeability sequence of rocks called the intermediate aquifer system/intermediate confining unit. Hillsborough County receives its water supply from all three sources, primarily the surficial aquifer system, and surface water. Charlotte County primarily receives its water supply from shallow sources due to the poor water quality of underlying aquifers (Watson, 1988). The relationship and make-up of the two aquifer systems and the intermediate aquifer system/intermediate confining unit is important in the understanding of local and regional water resources and the potential to increase resources through ASR programs.

Floridan aquifer system

The Floridan aquifer system (SEGS, 1986) underlies all of Florida, southeastern Alabama, the coastal plain of Georgia and southern-most South Carolina (Miller, 1986). This aquifer system is one of the most productive hydrologic units in the world. The system is a vertically continuous sequence of Tertiary carbonate rocks, hydraulically connected in varying degrees depending on texture and mineralogy, including fossil content, diagenesis, cementation and dissolution and fractured zones. The highly permeable zones are commonly solution riddled or fractured and generally conform to bedding planes or formation boundaries but locally cross formation boundaries. The Floridan aquifer system generally consists of an upper and lower aquifer separated by a less permeable unit. North of the study area, this confining unit is missing or does not significantly retard vertical flow in the aquifer (Ryder, 1985; Miller, 1986). In west-

central Florida, the upper Floridan aquifer system (Miller, 1986) is a major source of potable water and occurs within 25 feet of land surface in parts of Hillsborough County (Green et al., 1995). The lower Floridan aquifer system (Miller, 1986) generally contains saline water (Ryder, 1985) in this region. The lower Floridan aquifer system is not integral to this study and therefore will not be discussed.

The base of the upper Floridan aquifer system in the study area is a less permeable unit, the middle confining unit, and is marked by the first occurrence of vertically persistent evaporites (Ryder, 1985; Miller, 1986). The middle confining unit does not crop out and descriptions are therefore based on well data. Miller (1986) reports that the middle confining unit may locally contain thin zones of moderate to high permeability, but the unit as a whole acts as a single confining unit within the Floridan aquifer system. In west-central Florida, the evaporites of the middle confining unit include gypsiferous dolostone and dolomitic limestone (Miller, 1986) and anhydrite (Green et al., 1995).

Porosity of the middle confining unit in Hillsborough County is largely intergranular. Porosity has been oliterated by secondary pore-filling gypsum. Stringers, lenses, pods and thin beds of gypsum are also present (Miller, 1986). Miller (1986) reports that the highly mineralized water contained in the middle confining unit, compared to the high-quality fresh water contained in the upper Floridan aquifer system, suggests poor interconnection with the fresh water of the overlying upper Floridan aquifer system.

In Charlotte County, the middle confining unit consists of interbedded fine to coarse crystalline dolostone and fine pelletal, micritic argillaceous limestone. Gypsum fills much of the intergranular pore space in the rock (Miller, 1986).

Upper Floridan Aquifer System

In west-central Florida, the upper Floridan aquifer system consists of Middle Eocene to Oligocene rocks including the Avon Park Formation, the Ocala Limestone and the Suwannee Limestone. Locally, the Upper Oligocene to Lower Miocene Tampa Member of the Arcadia Formation, where it directly overlies Lower Oligocene rocks, is also considered part of the upper Floridan aquifer system (Miller, 1986). The upper Floridan aquifer system is present at or near the surface in the northern section of west-central Florida in Pasco, Hernando, Sumter, Citrus, Levy and Marion Counties (Miller, 1986). The aquifer system dips to the south with the top of the aquifer system approximately at +50 feet NGVD in Hillsborough County, to below -1000 feet NGVD in Charlotte County (FGS unpublished data). The thickness of the aquifer system averages about 1100 feet in Hillsborough County, thickening to the south, and approximately 1300 feet in Charlotte County, thickening to the west (Miller, 1986; Green et al., 1995).

Hillsborough and Charlotte Counties are part of the Southern West-Central Florida Ground-Water Basin (SWCFGWB), as delineated by the SWFWMD (Kelley, 1988). The basin is bounded on the east by the axis of the Green Swamp/Central Florida potentiometric high of the Floridan aquifer system, to the north by the axis of the Pasco and Green Swamp potentiometric highs, to the south by a ground-water divide aligned in a northeast-southwest direction that bisects Glades and Lee Counties, and to the west by the Gulf of Mexico (Kelley, 1988). Groundwater in the SWCFGWB flows south and west into either the Gulf of Mexico or the Tampa Bay-Ruskin potentiometric low (Kelley, 1988).

The upper Floridan aquifer system is the principal storage and water conveying component of the hydrologic system in the SWCFGWB, and is the principal source of water for consumptive use in the basin area. Recharge to the upper Floridan aquifer system is very important in terms of replenishing the aquifer for the area's needs, as well as stabilizing or slowing saltwater encroachment. The upper Floridan aquifer system in the SWCFGWB has a regional flow pattern with recharge occurring in the north, north-central and eastern portions of the basin, and discharge occurring along coastal and riverine areas (Kelley, 1988) and by way of springs (Ryder, 1985; Trommer, 1987).

In the northern section of the SWCFGWB, hydraulic heads in the intermediate aquifer system are as high or higher than those in the upper Floridan aquifer system; therefore, water in the intermediate aquifer system is transmitted downward into the upper Floridan aquifer system, serving as a means of recharge to the aquifer. In the south, the underlying upper Floridan aquifer system has higher heads than those of the intermediate aquifer system, thus transmitting water upward into the intermediate aquifer system (Kelley, 1988).

The SWFWMD (Kelley, 1988) created potentiometric maps and head difference maps for the upper Floridan aquifer system and the intermediate aquifer system. One set of maps was produced using September 1985 data, and another set using May 1986 data. The head difference is greater, farther south in May 1986 than in September 1985 due to the large groundwater withdrawals from the upper Floridan aquifer system for irrigation during the dry spring season in 1986 (Kelley, 1988).

SWFWMD maps (Kelley, 1988), as well as those in Ryder (1985) and Stewart (1980) show, on average, in the area of the Hillsborough County site in this study, very low to moderate recharge of 2 to 10 inches/year to the upper Floridan aquifer system, and generally no recharge to the aquifer at the Charlotte County site.

Intermediate Confining Unit/Intermediate Aquifer System

The Floridan aquifer system, in most of west-central Florida is overlain by the intermediate confining unit/intermediate aquifer system (Southeastern Geological Society, 1986). This unit is made up of permeable to semi-permeable carbonate and siliciclastic rocks but low-permeability zones exist where clays and somewhat continuous beds of fine-grained limestone or dolostone exist. The intermediate aquifer system is made up of the Hawthorn Group, including the Peace River Formation, the Arcadia Formation and the Nocatee Member of the Arcadia Formation. In areas where the Tampa Member of the Arcadia Formation does not directly overlie the upper Floridan aquifer system, it is part of the intermediate aquifer system as well (Green et al., 1995). In parts of northern Hillsborough County, the intermediate aquifer system is very thin and breached in places by sinkholes, allowing direct contact with the upper Floridan aquifer system.

In some of the study area, permeable zones within the Hawthorn Group are a useful source of water (Ryder, 1985). The intermediate aquifer system is not used as a source of water to the degree of the upper Floridan aquifer system; however, because the permeability of zones within the unit are at least an order of magnitude less than that of the Floridan aquifer system, they are separated from the Floridan aquifer system by confining beds, and the zones are discontinuous laterally and vertically.

Surficial Aquifer System

The surficial aquifer system overlies the Hawthorn Group and is located throughout the study area. The base of the unit generally coincides with the first occurrence of clay at the top of the Peace River Formation (Green et al., 1995). The surficial aquifer system is comprised predominantly of Pliocene-Pleistocene quartz sand with variable amounts of shell material, sandy clays, organics, and reworked and leached phosphates. South of Hillsborough County, the unit thickens and contains lenses of shell, shelly marl, or intermixed stringers of limestone (Trommer, 1993). Thickness of the surficial aquifer system ranges from 10 feet in northern Hillsborough County to 80 feet in southern Hillsborough County (Green et al., 1995), and is over 100 feet thick in Charlotte County (Ryder, 1985). In Hillsborough County, where water in the surficial aquifer system is of acceptable quality, it is used to a small degree for potable water and irrigation. However, in Charlotte County, where deeper aquifer systems contain saltwater, the system is a major source of potable water (Trommer, 1993).

Springs and Sinkholes

Ryder (1985) reports that spring discharge probably accounted for about 84% of all water discharging from the upper Floridan aquifer system under pre-development conditions in west-central Florida. The more significant springs in Hillsborough County include Crystal, discharging 39 mgd; Sulphur, discharging 28 mgd; Lettuce Lake, discharging 6 mgd; Eureka, discharging 1 mgd; Buckhorn, discharging 8 mgd, and Lithia, discharging 33 mgd. These springs, and others (Kelley, 1988), are located in central to northern Hillsborough County and may ultimately discharge upper Floridan aquifer system water to the Hillsborough River, or other surface-water sources in the county.

Sinclair (1982) studied sinkhole development resulting from groundwater withdrawal in Tampa, Florida. His study showed that collapse and subsidence is a result of downward migration of the surficial material overlying existing cavities in the rock near well fields, not by recent dissolution of the limestone. He concluded that sinkhole development will continue with water level changes, but the size of the sinkholes will be small (no more than 5 feet deep, 15 feet across) principally because of the moderate thickness of surficial materials. Sinclair (1982) concluded that the area of resultant recharge to the upper Floridan aquifer system through the sinkholes was negligible compared to county-wide recharge values, because most rock dissolution took place just at the surface of the limestone, instead of deeper into more hydraulically conductive zones.

Stewart and Mills (1984) discuss more highly developed sinkholes in the Tampa area. For example, Curiosity Sink is 25 feet deep and 40 feet in diameter and is the terminus of Curiosity Creek. Water that discharges into the sink flows downward to the upper Floridan aquifer system. Sinclair (1982) and Stewart and Mills (1984) indicate that the Floridan aquifer system is recharged in places; however, not to a significant extent.

Saltwater-Freshwater Interface

Trommer (1993) studied the saltwater-freshwater transition zone in aquifers along coastal west-central Florida. The transition zone is the zone between freshwater and more mineralized zones. He reports that water in the northern part of west-central Florida (including Hillsborough County) reflects saltwater-freshwater mixing. However, in the southern part of the study area (including Charlotte County) the transition zone is more mineralized and probably

reflects a longer residence time in the aquifers (as opposed to continuous tide-influenced flushing) and dissolution of gypsum from deep evaporite beds. Trommer (1993) considered the transition zone to be where all groundwater in a vertical section of the aquifer contains chloride concentrations of 19,000 mg/L or more, approximately equal to that of sea water. Landward movement of the transition zone can occur in an aquifer when the freshwater head is lowered. This not only causes water-flow direction to change and flow toward the well or well-field, it can also cause highly mineralized water from underlying zones to move upward towards the well or well field through upconing. Trommer's maps (1993) show the transition zone's extent and the 250 mg/L line of equal chloride concentration in the upper Floridan aquifer system (1987-1990) to be very close to the Hillsborough County ASR site. In the absence of artificial recharge to the storage zone in the immediate area of the ASR site, it is possible that upconing could occur as a result of pumping water from the zone. The upper Floridan aquifer system in Charlotte County is included within the limit of the saltwater zone and is therefore not a potable groundwater source; yet may be useful for ASR programs.

ROME AVENUE ASR SITE

Part of the feasibility study in evaluating whether the Rome Avenue site in Hillsborough County is suitable for ASR is the determination of sufficient hydraulic conductivity in the proposed storage zone. Initial hydrogeologic data at the site was obtained from the well 2-D, a deep observation well installed in 1990 to monitor for saltwater intrusion into the Floridan aquifer system (PEER Consultants, P.C. and CH2M Hill, 1995). SZOW-1 was then installed and was used to determine the optimum storage/production zone interval. Additional hydrogeologic data was obtained during drilling and testing of the additional wells at the site.

Hydrogeologic testing of TPW-1 and SZOW-1 included variable-rate step-drawdown tests, off-bottom and straddle packer tests (SZOW-1 only) and specific capacity testing during reverse air drilling. All the primary flow zones identified in the two wells occurred within the Suwannee Limestone, with some variability across the site between the two wells. The primary flow zones within SZOW-1 occurred at approximately 190, 230, 268, 290, 310, and 365 feet bls (PEER Consultants, P.C. and CH2M Hill, 1995).

PEER Consultants, P.C. and CH2M Hill (1995) reported specific capacity of SZOW-1 increased between 220 and 300 feet bls from 2.0 to 22.1 gpm/ft of drawdown during reverse air drilling. Specific capacity increased at 300 to 320 feet bls (from 22.1 to approximately 44 gpm/ft) indicating a good producing zone. Specific capacity increased moderately between 320 and 380 feet bls (approximately 44 to approximately 55 gpm/ft) and increased over the next 20 feet in the well from approximately 55 to approximately 65 gpm/ft. The peak specific capacity in the well was located at 400 feet.

Using geophysical log results from TPW-1, two primary flow zones were found to exist at 330 and 360 feet bls, and minor flow zones were identified at 306, 322, 376, and 382 feet bls (PEER Consultants, P.C. and CH2M Hill, 1995). PEER Consultants, P.C. and CH2M Hill (1995) also reported that little to no water was being introduced into the well from the lower 20 feet of the 400 foot deep borehole, and it was therefore determined to complete the open hole interval in TPW-1 from 295 to 385 feet bls.

Two off-bottom packer tests were completed during installation and testing of SZOW-1 to obtain hydraulic data on the permeability of specific lithologic zones; the following

data and conclusions are presented in PEER Consultants, P.C. and CH2M Hill (1995). The packer tests were completed on upper and lower confining units to insure they had significantly lower hydraulic conductivities than the proposed storage zone interval. The first packer test was conducted for the interval 436 to 470 feet (total depth) bls. The average transmissivities determined from the drawdown and recovery test data were 66 and 82 ft^2/d, respectively. Assuming an aquifer thickness of 34 feet (436 to 470 feet), the hydraulic conductivity of this interval is 2.0 and 4.4 fpd for drawdown and recovery, respectively. Water levels above this interval were monitored to determine if any detectable leakage occurred around the packers. No drawdown occurred above the interval and therefore no leakage during the packer test occurred. This data indicates there is reasonable confinement in this section of the well and aquifer.

The second packer test was a straddle packer test and was used to test the upper confining unit of the storage zone. The packers were set at 253 and 283 feet, a confining unit of 30 feet. Transmissivity and hydraulic conductivity were reported to be 107 ft^2/d and 3.6 fpd, respectively. Because of the extremely rapid recovery, calculations were not completed for the recovery test data. Water levels in the zone above the tested interval indicated 0.5 feet of drawdown, indicating leakage, probably around the packer (the zone just above the packer was reported to be 2 inches wider than the packer and probably compromised the tightness of the packer at that depth; PEER Consultants, P.C. and CH2M Hill, 1995).

Three variable-rate step-drawdown tests were completed on SZOW-1. The first test was conducted for the open hole interval 180 to 360 feet. Pumping rates were 100, 150 and 200 gpm. Specific capacities for the three pumping rates averaged 39.7 gpm/ft. The second test was conducted for the open hole interval 180 to 470 feet. Pumping rates were 355, 500 and 700 gpm (1 mgd). Specific capacity values were 55.9, 48.2 and 40.8 gpm/ft, respectively, averaging 48.3 gpm/ft. The third test was conducted on the completed well for the open hole interval 290 to 370 feet bls. Pump rates were 455, 512 and 520 gpm. Specific capacities were calculated to be 11.9, 11.0 and 11.1 gpm/ft, respectively.

A 10-hour variable-rate specific-capacity aquifer test was conducted on the completed TPW-1 well to evaluate well performance, estimate aquifer characteristics in the storage zone and semi-confining units, and to examine possible effects on water levels in nearby wells; the following results are discussed in PEER Consultants, P.C. and CH2M Hill (1995). Four pumping rates were used for the test: 600, 740, 880 and 940 gpm. Drawdown occurred from 33 to 53 feet as the flow rate increased from 600 to 940 gpm. The water level returned to static conditions after approximately five hours, the majority of which occurred in the initial 5 minutes of the recovery period, to approximately 2 feet below the initial water level in the well. Specific capacity of the well ranged from 18.2 gpm/ft at 600 gpm to 17.9 gpm/ft at 940 gpm. Well efficiency was computed to be 96.9% at 600 gpm to 95.2% at 940 gpm. Surrounding well effects were recorded as follows: SZOW-1 had 4.7 feet of drawdown and recovery to within 0.1 feet of static level conditions after five hours of recovery, SMW-1 had 2.5 feet drawdown and recovery within 0.3 feet of pre-pumping levels after 5 hours of recovery, and 2-D had 0.7 feet of drawdown and returned to within 0.9 feet of the previous level.

A 5-day aquifer performance test was conducted to provide operational startup of the pump and motor and to evaluate aquifer characteristics. An approximate 1 mgd rate was pumped from TPW-1. Average transmissivity, storage coefficient, and leakance values determined for the storage zone at the site were 1.52×10^5 gpd/ft, 9.8×10^{-5} (dimensionless), and 3.9×10^{-3} gpd/ft^3, respectively (PEER Consultants, P.C. and CH2M Hill, 1997).

Cycle 1 was designed to evaluate recoverability of short-term stored drinking water at the site; results from Cycle 1 and Cycle 2 are presented in PEER Consultants, P.C. and CH2M Hill (1997). Water from the Hillsborough River in Tampa was treated to drinking water standards and injected into the storage zone for almost 16 days at approximately 1.2 mgd, injecting a total of 18.2 mg. The water was stored overnight and then recovered for almost 20 days at 1.1 mgd. Results of Cycle 1 demonstrated that full volumetric recovery of drinking water could be anticipated for a short-term cycle test at this site.

Cycle 2 was designed to evaluate the performance of a 1 mgd ASR well at the site under what was projected to be a typical ASR operating period: recharge for 90 days during a typical wet season (September to December), storage for 90 days, and then recovery for 90 days during the typical dry season in the area (March to June). Water was recharged for 92 days at approximately 1 mgd, stored for 90 days and recovered for 90 days at the same rate. Total volume recharged was 98.9 mg with all but 6.5 mg recovered. Well-head pressure during recharge ranged from 16 psi to 24 psi at flow rates of 760 gpm and 770 gpm, respectively. The higher pressure in the later portion of recharge indicates a slight reduction in well capacity occurring over the recharge period. Approximately 99 million gallons of drinking water were recharged and 92.3 million gallons were recovered.

PEER Consultants, P.C. and CH2M Hill (1995) projected horizontal travel time of the injected water in the storage zone. They used the following aquifer characteristics: 20% porosity (conservative for the Suwannee Limestone), aquifer thickness of 90 feet (open hole interval with confining unit boundaries vertically), assuming a homogeneous aquifer with no vertical movement, and a pumping rate of 1 mgd. The estimated horizontal extent after 10 days is 154 feet (SZOW-1 is 192.5 feet from TPW-1) and 463 feet after 90 days.

Water levels at TPW-1 during the Cycle 2 recharge phase ranged from +85 feet NGVD to approximately -40 feet NGVD at the start of the recovery phase. No flow change was associated with this rise in water level, suggesting the well was becoming more efficient (PEER Consultants, P.C. and CH2M Hill, 1997). Static water levels at the end of Cycle 2 were similar to background water levels observed during the 5-day aquifer test.

Water level at SZOW-1 increased about 5 feet during recharge, averaging approximately 22 feet above NGVD. Approximately 5 feet of drawdown occurred during recovery, returning the water level to the pre-cycle level of +12 to +13 feet NGVD.

At SMW-1, water level increased approximately 2 feet during recharge and lowered the same distance during recovery. Well 2-D showed a water level increase of approximately 1.5 feet during recharge and lowered the same distance during recovery.

The Cycle 3 recharge phase began in December 1997 and ensued for 176 days, due to excess water availability. The Hillsborough County site is currently undergoing expansion to furnish the site with facilities capable of disinfection of the recovered water (including a chlorine contact basin to provide at least the minimum chlorine contact time required by the TWD) and pumping facilities to pump the recovered water back into the TWD's finished water transmission system. The recharged water is currently undergoing the storage phase until these facilities can be constructed.

PUNTA GORDA ASR SITE

Construction of ASR facilities at the Punta Gorda site in Charlotte County involved the construction of only one well on the site. This well was used to determine whether

the site was suitable for ASR activities including hydrogeologic testing and selection of the storage interval. The well was then utilized as the test-production well, or the well responsible for recharge to and recovery from the aquifer storage zone. Hydrogeologic testing and storage zone selection included single-packer testing, borehole geophysical logging, and specific capacity testing.

Two flow zones within the Suwannee Limestone were identified using flowmeter geophysical logging. The upper flow zone extends from approximately 700 to 760 feet bls, contributing over 25% of the flow from 700 to 1043 feet bls. The lower flow zone extends from approximately 800 to 950 feet bls, contributing approximately 60% of the total flow from 700 to 1043 feet bls (Watson, 1998).

Packer testing was conducted on the upper flow zone; the packer was installed at a depth of 780 feet bls. The water level and pumpage data were used to estimate the specific capacity of the well utilizing the upper flow zone. At a flow rate of 300 gpm, specific capacity was calculated to be 10.0 gpm/ft. At 440 and 550 gpm, specific capacity was calculated to be 5.7 and 5.6 gpm/ft, respectively (Watson, 1998).

The lower flow zone was not tested. It was plugged and abandoned to prevent upward movement of poor quality water. The upper flow zone was also preferred because it is limited in thickness and is confined above and below the interval. The hole was plugged from 764 to 1043 feet (total depth) bls (Watson, 1998).

A step-rate and a constant-rate specific capacity test were run on the completed well to quantify the hydraulic performance of the ASR well and to estimate transmissivity. The step-rate pump test included five flow rates at 231, 381, 448, 534 and 597 gpm. Drawdown results in the well were 44, 78, 100, 119 and 129 feet, respectively. Specific capacity for each step was calculated to be 5.3, 4.9, 4.5, 4.5 and 4.6 gpm/ft, respectively (Watson).

Constant-rate specific capacity testing was conducted for approximately 54 hours. The average pumping rate was 546 gpm and the maximum drawdown was 123 feet. The specific capacity of the well was calculated from this test data to be 4.4 gpm/ft Watson. From the various testing data, Montgomery Watson (1998) calculated the transmissivity of the storage zone to be 1305 ft^2/d (9764 gpd/ft).

Radial travel distance of the injected water from the well was estimated by Watson using the following aquifer characteristics and values: a pumping rate of 500 gpm, a homogeneous medium, a sharp mixing front, no vertical movement of injected water, a storage zone thickness of 60 feet and a storage zone porosity of 0.2. For 15, 30 and 90 day injection periods, travel distances were estimated to be 196, 277 and 479 feet, respectively.

During Cycle 1, treated water was recharged to the storage zone for six days and recovered for ten days (no storage phase). Water quality analyses indicate primarily native water was being recovered by the fourth day of the recovery phase (see **Progress and Development** section). In an oral communication from a representative of Montgomery Watson, (1998) it was explained that pressure problems during recharge were slowing the testing process. During Cycle 2 recharge, pressure was so great that backflushing of the production well was necessary before proceeding with the recharge phase. Because of the extreme difficulty in recharging throughout Cycle 2, the upper flow zone will be cased and the lower flow zone will be redrilled and utilized for further cycle testing.

METHOD OF INVESTIGATION

SAMPLING

ROME AVENUE ASR SITE

Several wells at the Rome Avenue ASR site were sampled periodically for this study. Table 3 lists the sample locations and their descriptions, open-hole intervals, and corresponding geologic formations. TPW-1 is the recharge and recovery well for this site. For this investigation, collection of water samples at the Rome Avenue ASR site began on March 3, 1997 just prior to the onset of the recovery phase (March 10, 1997) of Cycle 2.

Each ASR cycle includes three phases: recharge, storage and recovery. Table 4 lists the dates and time interval for each phase of the first two cycles and the recharge phase of Cycle 3. Note that the beginning of a cycle does not immediately follow the end of the previous cycle. During the time between cycles, some samples were taken for this investigation and by the TWD. Estimated travel time for water in the aquifer from SZOW-1 to TPW-1 is sixteen days (see also **Results and Discussion** section). In order to discern when the injected water reaches TPW-1 and to observe changes in the water as it travels within the aquifer, samples were taken every two to three days during the onset of recharge and recovery. After sixteen days, samples were taken weekly, bi-weekly and eventually monthly.

Table 5 lists the sampling schedule for this investigation at the Rome Avenue ASR site. Samples were taken for uranium, strontium, trace metal and standard water quality analyses. Note that a short recovery period of nine days was performed during the Cycle 3 storage phase. TPW-1 was sampled the first, second and third hour of recovery, and the second, third, fourth, seventh, eighth and ninth day of recovery. The final four samples were not available for this investigation. Due to the brevity of the period and because a full-scale recovery has not been carried out, these samples are considered Cycle 3 storage phase samples.

The TWD conducted metal analyses on samples throughout the Rome Avenue ASR site's operation. Their data, as presented in PEER Consultants, P.C. and CH2M Hill (1995, 1996, 1997) and from a personal communication (Mark McNeal, CH2M Hill, 1998), are used in this investigation as well. TWD analyses included sulfate, total dissolved solids, pH, total hardness, non-carbonate hardness, total alkalinity, turbidity, conductivity, chloride, fluoride, dissolved oxygen, chlorine, nitrate, iron, calcium, magnesium and others (Appendix B). Analyses were run on TPW-1, SZOW-1, 2-D and SMW-1. These and additional analyses were also carried out on native aquifer water sampled during aquifer testing (before cycle testing was initiated).

PUNTA GORDA ASR SITE

Native water from the Punta Gorda ASR site was sampled in November 1997 and in April 1998. Cycle 1 commenced on July 23, 1998. Recharge stopped on July 28, 1998, totaling six days of recharge. Cycle 1 had no storage phase. Water was recovered from July 29 to August 7, 1998, totaling ten days. The sampling schedule for this investigation at the Punta Gorda site is shown in Table 6.

Table 3. Water sampling locations at the Rome Avenue ASR site

Sample Location ID:	Description	Open-Hole Interval (feet)	Geologic Formation
TPW-1*	Test Production Well ASR well	295-385	Suwannee Limestone
SZOW-1	Storage Zone Observation Well	290-370	Suwannee Limestone
SMW-1	Shallow Aquifer Monitor Well	126-156	Tampa Member of Arcadia Formation Hawthorn Group
2-D	SWFWMD's Deep Observation Well	717-771	Avon Park
PTRW	Pre-Treated River Water (at or near source)	-	-
TRW*	Treated River Water Recharge water	-	-

*Note: TPW-1 and TRW are the same water during the recharge phase.

Table 4. ASR phase intervals for Cycle 1, Cycle 2 and Cycle 3 at the Rome Avenue ASR site.

PHASE:	RECHARGE	STORAGE	RECOVERY
Cycle 1:	7/01/96-7/16/96 16 days	no storage interval	7/17/96-8/05/96 20 days
Cycle 2:	9/09/96-12/09/96 92 days	12/10/96-3/09/97 90 days	3/10/97-6/09/97 92 days
Cycle 3:	12/08/97-6/01/98 176 days	6/01/98-NA -	NA -

The Cycle 2 recharge phase commenced in September, 1998. During recharge, injection problems prevented continuation of the phase until several back-flushing/recharge cycles were run. Samples were taken for this investigation during recharge and recovery, but were not available for processing and analysis due to the proximity of the investigation deadline. The samples are, however, available for future study.

Standard water quality and trace metal analyses by the City of Punta Gorda through Cycle 1 is presented in Montgomery Watson (1998) and in a written communication from Mark Abbott (1998). These data are presented in Appendix C.

LAB ANALYSIS

Rome Avenue and Punta Gorda five gallon (18.9 Liters) water samples were transported to the FDEP-approved (Approved Comprehensive QA Plan, April 1997) FSU Geochemistry Laboratory in Tallahassee, Florida. There, water samples were split for uranium

Table 5. Sampling schedule for the Rome Avenue ASR site (U-sampled for uranium analysis, T-trace metal analysis, S-$^{87}Sr/^{86}Sr$ activity ratio analysis).

Location:	TPW-1	SZOW-1	SMW-1	2-D	PTRW	TRW
Date:	CYCLE 2 STORAGE PHASE					
3/07/97		UT	UT	T		
CYCLE 2 RECOVERY PHASE						
3/10/97	UTS					
3/11/97	T					
3/14/97	UT	UTS	T	T	U	US
3/20/97	T				T	
3/21/97	U	U		U		
4/03/97	U		U			
4/17/97	U	U			U	U
5/01/97	U					
5/22/97	U					
6/09/97	UTS	U	UT			
6/19/97					U	U
BETWEEN CYCLE 2 AND CYCLE 3						
9/24/97		U				U
CYCLE 3 RECHARGE PHASE						
12/08/97		U				U
12/15/97		U				
12/22/97		U				
12/29/97		U				U
1/05/98		U	U	U	U	
1/12/98		U				
1/20/98		U				
1/26/98		U				
2/02/98		U				U
2/09/98		U				
2/17/98		U				
2/23/98		U				
3/02/98		U				
3/09/98		U				
3/16/98		U	U	U	U	U
4/13/98		U				
5/11/98		U				U
CYCLE 3 STORAGE PHASE						
8/03/98		UT				
10/13/98	U*					
10/14/98	U					
10/15/98	U					

*Three separate samples: first, second and third hour of the nine-day short recovery period.

Table 6. Sampling schedule for the Punta Gorda ASR site (U-sampled for uranium analysis, T-trace metal analysis).

Location: Date:	PRODUCTION WELL	PTRW	TRW	NATIVE WATER
Nov. 1997				U
3/25/98				U
CYCLE 1 RECHARGE PHASE				
7/23/98			U	
CYCLE 1 RECOVERY PHASE				
7/29/98	UT	UT	UT	
7/30/98	UT			
7/31/98	UT			
8/03/98	UT			
8/04/98	UT			
8/05/98	UT			
8/06/98	UT			

and strontium analyses. The uranium samples underwent a number of procedures, as described in Osmond and Cowart (1976) to create a thin source for uranium isotope analysis (see Appendix D). Using alpha pulse-height spectrometry, the $^{234}U/^{238}U$ activity ratio and uranium concentration in each sample were determined.

Samples for strontium isotopic analyses were concentrated in the FSU Geochemistry Laboratory (NHMFL, Appendix D), then transferred to the National High Magnetic Field Laboratory geochemistry laboratory for preparation and analysis. Preparation followed the procedure outlined in Hart and Brooks (1977). $^{87}Sr/^{86}Sr$ isotopic ratio was determined at the NHMFL geochemistry laboratory using an ionization coupled plasma mass spectrometer.

Samples (250 mL) for trace metal analysis were collected in amber-colored glass jars, and were preserved with 5% HNO_3. The samples were first transported to the Florida Geological Survey, and then to the FDEP Central Laboratory. Those sampled before July 29, 1998 (the first of two suites of samples) were analyzed for arsenic, barium, cadmium, calcium, manganese, potassium, sodium, strontium and zinc. For this first suite of samples, cadmium, potassium and zinc results were either below detection limits or showed little to no variability over time. As a result, analysis of these metals was not included in the second suite of samples. However, lead was added to the list for analysis of the second suite of samples. All samples were analyzed for trace metals by induced coupled plasma emission spectroscopy at the FDEP Central Laboratory.

PROGRESS AND DEVELOPMENT

ROME AVENUE ASR SITE

Previous Work

Drilling of the SZOW-1, TPW-1 and SMW-1 wells was completed in 1995 for the Tampa Water Department (well 2-D is a pre-existing SWFWMD well). Water samples were

the recharge phase of Cycle 3. During the storage phase of Cycle 3, the TWD also completed a short, nine-day recovery period for further testing.

Water sample collecting for this investigation was initiated just prior to the Cycle 2 recovery phase. Fifty-nine samples were collected and analyzed for uranium isotopic signatures, fourteen samples were analyzed for trace metals and five samples were analyzed for strontium ($^{87}Sr/^{86}Sr$) isotopic ratios. Cycle 2 preliminary results from this investigation were presented by Cowart et al.(1997). Cycle 2 and 3 results were presented by Cowart et al. (1998). A list of selected reading has been compiled and is presented in Appendix E.

Present and Future Work

The TWD is continuing water quality analysis on wells 2-D, TPW-1, SMW-1 and SZOW-1. The ASR site is currently in the Cycle 3 storage phase and will remain so until further facilities are constructed. The TWD plans to construct disinfection and pumping facilities at the site to enable pumping of the recovered water back into the TWD's finished water transmission system. The TWD also plans to construct ten new ASR production wells in and near the Rome Avenue site to achieve close to a 10 mgd ASR wellfield.

Further investigations at this site and others have been approved. Included in at least one future investigation will be an arsenic study at the ASR facilities. In order to determine possible health hazards, arsenic source and effect of water-rock interaction on arsenic concentrations, 26 samples from Cycle 2 and 3 are undergoing arsenic analysis at the FDEP Central Laboratory. Additional investigations at the Rome Avenue site will include geochemical analysis of borehole cores and cuttings from nearby wells and continued analysis of water samples for uranium and trace metals.

PUNTA GORDA ASR SITE

Previous Work

Drilling of the production well was completed in September, 1997. The production well is the only well located at the ASR site. Native water samples were collected for water quality analysis for the City of Punta Gorda. Native water samples were also collected for this investigation. Cycle 1 took place in July and August of 1998. Samples were collected for water quality analysis for the City of Punta Gorda and for this investigation.

Uranium isotope analyses were performed on twelve samples from Cycle 1. Trace metal analyses were carried out on nine of these samples for this investigation. Cycle 2 was completed, with difficulty, in the fall of 1998. Uranium and trace metal samples were collected but were not available for this investigation.

Present and Future Work

Due to pressure problems during recharge at the site, the upper flow zone of the storage zone has been abandoned. Plans are in effect to case the upper flow zone, drill through an existing plug to the lower flow zone, and utilize it for further testing cycles. The earliest expected date for cycle testing is April, 1999 (personal communication, Rob Denis of Montgomery Watson, 1998). Continuing investigations at the Punta Gorda ASR site will include uranium and trace metal analyses of the Cycle 2 samples, as well as those of future cycles.

RADIOISOTOPE GEOCHEMISTRY

URANIUM HYDROGEOCHEMISTRY

Uranium has three naturally occurring isotopes, ^{238}U, ^{235}U, and ^{234}U, all of which are radioactive. U-238 is the most abundant uranium isotope representing 99.2739% mass of all uranium. U-235 accounts for 0.7204% and ^{234}U accounts for 0.0057% mass of all uranium (Faure, 1977). U-238 and ^{235}U are long-lived uranium isotopes (Figure 5), each the parent of separate radioactive decay series (the uranium decay series and the actinium decay series, respectively). U-238 and ^{235}U were formed during a primary stellar nuclear synthesis process (Osmond and Cowart, 1976) and exhibit only minor mass differences between the two uranium isotopes. These two characteristics preclude significant isotopic fractionation between the two isotopes; therefore, the $^{235}U/^{238}U$ mass abundance ratio is almost everywhere fixed at 1/137.5 (Rogers and Adams, 1969).

U-234 is a shorter-lived isotope radiogenically produced in the uranium decay series. U-234 is produced by the alpha-decay of ^{238}U to ^{234}Th, beta-decay of ^{234}Th to ^{234}Pa, and beta-decay of ^{234}Pa to ^{234}U. U-234 then continues the decay series further until stability is met with ^{206}Pb. Because ^{234}U is continuously being produced and lost via decay, the worldwide abundance of ^{234}U is solely dependent upon the abundance of ^{238}U (Osmond and Cowart, 1976).

The radioactivity A (number of disintigrations per unit time) of an unstable isotope is defined as:

$$A=\lambda N$$

where N is the number of atoms of the isotope and λ is the decay constant. The decay constant represents the probability that an atom will decay within a stated unit of time and has units of reciprocal time. It may be expressed as λ=ln2/half-life, or 0.693/half-life. The half-life, or $t_{1/2}$, is the time required for the decay of one half of the original number of present nuclei. The half-lives of ^{238}U, ^{235}U, and ^{234}U are 4.49 X 10^9 years, 7.13 X 10^8 years, and 2.48 X 10^5 years, respectively (Ivanovich and Harmon, 1982).

Fractionation and Disequilibrium

In a closed natural system, the activity of a relatively short-lived daughter (D) will become equal to the activity of the long-lived parent (P):

$$N_P\lambda_P=N_D\lambda_D.$$

The situation in which every parent to daughter activity ratio in a decay series is equal to 1 is known as secular equilibrium. Thus, the activity ratio of parent to daughter in a decay series in secular equilibrium is 1.0:

$$N_{P1}\lambda_{P1}/N_{D1}\lambda_{D1}= N_{P2}\lambda_{P2}/N_{D2}\lambda_{D2}= \ldots =1.0.$$

In nature, however, this one-to-one ratio is not always observed.

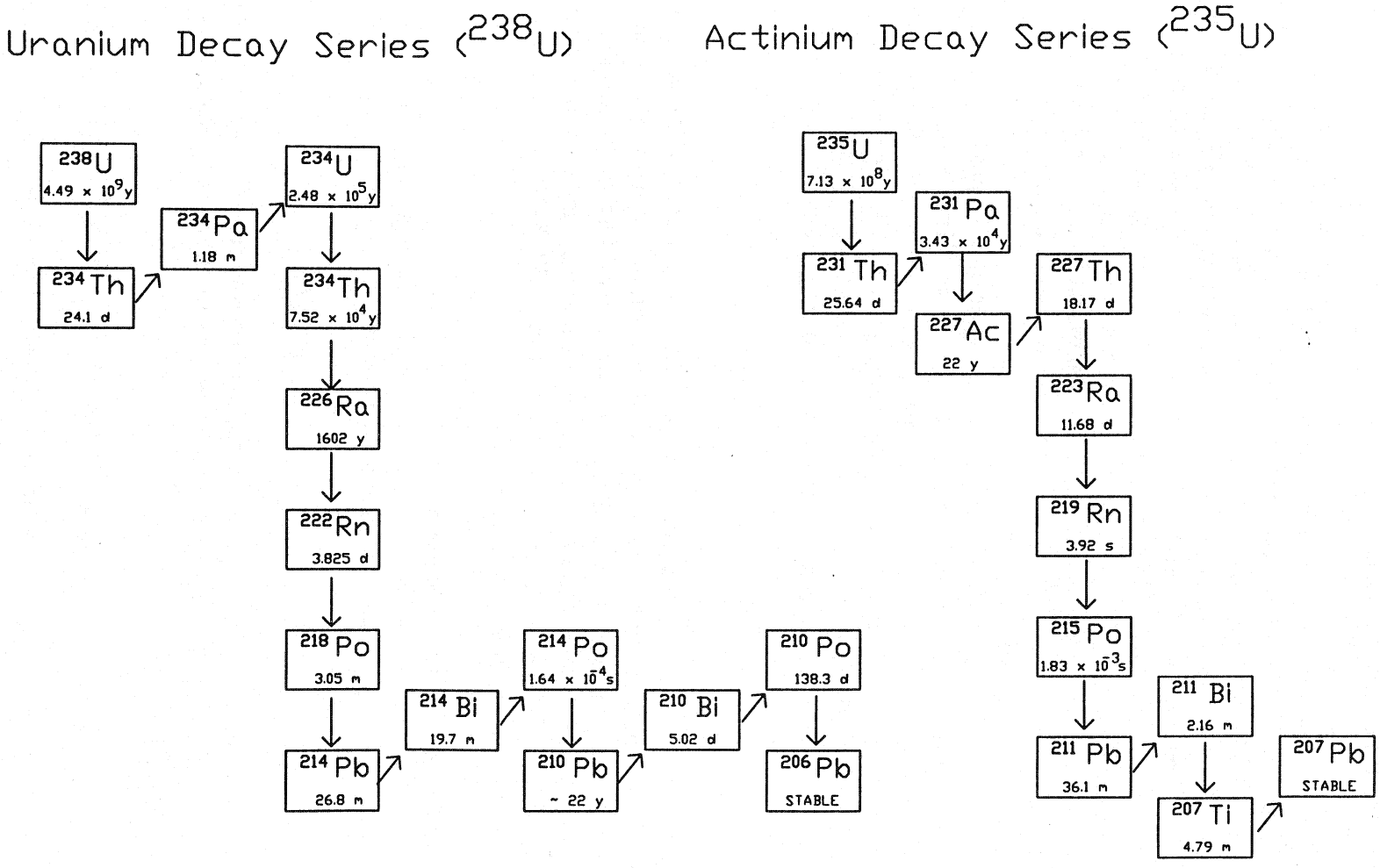


Figure 5. The uranium and the actinium decay series.

As early as 1955, large deviations in the $^{234}U/^{238}U$ activity ratio were found to commonly occur in nature (Cherdyntsev et al., 1971). Others later presented similar findings (Kronfeld, 1974; Cowart et al., 1978; Cowart, 1980a, b; Hussain and Krishnaswami, 1980; Asikainen, 1981a, b; and King et al., 1982). Osmond and Cowart (1976) noted these deviations especially in surface and ground waters.

The situation whereby one decay series daughter is more mobile than another results in radioactive or isotopic disequilibrium. The deviation from secular equilibrium occurs by a fractionation process. Isotopic fractionation can exist across all phase boundaries and is a process by which isotopes in a decay series are separated from others. For the purpose of this investigation, fractionation across the solid/liquid, or water/rock boundary, and in liquid/liquid, or mixing situations will be discussed. This study focuses primarily on the fractionation of ^{234}U from ^{238}U. U-234 is fractionated from ^{238}U in three ways: oxidation, leaching, and recoil mechanisms and results from physical, chemical and isotopic variations in the behavior of uranium (Ivanovich and Harmon, 1982).

Recoil effects result in uranium isotopic fractionation. Radioactive decay of ^{238}U involves an alpha decay with an energy of 4.195 milli-electron volts (Ivanovich and Harmon, 1982). This decay event creates enough energy to displace the daughter product, ^{234}Th, by 200 angstroms or more in crystalline materials (Ivanovich and Harmon, 1982). If the ^{238}U nuclide within the grain is within 200 angstroms or less from the surface of a grain, the daughter nuclide has up to a 50% chance of being ejected from that grain and into the surrounding environment (Figure 6). The distance between parent and daughter can be increased if the ^{234}Th atom is ejected into an oxidizing solution. Although ^{234}Th is not mobile in oxidizing conditions, it quickly decays through ^{234}Pa to ^{234}U which is mobile in oxidizing conditions.

The leaching process is another mechanism of fractionation. If the ^{234}Th atom is not ejected from the grain, but is near the grain surface, the dislocation of the nuclide from the original position of the ^{238}U atom in the grain, as well as the movement of the alpha particle, causes damage to the crystal lattice. The resulting ^{234}U atom is susceptible to leaching, or removal from the grain, by aggressive waters.

The redox condition of the environment affects the chemical mobility of uranium, as well. Uranium has two common valence states. In reducing conditions, uranium exists in the 4+ state and is immobile. Uranium can be oxidized to the 6+ state whereby the nuclide forms soluble uranyl complex ions (UO_2^{2+}), and is therefore mobile and can remain in solution (Ivanovich and Harmon, 1982).

Further mobilization may occur depending on pH, Eh, and the presence of certain ions in solution. Langmuir (1978) discussed the presence of uranium in natural waters in both oxic and anoxic conditions indicating that uranium in natural waters is usually complexed. Uranous (U^{4+}) fluoride complexes predominate below pH 3-4 in anoxic conditions with typical concentrations of carbonate, chloride, fluoride, phosphate and sulfate. At pH values greater than 4, uranous hydroxy complexes occur, but are below detection at pH 4-5 because of the insolubility of uraninite and coffinite. These two uranium rich minerals are associated with low temperature U ore deposits world wide, however, they are not reported to occur within the Floridan aquifer system. Further study of uranium-bearing phases associated with carbonates in Florida is warrented.

In oxidized natural waters, the uranyl ion (UO_2^{2+}) forms water-soluble complexes with carbonate, bi-carbonate, phosphate, sulfate, chloride and fluoride. Uranyl fluoride

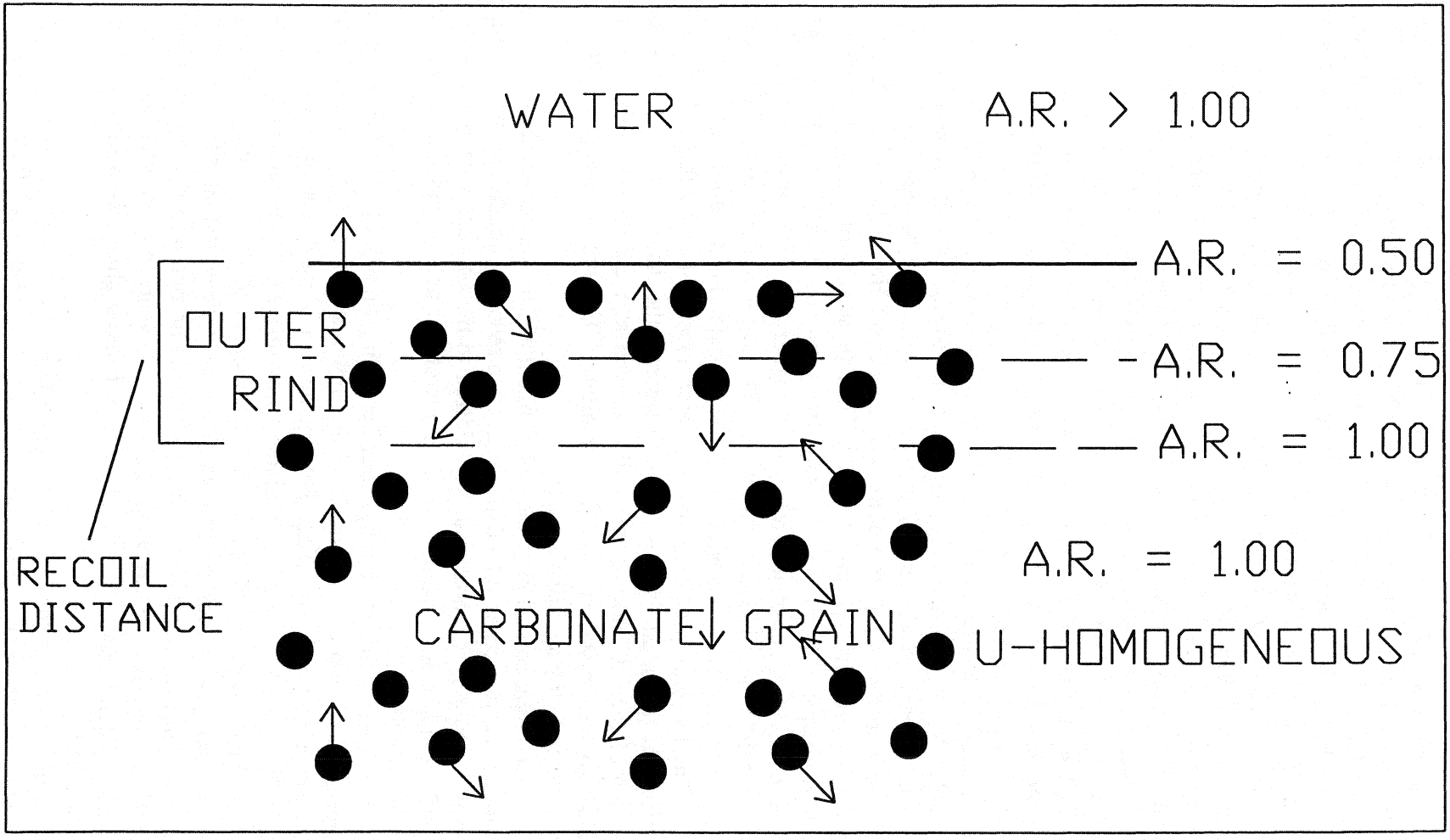


Figure 6. Recoil-ejection model depicting creation of the ^{234}U-deficient rind on carbonate grains (Cowart et al., 1997).

complexes predominate in pHs less than 5; the predominant species at pH 4 - 7.5 is $UO_2(HPO_4)_2^{2-}$ and at pHs greater than 7.5, uranyl di- and tri-carbonate complexes predominate (Langmuir, 1978).

Langmuir (1978) continues to discuss uranium behavior in varying Eh conditions: in low Eh conditions, and pH 4-8, the extreme insolubility of uraninite and coffinite makes uranium practically immobile. At higher Ehs, where phosphate and/or carbonate is present, oxidation and leaching of uraninite and coffinite are greatly enhanced.

STRONTIUM HYDROGEOCHEMISTRY

Strontium has four stable, naturally occurring isotopes: ^{88}Sr, ^{87}Sr, ^{86}Sr, and ^{84}Sr. Abundances are 82.53%, 7.04%, 9.87%, and 0.56%, respectively (Faure, 1977). The isotopic strontium composition is not constant, though, due to the radiogenic formation of ^{87}Sr. Sr-87 is formed by the beta-decay of ^{87}Rb; therefore, the exact composition of strontium in a rock or mineral that contains rubidium, depends on the age of the rock or mineral, and its Rb/Sr ratio.

The isotopic composition of strontium at the time the earth was formed is most precisely estimated from work on moon rocks and meteorites. Studies give ample evidence that they were formed at the same time as the earth, and because little to no chemical and physical weathering has taken place on the moon or within the meteorites (Faure and Powell, 1972; Faure, 1977). Meteorites and moon rocks can be considered a closed system with respect to addition of ^{87}Rb and strontium; therefore, the strontium in moon rocks and meteorites can be considered a time clock. The two reveal a primordial $^{87}Sr/^{86}Sr$ ratio of about 0.699 (Faure, 1977).

Strontium is a member of the alkaline earth elements of Group IIA. The occurrence of the strontium in calcium-bearing rocks is controlled by the extent to which Sr^{2+} can substitute for Ca^{2+}. Because Sr^{2+} favors eight-fold coordinal lattice positions, and Ca^{2+} is found in both eight-fold and six-fold coordinations, Sr^{2+} can replace some calcium in calcium-bearing rocks and minerals (Faure, 1977).

Because strontium can replace calcium in calcium-bearing rocks and minerals, it is removed with calcium carbonate from the marine water column. The concentration of strontium in calcium carbonate rocks depends on the mineralogy of the precipitating phase, the molar ratio of Sr^{2+} to Ca^{2+} in the water, the temperature of the water, and a variety of other factors (Faure and Powell, 1972). Rb-87 is small enough to incorporate itself into potassium-bearing rocks which are more resistant to chemical weathering than calcium-bearing rocks. Therefore, more strontium, relative to rubidium is released into the environment, and is more abundant to co-precipitate with calcium carbonate. As a result, there is little ^{87}Rb in calcium carbonate to produce ^{87}Sr. For this reason, the strontium composition, or isotopic ratio ($^{87}Sr/^{86}Sr$), in unaltered rocks will increase monotonically with time. each composition to the oceans. Global changes, then, can effect the level of contribution of each source to the ocean. These changes may include changes in spreading rates at the mid-oceanic ridge, sea-level changes, and mountain building (uplift) rates. The changes in $^{87}Sr/^{86}Sr$ through the Phanerozoic (Faure and Powell, 1972), are attributed to the decrease in the isotopic ratio in the Mesozoic due to the increased volcanic activity (of lower composition than marine carbonates and terrestrial rocks) at that time.

Because the residence time of strontium in the oceans is so much greater than the ocean mixing rate, it can be concluded that the isotopic composition of strontium in the oceans is everywhere the same (Faure and Powell, 1972). This information and the fact that strontium in

the ocean co-precipitates with calcium carbonates, allows us to conclude that unaltered calcium carbonate rocks and foram tests reflect the strontium composition of the oceans at the time of their formation.

In a study by Hess et al. (1986), well-dated fossil foraminifera samples were measured for ^{87}Sr and ^{86}Sr. The authors used the data to construct a precise graph comparing strontium composition with time for the last 100 million years. Their study demonstrates that there has been an almost steady increase in the strontium isotopic ratio since the Eocene, to the present value of about 0.709.

Other than dating rocks, strontium can be used as a tracer, or as an indicator of the mixing between two or more waters, and the interaction between water and rock. Examples of mixing waters include merging rivers, water seepage between aquifers or between lakes and aquifers, recharge into an aquifer, and rivers flowing into an ocean. When plotting the strontium isotopic composition versus concentration of a mixed water, the graph will show a hyperbola. A more useful graph will come from a plot of the strontium composition versus the reciprocal of the concentration. The values will plot on a straight line. The endpoints of the line mark the strontium composition of each of the two waters before they mixed. In the case of three waters mixing, the values will show three end members-all mixed values will plot within the triangle formed by connecting the three end members. Under favorable circumstances, it is possible that a reasonable estimate of the degree of rock dissolution due to water-rock interaction could be calculated.

RESULTS AND DISCUSSION

ROME AVENUE ASR SITE

The objective of this investigation is to analyze the geochemical effect of aquifer storage and recovery activities on the storage zone and recovered water; specifically, the introduction of oxygen-rich water into a less oxygen-rich environment. The primary focus of the investigation is the change in uranium concentration and isotopic signatures of various components of the mixing environment due to water-rock interactions during the recharge, storage and recovery processes. Water quality parameters and trace metals in the affected environment were studied to aid in the understanding of the processes that affect uranium isotopic signatures.

To analyze geochemical changes in an ASR system, the uranium isotopic signature of input, storage and output waters are characterized. These waters include: treated river water (TRW), or input water, before it is injected into the aquifer; the input water as it travels from TPW-1 to SZOW-1, is stored, and travels back to TPW-1 during recovery; water in the storage zone after the input water has been recovered (can be considered closest to native water signatures); water from a zone above the storage zone (SMW-1) and water from a zone below the storage zone (2-D) to determine if geochemical interaction is taking place outside the storage zone; and pre-treated river water (PTRW) to determine if significant geochemical changes occur during treatment. TPW-1 and SZOW-1 are the primary wells focused on in this investigation because they are open to the storage zone. Figure 4 depicts the distance of each well from TPW-1 and the open-hole interval and corresponding stratigraphic position of each.

Table 7 lists the $^{234}U/^{238}U$ activity ratios and the uranium concentrations for all water samples taken during this investigation. Recall that TPW-1 is the recharge/recovery well. During recharge, TPW-1 water samples are treated river water samples (input water) and are for that reason listed under the TRW heading.

Figure 7 illustrates the uranium isotopic signature ($^{234}U/^{238}U$ activity ratio versus the reciprocal of uranium concentration) for waters recovered from all wells during Cycles 2 and 3. The TRW, PTRW and water from zones above (SMW-1) and below (2-D) the storage zone have very low concentrations and activity ratios above 0.75 with some values higher than 1.5. Uranium concentration of water samples taken from TPW-1 and SZOW-1, representing input water which has spent time in the storage zone, are higher than those in TRW, 2-D, SMW-1 and most PTRW samples. Activity ratios are ~1.00 or less for all samples that have encountered aquifer-matrix rocks (TPW-1 and SZOW-1). Many of these activity ratios are lower than those of TRW samples.

Because this investigation was initiated after the first testing cycle, no native aquifer water samples were available. During each testing cycle, the same volume of water recharged to the aquifer is recovered. Dilution however, allows some input water to remain in the aquifer after recovery completion; hence, some native aquifer water that has mixed with input water is recovered. In SZOW, the water sampled between the Cycle 2 recovery phase and the Cycle 3 recharge phase can be considered to represent *approximate* native water uranium isotopic signatures. In this case, the activity ratio is 1.00 and the concentration is 1.84 µg/L. The change in isotopic signatures during cycle tests characterizes the degree of mixing or geochemical mechanisms.

Another step in understanding the processes affecting the isotopic signature of the storage environment is determining if water above and below the storage zone is affected by or affects water in the storage zone during ASR activities. If the three zones do not exhibit geochemical mixing, the storage zone could be considered a closed system for the purposes of this investigation.

Storage zone water was sampled from SMW-1 and 2-D for uranium, trace metals, and standard water quality analyses to determine the effect of water-rock interaction during the ASR processes. Figure 8 is a graph of uranium concentration through time. The concentrations of samples from 2-D and SMW-1 do not change significantly during the Cycle 2 recovery phase and the Cycle 3 recharge phase. SMW-1 and 2-D activity ratios (Figure 9) are varied and inconclusive in determining if they are a result of interaction with the storage zone.

Trace metals and water quality also support minimal interaction with the storage zone during ASR processes. Temporal variations exist in total alkalinity values (Figure 10) for TPW-1 and SZOW-1 samples. The 2-D and SMW-1 total alkalinity values exhibit slight variation over the two cycles as well. This variation, however, does not mirror the geochemical response in TPW-1 and SZOW-1. In a graph of dissolved oxygen values through time (Figure 11), 2-D and SMW-1 values are highly variable and do not follow a specific trend during the two cycles (this may be a result of oxygen contamination during sampling reflecting the difficulty in collecting an atmosphere-free sample). With the exception of two samples, total carbonate hardness values (Figure 12) for SMW-1 samples remain constant during Cycle 2 and Cycle 3. 2-D values are variable during the Cycle 2 recharge phase and the trend increases during the Cycle 2 recovery phase. This repeating trend is not evident in the SZOW-1 and TPW-1 samples. The Cycle 3 SMW-1 values vary negligibly and follow no trend during Cycle 3. A lack of change in

Table 7. Uranium data for water samples taken at the Rome Avenue ASR site.

Location	TPW-1		SZOW-1		SMW-1		2-D		PTRW		TRW	
Date:	Uranium conc. (µg/L)	$^{234}U/^{238}U$ A.R.	Uranium conc. (µg/L)	$^{234}U/^{238}U$ A.R.	Uranium conc. (µg/L)	$^{234}U/^{238}U$ A.R.	Uranium conc. (µg/L)	$^{234}U/^{238}U$ A.R.	Uranium conc. (µg/L)	$^{234}U/^{238}U$ A.R.	Uranium conc. (µg/L)	$^{234}U/^{238}U$ A.R.
CYCLE 2 STORAGE PHASE												
3/07/97			X	X	0.02±0.002	1.3±0.13						
CYCLE 2 RECOVERY PHASE												
3/10/97	1.27±0.04	0.47±0.02										
3/14/97	2.83±0.15	0.5±0.03	4.18±0.12	1.00±0.03					1.13±0.14	1.02±0.18	0.45±0.02	0.85±0.05
3/21/97	4.71±0.20	0.62±0.01	4.27±0.23	0.95±0.05			0.05±0.01	1.53±0.42				
4/03/97	6.44±0.28	0.74±0.02			0.12±0.01	0.9±0.09						
4/17/97	6.15±0.27	0.80±0.02	2.78±0.09	0.96±0.03					XX	XX	0.54±0.03	0.94±0.07
5/01/97	4.91±0.16	0.84±0.03										
5/22/97	3.53±0.15	0.83±0.02										
6/09/97	2.44±0.12	0.87±0.06	1.26±0.06	0.99±0.05	0.06±0.004	0.90±0.10						
6/19/97									0.60±0.08	0.77±0.16	0.37±0.02	0.80±0.06
BETWEEN CYCLE 2 AND CYCLE 3												
9/24/97			1.84±0.09	1.00±0.07							0.89±0.02	0.79±0.02
CYCLE 3 RECHARGE PHASE												
12/08/97			1.47±0.02	0.97±0.015							0.07±0.003	1.06±0.06
12/15/97			1.61±0.04	0.92±0.02								
12/22/97			2.24±0.05	0.87±0.015								
12/29/97			2.39±0.04	0.86±0.02							BDL	BDL
1/05/98			3.29±0.06	0.83±0.02	BDL	BDL	0.03±0.003	2.06±0.23	BDL	BDL		
1/12/98			3.88±0.07	0.83±0.02								
1/20/98			4.36±0.14	0.84±0.015								
1/26/98			5.05±0.10	0.82±0.02								

X-sample lost during processing
XX-analytical error associated with sample processing
BDL-below detection limits

Environmental Protection Agency's 1991 proposed maximum contaminant level for uranium in public water supplies is 20 µg/L (Federal Register, 1997). A regulation based on the proposal has not been promulgated. A decision is expected by November, 2000.

Table 7. Uranium data for water samples taken at the Rome Avenue ASR site (cont.).

Location	TPW-1		SZOW-1		SMW-1		2-D		PTRW		TRW	
Date:	Uranium conc. (µg/L)	$^{234}U/^{238}U$ A.R.	Uranium conc. (µg/L)	$^{234}U/^{238}U$ A.R.	Uranium conc. (µg/L)	$^{234}U/^{238}U$ A.R.	Uranium conc. (µg/L)	$^{234}U/^{238}U$ A.R.	Uranium conc. (µg/L)	$^{234}U/^{238}U$ A.R.	Uranium conc. (µg/L)	$^{234}U/^{238}U$ A.R.
2/02/98			5.59±0.16	0.81±0.014							0.03±0.006	1.23±0.28
2/09/98			5.77±0.13	0.80±0.013								
2/17/98			7.26±0.27	0.76±0.01								
2/23/98			5.77±0.10	0.79±0.01								
3/02/98			4.23±0.09	0.80±0.02								
3/09/98			3.77±0.08	0.80±0.02								
3/16/98			3.94±0.09	0.80±0.01	0.02±0.01	1.76±0.94	0.04±0.006	1.43±0.29	0.18±0.01	0.98±0.06	0.03±0.032	1.00±0.10
4/13/98			4.57±0.11	0.78±0.03								
5/11/98			6.82±0.16	0.78±0.03							BDL	BDL
CYCLE 3 STORAGE PHASE												
8/03/98			6.12±0.11	0.86±0.02								
10/13/98 HOUR 1	1.29±0.03	0.38±0.01										
HOUR 2	1.27±0.03	0.37±0.015										
HOUR 3	1.32±0.03	0.37±0.01										
10/14/98	1.42±0.03	0.37±0.01										
10/15/98	1.38±0.03	0.37±0.01										

X-sample lost during processing
XX-analytical error associated with sample processing
BDL-below detection limits

Environmental Protection Agency's 1991 proposed maximum contaminant level for uranium in public water supplies is 20 µg/L (Federal Register, 1997). A regulation based on the proposal has not been promulgated. A decision is expected by November, 2000.

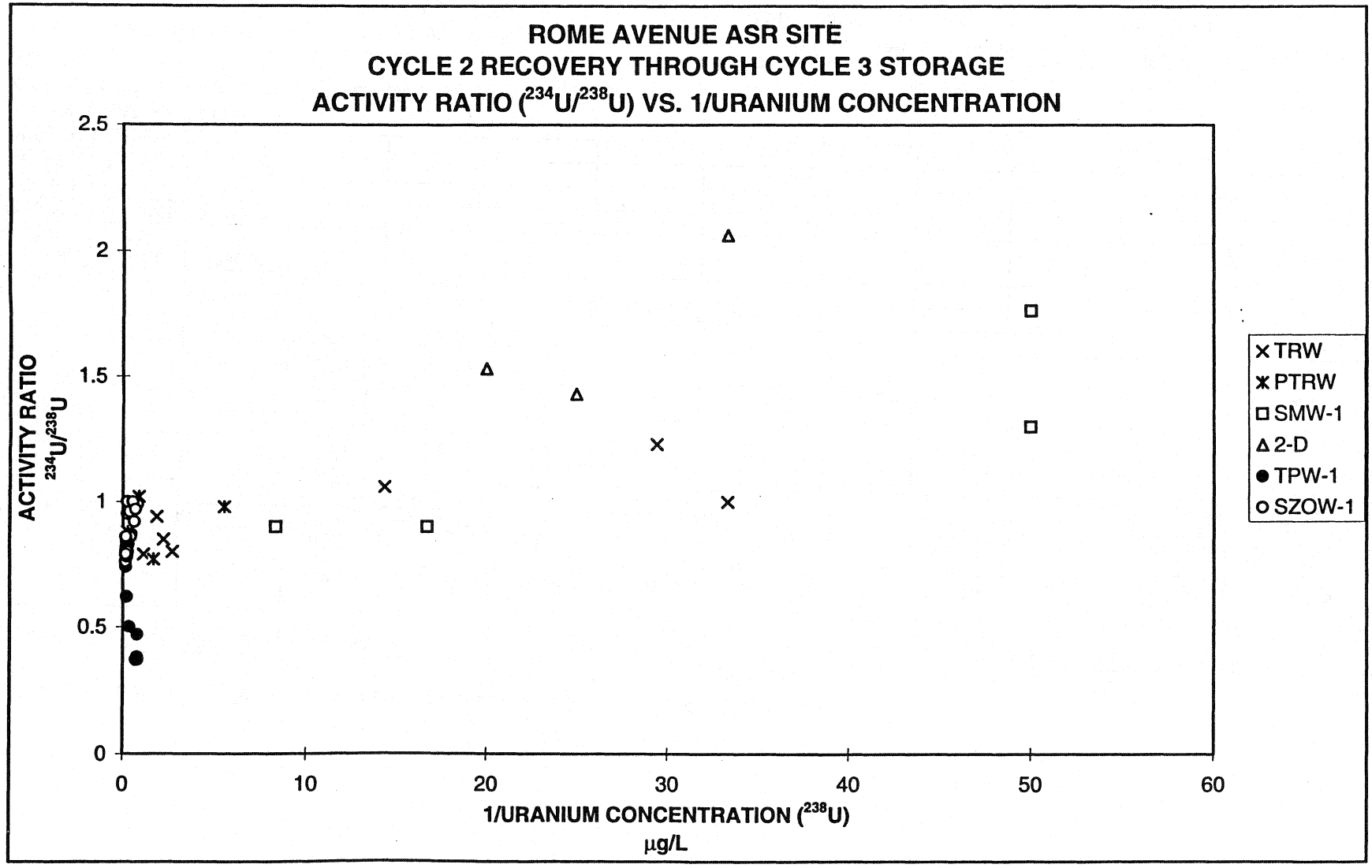


Figure 7. Uranium isotopic signatures for all Rome Avenue ASR samples.

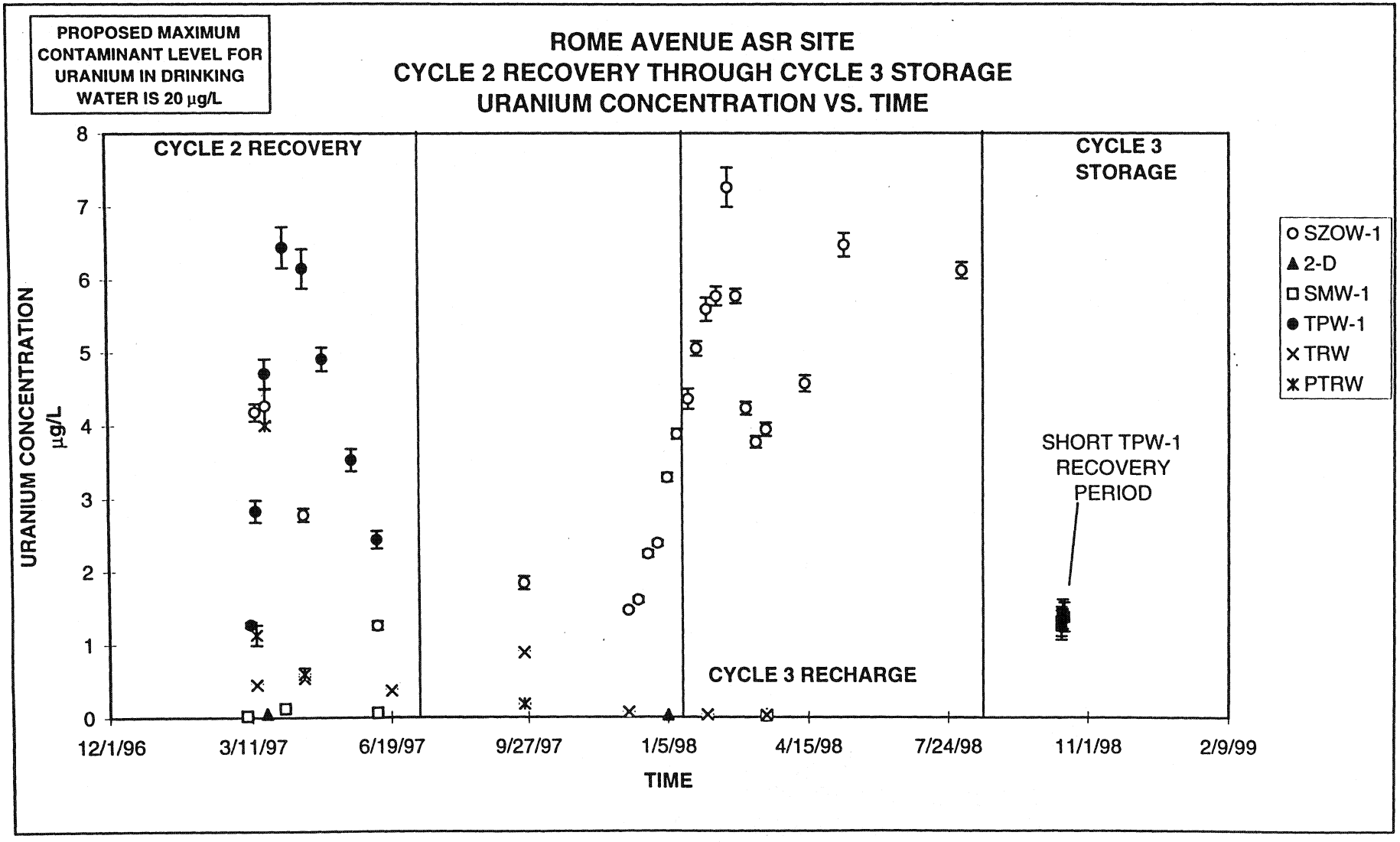


Figure 8. Uranium concentration through time at the Rome Avenue ASR site. Error bars represent one standard deviation.

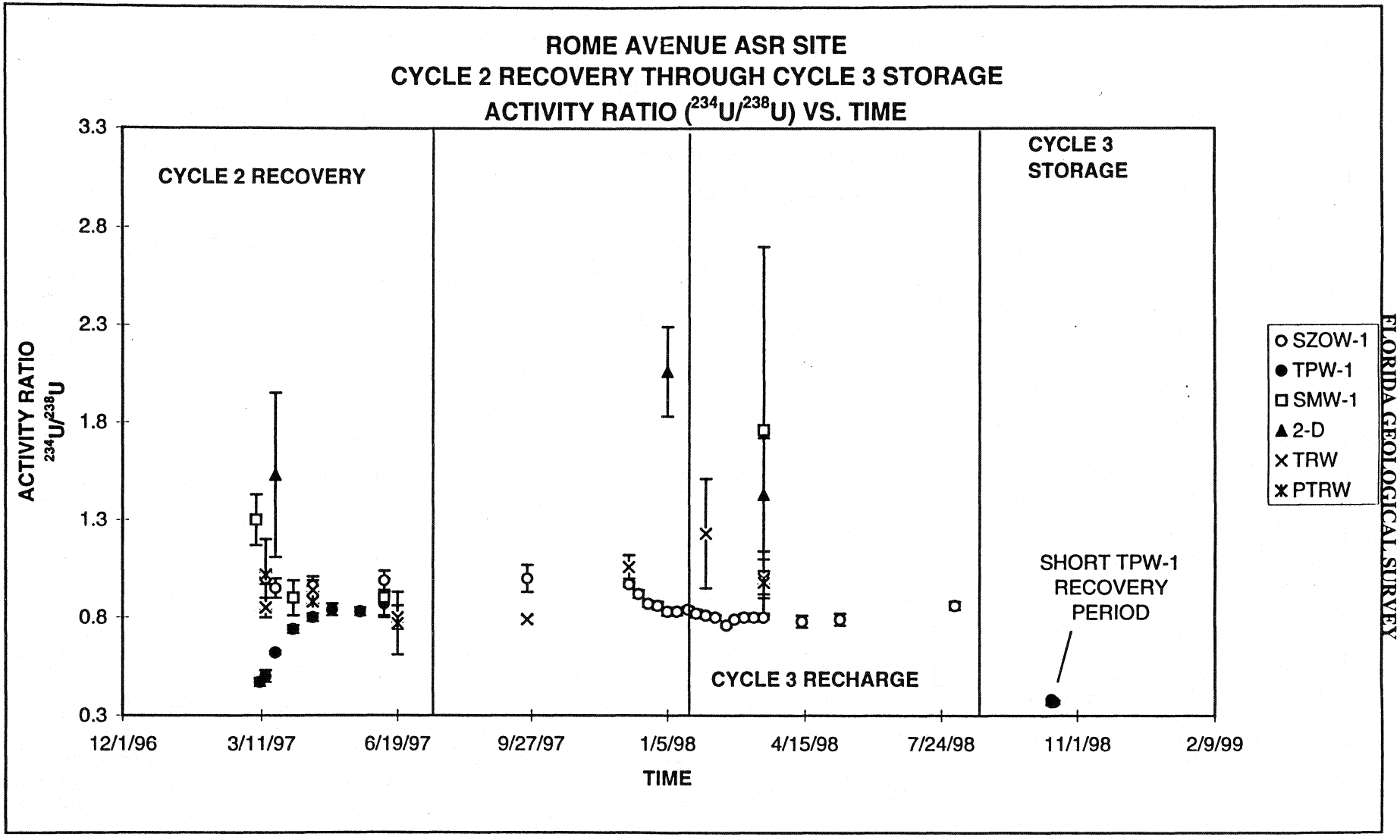


Figure 9. $^{234}U/^{238}U$ activity ratios through time at the Rome Avenue ASR site. Error bars represent one standard deviation.

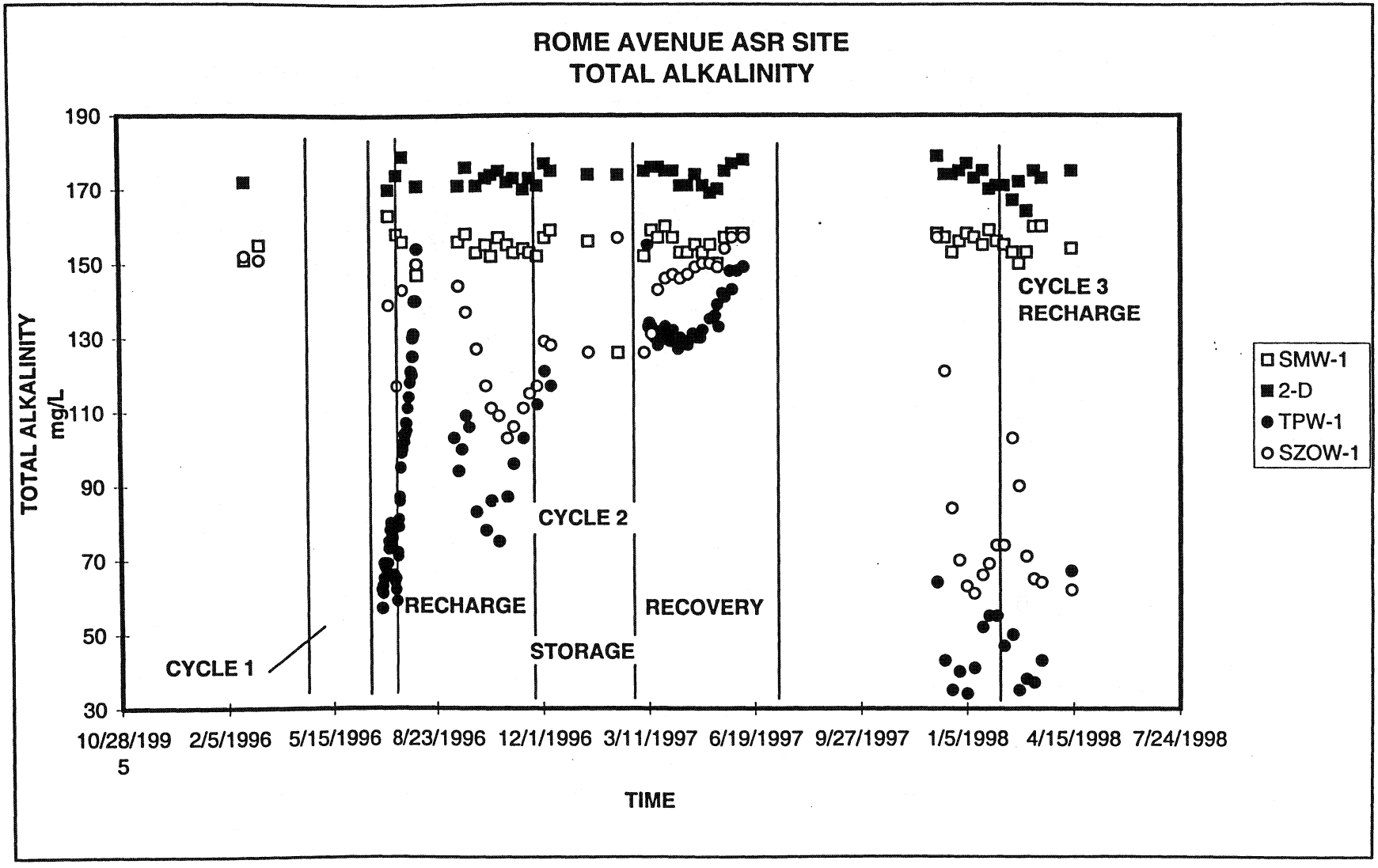


Figure 10. Total alkalinity values at the Rome Avenue ASR site.

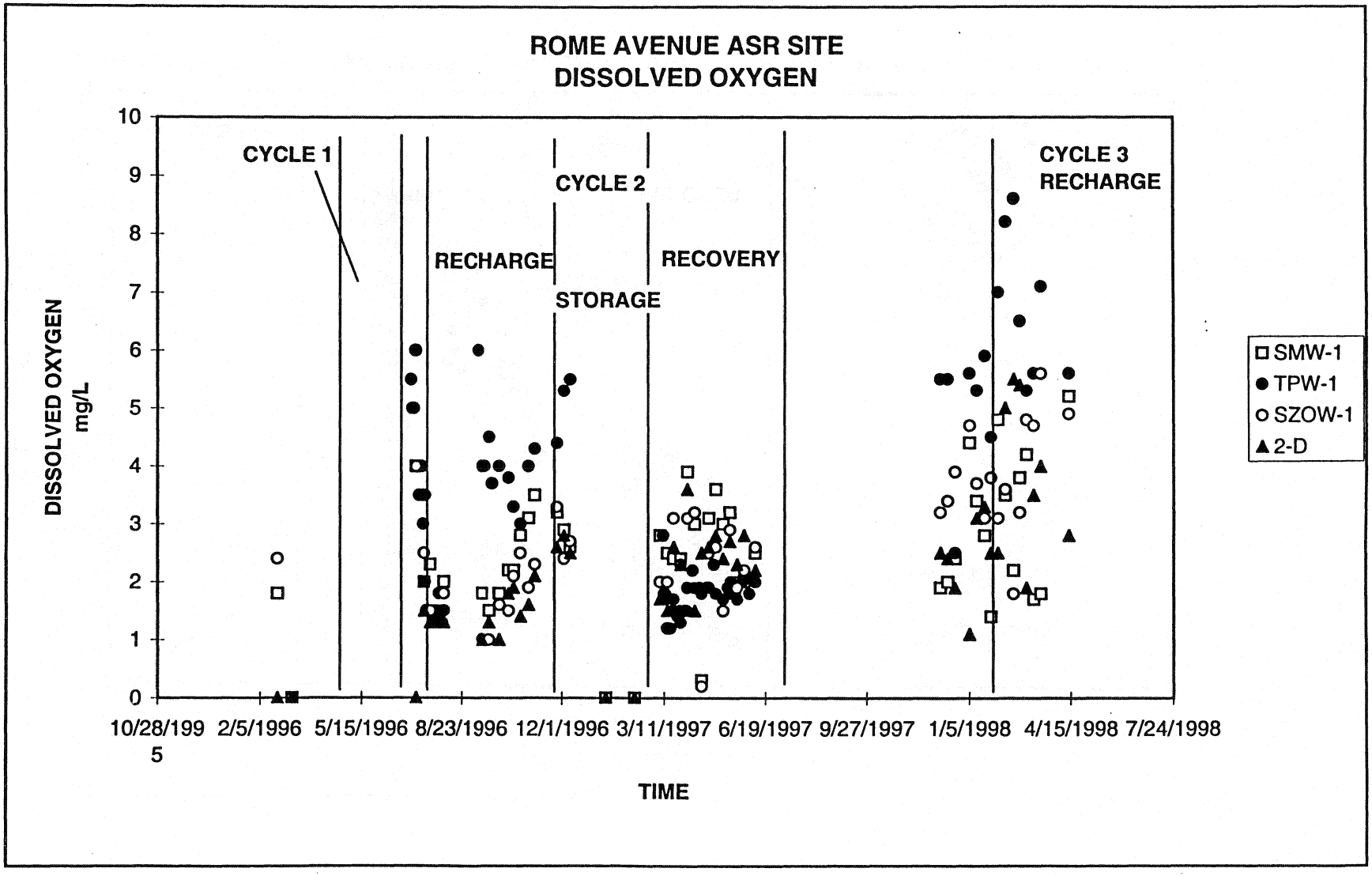


Figure 11. Dissolved oxygen values at the Rome Avenue ASR site.

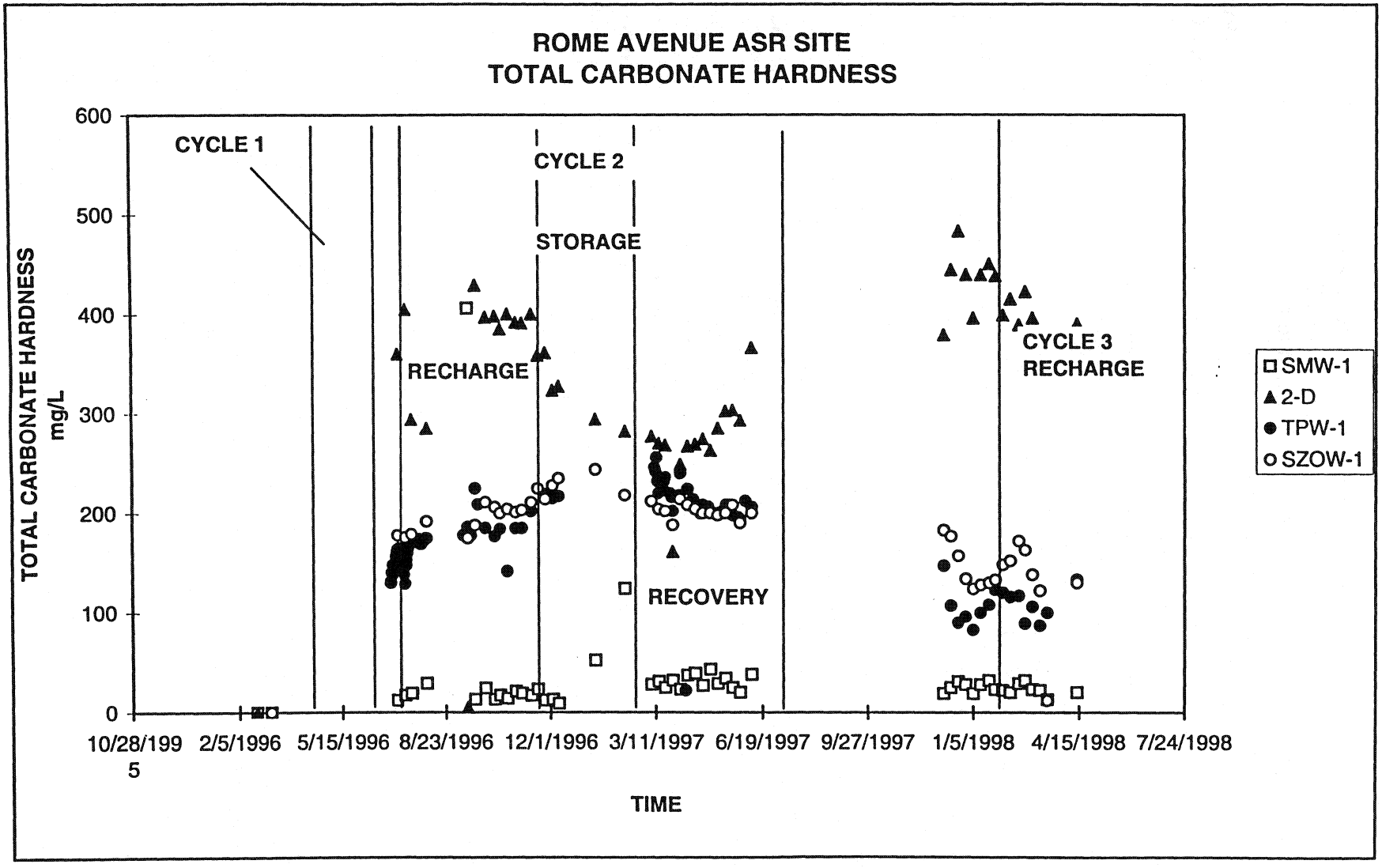


Figure 12. Total carbonate hardness values at the Rome Avenue ASR site.

Cycle 3 SMW-1 values vary negligibly and follow no trend whereas the TPW-1 and SZOW-1 values follow a repeating decreasing/increasing trend during Cycle 3. A lack of change in SMW-1 and 2-D total carbonate hardness values is attributed to minimal interaction with storage zone water. Also supporting little interaction with the storage zone, SO_4^{2-} (Figure 13) and chloride (Figure 14) values for SMW-1 vary negligibly, 2-D values are highly variable, TPW-1 and SZOW-1 SO_4^{2-} values decline during Cycle 2 recovery and Cycle 3 recharge, and Cl values remain constant during Cycle 2 and Cycle 3. Finally, SMW-1 and 2-D pH values (Figure 15) do not define a trend that supports interaction with the storage zone. The variability in SMW-1 values may be due to regional ground water flow or rainfall/recharge variability.

These data represent little, if any, interaction of the storage zone with the underlying and overlying zones. As noted above, a closed system is assumed for the storage zone, open only to water native to the storage zone, and water recharged to the zone through TPW-1. Therefore, only TPW-1, SZOW-1 and input water will be discussed further in this investigation. Furthermore, Cycle 2 and Cycle 3 will be discussed separately to lessen complication.

To interpret the data collected from the SZOW-1 and TPW-1 water samples, some assumptions must be made. Initially it is assumed that the recharge water forms a "bubble" in the aquifer, in a flattened cylindrical shape, by displacing the native water away from the well. Chemical changes in injected water over time is determine by sampling water from two wells, TPW-1 and SZOW-1, during recharge, storage and recovery. Given injection rate and physical parameters, the time the outer limit of the bubble takes to travel from TPW-1to SZOW-1 can be determined. SZOW-1 is located 192 feet from TPW-1, the recharge water is injected into TPW-1 at a rate of one million gallons per day, and the open interval is 90 feet thick (PEER Consultants, P.C. and CH2M Hill, 1995). If the effective porosity contributing to the rapid travel of the injected water is assumed to be 20%, one cubic foot of aquifer matrix holds 1.5 gallons of water. And assuming this porosity and homogeneous matrix (and no significant conduits), the leading edge of the expanding bubble of injected water recharged at TPW-1 should take about sixteen days to reach SZOW-1.

CYCLE 2

The first samples taken during this investigation were obtained at the end of the Cycle 2 storage phase from SMW-1. The Cycle 2 recovery phase began on March 10, 1997, as did sampling from TPW-1, SZOW-1, 2-D and TRW.

The change in uranium concentration (predominately ^{238}U) through the Cycle 2 recovery phase is illustrated in Figure 16. The uranium concentration in all recovered water (TPW-1 and SZOW-1) is higher than that of the input water (TRW). This is evidence that uranium is being mobilized to the injected water by way of water-rock interactions. Because the input water is recharged to and recovered from TPW-1, the earliest TPW-1 data point best represents the last sample of water recharged to the aquifer, stored for the least amount of time, and recovered first. This sample therefore had the least amount of contact with the aquifer. As a result, this sample has the lowest uranium concentration of 1.27 µg/L, somewhat greater than average TRW values of 0.25 µg/L. Each subsequent sample represents injected water that has spent a longer amount of time in the aquifer. The curve in Figure 16 portrays an increase in concentration with increasing time in the aquifer, through the first four samples. The increase in

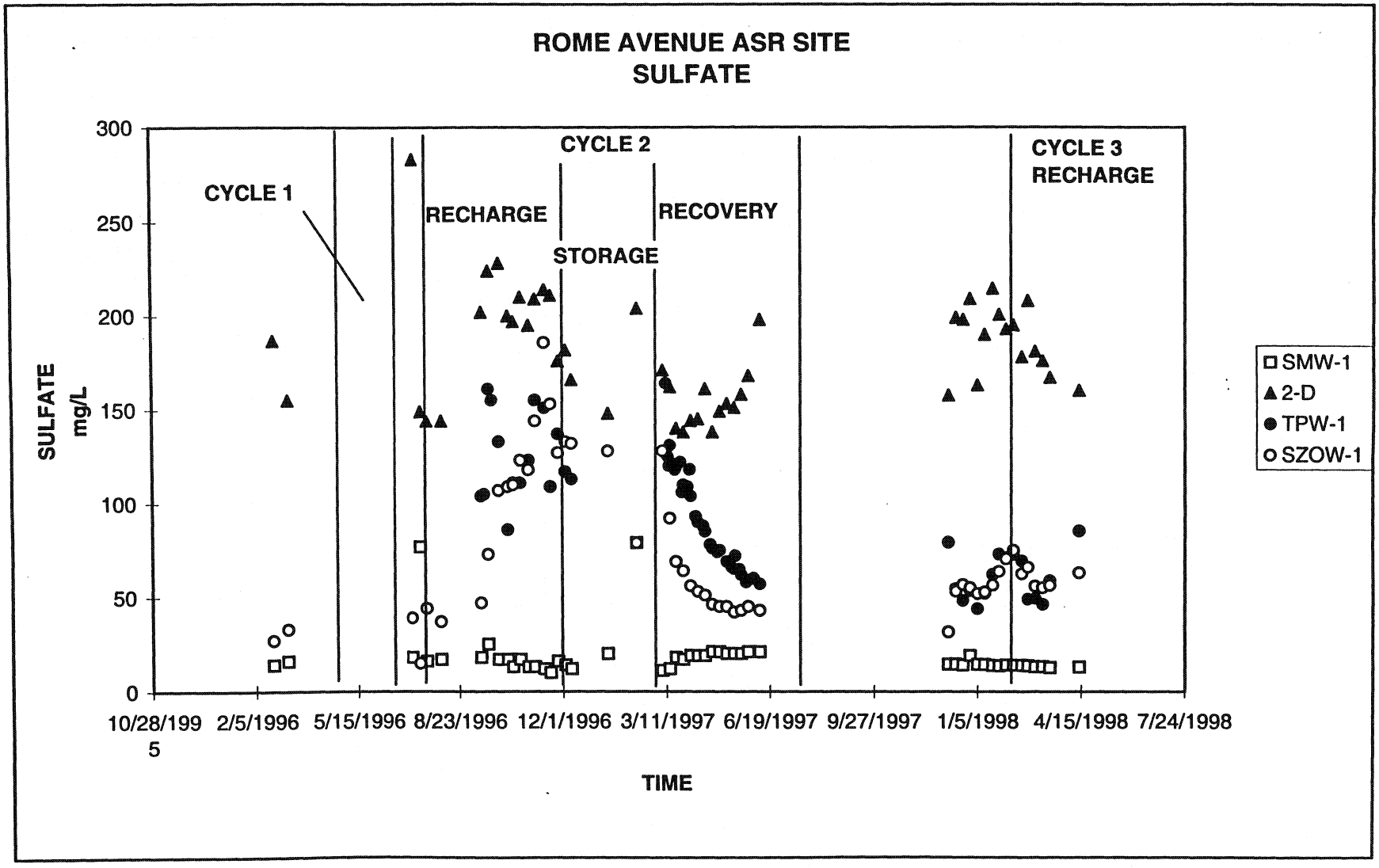


Figure 13. Sulfate values at the Rome Avenue ASR site.

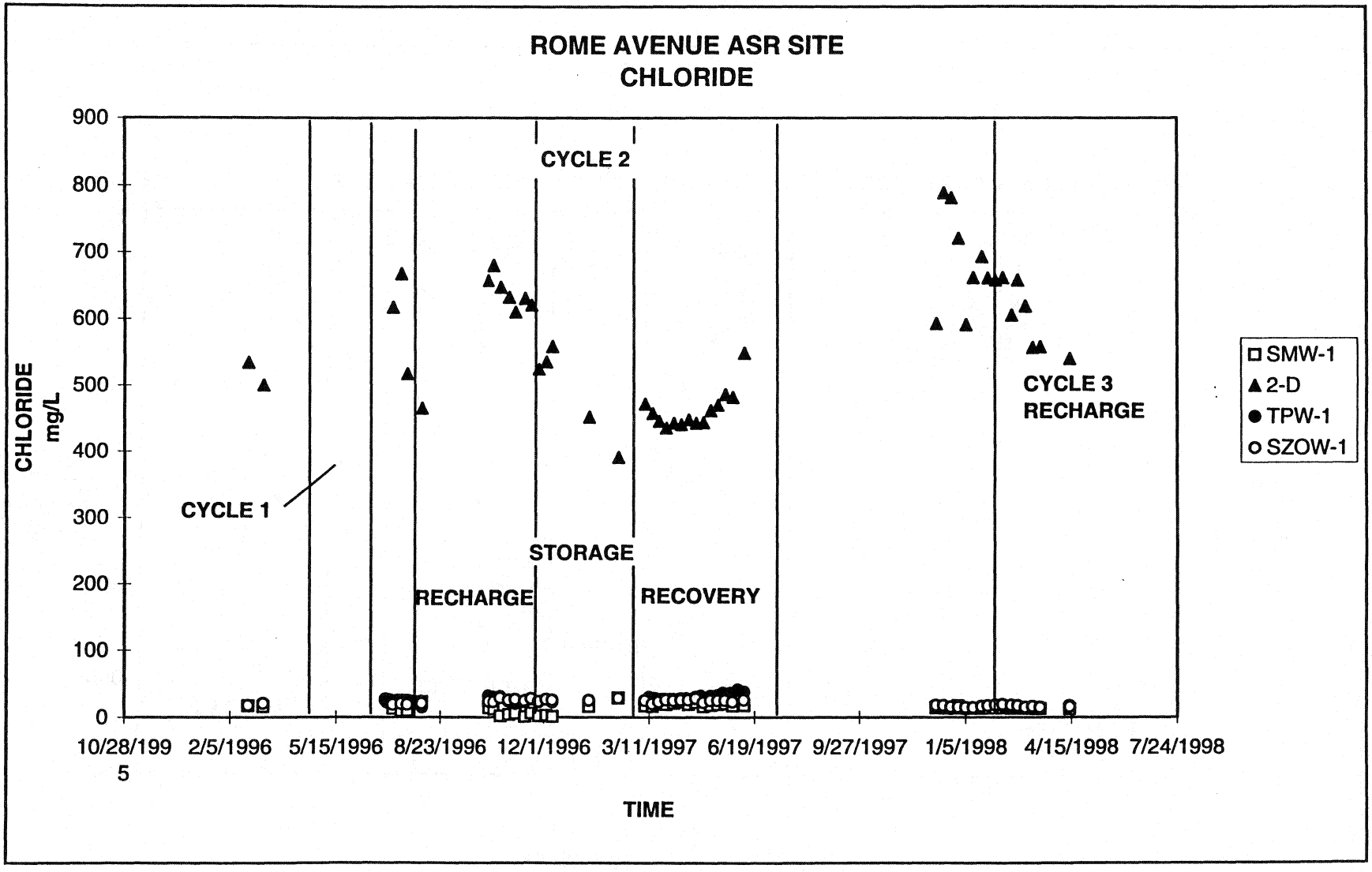


Figure 14. Chloride values at the Rome Avenue ASR site.

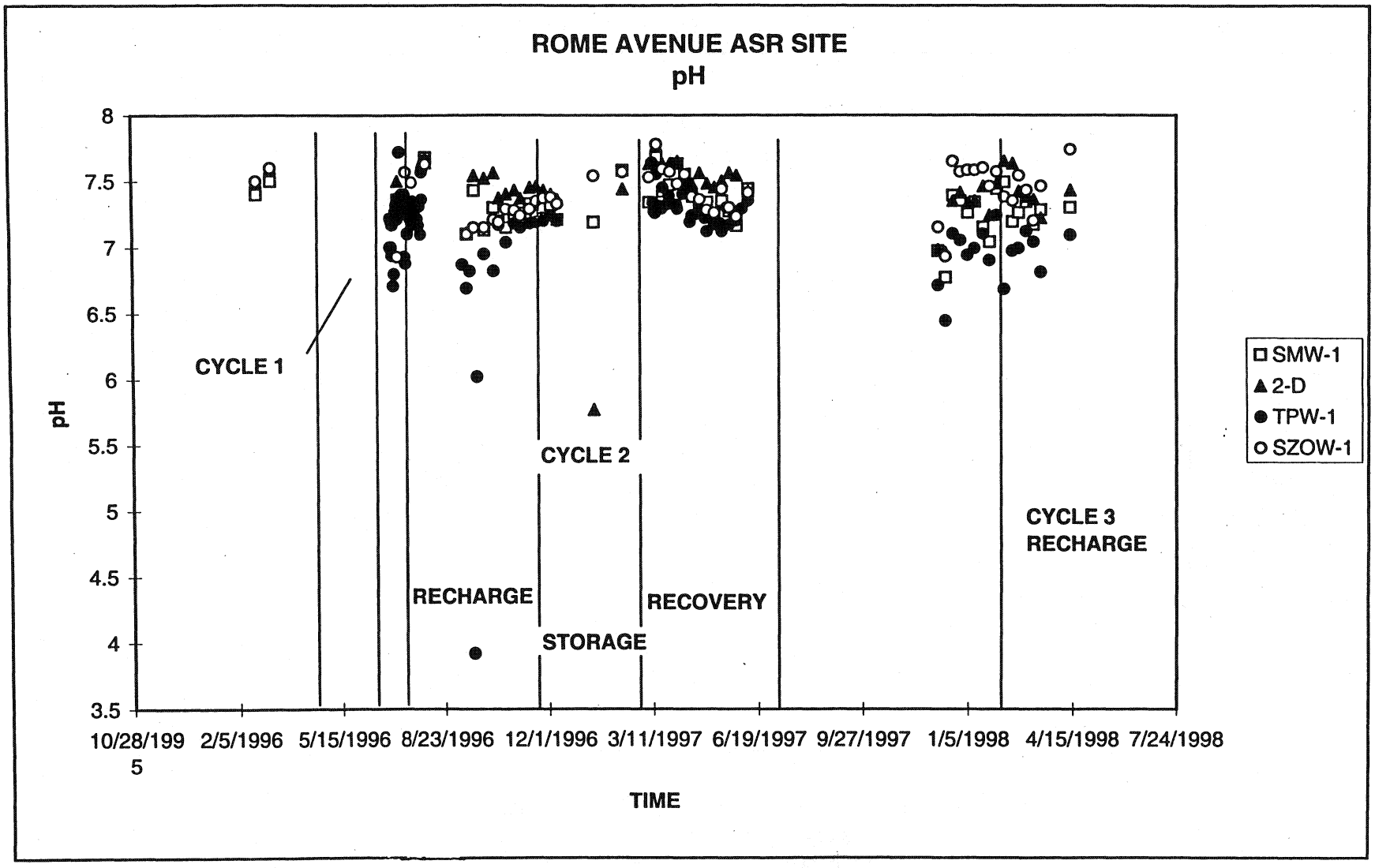


Figure 15. pH values at the Rome Avenue ASR site.

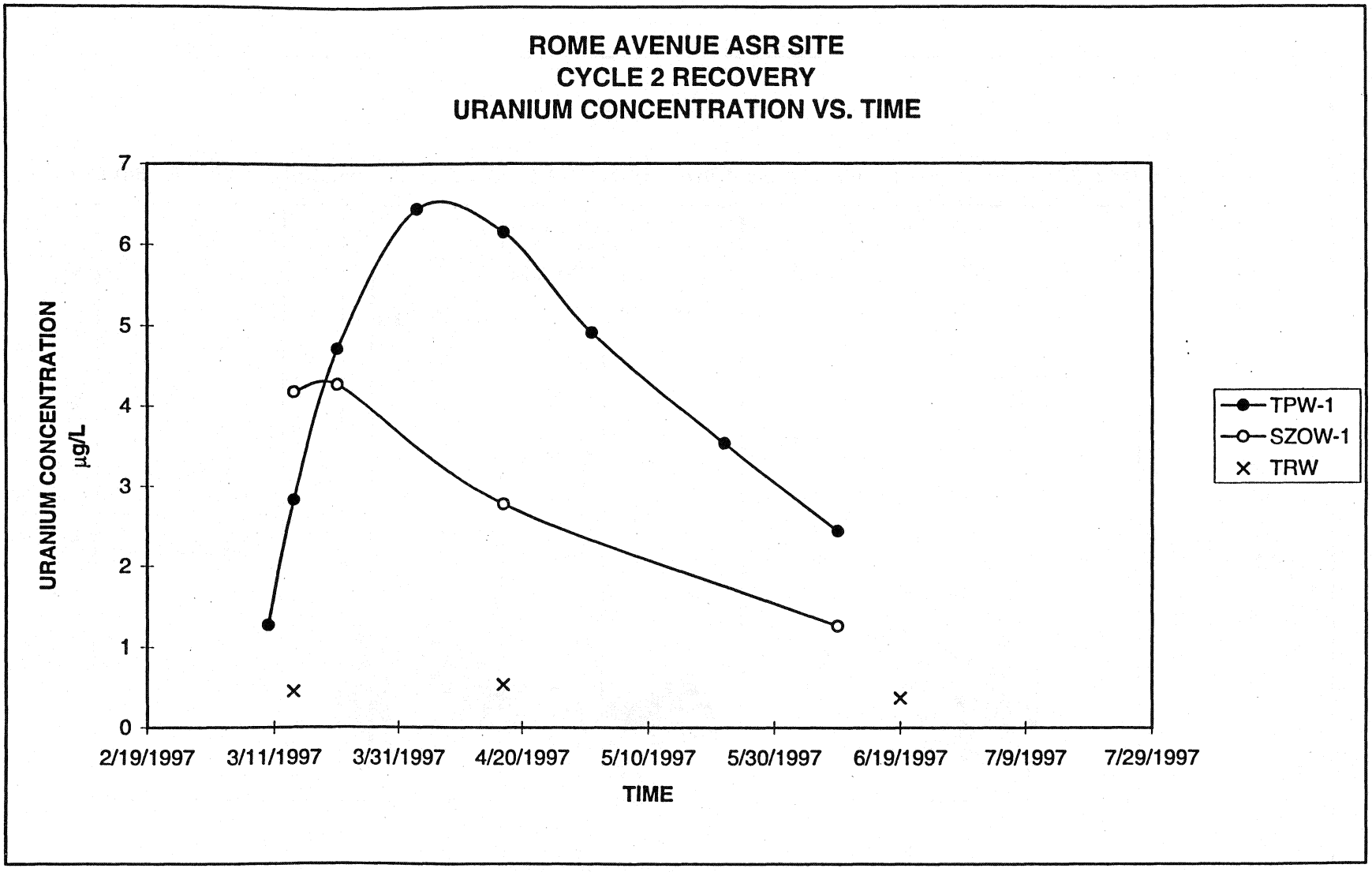


Figure 16. Uranium concentration through time during Cycle 2 at the Rome Avenue ASR site.

uranium concentration can be attributed to three uranium mobilization mechanisms: mobilization from the aquifer rock due to introduction of oxygen-rich waters, mobilization of an ultra-thin coating of uranium on the aquifer rock, and pre-injection changes in the recharge water chemistry.

In oxygen-rich conditions, uranium takes on a 6+ valence state and becomes mobile. The recharge process inputs surficial water, which has been in contact with the atmosphere, and is therefore oxygen-rich. The water is recharged to, in this case, an oxygen-poor aquifer. The oxygen-rich conditions mobilize uranium from the surface of carbonate grains to the water, increasing the uranium concentration of the input water. The input water is then recovered, before equilibrating with native, oxygen-poor water. If water masses were allowed to equilibrate, aquifer conditions could consequently precipitate some of the uranium in the water column back onto the aquifer rock.

A second mechanism that may increase the uranium concentration of the input water is the mobilization of uranium from an ultra-thin coating on the surface of the carbonate grains comprising the aquifer system (Cowart et al., 1997). In oxygen-poor waters, where uranium is immobile, the uranium in the water column precipitates on grain surfaces as an ultra-thin coating. With the introduction of oxygen-rich conditions, the coating of uranium, perhaps only a few atoms thick, is mobilized, effectively increasing the uranium concentration of the surrounding water.

A third mechanism of increasing uranium concentration in the input water is a change in the pH of the water in the aquifer. Slightly acidic (pH <7.00) input water may result in the dissolution of aquifer rock. During periods of high rainfall, the Hillsborough River receives more over-land flow; hence, there is more input to the river from water that has encountered organics (pH-reducing material). Also, greater discharge of the river prevents extended contact of river water with river-base carbonates, resulting in less buffering of the river water by the carbonates. These factors decrease the pH, slightly acidifying the water, which in turn will more effectively dissolve carbonate when recharged to the aquifer. During low-rainfall periods, the pH of river water is more neutral, pH~7.00, and will have less of an effect of dissolution on the carbonate grains. The hydrograph (Figure 17) of Hillsborough River discharge near the TRW withdrawal point illustrates the variability in river discharge during the Cycle 2 period. The input water (TRW) for the Cycle 2 recharge phase shows that pH values drop to less than 7.00 (Figure 15). Dissolution of carbonate aquifer rock can also be indicated by total alkalinity (effectively bicarbonate) values and calcium concentration. Cycle 2 recharge total alkalinity values (Figure 10) demonstrate an increase as water travels through the aquifer from TPW-1 to SZOW-1 and beyond. Dissolution of limestone also releases calcium to the surrounding water. Cycle 2 recharge calcium concentrations for SZOW-1 (Figure 18) are equal to or greater than those of TPW-1, suggesting a slight increase in calcium during recharge occurred. This evidence suggests that some aquifer rock dissolution took place. The dissolution of the carbonate aquifer matrix releases uranium into the water column. Also, the surface area in contact with the input water increases, allowing further uranium mobilization and leaching of uranium at radiation-damaged sites.

After the fourth sample (4/3/97), the uranium concentration in TPW-1 samples decreases with increasing storage time (Figure 16). This trend reversal is a result of dilution by, or mixing with, native aquifer water. During recharge, storage and recovery, the recharged water in the aquifer is mixing with native aquifer water.

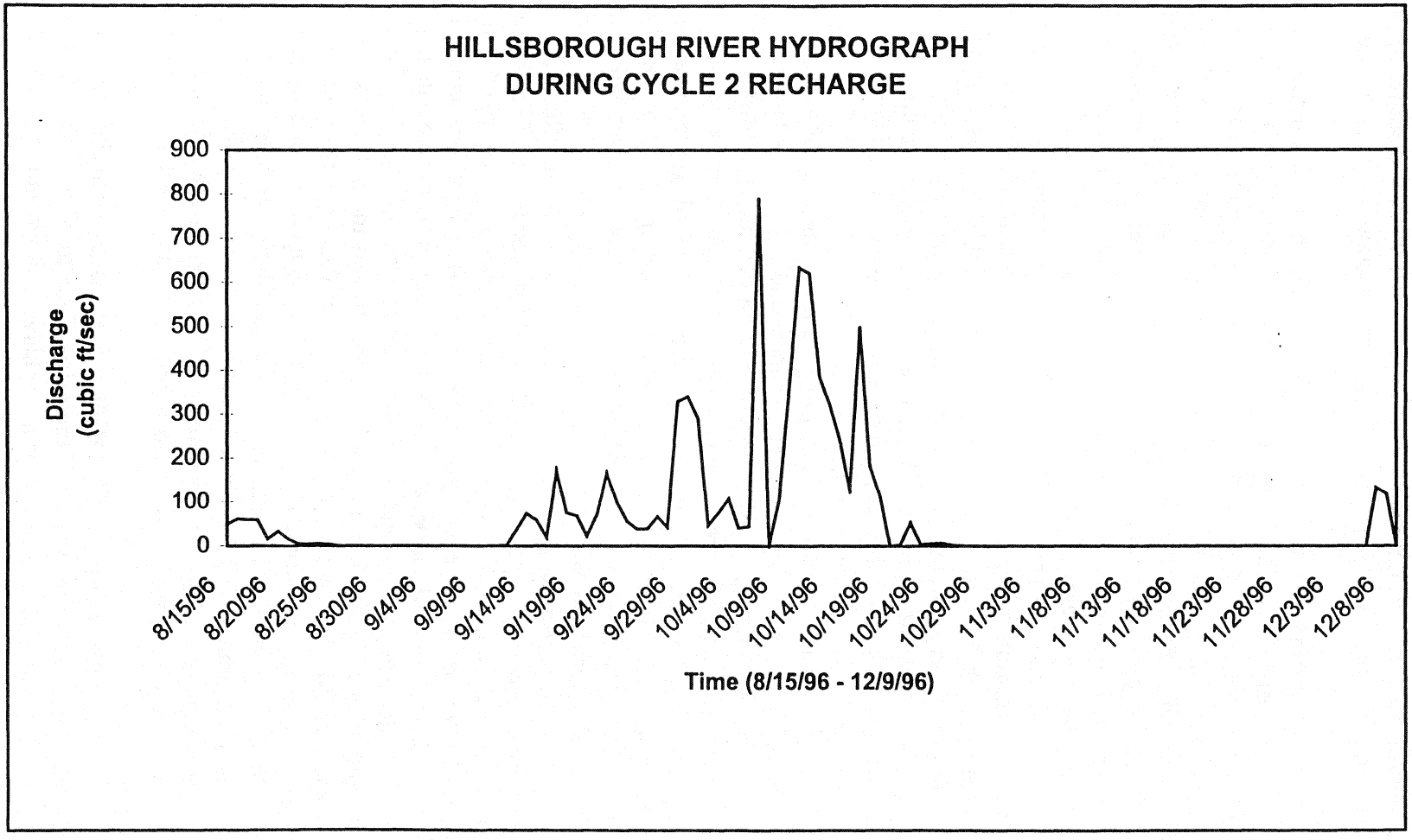


Figure 17. Hillsborough River hydrograph during Cycle 2 at the Rome Avenue ASR site.

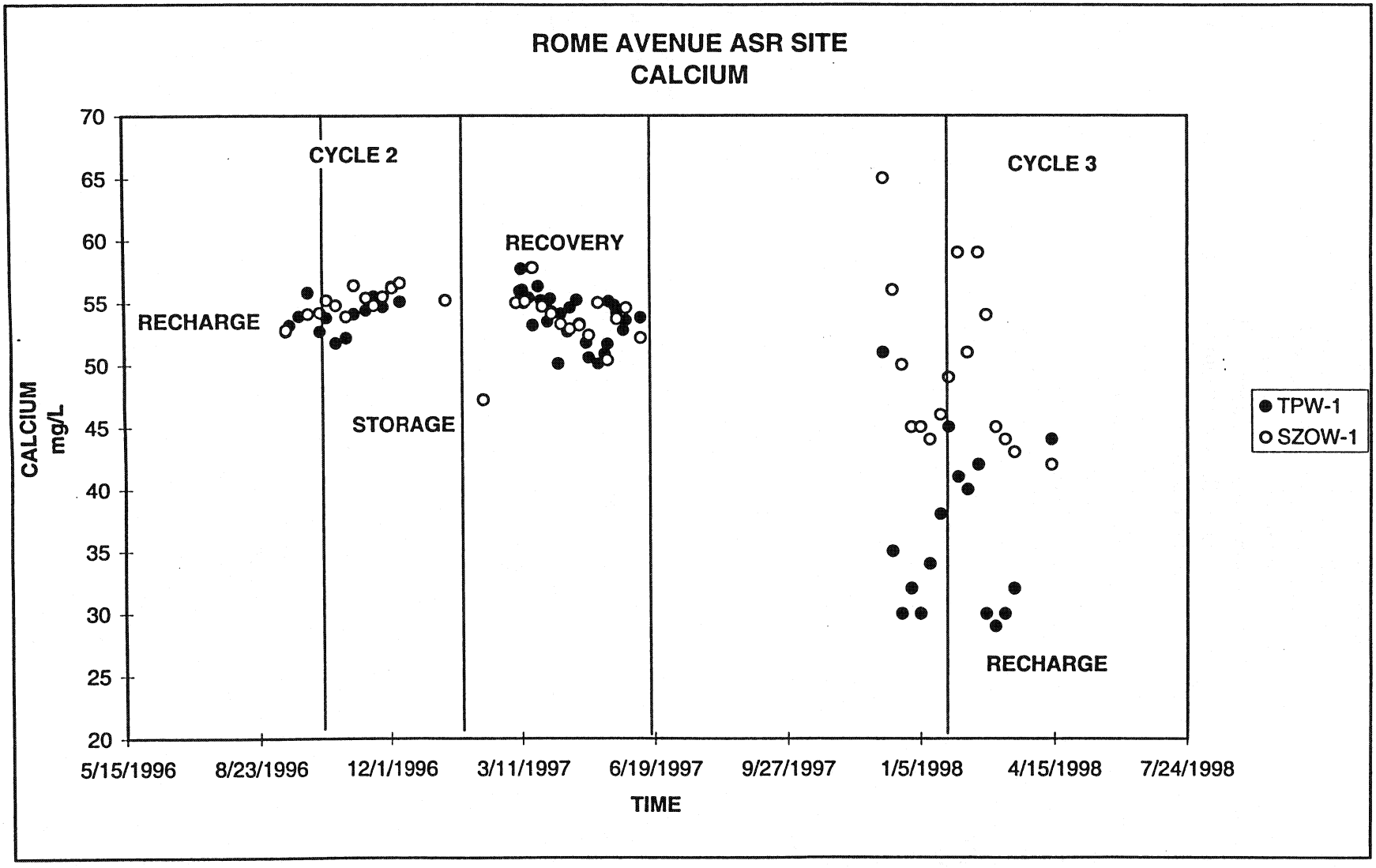


Figure 18. Calcium values at the Rome Avenue ASR site.

Dilution of recharged water increases with time and with distance traveled from the TPW-1 well. Hence, native (diluting) water approaches the monitor well (SZOW-1), continuing towards the center of the mass of water (TPW-1), with time. Dilution may affect the uranium concentration in four ways: uranium concentration in the recovered water is decreased, the rate of uranium mobilization by the injected water is decreased, aquifer rock dissolution decreases, and some uranium could precipitate out of the water column, back onto the rock; all of which result in decreasing uranium concentration with time.

Changes in uranium concentration during the calculated sixteen-day travel time between SZOW-1 and TPW-1 is demonstrated in Figure 19. The SZOW-1 data points in this graph were shifted sixteen days later (to the right) to account for the estimated lag time and allow direct visual comparison of trends. During recovery, water sampled at SZOW-1 represents the "same" water sampled sixteen days later. As constructed, the graph shows that the uranium concentration at TPW-1 is higher than its representative "same" water from SZOW-1. This suggests that not all uranium mobilization occurs during recharge and storage. During sixteen days of travel between SZOW-1 and TPW-1, a significant amount of uranium is still entering the water column. Also, the increase in uranium during recovery may be attributed to alternative paths through which the water travels in the aquifer, oxidizing areas not initially affected during recharge and storage. The effect of dilution of the input water can be seen in SZOW-1 as well. By extending the trendlines for the curves for both TPW-1 and SZOW-1, the two curves approach an asymptote, thus suggesting maximum dilution of input water with native water. Therefore, the curves approach native aquifer water uranium concentration values due to remaining diluted input water. These curves approach an estimated native uranium concentration value of approximately 1.2 µg/L.

A plot of Cycle 2 recovery activity ratios through time (Figure 20) shows that TPW-1 activity ratios increase with time. The values then approach consistency at about 0.85 in the last four samples, those that showed evidence of dilution in previous figures. Because ^{234}U is selectively leached from decay-damaged sites, and because it can be directly released to the water column by recoil mechanisms, a ^{234}U-deficient, low activity ratio rind developed on the carbonate grains develops. Due to the aggressive nature of the input water, dissolution of the rind occurs and the input water takes on activity ratios reflecting first, the exterior portion of the grain. Then, as more of the rind dissolves, the input water activity ratio reflects more interior parts of the grain. With time uranium isotope signatures reach unity (activity ratio =1.00); therefore, the interior portions of the carbonate grains not in contact with surrounding waters are expected to have an activity ratio of 1.00. Thus, as more of the carbonate grains dissolve, it is expected that the input water activity ratio should increase towards one.

During Cycle 2, the activity ratio of the water that spent the least amount of time in the aquifer is 0.47. At the surface of the grain, ^{234}Th nuclides (quickly decaying to ^{234}U) have a 50% chance of being directly ejected into the surrounding water. Therefore, the activity ratio of the surrounding water can not be lower than 0.50. Using the ultra-thin coating model, an activity ratio slightly below 0.50 is possible. The coating is only atoms thick, thinner than recoil distance; therefore, ^{234}Th nuclides have a much greater than 50% chance of being ejected directly into the water column, and/or into the interior of the grain. Because the ultra-thin layer coats the carbonate grains, it is the first source of uranium to mobilize when oxygen rich water is introduced to the environment. Therefore, the first sample recovered reflects the activity ratio of the coating of uranium.

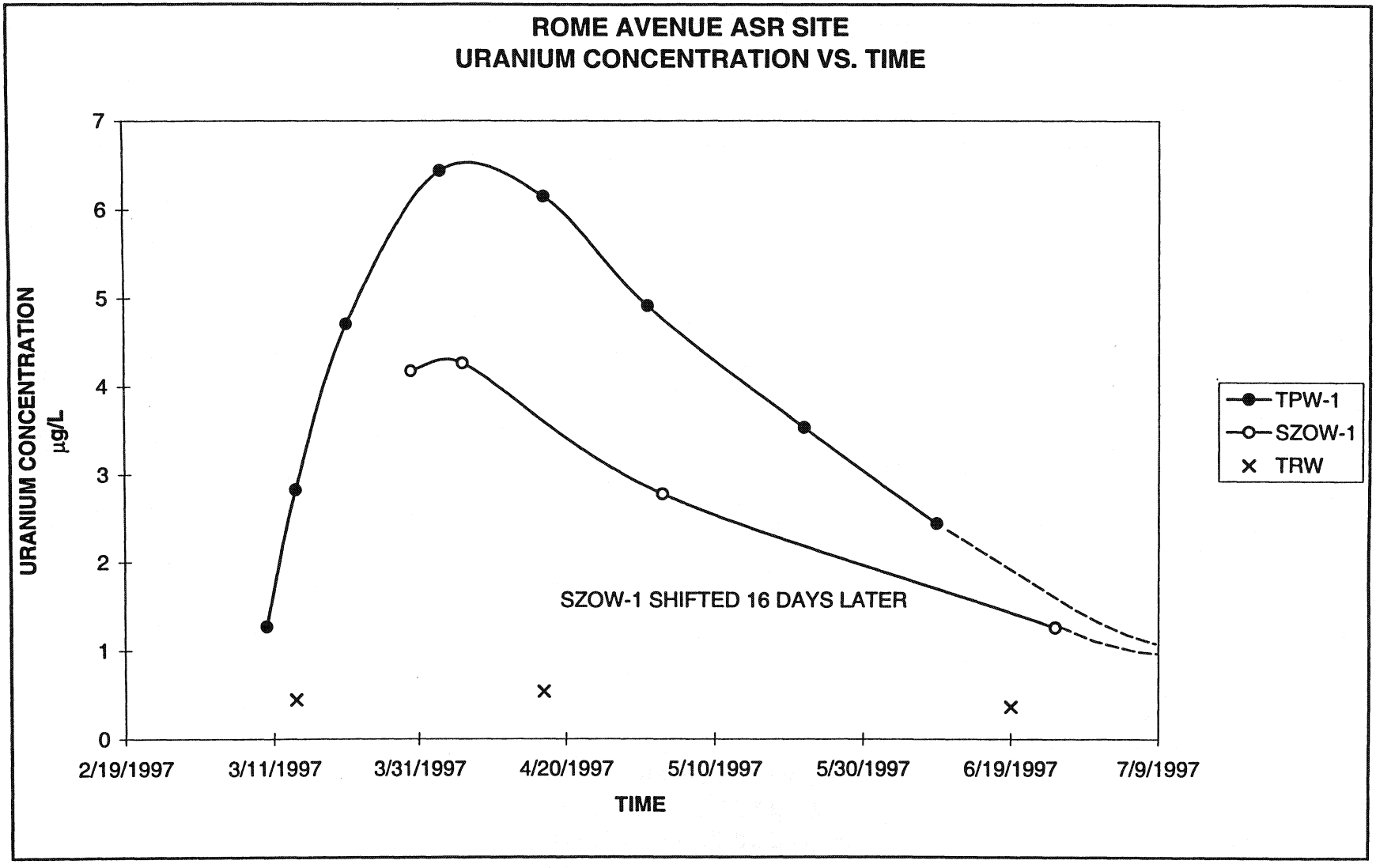


Figure 19. Uranium concentration through time at the Rome Avenue ASR site: SZOW-1 values shifted sixteen days later.

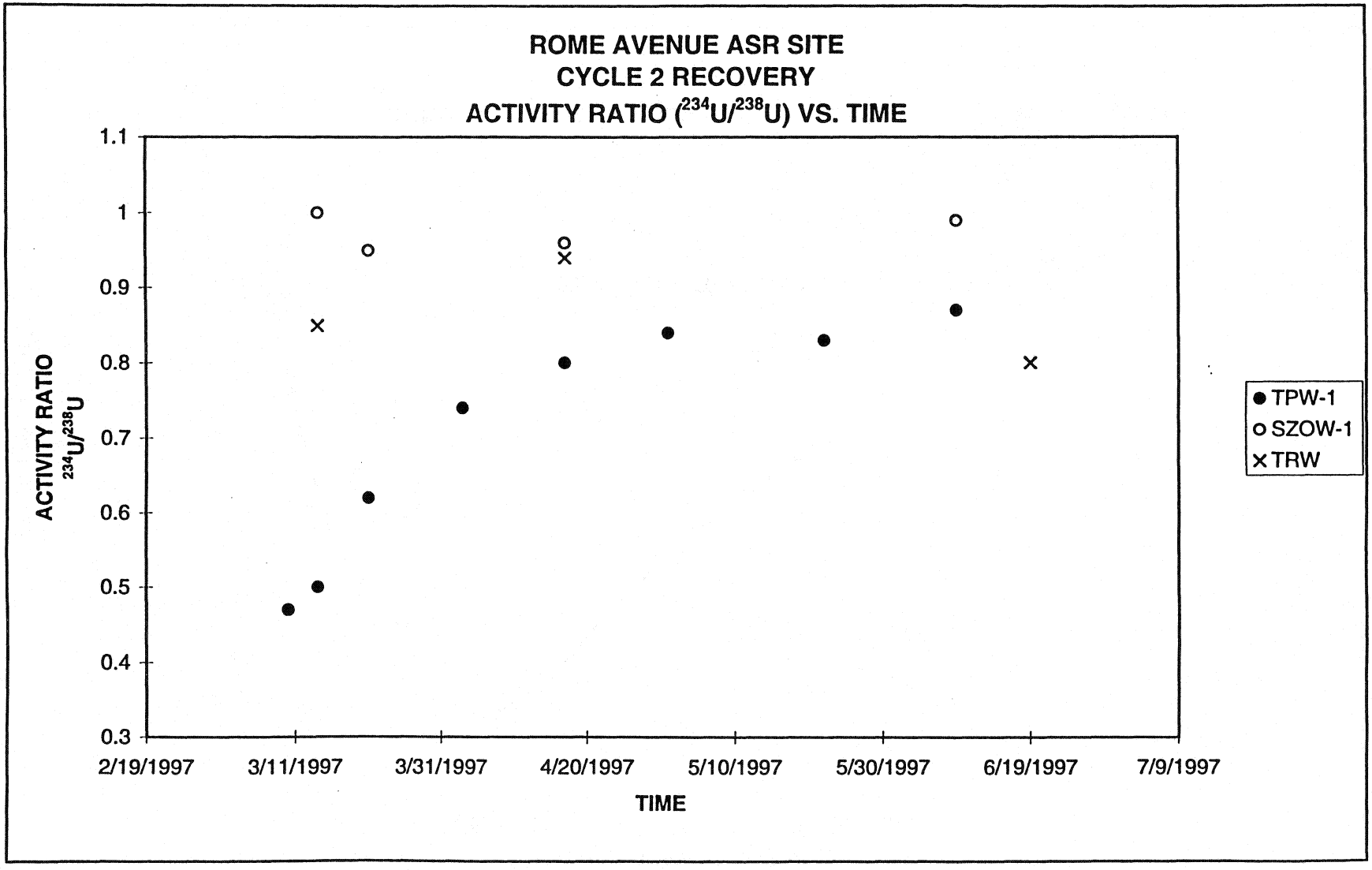


Figure 20. $^{234}U/^{238}U$ activity ratio through time during Cycle 2 at the Rome Avenue ASR site.

Figure 20 shows the effect of mobilization through time of the ultra-thin coating and the dissolution of ^{234}U-deficient rind with time. The activity ratios become somewhat constant, near 0.85. This is a result of two processes. First, with time the pH of the input water increases due to buffering by the carbonate rock. The input water is no longer acidic and therefore no longer aggressive. As a result, carbonate rock dissolution decreases and addition of uranium to the water column is limited to direct ejection, mobilization and leaching. Second, dilution of the input water by native, higher activity ratio water would also increase the activity ratio of the input water with time.

Dilution is evident in SZOW-1 samples that are near or equal to 1.00. The SZOW-1 sample taken on the last day of recovery is sixteen days from reaching TPW-1 and can therefore be considered nearest to the activity ratio of the estimated near-native aquifer water which is 0.99. It can be expected, then, that because most of the input water has been recovered, uranium remaining in the water column may precipitate as another ultra-thin coating on the carbonate grains. With the introduction of oxygen-rich water again, it can be predicted that the ultra-thin low activity ratio coating of uranium will mobilize, and then the ^{234}U-deficient rind will continue to dissolve, increasing the activity ratio of the surrounding water towards 1.00. The time-span between cycles, however, is probably insufficient to effectively precipitate uranium from the water column.

To further illustrate the processes taking place in the storage zone, activity ratio is plotted against the reciprocal of uranium concentration (Figure 21). Data points are labeled by date recovered. Two dissolution processes are shown: an increase in uranium concentration with increasing dissolution, and an increase in activity ratio with increasing dissolution of the fractionated rind. Recall that uranium sources are interacting in the mixing zone: TRW (plotted as an average of TRW samples), native aquifer water (considering the last SZOW-1 sample representative of native water signatures), and aquifer rock (the signature of which is varied due to the ultra-thin coating of uranium and variation with dissolution of portions of carbonate grains). A sample representing a mixture of two sources should plot on a straight line drawn on the graph between the two sources. A sample resulting from three sources should plot within the triangle formed by the three sources. It has been shown that the first four samples did not come in contact with native aquifer water; therefore, their uranium isotopic signatures are a result of two sources. By drawing a line from the average TRW value through the first recovery sample (TPW-1) and to the y-axis, the activity ratio of the aquifer rock can be estimated to be approximately 0.30. This value represents ^{234}U-deficient pore waters, or the result of mobilization of the ultra-thin coating of uranium on carbonate grains. As the coating mobilizes, the activity ratio of the newly exposed surface (^{234}U-deficient rind) increases, towards the center of the grain, increasing the activity ratio of the uranium, as well as the concentration, entering the water column. These values are shown in the next three recovered samples (TPW-1). The final four samples recovered represent a mixture of three uranium sources, and therefore plot within a triangle formed by the average TRW value, the near-native water value, and an estimated activity ratio value of the aquifer rock-chosen to include the fifth sample. Because dilution affects the injected water in the last four samples, the TPW-1 signature trends towards the representative native water sample (SZOW-1, activity ratio = 0.99) as the concentration decreases and the increase in activity ratio is muted.

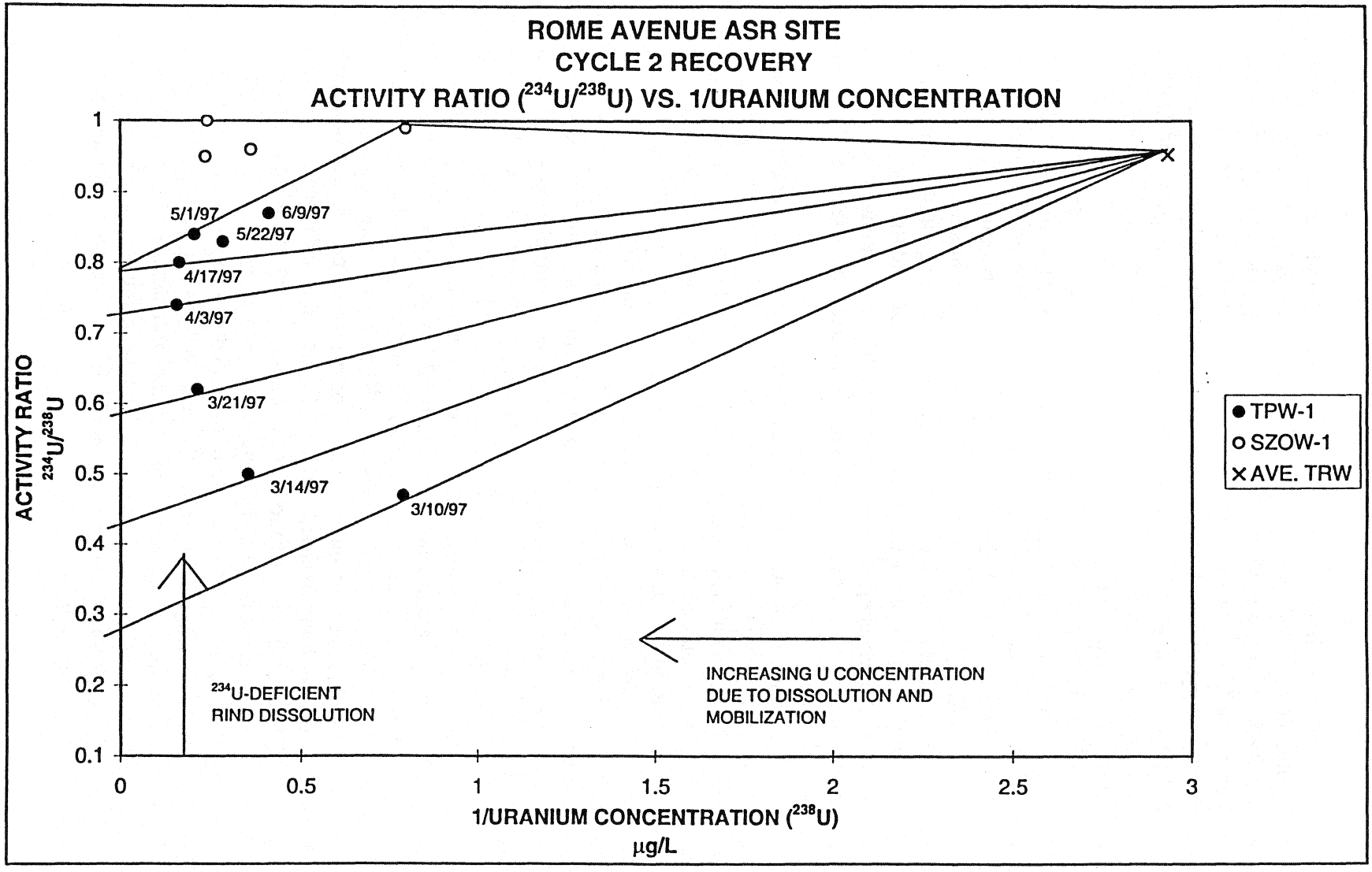


Figure 21. Uranium isotopic signatures during Cycle 2 at the Rome Avenue ASR site.

CYCLE 3

The change in uranium concentration through time at SZOW-1 during the Cycle 3 recharge and storage phases is illustrated in Figure 22. Also shown are uranium concentration values of the five samples taken during the short recovery period from TPW-1, within the storage phase. The first three samples represent water that has not interacted with TRW, but is being forced past SZOW-1 by the mass of input water. The uranium concentration in this water is increasing because the concentration of remaining Cycle 2 input water increases toward TPW-1. With time, the next SZOW-1 uranium-concentration values increase, again suggesting that uranium is being mobilized by oxic recharge water, leaching, and dissolution of the carbonate grains. After the eleventh sample (2/17/98), the uranium concentration drops sharply to approximately 4 µg/L, followed by an increase during the final stages of recharge. The variability in uranium concentration suggests a change in rate of uranium mobilization and possibly a change in rate of carbonate dissolution. These changes could be attributed to a change in input water (TRW) chemistry.

Input water chemistry, as discussed earlier, is subject to change with changing input to the Hillsborough River. Figure 23 is a hydrograph for the Hillsborough River during the Cycle 3 recharge phase. During times of high rainfall, river discharge is high. Where the hydrograph shows high discharge, water flowing into the river is lower in pH and therefore more acidic. The variability in river discharge at the time of this phase causes the pH of the input water to vary (Figure 15). The pH of input water (TPW-1 water during recharge is treated river water [TRW]) during Cycle 3 does demonstrate the repeating increasing/decreasing trend. With low-pH input water, higher bicarbonate (total alkalinity) values and higher calcium concentrations at SZOW-1 are expected. Because input water does not reach SZOW-1 for sixteen days, the trend with pH is also expected, but with about sixteen days of lag time.

Total alkalinity (Figure 10) follows the trend set by pH. Note where total alkalinity values are high and pH is low, the increase in total alkalinity in SZOW-1 is greater in magnitude due to increased dissolution of the carbonate rock. The same trend follows for calcium (Figure 18) in TRW samples (TPW-1), and the lag time from TPW-1 to SZOW-1 is also evident. The uranium concentration for the samples taken from TPW-1 during a short recovery phase in Cycle 3 storage show values close to those of the first TPW-1 samples recovered during the Cycle 2 recovery phase. Again, the low concentration characterizes the samples that spent the least amount of time in the aquifer, picking up the least amount of uranium. The change in $^{234}U/^{238}U$ activity ratio through time is shown in Figure 24 for SZOW-1 during the Cycle 3 recharge and storage phases. The first three samples taken from SZOW-1 demonstrate rapidly decreasing activity ratios. These samples represent native water mixed with the little remaining Cycle 2 input water that was not recovered because of dilution. These three samples are unaffected by Cycle 3 recharge water because the recharge water has not yet reached SZOW-1, and represent water that is being pushed past SZOW-1 by the mass of input water. The activity ratio of subsequent samples represent a mixture between recharge water and aquifer rock signatures. These activity ratios approach approximately 0.80 and then remain somewhat consistent. Recall that the Cycle 2 activity ratio vs. time curve also approached 0.80. The consistency of these data suggest that Cycle 1 and Cycle 2 dissolved the ^{234}U-deficient rind to an

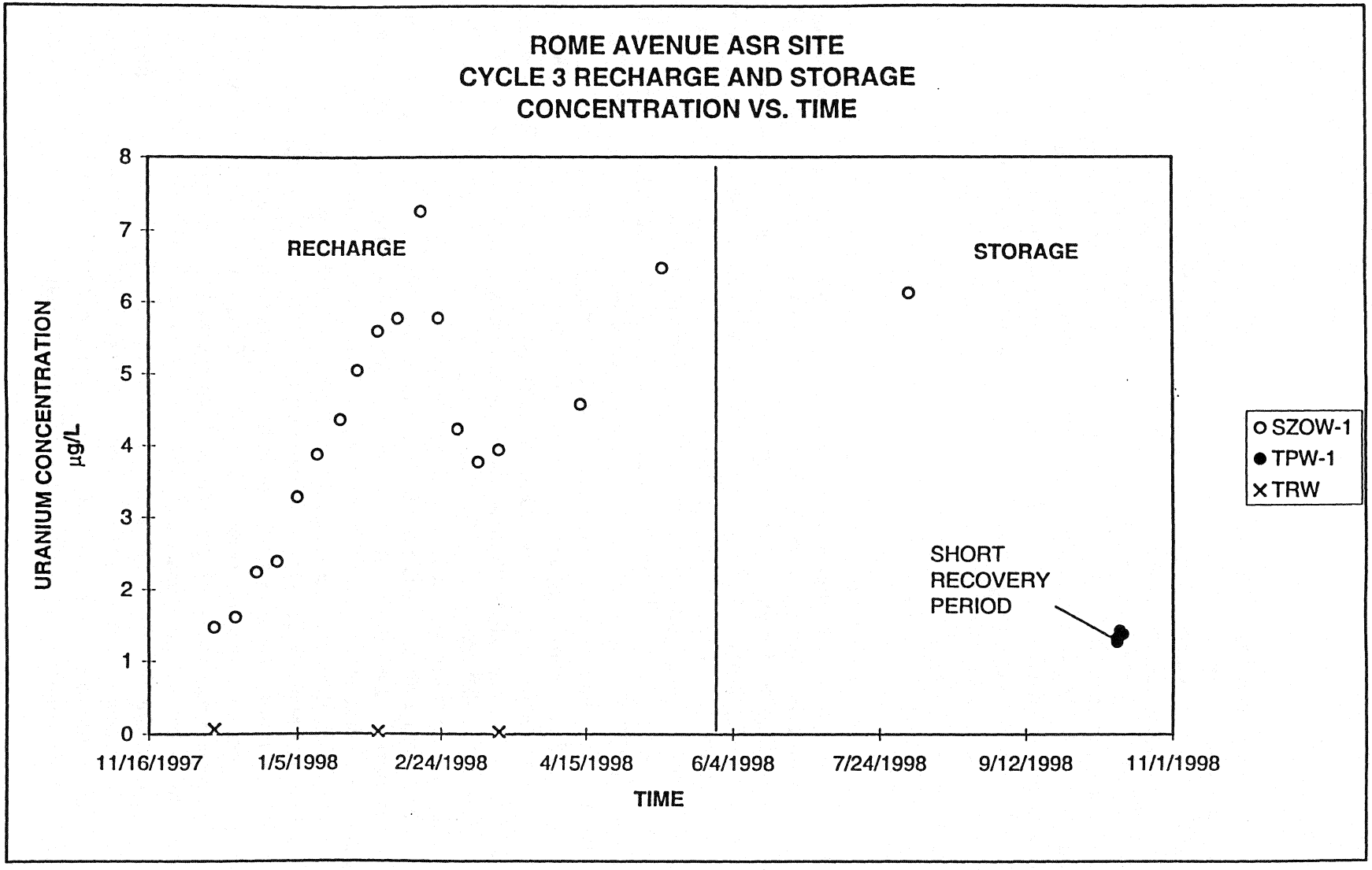


Figure 22. Uranium concentration through time during Cycle 3 at the Rome Avenue ASR site.

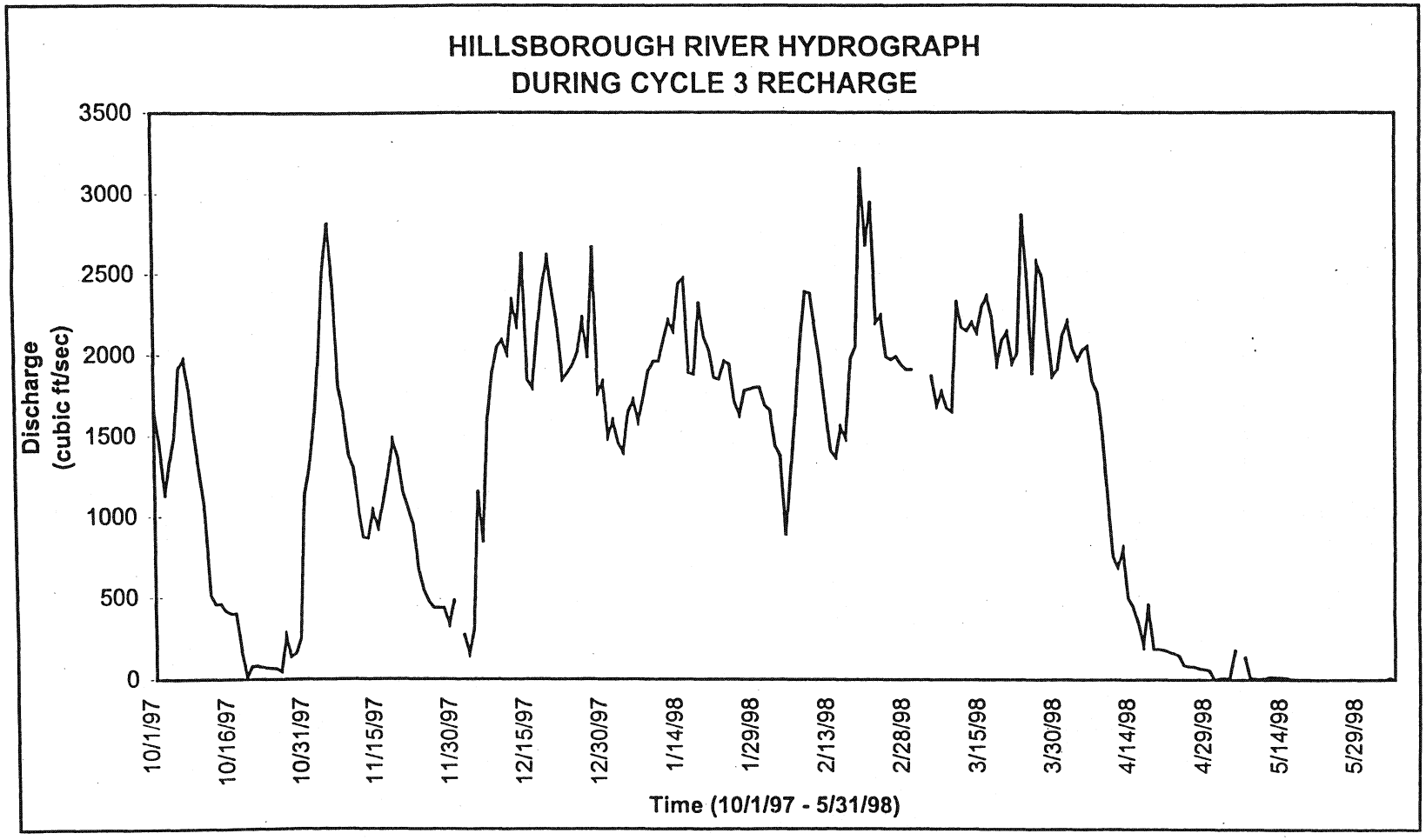


Figure 23. Hillsborough River hydrograph during Cycle 3 at the Rome Avenue ASR site.

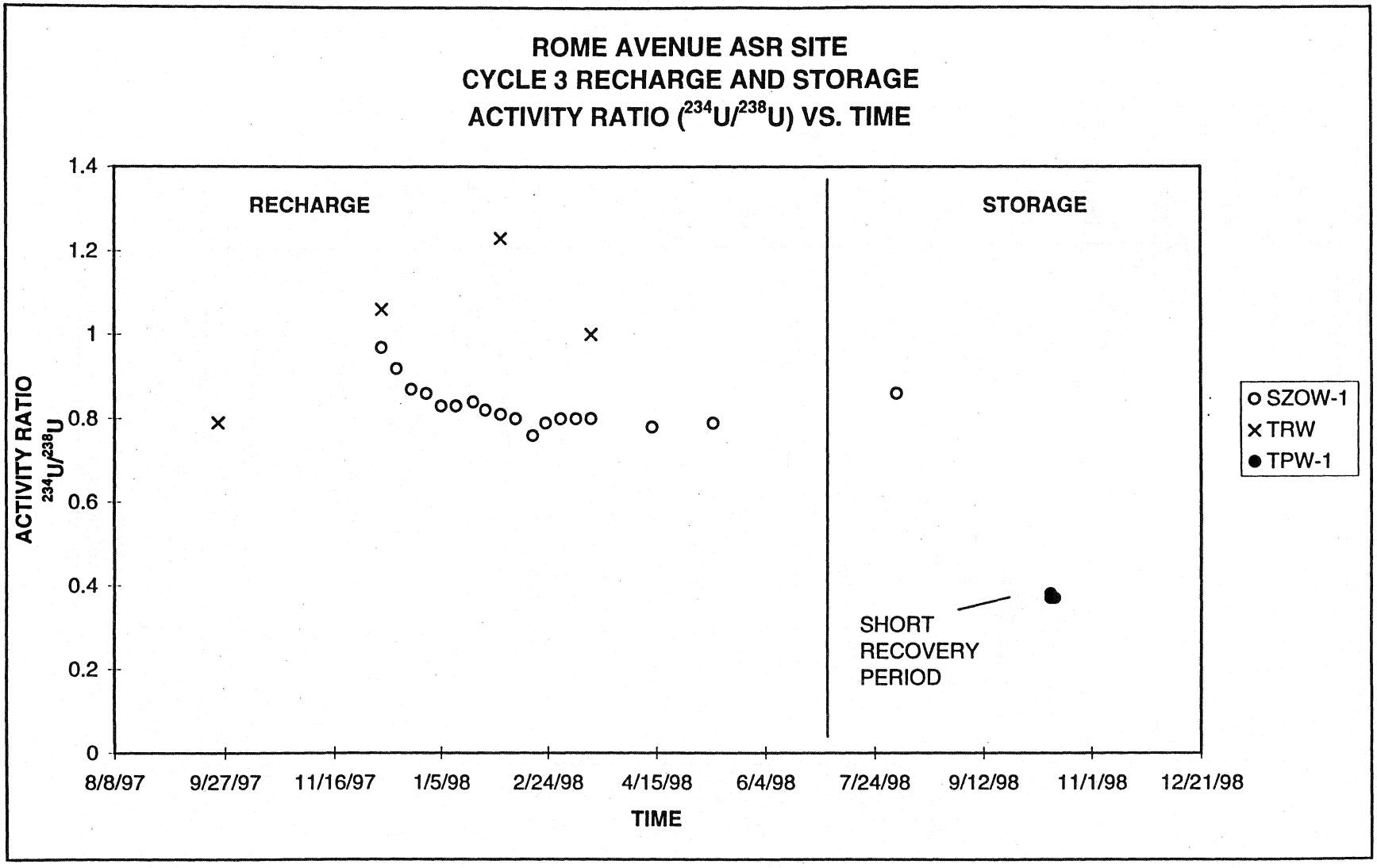


Figure 24. $^{234}U/^{238}U$ activity ratio through time during Cycle 3 at the Rome Avenue ASR site.

activity ratio of ~0.80. Cycle 3 storage and recovery should continue to dissolve the ^{234}U-deficient rind, possibly increasing activity ratios of storage and recovery samples. The Cycle 3 SZOW-1 storage sample shows an increase in activity ratio; however, additional SZOW-1 storage samples are necessary for a more reliable explanation of the activity ratio value increase.

The TPW-1 samples taken during the Cycle 3 storage phase are much lower in activity ratio than those of SZOW-1 (Table 7). They do however show values near those of the first samples recovered in Cycle 2 from TPW-1. Again, the low activity ratio (<0.50) represents input water that has spent the least amount of time in the aquifer, and shows values possibly due to an ultra-thin uranium coating that mobilized during recharge.

A plot of the activity ratio vs. the reciprocal of uranium concentration is shown in Figure 25. A line plotted from the average TRW value through an average of the SZOW-1 values again demonstrates close to 0.80 activity ratios for the exposed surfaces of the carbonate grains. The direction of the curve mimics that of the Cycle 2 recovery curve but trends in the opposite direction. This is to be expected because the recharge process is opposite that of the recovery process. The direction of the curve changes after the eleventh sample, and again after the fourteenth sample due to the changes in concentration discussed earlier. With time, dilution would decrease the concentration in SZOW-1 samples and drive the curve back toward native water values.

During the Cycle 3 storage phase, a short recovery period (10/13/98-10/21/98) was carried out from TPW-1. Five samples were taken in the first three days; therefore, little change in the uranium signature is expected between the samples. These samples demonstrate signatures close to those encountered during the first stages of Cycle 2 recovery. It is expected, then that during full scale recovery, the uranium signatures at TPW-1 (and SZOW-1) will mimic those of the Cycle 2 recovery phase.

The water quality and trace metal analyses present other interesting results, as well. Dissolved oxygen concentrations in surface water, for example, is greater than that of groundwater because of its contact with the atmosphere. A decrease in dissolved oxygen can be attributed to oxidation by metals or organics with which the water comes in contact. As expected, TPW-1 dissolved oxygen is greater than SZOW-1 values during both recharge cycles (Figure 11). During recovery, TPW-1 values are less than those of SZOW-1 possibly due to alternate travel paths/conduits. With each successive cycle, TRW may be forced into (during recharge) small organic-rich or "metal-rich" pore spaces or conduits not encountered in previous cycles. This would therefore oxidize those organics and/or metals in the pore spaces, using the dissolved oxygen in the water. For this reason, when traveling from SZOW-1 to TPW-1, during recovery, the dissolved oxygen decreases. The SZOW-1 and TPW-1 dissolved oxygen values in Cycle 3 are higher than those in Cycle 2, suggesting that there may be less opportunity for oxidation to occur with each successive cycle. However, as discussed earlier, these measurements may be affected by atmospheric contamination during sampling; hence, a conclusive explanation of dissolved oxygen measurements is difficult to make.

Fluoride concentrations also proved interesting (Figure 26). The fluoride levels in TRW (TPW-1) during Cycle 2 recharge are high due to fluoridation at the Tampa Water Department. During the onset of Cycle 2 recharge, TPW-1 concentrations are therefore much higher than those of SZOW-1. Although SZOW-1 increases during the Cycle 2 recharge phase, the values never reach those of the input water (TPW-1). During recovery, the TPW-1 fluoride values are still at input levels and steadily decrease with time. SZOW-1 fluoride values remain below TPW-1 values during recovery. It appears that the majority of fluoride never reaches

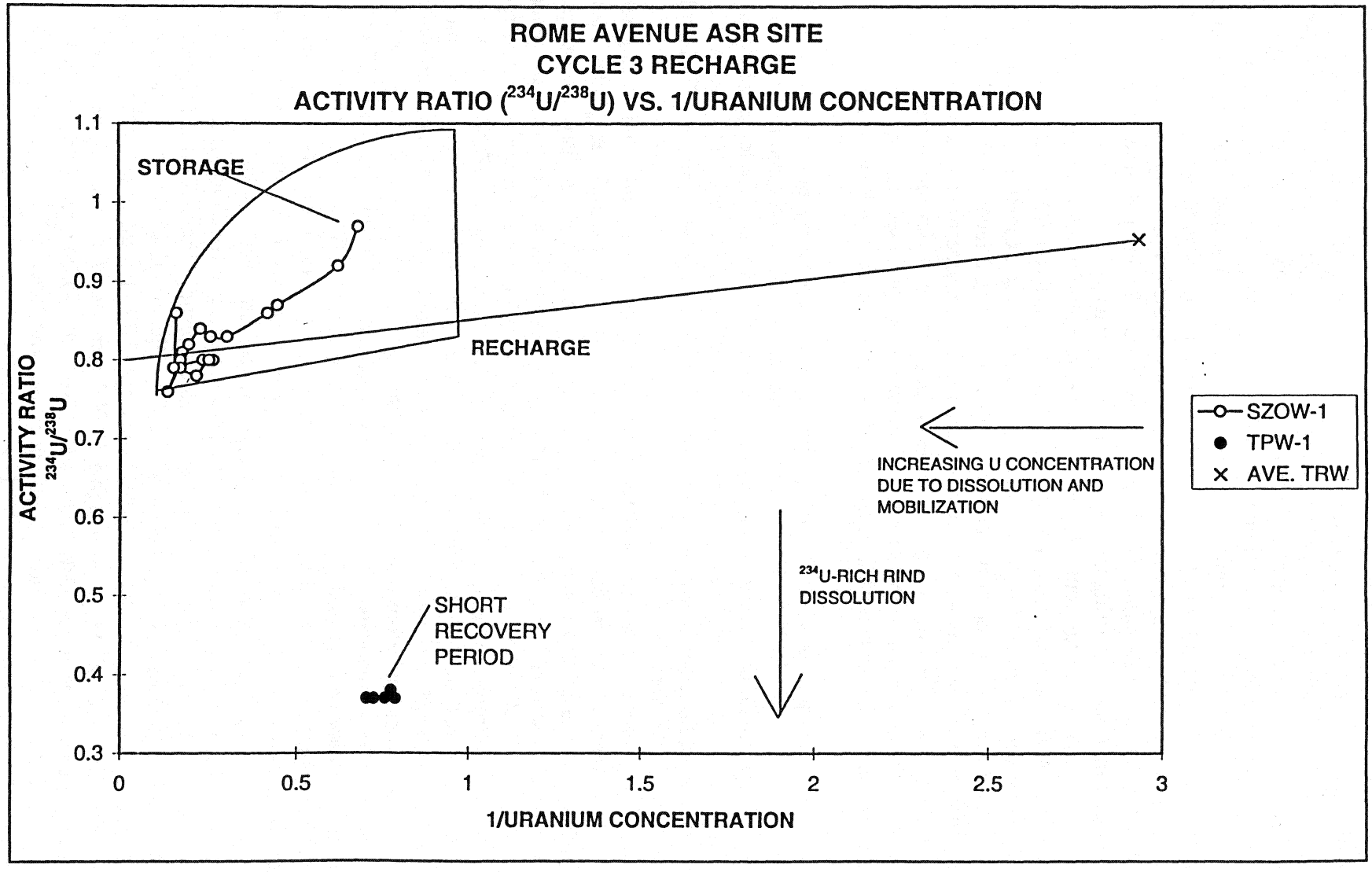


Figure 25. Uranium isotopic signatures during Cycle 3 at the Rome Avenue ASR site.

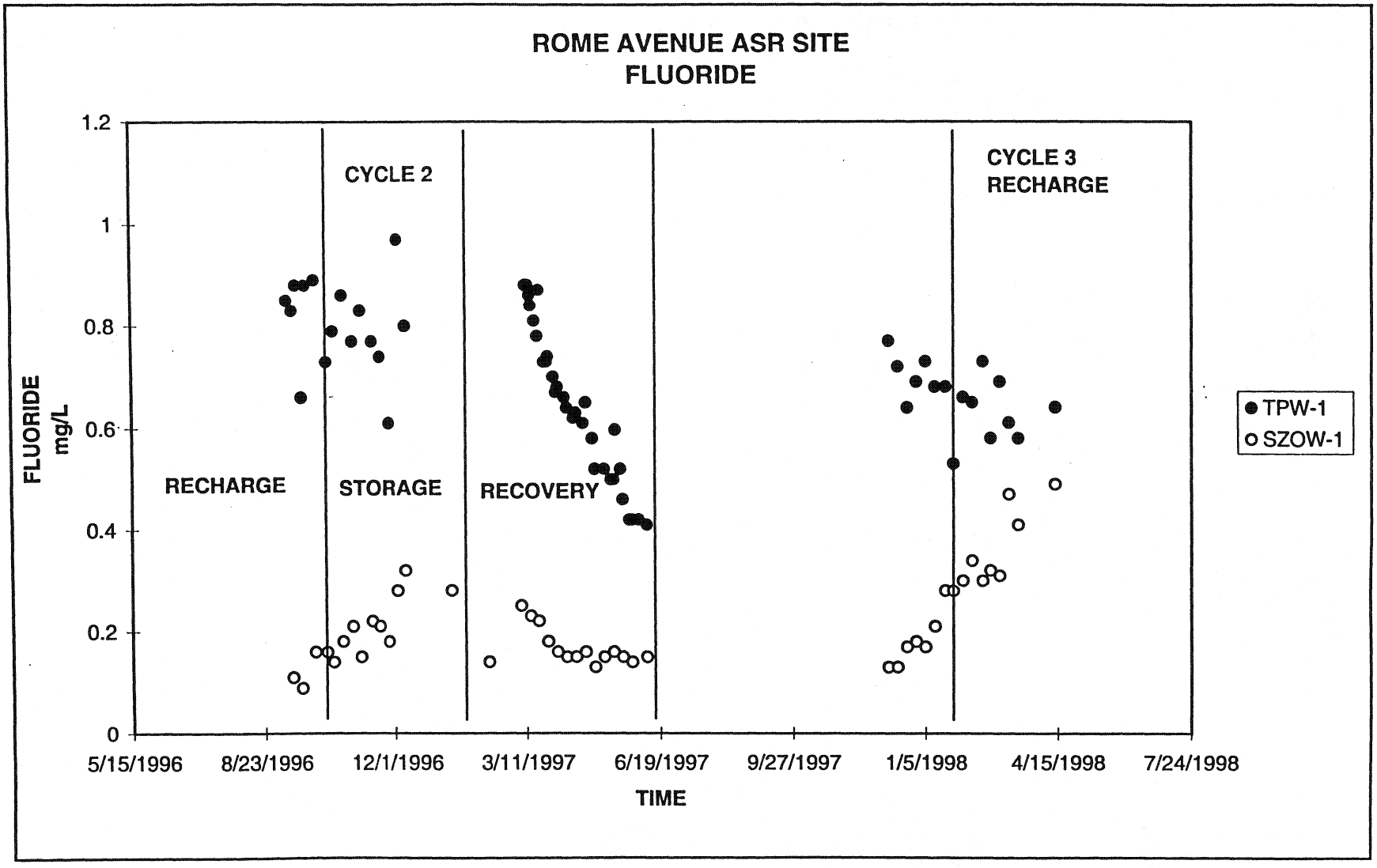


Figure 26. Fluoride values at the Rome Avenue ASR site.

SZOW-1, suggesting that fluoride movement was "halted" (perhaps by precipitation, or reaction with some favorable mineral) or retarded upon input to the aquifer, and then released and diluted during recovery. Cycle 3 recharge fluoride values in TRW (TPW-1) are again high, and SZOW-1 values increase towards TRW values, and may possibly reach the TRW values. This could suggest that the movement of the fluoride is not as decreased or "halted" with each new cycle or that alternate flow paths are encountered with subsequent cycles. This observation, among others mentioned herein possibly suggests that permeability has been increased between TPW-1 and SZOW-1 during successive ASR cycles.

If sulfate (SO_4^{2-}) acts in a conservative manner over the period of Cycle 2, then the SO_4^{2-} concentration data (Figure 13) support the assumption that recharge and recovery water travel time between TPW-1 and SZOW-1 is approximately 16 days. The initial "native water" SO_4^{2-} concentration value of approximately 40 mg/L increased to about 110 mg/L during about the first 16 days after injection began. Then, the concentration values in both TPW-1 and SZOW-1 slowly began to approach the same value. Of special interest is the observation that the concentration of SO_4^{2-} at TPW-1 starts to decrease almost immediately after commencement of water withdrawal. Since both TPW-1 and SZOW-1 have the same concentration at the beginning of the recovery period, it may be that diluting waters still exist within the cylinder of injected water, otherwise the sulfate concentration would not decrease at least until about 16 days of pumping had occurred. The even more rapid decrease in sulfate values recorded at SZOW-1 can be ascribed to the same phenomenon and to mixing that occurred at the outer fringes of the injected-water "bubble" or SO_4^{2-} -complexing redox reactions.

Strontium data for five samples are shown in Table 8. Strontium can be used as a tracer, or as an indicator of mixing between two or more sources. In the case of this investigation, strontium was sampled to indicate dissolution of the aquifer rock during ASR processes.

Table 8. $^{87}Sr/^{86}Sr$ isotopic ratios for water samples from the Cycle 2 recovery phase.

Sample Location	Collection Date	$^{87}Sr/^{86}Sr$ Isotopic Ratio
TPW-1	3/10/97	0.707949 ± 0.000012
	4/17/97	0.708062 ± 0.000010
	6/09/97	0.708037 ± 0.000009
	6/09/97-duplicate	0.708042 ± 0.000008
SZOW-1	3/14/97	0.708100 ± 0.000007
TRW	3/14/97	0.707869 ± 0.000009

Using the strontium isotopic signature of input water compared to that of the Oligocene aquifer rock, it should be possible to estimate the degree of rock dissolution. Based on Hess et al.'s (1986) graph of measured $^{87}Sr/^{86}Sr$ of well-dated fossil foraminifera plotted against stratigraphic age, rocks of Oligocene age range in strontium isotopic ratio from 0.707625 to 0.708500. The $^{87}Sr/^{86}Sr$ isotopic ratio of water collected from the Hillsborough River (TRW) and from SZOW-1 and TPW-1 collected during Cycle 2 recovery lie within the same range. A precision analysis of the separation process and the mass spectrometer data was completed on duplicate samples (TPW-1-6/9/97). The analytical results of the duplicate analyses are well within acceptable limits of precision. According to data in Hess et al. (1986), the TRW samples represent water

that has previously come in contact with Oligocene carbonates. Because the storage zone is located in Oligocene carbonates, TRW affected by the storage zone carbonates also reflect Oligocene $^{87}Sr/^{86}Sr$ signatures. Therefore, the strontium isotopic signatures can not be differentiated between input water and recovered water; hence, strontium can not be used as a mechanism for determining storage zone carbonate dissolution at the Rome Avenue site.

Arsenic concentrations during Cycle 2 recovery may prove to be useful for health standard purposes. A suite of samples tested for arsenic in the Floridan aquifer system in the SWFWMD (Maddox et al., 1992) showed a median value of less than 0.01 µg/L. Background levels at TPW-1 in storage zone native aquifer water are reported by PEER Consultants, P.C. and CH2M Hill (1995) at less than 2 µg/L. The Primary Drinking Water Standards maximum contaminant level for arsenic in drinking water is 50 µg/L. The arsenic levels in recovered TPW-1 and SZOW-1 samples (Figure 27) reach values as high as 36 µg/L. Input was no greater than 3 µg/L . The sources and temporal variations in arsenic in the ASR setting are the subject of current research at the Florida Geological Survey (Arthur and others, 2001).

PUNTA GORDA ASR SITE

The components of the mixing environment at the Punta Gorda ASR site include treated river water (TRW), or input water before it is injected into the aquifer, native aquifer water (Native), and water recovered from the ASR well, or input water that has spent time in the aquifer (ASR well). Pre-treated river water (PTRW) was sampled as well. ASR cycle testing was initiated late in this investigation; as a result, native aquifer water was available for sampling, but only Cycle 1 samples of the two cycles conducted at the site in 1998 were available due to time constraints. Two samples of native aquifer water were analyzed for $^{234}U/^{238}U$ activity ratio and uranium concentration. The earlier sample (11/1/97) measured below detection limits possibly due to low analytical-procedure yield. The later sample (3/25/98) measured an activity ratio of 1.61 and a concentration of 0.131 µg/L (Table 9). Two TRW samples and one PTRW sample were analyzed. The native water signature is plotted as a line on the concentration through time graph and the activity ratio versus time graph for simpler visualization purposes.

Cycle 1 was initiated July 23, 1998. The recharge phase ensued for six days (7/23/98-7/28/98). No storage phase transpired and recovery ensued from 7/29/98 to 8/7/98, ten days. According to Mark Abbott (personal communication, Montgomery Watson, 1998), the injected volume was fully recovered within two to three days. A graph of the uranium concentration versus time through Cycle 1 is shown in Figure 28. The earliest recovered sample (ASR well) value (7/29/98) represents water that was recharged to the aquifer last, spent the least amount of time in the aquifer, less than 24 hours, and was recovered first. The concentration value is closest to TRW and PTRW values, and the native water value, as well. The next two samples recovered illustrate increasing uranium concentrations. The final four samples depict decreasing uranium concentrations, trending towards native and TRW/PTRW concentrations. The uranium concentration of all recovered samples (excluding the first) is greater than that of native samples and TRW/PTRW samples. This is evidence that uranium is being mobilized from the aquifer rock. It is evident from the first three samples that uranium mobilization is continuing with time. The increase in concentration with time can be attributed to the

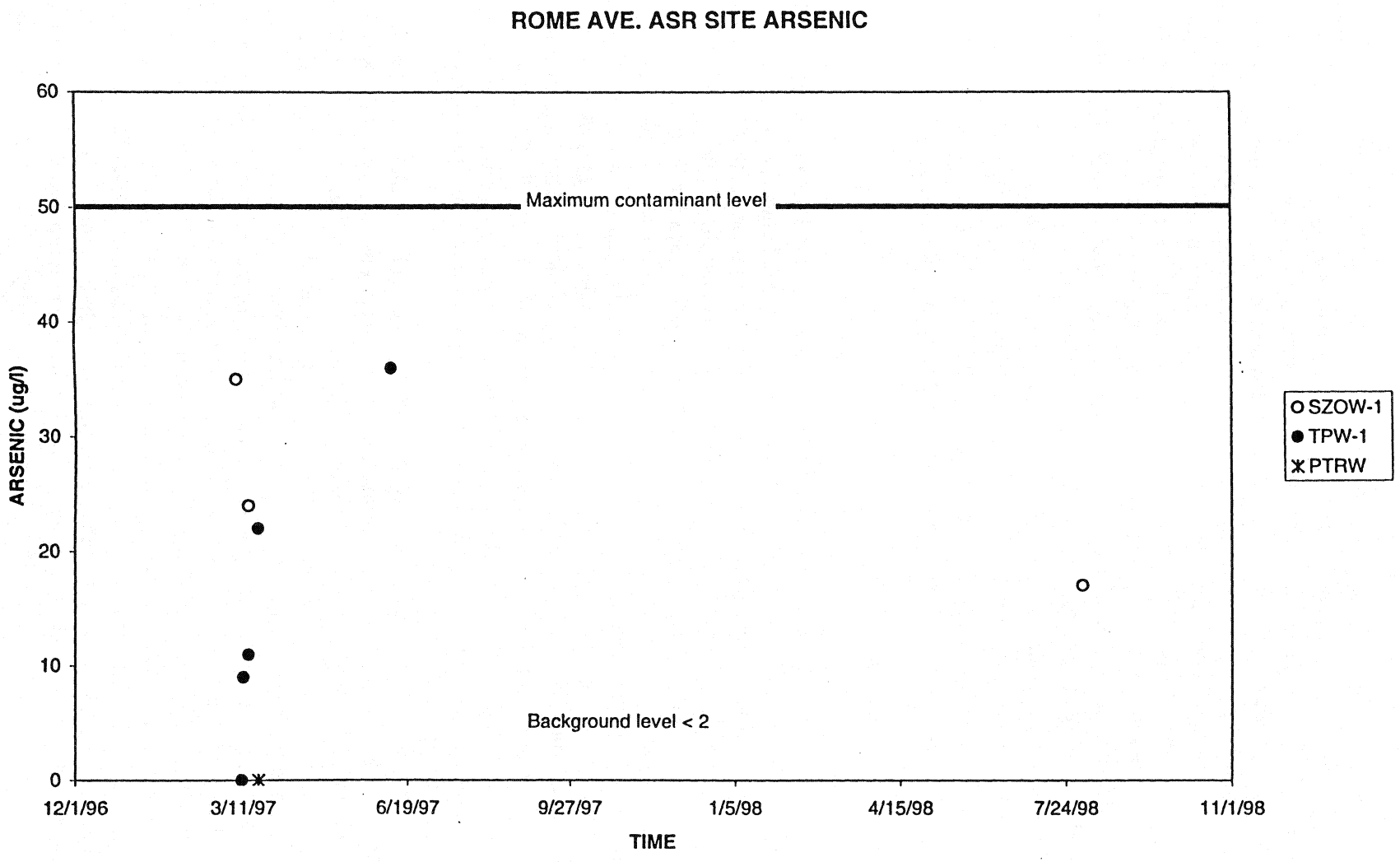


Figure 27. Arsenic values at the Rome Avenue ASR site.

Table 9. Uranium isotopic signatures of samples at the Punta Gorda ASR site through Cycle 1.

Location: Date	Native		ASR well		TRW		PTRW	
	Uranium conc.	$^{234}U/^{238}U$ A.R.	Uranium conc.	$^{234}U/^{238}U$ A.R.	Uranium conc.	$^{234}U/^{238}U$ A.R.	Uranium conc.	$^{234}U/^{238}U$ A.R.
11/01/97	BDL	BDL						
3/25/98	0.13	1.61						
CYCLE 1 RECHARGE PHASE								
7/23/98					0.03	0.7		
CYCLE 2 RECOVERY PHASE								
7/29/98			0.06	0.91	0.46	0.76	0.47	0.72
7/30/98			4.32	0.95				
7/31/98			5.79	1.04				
8/03/98			3.83	1.19				
8/04/98			3.20	1.21				
8/05/98			2.72	1.25				
8/06/98			2.28	1.3				

Uranium concentration in µg/L
BDL-below detection limits
Environmental Protection Agency's 1991 proposed maximum contaminant level for uranium in public water supplies is 20 µg/L (Federal Register, 1997).

mobilization of uranium from the aquifer rock due to oxygen-rich conditions. Water quality analyses are minimal at this site (Appendix C). pH measurements were taken weekly. The TRW value (7.7) differed by only 0.2 pH units of recovery samples (7.5). Therefore, an argument for a large change in input water chemistry can not be made using pH values.

The steady decrease in uranium concentration with the last four samples can be attributed to dilution, or mixing of the input water with the native water. Ultimately, dilution would drive the uranium concentration back to near-native water values. Dilution affects the uranium concentration of the input water in four ways as discussed previously: uranium concentration in the recovered water is decreased, the rate of uranium mobilization by the injected water is decreased, aquifer rock dissolution decreases, and uranium in the water column possibly precipitates back onto the rock; all of which result in decreasing concentration with time. Dilution is also evident from water quality analyses conducted for this investigation (Appendix C) and by the City of Punta Gorda, as discussed below.

Total dissolved solids for a native water sample, TRW samples recharged to the aquifer, and water samples recovered from the aquifer are shown in Figure 29. TRW values range from 290 to 493 mg/L. The first sample recovered lies within the TRW value range. Successive samples increase toward the native water value of 1918 mg/L. Figure 30 shows the change in chloride concentration in the native sample, and in the TRW and recovered water through time. TRW values range from 130 to 158 mg/L. The first recovered sample is within this range. Successive samples increase in chloride concentration with time towards the native water value of 850 mg/L. The same trends follow for conductivity and sodium (Appendix 1). It is evident from these data that after the first sample (the first day of recovery), input water is increasingly diluted (i.e., mixed) by native waters with time and distance traveled in the aquifer.

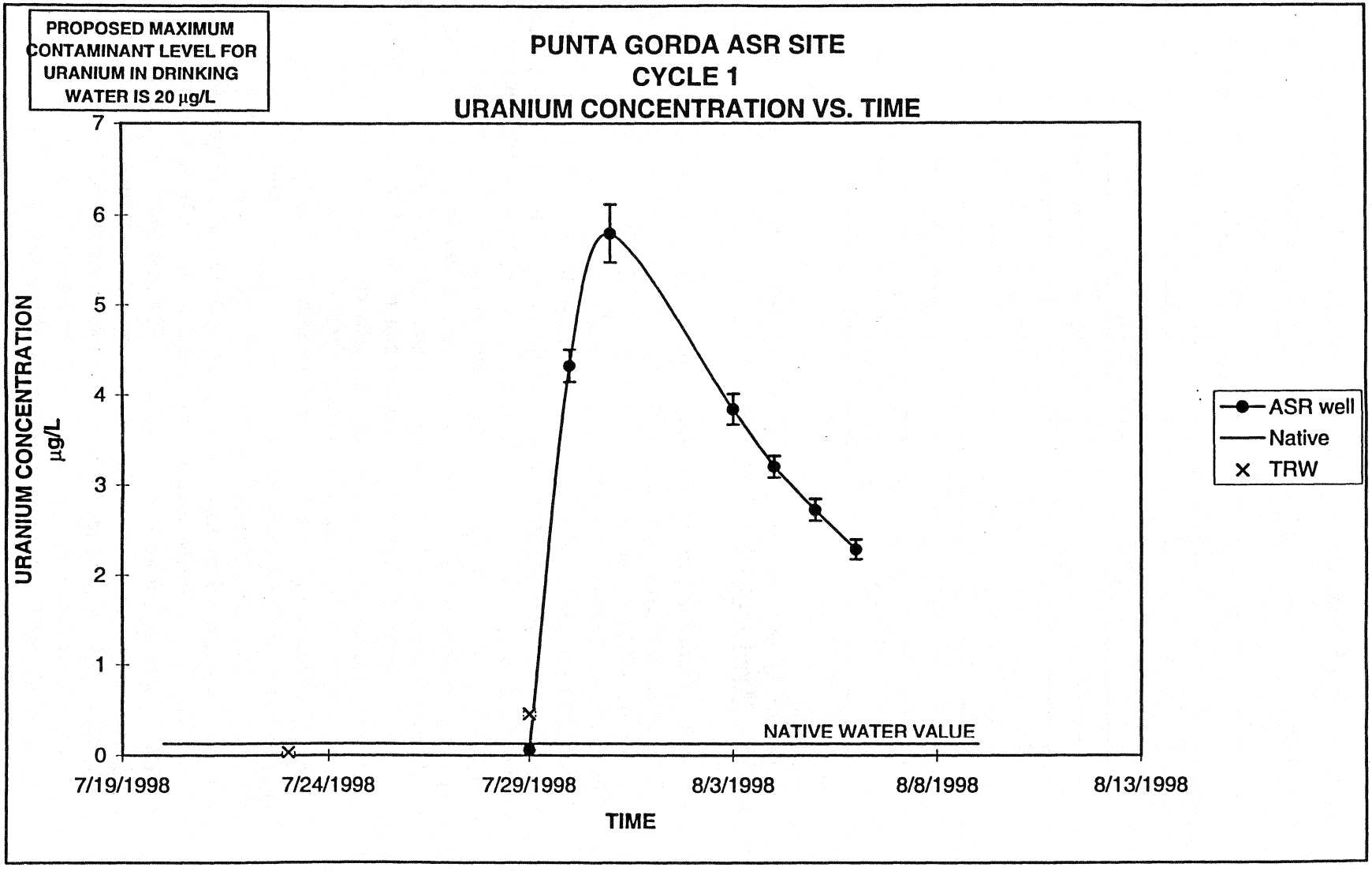


Figure 28. Uranium concentration through time at the Punta Gorda ASR site. Error bars represent two standard deviations.

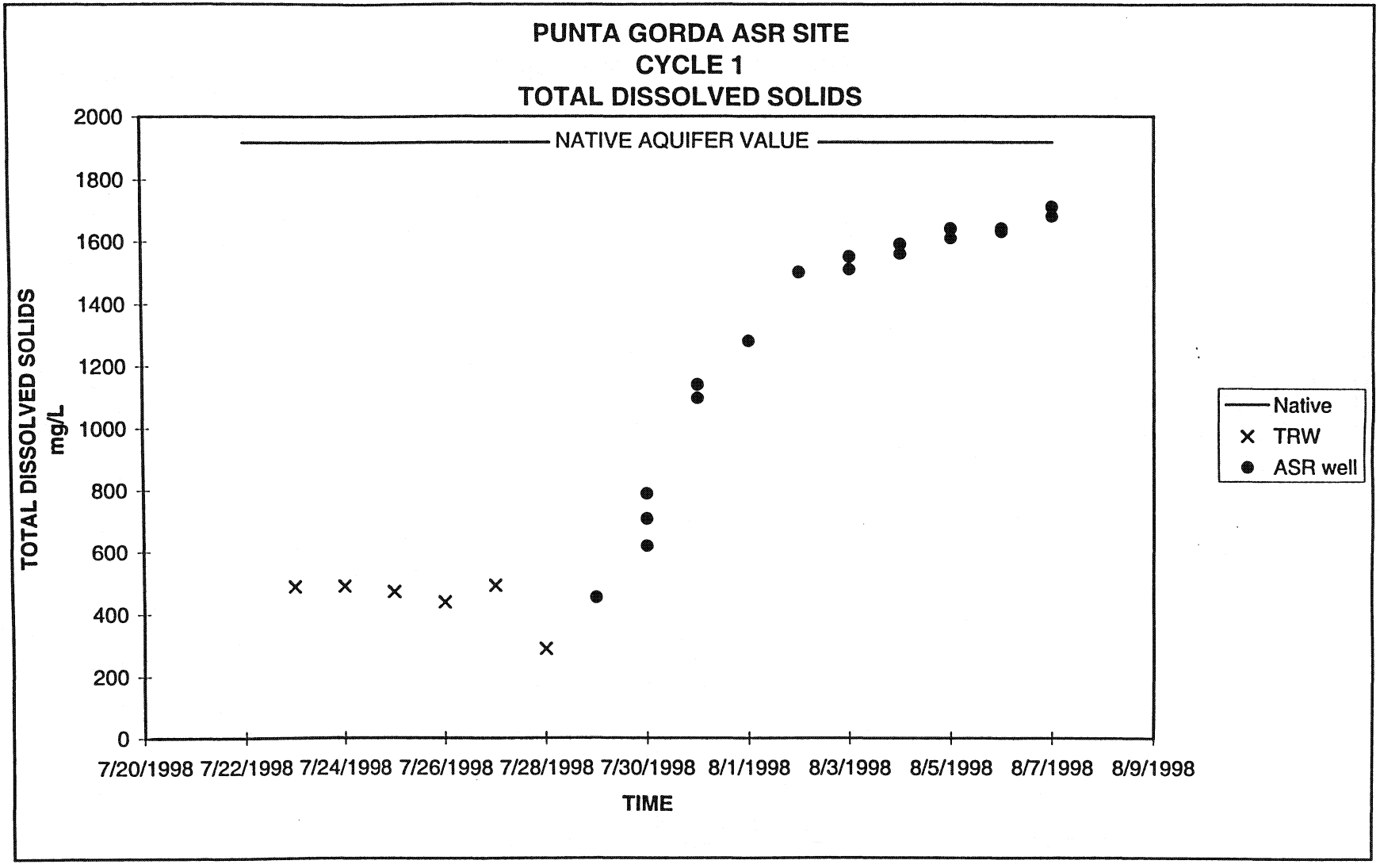


Figure 29. Total dissolved solids values at the Punta Gorda ASR site.

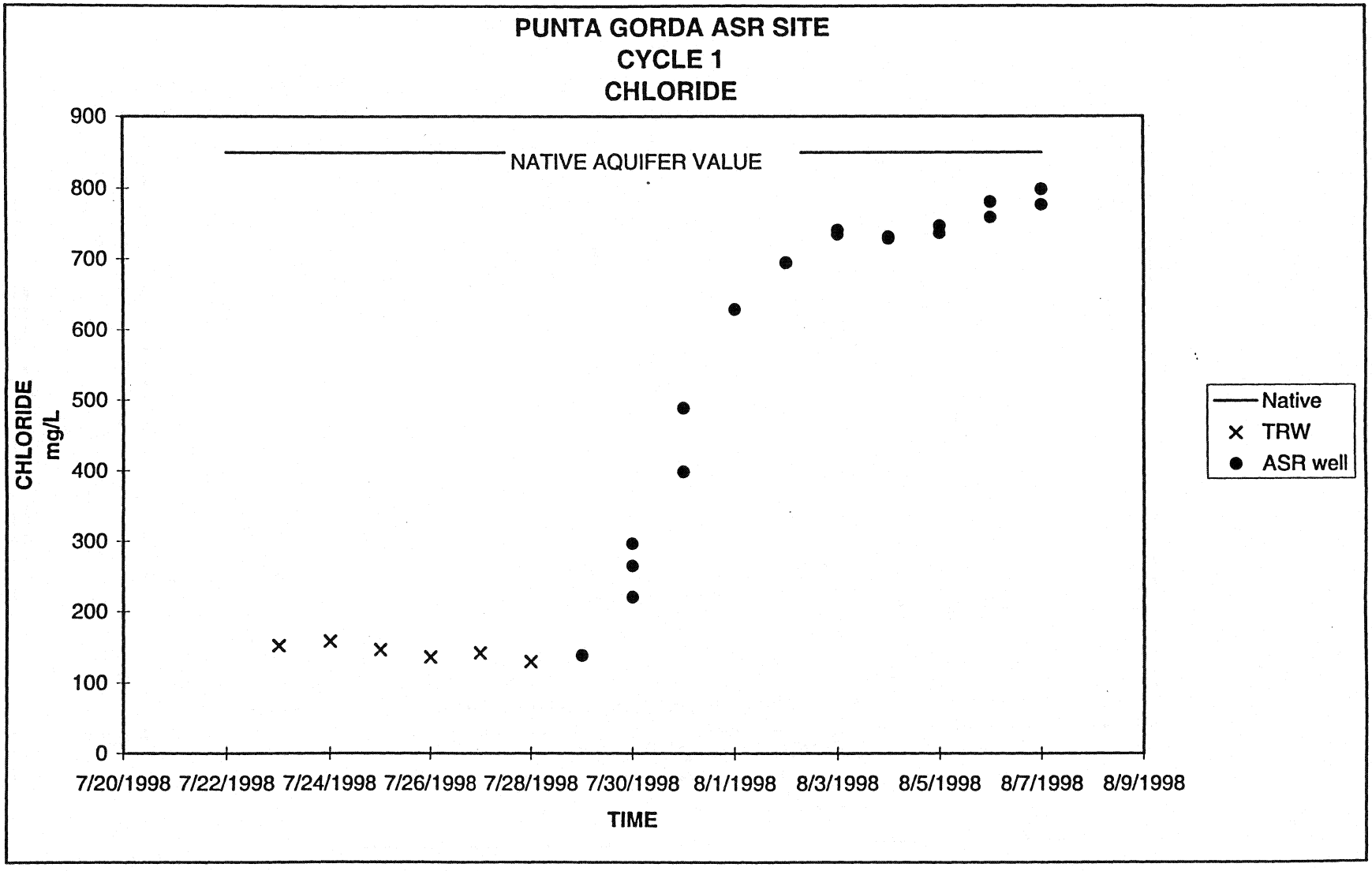


Figure 30. Chloride values at the Punta Gorda ASR site.

The mobilization of uranium from the aquifer rock effectively increases the concentration of the second and third samples. Successive samples are diluted to such a degree that uranium-concentration in the samples decreases, and mobilization in the aquifer decreases as well. The same process is true for arsenic concentrations (Figure 31). Arsenic values increase in recovered samples from the TRW value of 3 µg/L to 37 µg/L in the fourth sample. The mobilization of arsenic in the aquifer effectively increases the concentration of the second, third and fourth samples. Successive samples are diluted to such a degree that uranium-concentration in the samples decreases towards the native aquifer value of 0.002 µg/L (Montgomery Watson, 1998).

It has been shown that dilution affects all water values increasing with time spent in the aquifer. A plot of Cycle 1 activity ratios through time (Figure 32) illustrates recovered water values increasing with time spent in the aquifer. The sample from the first day showed an increase in activity ratio from TRW samples. The increase in activity ratio may be due to the following mechanism which is discussed in more detail in Osmond and Cowart (in press). Where an ultra-thin coating of uranium has precipitated onto carbonate grains, ^{234}Th nuclides (effectively ^{234}U nuclides) are ejected during ^{238}U-decay directly into either the surrounding water or into the carbonate grain. An increase in ^{234}U in the carbonate grain increases the activity ratio of the carbonate grain to values greater than 1.00. In the event that the environment becomes oxygen-rich (a regional or local change in sea-level, for example) the ultra-thin coating of uranium is mobilized and transported from the immediate area. In the case of the Punta Gorda site, the ultra-thin coating is no longer present, and the introduction of oxygen-rich conditions mobilizes the uranium from the ^{234}U-rich rind of the carbonate grains. This will, in effect, contribute to high activity ratios in the recovered water in the first few samples. As the rind dissolves, ^{234}U- input should increase with time. Dilution will also increase the activity ratio of the recovered water towards the native water activity ratio value of 1.61.

Activity ratio is plotted versus the reciprocal of concentration (Figure 33). Note that TRW values vary greatly. As discussed previously, during periods of high rainfall, more input to surficial water bodies (Shell Creek in this case) is by way of overland flow, water which has come in contact with pH-reducing (acidifying) material. Also, greater discharge from the river because of high rainfall limits contact of the river water with river-base carbonate material, preventing buffering of pH values (increasing pH) by the carbonates. Low rainfall periods result in extended contact with river-base carbonates and the significant source of input water to the river may be spring and aquifer water from carbonate zones resulting in an increase of the pH of the river water. Input water with lower pH values will effectively dissolve some carbonate when recharged to the aquifer. Higher pH values will have less of an effect on carbonate dissolution. The variability in TRW values therefore may be a result of changing local rainfall conditions. The difference in TRW uranium concentrations may result in significantly affecting concentration values of the first two samples of recovered water, also reflecting extreme variability in concentration values. Because the concentration values for the two TRW samples vary greatly, a mixing line can not be drawn to include TRW and aquifer rock.

CONCLUSIONS

Aquifer storage and recovery (ASR) is an alternative method of storing large volumes of water. ASR is a cyclic process that involves recharge of treated surficial water into

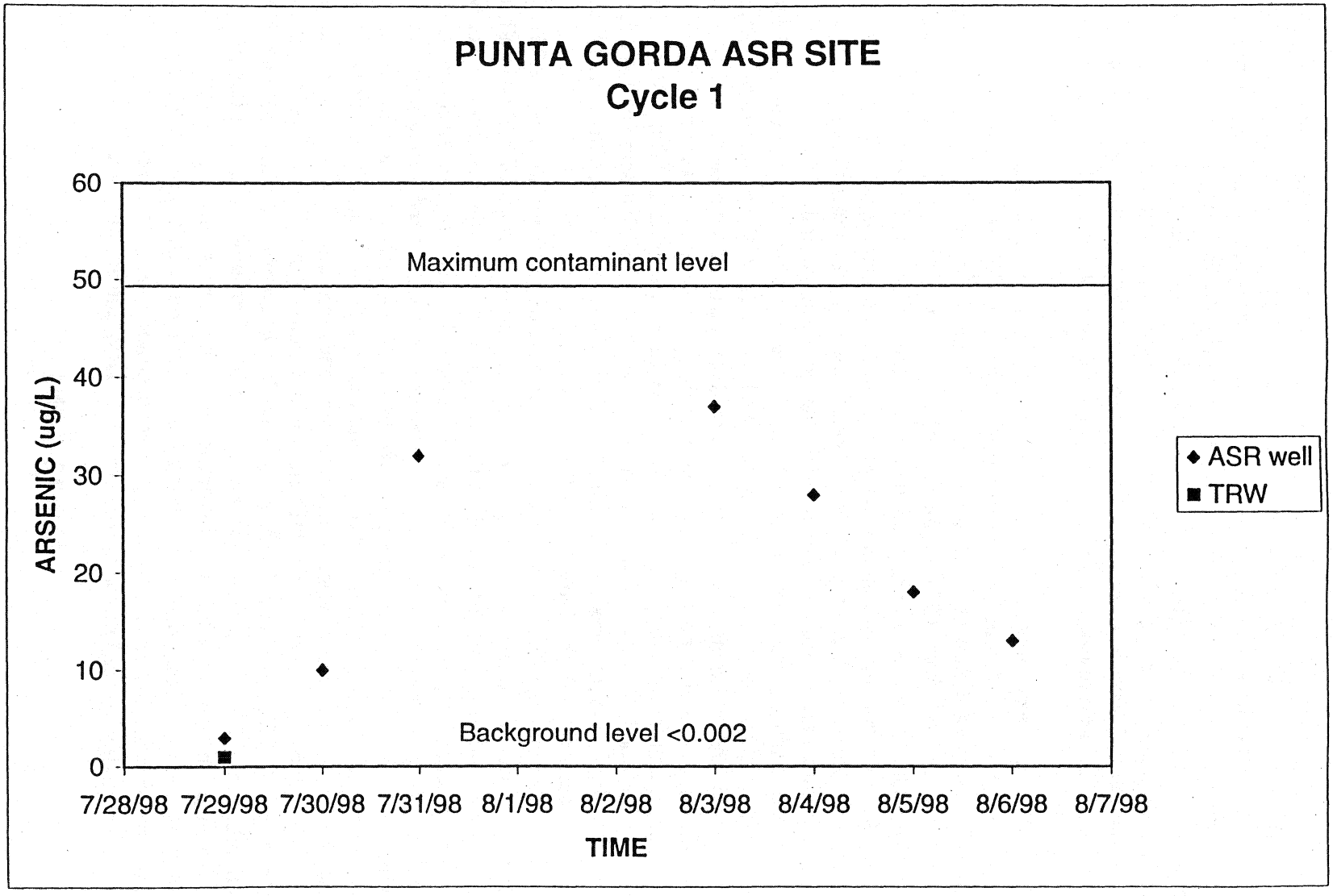


Figure 31. Arsenic values at the Punta Gorda ASR site.

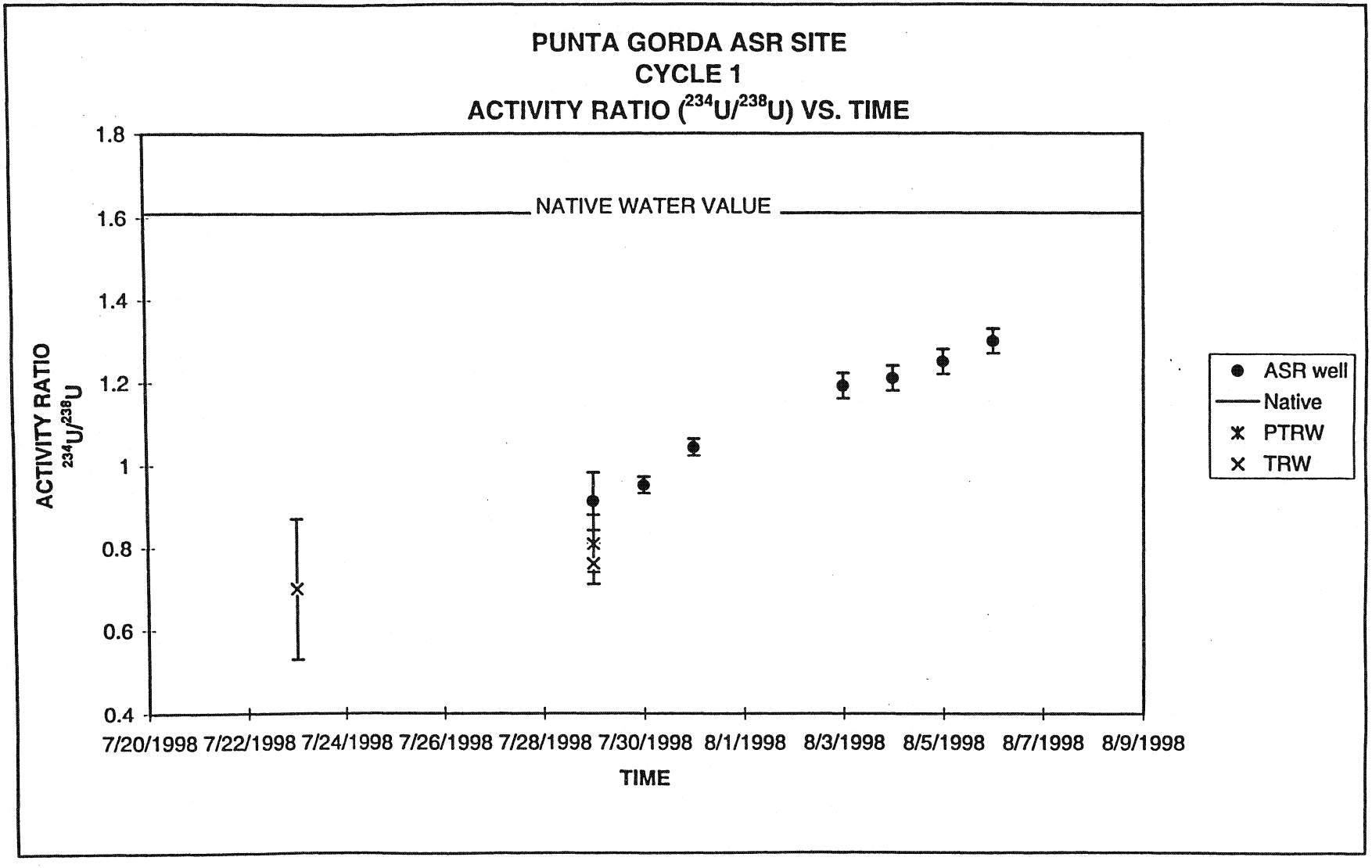


Figure 32. $^{234}U/^{238}U$ activity ratio through time at the Punta Gorda ASR site. Error bars represent two standard deviations.

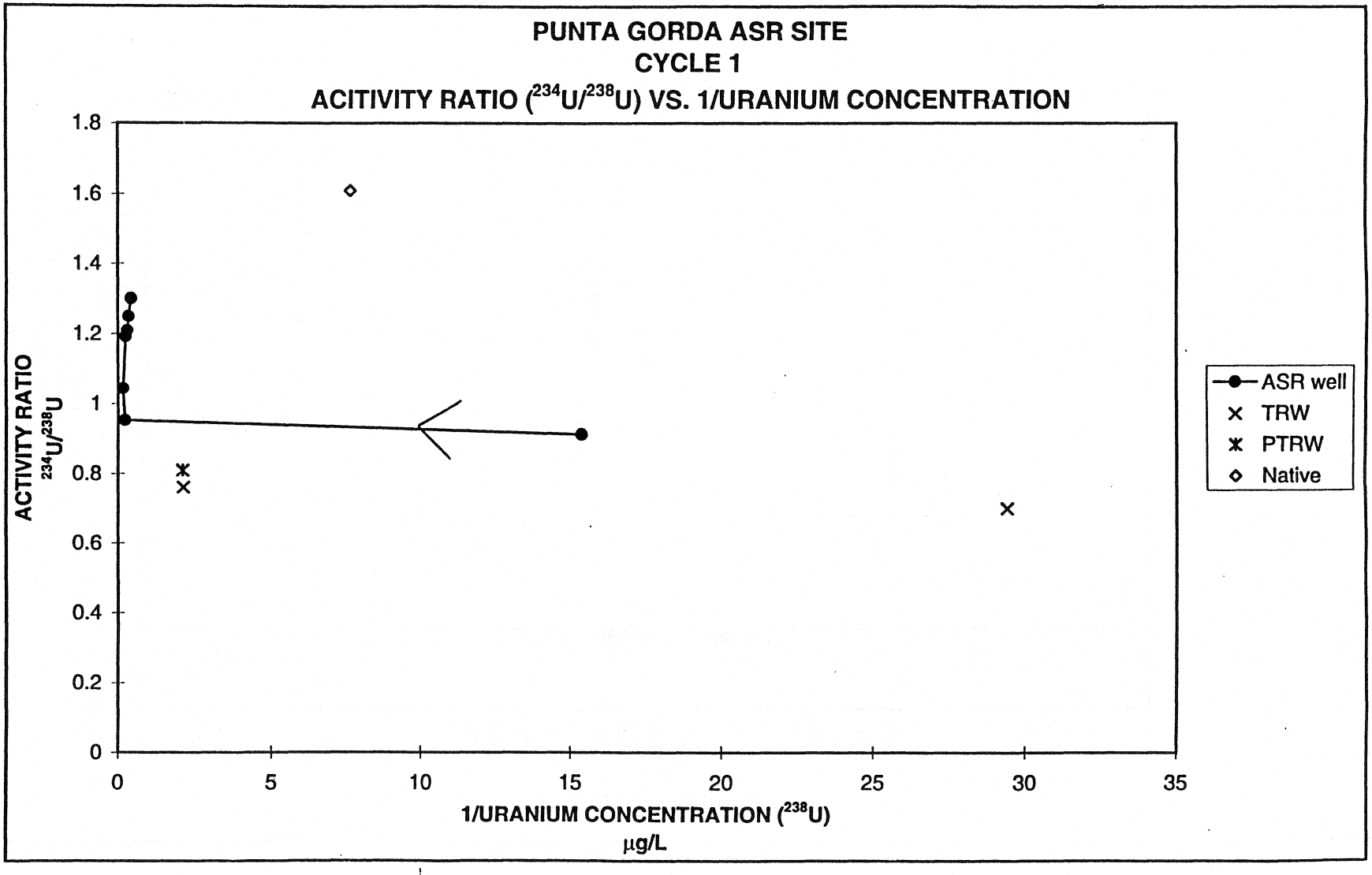


Figure 33. Uranium isotopic signatures at the Punta Gorda ASR site.

an aquifer where it is stored for a period of time, and then recovered when needed. The introduction of the oxygen-rich surficial water into a less oxygen-rich aquifer may result in geochemical and isotopic changes within the environment of mixing. Such water-rock interactions are poorly understood in many aspects, including the mobilization of uranium from the rock or sediment into the surrounding water. Other trace metals may be released to the water column by ASR activities, and mixing between the native and recharge waters may change the geochemical signature of the water that will ultimately be recovered.

Two ASR facilities in west-central Florida are selected for this investigation, the Rome Avenue site in Hillsborough County and the Punta Gorda site in Charlotte County. The Rome Avenue site includes two wells open to the storage zone (TPW-1 and SZOW-1) and wells open to zones above and below the storage zone (SMW-1 and 2-D). The Punta Gorda site consists of one well, the ASR well. These wells and pre-treated and treated river water (PTRW and TRW) were sampled for this investigation for uranium isotopic signature ($^{234}U/^{238}U$ activity ratio and uranium concentration), trace metals and other water quality parameters to aid in the understanding of water-rock interactions taking place in the storage zone during ASR activities.

Rome Avenue ASR site

At the Rome Avenue ASR site, it is demonstrated that ASR activities had little, if any, affect on, or interaction with, zones above and below the storage zone. Uranium isotopic signatures, trace metals and other water quality parameters in samples collected at 2-D and SMW-1 demonstrate no comparable trends to those in SZOW-1 and TPW-1 samples. Therefore, the storage zone is considered a closed system to waters and rocks above and below the storage zone for the purposes of this investigation. TPW-1 and SZOW-1, however, are both open to the storage zone and are hydrologically connected. Given an injection rate and physical aquifer parameters, the projected time for injected water to travel between TPW-1 and SZOW-1 during recharge or recovery is approximately sixteen days. As a result, chemical changes in injected water as it travels in the aquifer can be determined by sampling water from the two wells.

Uranium concentration values of water recovered from the storage zone are greater than those of the input water (TRW) in all cases during Cycle 2 and 3. This indicates that uranium is being mobilized into the injected TRW during recharge, storage and/or recovery, and is a result of water-rock interactions. Measured uranium concentrations of samples recovered during Cycle 2 increase with time from 1.26 to 6.44 µg/L at TPW-1 and 4.27 µg/L at SZOW-1. These values are less than half of that proposed by the Environmental Protection Agency (20 µg/L) for a uranium maximum contaminant level in public water supplies (Federal Register, 1997). Subsequent values decrease from the measured maximum values with time. Because this investigation began after cycle testing initiation, native aquifer water samples were not available. However, the minimum uranium concentration of water recovered during cycle testing is approximately 1.00 µg/L. This value may represent near-native aquifer water uranium concentration levels (this value is probably somewhat higher than the native uranium concentration value due to remnant oxic water from previous cycles continuing mobilization between cycles). The increase in uranium concentration in TPW-1 is attributed to:

- mobilization of uranium due to introduction of oxygen-rich input water, which mobilizes total uranium (^{234}U and ^{238}U) from a thin coating of uranium previously adsorbed onto the aquifer rock,
- mobilization of uranium from ^{234}U-deficient aquifer rock surfaces and micro-channels-again attributed to introduction of oxygen-rich input water, and
- some dissolution of carbonate aquifer rock due to contact with acidic input water (pH<7), that mobilized total uranium into the surrounding water.

The decrease in uranium concentration with time in Cycle 2 recovery samples can be attributed to dilution of input water by native aquifer water. Dilution of recharged water may result in:

- an overall decrease in aquifer rock dissolution,
- a decrease in uranium mobilization from the aquifer rock and the ultra-thin coating of uranium, and
- precipitation of uranium in the water column back on to the aquifer rock (this process should take place in a time frame beyond that of ASR activities).

The variability in the uranium concentrations of TRW may be attributed to changing rainfall totals, varying the source of input flow to the source water (the Hillsborough River). Cycle 3 recharge SZOW-1 uranium concentration values demonstrate an increase to 7.26 µg/L from 1.47 µg/L reflected in the first SZOW-1 sample collected during this phase. Again, as input water travels in the aquifer from TPW-1 past SZOW-1, uranium is mobilized into the oxidized input water. The decrease in uranium concentration during recharge, followed by another increase may be attributed to varying pH values (acidity) of the input water; thus, varying the rates of aquifer rock dissolution. Water sampled at TPW-1 during the short recovery period of the Cycle 3 storage phase had measured uranium concentration values close to those measured at TPW-1 during the recovery period in Cycle 2. It can be assumed that uranium concentrations during full recovery should trend similar to those in Cycle 2 recovery samples. A variation in values should be expected due to pH-related changes in dissolution rates as seen in SZOW-1 recharge samples.

$^{234}U/^{238}U$ activity ratios of water recovered from components of the mixing system were measured. TPW-1 samples during Cycle 2 recovery demonstrate increasing activity ratios from 0.47 to approximately 0.8 where they approach consistency between 0.8 and 0.9. The activity ratio less than 0.5 represented in the first recovered sample may be due to a ^{234}U-deficient thin coating of uranium mobilized as a result of introduced oxidizing conditions. The increase in activity ratio of the TPW-1 samples may be attributed to dissolution of less ^{234}U-deficient rind on the carbonate grains. The consistency of the last few samples may be attributed to dilution by native aquifer waters demonstrating activity ratios between 0.80 and 0.90 or higher. Near-native aquifer water values may be represented in diluted SZOW-1 samples at near-equilibrium values. SZOW-1 values remain constant between cycles, then decrease during recharge in Cycle 3. Decreasing SZOW-1 activity ratios during recharge demonstrate oxidized input water remaining from Cycle 2, diluted with native water. As TRW is recharged to the well, the mass of input water pushes the "ambient" water past SZOW-1. Subsequent values then represent activity ratios of TRW mobilizing uranium from the carbonate rock with a ^{234}U-deficient rind at an activity ratio of approximately 0.80 (with little to no dilution effects).

Water collected at TPW-1 during the short recovery period in the Cycle 3 storage phase demonstrates activity ratios close to those of TPW-1 samples first collected during Cycle 2

recovery. SMW-1 activity ratios decrease during Cycle 2 recovery and measure high again in Cycle 3. 2-D activity ratios during Cycle 2 and 3 are as high as 2.06. Activity ratios at both wells (2-D and SMW-1) are near equilibrium or higher demonstrating either older systems (not recently affected by natural or artificial recharge) or systems affected by conditions other than those affecting the storage zone.

Strontium isotopic ratio ($^{87}Sr/^{86}Sr$) analysis was performed on five samples during the Cycle 2 recovery phase. The strontium isotopic ratios of TRW, TPW-1 and SZOW-1 samples are very close in value and represent marine water of Oligocene age. Similar signatures of major components of the mixing system make source characterization unfeasible. This, in turn, makes difficult the calculation of aquifer rock dissolution based on changing strontium isotopic signatures. A quantitative evaluation of aquifer rock dissolution was therefore not possible in this investigation.

One other trace metal that showed interesting results is arsenic. Arsenic values approach, but are less than, the maximum contaminant level of 50 µg/L. Values increase to 36 µg/L, suggesting arsenic is being mobilized from the rock. Slowdown in increasing arsenic values (final TPW-1 sample) suggests that the arsenic is precipitated out of the water column, diluted to the native water concentration, and/or has reached the maximum concentration that may be released in the aquifer. Arsenic sources and temporal variations are the subject of current investigations at the Florida Geological Survey.

Measured uranium concentration values at the Rome Avenue site do not exceed 7.26 µg/L (Cycle 3 recharge phase) as of the Cycle 3 storage phase. The uranium concentration of water during Cycle 1, however, is unknown.

Punta Gorda ASR site

The earliest recovered sample from the ASR well represent water that was recharged to the aquifer last, spent the least amount of time in the aquifer (less than 24 hours), and was recovered first. The uranium concentration value of this sample is closest to TRW and PTRW values (0.46 to 0.47 µg/L) because it had little time to interact with the aquifer rock. The next two samples recovered illustrate rapidly increasing uranium concentrations to 5.79 µg/L. Measured uranium concentration values at the Punta Gorda ASR site do not exceed 5.79 µg/L. The final four samples depict decreasing uranium concentrations, trending towards native and TRW/PTRW concentrations. The uranium concentration of all recovered samples (excluding the first) is greater than that of native samples and TRW/PTRW samples. This is evidence that uranium is being mobilized from the aquifer rock to the input water. It is evident from the first three samples that uranium mobilization continues with the amount of time the input water remains in the aquifer. The increase in concentration with time can be attributed to the mobilization of uranium from the aquifer rock due to the introduction of oxygen-rich conditions. In the case of the Punta Gorda site, the uranium concentration increase may be attributed to:

- mobilization of total uranium from ^{234}U-rich aquifer rock surfaces and micro-channels, and
- some dissolution of carbonate aquifer rock due to contact with acidic (pH<7) input water or mixing between native and input water resulting in mobilization of uranium into the surrounding water.

The steady decrease in uranium concentration in the last four samples may be attributed to dilution of the input water by the native aquifer water. Dilution of the input water results in:

- decreasing the uranium concentration of the recovered water,

- decreasing the rate of uranium mobilization in the aquifer,
- decreasing the rate of rock dissolution,
- and with time after the system returns to equilibrium conditions, precipitating some of the uranium in the water column back on to the rock (this process should take place in a time frame beyond that of ASR activitites).

Dilution is also indicated by water quality analyses performed by the City of Punta Gorda. Total dissolved solids (TDS), conductivity and chloride were measured daily or more frequently during Cycle 1. In samples collected after the first day of recovery, TDS, conductivity and chloride values increased rapidly towards near-native aquifer values. The high variability in uranium concentration of TRW values between 7/23/98 and 7/29/98 may be attributed to varying precipitation totals effecting the acidity (pH) of inflow water to Shell Creek, the TRW source, and resulting in affecting the total uranium of inflow water.

It has been shown that dilution may affect all water samples subsequent to the first sample recovered. The first sample recovered demonstrates an increase in activity ratio compared to TRW values. This increase may be due to dissolution of carbonate grains that are increasingly ^{234}U-rich from the grain boundary to the grain center. This enrichment may be due to earlier dissolution of an ultra-thin coating of uranium on the carbonate grains that directly transferred ^{234}U nuclides into the grains increasing the activity ratio of the grains. The first recovery sample showing an increase in uranium concentration has a less than 1.00 activity ratio (0.95). This may be a remnant of the previously-mobilized ultra-thin coating which may have been almost totally mobilized during the first 24 hours of recovery. This mechanism may contribute to high activity ratios in the recovered water in the following few samples where carbonate rock dissolution is taking place. Activity ratios of subsequent samples also increase as a result of dilution with native aquifer water with an even higher activity ratio of 1.61.

Similar to Rome Avenue recovery samples, arsenic values demonstrate intriguing results. During recovery, an increase to 37 µg/L is observed, followed by a decrease suggesting arsenic is mobilized from the rock during exposure to injected waters. The decrease reflects arsenic precipitation and/or dilution by the native aquifer water which has an arsenic concentration of less than 0.002 µg/L. By fitting a curve to the arsenic data, it is suggested that the arsenic concentrations of the recovered water possibly reached values near the maximum contaminant level of 50 µg/L.

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APPENDIX A

LITHOLOGIC DESCRIPTION OF WELL 2-D,
LOCATED AT THE ROME AVENUE ASR SITE

LITHOLOGIC WELL LOG PRINTOUT SOURCE - FGS
WELL NUMBER: W-16574 COUNTY: HILLSBOROUGH
TOTAL DEPTH: 1180 FT. LOCATION: T.28S R.18E S.35
196 SAMPLES DESCRIBED FROM 0 TO 1130 FT. LAT: 28D 00M 11S
LON: 82D 28M 35S
ELEVATION: 15 FT
OWNER/DRILLER: NWHWRAP-2D (NORTHWEST HILLSBOROUGH WATER RESOURCES ASSESSMENT)
WORKED BY: HOLLY K. WILLIAMS

0 feet -30	UNDIFFERENTIATED SAND AND CLAY
30 - 180	ARCADIA FM.
30 - 180	TAMPA MEMBER OF ARCADIA FM.
180 - 195	NO SAMPLES
195 - 385	SUWANNEE LIMESTONE
385 - 425	OCALA LIMESTONE
425 - 530	NO SAMPLES
530 - TD	AVON PARK FM.

0 - 10 SAND; DARK GREENISH YELLOW; 25% POROSITY: INTERGRANULAR, INTERCRYSTALLINE; POSSIBLY HIGH PERMEABILITY; GRAIN SIZE: MEDIUM; RANGE: FINE TO COARSE; ROUNDNESS: SUB-ANGULAR TO SUB-ROUNDED; MEDIUM SPHERICITY; UNCONSOLIDATED; ACCESSORY MINERALS: PHOSPHATIC SAND-02%.

10 - 20 SAND; DARK GREENISH YELLOW; 25% POROSITY: INTERGRANULAR, INTERCRYSTALLINE; POSSIBLY HIGH PERMEABILITY; GRAIN SIZE: MEDIUM; RANGE: FINE TO COARSE; ROUNDNESS: SUB-ANGULAR TO SUB ROUNDED; MEDIUM SPHERICITY; UNCONSOLIDATED; ACCESSORY MINERALS: PHOSPHATIC SAND-02%, LIMESTONE-01%.

20 - 30 SAND; DARK GREENISH YELLOW; 25% POROSITY: INTERGRANULAR, INTERCRYSTALLINE; POSSIBLY HIGH PERMEABILITY; GRAIN SIZE: MEDIUM; RANGE: FINE TO COARSE; ROUNDNESS: SUB-ANGULAR TO SUB-ROUNDED; MEDIUM SPHERICITY; UNCONSOLIDATED; ACCESSORY MINERALS: PHOSPHATIC SAND-02%, LIMESTONE-05%.

30 - 40 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE; 25% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: CRYPTOCRYSTALLINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND 10%, PHOSPHATIC SAND-01%, SPAR-01%.

40 - 50 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE; 10% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: CRYPTOCRYSTALLINE TO FINE; POOR INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-07%, PHOSPHATIC SAND-01%.

50 - 55 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE; 20% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: CRYPTOCRYSTALLINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-10%, PHOSPHATIC SAND-01%,SPAR-01%.

55 - 60 AS ABOVE.

60 - 65 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE; 10% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: CRYPTOCRYSTALLINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-07%, PHOSPHATIC SAND-01%.

65 - 70 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE; 10% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: CRYPTOCRYSTALLINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-07%, PHOSPHATIC SAND-01%.

70 - 75 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE; 10% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: CRYPTOCRYSTALLINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-05%, PHOSPHATIC SAND-01%.

75 - 80 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE; 10% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: CRYPTOCRYSTALLINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-05%, PHOSPHATIC SAND-01%, SPAR-01%.

80 - 85 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE; 15% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: CRYPTOCRYSTALLINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-07%, PHOSPHATIC SAND-01%, SPAR-01%.

85 - 90 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE; 15% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: CRYPTOCRYSTALLINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-07%, PHOSPHATIC SAND-01%, SPAR-01%.

90 - 95 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE; 15% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: CRYPTOCRYSTALLINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-05%, PHOSPHATIC SAND-01%, SPAR-01%; FOSSILS: BENTHIC FORAMINIFERA; SORITES PRESENT.

95 - 100 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 25% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: CRYPTOCRYSTALLINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-05%, PHOSPHATIC SAND-01%, SPAR-01%; FOSSILS: BENTHIC FORAMINIFERA, MOLLUSKS; SORITES PRESENT.

100 - 105 AS ABOVE.

105 - 110 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 25% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: CRYPTOCRYSTALLINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-03%, PHOSPHATIC SAND-01%, SPAR-01%.

110 - 115 AS ABOVE.

115 - 120 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 30% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: CRYPTOCRYSTALLINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-05%, PHOSPHATIC SAND-01%, SPAR-02%; FOSSILS: BENTHIC FORAMINIFERA; SORITES PRESENT.

120 - 125 AS ABOVE.
125 - 130 AS ABOVE.

130 - 135 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 30% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: CRYPTOCRYSTALLINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-05%, PHOSPHATIC SAND-01%, SPAR-02%.

135 - 140 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 20% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: CRYPTOCRYSTALLINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-03%, PHOSPHATIC SAND-01%.

140 - 145 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 25% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: CRYPTOCRYSTALLINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-03%, PHOSPHATIC SAND-01%.

145 - 150 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 20% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: CRYPTOCRYSTALLINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-03%, PHOSPHATIC SAND-01%, SPAR-01%.

150 - 155 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 20% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: V. FINE; RANGE: CRYPTOCRYSTALLINE MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-03%, PHOSPHATIC SAND-1%.

155 - 160 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 30% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: CRYPTOCRYSTALLINE TO FINE; MOD. INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-03%, PHOSPHATIC SAND-01%, SPAR-01%; FOSSILS: ECHINOID, MOLLUSKS.

160 - 170 AS ABOVE.

170 - 175 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 25% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: CRYPTOCRYSTALLINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-03%, PHOSPHATIC SAND- 01%, SPAR-01%; FOSSILS: ECHINOID, MOLLUSKS, SPICULES, BENTHIC FORAMINIFERA; SORITES PRESENT.

175 - 180 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 25% ALLOCHEMICAL CONTITUENTS GRAIN SIZE: VERY FINE; RANGE: CRYPTOCRYSTALLINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-03%, PHOSPHATIC SAND- 01%, SPAR-01%; FOSSILS: ECHINOID, SPICULES, MOLLUSKS.

180 - 195 NO SAMPLES.

195 - 200 GRAINSTONE; YELLOWISH GRAY; 25% POROSITY: INTERGRANULAR, INTERCRYSTALLINE; POSSIBLY HIGH PERMEABILITY; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 95% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: FINE TO COARSE; POOR INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-01%, SPAR-03%; FOSSILS: ECHINOID, SPICULES, MOLLUSKS, BENTHIC FORAMINIFERA, BRYOZOA; PARAROTALIA (ROTALIA) PRESENT; GRAINS ARE UNCONSOLIDATED IN CUTTINGS SAMPLE.

200 - 205 GRAINSTONE; YELLOWISH GRAY; 25% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 90% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: FINE TO COARSE; POOR INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-01%, SPAR-03%; FOSSILS: ECHINOID, SPICULES, MOLLUSKS.

205 - 210 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 85% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-01%, SPAR-03%; FOSSILS: ECHINOID, SPICULES, MOLLUSKS, BENTHIC FORAMINIFERA,BRYOZOA;ROTALIA PRESENT.

210 - 215 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 85% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-01%, SPAR-03%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: ECHINOID, SPICULES, MOLLUSKS, BENTHIC FORAMINIFERA; ROTALIA PRESENT.

215 - 225 AS ABOVE.

225 - 230 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 80% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-01%, SPAR-03%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: ECHINOID, SPICULES, MOLLUSKS BENTHIC FORAMINIFERA, ROTALIA PRESENT.

230 - 235 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR, MOLDIC, VUGULAR; 85% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-01%, SPAR-03%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: ECHINOID, SPICULES, MOLLUSKS, BENTHIC FORAMINIFERA; ROTALIA PRESENT.

235 - 240 GRAINSTONE; YELLOWISH GRAY; 25% POROSITY: INTERGRANULAR, INTERCRYSTALLINE; POSSIBLY HIGH PERMEABILITY; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 95% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: FINE TO COARSE; POOR INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-01%, SPAR-03%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: ECHINOID, SPICULES, MOLLUSKS, BENTHIC FORAMINIFERA; ROTALIA PRESENT; GRAINS ARE UNCONSOLIDATED IN CUTTINGS SAMPLE.

240 - 245 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 85% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-01%, SPAR-03%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: ECHINOID, SPICULES, MOLLUSKS, BENTHIC FORAMINIFERA; ROTALIA PRESENT.

245 - 250 GRAINSTONE; YELLOWISH GRAY; 25% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 90% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-01%, SPAR-03%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: ECHINOID, SPICULES, MOLLUSKS, BENTHIC FORAMINIFERA; ROTALIA PRESENT.

250 - 255 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 85% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-01%, SPAR-03%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: ECHINOID, SPICULES, BENTHIC FORAMINIFERA; ROTALIA PRESENT.

255 - 260 AS ABOVE.

260 - 265 GRAINSTONE; YELLOWISH GRAY; 25% POROSITY: INTERGRANULAR, INTERCRYSTALLINE; POSSIBLY HIGH PERMEABILITY; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 95% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: FINE TO COARSE; POOR INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-01%, SPAR-03%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: ECHINOID, SPICULES, MOLLUSKS, BENTHIC FORAMINIFERA; ROTALIA PRESENT; GRAINS ARE UNCONSOLIDATED IN CUTTINGS SAMPLE.

265 - 270 AS ABOVE.

270 - 275 GRAINSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 90% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-01%, SPAR-03%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: ECHINOID, SPICULES, MOLLUSKS, BENTHIC FORAMINIFERA; ROTALIA PRESENT.

275 - 280 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 85% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-01%, SPAR-03%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: ECHINOID, SPICULES, MOLLUSKS, BENTHIC FORAMINIFERA; ROTALIA PRESENT.

280 - 305 AS ABOVE.

305 - 310 GRAINSTONE; YELLOWISH GRAY; 25% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 95% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: FINE TO COARSE; POOR INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-01%, SPAR-03%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: ECHINOID, SPICULES, MOLLUSKS, BENTHIC FORAMINIFERA; ROTALIA PRESENT.

310 - 330 AS ABOVE.

330 - 335 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 85% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: FINE TO COARSE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-01%, SPAR-03%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: ECHINOID, SPICULES, MOLLUSKS, BENTHIC FORAMINIFERA; ROTALIA PRESENT.

335 - 340 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 80% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: FINE TO COARSE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-01%, SPAR-03%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: ECHINOID, SPICULES, MOLLUSKS, BRACHIOPOD; ROTALIA PRESENT.

340 - 345 AS ABOVE.

345 - 350 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 85% ALLOCHEMICAL CONSTITUENTS GRAIN SIZE: MEDIUM; RANGE: FINE TO COARSE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-05%, SPAR-03%; OTHER FEATURES: LOW RECRYSTALLIZATION, POOR SAMPLE, SUCROSIC, MEDIUM RECRYSTALLIZATION; FOSSILS: BENTHIC FORAMINIFERA; ROTALIA PRESENT.

350 - 355 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 85% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: FINE TO COARSE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-01%, SPAR-05%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: ECHINOID, SPICULES, MOLLUSKS, BENTHIC FORAMINIFERA; ROTALIA, DICTYOCONUS COOKEI PRESENT.

355 - 360 AS ABOVE.

360 - 365 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 80% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: FINE; RANGE: FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-01%, SPAR-01%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: ECHINOID, BENTHIC FORAMINIFERA, SPICULES; ROTALIA PRESENT.

365 - 380 AS ABOVE.

380 - 385 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 80% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: FINE; RANGE: VERY FINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-01%, SPAR-03%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: ECHINOID, BENTHIC FORAMINIFERA, SPICULES, MOLLUSKS; ROTALIA PRESENT; MUCH OF THIS SAMPLE IS CAVINGS FROM THE SUWANNEE FORMATION.

385 - 390 AS ABOVE.

390 - 395 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 80% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: FINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: QUARTZ SAND-01%, SPAR-03%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: ECHINOID, BENTHIC FORAMINIFERA, SPICULES, MOLLUSKS; ROTALIA PRESENT; MUCH OF THIS SAMPLE IS CAVINGS FROM THE SUWANNEE FORMATION.

395 - 400 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 75% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: FINE; RANGE: VERY FINE TO VERY COARSE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; FOSSILS: MOLLUSKS, BENTHIC FORAMINIFERA LEPIDOCYCLINA AND NUMMULITES PRESENT.

400 - 405 AS ABOVE.

405 - 410 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 85% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: COARSE; RANGE: VERY FINE TO VERY COARSE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; FOSSILS: MOLLUSKS, BENTHIC FORAMINIFERA, ECHINOID; LEPIDOCYCLINA AND NUMMULITES PRESENT.

410 - 415 AS ABOVE.

415 - 420 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 80% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: FINE; RANGE: FINE TO COARSE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; FOSSILS: MOLLUSKS, BENTHIC FORAMINIFERA, BRYOZOA; LEPIDOCYCLINA AND NUMMULITES PRESENT.

420 - 425 AS ABOVE.

425 - 530 NO SAMPLES.

530 - 535 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 85% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: VERY FINE TO COARSE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: SPAR-05%; FOSSILS: BENTHIC FORAMINIFERA; LEPIDOCYCLINA AND NUMMULITES CAVINGS PRESENT.

535 - 540 GRAINSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 90% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: VERY FINE TO COARSE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: SPAR-05%, QUARTZ SAND-01%; FOSSILS: BENTHIC FORAMINIFERA; NUMMULITES CAVINGS PRESENT.

540 - 550 AS ABOVE.

550 - 555 GRAINSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 90% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: VERY FINE TO COARSE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: SPAR-05%, QUARTZ SAND-05%; FOSSILS: BENTHIC FORAMINIFERA; NUMMULITES CAVINGS PRESENT.

555 - 565 AS ABOVE.

565 - 570 GRAINSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 90% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: VERY FINE TO COARSE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: SPAR-03%, QUARTZ SAND-01%; FOSSILS: ECHINOID, BENTHIC FORAMINIFERA; NUMMULITES CAVINGS PRESENT.

570 - 590 AS ABOVE

590 - 595 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 80% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: VERY FINE TO MEDIUM; POOR INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: SPAR-03%; FOSSILS: BENTHIC FORAMINIFERA, ECHINOID; NUMMULITES CAVINGS, DICTYOCONUS AMERICANUS PRESENT.

595 - 600 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 85% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: VERY FINE TO MEDIUM; POOR INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: SPAR-03%; FOSSILS: BENTHIC FORAMINIFERA, ECHINOID; NUMMULITES CAVINGS, DICTYOCONUS AMERICANUS PRESENT.

600 - 605 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL 85% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: VERY FINE TO MEDIUM; POOR INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: SPAR-03%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: ECHINOID, BENTHIC FORAMINIFERA; NUMMULITES CAVINGS, DICTYOCONUS AMERICANUS PRESENT.

605 - 610 AS ABOVE.

610 - 615 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 85% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: VERY FINE TO MEDIUM; POOR INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: SPAR-03%; FOSSILS: ECHINOID, BENTHIC FORAMINIFERA; NUMMULITES CAVINGS, DICTYOCONUS AMERICANUS PRESENT.

615 - 620 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 80% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: VERY FINE TO MEDIUM; POOR INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: SPAR-03%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: ECHINOID, BENTHIC FORAMINIFERA; NUMMULITES CAVINGS, DICTYOCONUS AMERICANUS PRESENT.

620 - 625 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 75% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: VERY FINE TO MEDIUM; POOR INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: SPAR-03%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: ECHINOID, BENTHIC FORAMINIFERA; NUMMULITES CAVINGS, DICTYOCONUS AMERICANUS PRESENT.

625 - 630 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 70% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: VERY FINE TO MEDIUM; POOR INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: SPAR-03%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: ECHINOID, BENTHIC FORAMINIFERA; NUMMULITES CAVINGS, DICTYOCONUS AMERICANUS PRESENT.

630 - 635 PACKSTONE; YELLOWISH GRAY; 20% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 60% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MEDIUM; RANGE: VERY FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: DOLOMITE-15%; FOSSILS: BENTHIC FORAMINIFERA; NUMMULITES CAVINGS PRESENT.

635 - 640 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 45% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: FINE; RANGE: VERY FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: DOLOMITE-15%; FOSSILS: BENTHIC FORAMINIFERA; NUMMULITES CAVINGS PRESENT.

640 - 645 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 45% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: FINE; RANGE: VERY FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: DOLOMITE-30%; FOSSILS: BENTHIC FORAMINIFERA, ECHINOID; NUMMULITES CAVINGS PRESENT.

645 - 650 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 20% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: FINE; RANGE: VERY FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: DOLOMITE-15%; FOSSILS: BENTHIC FORAMINIFERA; NUMMULITES CAVINGS PRESENT.

650 - 655 AS ABOVE.

655 - 660 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 35% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: FINE; RANGE: VERY FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: DOLOMITE-10%, SPAR-01%; FOSSILS: BENTHIC FORAMINIFERA; NUMMULITES CAVINGS PRESENT.

660 - 675 AS ABOVE.

675 - 680 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 35% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: FINE; RANGE: VERY FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: DOLOMITE-25%; FOSSILS: BENTHIC FORAMINIFERA, ECHINOID; NUMMULITES CAVINGS PRESENT.

680 - 685 AS ABOVE.

685 - 690 DOLOSTONE; YELLOWISH GRAY TO MODERATE OLIVE BROWN; 20% POROSITY: INTERGRANULAR; 50-90% ALTERED; EUHEDRAL; GRAIN SIZE: FINE; RANGE: VERY FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): DOLOMITE CEMENT; ACCESSORY MINERALS: LIMESTONE-15%; FOSSILS: BENTHIC FORAMINIFERA; NUMMULITES CAVINGS PRESENT.

690 - 695 DOLOSTONE; YELLOWISH GRAY TO MODERATE OLIVE BROWN; 15% POROSITY: INTERGRANULAR; 10-50% ALTERED; SUBHEDRAL; GRAIN SIZE: VERY FINE; RANGE: VERY FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): DOLOMITE CEMENT; ACCESSORY MINERALS: LIMESTONE-20%; FOSSILS: BENTHIC FORAMINIFERA; NUMMULITES CAVINGS PRESENT.

695 - 720 AS ABOVE.

720 - 725 DOLOSTONE; YELLOWISH GRAY TO MODERATE OLIVE BROWN; 15% POROSITY: INTERGRANULAR; 10-50% ALTERED; SUBHEDRAL; GRAIN SIZE: FINE; RANGE: VERY FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): DOLOMITE CEMENT; ACCESSORY MINERALS: LIMESTONE-20%; FOSSILS: BENTHIC FORAMINIFERA, ECHINOID; NUMMULITES AND LEPIDOCYCLINA CAVINGS PRESENT.

725 - 750 AS ABOVE.

750 - 755 DOLOSTONE; YELLOWISH GRAY TO MODERATE OLIVE BROWN; 15% POROSITY: INTERGRANULAR; 10-50% ALTERED; SUBHEDRAL; GRAIN SIZE: FINE; RANGE: VERY FINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): DOLOMITE CEMENT; ACCESSORY MINERALS: LIMESTONE-30%; FOSSILS: BENTHIC FORAMINIFERA, ECHINOID; NUMMULITES CAVINGS PRESENT.

755 - 760 AS ABOVE.

760 - 765 DOLOSTONE; YELLOWISH GRAY TO MODERATE OLIVE BROWN; 15% POROSITY: INTERGRANULAR; 10-50% ALTERED; SUBHEDRAL; GRAIN SIZE: FINE; RANGE: VERY FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): DOLOMITE CEMENT; ACCESSORY MINERALS: LIMESTONE-20%; FOSSILS: BENTHIC FORAMINIFERA, ECHINOID; NUMMULITES AND LEPIDOCYCLINA CAVINGS PRESENT.

765 - 770 DOLOSTONE; YELLOWISH GRAY TO MODERATE OLIVE BROWN; 15% POROSITY: INTERGRANULAR; 10-50% ALTERED; SUBHEDRAL; GRAIN SIZE: VERY FINE; RANGE: VERY FINE TO FINE; GOOD INDURATION; CEMENT TYPE(S): DOLOMITE CEMENT; ACCESSORY MINERALS: LIMESTONE-10%; FOSSILS: BENTHIC FORAMINIFERA; NUMMULITES CAVINGS PRESENT.

770 - 775 DOLOSTONE; YELLOWISH GRAY TO MODERATE OLIVE BROWN; 15% POROSITY: INTERGRANULAR; 10-50% ALTERED; SUBHEDRAL; GRAIN SIZE: VERY FINE; RANGE: VERY FINE TO FINE; GOOD INDURATION; CEMENT TYPE(S): DOLOMITE CEMENT; ACCESSORY MINERALS: LIMESTONE-25%; FOSSILS: BENTHIC FORAMINIFERA; NUMMULITES CAVINGS PRESENT.

775 - 780 AS ABOVE

780 - 785 DOLOSTONE; YELLOWISH GRAY TO MODERATE OLIVE BROWN; 15% POROSITY: INTERGRANULAR; 10-50% ALTERED; SUBHEDRAL; GRAIN SIZE: VERY FINE; RANGE: VERY FINE TO FINE; GOOD INDURATION; CEMENT TYPE(S): DOLOMITE CEMENT; ACCESSORY MINERALS: LIMESTONE-05%; FOSSILS: BENTHIC FORAMINIFERA; NUMMULITES CAVINGS PRESENT.

785 - 800 AS ABOVE.

800 - 805 DOLOSTONE; YELLOWISH GRAY TO MODERATE OLIVE BROWN; 15% POROSITY: INTERGRANULAR; 10-50% ALTERED; SUBHEDRAL; GRAIN SIZE: VERY FINE; RANGE: VERY FINE TO FINE; GOOD INDURATION; CEMENT TYPE(S): DOLOMITE CEMENT; ACCESSORY MINERALS: LIMESTONE-15%; FOSSILS: BENTHIC FORAMINIFERA; NUMMULITES CAVINGS PRESENT.

805 - 810 AS ABOVE.

810 - 815 DOLOSTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; 10-50% ALTERED; SUBHEDRAL; GRAIN SIZE: VERY FINE; GOOD INDURATION; CEMENT TYPE(S): DOLOMITE CEMENT; ACCESSORY MINERALS: LIMESTONE-05%.

815 - 820 DOLOSTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; 10-50% ALTERED; SUBHEDRAL; GRAIN SIZE: VERY FINE; ACCESSORY MINERALS: LIMESTONE-15%.

820 - 825 DOLOSTONE; YELLOWISH GRAY TO MODERATE OLIVE BROWN; 15% POROSITY: INTERGRANULAR; 10-50% ALTERED; SUBHEDRAL; GRAIN SIZE: VERY FINE; RANGE: VERY FINE TO FINE; GOOD INDURATION; CEMENT
TYPE(S): DOLOMITE CEMENT; ACCESSORY MINERALS: LIMESTONE-10%.

825 - 830 AS ABOVE.

830 - 835 DOLOSTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; 10-50% ALTERED; SUBHEDRAL; GRAIN SIZE: VERY FINE; RANGE: VERY FINE TO FINE; GOOD INDURATION; CEMENT TYPE(S): DOLOMITE CEMENT; ACCESSORY MINERALS: LIMESTONE-15%.

835 - 840 DOLOSTONE; YELLOWISH GRAY TO MODERATE OLIVE BROWN; 15% POROSITY: INTERGRANULAR; 10-50% ALTERED; SUBHEDRAL; GRAIN SIZE: VERY FINE; RANGE: VERY FINE TO FINE; GOOD INDURATION; CEMENT TYPE(S): DOLOMITE CEMENT.

840 - 845 DOLOSTONE; YELLOWISH GRAY 15% POROSITY: INTERGRANULAR; 10-50% ALTERED; SUBHEDRAL; GRAIN SIZE: VERY FINE; RANGE: VERY FINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): DOLOMITE CEMENT; ACCESSORY MINERALS: LIMESTONE-35%.

845 - 850 DOLOSTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; 10-50% ALTERED; SUBHEDRAL; GRAIN SIZE: VERY FINE; RANGE: VERY FINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): DOLOMITE CEMENT; ACCESSORY MINERALS: LIMESTONE-25%.

850 - 865 AS ABOVE.

865 - 870 DOLOSTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; 10-50% ALTERED; SUBHEDRAL; GRAIN SIZE: VERY FINE; RANGE: VERY FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): DOLOMITE CEMENT; ACCESSORY MINERALS: LIMESTONE-05%.

870 - 880 AS ABOVE.

880 - 885 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 40% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: FINE; RANGE: VERY FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: DOLOMITE-25%; FOSSILS: ECHINOID, BENTHIC FORAMINIFERA; NUMMULITES CAVINGS PRESENT.

885 - 890 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 30% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: VERY FINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: DOLOMITE-05%; FOSSILS: ECHINOID, BENTHIC FORAMINIFERA; NUMMULITES CAVINGS PRESENT.

890 - 895 AS ABOVE.

895 - 900 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 20% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: DOLOMITE-05%; FOSSILS: BENTHIC FORAMINIFERA; NUMMULITES CAVINGS PRESENT.

900 - 905 AS ABOVE.

905 - 910 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR, VUGULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 20% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: VERY FINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: DOLOMITE-05%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: MOLLUSKS, FOSSIL MOLDS, ECHINOID; BENTHIC FORAMINIFERA; NUMMULITES CAVINGS PRESENT.

910 - 920 AS ABOVE.

920 - 925 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 45% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: FINE; RANGE: VERY FINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: DOLOMITE-01%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: ECHINOID, MOLLUSKS, BENTHIC FORAMINIFERA; NUMMULITES CAVINGS PRESENT.

925 - 930 AS ABOVE.

930 - 935 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR, VUGULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 40% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: FINE; RANGE: VERY FINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: DOLOMITE-01%, SPAR-01%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: ECHINOID.

935 - 940 AS ABOVE.

940 - 945 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR, VUGULAR, MOLDIC; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 40% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: FINE; RANGE: VERY FINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: DOLOMITE-03%; OTHER FEATURES: LOW RECRYSTALLIZATION; FOSSILS: BENTHIC FORAMINIFERA; NUMMULITES AND LEPIDOCYCLINA CAVINGS PRESENT.

945 - 950 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR, VUGULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 25% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: VERY FINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: DOLOMITE-03%; OTHER FEATURES: LOW RECRYSTALLIZATION.

950 - 980 AS ABOVE.

980 - 980 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 45% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: FINE; RANGE: VERY FINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: DOLOMITE-03%.

980 - 985 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 40% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: FINE; RANGE: VERY FINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: DOLOMITE-35%.

985 - 990 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 35% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: VERY FINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: DOLOMITE-05%.

990 - 995 AS ABOVE.

995 - 1000 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 35% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: VERY FINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: DOLOMITE-05%; FOSSILS: BENTHIC FORAMINIFERA; NUMMULITES AND LEPIDOCYCLINA CAVINGS, DICTYOCONUS; AMERICANUS PRESENT.

1000 - 1005 AS ABOVE.

1005 - 1010 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 40% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: VERY FINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: DOLOMITE-15%.

1010 - 1015 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 40% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: VERY FINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: DOLOMITE-20%.

1015 - 1020 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 35% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: VERY FINE; RANGE: VERY FINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: DOLOMITE-15%, SPAR-01%.

1020 - 1025 MUDSTONE; YELLOWISH GRAY; 10% POROSITY: INTERGRANULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 10% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: MICROCRYSTALLINE; RANGE: MICROCRYSTALLINE TO VERY FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: DOLOMITE-05%.

1025 - 1030 WACKESTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR, VUGULAR; GRAIN TYPE: BIOGENIC, CALCILUTITE, SKELETAL; 30% ALLOCHEMICAL CONSTITUENTS; GRAIN SIZE: FINE; RANGE: VERY FINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): CALCILUTITE MATRIX; ACCESSORY MINERALS: DOLOMITE-05%.

1030 - 1035 AS ABOVE.

1035 - 1040 DOLOSTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; 0-10% ALTERED; SUBHEDRAL; GRAIN SIZE: VERY FINE; MODERATE INDURATION;CEMENT TYPE(S): DOLOMITE CEMENT; ACCESSORY MINERALS: LIMESTONE-05%.

1040 - 1065 AS ABOVE.

1065 - 1070 DOLOSTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; 10-50% ALTERED; SUBHEDRAL; GRAIN SIZE: FINE; RANGE: VERY FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): DOLOMITE CEMENT; ACCESSORY MINERALS: LIMESTONE-05%.

1070 - 1075 DOLOSTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; 10-50% ALTERED; SUBHEDRAL; GRAIN SIZE: FINE; RANGE: VERY FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): DOLOMITE CEMENT; ACCESSORY MINERALS: LIMESTONE-45%.

1075 - 1080 AS ABOVE.

1080 - 1085 DOLOSTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; 10-50% ALTERED; SUBHEDRAL; GRAIN SIZE: FINE; RANGE: VERY FINE TO MEDIUM; MODERATE INDURATION; CEMENT TYPE(S): DOLOMITE CEMENT; ACCESSORY MINERALS: LIMESTONE-45%.

1085 - 1090 DOLOSTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR, VUGULAR; 0-10% ALTERED; SUBHEDRAL; GRAIN SIZE: VERY FINE; RANGE: VERY FINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): DOLOMITE CEMENT; ACCESSORY MINERALS: LIMESTONE-20%.

1090 - 1115 AS ABOVE.

1115 - 1120 DOLOSTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; 0-10% ALTERED; SUBHEDRAL; GRAIN SIZE: VERY FINE; RANGE: VERY FINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): DOLOMITE CEMENT; ACCESSORY MINERALS: LIMESTONE-30%.

1120 - 1125 AS ABOVE.

1125 - 1130 DOLOSTONE; YELLOWISH GRAY; 15% POROSITY: INTERGRANULAR; 0-10% ALTERED; SUBHEDRAL; GRAIN SIZE: VERY FINE; RANGE: VERY FINE TO FINE; MODERATE INDURATION; CEMENT TYPE(S): DOLOMITE CEMENT; ACCESSORY MINERALS: LIMESTONE-30%, ANHYDRITE-01%, SPAR-01%.

1130 - 1180 NOT DESCRIBED.

1180 TOTAL DEPTH.

APPENDIX B WATER QUALITY ANALYSES AT THE ROME AVENUE ASR SITE

NATIVE WATER (FROM TPW-1)

VARIABLE-RATE STEP-DRAWDOWN TEST WATER QUALITY DATA

PEER Consultants, P.C. and CH2M Hill, 1995

BACKGROUND SAMPLE: 10/19/95	
ANTIMONY	<0.001
ARSENIC	<0.002
ASBESTOS	N/A
BARIUM	<0.1
BERYLLIUM	<0.05
CADMIUM	<0.0002
CHROMIUM	<0.001
CYANIDE	<0.02
FLUORIDE	<0.1
LEAD	<0.001
MERCURY	<0.0002
NICKEL	<0.005
NITRATE (AS N)	<0.02
NITRITE (AS N)	<0.02
SELENIUM	<0.005
SODIUM	9.2
THALLIUM	<0.001

BACKGROUND: INORGANICS	
ALUMINUM	<0.1
CHLORIDE	N/A
COPPER	<0.05
COLOR	5
FLUORIDE	<0.1
FOAMING AGENTS	<0.02
IRON	0.041
MANGANESE	<0.005
ODOR	2
pH (AT COLLECTION POINT)	7.7
SILVER	<0.005
SULFATE	13
TOTAL DISSOLVED SOLIDS (TDS)	232
ZINC	0.008
TURBIDITY	0.63 NTU

BACKGROUND: RADIONUCLIDES

RADIUM 226 AND 228		NOT REQUIRED
GROSS ALPHA	4.5 +- 0.7	

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
N/A: DATA NOT AVAILABLE

TPW-1 (cont.)

(AQUIFER PERFORMANCE TEST BEFORE FIRST INJECTION)

PEER Consultants, P.C. and CH2M Hill, 1996

DATE	TIME	SO_4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
02/22/96	08:24	13	232	7.6	166	11	155	0.43	380	19	0.30	2.40	<1	<1	N/A	N/A	0.03	59	4.6	<0.5
02/24/96	10:15	10	202	7.7	171	11	160	0.89	340	18	0.33	1.40	<1	<1	N/A	N/A	BMDL	61	4.6	<0.5
02/25/96	10:30	11	222	7.5	164	8	156	0.76	340	18	0.28	1.00	<1	<1	N/A	N/A	0.027	58	4.7	<0.5
02/26/96	10:30	13	198	7.5	165	9	156	0.80	340	18	0.24	0.80	<1	<1	N/A	N/A	0.028	59	4.3	<0.5
02/27/96	11:00	12	200	7.5	179	22	157	0.46	340	18	0.26	1.30	<1	<1	N/A	N/A	<0.002	64	4.6	<0.5
02/28/96	08:45	11	262	7.6	190	32	158	0.46	360	18	0.32	1.00	<1	<1	N/A	N/A	<0.002	68	4.8	<0.5

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
N/A: DATA NOT AVAILABLE
BMDL-BELOW MAXIMUM DETECTION LEVEL

*explanation of abbreviations
SO_4-sulfate
TDS-total dissolved solids
TOTAL HARD.-total hardness
NON-CARB HARD.-non-carbonate hardness
TURB.-turbidity
COND.-conductivity
Cl-chloride
Fl-fluoride
TOTAL COLIF.-total coliform
FECAL COLIF.-fecal coliform
Cl_2-Chlorine
NH_3-ammonia
Mg-magnesium
THM-trihalomethanes

TPW-1 (cont.)

RECHARGE-CYCLE 1

PEER Consultants, P.C. and CH2M Hill, 1996

DATE	TIME	SO_4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
07/01/96	08:15			7.00	131	74	57	0.13	277	25	0.88	NA	<1	NA	NA	0.62	0.027	48.6	3.33	91.1
07/01/96	08:55			7.22	130	68	62	0.15	265	27	0.91	NA	<1	NA	NA	0.42	0.040	48.5	3.24	75.0
07/02/96	07:50			7.20	130	67	63	0.19	328	27	0.93	NA	NA	NA	NA	0.57	0.049	48.4	3.33	72.7
07/02/96	19:05			7.00	140	79	61	0.18	420	23	0.95	NA	NA	NA	2.00	0.55	0.013	49.4	3.66	71.7
07/03/96	08:00			7.17	148	83	65	0.11	390	23	0.97	NA	NA	NA	2.00	0.53	0.020	48.9	3.48	52.9
07/03/96	16:00			6.94	139	70	69	0.11	420	22	0.88	5.50	NA	NA	2.00	0.54	0.022	48.7	3.48	58.4
07/04/96	08:00			6.71	141	73	68	0.19	420	22	0.92	5.00	NA	NA	2.00	0.55	0.013	49.1	3.61	65.8
07/05/96	10:15			6.80	139	71	68	0.18	400	23	0.88	5.00	NA	NA	2.00	0.61	0.031	48.7	3.68	68.1
07/06/96	20:00			7.27	156	87	69	0.36	420	26	0.85	5.00	NA	NA	1.50	0.72	0.015	51.5	3.78	67.8
07/07/96	14:30			7.32	161	92	69	0.13	410	23	0.85	6.00	NA	NA	2.00	0.68	0.014	52.1	3.77	74.1
07/08/96	11:05			7.37	164	91	73	0.13	410	23	0.94	6.00	NA	NA	2.00	0.79	0.027	50.8	3.51	78.4
07/08/96	17:30			7.21	159	84	75	0.08	418	24	1.01	NA	NA	NA	NA	0.38	0.013	50.9	3.47	82.3
07/09/96	08:50			7.32	165	87	78	0.11	405	24	0.85	NA	NA	NA	NA	0.42	0.018	50.8	3.63	81.7
07/09/96	17:10			7.36	157	82	75	0.16	409	23	0.83	NA	NA	NA	NA	0.33	0.012	51.1	3.59	71.5
07/10/96	08:45			7.72	160	80	80	0.12	421	23	0.91	NA	NA	NA	NA	0.20	0.015	50.2	3.53	84.2
07/10/96	17:30			7.30	162	87	75	0.12	411	24	0.78	4.00	NA	NA	2.00	0.38	0.026	51.2	3.61	74.2
07/11/96	08:45			7.27	161	86	75	0.16	409	24	0.81	3.50	NA	NA	2.00	0.33	0.017	50.9	3.53	74.0
07/11/96	18:50			7.31	164	88	76	0.09	417	21	0.84	3.50	NA	NA	2.00	0.33	0.025	51.0	3.52	69.1
07/12/96	08:30			7.40	162	86	76	0.18	430	24	0.81	3.50	NA	NA	2.00	0.33	0.033	50.8	3.44	88.9
07/13/96	17:45			7.35	148	82	66	0.09	390	25	1.07	3.50	NA	NA	2.00	0.32	0.014	50.7	3.39	87.9
07/14/96	08:45			7.26	148	84	64	0.13	380	25	1.08	4.00	NA	NA	1.50	0.33	0.018	49.9	3.24	81.8
07/15/96	10:00			7.40	138	73	65	0.11	400	24	1.14	3.00	NA	NA	2.00	0.28	0.030	51.1	3.43	83.0
07/15/96	18:30			6.93	138	76	62	0.17	390	23	0.86	3.50	NA	NA	2.00	0.63	0.014	50.4	3.28	86.4
07/16/96	18:40			6.88	129	70	59	0.22	370	20	1	3.50	NA	NA	2.00	0.54	0.016	49.5	3.16	85.3

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
N/A: DATA NOT AVAILABLE

TPW-1 (cont.)

RECOVERY-CYCLE 1

PEER Consultants, P.C. and CH2M Hill, 1996

DATE	TIME	SO_4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
07/17/96	08:40			7.25	147	75	72	2.60	390	20	0.93	3.50	NA	NA	0.20	0.67	0.124	50.7	3.23	84.0
07/17/96	19:15			7.27	153	82	71	0.29	380	25	0.62	2.00	<1	<1	0.20	0.72	0.019	51.6	3.42	47.4
07/18/96	09:20			7.11	160	81	79	0.14	400	24	0.93	1.50	<1	<1	0.20	0.83	0.026	52.1	3.56	48.3
07/18/96	19:10			7.10	162	81	81	0.23	420	24	0.94	1.50	<1	<1	<0.2	0.86	0.027	53.0	3.60	47.1
07/19/96	08:00			7.31	165	79	86	0.14	390	23	0.91	1.50	<1	<1	<0.2	0.89	0.024	52.2	3.50	43.8
07/19/96	20:10			7.25	169	82	87	0.26	410	23	0.78	1.50	<1	<1	<0.2	0.80	0.025	52.4	3.56	54.0
07/20/96	15:00			7.22	174	79	95	0.08	430	23	0.79	1.50	<1	<1	<0.2	0.80	0.023	53.3	3.71	51.2
07/21/96	18:10			7.27	176	77	99	0.19	430	25	0.77	1.50	<1	<1	<0.2	0.74	0.020	52.9	3.78	46.3
07/22/96	08:40			7.27	173	73	100	0.10	430	22	0.76	1.50	NA	NA	<0.2	0.74	0.019	54.7	4.04	59.8
07/22/96	18:30			7.20	175	74	101	0.17	419	23	0.74	1.50	<1	<1	NA	0.70	0.022	53.1	3.85	58.0
07/23/96	07:20			7.35	175	73	102	0.21	430	22	0.7	1.50	<1	<1	NA	0.71	0.021	53.8	3.93	53.1
07/23/96	17:00			7.17	177	73	104	1.42	470	25	0.66	NA	<1	<1	<0.2	0.71	0.027	53.7	3.73	62.1
07/24/96	18:45			7.32	172	70	102	0.23	410	22	0.64	NA	<1	<1	<0.2	0.73	0.020	54.9	3.76	60.3
07/25/96	09:15			7.29	173	69	104	0.40	430	22	0.58	NA	5	<1	<0.2	0.74	0.020	53.7	3.82	64.8
07/25/96	18:00			7.20	173	66	107	0.14	430	22	0.55	1.50	33	<1	<0.2	0.74	0.026	54.1	3.86	46.4
07/26/96	09:00			7.22	173	66	107	0.13	420	22	0.46	1.50	5	<1	<0.2	0.73	0.023	53.8	3.90	45.3
07/26/96	16:00			7.20	172	67	105	0.25	430	24	0.59	1.30	NA	NA	<0.2	0.72	0.023	52.0	3.72	41.2
07/27/96	11:00			7.30	172	61	111	0.14	410	22	0.58	1.30	NA	NA	<0.2	0.72	0.024	53.9	3.92	38.4
07/28/96	15:00			7.22	173	59	114	0.15	430	24	0.55	1.50	NA	NA	<0.2	0.68	0.031	56.5	4.14	34.4
07/29/96	20:10			7.17	170	52	118	0.16	415	22	0.51	1.50	<1	<1	<0.2	0.64	0.037	53.7	4.28	34.4
07/30/96	10:30			7.31	174	53	121	0.41	400	22	0.49	1.30	<1	<1	<0.2	0.67	0.047	54.4	4.23	29.8
07/31/96	11:00			7.10	169	49	120	0.52	430	22	0.49	1.80	<1	<1	<0.2	0.62	0.084	52.5	4.22	28.0
08/01/96	10:30			7.57	171	46	125	0.16	368	22	0.46	1.30	<1	<1	<0.2	0.61	0.064	52.6	4.47	21.9
08/01/96	18:00			7.36	173	43	130	0.16	377	22	0.45	1.30	<1	<1	<0.2	0.55	0.072	52.3	4.48	22.1
08/02/96	16:45			7.60	172	41	131	0.19	379	22	0.42	1.30	NA	NA	<0.2	0.49	0.071	52.2	4.54	15.2
08/03/96	17:00			7.62	173	33	140	0.22	380	22	0.34	1.30	NA	NA	<0.2	0.40	0.099	52.5	4.65	15.4
08/04/96	10:45			7.64	175	35	140	0.31	378	24	0.37	1.50	<1	<1	NA	0.44	0.103	52.8	4.71	6.9
08/05/96	10:30			7.66	175	21	154	0.75	357	15	0.36	1.50	<1	<1	NA	0.30	0.106	52.7	4.73	9.1

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
N/A: DATA NOT AVAILABLE

TPW-1 (cont.)

RECHARGE-CYCLE 2

PEER Consultants, P.C. and CH2M Hill, 1997

DATE	TIME	SO_4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
09/09/96	08:50	NA	332	6.67	178	75	103	0.10	478	NA	0.85	6.0	0	NA	2.5	0.44	0.015	NA	4.10	55.5
09/13/96	10:10	104	329	6.69	186	92	94	0.26	460	NA	0.83	4.0	NA	NA	2.5	0.55	0.011	52.7	4.49	45.6
09/16/96	09:30	105	325	6.82	178	78	100	0.17	490	NA	0.88	4.0	0	NA	2.5	0.55	0.014	53.2	4.58	45.9
09/20/96	08:25	161	368	3.92	225	116	109	0.18	600	NA	0.66	4.5	NA	NA	2.5	0.58	D	NA	4.85	52.1
09/23/96	16:57	155	377	6.02	209	103	106	0.28	640	NA	0.88	3.7	NA	NA	2.0	NA	0.006	53.9	4.67	52.9
09/30/96	10:00	133	342	6.95	185	102	83	0.08	700	NA	0.89	4.0	0	NA	2.0	0.55	D	55.8	4.85	57.1
10/09/96	09:50	86	273	6.82	177	99	78	0.08	500	32	0.73	3.8	0	NA	1.0	D	D	52.7	3.79	59.3
10/14/96	09:40	111	301	7.17	184	98	86	0.08	470	30	0.79	3.3	0	NA	2.0	0.55	0.015	53.8	3.95	31.8
10/21/96	08:45	111	298	7.04	141	66	75	0.12	410	31	0.86	3.0	0	NA	1.5	0.57	0.034	51.8	3.76	72.1
10/29/96	07:52	123	312	7.18	185	98	87	0.23	430	24	0.77	4.0	0	NA	1.5	0.52	0.053	52.2	4.35	74.9
11/04/96	14:30	155	365	7.15	185	89	96	0.14	430	20	0.83	4.3	0	NA	1.5	D	0.041	54.1	4.46	81.0
11/13/96	08:55	151	386	7.18	202	99	103	0.17	420	23	0.77	NA	0	NA	1.5	0.58	0.056	54.4	4.52	66.8
11/19/96	13:30	109	447	7.19	225	110	115	0.13	470	27	0.74	NA	0	NA	1.5	0.47	0.048	55.5	5.34	47.8
11/26/96	10:55	137	347	7.20	219	107	112	0.01	425	23	0.81	4.4	11	NA	1.0	0.32	0.007	54.7	5.79	42.2
12/03/96	09:10	117	364	7.24	215	94	121	0.15	390	27	0.97	5.3	0	NA	1.5	0.47	0.011	56.3	6.19	45.5
12/09/96	11:20	113	385	7.20	217	100	117	0.09	385	23	0.80	5.5	0	NA	1.5	0.58	0.008	55.1	6.33	36.0

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
NA-NOT ANALYZED
D-LESS THAN DETECTION
TNTC-TOO NUMEROUS TO COUNT

TPW-1 (cont.)

RECOVERY-CYCLE 2

PEER Consultants, P.C. and CH2M Hill, 1997

DATE	TIME	SO_4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
03/10/97	09:18	164	430	7.64	246	91	155	9.99	600	27	0.88	2.8	0	NA		0.68	1.791	55.9	6.51	32.7
03/11/97	08:30	126	352	7.34	242	109	133	0.43	550	30	0.88	1.8	0	NA		0.17	0.058	57.7	6.1	NA
03/12/97	08:22	125	333	7.27	256	122	134	0.20	520	27	0.88	1.8	0	NA		D	0.062	56	5.87	24.7
03/13/97	08:37	120	333	7.26	232	99	133	0.14	510	28	0.86	1.7	1	NA		D	0.050	55	6.17	19.7
03/14/97	09:37	131	359	7.55	220	87	133	0.19	240	24	0.84	1.2	2	NA		D	0.083	55.5	5.96	17.2
03/17/97	09:45	121	356	7.31	226	96	130	0.35	270	28	0.81	1.2	0	NA		D	0.144	54.4	5.7	32.3
03/19/97	08:50	118	351	7.29	232	101	131	0.20	430	27	0.78	1.5	54	NA		D	0.155	57.8	5.69	7.93
03/20/97	08:50	119	346	7.45	236	108	128	0.10	240	26	0.87	1.7	0	NA		D	0.073	53.2	5.05	6.14
03/24/97	09:25	122	328	7.32	220	88	132	0.32	600	27	0.73	1.4	0	NA		0.14	0.166	56.3	5.37	9
03/26/97	08:16	106	348	7.39	216	86	130	0.25	562	27	0.73	1.5	0	NA		0.13	0.164	55.2	5.02	1.92
03/27/97	09:27	110	287	7.34	202	69	133	0.17	450	27	0.74	1.3	0	NA		0.31	0.152	55	5.25	2.05
03/31/97	09:20	109	325	7.32	216	87	129	0.18	500	27	0.70	1.5	0	NA		0.10	0.139	53.5	5.90	1.080
04/02/97	12:10	118	330	7.32	218	89	129	0.10	420	27	0.67	1.5	0	NA		0.16	0.142	55.3	4.97	1.030
04/03/97	09:54	104	331	7.29	240	108	132	0.29	430	27	0.68	1.9	0	NA		0.13	0.144	54.3	4.90	0.600
04/08/97	09:22	93	297	7.40	22	93	127	0.21	400	27	0.66	2.2	0	NA		0.14	0.405	50.1	4.57	0.917
04/10/97	10:50	90	282	7.44	224	94	130	0.11	420	28	0.64	1.9	0	NA	0.2	0.14	0.140	54.1	4.67	0.69
04/15/97	08:50	88	319	7.19	214	85	129	0.17	500	28	0.62	1.9	0	NA	0.2	0.26	0.145	52.7	4.76	0.362
04/17/97	09:58	85	307	7.24	210	82	128	0.14	500	27	0.63	1.6	0	NA	0.2	0.22	0.144	54.6	4.76	0.42
04/22/97	08:37	78	311	7.25	200	60	131	0.25	410	28	0.61	1.9	0	NA	0.2	0.24	0.176	55.2	4.88	4.47
04/24/97	09:11	76	272	7.28	208	78	130	0.15	360	30	0.65	1.9	0	NA	0.2	0.19	0.182	53.3	4.69	D
04/29/97	09:01	74	279	7.22	206	76	130	0.15	500	32	0.58	2.3	0	NA	0.2	0.18	0.230	51.8	4.61	1.93
05/01/97	10:11	75	292	7.12	202	70	132	0.16	500	27	0.52	1.8	0	NA	0.2	0.19	0.198	50.6	5.37	<0.5
05/06/97	12:06	72	327	7.15	208	75	133	0.22	500	27	0.6	2.0	0	NA	0.2	D	0.257	55.1	4.94	0.12
05/08/97	10:07	69	291	7.17	200	65	135	0.28	500	32	0.52	1.7	0	NA	0.2	0.21	0.225	50.1	5.08	<0.5
05/13/97	10:25	66	297	7.18	202	66	136	0.20	470	32	0.50	1.9	0	NA	<0.2	0.20	0.296	50.9	4.66	<0.5
05/15/97	10:50	65	296	7.12	204	65	139	0.44	425	33	0.50	1.8	0	NA	<0.2	0.20	0.282	51.7	4.87	<0.5
05/20/97	11:36	65	318	7.30	208	66	142	3.41	450	36	0.52	1.8	0	NA	<0.2	0.24	0.596	54.8	5.17	<0.5
05/22/97	07:10	62	300	7.17	198	57	141	0.36	430	34	0.46	1.7	0	NA	<0.2	0.25	0.261	54.2	5.19	<0.5
05/27/97	09:20	58	318	7.25	196	48	148	0.28	450	36	0.42	2.0	0	NA	<0.2	0.28	0.285	52.8	4.95	<0.5
05/29/97	10:06	59	339	7.20	194	51	143	0.78	450	36	0.42	2.1	0	NA	<0.2	0.27	0.280	53.6	4.96	<0.5
06/03/97	08:50	60	306	7.29	212	64	148	0.42	420	41	0.42	1.8	0	NA	<0.2	0.24	NA	NA	NA	1.5
06/09/97	10:35	57	292	7.35	206	57	149	1.49	440	38	0.41	2.0	0	NA	<0.2	0.25	0.438	53.8	5.32	0.94

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
NA-NOT ANALYZED
D-LESS THAN DETECTION
TNTC-TOO NUMEROUS TO COUNT

TPW-1 (cont.)

RECHARGE-CYCLE 3

Written communication from Mark McNeal, CH2M Hill, 1998

DATE	TIME	SO_4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
12/08/97	10:45	79.1	235	6.71	147	83	64	0.15	290	17.6	0.77	5.5	<1	<1	4.0	0.46	0.22	51	3.2	63.0
12/15/97	09:20	54.5	166	6.44	107	64	43	0.12	210	13.4	0.72	5.5	<1	<1	3.0	0.67	0.03	35	2.0	54.9
12/22/97	09:45	48.2	151	7.10	90	55	35	0.46	200	12.4	0.64	2.5	<1	<1	4.0	0.47	0.16	30	1.9	63.2
12/29/97	09:30	53.3	79	7.05	96	56	40	0.16	200	13.8	0.69	NA	<1	<1	4.0	<0.1	0.04	32	2.0	56.9
1/05/98	09:45	43.9	129	6.94	83	49	34	0.21	180	12.0	0.73	5.6	<1	<1	3.0	0.70	0.10	30	1.9	51.3
1/12/98	10:35	51.9	181	6.99	100	59	41	0.22	220	13.6	0.68	5.3	<1	<1	3.0	0.54	0.07	34	2.2	62.3
1/20/98	10:40	62.1	181	7.10	108	56	52	0.13	250	16.1	0.68	5.9	<1	<1	3.0	0.26	0.02	38	2.5	52.7
1/26/98	09:30	73.0	206	6.90	123	68	55	0.10	260	17.7	0.53	4.5	<1	<1	3.0	0.27	0.02	45	2.9	56.3
2/2/98	09:30	71.2	221	7.24	120	65	55	0.08	240	17.8	0.66	7.0	<1	<1	3.0	0.50	0.03	41	2.9	50.4
2/9/98	11:20	72.5	189	6.68	116	69	47	0.14	230	17.0	0.65	8.2	<1	<1	3.0	0.23	0.05	40	2.6	33.0
2/17/98	09:40	693	212	6.97	117	67	50	0.15	240	15.7	0.73	8.6	<1	<1	2.0	0.18	0.04	42	2.6	34.2
2/23/98	09:30	48.8	156	6.99	89	54	35	0.11	220	13.7	0.58	6.5	<1	<1	2.5	0.57	0.04	30	1.7	40.4
3/02/98	09:50	49.3	175	7.12	106	68	38	0.09	200	13.4	0.69	5.3	<1	<1	2.5	0.65	0.05	29	1.8	46.5
3/09/98	09:40	46.1	100	7.04	87	50	37	0.33	220	12.4	0.61	5.6	<1	<1	2.5	0.43	0.09	30	1.9	45.8
3/16/98	10:20	58.7	77	6.81	100	57	43	0.25	200	13.7	0.58	7.1	<1	<1	2.5	<0.1	0.06	32	2.1	53.1
4/13/98	10:20	85.2	220	7.09	133	66	67	0.38	320	17.4	0.64	5.6	<1	<1	2.5	0.13	0.08	44	3.0	61.1

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
NA-NOT ANALYZED
D-LESS THAN DETECTION
TNTC-TOO NUMEROUS TO COUNT

SZOW-1

LABORATORY DATA DURING REVERSE-AIR DRILLING

PEER Consultants, P.C. and CH2M Hill, 1995

DEPTH (FT bls)	CHLORIDE (mg/L)	TDS (mg/L)	SULFATE (mg/L)	CALCIUM (mg/L)	MAGNESIUM (mg/L)	ALKALINITY (mg/L)	NON-CARB. HARDNESS (mg/L)	HARDNESS (mg/L)
240	12	220	12	167	5.5	196	244	440
260	10	234	11	123	5	207	121	328
280	13	222	12	135	5.1	248	110	358
300	12	220	11	168	5.4	256	186	442
320	13	204	11	225	5.8	277	309	586
340	11	212	10	227	6.8	302	290	592
360	12	222	11	225	6.5	277	312	589
380	15	232	11	118	5.4	216	101	317
400	12	204	11	102	5.2	184	92	276
420	13	220	11	93	5.1	180	73	253
440	13	220	11	121	5.3	193	131	324
460	12	220	11	100	5.2	189	82	271
470	13	212	11	175	5.7	238	220	460

PACKER TEST WATER QUALITY DATA

PEER Consultants, P.C. and CH2M Hill, 1995

PUMPING TIME (hrs)	PUMPING RATE (gpm)	INTERVAL TESTED (ft)	CHLORIDE (mg/L)	SULFATE (mg/L)	TDS (mg/L)	ALKALINITY (mg/L)	TOTAL HARDNESS (mg/L)	CALCIUM (mg/L)	MAGNESIUM (mg/L)	NONCARB. HARDNESS (mg/L)	TURBIDITY (NTU)
5	50	438-470	10	BDL	212	146	153	54	4.4	7	4.2

PUMPING TIME (hrs)	PUMPING RATE (gpm)	INTERVAL TESTED (ft)	CHLORIDE (mg/L)	SULFATE (mg/L)	TDS (mg/L)	ALKALINITY (mg/L)	TOTAL HARDNESS (mg/L)	CALCIUM (mg/L)	MAGNESIUM (mg/L)	NONCARB. HARDNESS (mg/L)	TURBIDITY (NTU)
6	50	253-228	15	12	260	154	171	60	5.1	17	4.2

BDL-BELOW DETECTION LEVEL

SZOW-1 (cont.)

AMBIENT WATER (BEFORE CYCLE 1)

PEER Consultants, P.C. and CH2M Hill, 1996

DATE	TIME	SO_4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
2/22/96	9:00	27	216	7.5	N/A	N/A	152	0.38	390	18	N/A	2.4	N/A	N/A	N/A	N/A	0.09	N/A	N/A	<0.5
3/7/96	16:58	33	250	7.6	N/A	N/A	151	N/A	420	21	N/A	N/A	N/A	N/A	N/A	N/A	0.11	N/A	N/A	<0.5

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
N/A: DATA NOT AVAILABLE

RECHARGE CYCLE 1

PEER Consultants, P.C. and CH2M Hill, 1996

DATE	TIME	SO4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
7/8/96	10:00	39	234	6.93	178	39	139	0.54	390	19	0.1	4	N/A	N/A	N/A	0.33	0.05	51.8	4.96	12.1
7/16/96	18:00	15	256	7.57	176	59	117	0.38	400	20	0.13	2.5	N/A	N/A	N/A	0.57	0.12	51.8	4.65	35.2

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
N/A: DATA NOT AVAILABLE

RECOVERY-CYCLE 1

PEER Consultants, P.C. and CH2M Hill, 1996

DATE	TIME	SO4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
7/22/96	20:30	44	248	7.49	179	39	143	0.22	380	19	0.11	1.5	N/A	N/A	N/A	0.29	0.02	54.2	3.94	11.6
8/5/96	11:15	37	255	7.63	192	42	150	0.41	396	21	0.1	1.8	N/A	N/A	N/A	0.69	0.07	52.6	6.13	<0.5

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
NA-NOT ANALYZED
D-LESS THAN DETECTION
TNTC-TOO NUMEROUS TO COUNT

SZOW-1 (cont.)

RECHARGE-CYCLE 2

PEER Consultants, P.C. and CH2M Hill, 1997

DATE	TIME	SO4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
09/13/96	10:40	47	281	7.10	175	31	144	0.11	370	NA	0.11	1.0	NA	NA	NA	0.49	0.053	52.8	5.65	6.2
09/20/96	09:00	73	278	7.15	168	51	137	0.18	440	NA	0.09	1.0	NA	NA	NA	0.29	0.049		5.27	17.8
09/30/96	10:28	107	362	7.15	211	84	127	0.13	480	NA	0.16	1.6	0	NA	NA	0.30	0.049	54.1	5.27	24.5
10/09/96	10:25	109	332	7.21	206	89	117	0.18	490	24	0.16	1.5	0	NA	NA	0.29	D	54.2	5.02	40.8
10/14/96	10:13	110	319	7.19	200	58	111	0.18	475	23	0.14	2.1	0	NA	NA	0.11	0.051	55.2	4.96	D
10/21/96	09:29	123	320	7.29	204	95	109	0.24	460	29	0.18	2.5	0	NA	NA	D	0.054	54.8	4.80	29.2
10/29/96	08:08	118	314	7.28	201	98	103	0.23	460	26	0.21	1.9	0	NA	NA	D	0.166	53.9	4.35	47.4
11/04/96	14:52	144	326	7.24	203	97	106	0.42	435	27	0.15	2.3	TNTC	NA	NA	D	0.161	56.4	4.71	41.8
11/13/96	09:15	186	379	7.29	211	100	111	0.35	440	25	0.22	NA	TNTC	NA	NA	D	0.112	55.4	4.64	52.1
11/19/96	13:57	153	406	7.35	225	110	115	0.50	450	28	0.21	NA	1	NA	NA	0.11	0.161	54.8	4.90	40.6
11/26/96	11:10	127	358	7.37	214	97	117	8.86	450	24	0.18	3.3	TNTC	NA	NA	D	2.800	55.5	5.03	33.3
12/03/96	09:35	133	430	7.38	228	99	129	10.50	470	27	0.28	2.4	TNTC	NA	NA	D	2.798	56.2	5.34	25.6
12/09/96	11:35	132	407	7.33	235	107	128	1.45	450	26	0.32	2.7	TNTC	NA	NA	0.32	0.091	56.6	5.59	29.0

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
NA-NOT ANALYZED
D-LESS THAN DETECTION
TNTC-TOO NUMEROUS TO COUNT (INVALID SAMPLE-PROBABLY SAMPLING ERROR)

AMBIENT WATER (BEFORE RECOVERY-CYCLE 2)

PEER Consultants, P.C. and CH2M Hill, 1997

DATE	TIME	SO4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
01/13/97	11:24	128	364	7.54	244	118	126	4.77	460	25	0.28		2	NA	NA		0.362	55.2	5.44	9.68
02/10/97	09:48	79	269	7.58	250	124	126	3.46	568	29	0.27		TNTC	NA	NA		0.455	52.2	5.28	6.9
03/07/97	11:43	128	329	7.53	212	86	126	1.31	440	25	0.25	2.0	TNTC	NA	NA	D	0.285	55.0	5.34	0.22

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
NA-NOT ANALYZED
D-LESS THAN DETECTION
TNTC-TOO NUMEROUS TO COUNT (INVALID SAMPLE-PROBABLY SAMPLING ERROR)

SZOW-1 (cont.)

RECOVERY-CYCLE 2

PEER Consultants, P.C. and CH2M Hill, 1997

DATE	TIME	SO4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
03/14/97	09:43	92	290	7.78	204	73	131	1.64	500	20	0.23	2.0	29	NA	NA	D	0.912	55.1	5.22	D
03/20/97	09:37	69	293	7.59	202	59	143	2.00	400	23	0.22	3.1	3	NA	NA	D	0.139	57.8	5.54	D
03/27/97	09:49	64	246	7.57	188	42	146	0.25	410	26	0.18	2.3	4	NA	NA	D	0.158	54.7	5.99	D
04/03/97	10:18	56	473	7.48	214	67	147	0.22	390	25	0.16	3.1	0	NA	NA	D	0.161	54.1	5.71	D
04/10/97	11:30	53	230	7.55	208	62	146	0.31	390	26	0.15	3.2	6	NA	0.2	D	0.163	53.3	5.20	D
04/17/97	10:40	51	263	7.38	204	57	147	0.44	400	26	0.15	0.2	0	NA	0.2	D	0.242	52.9	5.58	D
04/24/97	10:45	46	238	7.38	200	51	149	0.48	456	28	0.16	2.5	0	NA	NA	D	0.194	53.2	5.66	0.101
05/01/97	10:11	45	204	7.28	200	50	150	0.52	420	22	0.13	2.6	0	NA	NA	D	0.244	52.4	5.46	<0.5
05/08/97	10:36	45	266	7.26	198	48	150	0.30	400	25	0.15	1.5	2	NA	NA	D	0.450	55.0	6.00	<0.5
05/15/97	11:10	42	264	7.44	200	51	149	0.29	390	25	0.16	2.9	0	NA	NA	D	0.213	50.4	5.46	<0.5
05/22/97	07:20	43	271	7.30	208	54	154	0.19	400	25	0.15	1.9	0	NA	NA	D	0.054	53.7	5.05	<0.5
05/29/97	10:16	45	267	7.23	190	33	157	0.27	420	23	0.14	2.2	0	NA	NA	D	0.216	54.6	5.89	<0.5
06/09/97	10:03	43	262	7.41	200	43	157	0.23	340	26	0.15	2.6	0	NA	NA	D	0.056	52.2	4.91	<0.5

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
NA-NOT ANALYZED
D-LESS THAN DETECTION
TNTC-TOO NUMEROUS TO COUNT (INVALID SAMPLE-PROBABLY SAMPLING ERROR)

SZOW-1 (cont.)

RECHARGE-CYCLE 3

Written communication from Mark McNeal, CH2M Hill, 1998

DATE	TIME	SO4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
12/08/97	11:30	31.5	237	7.15	183	26	157	1.66	390	18.4	0.13	3.2	600	<1	<0.2	0.11	0.20	65	5.6	<2.0
12/15/97	10:00	53.2	226	6.93	177	56	121	1.04	350	18.0	0.13	3.4	<1	<1	<0.2	0.40	0.06	56	4.2	<2.0
12/22/97	10:25	56.6	210	7.65	157	73	84	0.25	300	15.5	0.17	3.9	3	<1	<0.2	0.47	0.15	50	3.7	39.9
12/29/97	10:00	55.0	157	7.57	134	64	70	0.21	250	15.6	0.18	NA	<1	<1	<0.2	0.26	0.08	45	3.1	45.8
1/05/98	10:10	51.9	182	7.58	124	61	63	0.29	230	14.7	0.17	4.7	<1	<1	1.0	0.16	0.18	45	2.9	49.8
1/12/98	11:45	52.8	209	7.58	128	67	61	0.20	240	14.7	0.21	3.7	<1	<1	<0.2	0.15	0.08	44	2.6	17.4
1/20/98	11:00	56.4	196	7.60	130	64	66	0.32	250	16.3	0.28	3.1	<1	<1	0.2	<0.10	0.06	46	2.6	41.0
1/26/98	09:50	63.8	215	7.46	133	64	69	0.30	260	17.6	0.28	3.8	<1	<1	<0.2	<0.10	0.05	49	2.7	39.4
2/02/98	09:45	70.4	212	7.57	148	74	74	0.14	280	18.5	0.30	3.1	1	<1	0.2	<0.10	0.05	59	4.6	39.9
2/09/98	11:40	75.0	214	7.38	152	78	74	0.14	290	19.3	0.34	3.6	<1	<1	0.2	0	0.05	51	3.1	27.6
2/17/98	10:00	62.5	259	7.35	172	69	103	0.14	320	18.1	0.30	1.8	<1	<1	<0.2	<0.10	0.07	59	3.5	32.0
2/23/98	10:00	66.0	257	7.54	163	73	90	0.16	300	17.5	0.32	3.2	<1	<1	<0.2	<0.10	0.07	54	3.2	33.2
3/02/98	10:10	55.8	216	7.43	138	67	71	0.17	260	15.1	0.31	4.8	<1	<1	<0.2	<0.10	0.05	45	2.6	35.5
3/09/98	10:00	55.1	168	7.20	122	57	65	0.25	260	16.4	0.47	4.7	<1	<1	<0.2	<0.10	0.04	44	2.4	31.6
3/16/98	10:40	56.3	241	7.46	12	54	64	0.13	240	15.4	0.41	5.6	<1	<1	<0.2	<0.10	0.03	43	2.4	39.1
4/13/98	10:40	63.0	192	7.74	130	68	62	0.19	280	16.1	0.49	4.9	40	10	<0.2	<0.10	0.07	42	2.3	39.4

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
NA-NOT ANALYZED
D-LESS THAN DETECTION
TNTC-TOO NUMEROUS TO COUNT (INVALID SAMPLE-PROBABLY SAMPLING ERROR)

SMW-1

AMBIENT WATER (BEFORE CYCLE 1)

PEER Consultants, P.C. and CH2M Hill, 1996

DATE	TIME	SO4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
2/22/96	9:00	14	194	7.4	N/A	N/A	151	0.48	360	17	N/A	1.8	N/A	N/A	N/A	N/A	0.04	N/A	N/A	<0.5
3/7/96	16:58	16	212	7.5	N/A	NA/	155	N/A	370	16	N/A	N/A	N/A	N/A	N/A	N/A	0.09	N/A	N/A	<0.5

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
N/A: DATA NOT AVAILABLE

RECHARGE-CYCLE 1

PEER Consultants, P.C. and CH2M Hill, 1996

DATE	TIME	SO4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
7/8/96	9:35	18	206	7.36	175	12	163	0.66	349	13	0.12	4	N/A	N/A	0	0.36	0.03	51.7	4.65	1.78
7/16/96	18:15	77	214	7.3	175	17	158	0.22	340	9	0.15	2	N/A	N/A	N/A	0.37	0.07	52.1	4.75	3.96

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
N/A: DATA NOT AVAILABLE

RECOVERY-CYCLE 1

PEER Consultants, P.C. and CH2M Hill, 1996

DATE	TIME	SO4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
7/22/96	19:45	16	235	7.3	175	19	156	1.6	350	10	0.12	2.3	N/A	N/A	N/A	0.32	0.03	52.7	4.77	4.61
8/5/96	10:10	17	245	7.68	176	29	147	0.38	382	23	0.13	2	N/A	N/A	N/A	0.42	0.02	51.6	4.9	<0.5

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
N/A: DATA NOT AVAILABLE

SMW-1 (cont.)

RECHARGE-CYCLE 2

PEER Consultants, P.C. and CH2M Hill, 1997

DATE	TIME	SO4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	CI	FI	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
09/13/96	09:50	18	225	7.10	562	406	156	970	360	NA	0.12	1.8	NA	NA	NA	0.28	0.035	52.3	4.84	D
09/20/96	09:37	25	216	7.43	171	13	158	0.20	340	NA	0.09	1.5	NA	NA	NA	0.22	0.020	NA	4.59	D
09/30/96	11:03	17	235	7.13	177	24	153	0.24	340	NA	0.12	1.8	0	NA	NA	D	0.020	52.8	4.59	D
10/09/96	10:50	17	218	7.30	168	13	155	0.16	330	14	0.11	2.2	0	NA	NA	0.39	D	52.1	4.62	D
10/14/96	10:42	13	237	7.20	169	17	152	0.19	320	12	0.11	2.2	0	NA	NA	0.37	0.026	52.6	4.70	D
10/21/96	10:02	17	227	7.15	171	14	157	0.21	320	2	0.11	2.8	0	NA	NA	0.38	0.049	52.3	4.62	0.84
10/29/96	08:45	13	190	7.24	176	21	155	0.41	320	4	0.12	3.1	0	NA	NA	0.30	0.059	52.2	4.65	D
11/04/96	15:15	13	221	7.26	172	19	153	1.53	325	6	0.11	3.5	0	NA	NA	0.34	0.097	51.9	4.65	D
11/13/96	09:49	12	234	7.33	171	17	154	0.40	310	1	0.11	NA	40	NA	NA	0.41	0.091	52.6	4.64	D
11/19/96	14:30	10	241	7.24	176	23	153	0.47	300	6	0.14	NA	4	NA	NA	0.40	0.106	52.8	4.92	D
11/26/96	11:46	16	212	7.30	164	12	152	0.45	310	2	0.12	3.2	40	NA	NA	0.38	0.062	52.9	4.88	D
12/03/96	10:16	14	236	7.32	170	13	157	0.21	305	3	0.17	2.9	40	NA	NA	0.35	0.039	53.1	4.85	D
12/09/96	12:12	12	243	7.21	168	9	159	0.43	295	1	0.14	2.6	40	NA	NA	0.32	0.050	53.1	4.86	D

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
NA-NOT ANALYZED
D-LESS THAN DETECTION
TNTC-TOO NUMEROUS TO COUNT (INVALID SAMPLE-PROBABLY SAMPLING ERROR)

AMBIENT WATER (BEFORE RECOVERY-CYCLE 2)

PEER Consultants, P.C. and CH2M Hill, 1997

DATE	TIME	SO4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	CI	FI	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
01/13/97	11:07	20	236	7.19	208	52	156	0.30	329	16	0.13		0	NA	NA	NA	0.043	52.4	4.80	D
02/10/97	10:08	17	369	7.57	218	61	157	0.34	378	29	0.14		40	NA	NA	NA		52.2	4.78	0.50
03/07/97	11:25	11	267	7.34	180	28	152	0.11	1150	17	0.14	2.8	7	NA	NA	0.34	0.032	53.2	5.18	D

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
NA-NOT ANALYZED
D-LESS THAN DETECTION
TNTC-TOO NUMEROUS TO COUNT (INVALID SAMPLE-PROBABLY SAMPLING ERROR)

SMW-1 (cont.)

RECOVERY-CYCLE 2

PEER Consultants, P.C. and CH2M Hill, 1997

DATE	TIME	SO4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
03/14/97	09:10	12	226	7.68	190	31	159	0.65	320	16	0.14	2.5	0	NA	NA	0.33	0.044	54.7	5.20	D
03/20/97	09:15	18	233	7.42	182	25	157	0.19	320	20	156.00	2.4	0	NA	NA	0.39	0.167	56.3	5.49	D
03/27/97	09:41	17	184	7.47	192	32	160	0.26	320	19	0.13	2.4	0	NA	NA	0.10	0.059	52.7	5.08	0.516
04/03/97	10:07	19	246	7.63	180	23	157	0.14	330	21	0.12	3.9	0	NA	NA	0.33	0.046	52.5	5.14	D
04/10/97	11:15	19	188	7.55	190	37	153	0.31	340	23	0.12	3.0	0	NA	0.2	0.46	0.044	54.1	4.78	D
04/17/97	10:36	19	227	7.38	192	39	153	0.89	330	19	0.12	0.3	0	NA	0.2	0.38	0.099	52.1	4.89	D
04/24/97	09:45	21	195	7.34	182	27	155	0.31	300	22	0.14	3.1	0	NA	NA	0.33	0.055	52.6	4.93	D
05/01/97	09:54	21	206	7.34	196	43	153	0.26	280	16	0.11	3.6	0	NA	NA	0.32	0.051	50.8	4.76	<0.5
05/08/97	10:30	20	217	7.25	184	29	155	0.28	330	18	0.16	3.0	40	NA	NA	0.33	0.017	46.2	5.23	<0.5
05/15/97	11:30	20	221	7.35	184	34	150	0.30	340	19	0.15	3.2	1	NA	NA	0.33	0.060	49.0	4.68	<0.5
05/22/97	07:40	20	230	7.27	182	25	157	0.34	340	20	0.15	2.0	0	NA	NA	0.37	0.204	53.8	5.97	<0.5
05/29/97	10:37	21	230	7.16	178	20	158	0.27	360	17	0.16	2.0	0	NA	NA	0.33	0.062	51.7	4.77	<0.5
06/09/97	10:57	21	219	7.44	196	38	158	0.18	360	18	0.15	2.5	0	NA	NA	0.31	0.217	54.8	6.28	<0.5

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
NA-NOT ANALYZED
D-LESS THAN DETECTION
TNTC-TOO NUMEROUS TO COUNT (INVALID SAMPLE-PROBABLY SAMPLING ERROR)

SMW-1 (cont.)

RECHARGE-CYCLE 3

Written communication from Mark McNeal, CH2M Hill, 1998

DATE	TIME	SO4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
12/08/97	11:55	14.4	244	6.97	177	19	158	1.08	330	14.1	0.12	1.9	<1	<1	<0.2	0.36	0.05	62	4.8	<2.0
12/15/97	10:30	14.5	226	6.77	182	25	157	0.51	600	13.7	0.10	2.0	<1	<1	<0.2	0.36	0.13	58	4.4	<2.0
12/22/97	10:00	14.0	219	7.39	184	31	153	0.26	360	13.2	0.12	2.4	<1	<1	<0.2	0.36	0.09	62	4.8	<2.0
12/29/97	10:25	19.0	183	7.35	184	28	156	0.22	300	17.1	0.10	NA	<1	<1	<0.2	<0.1	0.07	61	4.7	<2.0
1/05/98	10:45	14.4	189	7.26	177	19	158	0.29	340	13.3	0.07	4.4	<1	<1	<0.2	0.40	0.09	62	4.8	<0.2
1/12/98	11:40	14.2	240	7.34	185	28	157	0.34	330	13.3	0.07	3.4	<1	<1	<0.2	0.34	0.07	62	4.7	<0.2
1/20/98	11:20	13.7	218	7.15	187	32	155	0.18	320	13.1	<0.10	2.8	<1	<1	<0.2	0.34	0.05	60	4.5	<0.2
1/26/98	10:20	13.6	214	7.04	182	23	159	0.46	320	13.3	<0.10	1.4	<1	<1	<0.2	0.34	0.05	64	4.7	<0.2
2/02/98	10:25	14.0	221	7.44	178	22	156	0.14	320	13.2	0.10	4.8	<1	<1	<0.2	0.40	0.04	49	3.0	<0.2
2/09/98	12:10	13.9	205	7.46	175	20	155	0.18	320	13.6	<0.10	3.5	<1	<1	<0.2	0.36	0.05	59	4.6	<0.2
2/17/98	10:25	13.8	228	7.19	182	29	153	0.12	320	13.0	<0.10	2.2	<1	<1	<0.2	0.37	0.04	59	4.6	<0.2
2/23/98	10:20	13.6	231	7.26	182	32	150	0.15	320	13.1	<0.10	3.8	<1	<1	<0.2	0.43	0.04	59	4.6	<0.2
3/02/98	10:40	13.0	182	7.34	176	23	153	0.17	320	12.8	<0.10	4.2	<1	<1	<0.2	0.31	0.05	57	4.3	<0.2
3/09/98	10:25	13.2	174	7.17	182	22	160	0.18	320	12.8	<0.10	1.7	<1	<1	<0.2	0.41	0.04	59	4.6	<0.2
3/16/98	11:00	12.6	227	7.28	173	13	160	0.16	320	12.5	<0.10	1.8	<1	<1	<0.2	0.32	0.04	59	4.4	<0.2
4/13/98	11:05	12.9	193	7.30	174	20	154	0.24	320	12.2	<0.10	5.2	<1	<1	<0.2	0.35	0.04	58	4.4	<0.2

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
NA-NOT ANALYZED
D-LESS THAN DETECTION
TNTC-TOO NUMEROUS TO COUNT (INVALID SAMPLE-PROBABLY SAMPLING ERROR)

2-D

AMBIENT WATER (BEFORE CYCLE 1)

PEER Consultants, P.C. and CH2M Hill, 1996

DATE	TIME	SO4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
2/22/96	9:40	187	1250	7.5	N/A	N/A	172	0.27	2200	534	N/A	N/A	N/A	N/A	N/A	N/A	0.23	N/A	N/A	<0.5
3/7/96	16:58	155	N/A	7.6	N/A	N/A	N/A	N/A	2300	500	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	<0.5
																	D	68.4	36.46	<0.5
																		69.2		
																		69.6		

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
N/A: DATA NOT AVAILABLE

RECHARGE-CYCLE 1

PEER Consultants, P.C. and CH2M Hill, 1996

DATE	TIME	SO4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
7/8/96	10:50	283	1599	7.5	530	360	170	18	2300	617	0.14	N/A	N/A	N/A	N/A	0.44	0.057	57.8	26.3	1.74
7/16/96	18:00	149	1719	7.4	579	405	174	6.56	2500	667	0.18	1.5	N/A	N/A	N/A	0.47	0.078	58.9	29.8	6.38
																	D	68.4	36.46	<0.5
																		69.2		
																		69.6		

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
N/A: DATA NOT AVAILABLE

2-D (cont.)

RECOVERY-CYCLE 1

PEER Consultants, P.C. and CH2M Hill, 1996

DATE	TIME	SO4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
7/22/96	19:15	144	1409	7.26	473	294	179	12.6	2100	517	0.15	1.3	N/A	N/A	N/A	0.41	0.117	59.1	24.6	3.1
8/5/96	9:45	144	1275	7.64	456	285	171	5.53	1899	465	0.12	1.3	N/A	N/A	N/A	0.45	0.187	57.8	28.35	<0.5
																	D	68.4	36.46	<0.5
																		69.2		
																		69.6		

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
N/A: DATA NOT AVAILABLE
D-LESS THAN DETECTION
TNTC-TOO NUMEROUS TO COUNT (INVALID SAMPLE-PROBABLY SAMPLING ERROR)

RECHARGE CYCLE 2

PEER Consultants, P.C. and CH2M Hill, 1997

DATE	TIME	SO4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
09/13/96	10:00	202	1837	7.11	176	5	171	0.18	2600	NA	0.13	1.0	NA	NA	NA	0.50	0.197	59.0	37.85	D
09/20/96	10:15	224	1842	7.54	605	429	176	13.40	2900	NA	0.10	1.3	NA	NA	NA	0.39	0.053		40.44	D
09/30/96	13:00	228	1699	7.52	568	397	171	8.86	2700	NA	0.14	1.0	0	NA	NA	0.37	0.053	59.9	36.46	D
10/09/96	11:20	200	1735	7.56	571	398	173	12.20	2650	657	0.13	1.8	6	NA	NA	0.38	0.199	58.5	38.99	D
10/14/96	11:06	197	1773	7.37	559	385	174	10.20	2600	679	0.13	1.9	0	NA	NA	0.43	0.200	60.1	36.97	D
10/21/96	10:40	210	1771	7.40	575	400	175	10.60	2500	647	0.12	1.4	0	NA	NA	0.42	0.197	59.9	37.06	D
10/29/96	09:37	195	1618	7.43	564	392	172	8.41	2400	632	0.13	1.6	0	NA	NA	0.44	0.204	59.1	36.47	D
11/04/96	15:50	209	1595	7.37	564	391	173	15.90	2200	610	0.14	2.1	0	NA	NA	0.48	0.201	60.6	36.26	D
11/13/96	10:20	214	1651	7.45	570	400	170	11.60	2150	630	0.13	NA	0	NA	NA	0.39	0.203	59.1	35.69	D
11/19/96	15:05	211	1819	7.46	531	358	173	8.04	2100	620	0.14	NA	0	NA	NA	0.46	0.189	59.0	35.65	D
11/26/96	12:29	176	1517	7.43	532	361	171	0.47	2050	524	0.13	2.6	0	NA	NA	0.43	0.113	58.5	35.46	D
12/03/96	10:55	182	1601	7.40	500	323	177	5.23	2000	535	0.19	2.8	0	NA	NA	0.47	0.186	59.1	34.41	1.980
12/09/96	12:55	166	1592	7.36	502	327	175	9.81	1900	558	0.15	2.5	0	NA	NA		0.183	58.4	33.95	D

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
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D-LESS THAN DETECTION
TNTC-TOO NUMEROUS TO COUNT (INVALID SAMPLE-PROBABLY SAMPLING ERROR)

2-D (cont.)

AMBIENT WATER (BEFORE RECOVERY-CYCLE 2)

PEER Consultants, P.C. and CH2M Hill, 1997

DATE	TIME	SO4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
01/13/97	10:29	148	1163	5.77	464	294	174	18.80	1750	451	0.15		0	NA	NA	NA	0.203	57.8	27.19	D
02/10/97	10:29	204	1156	7.44	456	282	174	19.90	2027	391	0.18		0	NA	NA	NA	0.341	49.9	21.13	1.5
03/07/97	12:20	171	1287	7.63	452	277	175	17.70	1900	471	0.18	1.7	12	NA		0.41	0.236	59.1	24.92	D

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
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D-LESS THAN DETECTION
TNTC-TOO NUMEROUS TO COUNT (INVALID SAMPLE-PROBABLY SAMPLING ERROR)

RECOVERY-CYCLE 2

PEER Consultants, P.C. and CH2M Hill, 1997

DATE	TIME	SO4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
03/14/97	10:13	162	1269	7.77	446	270	176	0.11	1000	457	0.16	1.5	80	NA		0.41	0.200	59.8	24.89	D
03/20/97	10:15	140	1190	7.63	444	268	176	0.11	1000	445	0.18	2.6	0	NA		0.43	0.239	59.1	30.02	D
03/27/97	10:25	138	1060	7.63	336	161	175	0.11	1800	435	0.15	2.3	0	NA		0.37	0.202	58.5	25.53	0.656
04/03/97	10:41	144	1169	7.65	424	249	175	0.12	1900	442	0.19	3.6	0	NA		0.39	0.263	56.3	26.93	D
04/10/97	11:50	145	1132	7.53	438	267	171	0.09	1080	440	0.14	1.5	0		0.2	0.36	0.145	59.8	27.10	D
04/17/97	11:07	161	1140	7.48	440	269	171	0.10	1600	447	0.15	2.5	0	NA	0.2	0.46	0.181	53.2	28.37	D
04/24/97	10:22	138	1135	7.56	448	274	174	0.48	1750	442	0.15	2.8	0	NA	NA	0.43	0.202	55.2	26.57	D
05/01/97	10:25	149	1183	7.48	434	263	171	0.19	1700	443	0.13	2.8	0	NA	NA	0.40	0.202	54.7	25.79	<0.5
05/08/97	11:02	153	1286	7.45	454	285	169	0.15	1900	461	0.17	2.4	0	NA	NA	0.39	0.127	57.3	29.22	<0.5
05/15/97	11:45	151	1297	7.50	472	302	170	0.13	1900	469	0.117	2.7	0	NA	NA	0.45	0.207	54.3	29.06	<0.5
05/22/97	08:00		1319	7.56	478	303	175	0.14	1900	485	0.14	2.3	0	NA	NA	0.43	0.211	59.1	29.16	<0.5
05/29/97	10:56		1329	7.54	470	293	177	0.22	200	481	0.16	2.8	0	NA	NA	0.42	0.213	56.9	27.10	<0.5
06/09/97	11:21	198	1507	7.42	544	366	178	0.17	2200	548	0.17	2.2	0	NA	NA	0.42	0.205	61.7	33.71	<0.5

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
NA-NOT ANALYZED
D-LESS THAN DETECTION
TNTC-TOO NUMEROUS TO COUNT (INVALID SAMPLE-PROBABLY SAMPLING ERROR)

2-D (cont.)

RECHARGE-CYCLE 3

Written communication from Mark McNeal, CH2M Hill, 1998

DATE	TIME	SO4	TDS	pH	TOTAL HARD.	NON-CARB HARD.	TOTAL ALKALINITY	TURB.	COND.	Cl	Fl	DISSOLVED OXYGEN	TOTAL COLIF.	FECAL COLIF.	Cl_2	NH_3	IRON	CALCIUM	Mg	THM
				pH units				NTU	umhos/cm				CFU/100mL	CFU/100mL						µg/L
12/08/97	11:05	157.5	1571	6.98	558	379	179	0.09	2400	592	0.68	2.5	100	<1	<0.2	0.38	0.26	149	32.5	<2.0
12/15/97	10:45	199.0	2030	6.96	618	444	174	0.09	3700	788	0.20	2.4	80	<1	<0.2	0.56	0.20	162	40.2	<2.0
12/22/97	10:40	198.0	2035	7.35	657	483	174	0.12	3000	781	0.13	1.9	50	<1	<0.2	0.47	0.14	173	43.6	<2.0
12/29/97	10:40	209.0	1861	7.41	614	439	175	0.06	2600	720	0.14	NA	<1	<1	<0.2	0.41	0.25	162	39.6	<2.0
1/05/98	11:00	163.0	1700	7.33	57	396	177	0.13	2500	590	0.13	1.1	<1	<1	<0.2	0.45	0.21	172	36.6	<2.0
1/12/98	12:00	190.0	1971	7.35	612	439	173	0.16	2500	661	0.10	3.1	3	<1	<0.2	0.39	0.24	175	37.4	<2.0
1/20/98	11:40	214.5	1960	7.46	625	450	175	0.06	2600	692	0.10	3.3	<1	<1	<0.2	0.46	0.24	182	40.2	<2.0
1/26/98	10:45	200.7	1875	7.24	608	438	170	0.13	2300	660	0.14	2.5	<1	<1	<0.2	0.44	0.27	198	41.7	<2.0
2/02/98	10:50	193.0	1837	7.48	570	399	171	0.19	2300	657	0.12	2.5	<1	<1	<0.2	0.40	0.25	168	37.7	<2.0
2/09/98	12:20	195.0	1664	7.65	586	415	171	0.03	2400	661	0.11	5.0	1	<1	<0.2	0.49	0.24	177	38.9	<2.0
2/17/98	10:40	178.0	1696	7.63	556	389	167	0.12	2300	604	0.12	5.5	<1	<1	<0.2	0.47	0.28	163	34.6	<2.0
2/23/98	10:40	208.0	1773	7.42	594	422	172	0.09	2500	657	0.16	5.4	1	<1	<0.2	0.53	0.25	172	38.0	<2.0
3/02/98	11:00	181.0	1710	7.38	560	396	164	0.08	2500	618	0.11	1.9	<1	<1	<0.2	0.49	0.24	169	36.3	<2.0
3/09/98	10:42	176.0	1454	7.36	542	367	175	0.09	2300	556	0.12	3.5	<1	<1	<0.2	0.49	0.23	158	34.0	<2.0
3/16/98	11:20	167.0	1735	7.22	537	364	173	0.18	2400	557	0.14	4.0	1	<1	<0.2	0.43	0.22	152	32.2	<2.0
4/13/98	11:25	160.0	1487	7.43	565	390	175	0.11	2300	539.	<0.1	2.8	<1	<1	<0.2	0.45	0.24	148	31.3	<2.0

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
NA-NOT ANALYZED
D-LESS THAN DETECTION
TNTC-TOO NUMEROUS TO COUNT (INVALID SAMPLE-PROBABLY SAMPLING ERROR)

TRW

HILLSBOROUGH RIVER WATER: TREATED FOR INJECTION AT TPW-1

PEER Consultants, P.C. and CH2M Hill, 1995

INORGANICS		COLLECTION DATE
ANTIMON	<0.001	12/7/94
ARSENIC	<0.001	12/7/94
ASBESTO	<0.12	12/1/94
BARIUM	<0.1	12/7/94
BERYLLIU	<0.0005	12/7/94
CADMIUM	<0.001	12/7/94
CHROMIU	<0.005	12/7/94
CYANIDE	<0.02	2/21/94
FLUORIDE	<0.8	12/7/94
LEAD	<0.001	12/7/94
MERCURY	<0.0005	12/7/94
NICKEL	<0.01	12/7/94
NITRATE	<0.38	11/2/94
NITRITE	<0.01	12/7/94
SELENIUM	<0.001	12/7/94
SODIUM	30.2	12/7/94
THALLIUM	<0.0005	12/7/94

RADIONUCLIDES		COLLECTION DATE
RADIUM 226 AND 228	NOT REQUIRED	12/7/94
GROSS ALPHA	1.4 +-1.3	12/7/94
ALUMINUM	<0.05	12/7/94
CHLORIDE	23	12/7/94
COPPER	0.01	12/7/94
COLOR	7	12/7/94
FLUORIDE	0.92	12/7/94
FOAMING AGENTS	<0.01	12/7/94
IRON	0.12	12/7/94
MANGANESE	0.03	12/7/94
ODOR	1	12/7/94
pH-(AT COLLECTION POINT)	7.92	12/7/94
SILVER	0.01	12/7/94
SULFATE	96.6	12/7/94
TOTAL DISSOLVED SOLIDS (TDS)	254	12/7/94
ZINC	<0.005	12/7/94
TURBIDITY	0.43 NTU	12/30/92

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE

TRACE METAL ANALYSES-ROME AVENUE ASR SITE

Florida Geological Survey-FDEP Central Laboratory

SOURCE	DATE	TIME	ARSENIC µg/L		BARIUM µg/L		CADMIUM µg/L		CALCIUM mg/L		LEAD µg/L		MANGANESE µg/L		POTASSIUM mg/L		SODIUM mg/L		STRONTIUM µg/L		ZINC µg/L	
TPW-1	3/10/97	09:17	3	U	16.0	J	0.4	U	117	Q			335	Q	2.50	Q	34.5	J	496	Q	58	Q
	3/11/97	08:30	9	I	12.5	I	0.4	U	91.9	Q			59.2	Q	1.97	Q	24.2	J	470	Q	167	Q
	3/14/97	09:37	11	Q	11.3	I	0.4	U	84.9	Q			9.40	Q	2.08	Q	25.6	J	413	Q	73	Q
	3/20/97	08:50	22	Q	11.4	I	0.4	U	80.4	Q			12.0	Q	2.15	Q	26.4	J	330	Q	42	Q
	6/09/97	10:35	36	Q	11.9	I	0.4	U	70.5	Q			6.04	Q	1.64	Q	23.9	J	216	Q	10	U
SZOW-1	3/07/97	11:45	35	Q	14.2	I	0.4	U	77.6	Q			7.29	Q	2.45	Q	26.3	J	197	Q	18	I
	3/14/97	09:43	24	Q	14.1	I	0.4	U	70.7	Q			13.8	Q	2.29	Q	21.2	J	178	Q	23	I
	8/03/98	12:00	17	A	11.9	I			72.1	A	2	U	5.54	J			31.8	A	185	A		
SMW-1	3/07/97	10:25	3	U	14.6	I	0.4	U	62.8	Q			6.20	Q	0.733	Q	7.9	J	137	Q	10	U
	3/14/97	09:10	3	U	15.9	J	0.4	U	62.7	Q			6.82	Q	0.743	Q	8.4	J	137	Q	10	U
	6/09/97	10:57	3	U	14.3	I	0.4	U	64.0	Q			5.44	Q	0.778	Q	9.4	J	139	Q	10	U
2-D	3/07/97	12:20	3	U	31.4	J	0.4	U	134	Q			13.2	Q	6.88	Q	219	J	2400	Q	13	I
	3/14/97	10:13	3	U	30.1	J	0.4	U	133	Q			10.8	Q	7.00	Q	218	J	2350	Q	13	I
PTRW	3/20/97	10:31	3	U	12.5	I	0.4	U	65.9	Q			9.25	Q	1.64	Q	10.7	J	553	Q	29	I

CODES: A-value reported is the mean of two or more determinations; U-material was analyzed for but not detected; the value reported is the minimum detection limit; I-value reported is less than the minimum quantitation limit, and greater than or equal to the minimum detection limit; Q-sample held beyond holding time; J-estimated value.

COMMENTS: The Ba recoveries were outside the control limits. The Na precision was not available due to the low analyte level in the QC sample. All samples except SZOW-1/8/03/98 were analyzed after the expiration date.

APPENDIX C WATER QUALITY ANALYSES AT THE PUNTA GORDA ASR SITE

NATIVE AQUIFER WATER (FROM ASR WELL)

VARIABLE-RATE STEP-DRAWDOWN TEST WATER QUALITY DATA

Montgomery Watson, 1998

BACKGROUND SAMPLE: 10/19/95 BACKGROUND: INORGANICS

ANTIMONY	<0.006	ALUMINUM	<0.2
ARSENIC	<0.0022	CHLORIDE	850
BARIUM	<0.2	COLOR	6 PCU
BERYLLIUM	<0.004	COPPER	0.011
CADMIUM	<0.003	FLUORIDE	1.06
CHROMIUM	<0.02	FOAMING AGENTS	<0.10
CYANIDE	<0.006	IRON	0.137
FLUORIDE	1.06	MANGANESE	<0.005
LEAD	<0.001	ODOR	50
MERCURY	<0.0002	pH (AT COLLECTION POINT)	7.18
NICKEL	<0.010	SILVER	<0.010
NITRATE (AS N)	<0.01	SULFATE	373
NITRITE (AS N)	<0.01	TOTAL DISSOLVED SOLIDS	1918
SELENIUM	<0.004	ZINC	0.024
SODIUM	382		
THALLIUM	<0.002		

BACKGROUND: RADIONUCLIDES

GROSS ALPHA	<6.3 ± 4.0 pCi/L
RADIUM 226	5.6 ± 0.5 pCi/L
RADIUM 228	<0.9 ± 0.6 pCi/L

NOTE: ALL UNITS IN mg/L UNLESS STATED

TRW

RECHARGE-CYCLE 1

Montgomery Watson, 1998

DATE	TIME	SO_4	TDS	pH	TOTAL ALKALINITY	COND.	Cl	DISSOLVED OXYGEN	IRON	COLOR
				pH units		umhos/cm				(pcu)
07/23/98	13:50		489			983	152			
07/24/98	13:55		490			979	158			
07/25/98	13:27	75	472	7.7	60	953	146	7.5	0.005	5
07/26/98	12:00		493			884	136			
07/27/98	14:30		493			415	142			
07/28/98	14:40		290			888	130			

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
N/A: DATA NOT AVAILABLE
*explanation of abbreviations
SO_4-sulfate
TDS-total dissolved solids
TOTAL HARD.-total hardness
NON-CARB HARD.-non-carbonate hardness
TURB.-turbidity
COND.-conductivity
Cl-chloride
Fl-fluoride
TOTAL COLIF.-total coliform
FECAL COLIF.-fecal coliform
Cl_2-Chlorine
NH_3-ammonia
Mg-magnesium
THM-trihalomethanes

ASR WELL

RECOVERY-CYCLE 1

Montgomery Watson, 1998

DATE	TIME	SO_4	TDS	pH	TOTAL ALKALINITY	COND.	Cl	DISSOLVED OXYGEN	IRON	COLOR
				pH units		umhos/cm				(pcu)
07/29/98	13:05		454			914	138			
07/30/98	07:00		620			1224	220			
07/30/98	07:15	73	708	7.5	84	1401	264	4.1	0.260	10
07/30/98	12:10		788			1568	296			
07/31/98	12:00		1098			1201	598			
07/31/98	12:05		1140			2260	488			
08/01/98	07:00		1280			2630	628			
08/02/98	13:50		1500			2970	694			
08/03/98	07:00		1510			3090	740			
08/03/98	13:50		1550			3170	734			
08/04/98	08:00		1560			3180	730			
08/04/98	14:00		1590			3200	728			
08/05/98	07:00		1610			3290	746			
08/05/98	14:00		1640			3340	730			
08/06/98	07:00		1640			3350	758			
08/06/98	13:15		1630			3320	780			
08/07/98	07:00	350	1680	7.5	100	3370	798	3.8	0.137	32
08/07/98	09:30		1710			3430	776			

NOTE: ALL UNITS IN mg/L UNLESS STATED OTHERWISE
N/A: DATA NOT AVAILABLE

TRACE METAL ANALYSES-PUNTA GORDA ASR SITE

Florida Geological Survey-FDEP Central Laboratory

SOURCE	DATE	TIME	ARSENIC µg/L		BARIUM µg/L	CADMIUM µg/L	CALCIUM mg/L	LEAD µg/L		MANGANESE µg/L		POTASSIUM mg/L	SODIUM mg/L	STRONTIUM µg/L	ZINC µg/L
TRW	7/29/98		3	U	40.7		63.1	2	U	22.8			80.5	4460	
PTRW	7/29/98		3	U	41.5		65.8	2	U	48.6			55.5	4590	
ASR well	7/29/98		3	U	729		65.0	9		29.9			82.8	4570	
	7/30/98		10		53.7		84.6	2	U	14.3	J		123	1.02E+04	
	7/31/98		32		52.2		104	2	U	9.52	J		206	1.91E+04	
	8/03/98		37		57.0		133	2	U	3.73	J		319	3.09E+04	
	8/04/98		28		56.8		135	2	U	3.93	J		327	3.30E+04	
	8/05/98		18		1630		141	11		3.85	J		354	3.27E+04	
	8/06/98		13		79.2		140	2	U	2.87	J		341	3.27E+04	

CODES: U-material was analyzed for but not detected; the value reported is the minimum detection limit; J-estimated value.

COMMENTS: The Mn PQL was outside the recovery limits; the Mn result may be biased high. Cadmium, potassium and zinc were not analyzed.

APPENDIX D

CHEMICAL PROCEDURE FOR CREATING A THIN SOURCE FOR URANIUM AND STRONTIUM ISOTOPE ANALYSIS

URANIUM

(procedure from Osmond and Cowart, 1976)

1. Transfer and apportion the water sample from the five gallon container to four 3.5 L containers, filter when suspended material is visible.
2. Acidify each sample bottle with 20 mL concentrated HNO_3 to lower pH to one or less.
3. Add 5 mL of 1N $Fe(NO_3)_3$ to each bottle.
4. Add appropriate uranium spike (^{232}U) to each sample (for groundwater samples, usually 2 mL per bottle-equivalent to 0.5 µg ^{238}U per liter).
5. Heat sample to at least 95°C to release dissolved CO_2.
6. Add NH_4OH to heated sample to increase pH to above ten to allow the iron oxides/hydroxides to precipitate and scavenge dissolved uranium.
7. After cooling, decant supernatant.
8. Centrifuge precipitate and decant supernatant.
9. Use 8 N HCl to dissolve the precipitate in centrifuge tubes.
10. Pour sample into a 250 mL beaker and take to dryness under heat lamps.
11. Add 20 mL 8 N HCl to dissolve precipitate.
12. Add 50 mL ethyl ether to a 125 mL separatory funnel.
13. Introduce sample into the separatory funnel.
14. Shake carefully to allow the ether to sequester most of the iron, and vent the separatory funnel as necessary.
15. Drain aqueous (bottom) portion of the separatory funnel (containing the uranium) into a 250 mL beaker, and discard the top portion (containing the ethyl ether and iron) into a hazard container.
16. Take sample to dryness under heat lamps.
17. Add 20 mL 8 N HCl to dissolve precipitate.
18. Prepare ion exchange columns by inserting glass wool in the lower most portion of the column to block the passage of resin (AGI-8 anion exchange resin). Add resin to the column and then add 20 mL 8N HCl to the column to clean the resin and prepare it for the next step.
19. Add sample to the ion exchange column--the iron and uranium will be retained by the resin and all other interferences will wash through.
20. Elute the uranium and iron with 0.1 N HCl and capture in a 250 mL beaker.
21. Take sample to dryness under heat lamps.
22. Add 5 mL 8 N HNO_3 to dissolve precipitate.
23. Add 15 mL 8 N HNO_3 to ion exchange columns to prepare resin for next step.
24. Add sample to the ion exchange column--the uranium will be retained by the resin and the iron will pass through (add HNO_3 to the column as needed to completely wash the iron through the resin).
25. Elute the uranium with 0.1 N HCl and capture in a 250 mL Teflon beaker.
26. Take sample to dryness under heat lamps.

27. Prepare electroplating cell by appropriately attaching a glass column to a 2.5 cm diameter stainless steel planchet.
28. Dissolve precipitate in the beaker with 5 mL NH_4Cl and pour into the electroplating cell.
29. Rinse beaker with 5 mL NH_4Cl and pour into the same electroplating cell (for a total of 10 mL).
30. Attach electrodes to the electroplating device and electroplate for one hour at 1 amp/12 V.
31. Remove planchet from the electroplating unit, rinse with double-distilled water, and fire over a flame to harden the uranium to the planchet.
32. Label planchet and set aside for alpha spectrometry.

STRONTIUM

(procedure from Hart and Brooks, 1977)

1. Transfer 100 mL of the water sample into a 250 mL beaker. Cover with a watch glass. Place the beaker in a larger beaker and cover with a watch glass as well (to prevent contamination from airborne particles). Dry sample under heat lamps to 8-10 mL.
2. Pour sample into a 10-15 mL beaker and bring to dryness on a hooded hot plate.
3. Add 5-7 mL of 4:1 HF:$HClO_4$ dissolution mix to the beaker. Cover tightly with fitted lid.
4. Heat beaker with sample on a hooded hot plate at 100 °C over night. Remove cover and bring to dryness on the hooded hot plate.
5. Add 3 mL 6.2 N HCl to the beaker, washing down any condensation on the sides of the beaker. Bring to dryness on the hooded hot plate. Repeat this step two more times to insure removal of all perchloric acid ($HClO_4$). Allow sample to cool.
6. Add 0.2 mL 2.5 N HCl to sample to dissolve the dried sample (30-60 minutes).
7. Pour solution into a centrifuge tube. Rinse the remainder from the beaker with small additional quantities of 2.5 N HCl and poor into the centrifuge tube. Centrifuge the sample for two minutes (until the solution is clear).
8. Prepare ion exchange column by backwashing the column with 2.5 N HCl.
9. Load 0.25 mL of the clear portion of the sample solution from the centrifuge tube to the column. Allow the sample to completely pass through. Catch the sample in a beaker and discard the liquid.
10. Load 8 mL 2.5 N HCl to the column. Discard the liquid.
11. Load 4.5-5 mL 2.5 N HCl to the column. Discard the liquid (this contains the alkalis).
12. Load 6.5-7 mL 2.5 N HCl to the column. Discard the liquid.
13. Load 6 mL 2.5 N HCl. Capture liquid in a clean beaker (this contains the strontium). Dry on a hooded hot plate.
14. Add three drops of $HClO_4$ to the dried sample. Dry on the hooded hot plate at 175 °C for 15 minutes, then at 225 °C until dry.
15. Add two drops of HNO_3 to the dried sample and dry on the hooded hot plate. Repeat this step two more times.
16. The sample is then dissolved in 0.25 N HNO_3 and placed on a filament (Ta, Re, or W) and is ready for mass spectrometry.

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