Evaluation of Passive Diffusion Bag Samplers, Dialysis Samplers, and Nylon-Screen Samplers in Selected Wells at Andersen Air Force Base, Guam, March–April 2002

Water-Resources Investigations Report 03-4157

Prepared in cooperation with the
AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE

U.S. Department of the Interior
U.S. Geological Survey

COVER PHOTOGRAPH:
The cliffs at Tarague Bay, Northern Guam, March 2002.
(By Don Vroblesky, U.S. Geological Survey)

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CONTENTS

FIGURES

TABLES

CONVERSION FACTORS, VERTICAL DATUM, ACRONYMS, AND ABBREVIATIONS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Volume	
gallon (gal)	3.785	liter
	Flow	
foot per day (ft/d)	0.3048	meter per day
foot per year (ft/yr)	0.3048	meter per year
gallon per minute (gal/min)	0.06309	liter per minute

Chemical Concentration: In this report, chemical concentration in water is expressed in metric units as milligrams per liter (mg/L) or micrograms per liter (µg/L).

Sea Level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

AFB	Air Force Base	µ	micron
AFCEE	Air Force Center for Environmental Excellence	mL	milligram per liter
CAH	chlorinated aliphatic hydrocarbon	mL	milliliter
EDTA	ethylenediaminetetra acetic acid	PDB	passive diffusion bag
LDPE	low-density polyethylene	TCE	trichloroethene
L	liter	PCE	tetrachloroethene
MARBO	Marianas Bonins	USGS	U.S. Geological Survey
µg	microgram	VOA	volatile organic analysis
µg/L	microgram per liter	VOC	volatile organic compound

Evaluation of Passive Diffusion Bag Samplers, Dialysis Samplers, and Nylon-Screen Samplers in Selected Wells at Andersen Air Force Base, Guam, March–April 2002

By Don A. Vroblesky[1], Manish Joshi[2], Jeff Morrell[3], *and* J E. Peterson[4]

ABSTRACT

During March-April 2002, the U.S. Geological Survey, Earth Tech, and EA Engineering, Science, and Technology, Inc., in cooperation with the Air Force Center for Environmental Excellence, tested diffusion samplers at Andersen Air Force Base, Guam. Samplers were deployed in three wells at the Main Base and two wells at Marianas Bonins (MARBO) Annex as potential ground-water monitoring alternatives. Prior to sampler deployment, the wells were tested using a borehole flowmeter to characterize vertical flow within each well. Three types of diffusion samplers were tested: passive diffusion bag (PDB) samplers, dialysis samplers, and nylon-screen samplers. The primary volatile organic compounds (VOCs) tested in ground water at Andersen Air Force Base were trichloroethene and tetrachloroethene. In most comparisons, trichloroethene and tetrachloroethene concentrations in PDB samples closely matched concentrations in pumped samples. Exceptions were in wells where the pumping or ambient flow produced vertical translocation of water in a chemically stratified aquifer. In these wells, PDB samplers probably would be a viable alternative sampling method if they were placed at appropriate depths. In the remaining three test wells, the trichloroethene or tetrachloroethene concentrations obtained with the diffusion samplers closely matched the result from pumped sampling.

In all of the tests, the regenerated cellulose dialysis samplers produced lower VOC concentrations than the passive diffusion bag samplers and most of the pumped results. The source of the difference is unknown, but a possible explanation may be the biodegradation of the dialysis membrane during the 22 to 23 days of deployment.

Chloride concentrations in nylon-screen samplers were compared with chloride concentrations in dialysis and pumped samples to test inorganic-solute diffusion into the samplers across a range of concentrations. The test showed that the results from nylon-screen samplers might have underestimated chloride concentrations at depths with elevated chloride concentrations. The reason for the discrepancy in this investigation is unknown, but may be related to nylon-screen-mesh size, which was smaller than that used in previous investigations.

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INTRODUCTION

Ground-water sampling at Andersen Air Force Base (AFB) (fig. 1), Guam, is complicated by the large depth to ground water (350 to 550 ft), necessitating the use of dedicated positive-displacement pumps. In addition, the pump-failure rate is high, possibly because of corrosion by the aquifer water. To explore alternative approaches for collecting ground-water samples at this site, EA Engineering, Science, and Technology, Inc., tested passive diffusion bag (PDB) samplers in wells at Andersen AFB in 1999 (T.L. Isakson, 2000, EA Engineering, Science, and Technology, Inc., written commun., 2000). PDB samplers were tested at single depths in six wells using duplicate samples. In three of the test wells, volatile organic compound (VOC) concentrations in the pumped and PDB samples differed by less than 5 µg/L. In one well, IRP-39 (fig. 1), the concentrations of trichloroethene (TCE) and tetrachloroethene (PCE) were about 10 µg/L higher in the PDB samples than in the pumped samples, which is not surprising considering that the pumped sample mixes water. EA Engineering, Science, and Technology, Inc., personnel expressed concern, however, because some compounds (acetone in some of the samples and benzene in samples from well IRP-51, fig. 1) were detected in PDB samplers, but not in the pumped samples and because concentrations of TCE in well IRP-31 were substantially higher in the pumped samples than in the PDB samples. The fact that acetone was detected in some of the PDB samples but not in the pumped samples is not a concern, because acetone does not easily diffuse through polyethylene (Vroblesky, 2001) and, thus, probably represents either a component of the water used to fill the samplers or a laboratory contaminant. However, concern about the detection of benzene in PDB samples from well IRP-51 and the higher concentrations of TCE and PCE in well IRP-31 could be addressed by repeating the comparison using PDB samplers deployed at multiple depths.

To clarify the questions regarding the PDB results in wells IRP-51 and IRP-31 and to examine PDB samplers in other wells, the U.S. Geological Survey, Earth Tech, and EA Engineering, Science, and Technology, Inc., in cooperation with the Air Force Center for Environmental Excellence (AFCEE), conducted an investigation to test diffusion samplers at Andersen AFB, Guam, in three wells at the Main Base and two wells at Marianas Bonins (MARBO) Annex during March-April 2002. The tested diffusion samplers were PDB samplers, dialysis samplers, and nylon-screen samplers.

PDB samplers constructed of low-density polyethylene (LDPE) have been shown to be a cost-effective alternative to conventional ground-water sampling methods for sampling VOCs (Vroblesky and Hyde, 1997; Parsons Engineering Science, Inc., 1999; Hare, 2000; McClellan AFB Environmental Management Directorate, 2000; Vroblesky and others, 2000; Vroblesky and Peters, 2000; Vroblesky and Petkewich, 2000). PDB samplers are not effective, however, for measuring inorganic ions in ground water.

Inorganic solutes in pore water have been measured by using a wide variety of diffusion samplers (Bottomly and Bayley, 1984; Ronen and others, 1986; Kaplan and others, 1991; Webster and others, 1998; Diog and Liber; 2000; Vroblesky and others, 2002, Vroblesky and Pravecek, 2002) that are variations of dialysis samplers introduced by Hesslein (1976) and Mayer (1976). In addition, experiments have been done using nylon screens as membranes (Paludan and Morris, 1999; Vroblesky and others, 2002). The dialysis and nylon-screen samplers tested in this investigation are modeled after those used by Vroblesky and others (2002).

Site Description

The U.S. Territory of Guam is the largest and southernmost of the islands in the Marianas chain. Andersen AFB is in the northern part of the island. The two areas of the base relative to this report are the Main Base and MARBO Annex (fig. 1). Ground-water contamination by chlorinated aliphatic hydrocarbons (CAH) is present in the ground water. The primary contaminants of concern are TCE and PCE. In some wells, inorganic constituents are also of concern.

The average annual rainfall at Andersen AFB is approximately 100 inches, primarily during the months of July through November (Ward and Brookhart, 1962). Despite the large amount of rainfall, there are no streams in the northern part of the island because of the highly permeable limestone terrane, which allows rapid infiltration of rainfall. Permeability in the limestone is controlled largely by porosity and channels that allow for substantial water movement. Surficial soils are thin to nonexistent. Hydraulic conductivity of the aquifer under the northern part of the island probably ranges between 1,000 and 5,000 ft/d, although calculations from the response of the water table to tidal action suggest values as high as 20,000 ft/d (Branch and others, 1982).

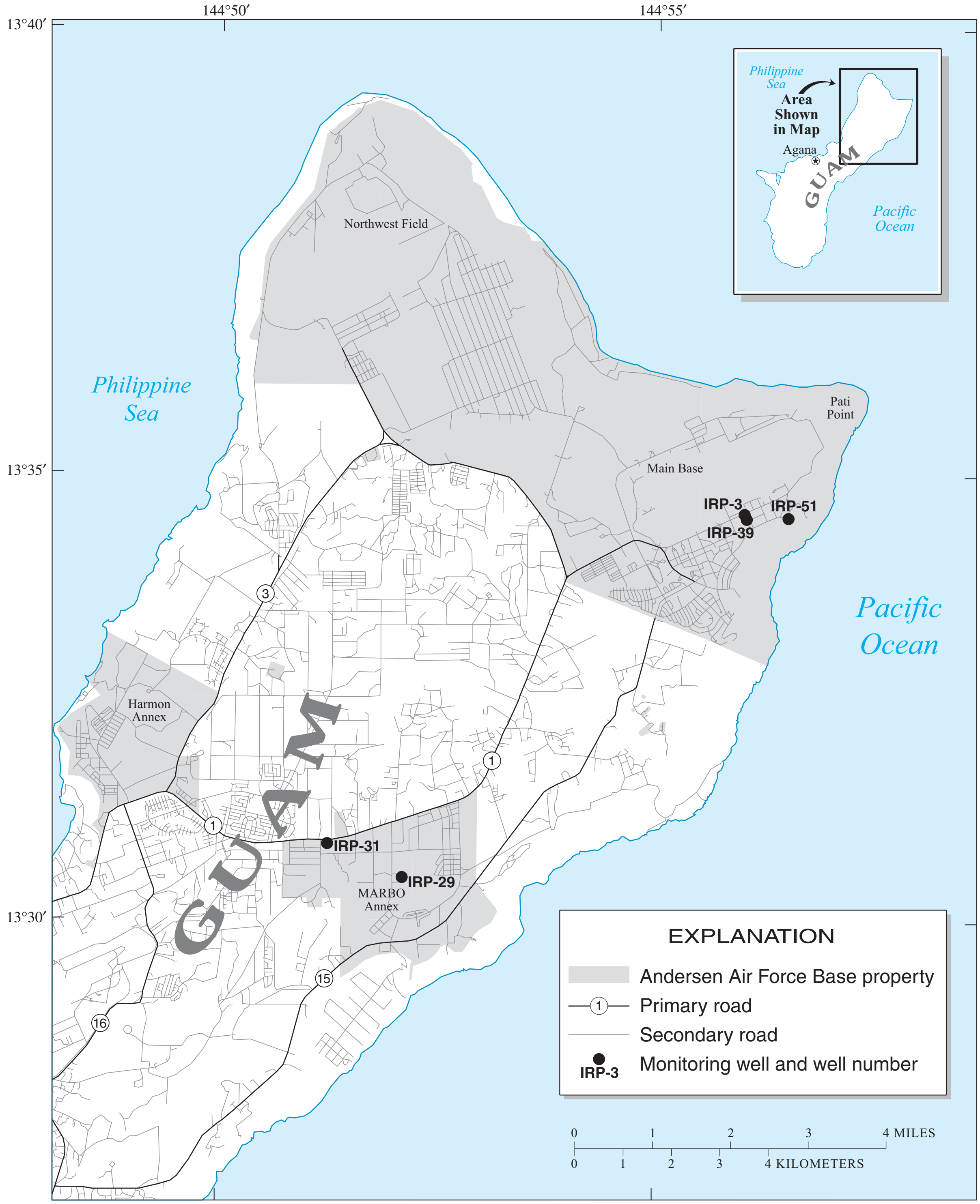

Figure 1. Location of monitoring wells sampled at Andersen Air Force Base, Guam, March-April 2002.

The surface elevation is about 450 to 550 ft above sea level at the Main Base and about 350 to 400 ft above sea level at MARBO Annex. Because of the highly permeable nature of the limestone, the water table in the northern part of the island constitutes a low dome standing about 5 to 7 ft above sea level in the central part of the area and slopes gradually to sea level at the shore (Ward and Brookhart, 1962). Thus, the depth to the water table is about 450 to 550 ft beneath the Main Base and about 350 to 400 ft beneath MARBO Annex.

The transition zone between fresh ground water and the underlying saltwater in northern Guam is relatively thin, and tidal mixing appears to be substantially less than is typical for many island aquifers (Gregg Ikehara, U.S. Department of Defense, oral commun., 2003). The large depth to water complicates ground-water sampling by necessitating pumps capable of lifting hundreds of feet of head. Moreover, there is a relatively high incidence of pump failure from corrosion, possibly related to salinity levels.

Diffusion samplers were tested in five wells at the facility. The wells were IRP-3, IRP-39, and IRP-51 at the Main Base and wells IRP-29 and IRP-31 at MARBO Annex (fig. 1, table 1). Although the total dissolved solids concentrations in all of these wells were in the range of freshwater (1 to 1,000 milligrams per liter), the screened interval of at least four (IRP-39, IRP-51, IRP-29, and IRP-31) of the five tested wells probably included part of the transition zone between fresh and saltwater.

Purpose

The purpose of this report is to (1) compare ground-water VOC concentrations obtained from side-by-side tests of dialysis and PDB samplers to concentrations obtained by pumped sampling in wells and (2) compare chloride concentrations obtained from side-by side tests of dialysis and nylon-screen samplers to concentrations obtained by pumped sampling. Although chloride is not a solute of concern at the facility, it was chosen as the representative solute because of the expection to see a large vertical variation in the concentration within the screened interval.

METHODS

Chemical concentrations in ground water obtained at wells by using passive sampling methods (dialysis, nylon-screen, and PDB) were compared to concentrations obtained by using pumped sampling. Borehole-flowmeter results aided in the interpretation of the data.

Borehole-Flowmeter Surveys

Borehole-flowmeter measurements were made in the screened intervals of the wells prior to deployment of the diffusion samplers. The measurements were made with a Mount Sopris HPF-2293 heat-pulse flowmeter, which is capable of quantifying vertical flow but is not capable of detecting horizontal flow. There is quantitation uncertainty in the flowmeter data presented here because the wells are screened, and the flowmeter cannot detect water movement through the sand pack outside of the well screen. The data, however, are useful in determining zones in which water is moving vertically in the borehole under nonpumped conditions and in determining which zones are contributing water to the well under pumped conditions. The heat-pulse flowmeter is capable of measuring flows ranging from 0.03 to 1.5 gal/min (Mount Sopris Instrument Company, Inc., 2001).

Borehole-flowmeter measurements were taken at several depths, approximately 2 to 3 ft apart, within each screened interval under nonpumping conditions. Prior to taking an initial reading at each depth, the probe was allowed to stabilize for at least 3 minutes and longer if it was suspected that water movement was related to movement of the probe. At least three readings were taken at each depth. Each well then was pumped from a shallow depth at a rate of about 0.5 gal/min, and additional measurements were made at the same horizons used during nonpumping conditions. At the Main Base wells, additional measurements were taken while pumping the wells at about 1 gal/min. In well IRP-31, a flowmeter reading was taken under pumping conditions within the closed casing of the well at a depth of 442 ft, allowing for a measurement of total upward flow. In this instance, the amount of flow was 0.38 gal/min.

For this investigation, the flowmeter data were divided into the approximate percentage of contribution to the well during pumping by comparing flowmeter data from one horizon with the flowmeter data from the next underlying horizon. The amount of

Table 1. Well information, Main Base and MARBO Annex, Andersen Air Force Base, Guam, March-April 2002
[TOC, top of casing; ft, feet; MLLW, mean lowest low water; BLS, below land surface; BTOC, below top of casing; all wells were 4-inch diameter PVC]

Well	Elevation of TOC[a] (ft relative to MLLW)	Sounded depth of well (ft below TOC)	Reported depth to well bottom[a] (ft BLS)	Height of stand pipe (ft)	Screen length (ft)	Screened interval (ft BTOC)	Depth to water at time of recovery (ft BTOC)	Elevation of the water table at time of sampler recovery (ft relative to MLLW)	Saturated screened interval at time of sampler recovery (ft)
Main Base									
IRP-3	559.79	581.74	584	2.1	41	545.1 - 586.1	556.18	3.61	30
IRP-39	556.96	629.22	625	2.8	20	607.8 - 627.8	553.41	3.55	20
IRP-51	459.46	510.22	507	1.8	20	588.8 - 508.8	458.52	.94	20
MARBO Annex									
IRP-29	383.13	481.44	479	2.4	20	461.4 - 481.4	377.74	5.39	20
IRP-31	363.64	465.92	465	2.1	20	447.1 - 467.1	358.25	5.39	20

[a] Data from Dames and Moore (2001).

upward-flow increase between the two horizons divided by the amount of upward flow measured at the shallowest flowmeter-data point in the well indicated the fractional contribution of water from the zone between the two horizons. If one or more consecutive measuring points showed little or no change in flow (about 5 percent accuracy), then the horizons between the points were considered to make no measurable flow contribution to the pumpage. In this case, the average flow measured across that noncontributing interval was used as a comparison to shallower and deeper measurements to determine approximate relative flow contributions of the bounding zones. The amount of flow up the well typically does not total 100 percent of the pumpage because of (1) water movement in the annular space outside the well screen and (2) because the location of the water table in some wells necessitated that both the pump and the uppermost borehole flowmeter reading were within the screened interval rather than in the closed casing above the screen.

Diffusion Sampler Construction and Deployment

The PDB samplers were purchased commercially (Eon Products, Inc., Snellville, Georgia). The PDB samplers consisted of 4-mil-thick polyethylene bags attached to a bottom-discharging device, and are described in detail in Vroblesky (2001). Each dialysis sampler was constructed onsite and consisted of a perforated acetate or plastic pipe inside a sleeve of high-grade regenerated cellulose tubular dialysis membrane (Membrane Filtration Products, Inc., Seguin, Texas) (Vroblesky and others, 2002). The nylon-screen samplers each consisted of three 30-mL polyethylene wide-mouth bottles with a nylon-screen cloth secured over the openings (Vroblesky and others, 2002). Because the aquifer was known to be aerobic, the PDB samplers and dialysis samplers were filled with aerobic de-ionized water at the time of sampler deployment.

The dialysis samplers were prepared from pretreated tubular regenerated cellulose dialysis membrane having a nominal molecular-weight cutoff of 8,000 daltons, or approximately 18 angstroms pore size. The pretreatment was designed to remove sulfur compounds and residual metals. The pretreated membrane is packaged in a solution of methanol and ethylenediaminetetra acetic acid (EDTA), which is removed by rinsing with de-ionized water prior to use.

To construct a dialysis sampler, the cellulose acetate dialysis tube was cut to a length of approximately 2 ft. The dialysis membrane was thoroughly washed with de-ionized water. One end of the tube was tied in a knot. A pipe of perforated plastic was slid into the dialysis tube for structural support. The sampler was filled with de-ionized water at the time of sampler deployment, and the open end of the membrane was tied. The assembly was slid into a length of LDPE mesh for abrasion protection.

To prepare a nylon-screen sampler, a 2- by 2-in. section of nylon screen was secured by holding it in place over the jar opening and screwing the open-top cap onto the jar and screen. The screen-opening size used in this investigation was 48 μ. This is a smaller size than that used in a previous successful field test (125 and 250 μ) at Fort Worth, Texas (Vroblesky and others, 2002). Each sampler consisted of two such jars held in a sleeve of 2-in-diameter flexible LDPE mesh, giving a total of approximately 50 to 60 mL of available water. The jars were oriented horizontally in the 4-in-diameter well screens, with the openings facing opposite directions. Webster and others (1998) found that vials oriented with the membrane facing downward failed to equilibrate with saltwater after 60 hours because density differences eliminated the tendency for saline convection to develop within the samplers. Vials oriented with the membrane facing upward or to the side equilibrated much faster (85 percent equilibration in 15 hours) than samplers oriented downward; however, samplers oriented with the membrane facing upward equilibrated more slowly than samplers oriented with the membrane facing sideways.

The diffusion samplers were deployed at Andersen AFB in three wells at the Main Base and in two wells at MARBO Annex (table 1). Deployment of the samplers consisted of attaching the samplers to a weighted support line and lowering them into the well. A PDB sampler was attached to a dialysis sampler at each targeted horizon. Each well consisted of at least seven targeted horizons (table 2). Three days following initial deployment, the samplers were removed from wells IRP-3, IRP-29, and IRP-51, the depths were adjusted for better vertical coverage, and the samplers were redeployed in wells. In IRP-29, nylon-screen samplers were added. In IRP-3, the adjustment included attaching additional PDB samplers and redeploying them. The samplers were out of the water less than 45 minutes at each well.

Some uncertainty is associated with the depths of the upper two PDB samplers in well IRP-3. In the original deployment, the upper PDB sampler was positioned at a depth of 556 ft to the center of the sampler, which was partly above the water table at a depth of 556.79 ft. The close match in concentration between samples IRP-3A and IRP-3B indicates that sampler IRP-3A almost certainly was not above the water table. A probable scenario is that the weight of sampler IRP-3A suspended above the water table caused the rope to stretch, allowing the PDB sampler to become immersed. Thus, samplers IRP-3A and IRP-3B probably represent similar depths at the top of the water table.

Water-Sample Collection and Diffusion-Sampler Recovery

Ground-water samples were collected by pumping the wells at Andersen AFB, Guam. The wells were purged at a rate of approximately 0.5 gal/min until the tubing volume was purged (about 7 gal), followed by a minimum of 14 gal to purge the well volume. During pumping, field readings of temperature, pH, specific conductance, turbidity, dissolved oxygen, redox, and chlorides were taken every 3 to 4 minutes. If after purging the 14 gal of casing water by pumping, the field properties had not stabilized, then the pumping was continued until stabilization was achieved. Stabilization meant that the field properties had three consecutive sets of readings, all within defined ranges. Water levels were monitored during pumping, but drawdowns typically were slight. Ground-water samples were collected after field properties stabilized. The pumped ground-water samples were collected between 3 and 8 days following retrieval of the diffusion samplers from the well (table 2).

Samples were analyzed for chloride by method E300.0 (U.S. Environmental Protection Agency, 1983, 1992). Because of the limited sample volumes available from the nylon-screen samplers, a minimum of 15 mL was analyzed for chloride.

Water from the dialysis and PDB samplers was analyzed for TCE and PCE in the field by gas chromatography (SRI 8610 gas chromatograph with photoionization detection). Based on the results of the field gas chromatography, water from diffusion samples collected at selected horizons was sent to a commercial laboratory for VOC analysis using Environmental Protection Agency Method 8260B (U.S. Environmental Protection Agency, 1999). In general, the selected horizons represented the depths of highest concentrations as detected with the field gas chromatography. The laboratory results were used to obtain an adjustment factor with which to standardize the results from the gas chromatograph in the field. All field gas chromatography results for a particular well were uniformly adjusted by the percentage difference between the field result and the laboratory result for the coanalyzed depth in that well. Thus, the field gas chromatography results are reported as “standardized.” The standardized values should be considered to be estimated concentrations.

Table 2. Diffusion sampler and pumped sampling information, Main Base and MARBO Annex, Andersen Air Force Base, Guam, March-April 2002

[ft, feet; ft BTOC, feet below top of casing; ft BLS, feet below land surface; # depth uncertain because of probable shifting of samplers; ---, data not collected or not applicable; *, depth at which monitoring data are routinely collected]

		Diffusion samples					Pumped samples			Number of samples collected			
Well number	Sample identifier	Distance from well bottom to sampler center (ft)	Depth to sampler center (ft BTOC)	Diffusion sampler deployment date	Diffusion sampler recovery date	Days of diffusion-sampler equilibration	Pumped sample depth (ft BLS)	Pumped sample depth (ft BTOC)	Pumped sampling date	Passive diffusion bag sample	Dialysis sample	Nylon-screen sample	Pumped sample
Main Base													
IRP-3	IPR-3A	24.5#	556.5#	3/11/02	4/3/02	23	---	---	---	1	1	---	---
	IPR-3B	24#	557#	3/11/02	4/3/02	23	---	---	---	1	1	---	---
	IPR-3C	23.3	557.7	3/14/02	4/3/02	20	---	---	---	1	---	---	1
	IPR-3D	21.3	559.7	3/11/02	4/3/02	23	558.5	560.6	4/11/02	1	1	---	1
	IPR-3E	18.3	562.7	3/11/02	4/3/02	23	560.5	562.6	4/11/02	1	1	---	2
	IPR-3F	16.8	564.2	3/14/02	4/3/02	20	---	---	---	1	---	---	---
	IPR-3G	15.3	565.7	3/11/02	4/3/02	23	564*	566.1*	4/11/02	1	1	---	---
	IPR-3H	13.3	567.7	3/11/02	4/3/02	23	---	---	---	1	1	---	---
	IPR-3I	11.3	569.7	3/11/02	4/3/02	23	---	---	---	1	2	---	---
	IPR-3J	7.3	573.7	3/11/02	4/3/02	23	---	---	---	1	1	---	---
	IPR-3K	3.3	577.7	3/11/02	4/3/02	23	---	---	---	1	1	---	---
IRP-39	IRP-39A	17.3	611.2	3/11/02	4/2/02	22	610	612.9	4/9/02	1	1	---	2
	IRP-39B	12.3	616.2	3/11/02	4/2/02	22	611*	613.8*	4/9/02	1	1	---	2
	IRP-39C	9.3	619.2	3/11/02	4/2/02	22	---	---	---	1	1	---	---
	IRP-39D	7.3	621.2	3/11/02	4/2/02	22	---	---	---	1	1	---	
	IRP-39E	4.5	624.0	3/11/02	4/2/02	22	---	---	---	1	1	---	---
	IRP-39F	2.7	625.9	3/11/02	4/2/02	22	---	---	---	1	1	---	---
	IRP-39G	1.2	627.2	3/11/02	4/2/02	22	---	---	---	1	1	---	---
IRP-51	IRP-51A	18.9	490.6	3/11/02	4/2/02	22	490*	491.8*	4/10/02	1	1	---	2
	IRP-51B	16.9	492.6	3/11/02	4/2/02	22	491.5	493.3	4/10/02	1	1	---	1
	IRP-51C	14.9	494.6	3/11/02	4/2/02	22	---	---	---	1	1	---	---
	IRP-51D	12.9	496.6	3/11/02	4/2/02	22	---	---	---	1	1	---	---
	IRP-51E	10.9	498.6	3/11/02	4/2/02	22	---	---	---	1	1	---	---
	IRP-51F	6.9	502.6	3/11/02	4/2/02	22	503.5	505.3	4/10/02	1	1	---	1
	IRP-51G	2.9	506.6	3/11/02	4/2/02	22	---	---	---	1	1	---	---

Table 2. Diffusion sampler and pumped sampling information, Main Base and MARBO Annex, Andersen Air Force Base, Guam, March-April 2002 (Continued)

[ft, feet; ft BTOC, feet below top of casing; ft BLS, feet below land surface; # depth uncertain because of probable shifting of samplers; ---, data not collected or not applicable; *, depth at which monitoring data are routinely collected]

		Diffusion samples					Pumped samples			Number of samples collected			
Well number	Sample identifier	Distance from well bottom to sampler center (ft)	Depth to sampler center (ft BTOC)	Diffusion sampler deployment date	Diffusion sampler recovery date	Days of diffusion-sampler equilibra-tion	Pumped sample depth (ft BLS)	Pumped sample depth (ft BTOC)	Pumped sampling date	Passive diffusion bag sample	Dialysis sample	Nylon-screen sample	Pumped sample
Marbo Annex													
IRP-29	IRP-29A	18.8	461.9	3/13/02	4/1/02	19	---	---	---	---	---	1	---
	IRP-29A	18.3	462.4	3/10/02	4/1/02	22	---	---	---	1	1	---	1
	IRP-29B	16.3	464.4	3/10/02	4/1/02	22	---	---	---	1	1	---	---
	IRP-29C	14.8	465.9	3/13/02	4/1/02	19	463	465.4	4/4/02	---	---	1	---
	IRP-29C	14.3	466.4	3/10/02	4/1/02	22	---	---	---	1	1	---	---
	IRP-29D	12.8	467.9	3/13/02	4/1/02	19	---	---	---	---	---	1	---
	IRP-29D	12.3	468.4	3/10/02	4/1/02	22	---	---	---	1	1	---	---
	IRP-29E	8.8	471.9	3/13/02	4/1/02	19	---	---	---	---	---	1	---
	IRP-29E	8.3	472.4	3/10/02	4/1/02	22	---	---	---	1	1	---	---
	IRP-29F	4.8	475.9	3/13/02	4/1/02	19	---	---	---	---	---	1	---
	IRP-29F	4.3	476.4	3/10/02	4/1/02	22	475*	477.4*	4/4/02	1	1	---	2
	IRP-29G	1.8	478.9	3/13/02	4/1/02	19	---	---	---	---	---	1	---
	IRP-29G	1.3	479.4	3/10/02	4/1/02	22	---	---	---	1	1	---	---
IRP-31	IRP-31A	18.3	446.9	3/10/02	4/1/02	22	447	449.1	4/4/02	2	1	---	1
	IRP-31B	15.3	449.9	3/10/02	4/1/02	22	---	---	---	2	1	---	---
	IRP-31C	12.3	452.9	3/10/02	4/1/02	22	---	---	---	1	1	---	---
	IRP-31D	9.3	455.9	3/10/02	4/1/02	22	---	---	---	1	1	---	2
	IRP-31E	6.3	458.9	3/10/02	4/1/02	22	456*	458.1*	---	2	1	---	---
	IRP-31F	3.3	461.9	3/10/02	4/1/02	22	---	---	---	1	1	---	---
	IRP-31G	1.3	463.9	3/10/02	4/1/02	22	---	---	---	1	1	---	---

Duplicate samples were collected from approximately 10 percent of the sampling sites. In general, both diffusion samples and pumped samples compared well with their respective duplicate samples. All samples and corresponding duplicate samples at concentrations less than 5 µg/L differed by less than 1 µg/L. At concentrations greater than 10 µg/L, the samples and corresponding duplicates differed by a relative percentage difference of 0 to 13.3 percent, with an average relative percentage difference of 5.2 percent.

RESULTS AND DISCUSSION

The test wells at Andersen AFB Main Base and MARBO Annex are characterized by both hydraulic and chemical differences along the screened intervals. The following sections discuss hydraulic results obtained from borehole-flowmeter tests and the distribution and comparison of chemical concentrations in the diffusion samplers and pumped samples.

Distribution of Ground-Water Flow in Wells

Vertical flow was detected by the heat-pulse flowmeter under nonpumping conditions in all of the test wells (table 3; figs. 2A, 3A, 4A, 5A, and 6A), indicating differences in head along the length of the screened intervals. The direction of flow was upward in the wells at MARBO Annex and a mixture of upward and downward in the wells at the Main Base. Nearly all of the vertical flow detected under nonpumping conditions, however, was at amounts less than the quantitation limit of the borehole flowmeter (0.03 gal/min). Thus, there is uncertainty in the evaluation of vertical flow under nonpumping conditions at most locations. Exceptions are in wells IRP-3 and IRP-39, in which downward flow near the bottoms of the wells was detected at rates greater than the minimum quantitation limit for the borehole flowmeter (figs. 2A and 3A, respectively). The downward movement of water near the base of wells IRP-3 and IRP-39 indicates some degree of in-well mixing under nonpumping conditions. The lower-than-quantifiable vertical flow rates in the remaining wells may represent actual movement of water or may be an artifact of the method used.

A variety of factors influence vertical movement of water in wells at Andersen AFB and probably influence solute mixing in the wells. Part of the vertical movement under nonpumping conditions probably is in response to tides. The wells at the Main Base have not been tested for tidal efficiency, which is the ratio of well-water level range during a tidal cycle to the tidal range. An investigation, however, in wells at MARBO Annex in 1995 showed that the tidal efficiency ranged between 0.7 to 3.9 percent in wells (Jeff Morrell, EA Engineering, Science, and Technology, Inc., written commun., 2002), with water-level responses of 0.5 to 3 in. A well near well IRP-29 (approximately 1.5 miles from the shoreline had a tidal efficiency of 3.1 percent. Well IRP-31 (approximately 2.5 miles from the shoreline) had a tidal efficiency of 3.4 percent. These responses indicate that tidal movement causes some degree of ground-water fluctuation even 2.5 miles inland. Although these water-level responses are small, the very high aquifer hydraulic conductivity [probably between 1,000 to 5,000 ft/d and possibly as high as 20,000 ft/d (Branch and others, 1982)] suggests that even small water-level changes can indicate water movement. The fact that the wells at the Main Base used in this investigation had a lower water elevation and were closer to the shoreline than the wells at MARBO Annex, implies that the test wells at the Main Base also probably are influenced by tides. Thus, the direction of ambient water movement in these wells may change with the tides, and the chemical concentrations may represent some degree of mixing. Rainfall infiltration may be an additional influence on vertical fluctuations in the ground water at this site. Additional water-level changes in the wells occur from barometric changes, as indicated by the high barometric efficiency (about 95 to 100 percent in wells at MARBO Annex; Jeff Morrell, EA Engineering, Science, and Technology, Inc., written commun., 2002).

In well IRP-3, the predominant zone of inflowing water during pumping was at a depth below the top of casing of about 573 ft (fig. 2C). This depth approximately coincides with the depth where downward flow begins under nonpumping conditions (fig. 2A). The downward flow implies that water enters the well at a depth between 571 and 577 ft under nonpumping conditions. This downward flow appears to exit the borehole at a depth of about 578 to 579 ft (fig. 2A). Despite this downward flow under nonpumping conditions, the apparent exit zone did not appear to contribute water to the well under pumping conditions. One explanation is that the pumping may have reduced the amount of downward flow to that horizon, making it appear to be a nonflowing zone.

Table 3. Borehole-flowmeter data, Main Base and MARBO Annex, Andersen Air Force Base, Guam, March-April 2002

[ft below TOC, feet below top of casing: gal/min, gallons per minute; negative values under nonpumping conditions indicate downward flow; ---, data not available; *, pumping rate was 0.34 gallons per minute]

Well number	Depth of measurement (ft below TOC)	Vertical flow under non-pumping conditions (gal/min)	Upward flow (gal/min) when pumped at about 0.5 gal/min	Upward flow (gal/min) when pumped at about 1.0 gal/min	Estimated depth of contribution (ft below TOC)	Approximate percent of contribution when pumped at 0.5 gal/min	Approximate percent of contribution when pumped at 1.0 gal/min
Main Base							
IRP-3	556	0.01	0.54	1.16	557	30	23
	558	0	0.38	0.89	559	21	34
	560	0.01	0.24	0.5	561	0	7
	562	0.01	0.15	0.42	563	0	3
	564	0.02	0.22	0.21	565	0	0
	566	0.02	0.27	0.38	567	0	6
	568	0.01	0.01	0.31	569	0	3
	570	0.02	0.26	0.28	571	9	3
	572	-0.03	0.21	0.25	573	26	13
	574	-0.05	0.07	0.01	575	6	5
	576	-0.08	0.04	0.04	577	7	3
	578	-0.08	0	0	579	0	0
	580	0	0	0	580	0	0
	582	0	0	0	581	0	0
IRP-39	605	0.02	0.64	1.45	606	18	11
	607	0.02	0.5	1.29	608	0	9
	609	0.02	0.53	1.16	610	0	0
	611	0	0.5	1.16	612	0	8
	613	0	0.56	1.04	614	0	9
	615	0	0.53	0.87	616	16	0
	617	-0.04	0.42	0.95	618	36	23
	619	0.01	0.19	0.6	620	0	0
	621	-0.02	0.17	0.56	622	0	17
	623	-0.04	0.09	0.33	624	0	8
	625	0.02	0.18	0.22	626.5	28	15
IRP-51	487	0	0.87	1.45	488	8	0
	489	0	0.8	1.45	490	18	20
	491	0	0.64	1.16	492	9	8
	493	0	0.56	1.04	494	10	12

Table 3. Borehole-flowmeter data, Main Base and MARBO Annex, Andersen Air Force Base, Guam, March-April 2002 (Continued)

[ft below TOC, feet below top of casing: gal/min, gallons per minute; negative values under nonpumping conditions indicate downward flow; ---, data not available; *, pumping rate was 0.34 gallons per minute]

Well number	Depth of measurement (ft below TOC)	Vertical flow under non-pumping conditions (gal/min)	Upward flow (gal/min) when pumped at about 0.5 gal/min	Upward flow (gal/min) when pumped at about 1.0 gal/min	Estimated depth of contribution (ft below TOC)	Approximate percent of contribution when pumped at 0.5 gal/min	Approximate percent of contribution when pumped at 1.0 gal/min
	495	0.01	0.47	0.87	496	10	5
	497	0	0.38	0.8	498	24	14
	499	0.02	0.17	0.6	500	0	9
	501	0.01	0.19	0.47	502	13	17
	503	0.01	0.08	0.22	504	0	6
	505	-0.01	0.08	0.14	506	7	6
	507	0	0.02	0.06	507.5	2	4
MARBO Annex							
IRP-29	460	0.01	0.44	---	461	20	---
	462	0.01	0.35	---	463	11	---
	464	0.01	0.3	---	465	27	---
	466	0.01	0.18	---	467	20	---
	468	0	0.09	---	469	0	---
	470	0	---	---	471	0	---
	472	0.01	0.09	---	473	0	---
	474	0.01	0.09	---	475	0	---
	476	0.02	0.09	---	477	5	---
	478	0	0.07	---	479	7	---
	480	0	0.04	---	480.5	9	---
IRP-31	444	0	0.38*	---	445	34	---
	446	0	0.25*	---	447	18	---
	448	0	0.18*	---	449	5	---
	450	0	0.16*	---	451	3	---
	452	0.02	0.15*	---	453	8	---
	454	0.01	0.12*	---	455	3	---
	456	0.02	0.11*	---	457	0	---
	458	0	0.1*	---	459	11	---
	460	0.01	0.06*	---	461	8	---
	462	0.02	0.03*	---	463	3	---
	464	0	0.02*	---	465	5	---

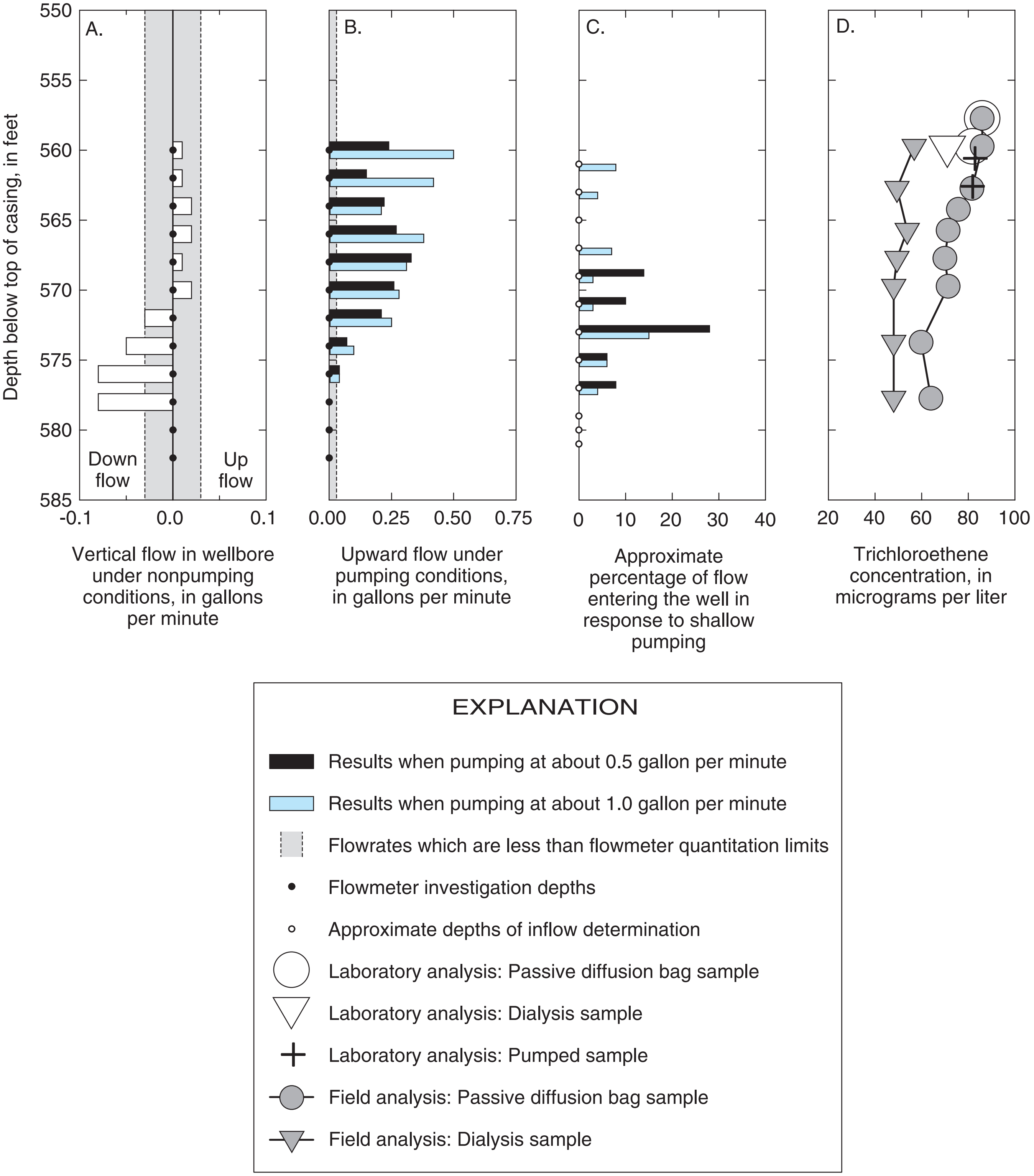

Figure 2. Borehole-flowmeter data under nonpumped and pumped conditions, approximate water-yielding zones during pumping, and trichloroethene concentrations in dialysis samples, passive diffusion bag samples, and pumped samples at well IRP-3, Main Base, Andersen Air Force Base, Guam, April 2002.

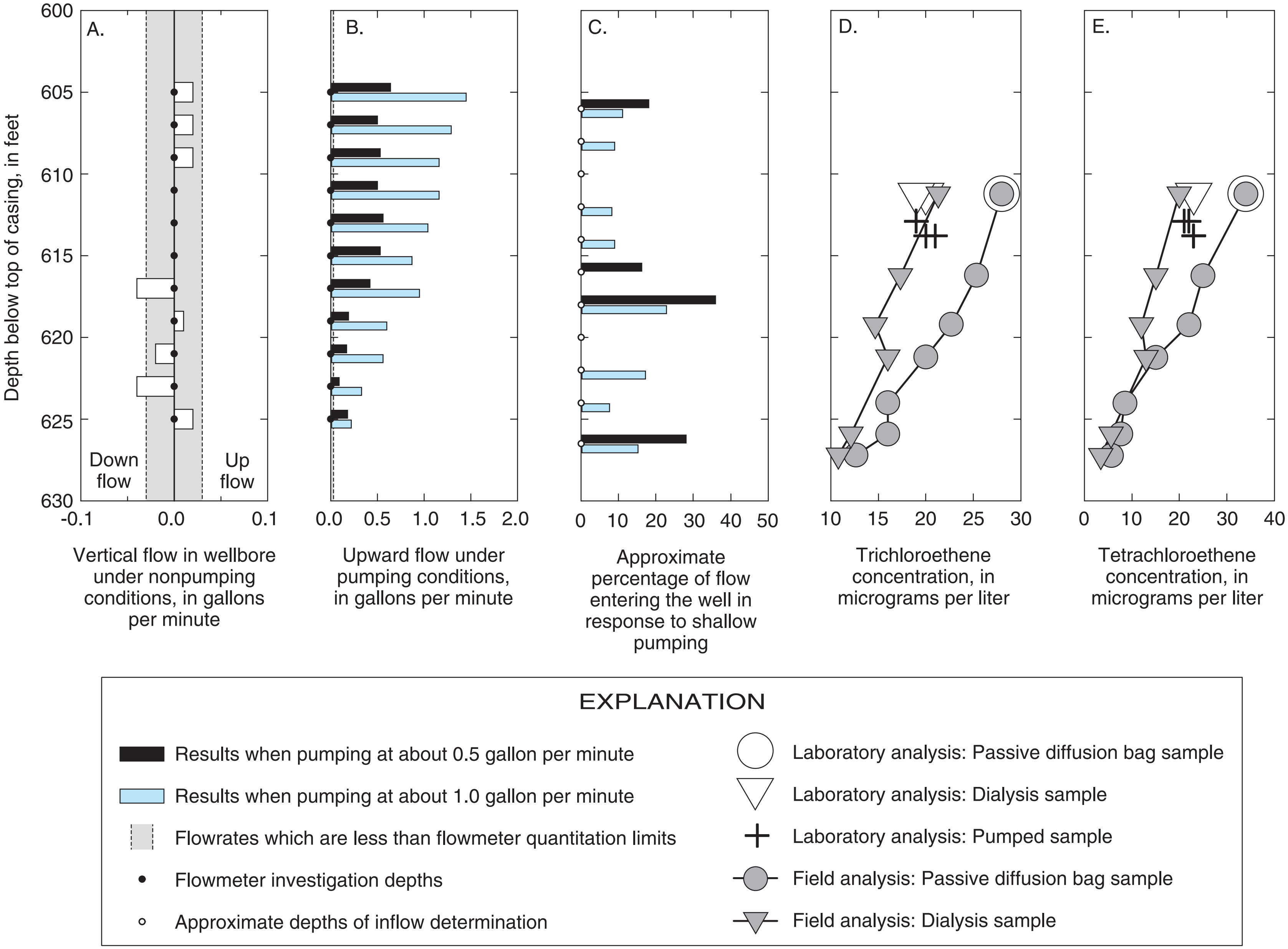

Figure 3. Borehole-flowmeter data under nonpumped and pumped conditions, approximate water-yielding zones during pumping, and trichloroethene concentrations in dialysis samples, passive diffusion bag samples, and pumped samples at well ell IRP-39, Main Base, Andersen Air Force Base, Guam, April 2002.

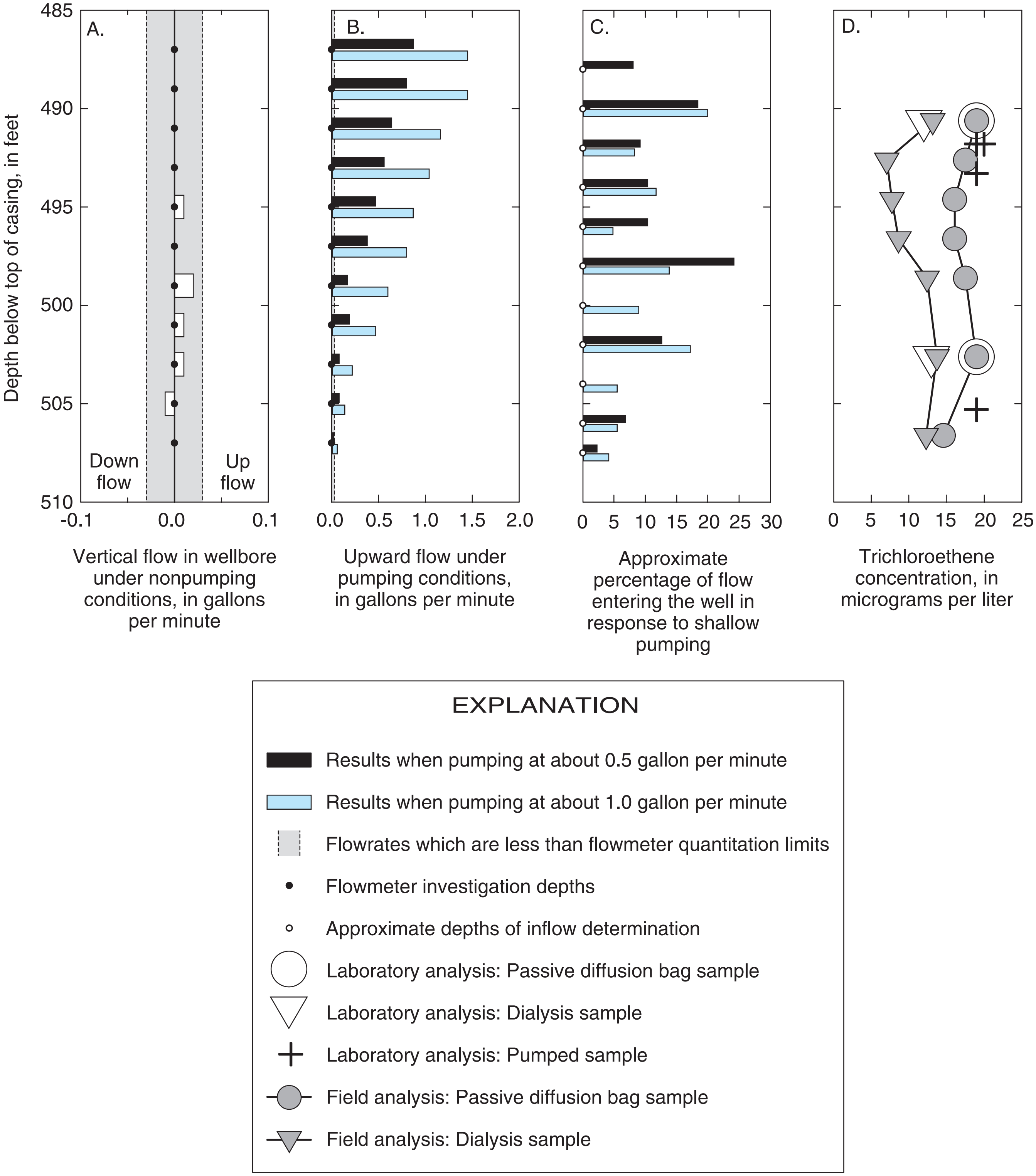

Figure 4. Borehole-flowmeter data under nonpumped and pumped conditions, approximate water-yielding zones during pumping, and trichloroethene concentrations in dialysis samples, passive diffusion bag samples, and pumped samples at well ell IRP-51, Main Base, Andersen Air Force Base, Guam, April 2002.

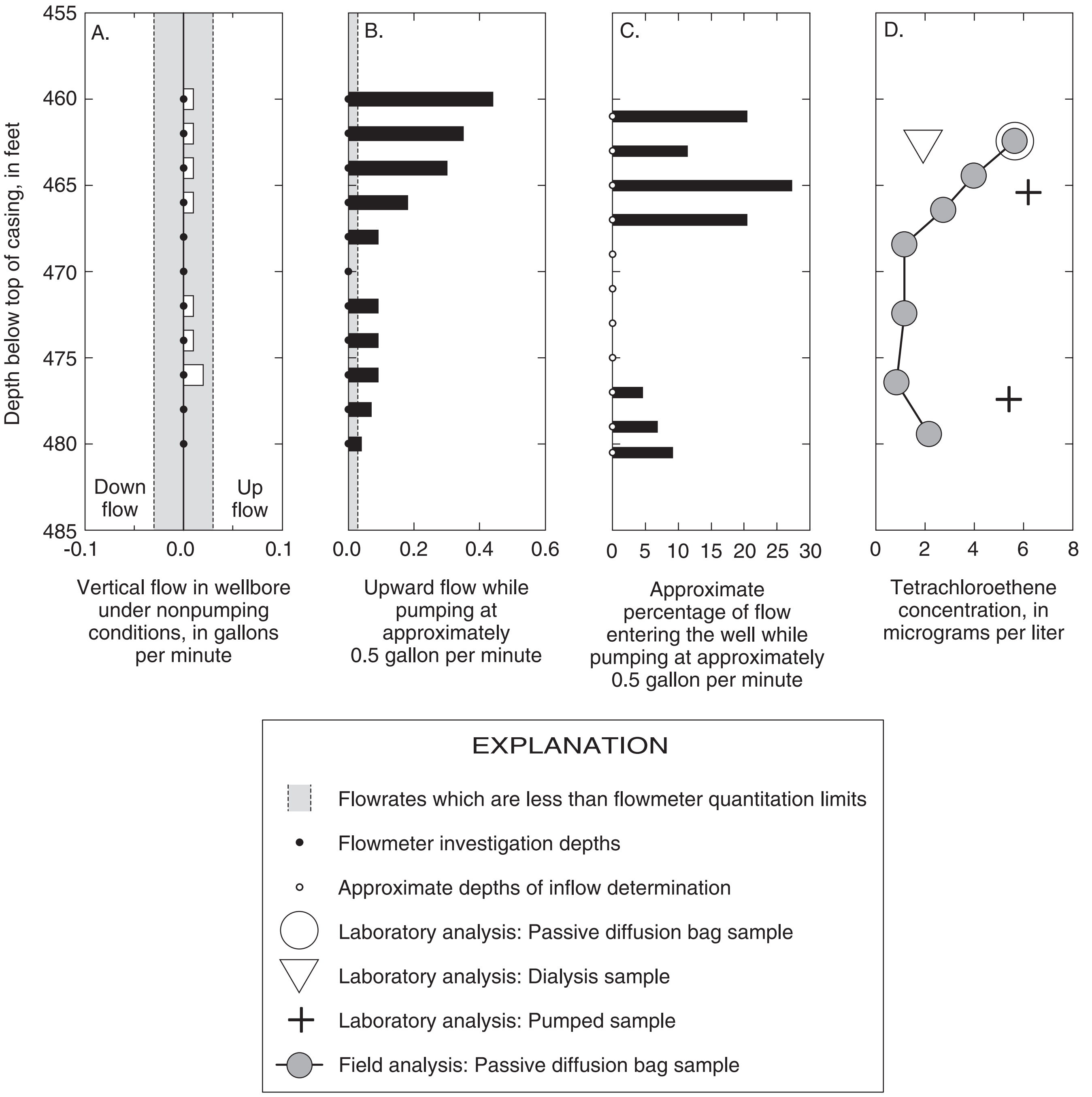

Figure 5. Borehole-flowmeter data under nonpumped and pumped conditions, approximate water-yielding zones during pumping, and trichloroethene concentrations in dialysis samples, passive diffusion bag samples, and pumped samples at well ell IRP-29, MARBO Annex, Andersen Air Force Base, Guam, April 2002.

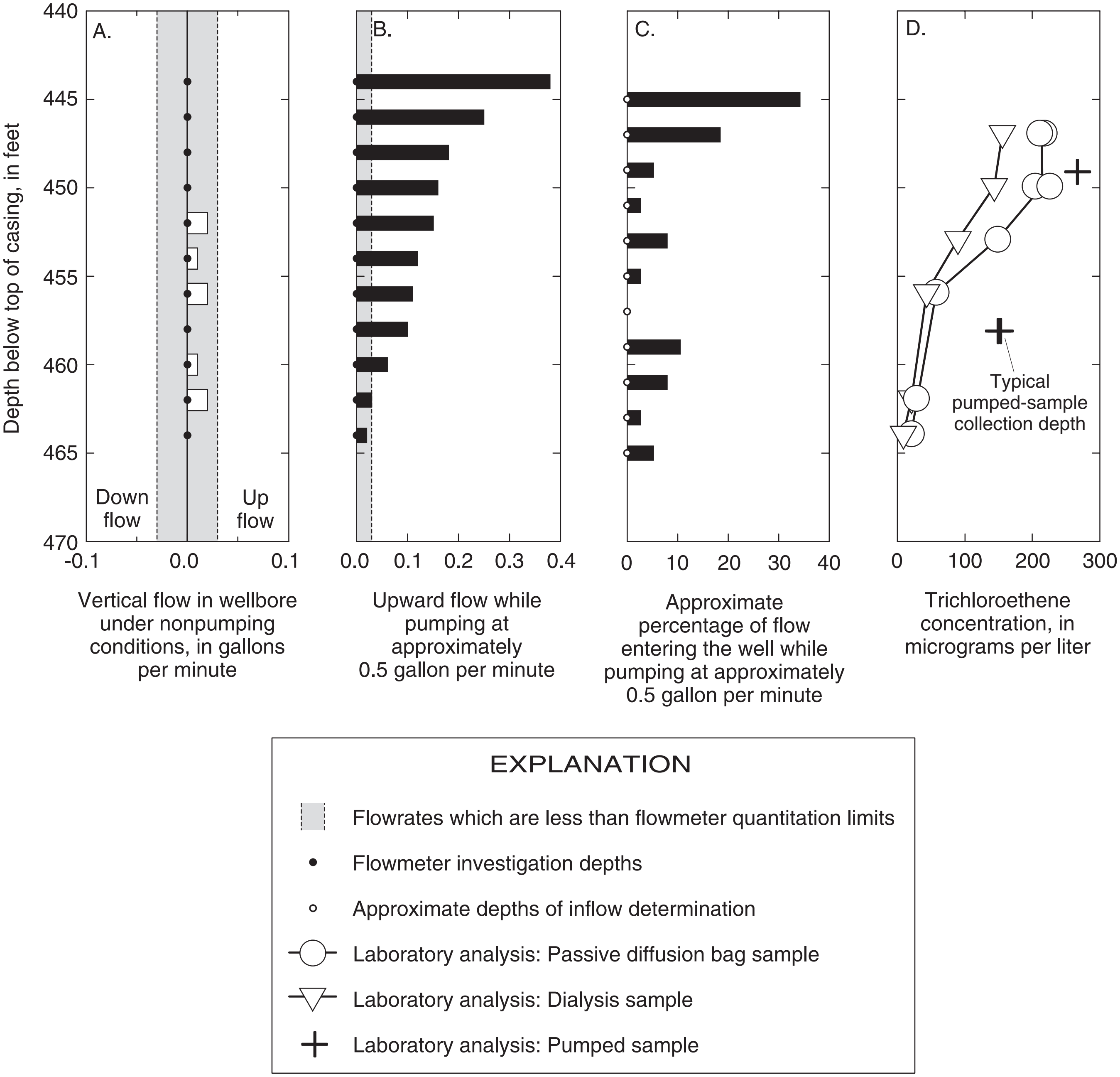

Figure 6. Borehole-flowmeter data under nonpumped and pumped conditions, approximate water-yielding zones during pumping, and trichloroethene concentrations in dialysis samples, passive diffusion bag samples, and pumped samples at well ell IRP-31, MARBO Annex, Andersen Air Force Base, Guam, April 2002.

A decrease in upward flow under pumping conditions also was observed at some horizons, such as at a depth of 564 ft (fig. 2B). In some cases, small decreases in flow may be due to instrument noise, but because the decrease was observed at 564 ft under pumping conditions of both 0.5 and 1 gal/min, the decrease likely is related to factors outside the well screen. One probable explanation is that the decrease represents a zone of widened borehole outside the casing, such as a dissolution feature or a fracture that straddled the borehole-flowmeter diverter, causing the appearance of water loss by allowing flow around the diverter. The dissolution feature or fracture may not be water-yielding, or the amount of water inflowing from the zone may be small relative to the loss of water by leakage around the diverter. For the purposes of this investigation, such zones are not considered to be major contributors of water to the well under pumping conditions, although there is some uncertainty in this determination.

The borehole-flowmeter data collected under pumping conditions indicate the zones within the borehole that transmit water. The borehole-flowmeter data collected at the Main Base showed that water was entering the boreholes at several horizons in response to pumping (wells IRP-3, IRP-39, and IRP-51; figs. 2B, 3B, and 4B, respectively). In well IRP-51, the amount of flow entering the well at 0.5 gal/min was more uniform along the screen length (fig. 4C) than at wells IRP-3 and IRP-39, where the inflow zones appeared to be more localized (figs. 2C and 3C, respectively). In well IRP-39, the predominant zone of inflowing water was at a depth of 618 ft, with contributing zones at 606 ft and 621 to 625 ft (fig. 3C).

At MARBO Annex in wells IRP-29 and IRP-31, the vertical flow under nonpumping conditions was at amounts below the quantitation limits of the borehole flowmeter (figs. 5A and 6A, respectively), but several horizons yielded water under pumping conditions (figs. 5B and 6B, respectively). Borehole-flowmeter tests in IRP-29 while pumping showed that the screened interval encompassed two distinct water-yielding depths (about 461 to 467 ft and about 477 to 480 ft) separated by a zone of relatively low yield (about 469 to 475 ft) (fig. 5C). Of the two relatively high-yielding zones, the shallowest zone (about 461 to 467 ft) appears to provide most of the water during pumping.

In well IRP-31 at MARBO Annex, inflow to the well during pumping is predominantly through the upper part of the screened interval at depths of about 445 to 447 ft (fig. 6C). In this well, the predominant inflow depth is slightly shallower than the uppermost diffusion sampler.

Comparison of Trichloroethene and Tetrachloroethene Concentrations in Passive Diffusion Bag Samples and Pumped Samples

A number of chlorinated aliphatic compounds were found in ground water from wells tested at the Main Base and MARBO Annex of Andersen AFB (table 4); however, the primary compounds were TCE and PCE. In most comparisons, TCE and PCE concentrations in PDB samples closely matched concentrations in pumped samples (figs. 7 and 8, respectively). Exceptions were in well IRP-31, where the shallowest TCE concentrations were lower in the diffusion samplers than in the pumped sample (fig. 7), and in well IRP-39, where the TCE and PCE concentrations were higher in the diffusion samplers than in the pumped samples (figs. 7 and 8, respectively). As will be discussed, these differences probably are related to vertical translocation of water by the pump or ambient flow during sampling in a chemically stratified aquifer. Both wells IRP-31 (fig. 6D) and IR-39 (fig. 3D) showed stratification of TCE, with higher concentrations near the top than the bottom of the screened interval.

Substantial stratification of TCE was observed in well IRP-31. The TCE concentration was about 211 to 218 µg/L at a depth of 446.9 ft and only 20 µg/L at a depth of 463.9 ft, based on PDB-sampler results (fig. 6D, table 4). The upward increasing concentration in well IRP-31 implies that there may be higher concentrations at shallower depths than the uppermost zone sampled by the PDB samplers (fig. 6D). Because during pumping, most of the water in this well is derived from a horizon shallower than the PDB samplers (fig. 6C), it is probable that the PDB samples represent local concentrations, and the pumped sample primarily represents water derived from a more contaminated zone at a depth of about 444 to 446 ft, slightly shallower than the PDB samplers (fig. 6D). Therefore, it is not surprising that the uppermost PDB sample TCE concentration is slightly lower than the adjacent pumped sample.

Table 4. Laboratory analysis of chlorinated aliphatic compounds showing detections in dialysis samples, passive diffusion bag samples, or pumped samples from ground water in wells, Main Base and MARBO Annex, Andersen Air Force Base, Guam, March-April 2002

[µg/L, micrograms per liter; PDB, passive diffusion bag sample; <, less than; two numbers separated by a comma indicate a sample and duplicate; F, the analyte was positively identified, but the associated numerical value was below the reporting limit; J, the analyte was positively identified, the quantitation is an estimation because it is outside the calibration limits or other Air Force Center for Environmental Excellence acceptance criteria were not met; ---, data not collected or not applicable; shaded values indicate detected concentrations that were not accompanied by data qualifiers]

Well number	Sample identifier	1,1,2-Trichloroethane (µg/L)			1,1-Dichloroethene (µg/L)			Carbon tetrachloride (µg/L)		
		Dialysis	PDB	Pumped	Dialysis	PDB	Pumped	Dialysis	PDB	Pumped
Main Base										
IRP-3	IRP3C	---	<1	<1	---	<1.2	<1.2	---	2.82F	2
	IRP3D	<1	<1	<1	<1.2	<1.2	<1.2	1.52F	3	2
	IRP3E	---	---	<8, <8	---	---	<8, <8	---	---	2.5J, 2.3J
IRP-39	IRP39A	<1, <1	<1	<1, <1	<1.2, <1.2	<1.2	<1.2, <1.2	0.59F, 0.68F	0.93F	0.39F, 0.38F
	IRP39B	---	---	<1, <1	---	---	<1, <1	---	---	0.4J, 0.4J
IRP-51	IRP51A	<1	<1	<1, <1	<1.2	<1.2	<1, <1	<2.1	<2.1	<1, <1
	IRP51B	---	---	<1	---	---	<1.2	---	---	<2.1
	IRP51F	<1	<1	<1	<1.2	<1.2	<1.2	<2.1	<2.1	<2.1
Marbo Annex										
IRP-29	IRP29A	<1	<1	<1	<1.2	<1.2	<1.2	0.35F	0.61F	1.2F
	IRP29F	---	---	<1, <1	---	---	<1, <1	---	---	0.5J, 0.5J
IRP-31	IRP31A	1	1.88, 2.02	2	2	1.7, 2.1	2	<2.1	<2.1, <2.1	<2.1
	IRP31B	1	1.85, 1.97	---	1	1.9, 2.3	---	<2.1	<2.1, <2.1	---
	IRP31C	0.8F	1	---	1F	2	---	<2.1	<2.1	---
	IRP31D	0.37F	0.8F, 0.7F	0.8, 0.9	0.4F	0.8F, 0.9F	1.5, <10	<2.1	<2.1, <2.1	<10, <10
	IRP31E	0.29F	0.3F	---	0.4F	0.6F	---	<2.1	<2.1	---
	IRP31F	<1	0.2J, 0.2F	---	<1.2	0.3F, 0.3J	---	<2.1	<2.1, <2.1	---
	IRP31G	<1	<1	---	<1.2	<1.2	---	<2.1	<2.1	---

Table 4. Laboratory analysis of chlorinated aliphatic compounds showing detections in dialysis samples, passive diffusion bag samples, or pumped samples from ground water in wells, Main Base and MARBO Annex, Andersen Air Force Base, Guam, March-April 2002 (Continued)

Well number	Sample identifier	Chloroform (µg/L)			Chloromethane (µg/L)			*cis*-1,2-Dichloroethene (µg/L)		
		Dialysis	PDB	Pumped	Dialysis	PDB	Pumped	Dialysis	PDB	Pumped
Main Base										
IRP-3	IRP3C	---	0.8F	0.6	---	<1.3	<1.3	---	4.38F	3.4
	IRP3D	0.6	0.7	0.6	0.25F	0.28F	0.23F	2.8	4.1	3.5
	IRP3E	---	---	0.6, 0.6	---	---	<8, <8	---	---	3.5J, 3.4J
IRP-39	IRP39A	0.2F, 0.2F	0.3	0.3F, 0.3F	<1.3, <1.3	<1.3	<1.3, <1.3	0.49F, 0.54F	0.65F	<1.2, <1.2
	IRP39B	---	---	0.2J, 0.3J			<1, <1	---	---	<1, <1
IRP-51	IRP51A	0.2F	0.2F	<1, <1	<1.3	<1.3	<1, <1	<1.2	<1.2	<1, <1
	IRP51B	---	---	0.2F	---	---	0.29F	---	---	<1.2
	IRP51F	0.2F	0.2F	0.2F	<1.3	<1.3	0.47F	<1.2	<1.2	<1.2
Marbo Annex										
IRP-29	IRP29A	0.28F	0.28F	0.4	<1.3	0.3F	0.3F	<1.2	<1.2	<1.2
	IRP29F	---	---	<1, <1	---	---	<1, <1	---	---	<1, <1
IRP-31	IRP31A	0.5	0.6, 0.5	0.7	0.23F	<1.3, <1.3	0.41F	<1.2	<1.2, <1.2	<1.2
	IRP31B	0.4	0.6, 0.6	---	0.45F	<1.3, <1.3	---	<1.2	<1.2, <1.2	---
	IRP31C	0.3F	0.5	---	<1.3	<1.3	---	<1.2	<1.2	---
	IRP31D	0.1F	0.3F, 0.3F	0.3, 0.3	0.24F	0.31F, <1.3	<10, <10	<1.2	<1.2, <1.2	<10, <10
	IRP31E	0.2F	0.2F	---	<1.3	<1.3	---	<1.2	<1.2	---
	IRP31F	0.1F	0.1F, 0.1F	---	<1.3	<1.3, <1.3	---	<1.2	<1.2, <1.2	---
	IRP31G	<0.3	<0.3	---	<1.3	<1.3	---	<1.2	<1.2	---

Table 4. Laboratory analysis of chlorinated aliphatic compounds showing detections in dialysis samples, passive diffusion bag samples, or pumped samples from ground water in wells, Main Base and MARBO Annex, Andersen Air Force Base, Guam, March-April 2002 (Continued)

Well number	Sample identifier	Methylene chloride (μg/L)			Trichloroethene (μg/L)			Tetrachloroethene (μg/L)		
		Dialysis	PDB	Pumped	Dialysis	PDB	Pumped	Dialysis	PDB	Pumped
Main Base										
IRP-3	IRP3C	---	<0.3	<0.3	---	86	83	---	4	4
	IRP3D	<0.3	<0.3	<0.3	71	82	82	2	3	4
	IRP3E	---	---	0.4, <8	---	---	107, 102			4.9J, 4.2J
IRP-39	IRP39A	<0.3, <0.3	<0.3	<0.3, <0.3	19, 20	28	19, 19	23, 23	34	21, 22
	IRP39B	---	---	<1, <1	---	---	20, 21	---	---	23, 24
IRP-51	IRP51A	<0.3	<0.3	<1, <0.3J	12	19	20, 19	0.3F	0.7F	1J, 1J
	IRP51B	---	---	<0.3	---	---	19			0.8F
	IRP51F	<0.3	<0.3	<0.3	13	19	19	0.3F	0.6F	0.8F
Marbo Annex										
IRP-29	IRP29A	<0.3	<0.3	<0.3	0.19F	0.31F	0.98F	1.92	5.64	6.19
	IRP29F	---	---	<1, <1	---	---	1.1, 1.1	---	---	5.4, 5.5
IRP-31	IRP31A	0.18F	<0.3, <0.3	<0.3	156	218, 211	267	0.63F	1.4F, 1.2F	2
	IRP31B	<0.3	<0.3, <0.3	---	144	204, 226	---	0.7F	1.1F, 1.0F	---
	IRP31C	0.21F	<0.3	---	89.64J	149	---	0.3F	0.6F	---
	IRP31D	0.2F	<0.3, <0.3	<10, <10	43	57, 63	153.1, 149.7	<1.4	0.3J, 0.2J	1.1, 1.0
	IRP31E	<0.3	<0.3	---	33	37	---	<1.4	0.2F	---
	IRP31F	<0.3	<0.3, <0.3	---	21	32, 28	---	<1.4	<1.4, <1.4	---
	IRP31G	<0.3	<0.3	---	9	20	---	<1.4	<1.4	---

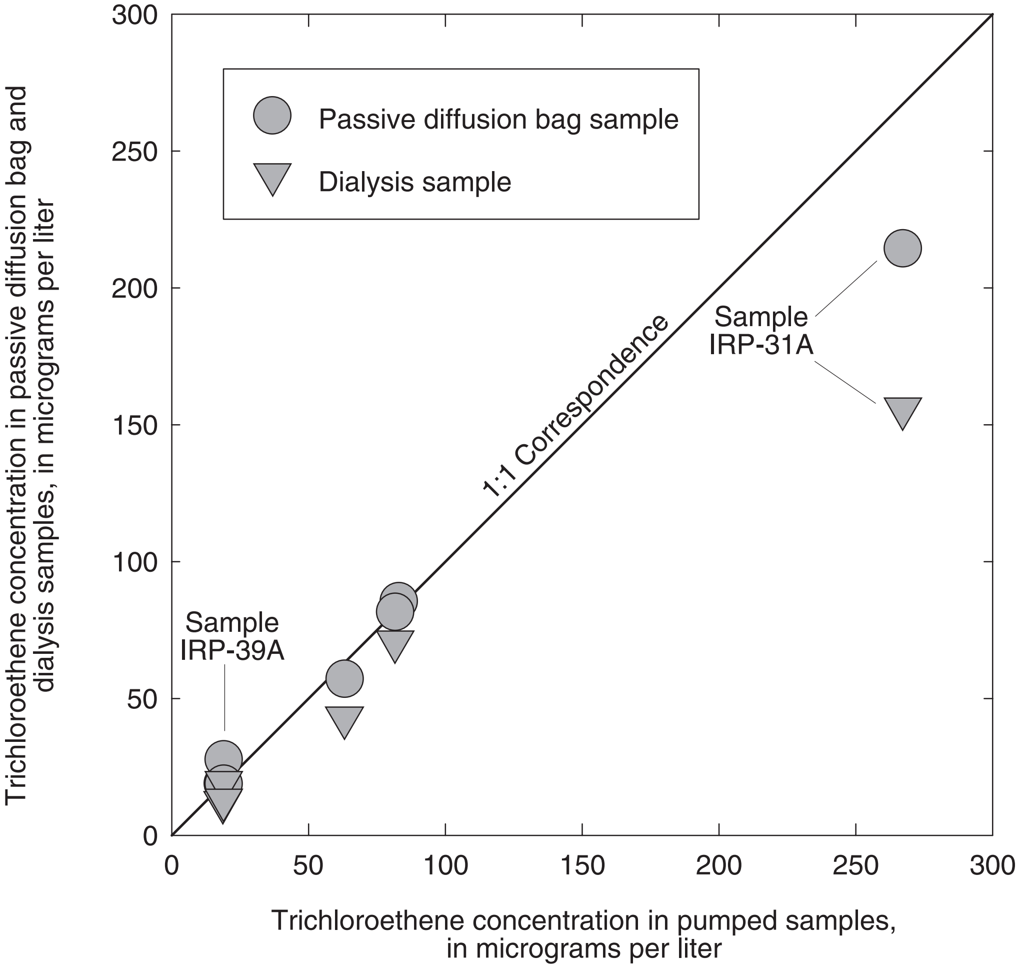

Figure 7. Comparison of trichloroethene concentrations in passive diffusion bag and dialysis samples to trichloroethene concentrations in pumped samples, Main Base and MARBO Annex, Andersen Air Force Base, Guam, April 2002.

The TCE concentration in well IRP-31 at the depth from which pumped samples typically are collected (about 458 ft) was higher in the pumped samples (150 to 153 µg/L) than in the PDB samples (57 to 63 µg/L), as was the case in the 1999 investigation by EA Engineering, Science, and Technology, Inc. (359.3 to 466.8 µg/L in the pumped samples and 37 to 149.7 µg/L in the PDB samples) (T.L. Isakson, EA Engineering, Science, and Technology, Inc., written commun., 2000). The vertical concentration and flowmeter profiles in the well shows that most of the water during pumping is derived from a shallower zone having higher TCE concentrations than the typical pumped-sample collection depth (fig. 6D). Therefore, the most probable explanation for the difference is that the pumped sample represents higher concentration water from a shallower horizon transported downward in response to pumping. A less probable, but possible, alternative explanation is that upward flowing water in the borehole under ambient conditions may have diluted water in contact with the PDB samples below a depth of about 453 ft. There is some uncertainty, however, in attributing the difference to upward flowing water because the amount of potentially upward flowing water is so small that it is less than the quantitation limit of the borehole flowmeter, and may in fact be an artifact of measurement (fig. 6A).

Regardless, it appears that the typical pumping depth in well IRP-31 is deeper than the zone of maximum contamination and maximum yield, and in the shallower, more contaminated part of the well screen, the PDB and pumped-sample concentrations more closely correspond (fig. 6D). At a depth of 446.9 ft, the TCE concentration in the pumped sample was 267 µg/L,

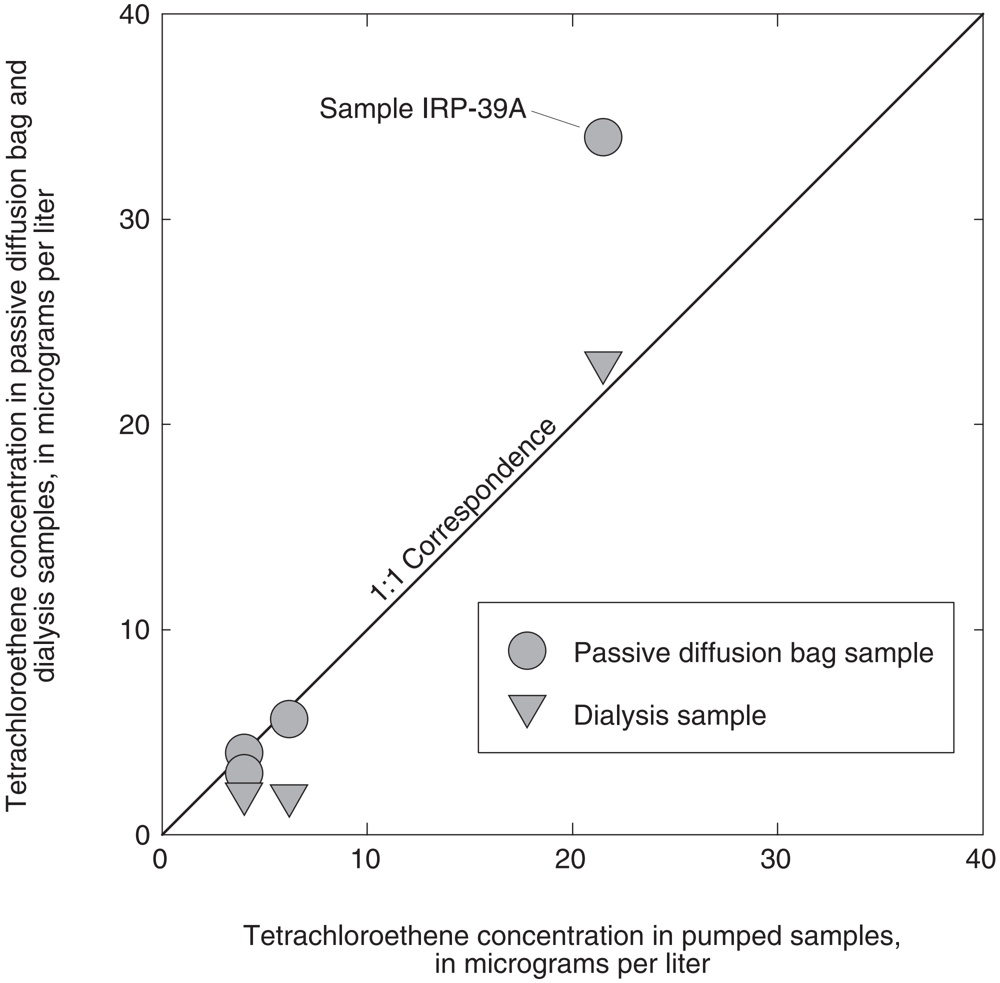

Figure 8. Comparison of tetrachloroethene concentrations in passive diffusion bag and dialysis samples to tetrachloroethene concentrations in pumped samples, Main Base and MARBO Annex, Andersen Air Force Base, Guam, April 2002.

and the average TCE concentration in the PDB samples was 214 µg/L. Moreover, it is highly probable that the PDB samples would more closely correspond to the pumped sample if they were placed at a depth of about 445 ft, corresponding to the zone of maximum water movement into the well during pumping. Therefore, PDB samplers probably are a viable alternative sampling method for well IRP-31 if the samplers are placed at an appropriate depth.

Well IRP-39 also showed contaminant stratification, with the higher concentrations of TCE and PCE at a depth of 611.2 ft than at 627.2 ft (fig. 3D and 3E). In this case, however, the pumped TCE and PCE concentrations (19 and 21.5 µg/L, respectively) at the shallowest sampling depth were lower than the concentrations in the adjacent PDB sampler (28 and 34 µg/L, respectively). Most of the pumped water in well IRP-39 appears to enter the well at a depth of about 618 ft (fig. 3C). Therefore, the pumped samples from depths of 612.9 and 613.8 primarily represent water from a depth of about 618 ft, which contains slightly lower TCE and PCE concentrations than at the pumping depth. The small difference between methods (only 9 µg/L for TCE and 12.5 µg/L for PCE) implies that the use of PDB samplers is a viable sampling alternative for well IRP-39.

In the remaining three test wells (IRP-3, IRP-51, and IRP-29), the TCE or PCE concentrations obtained with the diffusion samplers closely matched the results from pumped sampling (figs. 2D, 4D, and 5D, respectively). The wells appeared to contain less contaminant stratification than in wells IRP-31 and IRP-39, possibly contributing to the closer match between PDB samples and pumped samples than in wells IRP-31 and IRP-39.

No benzene was detected in PDB or pumped samples from well IRP-51, in contrast to an earlier test by EA Engineering Science Inc. (T.L. Isakson, EA Engineering, Science, and Technology, Inc., written commun., 2000).

The analytical results from well IRP-29 demonstrate the ability of PDB samplers to accurately reflect low concentrations (less than 7 µg/L) of PCE. The PCE concentrations in pumped and PDB samples differed by less than 1 µg/L at a depth of about 465 ft in the most productive part of the screened interval (fig. 5D). Although there is some uncertainty in terms of laboratory variations at these low concentrations, the close agreement implies a close correlation between pumped- and PDB-sample results.

In addition, PCE concentrations in well IRP-29 obtained with the PDB samplers appear to reflect zones of water production. The highest PCE concentration (fig. 5D) is associated with the zone showing the greatest percentage of flow entering the well during pumping (fig. 5C). The lowest PCE concentrations are found in the middle of the screened interval adjacent to zones showing little or no water inflow during pumping. The PCE concentration is slightly increased near the bottom of the well screen adjacent to a zone showing a higher degree of water inflow than near the middle of the well screen. These data also are consistent with the PCE concentration from pumped sampling at a depth of 477.4 ft, which was higher than the standardized field analysis of PCE from a PDB sampler at about the same depth (fig. 5D). The pumped sample from 477.4 ft depth probably represents downward movement of water in the wellbore from the productive horizon near the shallower pumped sample. This would explain why the pumped samples are similar in concentration despite the apparent change in concentration indicated by the PDB samplers. In this well, it appears that the PCE concentrations in PDB samplers represent the slight concentration changes with depth and differ by less than 5 µg/L from concentrations in low-flow samples from corresponding depths.

The close match between PDB sample and pumped sample results shows that PDB samples are a viable alternative sampling method to the existing method of pumped sampling in the test wells at Andersen AFB, Guam. The data also show that, because of contaminant stratification, placement of PDB samplers in the screened interval at an arbitrary depth can produce results that do not represent the zone of highest concentrations. As a general guide to sampler placement in wells at Andersen AFB, VOC concentrations in four out of the five test wells were highest in the shallowest tested horizon (table 5).

Comparison of Passive Diffusion Bag Samples to Dialysis Samples

In all of the side-by-side tests, the regenerated cellulose dialysis samplers produced lower VOC concentrations than the PDB samplers (figs. 2D, 3D, 4D, 5D, and 6D) and in most cases, underestimated the pumped-sample results (figs. 7 and 8). The source of the difference is unknown, but a possible explanation is related to the biodegradation of the dialysis membrane. Carignan (1984) examined several types of dialysis membranes for suitability in lakebed studies. He found that raw cellulose membranes rapidly degraded in lakebed sediments, and the degradation created a local nutrient demand resulting in high methane and dissolved inorganic carbon concentrations and low dissolved reactive phosphorus and ammonium. He also noted marked deformation of cellulose acetate membranes, as did Martens and Klump (1980) and Hopner (1981).

A previous investigation of regenerated cellulose samplers in wells showed that in an anaerobic petroleum hydrocarbon-contaminated aquifer, marked degradation was observed on several of the membranes, as evidenced by discoloring (Vroblesky and Pravecek, 2002). Despite the discoloring, the concentrations of VOCs appeared similar to those in the PDB samplers. In the present investigation, however, the VOC concentrations in the degraded regenerated cellulose dialysis samplers were consistently lower than in the PDB samplers.

This investigation differed from the previous investigation in the type of contaminant examined and in the length of time the samplers were deployed. The previous investigation was in anaerobic water with a high availability of oxidizable organic carbon, and the primary contaminants were petroleum hydrocarbons. In the present investigation, the aquifer was aerobic with an extremely low concentration of oxidizable organic carbon, and the primary contaminants were chlorinated solvents. It is possible that in the organic carbon-limited aquifer of northern Guam, the cellulose membrane may have provided sufficient organic carbon to create local environments that were more conducive

Table 5. Standardized concentrations of trichloroethene and tetrachloroethene by field gas chromatography in passive diffusion bag samples and dialysis samples, Main Base and MARBO Annex, Andersen Air Force Base, Guam, April 2002

[µg/L, micrograms per liter; ---, sample not analyzed or not collected; J, the analyte was positively identified, the quantitation is an estimate because it is ouside the calibration limits or other Air Force Center for Environmental Excellence acceptance criteria were not met; two values separated by a comma indicate a sample and duplicate]

Well number	Trichlorothene in passive diffusion bag samples, in µg/l	Trichlorothene in dialysis samples, in µg/L	Tetrachlorothene in passive diffusion bag samples, in µg/L	Tetrachlorothene in dialysis samples, in µg/L
Main Base				
IPR-3A	87	60	5J	3J
IPR-3B	87	50	6	2J
IPR-3C	86	---	4J	---
IPR-3D	86	57	4J	2J
IPR-3E	82	50	3J	2J
IPR-3F	76, 71	---	3J, 3J	---
IPR-3G	71	54	3J	2J
IPR-3H	70	50	3J	1J
IPR-3I	71	48	3J	1J
IPR-3J	60	48	3J	1J
IPR-3K	64	48	2J	1J, 1J
IRP-39A	28	21	34	20
IRP-39B	25	17	25	15
IRP-39C	23	15	22	12
IRP-39D	20	16	15	13
IRP-39E	16	---	9	---
IRP-39F	16	12	8	6
IRP-39G	13	11	6	3
IRP-51A	19	13	<6	<6
IRP-51B	18	7J	<6	<6
IRP-51C	16	8	<6	<6
IRP-51D	16	9	<6	<6
IRP-51E	18	12	<6	<6
IRP-51F	19	14	<6	<6
IRP-51G	15	12	<6	<6
MARBO Annex				
IRP-29A	---	---	6	---
IRP-29B	---	---	4	---
IRP-29C	---	---	3	---
IRP-29D	---	---	1	---
IRP-29E	---	---	1	---
IRP-29F	---	---	1	---
IRP-29G	---	---	2	---
IRP-31A	218	---	---	---
IRP-31B	196	---	---	---
IRP-31C	149	---	---	---
IRP-31D	76	---	---	---
IRP-31E	50	---	---	---
IRP-31F	37	---	---	---
IRP-31G	27	---	---	---

to TCE and PCE degradation than in the aquifer, resulting in decreased concentrations. Although no elevated concentrations of dehalogenation byproducts (such as *cis*-1,2-dichloroethene or vinyl chloride) were observed in dialysis samples relative to PDB and pumped samples, these compounds would not be expected to persist in the aerobic ground water of Guam. In addition, the samplers in the previous investigation were left in place for only 14 days, whereas the samplers in the present investigation were left in place for 22 to 23 days. The extra time the samplers were deployed during the present investigation may have allowed for increased effects from sampler degradation, resulting in anomalously low concentrations. The observation by Carignan (1984) that membrane degradation can affect water chemistry indicates that microbial activity on the membrane surface can affect sampling results.

Comparison of Chloride in Nylon-Screen Samples, Dialysis Samples, and Pumped Samples

Chloride concentrations in nylon-screen samplers were compared with chloride concentrations in dialysis samples to examine the ability of the samplers to provide concentrations of inorganic solutes. Although chloride is not a solute of concern at the facility, it was chosen as the representative solute because a large vertical variation in the concentration within the screened interval was expected. The results showed both nylon-screen and dialysis samplers were capable of determining the depth of chloride stratification in well IRP-29, however, the nylon-screen samplers produced slightly lower chloride concentrations than the corresponding dialysis samplers at depths with elevated chloride concentrations (table 6, fig. 9). The chloride concentration (188.3 mg/L) measured in the pumped sample from well IRP-29 from a depth of 477.4 ft was between the concentrations detected in the nearby nylon-screen samples (114.3 mg/L at 1.5 ft shallower and 227.7 mg/L at 1.5 ft deeper) and dialysis samples (188.8 mg/L 1 ft deeper), making it unclear whether the dialysis sample or the nylon-screen sample provided the more accurate result. The reason for the discrepancy is unknown. Previous investigations in Minnesota and Texas showed close matches between chloride concentrations in nylon-screen and pumped samples (Vroblesky and others, 2002).

One difference in methods between the historical and the present investigation is screen-mesh size. The mesh size used in the present investigation (47 μ was substantially smaller than that used in the previous investigation (125 and 250 μ). To determine whether mesh size could be a factor in the results of the present investigation, the mesh sizes were compared under laboratory conditions in a saltwater solution. The results of the investigation showed that after 13 days of equilibration in constantly stirred water containing 73,300 mg/L of chloride, a dialysis sampler produced 72,400 mg/L, and a nylon-screen sampler with a 125-μ mesh produced 73,400 mg/L, whereas a nylon-screen sampler with a 47-μ mesh produced only 60,700 mg/L. Thus, screen size may be a factor affecting equilibration, and the nylon-screen samplers at well IRP-29 may have underestimated the chloride concentrations.

Practical Considerations for the Use of Passive Diffusion Bag Samplers in Wells at Andersen Air Force Base

There are substantial practical differences between pumped sampling and passive diffusion bag sampling at Andersen AFB. The time onsite per well is about 2 to 2.5 hours with pumped sampling and about 1 hour with diffusion sampling using multiple diffusion samplers. Less time would be required for diffusion sampling once a target horizon was determined and that horizon was targeted with only one or two PDB samplers. When the pumped sampling approach is used at the site with a portable pump, the pump and equipment must be decontaminated between wells by pumping 30 gal of carbon-filtered water with detergent and 30 gal of carbon-filtered water through the system. The pump must then be scrubbed, which requires about 1.5 hours, including transport to the decontamination station. The method requires periodic rinsate blanks to verify the quality of the decontamination procedure. PDB samplers are disposable and require no decontamination. In addition, there is substantially more wastewater produced in pumped sampling than in diffusion sampling.

The large depth to ground water (350 to 550 ft) at Andersen AFB limits the available conventional sampling tools to positive-displacement pumps; however, the pump-failure rate is high because of corrosion by the aquifer water. The pumps and associated air compressor are not needed with PDB sampling. Moreover, the PDB samplers allow collection of samples from more discrete horizons than with pumped sampling.

Table 6. Concentrations of chloride in nylon-screen, dialysis, and pumped samples from ground water in wells at the Main Base and MARBO Annex, Andersen Air Force Base,Guam, April 2002

[<, less than; two numbers separated by a comma indicate a sample and duplicate; ---, data not collected or not applicable]

Well number	Chloride, in milligrams per liter		
	Nylon-screen sample	Dialysis sample	Pumped sample
Main Base			
IRP3C	---	---	30.2
IRP3D	---	28.78	30.7
IRP3E	---	28.95	---
IRP3G	---	27.85	---
IRP3H	---	28.58	---
IRP3I	---	29.19	---
IRP3J	---	29.04	---
IRP3K	---	27.15	---
IRP39A	---	16.25J	127.4, 166.2J
IRP39B	---	67.3	---
IRP39C	---	115.4	---
IRP39D	---	134.8	---
IRP39E	---	159.5	---
IRP39F	---	172.8	---
IRP39G	---	178.4	---
IRP51A	---	99.8	390.2
IRP51B	---	99.5	---
IRP51C	---	104.3	---
IRP51D	---	106.3	---
IRP51E	---	122.3	---
IRP51F	---	308.5	588.3
IRP51G	---	628.5	---
MARBO Annex			
IRP29A	36.44	36.32, 36.23	38.36
IRP29B	---	35.95	---
IRP29C	35.45	35.27	---
IRP29D	83.33	117.2	---
IRP29E	103.1	144.3	---
IRP29F	114.3	188.8, 188.1	188.3
IRP29G	222.7	440.4, 432	---
IRP31A	---	144.7	133.8
IRP31B	---	140.5, 140.5	---
IRP31C	---	168.4	---
IRP31D	---	211	---
IRP31E	---	250.1	---
IRP31F	---	305.3 ,302.5	222.8
IRP31G	---	342.7	---

The pumping approach does have some advantages over PDB sampling. Pumps allow water samples to be collected for a variety of contaminants other than VOCs. At the present time (2002), diffusion sampling has been extensively tested only in relation to VOC sampling. In addition, for this investigation, three trips to the site were required to install and recover the PDB samplers. The first trip involved flowmeter testing, the second involved deployment, and the third trip was for sampler recovery; however, these trips were for initial setup only. If PDB sampling were used as a long-term monitoring option, then once the deployment depth was determined, future sampling events would involve only a single trip to the wells for sampler recovery, at which time a new sampler could be deployed and left in place until the next sampling event. Table 7 lists suggested placement depths of PDB samplers as monitoring tools for wells examined in this investigation. For application of diffusion samplers in others wells, optimum diffusion-sampler placement within the screened interval would need to be determined by an initial vertical profile using multiple diffusion samplers.

SUMMARY AND CONCLUSIONS

The test wells at Andersen AFB and MARBO Annex are characterized by both hydraulic and chemical differences along the screened intervals. Small amounts of vertical flow were found in all of the test wells, indicating differences in head along the length of the screened intervals, but the flow typically was less than the quantitation limit of the borehole flowmeter. Exceptions are in wells IRP-3 and IRP-39, where downward flow near the bottoms of the wells was detected at rates above the minimum quantitation limit for the borehole flowmeter.

The primary VOC contaminants in wells tested at Andersen AFB and MARBO Annex were TCE and PCE. In most comparisons, TCE and PCE concentrations in PDB samples closely matched concentrations in pumped samples. Exceptions were in wells where pumping or ambient flow may have produced vertical translocation of water in a chemically stratified aquifer (wells IRP-31 and IRP-39). In well IRP-39, the concentrations in the PDB samples were slightly higher (by only 9 μg/L for TCE and 12.5 μg/L for PCE) than the pumped sample, indicating that the PDB samplers are a viable ground-water-sampling option for well IRP-39.

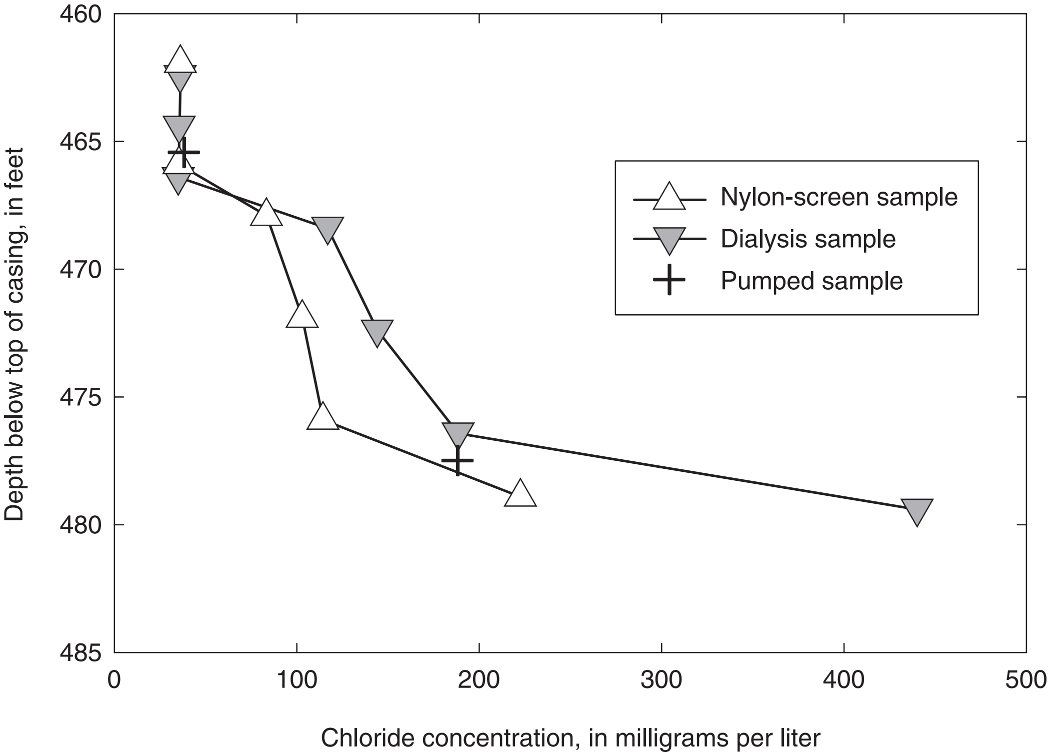

Figure 9. Chloride concentrations in nylon-screen, dialysis, and pumped samples at well IRP-29, MARBO Annex, Andersen Air Force Base, Guam, April 2002.

Table 7. Optimum deployment depths for using passive diffusion bag samplers as monitoring tools for the maximum volatile organic compound concentration, Main Base and MARBO Annex, Andersen Air Force Base, Guam

[ft, feet; ft BTOC, feet below top of casing; ft BLS, feet below land surface}

Well number	Suggested passive diffusion bag sampler deployment information		Depth at which monitoring data are routinely collected (ft BTOC)
	Distance from well bottom to sampler center (ft)	Depth to sampler center (ft BTOC)	
Main Base			
IRP-3	23.3	559.0	566.1
IRP-39	17.3	611.9	613.8
IRP-51	18.9	491.5	491.8
MARBO Annex			
IRP-29	18.3	463.4	477.4
IRP-31	19.2	446.0	458.1

The TCE concentration in well IRP-31 at the depth from which pumped samples typically are collected was higher in the pumped samples than in the PDB samples, as in the 1999 investigation by EA Engineering, Science, and Technology, Inc. Because the highest TCE concentrations and the source of most of the pumped water is shallower than the typical sampling depth in well IRP-31, the most probable explanation for the difference is that the PDB samples represent local concentrations and the pumped sample represents downward movement of more contaminated water. The PDB and pumped-sample concentrations more closely correspond in the shallower, more contaminated part of the well screen, near the zone of maximum pumpage contribution. Therefore, PDB samplers probably are a viable alternative sampling method for well IRP-31, if the samplers are placed at an appropriate depth.

In the remaining three test wells (IRP-3, IRP-29, and IRP-51), the TCE or PCE concentrations obtained with the PDB samplers closely matched the result from pumped sampling. These three wells appeared to contain less contaminant stratification than wells IRP-31 and IRP-39, possibly contributing to the closer match between PDB samples and pumped samples from the wells compared to wells IRP-31 and IRP-39. In well IRP-29, the PDB samplers appeared to accurately represent aquifer PCE concentrations at low levels (less than 7 μg/L).

The close match between PDB sample and pumped sample results shows that PDB samples are a viable sampling alternative to the existing method of pumped sampling in the test wells at Andersen AFB, Guam. The data indicate that placement of PDB samplers in the screened interval at an arbitrary depth can produce results that do not represent the zone of highest concentrations. As a general guide to sampler placement in wells at Andersen AFB, VOC concentrations in four out of the five test wells were highest in the shallowest tested horizon.

In all of the side-by-side tests, the regenerated cellulose dialysis samplers produced lower VOC concentrations than the PDB samplers, and in most cases, underestimated the pumped results. The source of the difference is unknown, but the samplers were deployed for a longer time (22 to 23 days) than in a previous investigation (14 days), possibly allowing biodegradation of the dialysis membrane to influence the contaminant concentration.

The comparison of chloride concentrations in nylon-screen samplers to chloride concentrations in dialysis and pumped samples showed both nylon-screen and dialysis samplers were capable of determining the depth of chloride stratification in well IRP-29; however, the nylon-screen samples showed lower chloride concentrations than the dialysis samples at several depths. The reason for the discrepancy in this investigation is unknown but may be related to nylon-screen-mesh size.

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USGS **Vroblesky** Evaluation of Passive Diffusion Bag Samplers, Dialysis Samplers, and Nylon-Screen Samplers in Selected Wells at Andersen Air Force Base, Guam, March–April 2002

WRIR 03-4157