AP - 077

STAGE 1
WORKPLAN

4/14/2008

R. T. HICKS CONSULTANTS, LTD.

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April 14, 2008

Mr. Glenn von Gonten
New Mexico Oil Conservation Division
1220 South St. Francis Drive
Santa Fe, New Mexico 87505

RE: Pride Energy South Four Lakes #14 Pit
NMOCD #AP-077

Dear Mr. von Gonten:

Please accept this Stage 1 Abatement Plan for the above-referenced site as fulfillment of Pride Energy's mandate to submit an Abatement Plan.

The schedule calls for a drilling rig to commence characterization activities as early as late April. By June, the results of the proposed characterization program will permit the design of a ground water remedy for the site. A second submission to NMOCD describing the proposed remedy should be ready by August. Because Rule 19 requires public notice within 15-days after the Division determines the plan is administratively complete, we ask that the Division withhold such a determination until your review of the second planned submission. This protocol will allow Pride to implement a single public notice for a Stage 1 & 2 Abatement plan. Your thoughts on this idea are appreciated.

Sincerely,
R.T. Hicks Consultants, Ltd.

Randall T. Hicks
Principal

Copy: Pride Energy
NMOCD District II
New Mexico State Land Office

April 14, 2008

South Four Lakes #14 Site
Stage 1 Abatement Plan

T11S R34E Section 35 Unit Letter I
NMOCD #AP-77

R.T. Hicks Consultants, Ltd.
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April 14, 2008

South Four Lakes #14 Site
Stage 1 Abatement Plan

T11S R34E Section 35 Unit Letter I
NMOCD #AP-77

prepared for :

New Mexico Oil Conservation Division

1220 South St. Francis Drive
Santa Fe, NM 87505

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Appendix B: Laboratory Certificate of Analysis

Appendix C: Chloride Conceptual Model

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Plate 1: Regional Location Map

Plate 2: 2004 Aerial Photograph of Site and Environs

Plate 3: Geologic Map

Plate 4: USGS Regional Water Table Map

Plate 5: Soil Sampling Map

Plate 6: Proposed Boring Location Map

1.0 Description of the Site

1.1 Location

Plate 1 shows the location of the South Four Lakes #14 reserve pit site relative to four additional Pride Energy Company sites and Tatum, New Mexico. Plate 2 is a 2004 aerial photograph showing the general area of the site. The site is in T11S R34E Section 35 Unit Letter I (N 33° 19' 13.7", W 103° 28' 30.31", API # 30-025-36844). To access the site:

1. Drive west on Highway 380 ten miles from the intersection of Highway 380 and Highway 206 in Tatum, New Mexico
2. Proceed north about 1.0 miles on the dirt access road, then proceed northwest at the fork in the access road.
3. The site is at the end of the access road.

1.2 Site History

Date	Description
August 30, 2004	Pride submits APD (C-101) for South Four Lakes Unit #14
September 8, 2004	Well spudded
October 25, 2004	Well drilled to total depth
March 10, 2005	Set pump in well
August 21, 2007	C-144 Pit Closure Form submitted to NMOCD
December 10, 2007	Revised C-144 submitted by Elke Environmental to NMOCD
January 30, 2008	C-141 submitted by Elke Environmental to NMOCD
February 12, 2008	NMOCD requires submission of Abatement Plan

2.0 Site Investigation Results

2.1 Inventory of Water Wells

See Appendix A for a map and table showing the water wells within one mile of the South Four Lakes sites. Copies of driller's logs of wells near the site are also included in Appendix A.

2.2 Site Geology

The South Four Lakes Unit and associated State lease areas are located in the High Plains portion of the Great Plains physiographic province with flat-laying sedimentary rocks, ranging in age from Permian to Miocene. The majority of the area is covered with a shallow soil horizon (Kimbrough-Lea Complex; sandy loams overlying caliche) and sparsely vegetated with grasses, and brush. Plate 3 depicts a geologic map that shows the Ogallala Formation is present throughout much of the area. The Ogallala Formation is underlain by the Triassic Dockum Group red beds. The Chinle Formation, the uppermost unit of the Dockum Group, is composed of a thick sequence of red clays that act as an aquiclude.

The sediments which form the Ogallala Formation were carried eastward from uplifted areas to the west as braided fluvial deposits which consist of clays, very fine-grained sands, some gravels and occasional lenses of calcite-cemented sands and clays. The Ogallala Formation is generally coarser-grained in the lower portion of the unit with a basal conglomerate present at some locations. Finer-grained sand and caliche are common in the upper portion of the Ogallala Formation. The base of the Ogallala Formation (and thus the top of the Chinle Formation) is estimated between 90 to 110 feet below ground surface (bgs).

2.3 Site Ground Water Hydrology

This section provides an estimate of subsurface hydraulic characteristics and an estimate of the rate and direction of contaminant migration.

Depth to ground water in the area ranges from approximately 24 ft to 38 ft bgs. The saturated thickness of the Ogallala Formation is estimated at approximately 65 to 85 ft based on driller logs for area water wells permitted by the New Mexico Office of the State Engineer (OSE).

A regional potentiometric surface map created using 1996 water level data obtained from the USGS database indicates that ground water in the area is flowing in a southeast direction (see Plate 4) with a hydraulic gradient of approximately 0.003 ft/ft. Data from wells within several miles of the site demonstrate that the ground water gradient at the site likely flows to the southeast with a gradient of approximately 0.002 ft/ft. This is local condition is consistent with the prevailing regional characteristics.

Site-specific values for hydraulic conductivity of the Ogallala Formation range between 0.5 ft/day to 50 ft/day based on published information (Nicholson and Clebsch, 1961; Ash, 1963; McAda and Hart, 1985; Secor, 1995; and Musharrafieh, 1999). Based on professional experience in determining hydraulic conductivity values from aquifer tests of the uppermost portion of the Ogallala Aquifer in Lea County, we estimate a value of 3 ft/day to 10 ft/day for the portion of the saturated zone most likely impacted by the release.

Application of Darcy's Law with the aforementioned estimates suggests an average linear ground water velocity as low as 10 ft/year for the uppermost portion of the Ogallala Aquifer if we assume a porosity of 25%, a hydraulic conductivity of 3 ft/day and a hydraulic gradient of 0.002. Using the higher values of 10 ft/year for hydraulic conductivity and 0.003 for the gradient yields an average linear velocity of about 40 feet/year. An aquifer test is necessary to quantify hydraulic conductivity values, ground water velocity rates, specific capacity, well yields, and other parameters at the site.

The chloride migration rate from a source is approximately the same as the ground water velocity.

2.4 Vertical and Horizontal Extent and Magnitude of Vadose-Zone Impairment

Plate 5 is a reproduction of the field map created by Elke Environmental showing the locations of the five sample borings within the former pit. The chloride concentrations with depth were derived from data in NMOCD on-line files for Case #AP-077.

Based upon these data and experience at similar sites, brine from the pit probably migrated through the vadose zone to ground water via saturated flow during operation of the drilling pit or sometime during the drying process. At this site the depth to water is about 23 feet below ground surface and borehole characterization within the excavation terminated at 10-18 feet below the excavation (or 15-23 feet below grade). Unlike several other sites, chloride concentrations do not decline with depth. The data from the vadose zone suggest that saturated flow between the bottom of the pit and ground water occurred throughout the area of the pit.

The Laws of Fluid Dynamics, the Law of Gravity, the lithology of the unsaturated zone and years of experience characterizing releases from pits, ponds, lagoons, pipeline releases and tanks allow us to conclude with a very high degree of scientific certainty that the migration of brine released from the former reserve pit migrated vertically and a horizontal dispersion in the vadose zone of only a few feet.

2.5 Surface-Water Hydrology

There are no surface water bodies within a mile of any of the South Four Lakes reserve pit sites with the exception of a windmill pond located approximately 1,500 ft northwest (up-gradient) from the South Four Lakes #13 well site. A recent water quality analysis from this windmill indicates concentrations of constituents of concern (chlorides – 167 mg/L, sulfate – 218 mg/L, TDS – 1,210 mg/L, and BTEX - <0.001 mg/L) are near or below WQCC standards.

3.0 Define Vertical and Horizontal Extent and Magnitude of Ground-Water above WQCC Standards

3.1 Evaluation of Existing Data

At the South Four Lakes #14 site, a ground water sample from Monitoring Well #1 collected on January 24th, 2008 shows a chloride concentration of 1,910 mg/L. The March 13th sampling event shows a chloride concentration of 1,710 mg/L and a total dissolved solids (TDS) concentration of 4,260 mg/L. The laboratory did not detect regulated hydrocarbons in the March sample. Analyses for regulated hydrocarbons did not occur in the January sampling event.

On March 27th, Hicks Consultants performed a conductivity profile of the screened interval at MW-1 at the South Four Lakes Unit #15 reserve pit site (located 4,500 feet south-southwest of the #14 site) to determine if any chemical stratification in the uppermost saturated zone is present. First, we obtained a sample from the un-purged well by slowly lowering a bailer (to minimize mixing within the well) into the upper 3-feet of the water table to retrieve a sample for chloride, TDS, and specific conductivity analysis. We then slowly lowered the bailer to the base of the well and obtained a sample from a depth of 20-feet below the water table. In theory the flow-through bailer with a ball seal should capture a discrete sample from the base of the well, provided the ball valve does not leak and disturbance in the well is minimal. In addition, the well was purged of more than 3 wells volumes (12 gallons) by hand bailing and a third sample was collected for the same suite of analyses. The results of these procedures are as follows:

Sample Interval	Specific Conductance	Chloride	TDS
	mS/cm	mg/L	mg/L
0-3 feet below water table	3.72	1,100	2,200
17-20 feet below	9.33	3,100	5,400

water table			
After purging	13.3	4,700	8,100

These data suggest that chemical stratification of the uppermost ground water zone is present at the #15 site. The uppermost portion of the aquifer is moderately impacted by the release from the reserve pit. The observation that the "discrete" sample from the lower 3-feet of the well exhibits a lower chloride concentration than the sample after purging may indicate that the center of mass of released brine is present between the upper 3-feet of the aquifer and the 17-20 foot depth of the lower "discrete" sample. Because all of the South Four Lakes reserve pit sites share a common history, we strongly suspect that the same phenomenon of chemical stratification will be present at all of these sites, including South Four Lakes #14. Additional testing is necessary to confirm these initial findings.

Laboratory analytical reports are included in Appendix B.

Assuming that the release of brine occurred soon after drilling was completed at South Four Lakes #14 (November 2004), then the down gradient extent of ground water impairment could be 150 feet southeast (down gradient) of the pit.

3.2 Proposed Characterization Program

Appendix C presents a conceptual model of chloride fate and transport in an aquifer below a reserve pit release. The following phased-approach is based upon the conceptual model and is intended:

(i) To quantify the volume and geometry of ground water impairment caused by the release from the former reserve pit, and
(ii) To collect data necessary for developing an appropriate ground water restoration strategy.

The characterization program will commence in May and will include:

1. **Install Boring, Temporary Monitoring Wells, or Permanent Monitoring Wells**
   Using a hollow stem auger, drill one boring about 35 feet due east of the eastern edge of the former pit, a second boring about 35 feet due south of the former pit, and a third boring approximately 75 feet southeast (down gradient) of existing MW-1 as shown (See B-1, B-2 and B-3) on Plate 6. During this activity this plan calls for:
   a. Collection of a ground water grab sample through the drill pipe after penetration of the upper 5-feet of the saturated zone. Field determination of specific conductance will be performed at 10-foot intervals starting at 5-feet into the saturated zone until the on-site hydrogeologist is satisfied that the vertical extent of ground water impairment is sufficiently defined, or until the Red Beds of the Dockum group is encountered;
   b. Installation of additional borings as necessary such that the on-site hydrogeologist is satisfied that the vertical and horizontal extent of ground water impairment is sufficiently defined;
   c. Based upon the results of ground water sampling program described above, the on-site hydrogeologist may elect to install a temporary ground water monitoring well (or well cluster) at a boring location to confirm the findings through the collection of a sample consistent with standard industry methods (see Appendix D).

d. After consideration of maintaining integrity of oil field equipment, access to the producing well, and other technical factors, the on site hydrogeologist will either convert a temporary well to a permanent down gradient monitoring well or install new wells such that the site will have two monitoring wells that are located near the down gradient edge of ground water quality impairment as defined by a field conductivity that correlates into a total dissolved solids concentration of less than 1000 mg/L based on comparison with previous laboratory results.

e. The permanent monitoring wells will be installed and sampled following development using methods that are consistent with industry standards (see Appendix D).

2. Install Monitoring/Recovery Well

After the boring and sampling program described above defines the approximate geometry of the zone of aquifer impairment, this plan proposes to drill a 4-inch monitor/recovery well at a point where highest salinity can be expected provided that the expected salinity exceeds 5,000 mg/L (a salinity that may be acceptable to mature livestock according to NMSU Guide M-112, 1995).

a. The construction of any recovery well will be determined on-site and based upon the results of the boring characterization. This well construction will allow the collection of representative samples from the ground water depth zone exhibiting the highest impact (as measured by specific conductance) as well as recovery pumping from this zone.

b. If data suggest that downward vertical migration of released brine may continue within the aquifer, the on-site hydrogeologist may install a recovery will with two screened intervals permitting focused recovery pumping via well packers or a second recovery well completed in a deeper horizon.

3. Evaluation of Well Boring Data

The on-site geologist will create a lithologic log of the soil borings and refine the geologic and hydrologic characteristics.

4. Source Removal and Testing

If the characterization program shows that ground water at this site exceeds 5,000 mg/L TDS, this plan proposes a 3-month source removal and test pumping program. The purpose of this pumping program is to determine if ground water may be restored within a short time and to assist in the evaluation of ground water abatement alternatives. Water from the recovery well will flow to the produced water storage tanks and thence to the nearby disposal well. Experience at similar sites suggests a pumping rate of 2 to10 gallons per minute is possible from wells completed in the upper portion of the Ogallala Aquifer. The proposed testing program consists of:

a. Measurement of water levels in the recovery well and monitoring well(s):
    i. On a daily/hourly basis for the first two days of pumping,
    ii. On a weekly basis for the first month of pumping, and
    iii. On a monthly basis for the next two months,
    iv. On a daily/hourly basis after cessation of pumping (after at least 2-days of pumping) to collect recovery data for calculation of hydrologic parameters.

b. Collection of ground water samples for chloride and TDS analysis on a monthly basis from the recovery well
c. Measurements of the flow rate and total flow from the recovery well at each site visit
d. Collection of ground water samples from all monitor wells before and after the 3-month pumping program.

4.0 Assessment of Restoration Options

4.1 Vadose Zone Remedy

To prevent infiltration of precipitation through the impacted vadose zone below the former pit and the attendant flux of chloride to ground water, this plan proposes to submit a vadose zone remedy proposal after characterization of ground water is complete.

4.2 Ground Water Remedy

Our preliminary evaluation of alternatives does not support a program that treats ground water and creates a waste (e.g. brine) that must be managed. Our analysis suggests that creation of a brine waste and the management of the waste and treatment system results in less benefit to the environment by creating more contamination (i.e. air pollution, dust, energy consumption) than it cures.

A strategy of pump-and-use without treatment provides the highest environmental benefit if a bona fide use presently exists for the ground water. In the absence of a bona fide use for this ground water (e.g. future oil well drilling in the immediate area), a pump-and-use strategy probably does not create the highest environmental benefit.

If the ground water at the site is suitable for mature livestock (i.e. less than 5,000 mg/L TDS), then a pump-and-dispose ground water restoration strategy results in the loss of a useful commodity and is not consistent with conservation and best management practices for the ground water resource. A pump-and-dispose strategy may be reasonable where the migration of 5,000+ mg/L TDS ground water threatens a drinking water well, where ground water must be less than 1,000 mg/L. However, such a scenario is not probable at this site in the near-term.

If a pump-and-use ground water restoration program is not possible and pump-and-dispose provides little benefit, the evaluation of alternatives suggests that natural restoration in conjuction with a ground water monitoring program provides the highest environmental benefit.

5.0 Report to NMOCD

After 3-months of monitoring ground water via the above mentioned wells, a report will evaluate the data collected and:

1. Identify the location of any additional monitoring wells necessary to define the extent and magnitude of ground water impairment to the extent necessary for completing a ground water restoration program,
2. Recommend:
   a. Implementation of a pump-and-use ground water restoration program, or

    b. Implementation of a natural restoration strategy.

3. Provide a description, justification and design of the preferred ground water restoration strategy
4. Provide a long-term monitoring program.

5.1 Quality Assurance Plan

The quality protocols proposed for this program are presented in Appendix D

5.2 Order of Proposed Activities

1. Submit this Abatement Plan to NMOCD
2. Conduct characterization program
3. Commence ground water testing program
4. Submit a vadose zone remedy proposal
5. Submit an ground water remedy proposal to NMOCD
6. Implement NMOCD-approved ground water remedy and begin long-term monitoring

Plates

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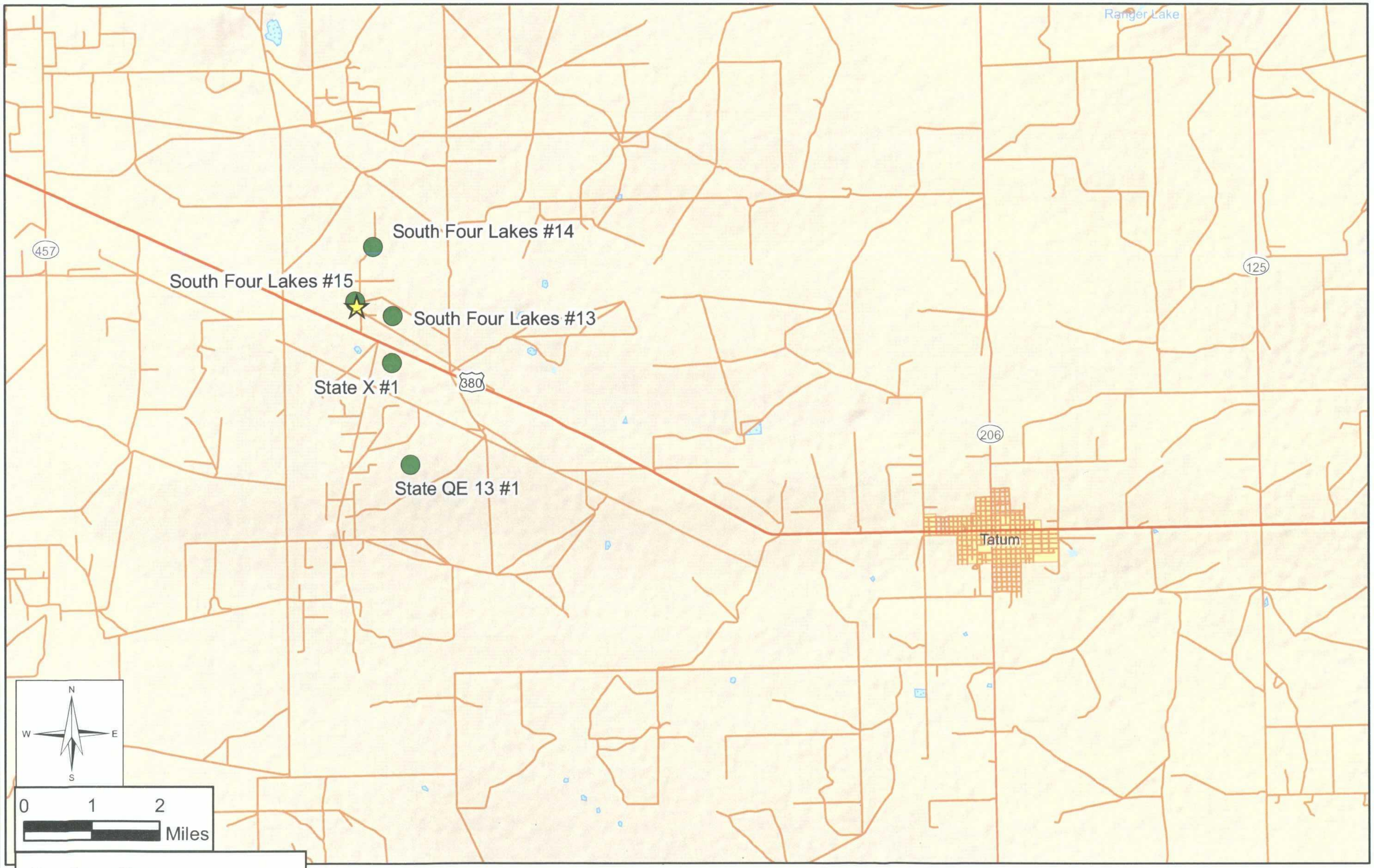

Explanation

☆ South Four Lakes Tank Battery

● Pride Energy Site

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Region Location Map Relative to Tatum, NM

Pride Energy Company: South Four Lakes Abatement Plans

Plate 1

April 2008

4/1/2008

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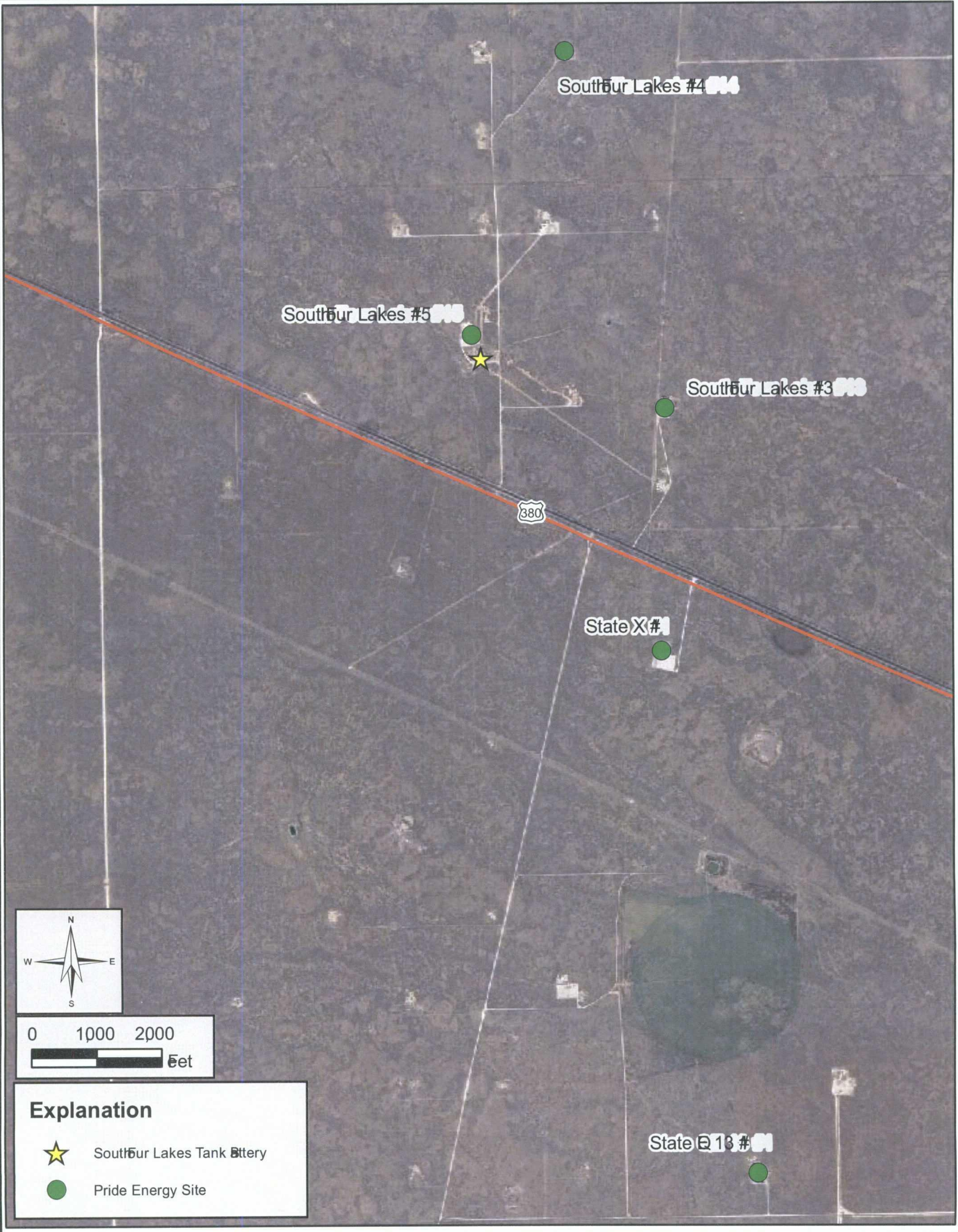
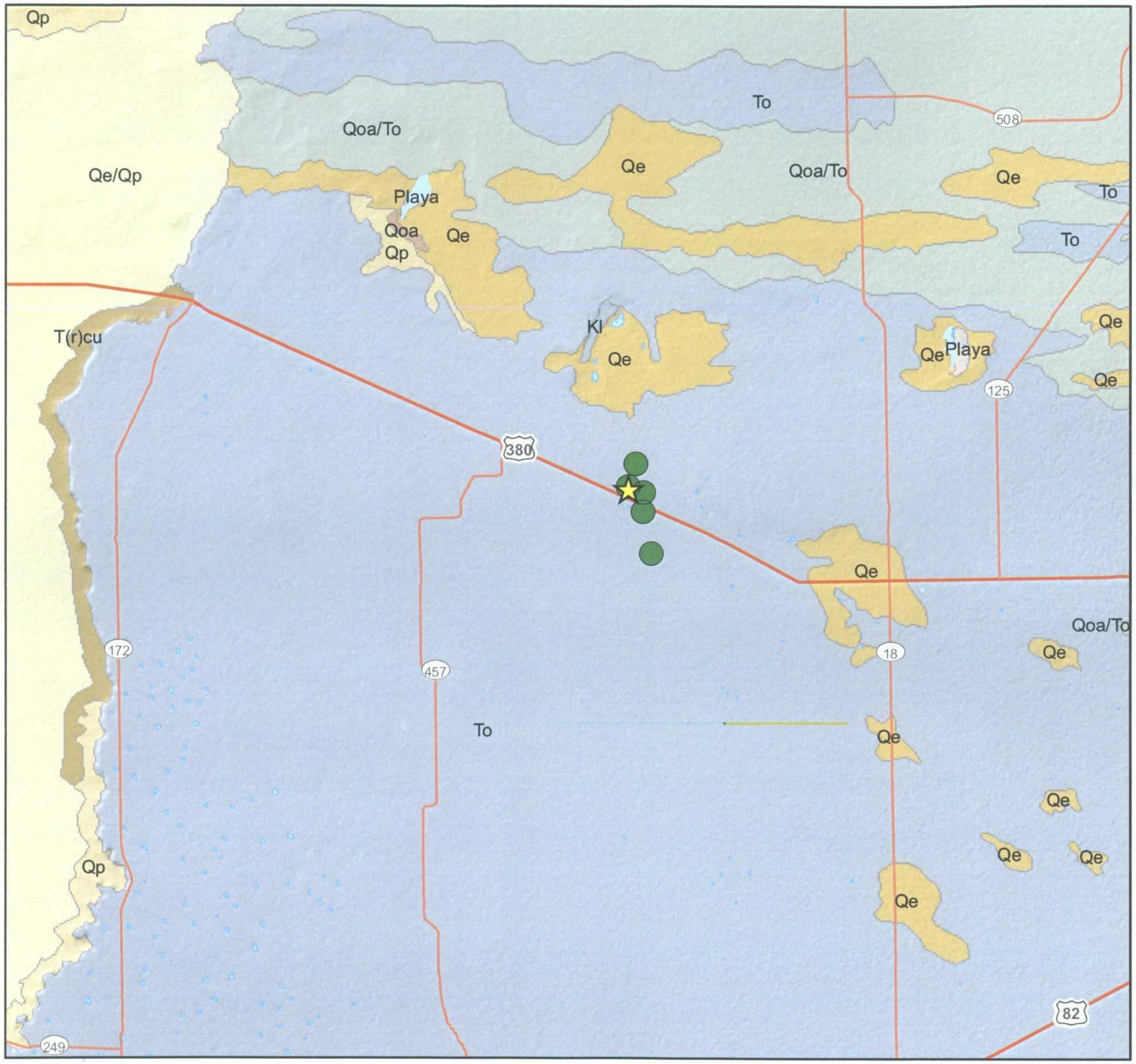


R.T. Hicks Consultants, Ltd 901 Rio Grande Blvd NW Suite F-142 Albuquerque, NM 87104 Ph: 505.266.5004	2004 Aerial of Site and Environs	Plate 2
	Pride Energy Company: South Four Lakes Abatement Plans	April 2008

4/10/2008



Explanation

● Pride Energy Site

☆ South Four Lakes Tank Battery

Geologic Map

Map Unit, Description

▨	Kl, Lower Cretaceous, undivided
▨	Playa, Playa Deposits
▨	Qe, Quaternary-Eolian Deposits
▨	Qe/Qp, Quaternary-Eolian Piedmont Deposits
▨	Qoa, Quaternary-Older Alluvial Deposits
▨	Qoa/To, Quaternary-Older Alluvial Deposits/Ogalalla
▨	Qp, Quaternary-Piedmont Alluvial Deposits
▨	T(r)cu, Triassic-Upper Chinle Group
▨	To, Tertiary-Ogallala Formation

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Geologic Map

Pride Energy Company: South Four Lakes
Abatement Plans

Plate 3

April 2008

4/10/2008

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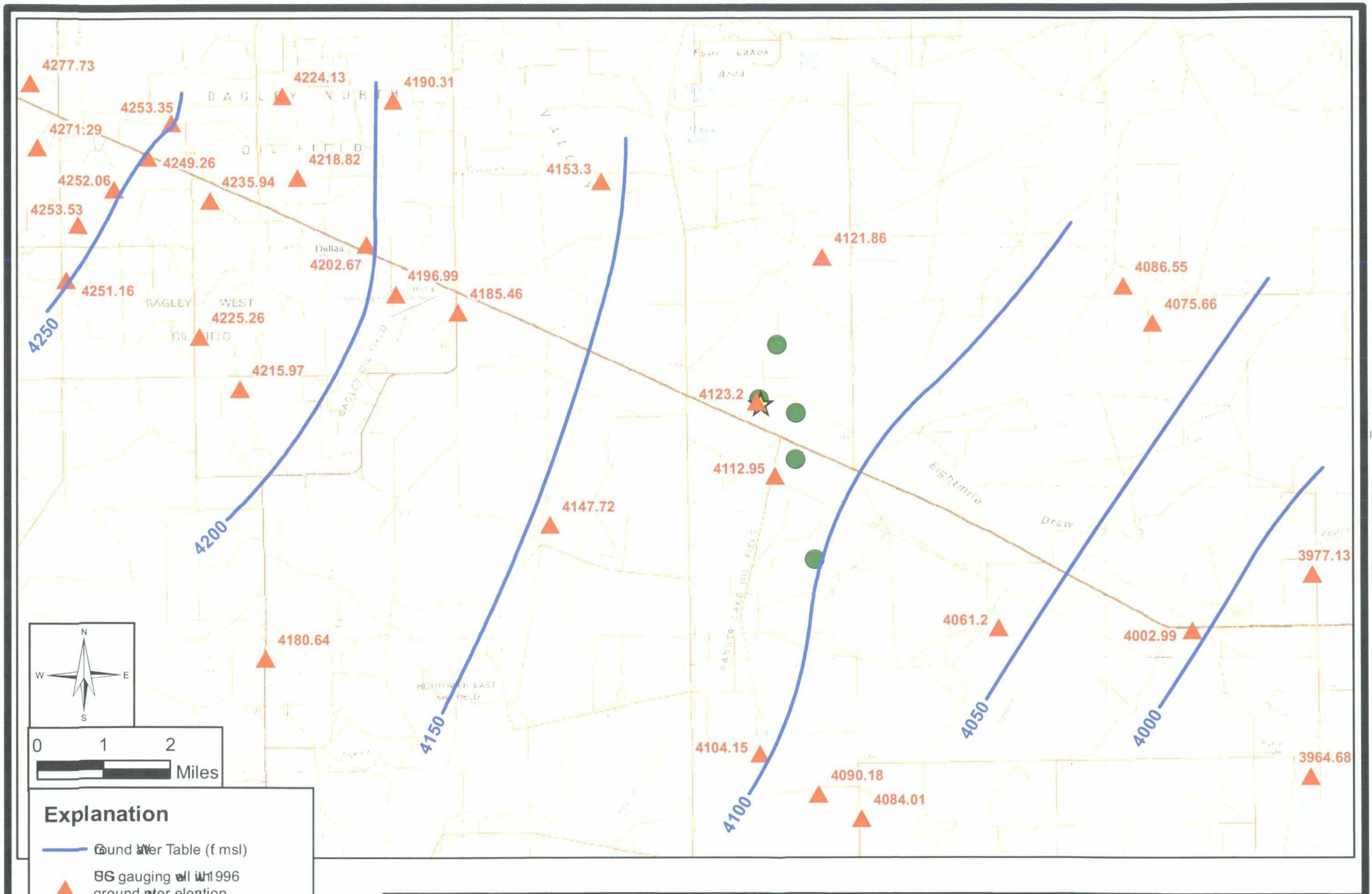

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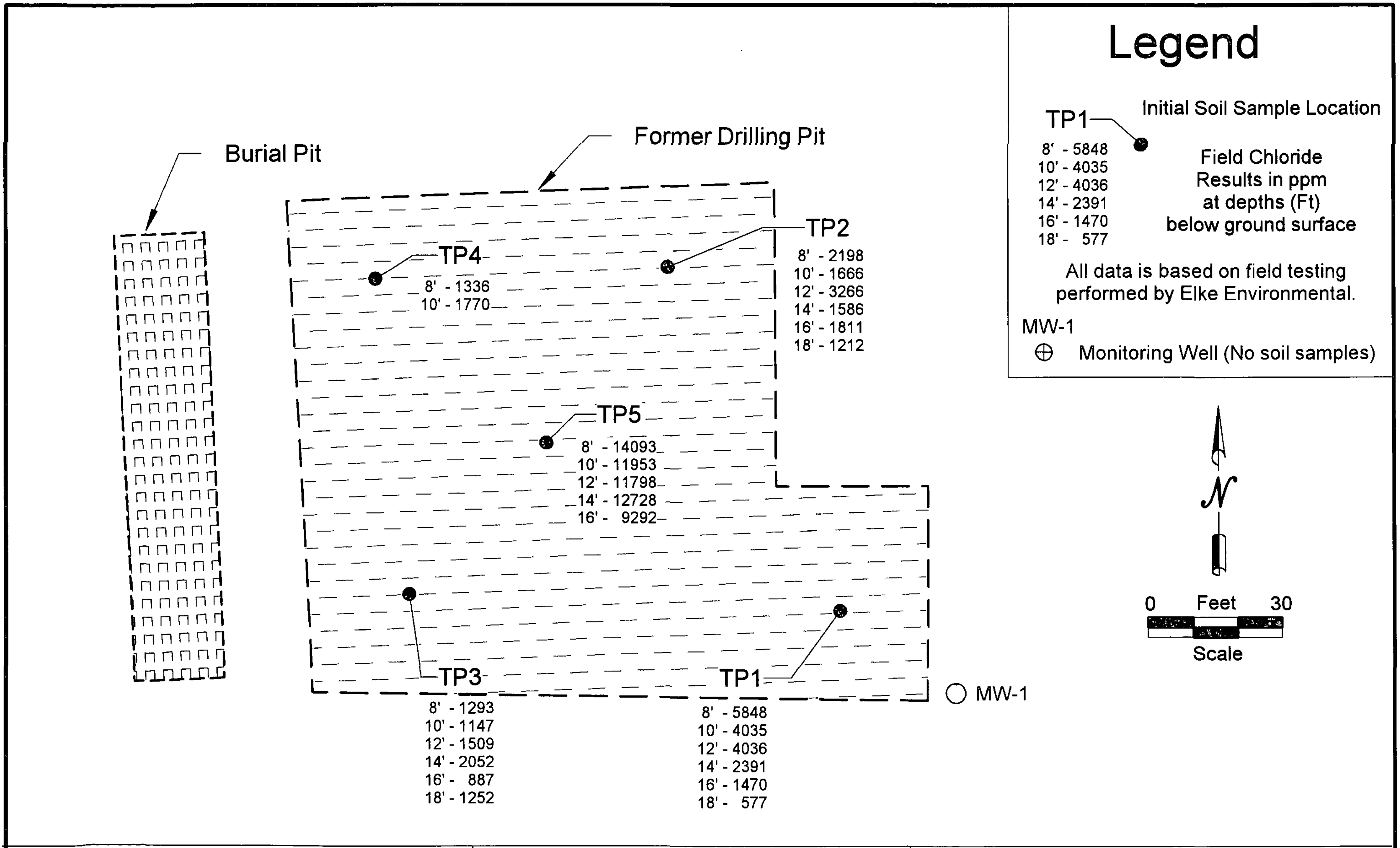
Regional Ground Water Table Map (USGS, 1996)

Pride Energy Company: South Four Lakes
Abatement Plans

Plate 4

April 2008

4/10/2008



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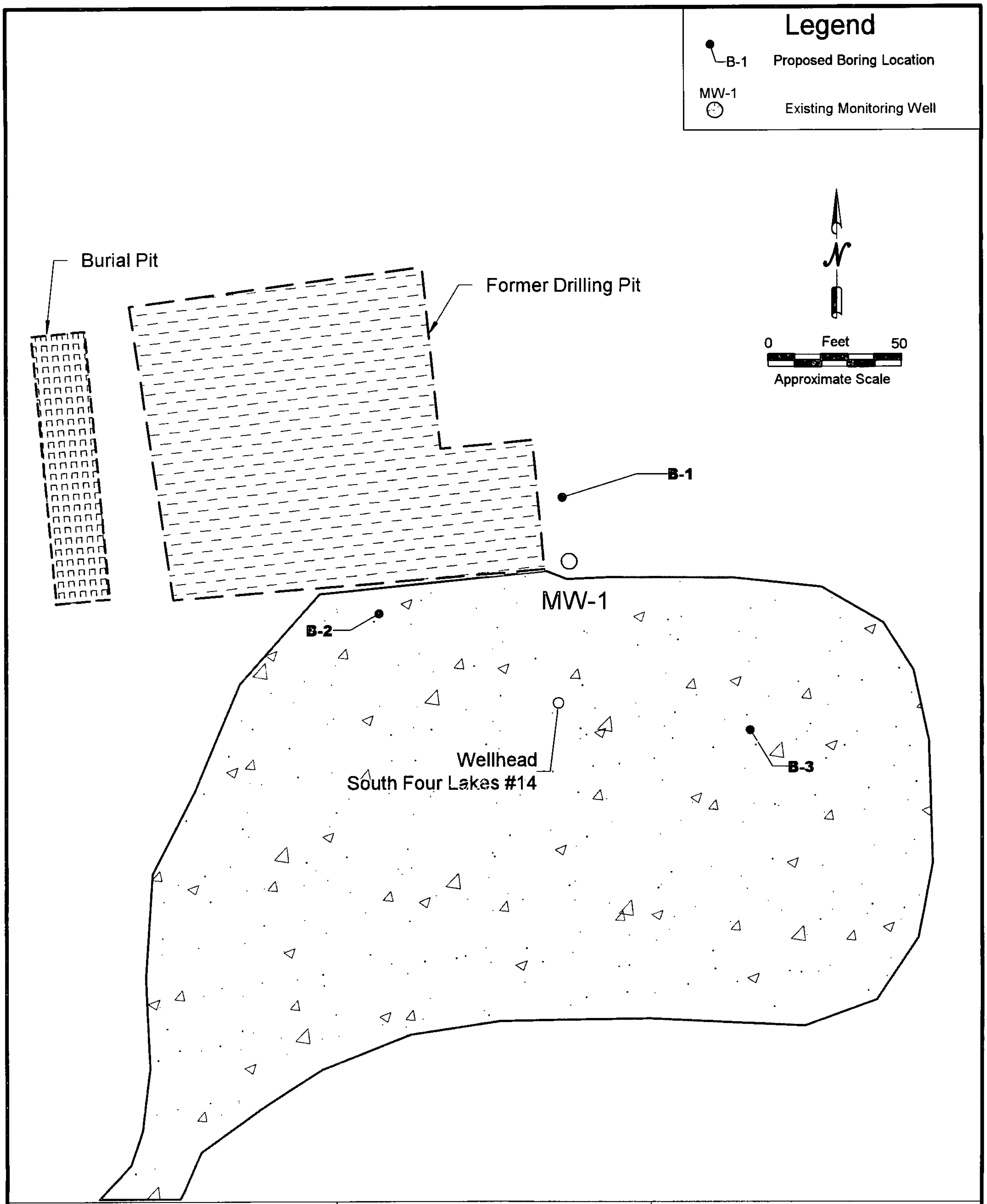
PRIDE ENERGY COMPANY
SOUTH FOUR LAKES #14
T11S - R34E - Section 35 - Unit I
Lea County, New Mexico

Plate 5

SOIL SAMPLING MAP
January 10-11, 2008



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PRIDE ENERGY COMPANY
SOUTH FOUR LAKES #14
T11S - R34E - Section 35 - Unit I
Lea County, New Mexico

Plate 6

PROPOSED BORING LOCATIONS

Appendix A

OSE well locations within 1/2 mile;

OSE well logs

R.T. Hicks Consultants, Ltd.

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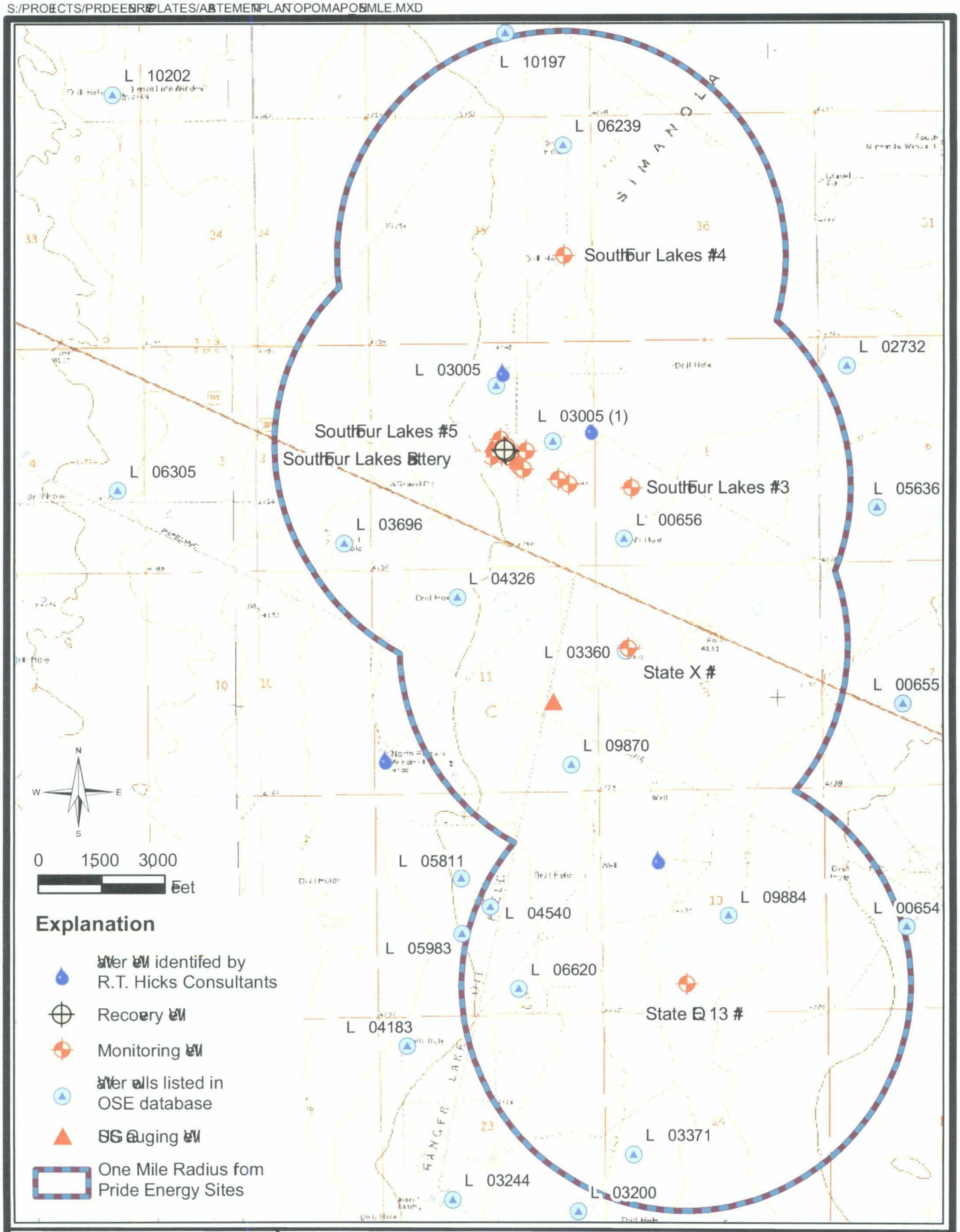


R.T. Hicks Consultants, Ltd 901 Rio Grande Blvd NW Suite F-142 Albuquerque, NM 87104 Ph: 505.266.5004	Topographic Map Showing Water Wells Within One Mile of Pride Energy Sites	Plate A-1
	Pride Energy Company: South Four Lakes Abatement Plans	April 2008

Table A-1
OSE Wells within one mile of Pride Energy Sites

Well Number	File Number	USE	Start Date	Finish Date	Well Depth	Depth to Water	TWS	RNG	SEC	Q	Q2	Q3	EASTING	NORTHING	X_COORD	Y_COORD
L 00654 DCL	L 00654	STK			0	0	12S	35E	18	3	2		644464	3682854	644413	3683058
L 00655 DCL	L 00655	STK			0	0	12S	35E	7	3	2		644440	3684458	644389	3684662
L 00656 DCL	L 00656	STK			0	0	12S	34E	1	3	3		642442	3685633	642391	3685837
L 02732	L 02732	PRO	1/5/1955	1/5/1955	155	48	12S	35E	6	1	1		644036	3686864	643985	3687068
L 02732 APPRO	L 02732	PRO	1/5/1955	1/5/1955	155	48	12S	35E	6	1	1		644036	3686864	643985	3687068
L 03005	L 03005	PRO			0	0	12S	34E	2	2	1	3	641520	3686724	641469	3686928
L 03005 (1)	L 03005 (1)	PRO			0	0	12S	34E	2	2	4	3	641928	3686329	641877	3686533
L 03200	L 03200	PRO	5/14/1956	5/15/1956	128	50	12S	34E	23	4	4		642120	3680809	642069	3681013
L 03200 APPRO	L 03200	PRO	5/14/1956	5/15/1956	128	50	12S	34E	23	4	4		642120	3680809	642069	3681013
L 03244	L 03244	DOM	8/1/1956	8/2/1956	75	40	12S	34E	23	3	4	1	641212	3680893	641161	3681097
L 03244 APPRO	L 03244	DOM	8/1/1956	8/2/1956	75	40	12S	34E	23	3	4	1	641212	3680893	641161	3681097
L 03360	L 03360	PRO	11/6/1956	11/6/1956	110	36	12S	34E	12	1	3		642453	3684830	642402	3685034
L 03360 APPRO	L 03360	PRO	11/6/1956	11/7/1956	110	36	12S	34E	12	1	3		642453	3684830	642402	3685034
L 03371	L 03371	PRO	11/27/1956	11/28/1956	120	35	12S	34E	24	3	1		642518	3681217	642467	3681421
L 03371 APPRO	L 03371	PRO	11/27/1956	11/28/1956	120	35	12S	34E	24	3	1		642518	3681217	642467	3681421
L 03696	L 03696	PRO	9/21/1957	9/21/1957	112	43	12S	34E	3	4	4		640430	3685602	640379	3685806
L 03696 APPRO	L 03696	PRO	9/21/1957	9/21/1957	112	43	12S	34E	3	4	4		640430	3685602	640379	3685806
L 04146	L 04146	PRO	5/21/1959	5/22/1959	105	40	12S	34E	15	0	0		639873	3682970	639822	3683174
L 04146 APPRO	L 04146	PRO	5/21/1959	5/22/1959	105	40	12S	34E	15	0	0		639873	3682970	639822	3683174
L 04183	L 04183	PRO	6/10/1959	6/11/1959	135	45	12S	34E	23	1	1		640885	3681991	640834	3682195
L 04183 APPRO	L 04183	PRO	6/10/1959	6/11/1959	135	45	12S	34E	23	1	1		640885	3681991	640834	3682195
L 04326	L 04326	PRO	11/17/1959	11/18/1959	85	35	12S	34E	11	1	2		641241	3685213	641190	3685417
L 04326 APPRO	L 04326	PRO	11/17/1959	11/18/1959	85	35	12S	34E	11	1	2		641241	3685213	641190	3685417
L 04540	L 04540	PRO			0	0	12S	34E	14	0	0		641480	3682995	641429	3683199
L 04540 APPRO	L 04540	PRO			0	0	12S	34E	14	0	0		641480	3682995	641429	3683199
L 05636 EXP	L 05636	STK			0	0	12S	35E	6	3	0		644255	3685859	644204	3686063
L 05811	L 05811	PRO	11/10/1965	11/11/1965	114	43	12S	34E	14	1	4		641270	3683203	641219	3683407
L 05983	L 05983	PRO	7/6/1966	7/6/1966	94	47	12S	34E	14	3	2		641277	3682801	641226	3683005
L 06239	L 06239	PRO	12/1/1967	12/1/1967	72	25	11S	34E	35	2	2		642001	3688442	641950	3688646
L 06305 EXP	L 06305	PRO			0	0	12S	34E	4	4	2		638812	3685981	638761	3686185
L 06620 EXP	L 06620	STK			0	0	12S	34E	14	4	3		641689	3682405	641638	3682609
L 09870 EXP	L 09870	PRO			0	0	12S	34E	11	4	4		642062	3684020	642011	3684224
L 09884	L 09884	PRO	11/28/1986	11/28/1986	132	40	12S	34E	13	4	1	1	643192	3682933	643141	3683137
L 10197	L 10197	STK		1/1/1939	50	0	11S	34E	26	4	1		641588	3689243	641537	3689447
L 10202	L 10202	STK	1/1/1939	1/1/1939	70	0	11S	34E	28	4	4		638774	3688804	638723	3689008

Well logs are included on the attached cd.

Appendix B

Laboratory Certificate of Analysis

R.T. Hicks Consultants, Ltd.
901 Rio Grande Blvd. NW, Suite F-142
Albuquerque, NM 87104

Analytical Report 299691

for

R.T. Hicks Consultants, LTD

Project Manager: Randy Hicks

Pride Energy Company

South Four Lakes #14

20-MAR-08

ENVIRONMENTAL
LAB OF

12600 West I-20 East Odessa, Texas 79765

Texas certification numbers:
Houston, TX T104704215

Florida certification numbers:
Houston, TX E871002 - Miami, FL E86678 - Tampa, FL E86675
Norcross(Atlanta), GA E87429

South Carolina certification numbers:
Norcross(Atlanta), GA 98015

North Carolina certification numbers:
Norcross(Atlanta), GA 483

Houston - Dallas - San Antonio - Austin - Tampa - Miami - Latin America
Midland - Corpus Christi - Atlanta

XENCO Laboratories

20-MAR-08

Project Manager: **Randy Hicks**
R.T. Hicks Consultants, LTD
901 Rio Grande Blvd. NW, Suite F-142
Albuquerque, NM 87104

Reference: XENCO Report No: **299691**
Pride Energy Company
Project Address: T11S-R34E, Section 35, Unit Letter I

Randy Hicks:

We are reporting to you the results of the analyses performed on the samples received under the project name referenced above and identified with the XENCO Report Number 299691. All results being reported under this Report Number apply to the samples analyzed and properly identified with a Laboratory ID number. Subcontracted analyses are identified in this report with either the NELAC certification number of the subcontract lab in the analyst ID field, or the complete subcontracted report attached to this report.

Unless otherwise noted in a Case Narrative, all data reported in this Analytical Report are in compliance with NELAC standards. Estimation of data uncertainty for this report is found in the quality control section of this report unless otherwise noted. Should insufficient sample be provided to the laboratory to meet the method and NELAC Matrix Duplicate and Matrix Spike requirements, then the data will be analyzed, evaluated and reported using all other available quality control measures.

The validity and integrity of this report will remain intact as long as it is accompanied by this letter and reproduced in full, unless written approval is granted by XENCO Laboratories. This report will be filed for at least 5 years in our archives after which time it will be destroyed without further notice, unless otherwise arranged with you. The samples received, and described as recorded in Report No. 299691 will be filed for 60 days, and after that time they will be properly disposed without further notice, unless otherwise arranged with you. We reserve the right to return to you any unused samples, extracts or solutions related to them if we consider so necessary (e.g., samples identified as hazardous waste, sample sizes exceeding analytical standard practices, controlled substances under regulated protocols, etc).

We thank you for selecting XENCO Laboratories to serve your analytical needs. If you have any questions concerning this report, please feel free to contact us at any time.

Respectfully,

Brent Barron, II
Odessa Laboratory Manager

Sample Cross Reference 299691

R.T. Hicks Consultants, LTD, Albuquerque, NM

Pride Energy Company

Sample Id	Matrix	Date Collected	Sample Depth	Lab Sample Id
MW-1	W	Mar-13-08 10:10		299691-001

ENVIRONMENTAL LAB OF

Certificate of Analysis Summary 299691

R.T. Hicks Consultants, LTD, Albuquerque, NM

Project Name: Pride Energy Company

Project Id: South Four Lakes #14
Contact: Randy Hicks
Project Location: T11S-R34E, Section 35, Unit Letter I

Date Received in Lab: Mar-14-08 05:16 pm
Report Date: 20-MAR-08
Project Manager: Brent Barron, II

Analysis Requested	*Lab Id:*	299691-001				
	Field Id:	MW-1				
	Depth:					
	Matrix:	WATER				
	Sampled:	Mar-13-08 10:10				
Anions by EPA 300/300.1	*Extracted:*					
	Analyzed:	Mar-15-08 10:29				
	Units/RL:	mg/L	RL			
Chloride		1710	25.0			
Sulfate		390	25.0			
BTEX by EPA 8021B	*Extracted:*	Mar-19-08 10:00				
	Analyzed:	Mar-19-08 17:44				
	Units/RL:	mg/L	RL			
Benzene		ND	0.0010			
Toluene		ND	0.0020			
Ethylbenzene		ND	0.0010			
m,p-Xylenes		ND	0.0020			
o-Xylene		ND	0.0010			
Xylenes, Total		ND				
Total BTEX		ND				
Metals per ICP by SW846 6010B	*Extracted:*					
	Analyzed:	Mar-17-08 16:36				
	Units/RL:	mg/L	RL			
Calcium		585	0.100			
Magnesium		112	0.010			
Potassium		5.05	0.500			
Sodium		511	0.500			
TDS by SM2540C	*Extracted:*					
	Analyzed:	Mar-17-08 16:00				
	Units/RL:	mg/L	RL			
Total dissolved solids		4260	5.00			
Total Alkalinity by EPA 310.1	*Extracted:*					
	Analyzed:	Mar-17-08 14:15				
	Units/RL:	mg/L	RL			
Alkalinity, Total (as CaCO3)		230	4.00			

Brent Barron
Odessa Laboratory Director

Flagging Criteria

X In our quality control review of the data a QC deficiency was observed and flagged as noted. MS/MSD recoveries were found to be outside of the laboratory control limits due to possible matrix /chemical interference, or a concentration of target analyte high enough to effect the recovery of the spike concentration. This condition could also effect the relative percent difference in the MS/MSD.

B A target analyte or common laboratory contaminant was identified in the method blank. Its presence indicates possible field or laboratory contamination.

D The sample(s) were diluted due to targets detected over the highest point of the calibration curve, or due to matrix interference. Dilution factors are included in the final results. The result is from a diluted sample.

E The data exceeds the upper calibration limit; therefore, the concentration is reported as estimated.

F RPD exceeded lab control limits.

J The target analyte was positively identified below the MQL(PQL) and above the SQL(MDL).

U Analyte was not detected.

L The LCS data for this analytical batch was reported below the laboratory control limits for this analyte. The department supervisor and QA Director reviewed data. The samples were either reanalyzed or flagged as estimated concentrations.

H The LCS data for this analytical batch was reported above the laboratory control limits. Supporting QC Data were reviewed by the Department Supervisor and QA Director. Data were determined to be valid for reporting.

K Sample analyzed outside of recommended hold time.

* Outside XENCO'S scope of NELAC Accreditation

Recipient of the Prestigious Small Business Administration Award of Excellence in 1994.
Certified and approved by numerous States and Agencies.
A Small Business and Minority Status Company that delivers SERVICE and QUALITY
Houston - Dallas - San Antonio - Austin - Tampa - Miami - Atlanta - Corpus Christi - Latin America

	Phone	Fax
11381 Meadowglen Lane Suite L Houston, Tx 77082-2647	(281) 589-0692	(281) 589-0695
9701 Harry Hines Blvd , Dallas, TX 75220	(214) 902 0300	(214) 351-9139
5332 Blackberry Drive, Suite 104, San Antonio, TX 78238	(210) 509-3334	(210) 509-3335
2505 N. Falkenburg Rd., Tampa, FL 33619	(813) 620-2000	(813) 620-2033
5757 NW 158th St, Miami Lakes. FL 33014	(305) 823-8500	(305) 823-8555
6017 Financial Dr., Norcross, GA 30071	(770) 449-8800	(770) 449-5477

Page 5 of 14

Form 2 - Surrogate Recoveries

Project Name: Pride Energy Company

Work Order #: 299691 **Project ID:** South Four Lakes #14

Lab Batch #: 717610 **Sample:** 299447-003 S / MS **Batch:** 1 **Matrix:** Water

Units: mg/L

	SURROGATE RECOVERY STUDY				
BTEX by EPA 8021B **Analytes**	**Amount Found [A]**	**True Amount [B]**	**Recovery %R [D]**	**Control Limits %R**	**Flags**
1,4-Difluorobenzene	0.0307	0.0300	102	80-120	
4-Bromofluorobenzene	0.0320	0.0300	107	80-120	

Lab Batch #: 717610 **Sample:** 299447-003 SD / MSD **Batch:** 1 **Matrix:** Water

Units: mg/L

	SURROGATE RECOVERY STUDY				
BTEX by EPA 8021B **Analytes**	**Amount Found [A]**	**True Amount [B]**	**Recovery %R [D]**	**Control Limits %R**	**Flags**
1,4-Difluorobenzene	0.0309	0.0300	103	80-120	
4-Bromofluorobenzene	0.0322	0.0300	107	80-120	

Lab Batch #: 717610 **Sample:** 299691-001 / SMP **Batch:** 1 **Matrix:** Water

Units: mg/L

	SURROGATE RECOVERY STUDY				
BTEX by EPA 8021B **Analytes**	**Amount Found [A]**	**True Amount [B]**	**Recovery %R [D]**	**Control Limits %R**	**Flags**
1,4-Difluorobenzene	0.0325	0.0300	108	80-120	
4-Bromofluorobenzene	0.0329	0.0300	110	80-120	

Lab Batch #: 717610 **Sample:** 506150-1-BKS / BKS **Batch:** 1 **Matrix:** Water

Units: mg/L

	SURROGATE RECOVERY STUDY				
BTEX by EPA 8021B **Analytes**	**Amount Found [A]**	**True Amount [B]**	**Recovery %R [D]**	**Control Limits %R**	**Flags**
1,4-Difluorobenzene	0.0336	0.0300	112	80-120	
4-Bromofluorobenzene	0.0353	0.0300	118	80-120	

Lab Batch #: 717610 **Sample:** 506150-1-BLK / BLK **Batch:** 1 **Matrix:** Water

Units: mg/L

	SURROGATE RECOVERY STUDY				
BTEX by EPA 8021B **Analytes**	**Amount Found [A]**	**True Amount [B]**	**Recovery %R [D]**	**Control Limits %R**	**Flags**
1,4-Difluorobenzene	0.0327	0.0300	109	80-120	
4-Bromofluorobenzene	0.0328	0.0300	109	80-120	

** Surrogates outside limits; data and surrogates confirmed by reanalysis
*** Poor recoveries due to dilution
Surrogate Recovery [D] = 100 * A / B
All results are based on MDL and validated for QC purposes.

Form 2 - Surrogate Recoveries

Project Name: Pride Energy Company

Work Order #: 299691
Project ID: South Four Lakes #14
Lab Batch #: 717610
Sample: 506150-1-BSD / BSD
Batch: 1
Matrix: Water
Units: mg/L

SURROGATE RECOVERY STUDY

BTEX by EPA 8021B Analytes	Amount Found [A]	True Amount [B]	Recovery %R [D]	Control Limits %R	Flags
1,4-Difluorobenzene	0.0306	0.0300	102	80-120	
4-Bromofluorobenzene	0.0331	0.0300	110	80-120	

** Surrogates outside limits; data and surrogates confirmed by reanalysis
*** Poor recoveries due to dilution
Surrogate Recovery [D] = 100 * A / B
All results are based on MDL and validated for QC purposes.

Blank Spike Recovery

Project Name: Pride Energy Company

Work Order #: 299691 **Project ID:** South Four Lakes #14

Lab Batch #: 717368 **Sample:** 717368-1-BKS **Matrix:** Water
Date Analyzed: 03/17/2008 **Date Prepared:** 03/17/2008 **Analyst:** WRU
Reporting Units: mg/L **Batch #:** 1

Total Alkalinity by EPA 310.1 **Analytes**	**BLANK /BLANK SPIKE RECOVERY STUDY** **Blank Result [A]**	**Spike Added [B]**	**Blank Spike Result [C]**	**Blank Spike %R [D]**	**Control Limits %R**	**Flags**
Alkalinity, Total (as CaCO3)	ND	200	172	86	80-120	

Lab Batch #: 717419 **Sample:** 717419-1-BKS **Matrix:** Water
Date Analyzed: 03/15/2008 **Date Prepared:** 03/15/2008 **Analyst:** LATCOR
Reporting Units: mg/L **Batch #:** 1

Anions by EPA 300/300.1 **Analytes**	**BLANK /BLANK SPIKE RECOVERY STUDY** **Blank Result [A]**	**Spike Added [B]**	**Blank Spike Result [C]**	**Blank Spike %R [D]**	**Control Limits %R**	**Flags**
Chloride	ND	10.0	9.45	95	85-115	
Sulfate	ND	10.0	8.71	87	90-110	L

Blank Spike Recovery [D] = 100*[C]/[B]
All results are based on MDL and validated for QC purposes.

BS / BSD Recoveries

Project Name: Pride Energy Company

Work Order #: 299691
Analyst: SHE
Lab Batch ID: 717610
Sample: 506150-1-BKS
Date Prepared: 03/19/2008
Batch #: 1
Project ID: South Four Lakes #14
Date Analyzed: 03/19/2008
Matrix: Water

Units: mg/L

BLANK /BLANK SPIKE / BLANK SPIKE DUPLICATE RECOVERY STUDY

BTEX by EPA 8021B Analytes	Blank Sample Result [A]	Spike Added [B]	Blank Spike Result [C]	Blank Spike %R [D]	Spike Added [E]	Blank Spike Duplicate Result [F]	Blk. Spk Dup. %R [G]	RPD %	Control Limits %R	Control Limits %RPD	Flag
Benzene	ND	0.1000	0.0867	87	0.1	0.0848	85	2	70-125	25	
Toluene	ND	0.1000	0.0868	87	0.1	0.0848	85	2	70-125	25	
Ethylbenzene	ND	0.1000	0.0916	92	0.1	0.0885	89	3	71-129	25	
m,p-Xylenes	ND	0.2000	0.1841	92	0.2	0.1774	89	4	70-131	25	
o-Xylene	ND	0.1000	0.0998	100	0.1	0.0959	96	4	71-133	25	

Relative Percent Difference RPD = 200*|(D-F)/(D+F)|
Blank Spike Recovery [D] = 100*(C)/[B]
Blank Spike Duplicate Recovery [G] = 100*(F)/[E]
All results are based on MDL and Validated for QC Purposes

Form 3 - MS Recoveries

Project Name: Pride Energy Company

Work Order #: 299691
Lab Batch #: 717419
Date Analyzed: 03/15/2008
QC- Sample ID: 299690-001 S
Reporting Units: mg/L

Date Prepared: 03/15/2008
Batch #: 1

Project ID: South Four Lakes #14
Analyst: LATCOR
Matrix: Water

	MATRIX / MATRIX SPIKE RECOVERY STUDY					
Inorganic Anions by EPA 300 **Analytes**	**Parent Sample Result [A]**	**Spike Added [B]**	**Spiked Sample Result [C]**	**%R [D]**	**Control Limits %R**	**Flag**
Chloride	4150	1000	5250	110	85-115	
Sulfate	415	1000	1400	99	90-110	

Matrix Spike Percent Recovery [D] = 100*(C-A)/B
Relative Percent Difference [E] = 200*(C-A)/(C+B)
All Results are based on MDL and Validated for QC Purposes

Form 3 - MS / MSD Recoveries

Project Name: Pride Energy Company

Work Order # : 299691 **Project ID:** South Four Lakes #14

Lab Batch ID: 717610 **QC- Sample ID:** 299447-003 S **Batch #:** 1 **Matrix:** Water

Date Analyzed: 03/19/2008 **Date Prepared:** 03/19/2008 **Analyst:** SHE

Reporting Units: mg/L

MATRIX SPIKE / MATRIX SPIKE DUPLICATE RECOVERY STUDY

BTEX by EPA 8021B Analytes	Parent Sample Result [A]	Spike Added [B]	Spiked Sample Result [C]	Spiked Sample %R [D]	Spike Added [E]	Duplicate Spiked Sample Result [F]	Spiked Dup. %R [G]	RPD %	Control Limits %R	Control Limits %RPD	Flag
Benzene	ND	0.1000	0.1038	104	0.1000	0.1121	112	7	70-125	25	
Toluene	ND	0.1000	0.1030	103	0.1000	0.1122	112	8	70-125	25	
Ethylbenzene	ND	0.1000	0.1055	106	0.1000	0.1161	116	9	71-129	25	
m,p-Xylenes	ND	0.2000	0.2079	104	0.2000	0.2291	115	10	70-131	25	
o-Xylene	ND	0.1000	0.1095	110	0.1000	0.1212	121	10	71-133	25	

Matrix Spike Percent Recovery [D] = 100*(C-A)/B Matrix Spike Duplicate Percent Recovery [G] = 100*(F-A)/E
Relative Percent Difference RPD = 200*(D-G)/(D+G)

ND = Not Detected, J = Present Below Reporting Limit, B = Present in Blank, NR = Not Requested, I = Interference, NA = Not ApplicableN = See Narrative, EQL = Estimated Quantitation Limit

Sample Duplicate Recovery

Project Name: Pride Energy Company

Work Order #: 299691

Lab Batch #: 717419
Project ID: South Four Lakes #14
Date Analyzed: 03/15/2008
Date Prepared: 03/15/2008
Analyst: LATCOR
QC- Sample ID: 299690-001 D
Batch #: 1
Matrix: Water
Reporting Units: mg/L

Anions by EPA 300/300.1 Analyte	Parent Sample Result [A]	Sample Duplicate Result [B]	RPD	Control Limits %RPD	Flag
Chloride	4150	4140	0	20	
Sulfate	415	406	2	20	

Lab Batch #: 717329
Date Analyzed: 03/17/2008
Date Prepared: 03/17/2008
Analyst: LATCOR
QC- Sample ID: 299654-001 D
Batch #: 1
Matrix: Water
Reporting Units: mg/L

Metals per ICP by SW846 6010B Analyte	Parent Sample Result [A]	Sample Duplicate Result [B]	RPD	Control Limits %RPD	Flag
Calcium	45.1	45.8	2	25	
Magnesium	22.6	21.8	4	25	
Potassium	8.64	8.45	2	25	
Sodium	172	172	0	25	

Lab Batch #: 717538
Date Analyzed: 03/17/2008
Date Prepared: 03/17/2008
Analyst: RBA
QC- Sample ID: 299683-002 D
Batch #: 1
Matrix: Water
Reporting Units: mg/L

TDS by SM2540C Analyte	Parent Sample Result [A]	Sample Duplicate Result [B]	RPD	Control Limits %RPD	Flag
Total dissolved solids	978	972	1	30	

Lab Batch #: 717368
Date Analyzed: 03/17/2008
Date Prepared: 03/17/2008
Analyst: WRU
QC- Sample ID: 299680-001 D
Batch #: 1
Matrix: Water
Reporting Units: mg/L

Total Alkalinity by EPA 310.1 Analyte	Parent Sample Result [A]	Sample Duplicate Result [B]	RPD	Control Limits %RPD	Flag
Alkalinity, Total (as $CaCO_3$)	228	236	3	20	
Alkalinity, Carbonate (as $CaCO_3$)	ND	ND	NC	20	
Alkalinity, Bicarbonate (as $CaCO_3$)	ND	ND	NC	20	

Spike Relative Difference RPD 200 * | (B-A)/(B+A) |
All Results are based on MDL and validated for QC purposes.

XENCO Laboratories / Environmental Lab of Texas

12600 West I-20 East
Odessa, Texas 79765
Phone: 432-563-1800
Fax: 432-563-1713

CHAIN OF CUSTODY RECORD AND ANALYSIS REQUEST

Project Manager: Randy Hicks
Company Name: R. T. Hicks Consultants, Ltd.
Company Address: 901 Rio Grande Blvd NW
City, State, Zip Code: Albuquerque NM 87104
Telephone No: 505-266-5004
Fax No: 505-266-0745
Sampler: Gil Van Deventer
Printed / Signature

Project Name: Pride Energy Company
Project #: South Four Lakes #14
Project Location: T11S-R34E, Section 35, Unit Letter I
COC #: S4L 14-0308

					Preservative							Matrix				Analyze For:															
LAB # (lab use only)	FIELD CODE	Date Sampled	Time Sampled	No. of Containers	Ice [illegible]	HNO_3	HCl BTEX only) [illegible]	NaOH	H_2SO_4	None	Other (Specify)	Water	Sludge	Soil	Other (specify).	TPH: 418.1 8015M 1005 1006	Cations (Ca, Mg, Na, K, F)	Anions (Cl, SO4, CO3, HCO3)	SAR / ESP / CEC	Metals: As Ag Ba Cd Cr Pb Hg Se	Volatiles	Semivolatiles	BTEXN 8021B/5030 or BTEXN 8260	RCI	N.O.R.M.	Total Dissolved Solids (160.1)	SPLP 1312	Nitrate (N-NO³)	Total Fe and Mn	RUSH TAT (Pre-Schedule	Standard TAT
299691	MW-1	3/13/08	1010	3	X		X					X					X	X					X			X					X

TCLP:
TOTAL:

Special Instructions:
Email results to: r@rthicksconsult.com and gilbertvandeventer@suddenlink.net

Sample Containers Intact? [✓ Y] N
Temperature Upon Receipt: 1.5
Laboratory Comments:
w/ labels & seals on cooler

Relinquished by:	Date	Time	Received by	Date	Time
	3/14/08	4:15pm			

Relinquished by:	Date	Time	Received by ELOT:	Date	Time
			Andrea	3/14/08	4:15

Environmental Lab of Texas

Variance/ Corrective Action Report- Sample Log-In

Client: R.T. Hicks

Date/ Time: 3·14·08 4:15

Lab ID # : 299691

Initials: AL

Sample Receipt Checklist

				Client Initials
#1 Temperature of container/ cooler?	[✓ Yes]	No	-1.5 °C	
#2 Shipping container in good condition?	[✓ Yes]	No		
#3 Custody Seals intact on shipping container/ cooler?	[✓ Yes]	No	Not Present	
#4 Custody Seals intact on sample bottles/ container?	Yes	No	[✓ Not Present]	
#5 Chain of Custody present?	[✓ Yes]	No		
#6 Sample instructions complete of Chain of Custody?	[✓ Yes]	No		
#7 Chain of Custody signed when relinquished/ received?	[✓ Yes]	No		
#8 Chain of Custody agrees with sample label(s)?	[✓ Yes]	No	ID written on Cont./ Lid	
#9 Container label(s) legible and intact?	[✓ Yes]	No	Not Applicable	
#10 Sample matrix/ properties agree with Chain of Custody?	[✓ Yes]	No		
#11 Containers supplied by ELOT?	[✓ Yes]	No		
#12 Samples in proper container/ bottle?	[✓ Yes]	No	See Below	
#13 Samples properly preserved?	[✓ Yes]	No	See Below	
#14 Sample bottles intact?	[✓ Yes]	No		
#15 Preservations documented on Chain of Custody?	[✓ Yes]	No		
#16 Containers documented on Chain of Custody?	[✓ Yes]	No		
#17 Sufficient sample amount for indicated test(s)?	[✓ Yes]	No	See Below	
#18 All samples received within sufficient hold time?	[✓ Yes]	No	See Below	
#19 Subcontract of sample(s)?	Yes	No	[✓ Not Applicable]	
#20 VOC samples have zero headspace?	[✓ Yes]	No	Not Applicable	

Variance Documentation

Contact: ______ Contacted by: ______ Date/ Time: ______

Regarding: ______

Corrective Action Taken:

Check all that Apply:
- ☐ See attached e-mail/ fax
- ☐ Client understands and would like to proceed with analysis
- ☐ Cooling process had begun shortly after sampling event

WELL SAMPLING DATA FORM

CLIENT: Pride Energy Company

WELL ID: MW- 1

SITE NAME: S. Four Lakes #14

DATE: March 13, 2008

SITE LOCATION: T11S-R34E-Sec 35 Unit I

SAMPLER: Gil Van Deventer / Jason Jessup

LAT/LONG: N 33° 19' 14.0", W 103° 28' 29.7"

PURGING METHOD: ☑ Hand Bailed ☐ Pump If Pump, Type:

SAMPLING METHOD: ☑ Disposable Bailer ☐ Direct from Discharge Hose ☐ Other:

DESCRIBE EQUIPMENT DECONTAMINATION METHOD BEFORE SAMPLING THE WELL:

☑ Gloves ☑ Alconox ☑ Distilled Water Rinse ☐ Other:

DISPOSAL METHOD OF PURGE WATER: ☐ Surface Discharge ☐ Drums ☑ SWD Disposal Facility

TOTAL DEPTH OF WELL: 48.2 Feet

DEPTH TO WATER: 25.22 Feet

HEIGHT OF WATER COLUMN: 22.98 Feet

WELL DIAMETER: 2.0 Inch

30'-50' bgs Well Screen Interval

11.3 Minimum gallons to purge 3 well volumes

12 Actual Gallons purged

TIME	VOLUME PURGED	TEMP. °C	COND. mS/cm	pH	DO mg/L		PHYSICAL APPEARANCE AND REMARKS
9:54 AM	4	16.5	5.76	6.55	3.4		
10:02 AM	8	17.2	5.47	6.82	3.5		
10:10 AM	12	17.0	6.32	6.74	3.0		Collected samples in the following containers:
							2 - 40 ml VOA + 1 - 1,000 ml plastic + 1 - 500 ml plastic
:Total Time (hr:min)			:Total Vol (gal)			:Average Flow Rate (gal/min)	

COMMENTS: Hanna Model HI98130 used to obtain temperature, conductivity, & pH, measurements.

Milwaukee Model SM600 used to obtain dissolved oxygen measurements.

Delivered samples to Xenco Laboratories /Environmental Lab of Texas for BTEX, Major Ions, TDS, nitrate, Total Fe, and total Mn analyse

Appendix C

Chloride Conceptual Model

R.T. Hicks Consultants, Ltd.

901 Rio Grande Blvd. NW, Suite F-142
Albuquerque, NM 87104

Appendix C: Conceptual Model of Chloride Fate and Transport in an Aquifer Underlying a Reserve Pit Release

The conceptual model considers the following factors:

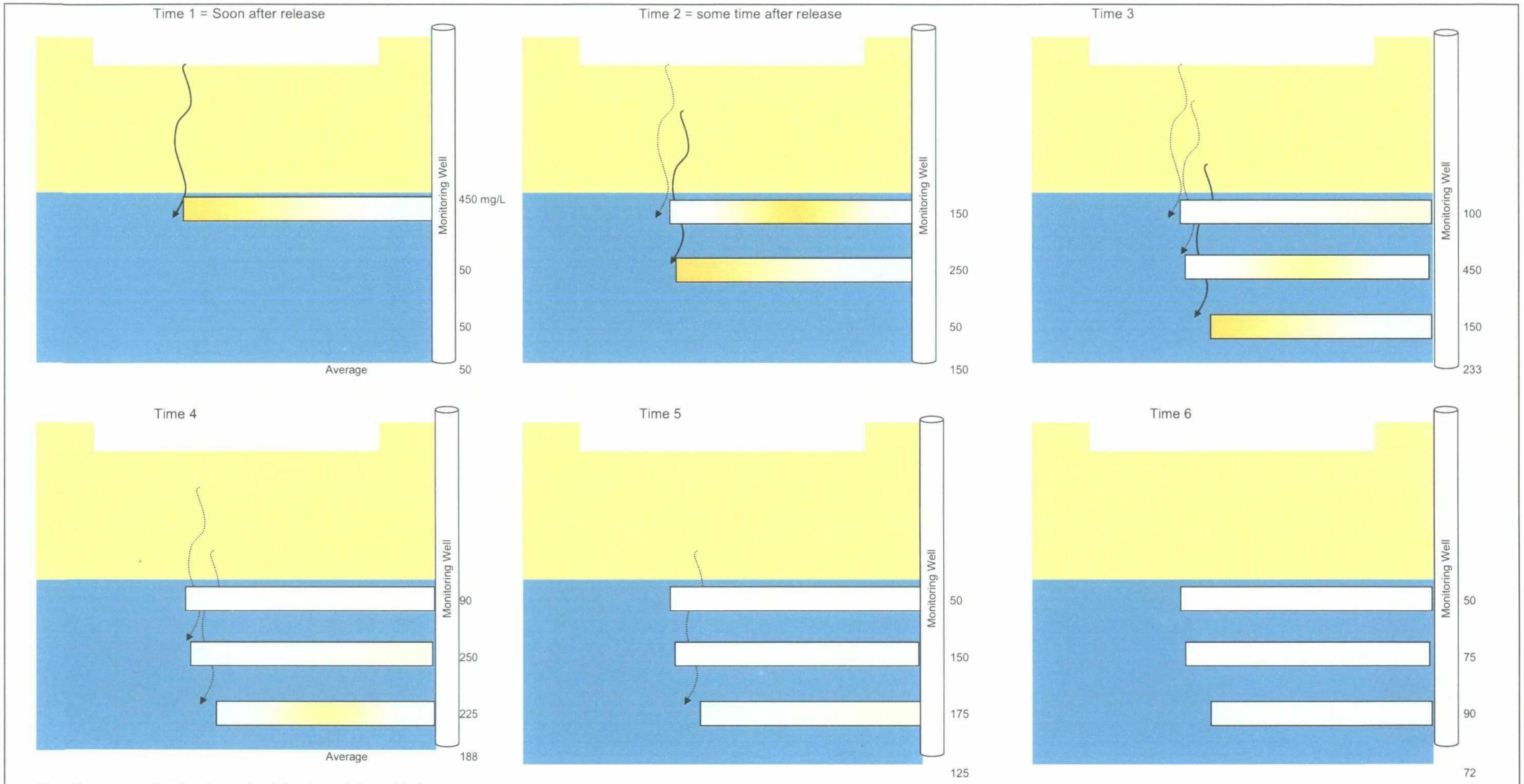
1. A release of chloride-rich drilling fluid occurred during the operation of the pit or during the drying process when the pit held fluid, creating saturated flow between the pit and ground water.
2. Unsaturated transport of chloride from the residual pit material through the vadose zone to ground water after the pit dried is insignificant relative to transport via saturated flow described above.
3. The fluid released from the pit was saturated brine or brine diluted with residual water from the fresh water drilling pit. Saturated brine has a significantly higher density than the fresh water in the aquifer. Saturated brine weighs almost 11 pounds/gallon. Fresh water weight approximately 8.3 pounds/gallon.
4. Saturated brine released from a drilling pit can:
    a. Move through the vadose zone via preferential pathways of saturated flow (e.g. through fractures) at the point of release, or
    b. Move in the voids between the liner and earth material then through preferential pathways of saturated flow
5. When saturated brine enters the aquifer it will behave like a dense non-aqueous phase liquid (DNAPL) until diffusion, dilution and dispersion in the aquifer reduces the density of the brine and creates a mixed solution of brine and ground water.
6. The depth of penetration of brine as a DNAPL depends upon many factors including:
    a. the total volume of brine released from the pit;
    b. the density of the brine when it enters the aquifer;
    c. the flux of brine into the aquifer through each preferential pathway;
    d. the vertical hydraulic conductivity, hydraulic gradient, porosity, aquifer thickness, and the longitudinal, transverse, and vertical dispersivities;
    e. the presence or absence of vertical pathways for DNAPL flow.

Figure C-1 illustrates a possible result where a relatively minor brine release enters an aquifer with a relatively high ground water flux. The mass of chloride released from the reserve pit is quickly dispersed and diluted, resulting in short-term minor impairment of ground water quality.

Figure C-2 shows a possible result of a relatively large brine release to an aquifer with a ground water flux that is equal to or less than the first example. Note that Time 6 is 3-4 years after the release, not 2-3 years as in the first example. Chloride concentrations in the monitoring well are higher due to the larger flux of brine into the aquifer.

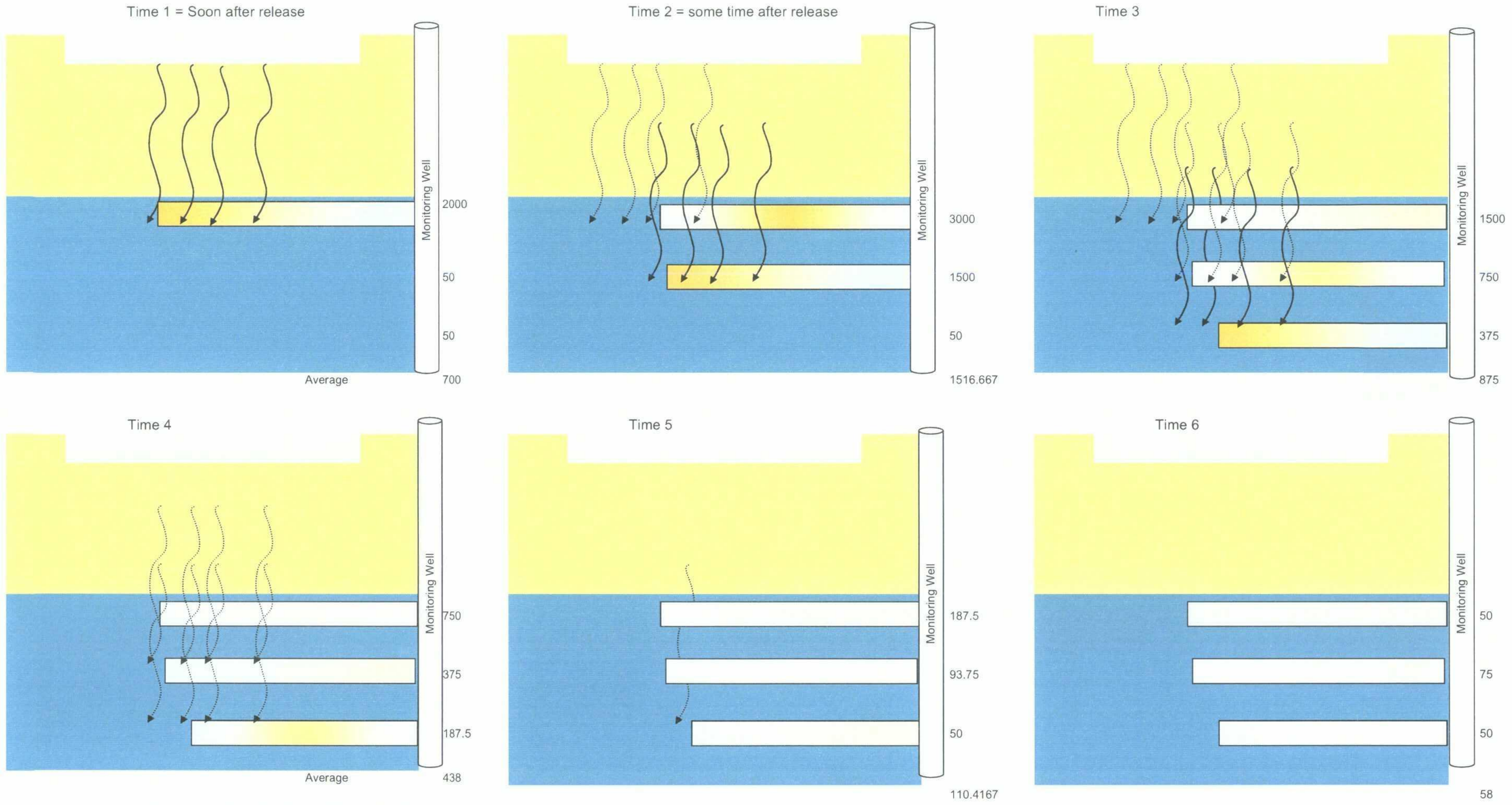
Figure C-3 shows a possible result where a relatively large brine release flows through a limited number of preferential pathways, causing a focused impact to a thin, fine-grained aquifer with a relatively low ground water flux. Because of these conditions, the depth of DNAPL penetration is greater than the previous examples. The brine DNAPL flows to the bottom of the aquifer and "settles" on the underlying aquiclude.

Each brine release site will exhibit a unique set of conditions that will create a unique geometry of the impacted aquifer. These conceptual models of various brine release scenarios can assist in guiding the characterization effort at a given site. For example, deep ground water sampling points may not be necessary for the conditions described by Figure C-1. The conditions presented in Figure C-3 not only require monitoring of ground water at the base of the aquifer but may allow for cost-effective ground water restoration using a pumping well that focuses pumping at the base of the aquifer.



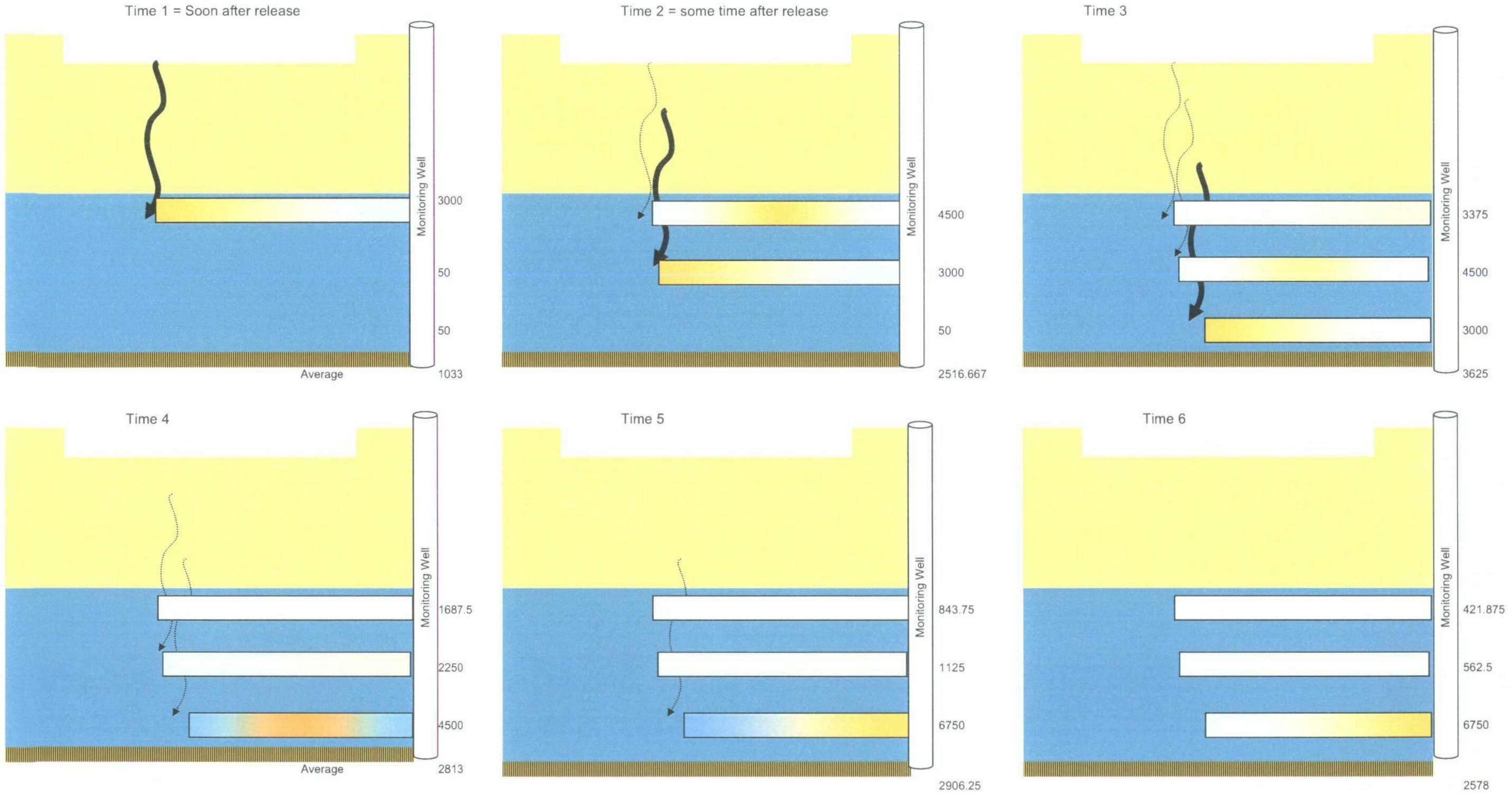
Time 1 is very soon after the release - the pit is active or drying at this time
Time 2 is later and could be the time when the operatero installs a monitoring well
Time 3 might be 6-8 months or more after well installation, the vadose zone remedy is effective and DNPL flow stops due to flow shearing of the DNAPL and natural dilution
Time 4 is several months after drying or implementation of the vadose zone remedy stops input of chloride to ground water and the upper zone begins to restore due to natural dilution and dispersion
Time 5 might be 1-2 years after installation of the monitoring well
Time 6 is 2-3 years after the release and the site is in the middle of the 2-year closure monitoring program

Figure C-1: Conceptual model of a minor release to a "high ground water flux" aquifer



Time 1 is very soon after the release - the pit is active or drying at this time
Time 2 is later and could be the time when the operatero installs a monitoring well
Time 3 might be 6-8 months or more after well installation, the vadose zone remedy is effective and DNPL flow stops due to flow shearing of the DNAPL and natural dilution
Time 4 is several months after drying or implementation of the vadose zone remedy stops input of chloride to ground water and the upper zone begins to restore due to natural dilution and dispersion
Time 5 might be 1-3 years after installation of the monitoring well
Time 6 is 3-4 years after the release and the site is in the middle of the 2-year closure monitoring program

Figure C-2: Conceptual model of a relatively large brine release to an aquifer with a moderate ground water flux.



Time 1 is very soon after the release - the pit is active or drying at this time
Time 2 is later and could be the time when the operatero installs a monitoring well
Time 3 might be 6-8 months or more after well installation, the vadose zone remedy is effective and DNPL flow stops due to flow shearing of the DNAPL and natural dilution
Time 4 is several months after drying or implementation of the vadose zone remedy stops input of chloride to ground water and the upper zone begins to restore due to natural dilution and dispersion
Time 5 might be 2-4 years after installation of the monitoring well
Time 6 is 4-5 years after the release and the site is in the middle of the 2-year closure monitoring program

Figure C-3: Brine release to a thin fine-grained aquifer

Appendix D

Quality Assurance Protocols

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Designation: D 5784 – 95 (Reapproved 2000)

Standard Guide for Use of Hollow-Stem Augers for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices[1]

1. Scope

1.1 This guide covers how hollow-stem auger-drilling systems may be used for geoenvironmental exploration and installation of subsurface water-quality monitoring devices.

1.2 Hollow-stem auger drilling for geoenvironmental exploration and monitoring device installations often involves safety planning, administration, and documentation. This guide does not purport to specifically address exploration and site safety.

NOTE 1—This guide does not include considerations for geotechnical site that are addressed in a separate Guide.

1.3 The values stated in SI units are to be regarded as the standard. The inch-pound units given in parentheses are for information only.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This guide offers an organized collection of information or a series of options and does not recommend a specific course of action. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this guide may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[2]

D 1452 Practice for Soil Investigation and Sampling by Auger Borings[2]

D 1586 Test Method for Penetration Test and Split-Barrel Sampling of Soils[2]

D 1587 Test Method for Thin-Walled Tube Sampling of Soils[2]

D 2113 Test Method for Diamond Core Drilling for Site Investigation[2]

D 2487 Test Method for Classification of Soils for Engineering Purposes[2]

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[2]

D 3550 Practice for Ring-Lined Barrel Sampling of Soils[2]

D 4220 Practices for Preserving and Transporting Soil Samples[2]

D 4428/D4428M Test Methods for Crosshole Seismic Testing[2]

D 4700 Guide for Soil Sampling from the Vadose Zone[2]

D 4750 Test Method for Determining Subsurface Liquid Levels in a Borehole or Monitoring Well (Observation Well)[2]

D 5079 Practices for Preserving and Transporting of Rock Core Samples[3]

D 5088 Practice for Decontamination of Field Equipment Used at Non-Radioactive Waste Sites[3]

D 5092 Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers[3]

D 5099 Test Method for Rubber—Measurement of Processing Properties Using Capillary Rheometry[4]

D 5254 Practice for Minimum Set of Data Elements to Identify a Ground-Water Site[3]

3. Terminology

3.1 *Definitions:*

3.1.1 Terminology used within this guide is in accordance with Terminology D 653. Definitions of additional terms may be found in Terminology D 653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *bentonite*—the common name for drilling fluid additives and well-construction products consisting mostly of naturally occurring montmorillonite. Some bentonite products have chemical additives that may affect water-quality analyses.

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[1] This guide is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.21 on Ground Water and Vadose Zone Investigations.

Current edition approved Oct. 10, 1995. Published December 1995.

[2] *Annual Book of ASTM Standards*, Vol 04.08.

[3] *Annual Book of ASTM Standards*, Vol 04.09.

[4] *Annual Book of ASTM Standards*, Vol 09.01.

3.2.2 *bentonite granules and chips*—irregularly shaped particles of bentonite (free from additives) that have been dried and separated into a specific size range.

3.2.3 *bentonite pellets*—roughly spherical- or disk-shaped units of compressed bentonite powder (some pellet manufacturers coat the bentonite with chemicals that may affect the water-quality analysis).

3.2.4 *coefficient of uniformity*— C_u *(D)*, the ratio D_{60}/D_{10}, where D_{60} is the particle diameter corresponding to 60 % finer on the cumulative particle-size distribution curve, and D_{10} is the particle diameter corresponding to 10 % finer on the cumulative particle-size distribution curve.

3.2.5 *continuous-sampling devices*—barrel-type samplers that fit within the lead auger of the hollow-auger column. The sampler barrel fills with material as the augers advance.

3.2.6 *drill hole*—a cylindrical hole advanced into the subsurface by mechanical means. Also known as borehole or boring.

3.2.7 *drawworks*—a power-driven winch, or several winches, usually equipped with a clutch and brake system(s) for hoisting or lowering a drilling string.

3.2.8 *filter pack*—also known as a gravel pack or a primary filter pack in the practice of monitoring-well installations. The gravel pack is usually granular material, having specified grain-size characteristics, that is placed between a monitoring device and the borehole wall. The basic purpose of the filter pack or gravel envelope is to act as: *(1)* a nonclogging filter when the aquifer is not suited to natural development or, *(2)* act as a formation stabilizer when the aquifer is suitable for natural development.

3.2.8.1 *Discussion*—Under most circumstances a clean, quartz sand or gravel should be used. In some cases a pre-packed screen may be used.

3.2.9 *fluid-injection devices*—usually consist of various auger components or drill-rig attachments that may be used to inject a fluid within a hollow-auger column during drilling.

3.2.10 *grout packer*—an inflatable or expandable annular plug that is attached to a tremie pipe, usually positioned immediately above the discharge end of the pipe.

3.2.11 *grout shoe*—a drillable plug containing a check valve that is positioned within the lowermost section of a casing column. Grout is injected through the check valve to fill the annular space between the casing and the borehole wall or another casing.

3.2.11.1 *Discussion*—The composition of the drillable plug should be known and documented.

3.2.12 *hoisting line*—or drilling line, is wire rope used on the drawworks to hoist and lower the drill string.

3.2.13 *in situ testing devices*—sensors or probes, used to obtain mechanical or chemical-test data, that are typically pushed, rotated, or driven below the bottom of a borehole following completion of an increment of drilling. However, some in situ testing devices (such as electronic pressure transducers, gas-lift samplers, tensiometers, and and so forth) may require lowering and setting of the device(s) in a preexisting borehole by means of a suspension line or a string of lowering rods or pipe. Centralizers may be required to correctly position the device(s) in the borehole.

3.2.14 *intermittent-sampling devices*—usually barrel-type samplers that may be rotated, driven, or pushed below the bottom of a borehole with drill rods or with a wireline system to lower, drive, and retrieve the sampler following completion of an increment of drilling. The user is referred to the following ASTM standards relating to suggested sampling methods and procedures: Practice D 1452, Test Method D 1586, Practice D 3550, and Practice D 1587.

3.2.15 *mast*—or derrick, on a drilling rig is used for supporting the crown block, top drive, pulldown chains, hoisting lines, and so forth. It must be constructed to safely carry the expected loads encountered in drilling and completion of wells of the diameter and depth for which the rig manufacturer specifies the equipment.

3.2.16 *Discussion*—To allow for contingencies, it is recommended that the rated capacity of the mast should be at least twice the anticipated weight load or normal pulling load.

3.2.17 *piezometer*—an instrument for measuring pressure head.

3.2.18 *subsurface water-quality monitoring device*— an instrument placed below ground surface to obtain a sample for analyses of the chemical, biological, or radiological characteristics of subsurface pore water or to make in-situ measurements.

4. Significance and Use

4.1 Hollow-stem auger drilling may be used in support of geoenvironmental exploration (Practice D 3550, Test Method D 4428) and for installation of subsurface water-quality monitoring devices in unconsolidated materials. Hollow-stem auger drilling may be selected over other methods based on the advantages over other methods. These advantages include: the ability to drill without the addition of drilling fluid(s) to the subsurface, and hole stability for sampling purposes (see Test Methods D 1586, D 1587, D 2487, and D 2488) and monitor-well construction in unconsolidated to poorly indurated materials. This drilling method is generally restricted to the drilling of shallow, unconsolidated materials or softer rocks. The hollow-stem drilling method is a favorable method to be used for obtaining cores and samples and for the installation of monitoring devices in many, but not all geologic environments.

NOTE 2—In many geologic environments the hollow-stem auger drilling method can be used for drilling, sampling, and monitoring-device installations without the addition of fluids to the borehole. However, in cases where heaving water-bearing sands or silts are encountered, the addition of water or drilling mud to the hollow-auger column may become necessary to inhibit the piping of these fluid-like materials into the augers. These drilling conditions, if encountered, should be documented.

4.1.1 The application of hollow-stem augers to geoenvironmental exploration may involve ground water and soil sampling, in-situ or pore-fluid testing, or utilization of the hollow-auger column as a casing for subsequent drilling activities in unconsolidated or consolidated materials (Test Method D 2113).

NOTE 3—The user may install a monitoring device within the same auger borehole wherein sampling or in-situ or pore-fluid testing was performed.

4.1.2 The hollow-stem auger column may be used as a temporary casing for installation of a subsurface water-quality monitoring device. The monitoring device is usually installed as the hollow-auger column is removed from the borehole.

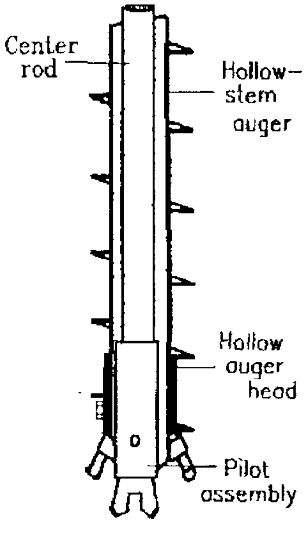
4.2 The subsurface water-quality monitoring devices that are addressed in this guide consist generally of a screened or porous intake device and riser pipe(s) that are usually installed with a filter pack to enhance the longevity of the intake unit, and with isolation seals and low-permeability backfill to deter the movement of fluids or infiltration of surface water between hydrologic units penetrated by the borehole (see Practice D 5092). Inasmuch as a piezometer is primarily a device used for measuring subsurface hydraulic heads, the conversion of a piezometer to a water-quality monitoring device should be made only after consideration of the overall quality and integrity of the installation, to include the quality of materials that will contact sampled water or gas.

NOTE 4—Both water-quality monitoring devices and piezometers should have adequate casing seals, annular isolation seals, and backfills to deter the movement of fluids between hydrologic units.

5. Apparatus

5.1 Each *auger section* of the hollow-stem auger-column assembly consists of a cylindrical tube with continuous helical flighting rigidly attached to the outer surface of the tube (see Fig. 1). The hollow-auger section has a coupling at each end for attachment of a hollow-auger head to the bottom end of the lead auger section and for attachment of additional auger sections at the top end to make up the articulated hollow-stem auger column.

NOTE 5—The inside diameter of the hollow-stem auger column is usually selected to provide an opening large enough for insertion of monitoring-device components such as the screened intake and filter pack and installation devices such as a tremie pipe. When media sampling is required, the optimum opening should permit easy insertion and retraction of a sampler or core barrel. When a monitoring device is installed, the annular opening should provide easy insertion of a pipe with an inside diameter large enough for placing completion materials adjacent to the riser.



NOTE 1—Various pilot assemblies not shown here may vary.

FIG. 1 Sketch Showing Basic Hollow-Stem Auger Components

5.1.1 *Hollow-Auger Head*, attached to the lead auger of the hollow-auger column and usually contains replaceable, abrasion-resistant cutters or teeth (see Fig. 1). As the hollow-auger head is rotated, it cuts and directs the cuttings to the auger flights which convey the cuttings to the surface.

5.1.2 *Auger-Drive Assembly*, attaches to the uppermost hollow-auger section and transfers rotary power and axial force from the drill rig to the auger-column assembly.

5.1.3 *Pilot Assembly*, may consist of: (*1*) an auger head aperture-plugging device with or without a center cutting head, or (*2*) a sampling device that is used to sample simultaneously with advancement of the auger column.

5.1.4 *Auxiliary Components of a Hollow-Auger Drilling System*, consist of various devices such as auger-connector wrenches, auger forks, hoisting hooks, and fluid-injection swivels or adapters.

5.2 *Drill Rig*, used to rotate and advance the auger column. The drill rig should be capable of applying the rated power at a rotary velocity of 50 to 100 r/min. The drill rig should have a feed stroke of at least the effective length of the auger sections plus the effective length of the auger couplings plus about 100 mm (4 in.).

6. Drilling Procedures

6.1 As a prelude to and throughout the drilling process stabilize the drill rig and raise the drill-rig mast. Attach an initial assembly of hollow-auger components (see Fig. 1) to the rotary drive of the drill rig.

NOTE 6—The drill rig, drilling and sampling tools, the rotary gear or chain case, the spindle, and all components of the rotary drive above the auger column should be cleaned and decontaminated prior to drilling according to Practice D 5088. All lubricated rotary gear or chain cases should be monitored for leaks during drilling. Any lubricants used should be documented. Lubricants with organic or metallic constituents that could be interpreted as contaminants if detected in a soil or water sample should not be used on auger couplings. Any instances of possible contamination should be documented.

6.2 Push the auger-column assembly below the ground surface and initiate rotation at a low velocity.

NOTE 7—If surface contamination is suspected, special drilling procedures may be required to deter transport of contaminated materials downhole. For example, the augers and auger head may be removed and cleaned according to Practice D 5088 following drilling of the initial increments. Complete removal of the augers from a boring may allow caving and cross contamination of materials (especially below the water table). When augers are reinserted, attempts should be made to note if caving or sloughing, or both, has occurred in the borehole and the information documented.

6.3 Then continue drilling, usually at a rotary velocity of about 50 to 100 r/min, and to a depth where intermittent sampling or in situ testing is required, or until the drive assembly is advanced to within about 0.15 to 0.45 m (6 to 18 in.) of the ground surface. Soil sampling is usually accomplished by either of two methods: (*1*) removing the pilot assembly, if being used, and inserting and driving a sampler through the hollow stem of the auger column, or (*2*) using a continuous sampling device within the lead auger section. In the latter case the sampler barrel fills with material as the hollow-auger column is advanced. It should be noted that the pilot assembly and any sampling devices should be cleaned and decontaminated according to Practice D 5088 after each use and prior to reinsertion in the hollow-auger column. Water sampling can also be done through the hollow-stem augers when using augers with watertight connections to prevent fluid leakage from occurring at the connections: (*1*) by allowing the auger column to fill with water through the use of a screened lead auger section; (*2*) by allowing the auger column to fill from the bottom; (*3*) by using a soil-penetrating water sampling device that can be lowered into the hollow-auger column and either driven, rotated, or pushed out through the bottom or lead auger into the undisturbed material below the auger head.

NOTE 8 – Under some circumstances it may be effective to drill without using a pilot assembly. If a pilot assembly is not used, however, and water is not injected into the auger column simultaneously with advancement, material will often enter the hollow stem of the auger column. The addition of water to the auger column during drilling may deter material entrance but, on the other hand, may also affect both the mechanical and chemical characteristics of soil samples and the quality of water samples. Therefore, if water is added and the chemistry determined, the approximate volume(s) added over specific intervals and the water chemistry should be documented.

6.4 Accomplish drilling at greater depths by attaching additional hollow-auger sections to the top of the previously advanced hollow-auger column assembly.

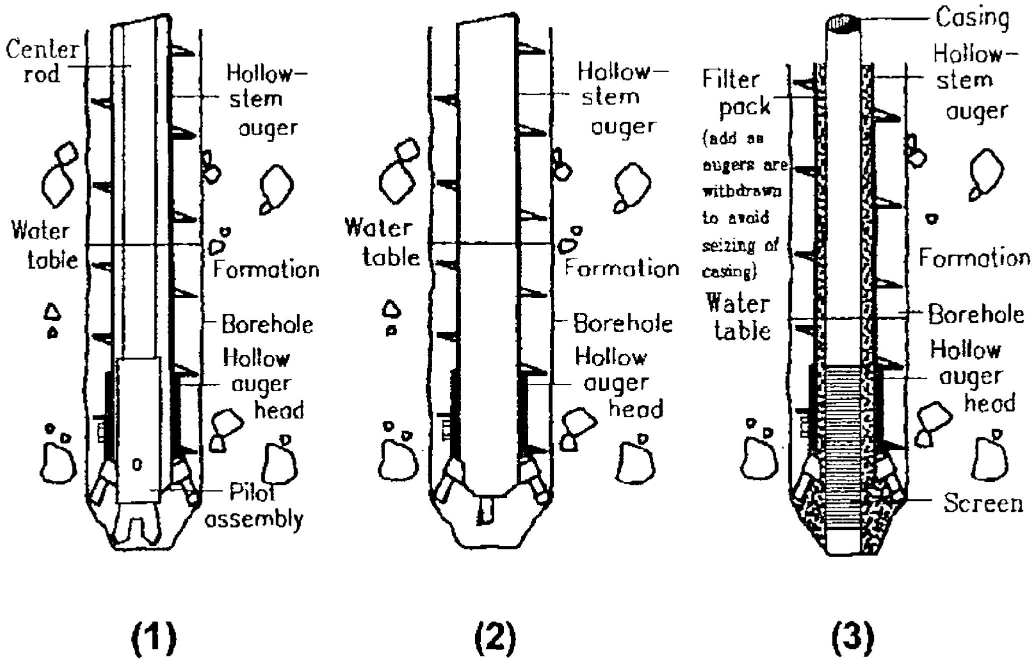
NOTE 9—Cuttings are removed periodically from around the top of the auger column. Soil cuttings above the ground water may be representative of deposits being penetrated if proper cuttings-return rates are maintained. Cuttings from below the ground water surface are likely to be mixed from varying formations in the hole and are usually not representative of deposits at the end of the auger if cuttings are sampled for classification (see Practice D 2488) and relation to lithology report and document the intervals sampled. If drilling is performed in contaminated soil and cuttings control is required, drilling through a hole in a sheet of plywood or similar material held securely above the borehole by the stabilizing jacks of the drill rig will usually facilitate cuttings control. Containment and disposal of contaminated and potentially contaminated drilling fluids and associated cuttings should be in accordance with applicable regulations.

6.5 When drilling must progress through material suspected of being contaminated, installation of single or multiple (nested) casings may be required to isolate zones of suspected contamination. Install isolation casings in a predrilled borehole or by using a casing advancement method. However, when attempting to auger inside the casing, the column of cuttings return may cause the augers to bind in the casing. Then install a grout seal usually by applying the grout at the bottom of the annulus with the aid of a tremie pipe, and a grout shoe or a grout packer. Allow the grout to set before drilling activities are continued.

7. Installation of Monitoring Devices

7.1 Subsurface water-quality monitoring devices are generally installed using hollow-stem augers following the three-step procedure shown in Fig. 2. The three steps are: (*1*) drilling, with or without sampling, (*2*) removal of the pilot assembly, if being used, and insertion of the monitoring device, and (*3*) incremental removal of the hollow-auger column as completion materials such as filter pack, annular seals, and backfill are installed as required.

NOTE 10—Removal of the pilot assembly following an increment of drilling or prior to installation of a monitoring device should be performed so that the entrance of material into the bottom of the hollowauger stem is minimized. The efficacy of pilot assembly removal will depend upon several principal factors: (*1*) the character of the soil at the auger head, (*2*)



(1)

(2)

(3)

FIG. 2 Sketch Showing Basic Three-Step Procedure for Installation of Subsurface Water-Quality Monitoring Device Using the Hollow-Stem Auger Drilling Method the water levels inside and outside the auger prior to removal of the pilot assembly, (*3*) the type of pilot assembly used (special designs of pilot assemblies can be used to reduce the suction effect of removing the pilot bit), and (*4*) the speed of removal. As drilling progresses in saturated, granular materials, it usually becomes progressively more difficult to maintain the stability of the material below the auger column because of unbalanced hydraulic heads. The stability of the material below the auger head may be enhanced by using special pilot assemblies or injecting water of known chemistry into the hollow auger during drilling. The injection of water into a borehole usually requires consideration and documentation of the effects of injected water on (*1*) quality of subsequent chemical analyses of sampled water, and (*2*) the possible addition of moisture or contaminants to sampled materials.

7.1.1 If materials enter the bottom of the auger hollow stem during removal of the pilot assembly, remove it with a bailer, drive sampler, or other device.

NOTE 11—If heaving occurs, the amount of material entering the hollow-stem auger column should be documented. The effective use of a bailer may require the addition of a fluid to the auger stem.

7.1.2 If sampling or in situ testing is not required during drilling for installation of a monitoring device, advance the boring (for some geologic conditions) by using an expendable knockout plate or plug of known chemistry instead of a pilot assembly.

NOTE 12—Knockout plates or plugs usually remain in the ground close to the monitoring device. Therefore, the material components for knockout plates or plugs should be selected based on their possible effects on subsequent measurements or analyses and the information documented. It may be necessary to fill or partially fill the auger stem with water of known chemistry to prevent blow-in, piping, or sanding in at the time of the plate or plug removal. Refer to Note 7 for considerations regarding adding water to the hollow-auger stem.

7.1.3 Use an auger head with an integral, hinged aperture cover to deter entrance of materials into the auger stem.

7.2 Assemble water-quality monitoring devices, with attached fluid conductors (risers), and suspend in tension prior to placement of filter pack and during placement of filter pack in the borehole (with the least possible addition of contaminants).

7.2.1 Some materials, such as screens and risers, may require cleaning or decontamination, or both, at the job site (see Practice D 5088).

7.2.2 Prior to installation, store all monitoring device materials under cover and place upwind and well away from the drill rig and other sources of potential contamination such as electrical generators, air compressors, or industrial machinery.

7.2.3 Clean hoisting tools, particularly wire rope and hoisting swivels, and decontaminate according to Practice D 5088 before using.

7.3 Select filter materials, bentonite pellets, granules and chips, and grouts and install to specific subsurface monitoring requirements. The thickness of the emplaced materials and extension of the materials above the top of the screen should be sufficient to adequately seal the well and monitoring device(s) against contamination effects of fluid movement between hydrologic units and infiltration of surface contaminants.

7.3.1 Filter packs for monitoring devices are typically installed by withdrawing the hollow augers in small increments, while simultaneously adding small increments of filter material. Record the total volume of filter materials installed and the depth to the upper surface of the filter pack and compare to calculated volumes of material required for completion. Consider any discrepancies occurring between the actual volume of material used and the calculated volume required prior to proceeding to ensure proper completion. If filter material bridges within the hollow auger-riser annulus during installation, use tamping rods or other tamping devices to dislodge the bridge.

NOTE 13—Filter packs for monitoring devices installed in a saturated zone are typically selected on the basis of the grain size characteristics of the hydrologic unit adjacent to the screened intake (screen size should be less than the grain size of the formation adjacent to the screened intake). Filter-pack material is often inserted from above ground surface within the annulus of the hollow auger and the riser and is distributed by gravity around the screened intake. Filter-pack material with a uniformity coefficient of less than 2.5 is ordinarily selected to minimize in-place segregation of grain sizes. For some circumstances, such as installations under water in uniform, fine to very fine sand soils, the filter should be installed with a tremie pipe to minimize segregation of particle sizes. Filter packs for vadose-zone monitoring devices may be predominantly silt sized. These filter materials are often mixed with water of known quality, inserted through a tremie pipe, and tamped into place around the device.

NOTE 14—Effective installation of the filter pack, the seal above the filter pack, and the grout above the seal may be difficult to achieve. Consideration should be given to allow for sufficient annular space between the monitoring device and the hollow-stem auger to accommodate the tremie pipe. Under some circumstances, the filter pack may be more successfully installed by injecting or inserting water of known chemistry into the hollow-auger annulus either before or during incremental pull-back of the auger column. Enough water should be injected to both fill the space previously occupied by the auger flights and to maintain or slightly increase the head within the auger-hollow stem. This additional head within the auger-hollow stem provides an outward seepage force on the wall of the borehole as the augers are retracted. The additional head deters caving prior to installation of filter or seal materials. Approximate volumes of water used and water losses should be documented.

7.4 Usually place sealing materials consisting of either bentonite pellets, chips, or granules directly above the filter pack.

NOTE 15—It may be effective, when granular filters are used, to install a thin, fine sand, secondary filter either below the annular seal or both above and below the seal. These secondary filters are installed to protect the monitoring device, primary filter pack, and seal from intrusion of grout installed above the seal.

NOTE 16—A measured volume of water of known chemistry is often placed in the annulus on top of a dry bentonite seal to initiate hydration; however, hydration of a seal may require from 6 to 24 h.

7.5 The backfill that is placed above the annular seal is usually a bentonite- or cement-base grout.

NOTE 17—Grouts should be designed and installed in consideration of the ambient hydrogeologic conditions. The constituents should be selected and documented according to specific performance requirements. Typical grout mixtures are given in Practice D 5092 and Test Method D 4428.

NOTE 18—Grouting equipment and pipes should be cleaned and decontaminated according to Practice D 5088 prior to use and should be constructed of materials that do not "leach" significant amounts of contaminants to the grout.

7.5.1 When a tremie pipe is used, control its initial position and grouting pressures to prevent materials from being jetted into underlying seal(s) and filter(s) (use of a tremie pipe having a plugged bottom and side-discharge ports should be considered to minimize bottom-jetting problems).

7.5.2 After placement of the initial 1.5 to 3 m (5 to 10 ft) of grout above the underlying filter or seal, discharge additional grout at a depth of about 1.5 to 3 m below the grout surface.

NOTE 19—The need for chemical analysis of samples of each grout component and the final mixture should be considered and documented.

7.5.3 Install the grout from the bottom of the borehole to the top of the borehole so as to displace fluids in the borehole.

8. Development

8.1 Most monitoring device installations should be developed to remove suspended solids from disturbance of geologic materials during installation and to improve the hydraulic characteristics of the filter pack and the hydrologic unit adjacent to the intake. The method(s) selected and time expended to develop the installation and changes in quality of water discharged at the surface should be observed and recorded.

NOTE 20—Under most circumstances, development should be initiated as soon as possible following grouting and well completion operations. For suggested well-development methods and techniques, the user is referred to Test Method D 5099. However, time should be allowed for setting of grout.

9. Field Report and Project Control

9.1 The field report should include information recommended under Guide D 5434, and identified as necessary and pertinent to the needs of the exploration program.

9.2 Other information in addition to Guide D 5434 should be considered if deemed appropriate and necessary to the requirements of the exploration program. Additional information should be considered as follows:

9.2.1 *Drilling Methods*:

9.2.1.1 Description of the hollow-stem auger system,

9.2.1.2 Type, quantities, and locations in the borehole of use of water or additives added,

9.2.1.3 Description of cuttings return, including quantities, and

9.2.1.4 Descriptions of drilling conditions related to rotation rates, and general ease of drilling as related to subsurface materials encountered.

9.2.2 *Sampling*—Document conditions of the bottom of the borehole prior to sampling and report any slough or cuttings present in the recovered sample.

9.2.3 *In Situ Testing*:

9.2.3.1 For devices inserted below the bottom of the borehole, document the depths below the bottom of the hole and any unusual conditions during testing, and

9.2.3.2 For devices testing or seating at the borehole wall, report any unusual conditions of the borehole wall.

9.2.4 *Installations*—A description of well-completion materials and placement methods, approximate volumes placed, depth intervals of placement, methods of confirming placement, and areas of difficulty of material placement or unusual occurrences.

10. Keywords

10.1 drilling; geoenvironmental exploration; ground water; vadose zone

APPENDIX

(Nonmandatory Information)

X1. ADDITIONAL REFERENCES

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Standard Guide for Sampling Ground-Water Monitoring Wells[1]

1. Scope

1.1 This guide covers sampling equipment and procedures and "in the field" preservation, and it does not include well location, depth, well development, design and construction, screening, or analytical procedures that also have a significant bearing on sampling results.This guide is intended to assist a knowledgeable professional in the selection of equipment for obtaining representative samples from ground-water monitoring wells that are compatible with the formations being sampled, the site hydrogeology, and the end use of the data.

1.2 This guide is only intended to provide a review of many of the most commonly used methods for collecting ground-water quality samples from monitoring wells and is not intended to serve as a ground-water monitoring plan for any specific application. Because of the large and ever increasing number of options available, no single guide can be viewed as comprehensive. The practitioner must make every effort to ensure that the methods used, whether or not they are addressed in this guide, are adequate to satisfy the monitoring objectives at each site.

1.3 The values stated in SI units are to be regarded as standard. The values given in parentheses are provided for information only.

1.4 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 4750 Test Method for Determining Subsurface Liquid Levels in a Borehole or Monitoring Well (Observation Well)[2]

D 5088 Practice for Decontamination of Field Equipment Used at Nonradioactive Waste Sites[2]

D 5792 Practice for Generation of Environmental Data Related to Waste Management Activities: Development of Data Quality Objectives[3]

D 5903 Guide for Planning and Preparing a Ground-Water Sampling Event[4]

D 6089 Guide for Documenting a Ground-Water Sampling Event[4]

D 6452 Guide for Purging Methods for Wells Used for Ground-Water Quality Investigations[4]

D 6517 Guide for Field Preservation of Ground-Water Samples[4]

2.2 *EPA Standards:*

EPA Method 9020A

EPA Method 9022

3. Terminology

3.1 *Definitions:*

3.1.1 *low-flow sampling*—a ground water sampling technique where the purge and sampling rates do not result in significant changes in formation seepage velocity.

3.1.2 *minimal purge sampling*—the collection of ground water that is representative of the formation by purging only the volume of water contained by the sampling equipment (that is, tubing, pump bladder).

3.1.2.1 *Discussion*—This sampling method should be considered in situations where very low yield is a consideration and results from this sampling method should be scrutinized to confirm that they meet data quality objectives (DQOs) and the work plan objectives.

3.1.3 *passive sampling*—the collection of ground-water quality data so as to induce no hydraulic stress on the aquifer.

3.1.4 *water quality indicator parameters*—refer to field monitoring parameters that include but are not limited to pH, specific conductance, dissolved oxygen, oxidation-reduction potential, temperature, and turbidity that are used to monitor the completeness of purging.

4. Summary of Guide

4.1 The equipment and procedures used for sampling a monitoring well depend on many factors. These include, but are not limited to: the design and construction of the well, rate of ground-water flow, and the chemical species of interest. Sampling procedures may be different if analyses for trace organics, volatiles, oxidizable species, or trace metals are

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[1] This guide is under the jurisdiction of ASTM Committee D34 on Waste Management and is the direct responsibility of Subcommittee D34.01 on Sampling and Monitoring.

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[2] *Annual Book of ASTM Standards*, Vol 04.08.

[3] *Annual Book of ASTM Standards*, Vol 11.04.

[4] *Annual Book of ASTM Standards*, Vol 04.09.

needed. This guide considers all of these factors by discussing equipment and procedure options at each stage of the sampling sequence. For ease of organization, the sampling process can be divided into three steps: well purging, sample withdrawal, and field preparation of samples. Certain sampling protocols eliminate the first step.

4.2 The sampling must be well planned and all sample containers must be prepared prior to going to the field. These procedures should be incorporated in the approved work plan that should accompany the sampling crew so that they may refer to it for guidance on sampling procedures and analytes to be sampled (see Guide D 5903).

4.3 Monitoring wells must be either purged to remove stagnant water in the well casing or steps must be taken to ensure that only water meeting the DQOs and the work plan objectives is withdrawn during sampling (see Practice D 5792). When well purging is performed, it is accomplished by either removing a predetermined number of well volumes or by the removal of ground water until stable water quality parameters have been obtained. Ideally this purging is performed with minimal well drawdown and minimal mixing of the formation water with the stagnant water above the screened interval in the casing. Passive sampling and the minimal purge methods do not attempt to purge the water present in the monitoring well prior to sampling (**1**).[5] The minimal purge method attempts to purge only the sampling equipment. Each of these methods is discussed in greater detail in Section 6.

4.4 The types of chemical species that are to be sampled as well as the reporting limits are prime factors for selecting sampling devices (**2, 3**). The sampling device and all materials and devices the water contacts must be constructed of materials that will not introduce contaminants or alter the analytes of concern in any way. Material compatibility is further discussed in Section 8.

4.5 The method of sample collection can vary with the parameters of interest. The ideal sampling scheme employs a completely inert material, does not subject the sample to pressure change, does not expose the sample to the atmosphere, or any other gaseous atmosphere before conveying it to the sample container or flow cell for on-site analysis. Since these ideals are not always obtainable, compromises must be made by the knowledgeable individual designing the sampling program. These concerns should be documented in the data quality objectives (DQOs) of the sampling plan (see Practice D 5792) (**4**).

4.6 The degree and type of effort and care that goes into a sampling program is always dependent on the chemicals of concern and their reporting levels as documented in the project's DQOs. As the reporting level of the chemical species of analytical interest decreases, the precautions necessary for sampling generally increase. Therefore, the sampling objective must clearly be defined ahead of time in the DQOs. The specific precautions to be taken in preparing to sample for trace organics are different from those to be taken in sampling for trace metals. A draft U.S. EPA guidance document (**5**) concerning monitoring well sampling, including considerations for trace organics, is available to provide additional guidance.

4.7 Care must be taken not to contaminate samples or monitoring wells. All samples, sampling devices, and containers must be protected from possible sources of contamination when not in use. Water level measurements should be made according to Test Method D 4750 before placing, purging, or sampling equipment in the well. Redox potential, turbidity, pH, specific conductance, DO (dissolved oxygen), and temperature measurements should all be performed on the sample in the field, if possible, since these parameters change too rapidly to be conducted by a fixed laboratory under most circumstances. Field meter(s) or sondes equipped with flow-through cells are available that are capable of continuously monitoring these parameters during purging if they are being used as water quality indicator parameters. These devices prevent the mixing of oxygen with the sample and provide a means of determining when the parameters have stabilized. Certain measurements that are used as indicators of biological activity, such as ferrous iron, nitrite, and sulfite, may also be conducted in the field since they rapidly oxidize. All temperature measurements must be done prior to any significant atmospheric exposure.

5. Significance and Use

5.1 The quality of ground water has become an issue of national concern. Ground-water monitoring wells are one of the more important tools for evaluating the quality of ground water, delineating contamination plumes, and establishing the integrity of hazardous material management facilities.

5.2 The goal in sampling ground-water monitoring wells is to obtain samples that meet the DQOs. This guide discusses the advantages and disadvantages of various well sampling methods, equipment, and sample preservation techniques. It reviews the variables that need to be considered in developing a valid sampling plan.

6. Well Purging

6.1 Water that stands within a monitoring well for a long period of time may become unrepresentative of formation water because chemical or biochemical change may alter water quality or because the formation water quality may change over time (see Guide D 6452). Even if it is unchanged from the time it entered the well, the stagnant water may not be representative of formation water at the time of sampling. There are two approaches to purging that reflect two differing viewpoints: to purge a large volume of ground water and to purge a minimum of, or no ground water before collecting a sample. The approach most often applied is to purge a sufficient volume of standing water from the casing, along with sufficient formation water to ensure that the water being withdrawn at the time of sampling is representative of the formation water. Typically, three to five well volumes are used. An alternative method that is gaining acceptance is to minimize purging and to conduct purging at a low flow rate or to eliminate purging entirely.

6.2 In any purging approach, a withdrawal rate that minimizes drawdown while satisfying time constraints should be used. Excessive drawdown distorts the natural flow patterns

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[5] The boldface numbers in parentheses refer to a list of references at the end of this guide.

around the well. Two potential negative effects are the introduction of ground water that is not representative of water quality immediately around the monitoring well and artificially high velocities entering the well resulting in elevated turbidity and analytical data that reflects the absorption of contaminants to physical particles rather than soluble concentrations in ground water. It may also result in cascading water from the top of the screen that can result in changes in dissolved gasses, redox state, and ultimately affect the concentration of the analytes of interest through the oxidation of dissolved metals and possible loss of volatile organic compounds (VOCs). There may also be a lingering effect on the dissolved gas levels and redox state from air being introduced and trapped in the sandpack. In no instance shall a well be purged dry. If available, the field notes or purge logs generated during previous sampling or development of the well as well as construction logs should be reviewed to assist in the selection of the most appropriate sampling method.

6.3 The most often applied purging method has an objective to remove a predetermined volume of stagnant water from the casing prior to sampling. The volume of stagnant water can either be defined as the volume of water contained within the casing and screen, or to include the well screen and any gravel pack if natural flow through these is deemed insufficient to keep them flushed out. Research with a tracer in a full scale model 2-in. polyvinyl chloride (PVC) well **(6)** indicates that pumping 5 to 10 times the volume of the well via an inlet near the free water surface is sufficient to remove all the stagnant water in the casing. This approach (with three to five casing volumes purged) was suggested by the U.S. EPA **(7)**.

6.4 In deep or large diameter wells having a volume of water so large as to make removal of all the water impractical, it may be feasible to lower a pump or pump inlet to some point well below the water surface, purge only the volume below that point then withdraw the sample from a deeper level. Research indicates this approach should avoid most contamination associated with stagnant water **(6, 8)**. Sealing the casing above the purge point with a packer may make this approach more dependable by preventing migration of stagnant water from above. But the packer must be above the top of the screened zone, or stagnant water from above the packer may flow into the purged zone through the well's gravel/sand pack.

6.5 An alternate method is based on research by Barcelona, Wehrmann, and Varljen **(1)** and Puls and Powell **(2)**. Their research suggests that purging at rates less than 1 L/min (approximately 0.25 gal/min) provides more reproducible VOCs and metals analytical results than purging at high rates. This method is based on the premise that at very low pumping rates, there is little mixing of the water column and laminar ground-water flow through the screen provides a more consistent sample. This sampling method also produces less turbid samples that may eliminate the need for filtration when collecting metals. This method is commonly referred to as low-flow sampling.

6.6 The low-flow sampling approach is most applicable to wells capable of sustaining a yield approximately equal to the pumping rate. A monitoring well with a very low yield may not be applicable to this technique since it may be difficult to reduce the pumping rate sufficiently to prevent mixing of the water column in the well casing in such a well. The water level in the well being sampled should be continuously monitored using an electronic water-level indicator during low-flow sampling. Such a water-level indicator could be set below the water surface after sufficient water has been withdrawn to fill the pump, tubing, and flow cell. The water-level indicator would then produce a continuous signal indicating submersion. When the well is purged, if the water level falls below the water-level indicator probe, the signal indicates that the water level has fallen below the maximum allowable drawdown and the pumping rate should be decreased. Pumping is started at approximately 100 mL/min discharge rate and gradually adjusted to match the well's recharge rate. The selection of the type of pump is dependent on site-specific conditions and DQOs. The bladder pump design is most commonly used in this sampling method, however, the depth limitation of this pump may necessitate the use of a gas-driven piston pump in some instances.

6.7 A variation on the above purging approaches is to monitor one or more indicator parameters until stabilization of the selected parameter(s) has been achieved. Stabilization is considered achieved when measurements are within a predefined range. This range has been suggested to be approximately 10 % over two successive measurements made 3 min apart by the U.S. EPA **(4)**. More recent documents **(9)** have suggested ranges ±0.2°C for temperature, ±0.1 standard units for pH, ±3 % for specific conductance, ±10 % for DO, and ±10 mV for redox potential. A disadvantage of the stabilization approach is that there is no assurance in all situations that the stabilized parameters represent formation water. These criteria should therefore be set on a site by site basis since if set too stringent, large volumes of contaminated purge water may be generated without ensuring that the samples are any more representative. In a low yielding formation, this could result in the well being emptied before the parameters stabilize. Also, if significant drawdown has occurred, water from some distance away may be pulled into the screen causing a steady parameter reading but not a representative reading. If these criteria are properly selected, the volume of investigative derived waste water may be reduced.

6.8 The indicator parameters that may be monitored include pH, temperature, specific conductance, turbidity, redox potential, and DO. A combination of a pump and field meter(s) or sondes equipped with a flow-through cell is ideal for this purpose since it allows the monitoring of one or more of these parameters on a continuous basis without exposure to the atmosphere. A typical flow-through cell application is shown in Fig. 1. The pump used in this technique may be any pump capable of producing a steady flow such as a peristaltic or bladder pump. If a submersible pump is used, the hydraulic pressure developed in the flow-through cell may be sufficient to force the probes out of their position. This problem may be eliminated by installing a tee connector in the discharge line to allow only a portion of the flow to enter the flow-through cell. Another concern with the low-flow sampling method is sorption onto the tubing. Studies have indicated that at flow rates of 0.1 L/min (0.026 gal/min), low-density polyethylene (LDPE)

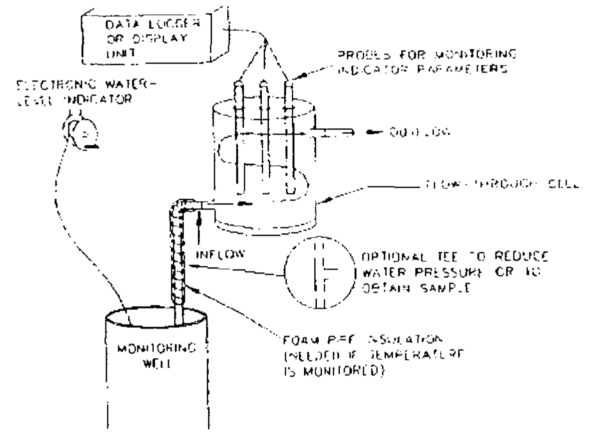

FIG. 1 Flow-Through Cell

and plasticized polypropylene tubings are prone to sorption and TFE-fluorocarbon should be used. This is especially a concern if tubing lengths of 15 m (50 ft) or longer are used (**10**).

6.9 Gibb and Schuller (**11**) have described a time-drawdown approach using knowledge of the well hydraulics to predict the percentage of stagnant water entering a pump inlet near the top of the screen at any time after flushing begins. Samples are collected when the percentage is acceptably low. As before, the advantage is that well volume has no direct effect on the duration of pumping. A current knowledge of the well's hydraulic characteristics is necessary to employ this approach. Downward migration of stagnant water due to effects other than drawdown (for example, density differences) is not accounted for in this approach.

6.10 An alternative to purging a well before sampling is to collect a water sample within the screened zone without purging. These techniques are based on studies that under certain conditions, natural ground-water flow is laminar and horizontal with little or no mixing within the well screen (**12, 13**). To properly use these sampling techniques, a water sample must be collected within the screened interval with little or no mixing of the water column within the casing. Examples of these techniques include minimal purge sampling which uses a dedicated sampling pump capable of pumping rates of less than 0.1 L/min, discrete depth sampling using a bailer that allows ground water entry at a controlled depth, (for example, differential pressure bailer (**14**)), or diffusion sampling. These sampling techniques are discussed in 8.1.10.

7. Materials and Manufacture

7.1 The choice of materials used in the construction of sampling devices should be based upon knowledge of what compounds may be present in the sampling environment and how the sample materials may interact via leaching, adsorption, or catalysis. A second concern is that corrosion or degradation may compromise the structural integrity of the sampling device. In some situations, PVC or other plastic may be sufficient. In others, an all TFE-fluorocarbon apparatus may be necessary. The potential presence of nonaqueous phase liquid (NAPL) should also be a consideration since its presence would expose the sampling equipment to high concentrations of potential solvents. No one material is ideal in that each material will to some degree absorb or leach chemicals or may degrade on exposure to a chemical.

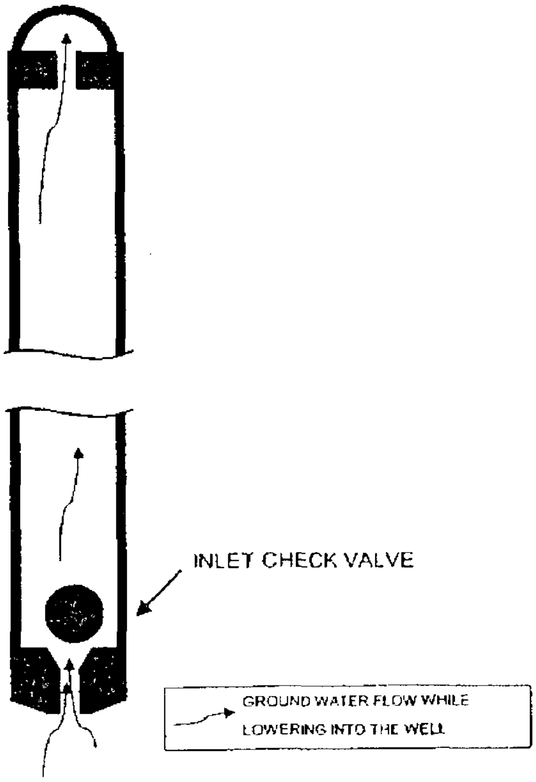

FIG. 2 Single Check Valve Bailer

7.2 The advantages and disadvantages of these materials for sampling equipment are summarized in Table 1.

7.3 *PVC:*

7.3.1 If adhesives are avoided, PVC is acceptable in many cases although their use may still lead to some problems if trace organics are of concern or NAPL is present (**15**). At present, interactions occurring between PVC and ground water are not well understood. Tin, in the form of an organotin stabilizer added to PVC, may enter samples taken from PVC (**16**).

7.3.2 The structural integrity concerns with PVC increase with the concentration of PVC solvents in ground water. As such, NAPLs that are PVC solvents are a primary concern. Potential NAPLs that are of a concern for PVC and other commonly used plastics are listed in Table 2. Degradation of these materials is primarily by solvation, which is the penetration of the material by the solvent that ultimately causes softening and swelling that can lead to failure. Even in lower concentrations, however, PVC solvents may deteriorate PVC. Methylene chloride, which is a very effective PVC solvent, will soften PVC at one tenth its solubility limit while trichloroethylene, which is a less effective solvent, will begin to soften PVC at six tenths its solubility limit (**17**).

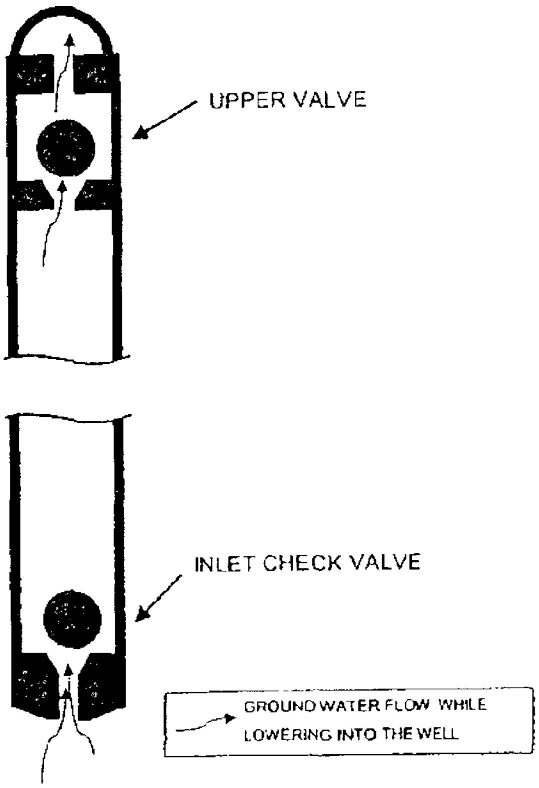

FIG. 3 Double Check Valve Bailer

7.4 *TFE-Fluorocarbon Resins:*

7.4.1 TFE-fluorocarbon resins are highly inert and have sufficient mechanical strength to permit fabrication of sampling devices. Molded parts are exposed to high temperature during fabrication that destroys any organic contaminants. The evolution of fluorinated compounds can occur during fabrication, will cease rapidly, and does not occur afterwards unless the resin is heated to its melting point. Relative to PVC and stainless steel, TFE-fluorocarbon is less sorptive of cations **(18)**.

7.4.2 Extruded TFE-fluorocarbon tubing may contain surface traces of an organic solvent extrusion aid. This can be removed easily by the fabricator and, once removed by flushing, should not affect the sample. TFE-fluorocarbon fluorinated ethylene propylene (FEP) and TFE-fluorocarbon perfluoroalkoxy (PFA) resins do not require this extrusion aid and may be suitable for sample tubing as well. Unsintered thread-sealant tape of TFE-fluorocarbon is available in an "oxygen service" grade and contains no extrusion aid and lubricant.

7.5 *Glass and Stainless Steel:*

7.5.1 Glass and stainless steel are two other materials generally considered inert in aqueous environments. Glass is generally not used, however, because of difficulties in handling and fabrication. Stainless steel is strong and easily machined to fabricate equipment. It is, however, not totally immune to corrosion that could release metallic contaminants (see Table 1). Stainless steel contains various alloying metals, some of these (that is, Nickel) may catalyze reactions. The alloyed constituents of some stainless steels can be solubilized by the pitting action of nonoxidizing anions such as chloride, fluoride, and in some instances sulfate, over a range of pH conditions. Aluminum, titanium, polyethylene, and other corrosion resistant materials have been proposed by some as acceptable materials, depending on ground-water quality and the constituents of interest.

7.5.2 Where temporarily installed sampling equipment is used, the sampling device that is chosen should be able to be cleaned of trace organics, and must be cleaned between each monitoring well use to avoid cross-contamination of wells and samples. Decontamination of equipment PVC and stainless steel constructed sampling equipment exposed to organic chemicals, pesticides or nitroaromatic compounds generally can be successfully accomplished using a hot detergent solution followed by a hot water rinse. Equipment constructed of LDPE and TFE-fluorocarbon should also be hot air dried or oven dried at approximately 105°C to remove residual pesticides and organic contaminants, respectively **(19, 20)**. A common method to verify that the device is "clean" and acceptable is to analyze a sample (equipment blank) that has been soaked in or passed through the sampling device, or both, to check for the background levels that may result from the sampling materials or from field conditions. Thus, all samplings for trace materials should be accompanied by samples that represent the sampling equipment blank, in addition to other blanks (field blank and trip blank). Decontamination procedures are further discussed in Practice D 5088.

7.6 Additional samples are often collected in the field and spiked (spiked-field samples) in order to verify that the sample handling procedures are valid. The American Chemical Society's committee on environmental improvement has published guidelines for data acquisition and data evaluation, which should be useful in such environmental evaluations **(21)**.

8. Sampling Equipment

8.1 The choice of sampling technique must be based on an understanding of the hydrogeology of the site under investigation and the end use of the data. Since each technique has its advantages and disadvantages, no one technique can be chosen as the best overall technique. Since different techniques will likely yield different results, it is best to be consistent throughout an investigation to facilitate the comparison of data values over time. There is a fairly large choice of equipment presently available for ground-water sampling. The sampling devices can be categorized into the following nine basic types as described in the following sections:

8.1.1 *Down-Hole Collection Devices:*

8.1.1.1 Bailers, messenger bailers, or thief **(22, 23)** are examples of down-hole collection devices. They are not practical for removal of large volumes of water but are relatively inexpensive permitting their dedicated use and are widely used. These devices can be constructed in various shapes and sizes from a variety of materials. They do not subject the sample to pressure extremes.

8.1.1.2 A schematic of a single check valve unit is illustrated in Fig. 2. The bailer may be threaded in the middle so that additional lengths of blank casing may be added to

TABLE 1 Material Considerations In Selection Of Sampling Equipment (**76**)

Material	Considerations
Polytetrafluoroethylene	• Virgin PTFE readily sorbs some organic solutes (**17**) • Ideal material in corrosive environments where inorganic compounds are of interest • Useful where pure product (organic compound) or high concentrations of PVC solvents exist • Potential structural problems because of its low tensile and compressive strengths low wear resistance, and the extreme flexibility of the casing string as compared to other engineering plastics (**40, 70, 71**) • Potential problems with obtaining a seal between the casing and the annular sealant because of PTFEs low coefficient of friction and antistick properties as compared to other plastics (**71**) • Maximum string length of 2-in (~5-cm) diameter schedule PTFE casing should not exceed about 375 ft (~115 m) (**72**) • Expensive
Polyvinylchloride	• Leaching of compounds of tin or antimony, which are contained in original heat stabilizers during polymer formulation, could occur after long exposure • When used in conjunction with glued joints, leaching of volatile organic compounds from PVC primer and glues, such as THF (tetrahydrofuran), MEK (methylethylketone), MIBK (methylisobutylketone) and cyclohexanone could leach into ground water Therefore, threaded joints below the water table, sealed with O-rings or Teflon tape, are preferred • Cannot be used where pure product or high concentrations of a PVC solvent exist • There is conflicting data regarding the resistance of PVC to deterioration in the presence of gasoline (**73**) • Maximum string length of 2-in (~5-cm) diameter threaded PVC casing should not exceed 2000 ft (~610 m) (**72**) • PVC can warp and melt if neat cement (cement and water) is used as an annular or surface seal because of heat of hydration (**74, 40**) • PVC can volatilize CFCs into the atmosphere within the unsaturated zone, which can be a potential problem for studies of gas and moisture transport through the unsaturated zone • Easy to cut, assemble, and place in the borehole • Inexpensive
Stainless steel	• Generally has high corrosion resistance, which differs with type • Corrosion can occur under acidic and oxidizing conditions • Corrosion products are mostly iron compounds, with some trace elements • Primarily two common types: (*1*) Type 304 Stainless Steel: Iron alloyed with the following elements (percentages). Chromium (18-20 %), Nickel (8-11 %), Manganese (2 %), Silicon (0.75 %), Carbon (0.08 %), Phosphorus (0.04 %), Sulfur (0.03 %) (*2*) SS 316: Iron alloyed with the following elements (in percentages): Chromium (16-18 %), Nickel (11-14 %), Manganese (2 %), Molybdenum (2-3 %), Silicon (0.75 %), Carbon (0.08 %), Phosphorus (0.04 %), Sulfur (0.03 %) • Corrosion resistance is good for Type 304 stainless steel under aerobic conditions. Type 316 stainless steel has improved corrosion resistance over Type 304 under reducing conditions (**75**) • Expensive
Galvanized steel	• Less corrosion resistance than stainless steel and more resistance to corrosion than carbon steel (see Carbon steel entry) • Oxide coating could dissolve under chemically reduced conditions and release zinc and cadmium, and raise pH • Weathered or corroded surfaces present active adsorption sites for organic and inorganic constituents • Inexpensive
Carbon steel	• Corrosion products can occur (for example, iron and manganese oxides, metal sulfides, and dissolved metal species) • Sorption of organic compounds onto metal corrosion products is possible • Weathered surfaces present active adsorption sites for organic and inorganic constituents • Inexpensive

increase the sampling volume. TFE-fluorocarbon, stainless steel, and PVC are the most common materials used for construction (**24**).

8.1.1.3 In operation, the single check valve bailer is gently lowered into the well to a depth just below the water surface, water enters the chamber through the bottom, and the weight of the water column closes the check valve upon bailer retrieval. The specific gravity of the ball should be about 1.4 to 2.0 so that the ball almost sits on the check valve seat during chamber filling. Upon bailer withdrawal, the ball will immediately seat without sample loss through the check valve.

8.1.1.4 A double check valve bailer allows point source sampling at a specific depth (**25, 26**). The double check valve bailer is also effective at collecting dense, non-aqueous phase liquid (DNAPL) from the bottom of a monitoring well. An example is shown in Fig. 3. In this double check valve design, water flows through the sample chamber as the unit is lowered. A venturi tapered inlet and outlet ensures that water passes through the unit with limited restriction. When a depth where the sample is to be collected is reached, the unit is retrieved. Because the difference between each ball and check valve seat is maintained by a pin that blocks vertical movement of the check ball, both check valves close simultaneously upon retrieval. A drainage pin is placed into the bottom of the bailer to drain the sample directly into a collection vessel to reduce the possibility of air oxidation.

8.1.1.5 A top-filling bailer is a closed bottom tubular device, opened on top and provided with a loop or other fixture to attach to the drop line. The top-filling bailer is gently lowered below the water surface in the well and water pours into the bailer from the top. Although this variation on the bailer design results in greater agitation of the sample, it may be used to collect a sample of light, non-aqueous phase liquid (LNAPL) by lowering it just below the surface of the LNAPL and

TABLE 2 Chemical Compatibility Table For Selected NAPL (78)

Chemical	PTFE (Teflon)	PP (Polypropylene)	PVC (Type I)	PVC (Type II)	304 Stainless	316 Stainless	Carbon Steel
Benzene	R	X	U	U	G	G	G
Carbon Tetrachloride	R	U	X	U	E	E	G
Dichlorobenzene	R	R	U	U	...	G	...
Dichloroethane (DCA)	R	X	U	U	G	G	G
Dichloroethylene (DCE)	R	R	U	U	G	G	...
Diesel Fuel	R	R	R	...	E	E	G
Ethyl Benzene	R	U	U	U	S	G	U
Gasoline	R	X	R	...	G	G	G
Hydraulic Oil (petro.)	R	X	R	...	R	R	...
Hydraulic Oil (synthetic)	R	X	R	.	R	R	...
Jet Fuels	R	X	R	R	G	G	G
Kerosene	R	R	R	R	G	G	G
Motor Oil	R	X	R	R	G	G	G
Napthalene	R	R	U	U	E	E	G
Tetrachloroethylene (PCE)	R	U	U	U	E	E	G
Toluene	R	R	U	U	E	E	E
Trichloroethylene (TEC)	R	R	U	U	G	G	G
Xylenes	R	R	U	U	G	G	G

For Metals
E < 2 mills Penetration/Year
G < 20 mills Penetration/Year
S < 50 mills Penetration/Year
U > 50 mills Penetration/Year
(1 mil = 0.001 in.)
R = Resistant (No corrosion rate reported)

For All Non-Metals
R = Resistant
U = Unsatisfactory
X = Conflicting Data, at least one reference reported unsatisfactory

allowing the bailer to skim the LNAPL from the surface of the water column.

8.1.1.6 The differential pressure bailer is a sealed canister body with two small diameter tubes of different heights built into its removable top (**14**). The bailer is usually constructed of stainless steel to provide sufficient weight to allow it to sink relatively quickly to the desired sampling depth. Once the bailer's downward progress is stopped, differences in hydrostatic pressure between the two tubes allows the bailer to fill through the lower tube as air is displaced through the upper tube. This type of bailer minimizes the exposure of the sample to air especially if fitted with internal 40 mL vials for direct sample bottle filling.

8.1.1.7 Special care must be taken to minimize exposing the sample to the atmosphere during the transfer of the sample from the bailer to the sample bottle. There are several approaches to overcome this issue. Bottom-emptying bailers used for sampling of VOCs, for example, should have an insertable sample cock or draft valve cock (often referred to as a bottom or bailer emptying device) in or near the bottom of the sampler allowing withdrawal of a sample from the bailer with minimal atmosphere exposure.

8.1.1.8 Suspension lines for bailers and other samplers should be kept off the ground and free of other contaminating materials that could be carried into the well. A plastic sheet may be spread out on the ground around the monitoring well for this purpose. Disposable TFE-fluorocarbon, PVC, polyethylene, and polypropylene bailers are available which offer time savings and all but eliminates the potential for cross contamination during sampling.

8.1.1.9 Sample oxidation is a concern with single check valve and top filling bailers. Sample oxidation might occur during the extended time it takes to bail a sample if water levels are a great depth below the ground surface or if there is a delay in the transfer of the sample from the bailer to the sample bottles. Using point source bailers, however, minimizes the oxidation problem.

8.1.1.10 Another approach for obtaining point source samples employs a weighted messenger or pneumatic change to "trip" plugs at either end of an open tube (for example, tube water sampler or thief sampler) to close the chamber (**27**). Foerst, Kemmerer, and Bacon samplers are of this variety (**23, 24, 26**). A number of thief or messenger devices are available in various materials and shapes. Differential pressure bailers (**14**) also provide a point source sample but do not require manual tripping.

8.1.2 *Bladder Pumps:*

8.1.2.1 Bladder pumps consist of a flexible membrane enclosed by a rigid housing. Water enters the pump cavity through an inlet, usually located on the bottom of the pump. Compressed gas either from a compressor or air cylinder is injected into a bladder within the pump cavity forcing the check valve on the inlet to close and the sample up through a second check valve at the top of the pump and into a discharge line (Fig. 4). Water is prevented from re-entering the bladder by the top check valve. The bladder is then depressurized, allowing the pump to refill. The process is repeated to cycle the water to the surface. Samples taken from depths of 122 m (400 ft) have been reported.

8.1.2.2 A variety of design modifications and materials are available (**29, 30**) however, TFE-fluorocarbon bladders, either PVC, TFE-fluorocarbon resin or stainless steel bodies and fittings are most common. An automated controller system is

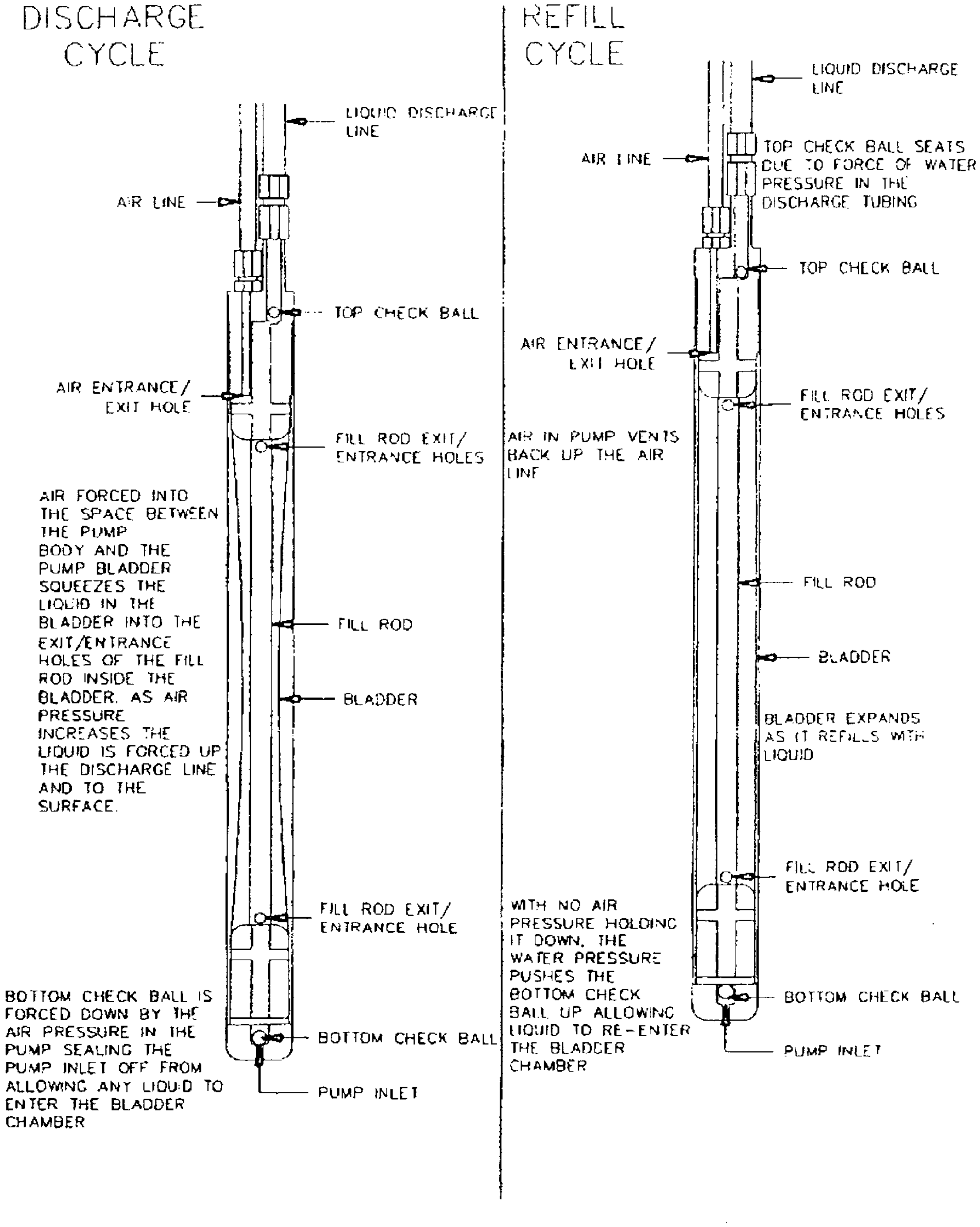

FIG. 4 Squeeze Type Bladder Pump

used to control the time between pressurization cycles and regulate pressure.

8.1.2.3 Bladder pumps have a distinct advantage over gas displacement pumps in that there is no contact with the driving gas. Disadvantages include the large gas volumes required, and difficulty in decontaminating the pump. This pump design is most applicable to dedicated well installations and where low pump rate or flow rate (less than 0.5 L/min) are required. The flow rate from a bladder pump is dependent on the dimensions of the bladder pump, controller settings, gas pressure, and total dynamic head.

8.1.3 *Suction Lift Pumps*:

8.1.3.1 Three types of suction lift pumps are the direct line, centrifugal, and peristaltic. A major disadvantage of any suction pump is that it is limited in its ability to raise water by the head available from atmospheric pressure. The theoretical suction limit is about 10.4 m (34 ft), but most suction pumps are capable of maintaining a water lift of only 7.6 m (25 ft) **(31)**.

8.1.3.2 Many suction pumps draw water through a volute in which impellers, pistons, or other devices operate to induce a vacuum. Such pumps are probably unacceptable for most sampling purposes because they are usually constructed of non-inert materials such as brass or mild steel and may expose samples to lubricants. They often induce very low pressures around rotating vanes or other such parts such that degassing or potentially cavitation may occur. They can mix air with the sample via small leaks in the casing, and they are difficult to adequately clean between uses. Such pumps may be acceptable for purging of wells, but should not generally be used for sampling.

8.1.3.3 An exception to the above statements is a peristaltic pump (also known as a rotary peristaltic pump). A peristaltic pump is a self-priming, low-volume suction pump that consists of a rotor with rollers **(32)**. Flexible tubing is inserted around the pump rotor and squeezed by rollers as they rotate. One end of the tubing is placed into the well (a weighted end may be used) while the other is connected directly to a receiving vessel. As the rotor moves, reduced pressure is created in the well tubing and an increased pressure on the tube leaving the rotor head. Pumping rates may be controlled by varying the speed of the rotor or by changing the size of the pump head, which contains the pump rotor.

8.1.3.4 The peristaltic pump moves the liquid totally within the sample tube. No part of the pump contacts the liquid. The sample may be degassed (cavitation is unlikely), but the problems due to contact with the pump mechanism are eliminated. Peristaltic pumps do require a fairly flexible section of tubing within the pump head itself. A section of silicone tubing is commonly used within the peristaltic pump head, but other types of tubing can be used particularly for the sections extending into the well or from the pump to the receiving container. The National Council of the Paper Industry for Air and Stream Improvement **(33)** recommends using medical grade silicone tubing for VOC sampling purposes as the standard grade uses an organic vulcanizing agent which has been shown to leach into samples. Various manufacturers offer tubing lined with TFE-fluorocarbon or Viton[6] for use with their pumps. Plasticized polypropylene tubings and LDPE should be avoided if flow rates less than 0.1 L/min (0.025 g/min) are used **(10)**. The extraction rate with this method can range from 0.04 to 30 L/min (0.01 to 8 gal/min) **(34)**.

8.1.3.5 There is disagreement on the applicability of peristaltic pumps for the collection of groundwater samples. Research by Tai, et al **(35)** has shown that peristaltic pumps provide adequate recovery of VOCs. The U.S. EPA **(4)** does not recommend its use because of studies that suggest that VOCs may be lost during sampling **(36)**.

8.1.3.6 A direct method of collecting a sample by suction consists of lowering one end of a length of plastic tubing into the well or piezometer. The opposite end of the tubing is connected to a two-way stopper bottle and a hand held or mechanical vacuum pump is attached to a second tubing leaving the bottle. A check valve is attached between the two lines to maintain a constant vacuum control. A sample can then be drawn directly into the collection vessel without contacting the pump mechanism **(37, 38)**.

8.1.3.7 A centrifugal pump can be attached to a length of plastic tubing that is lowered into the well. A foot valve is usually attached to the end of the well tubing to assist in priming the tube. The maximum lift is about 4.6 m (15 ft) for such an arrangement **(37, 38, 39)**.

8.1.3.8 Suction pump approaches offer a simple sample retrieval method for shallow monitoring wells. The direct line method is portable though considerable oxidation and mixing may occur during collection. A centrifugal pump will agitate the sample to an even greater degree although pumping rates of 19 to 151 L/min (5 to 40 gal/min) can be attained. A peristaltic pump provides a lower sampling rate with less agitation than the other two pumps, as discussed in 8.1.3.4.

8.1.3.9 All three systems can be specially designed so that the water sample contacts only the TFE-fluorocarbon or silicone tubing prior to sample bottle entry. Dedicated tubing is recommended for each well or piezometer sampled. Each of these methods that relay on suction can change solution chemistry by causing degassing which may result in loss of volatile compounds and dissolved gasses and this should be a consideration in their application **(34)**.

8.1.4 *Electric Submersible Pumps*:

8.1.4.1 A submersible pump consists of a sealed electric motor that powers a piston, impeller, or helical single thread worm. Water is brought to the surface through a discharge tube. Similar pumps are commonly used in the water well industry and many designs exist **(40)**.

8.1.4.2 Submersible pumps provide relatively high discharge rates for water withdrawal at depths beyond suction lift capabilities. A battery operated unit 3.6 cm (1.4 in.) in diameter and with a 4.5 L/min (1.2 gal/min) flow rate at 33.5 m (110 ft) has been developed **(41)**. Another submersible pump has an outer diameter of 11.4 cm (4.5 in.) and can pump water from 91 m (300 ft). Pumping rates vary up to 53.0 L/min (14 gal/min) depending upon the depth of the total dynamic head **(42)**.

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[6] Viton is a trademark of E. I. du Pont de Nemours & Co., Wilmington, DE 19898 and has been found suitable for this purpose.

8.1.4.3 A submersible pump provides higher extraction rates than many other methods. Considerable sample agitation results, however, in the well and in the discharge tube during sampling. The possibility of introducing trace metals into the sample from pump materials also exists; however, submersible pumps designed specifically for environmental work do exist. These pumps are constructed of relatively inert materials such as stainless steel, TFE-fluorocarbons and Viton. Decontamination procedures are discussed in Practice D 5088. Recent research, however, has suggested that steam cleaning followed by rinsing with unchlorinated, deionized water should be used between samplings when analysis for VOCs is required **(43)**. Complete decontamination of submersible pumps is difficult and should be confirmed by the collection of equipment blanks.

8.1.4.4 Submersible pumps have several disadvantages that should be considered. The silt and fine sand commonly present in monitoring wells may cause excessive wear to internal impellers and staters. These pumps also commonly require a high-amperage 120/220-V power source and a reel and winch system that limit their mobility. Submersible pumps may also not be suitable for collecting liquids containing VOCs or dissolved gasses because of their potential to degas the sample.

8.1.5 *Gas-Lift Pumps*:

8.1.5.1 Gas-lift pumps use compressed air to bring a water sample to the surface. Water is forced up an eductor pipe that may be the outer casing or a smaller diameter pipe inserted into the well annulus below the water **(44, 45)**.

8.1.5.2 A similar principle is used for a unit that consists of a small diameter plastic tube perforated in the lower end. This tube is placed within another tube of slightly larger diameter. Compressed air is injected into the inner tube; the air bubbles through the perforations, thereby lifting the water sample via the annulus between the outer and inner tubing **(45)**. In practice, the eductor line should be submerged to a depth equal to 60 % of the total submerged eductor length during pumping **(40)**. A 60 % ratio is considered optimal although a 30 % submergence ratio is adequate.

8.1.5.3 The source of compressed gas may be a hand pump for depths generally less than 7.6 m (25 ft). For greater depths, air compressors, and pressurized air cylinders have been used. When air compressors are used, an air-oil filter must be installed to minimize the introduction of oil to the well.

8.1.5.4 As already mentioned, gas-lift methods result in considerable sample agitation and mixing within the well, and cannot be used for samples which will be tested for VOCs or dissolved gasses (for example, DO, methane). The eductor pipe or weighted plastic tubing is a potential source of sample contamination. In addition, Gibb **(11)** expressed concerns in sampling for inorganics. These concerns were attributed to changes in redox, pH, and species transformation due to solubility constant changes resulting from stripping, oxidation, and pressure changes.

8.1.6 *Gas Displacement Pumps*:

8.1.6.1 Gas displacement or gas drive pumps are distinguished from gas-lift pumps by the method of sample transport. Gas displacement pumps force a discrete column of water to the surface via mechanical lift without extensive mixing of the pressurized gas and water as occurs with air-lift equipment. The principle is shown schematically in Fig. 5. Water fills the chamber. A positive pressure is applied to the gas line closing the sampler check valve and forcing water up the sample line. The cycle is repeated by removing the pressure. Vacuum can also be used in conjunction with the gas **(46)**. The device can be permanently installed in the well **(47, 48, 49)** or lowered into the well **(50, 51)**.

8.1.6.2 A more complicated two stage design constructed of glass with check valves made of TFE-fluorocarbon has been constructed **(52, 53)**. The unit was designed specifically for sample testing for trace level organics. Continuous flow rates of up to 38 L/min (10 gal/min) are possible.

8.1.6.3 Gas displacement pumps offer reasonable potential for preserving sample integrity because little driving gas comes in contact with the sample as the sample is conveyed to the surface by a positive pressure. There is, however, a potential loss of dissolved gasses and contamination from the driving gas and the housing materials.

8.1.7 *Gas Driven Piston Pumps*:

8.1.7.1 A double piston pump powered by compressed air is illustrated in Fig. 6. Pressurized gas enters the chamber between the pistons; the alternating chamber pressurization activates the piston that allows water entry during the suction stroke of the piston and forces the sample to the surface during the pressure stroke **(54)**. Pumping rates between 0.16 and 0.51 L/min (0.04 and 0.13 gal/min) have been reported from 30.5 m (100 ft). Depths in excess of 457 m (1500 ft) are possible.

8.1.7.2 The gas piston pump provides continuous sample withdrawal at depths greater than is possible with most other approaches. Nevertheless, contribution of trace elements from

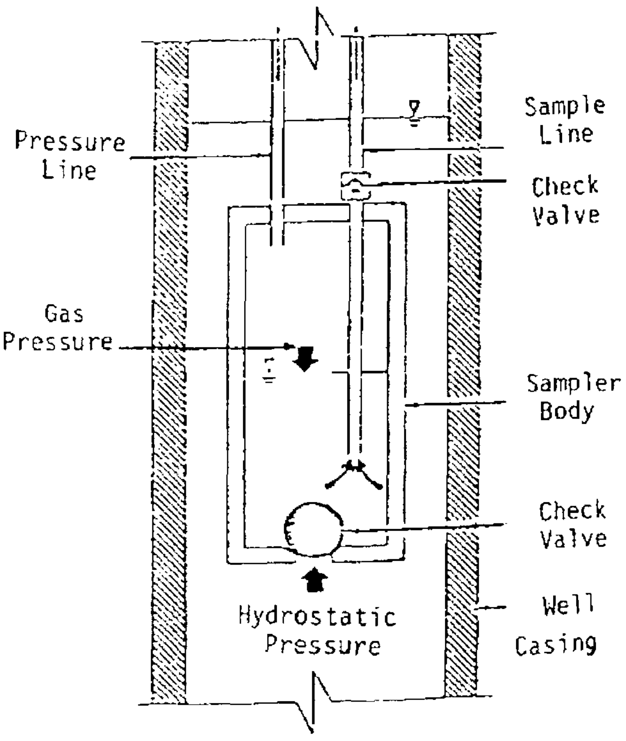


FIG. 5 The Principle of Gas Dispalcement Pumping

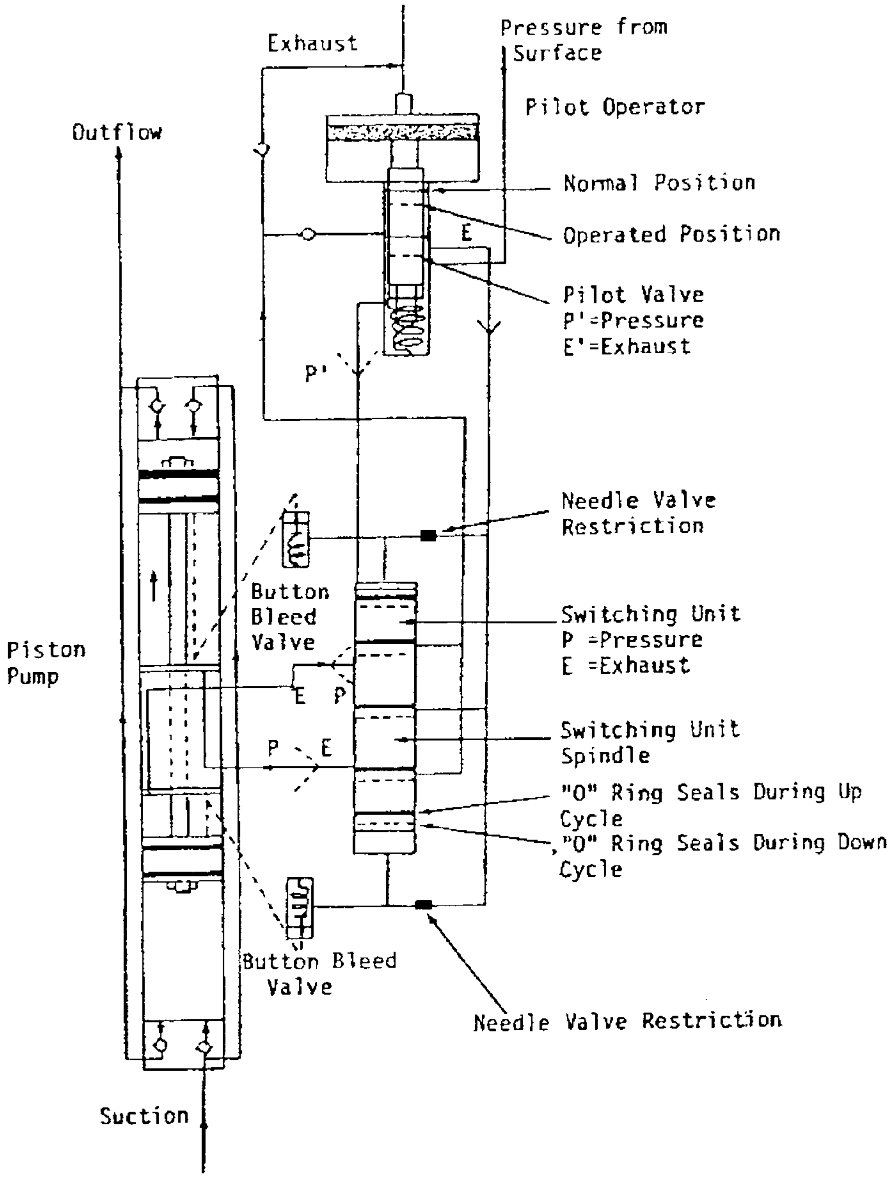


FIG. 6 Gas-Driven Piston Pump

the stainless steel and brass is a potential problem and the quantity of gas used is significant.

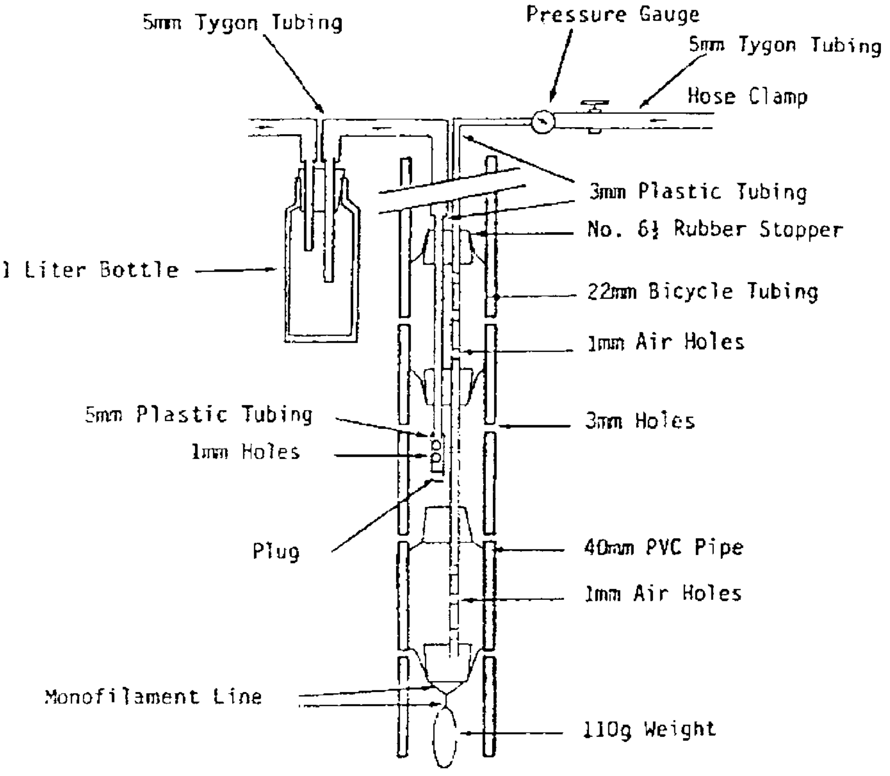
8.1.8 *Packer Pump Arrangement:*

8.1.8.1 A packer pump arrangement provides a means by which two expandable "packers" isolate a sampling unit between packers within a well. Since the hydraulic or pneumatic activated packers are pressed against the casing wall, the sampling unit will obtain water samples only from the isolated well portion. The packers are deflated for vertical movement within the well and inflated when the desired depth is attained. Submersible, gas lift, and suction pumps can be used for sampling. The packers are usually constructed of a rubber compound (54-57). A packer pump unit consisting of a vacuum sampler positioned between packers is illustrated in Fig. 7 (58).

8.1.8.2 A packer assembly allows the isolation of discrete sampling points within a well. A number of different samplers can be situated between the packers depending upon the analytical specifications for sample testing. Because access to the interval between packers is blocked once the packers are inflated, the selection of sampling devices is limited to sampling pumps. Vertical movement of water outside the well casing during sampling is possible with packer pumps but depends upon the pumping rate and subsequent disturbance. Deterioration of the expandable materials will occur with time with the increased possibility of undesirable organic contaminants contributing to the water sample.

8.1.9 *Inertial-Lift Pumps:*

8.1.9.1 The inertial-lift pump consists of a foot valve at the



Taken from Ref (79)

FIG. 7 Packer Pump Arrangement

end of a flexible tube. The tube and foot valve is inserted into the well with one end of the tube remaining at the surface. The tube is then rapidly moved in a continuous up-and-down motion. Each upward stroke lifts the water column in the tubing a distance equal to the stroke length. At the end of the upstroke, the water continues to move slightly upward by inertia. On the down stroke, the foot valve opens allowing fresh water to enter the tube. This process continues resulting in a flow to the surface.

8.1.9.2 The inertial-lift pump is capable of operating efficiently at depths to 30 m (100 ft). It is effective in small diameter wells or direct-push technology probes which are typically 12.5 mm (½-in.) diameter. The pumping rate ranges from 0 to 7.6 L/min (0 to 2 gal/min) (34), depending on the rate of the up and down pumping stroke and the tube diameter. The equipment used in this pump is inexpensive enough to be dedicated to a well with the exception of the pump handle or motor drive that do not contact the sample.

8.1.9.3 The inertial-lift pump, however, has several disadvantages. It is difficult to operate in deep, large diameter wells. Although a motor drive can overcome this limitation, the incorporation of a motor drive limits the portability of the equipment. The foot valve must be selected to match the casing material since it will tend to ride against the casing and potentially will either damage the casing or wear out. The discharge tubing must be stiff for the pump to operate properly. This makes the tubing awkward to install and remove from a monitoring well.

8.1.10 *Minimal Purge, Discrete Depth, and Passive Sampling*—Sampling techniques that do not rely on, or require only minimal purging may be used if a particular zone within a screened interval is to be sampled or if a well is not capable of yielding sufficient ground water for purging. These techniques include minimal purge, discrete depth sampling, and passive sampling.

8.1.10.1 A dedicated pump is used for minimal purge sampling so that only enough water is purged through the pump so that the volume of water contained by the pump and discharge tube is removed before sampling. No attempt is made to purge the casing, screen, or formation. This volume should be minimized by the selection of small diameter tubing and the smallest possible pump chamber. This initial volume of discharged water is discarded since it had prolonged contact with the sampling device.

8.1.10.2 The discrete depth sampler is often non-dedicated. It is lowered very slowly to the depth of the screen where a water sample is drawn into the sampling chamber. This is accomplished either manually by using a triggering mechanism such as a cable or automatically such as with a differential pressure bailer (14). Discrete depth samplers, however, must be used with great caution because of the potential of mixing of the water column in the well casing while lowering the sampler to its sampling depth.

8.1.10.3 Passive sampling, using diffusion samplers (a water-filled membrane), is based on the principle of molecular diffusion of VOCs from the ground water into the sampler.

(Research is currently being conducted by the U. S. Geological Survey to evaluate diffusion samplers for the collection of non-VOC parameters, however, study results have not been published.) The samplers must remain in the borehole for an adequate time for the water initially within the sampler to equilibrate with that in the borehole. The diffusion sampler typically consists of water-filled, low-density polyethylene tubing, which acts as a semi-permeable membrane. The sampler is attached to a weighted line, and lowered to a predetermined depth within the screened interval. Since the sample is depth specific, multiple samplers may be strung together to provide samples from different depths within the well. After adequate residence time has elapsed, the sampler(s) are removed from the well, punctured and the sample transferred into sample bottles. The samples are preserved and submitted to the laboratory for analysis. In a study of this technique, a minimum of 11 days was required to achieve equilibration (**59, 60**). Concerns about the applicability of this sampling method to specific VOCs have been raised, however, no detailed evaluation of this issue has been published. In a comparison of sampling techniques, samples collected by the diffusion method were found to be biased lower than samples collected using a low-flow method (**61**), however, this difference was attributed to issues with the laboratory or to the depth-specific nature of diffusion samplers.

9. Sample Containers and Preservation

9.1 The order of sample container filling, method of filling, selection of sample container type, and preservation method should be provided in the sampling and analysis plan. Generally, the order of sample container filling should proceed from most volatile to least volatile compound.

9.2 Complete and unequivocal preservation of samples, whether domestic wastewater, industrial wastes, or natural waters, is practically impossible. At best, preservation techniques only retard the chemical and biological changes that inevitably continue after the sample is removed from the source. Therefore, insuring the timely analysis of a sample should be one of the foremost considerations in the sampling plan schedule. Methods of preservation are somewhat limited and are intended to retard biological action, retard chemical reactions and complexes, and reduce the volatilization of constituents. Preservation methods are generally limited to pH control, chemical addition, refrigeration, and freezing. For water samples, immediate refrigeration just above freezing (4°C in wet ice) is often the best preservation technique available, but it is not the only measure nor is it applicable in all cases. There may be special cases where it might be prudent to include the temperature to which the samples were exposed. Inexpensive devices for this purpose, such as a recording thermometer, are available for this purpose. A water-filled bottle may be included in the sample-shipping container for temperature measurement by the laboratory receiving the samples.

9.3 All bottles and containers must be specially pre-cleaned, and organized in ice chests (isolating samples and sampling equipment from the environment) before one goes into the field. The time in the field is very valuable and should be spent on taking field notes, measurements, and in documenting samples, not on labeling and organizing samples. Therefore, the sampling plan should include clear instructions to the sampling personnel concerning the information required in the field data record logbook (notebook), the information needed on container labels for identification, the chain-of-custody protocols, and the methods for preparing field blanks and spiked samples. Examples of detailed plans and documentation procedures have been published (**23, 62**, see Guide D 6089).

9.4 The exact requirements for the volumes of sample needed and the number of containers to use may vary from laboratory to laboratory. This will depend on the specific analyses to be performed, the concentration levels of interest, the individual laboratory protocols, and the required QC samples. Since a well may not be capable of yielding adequate sample volume, a minimum required sample volume should be provided to the sample crew. The manager of the sampling program should make no assumptions about the laboratory analyses. He should discuss the analytical requirements of the sampling program in detail with the laboratory coordinator beforehand. This is especially the case since some analyses and preservation measures must be performed at the laboratory as soon as possible after the samples arrive. Thus, appropriate arrangements must be made.

9.5 There are a number of excellent references available which list the containers and preservation techniques appropriate for water and soils (**22, 23, 29, 58, 63-65**). Some of this information is summarized in Table X1.1 and Guide D 6517, however, different regulatory programs have specific requirements that must be met.

9.6 Sample containers for VOC samples require special cleaning and handling considerations (**66**). The sample container for purgeable organics consist of a screw-cap vial (25 to 125 mL) fitted with a TFE-fluorocarbon faced silicone septum. The vial is sealed in the laboratory immediately after cleaning and is only opened in the field just prior to pouring a sample into it. The water sample then must be sealed into the vial headspace free (no air bubbles) and immediately cooled (4°C) for shipment. Multiple samples are taken because leakage of containers may cause losses, may allow air to enter the containers, and may cause erroneous analysis of some constituents. Also, some analyses are best conducted on independently preserved samples. The sampling program for VOCs should include at a minimum trip blanks. Trip blanks and field spikes should also be considered for low level analysis.

9.7 The laboratory must analyze the purgeable samples within 14 days after collection. For samples for solvent extractions (extractable organics-base neutrals, acids, pesticides, herbicides), the sample bottles are narrow mouth, screw cap quart bottles or half-gallon bottles that have been precleaned, rinsed with the extracting organic solvent and oven dried at 105°C for at least 1 h. These bottles must be sealed with TFE-fluorocarbon lined caps (Note 1). Samples for organic extraction must be extracted within 7 days and analyzed within 40 days after extraction.

NOTE 1—When collecting samples, the bottles should not be overfilled or prerinsed with sample before filling because oil and other materials may remain in the bottle. This can cause erroneously high results.

9.8 For a number of ground-water parameters, the most meaningful measurements are those made in the field at the time of sample collection or at least at an on-site laboratory. These include the water level in the well (see Test Method D 4750) and parameters that can change rapidly with storage. A discussion of the various techniques for measuring the water level in the well is contained in a NCASI publication **(67)** and detailed procedures are outlined in a U.S. Geological Survey publication **(68, 69)**. Although a discussion of water level measuring techniques is beyond the scope of this guide, it is important to point out that accurate measurements must be made either before a well is purged or after it has had sufficient time to recover. Parameters that can change rapidly with storage include pH, turbidity, redox potential, DO, and temperature. Specific conductance, although most accurately determined in a laboratory setting, often is measured in the field where it is used as an indicator parameter to determine the completeness of purging. For some of the other parameters, the emphasis in ground-water monitoring is on the concentration of each specific dissolved component, not the total concentration of each. Samples for these types of measurements should be filtered through 0.45 µm membrane filters ideally in the field or possibly at an on-site laboratory as soon as possible. Analyses often requiring filtered samples include metals, radioactivity parameters, dissolved organic carbon, dissolved orthophosphate, and total dissolved phosphorous **(22, 23)**. If metals are to be analyzed, filter the sample prior to acid preservation. If concerns related to the loss of mobile colloidal material by filtering is a consideration, sampling protocol should be modified to limit sample turbidity during collection so that filtering is not necessary. This is often done by using very low purge and sample flow rates. For total organic carbon (TOC), the filter material should be tested to assure that it does not contribute to the TOC. The type or size of the filter to be used is not well determined. However, if results of metal, TOC or other parameters that could be affected by solids are to be compared, the same filtering procedure must be used in each case. Repeated analytical results should state whether the samples were filtered and how they were filtered.

9.9 Shipment and receipt of samples must be coordinated with the laboratory to minimize time in transit or weekend delivery receipt. All samples for organic analysis (and many other parameters), should be maintained at 4°C (±2°C) **(65)** during storage and shipping and should arrive at the laboratory within one day after shipment. Sample receipt should be verified to provide an opportunity to trace a lost shipment or to resample if breakage occurs during shipment.

9.10 A commonly used shipping container is an insulated ice chest (cooler) equipped with bottle dividers. An overnight courier service is recommended, if personal delivery service is not practical. Care must be taken in packaging the ice so that no leakage occurs. Such leakage may damage sample labels or, if it escapes the sample cooler, may be misconstrued to be hazardous liquid by the courier. Sample paperwork, including the chain-of-custody, should be enclosed in a sealed plastic bag and taped to the inside lid of the shipping container to protect it from water. Sample containers may be sealed in plastic bags to protect sample labels from water damage from melting ice or sample leakage from other bottles.

9.11 Many courier services have strict shipping requirements for samples that are "hazardous." The courier service should be contacted prior to field activities if there is a concern about how to ship a sample.

10. Keywords

10.1 diffusion sampling; ground water; low flow; low stress; minimal purge; monitoring; purge; sampling; stabilization; well

APPENDIX

(Nonmandatory Information)

X1. SAMPLE HANDLING PROCEDURES FOR GROUND WATER MONITORING PARAMETERS

X1.1 See Table X1.1 for procedures for handling samples.

TABLE X1.1 Sample Handling Procedures For Ground Water Monitoring Parameters (77)

Parameter[A]	Bottle Type[A]	Preservative	Volume Required for Analysis, min (mL)[B]	Storage Time[C] (with Preservation, where applicable), max
pH	P,G	None, analyze immediately for field measurement	25	ASAP (≤48 h) for lab measurement
Specific Conductance	P,G	Cool (4°C)	100	28 days
Alkalinity and Bicarbonate	P,G	Cool (4°C)	100	14 days
COD	P,G	Analyze ASAP (≤48h) or add H_2SO_4 to pH<2; cool (4°C)	100	28 days
TDS	P,G	Cool (4°C)	100	7 days
TSS	P,G	Cool (4°C)	100	7 days
Chloride	P,G	None	50	28 days
Fluoride	P	None	300	28 days
Nitrate	P,G	Analyze ASAP (≤48h) or add H_2SO_4 to pH<2; cool (4°C)	100	28 days
Sulfate	P,G	Cool (4°C)	50	28 days
Ammonia	P,G	Analyze ASAP (≤48h) or add H_2SO_4 to pH<2; cool (4°C)	500	28 days
Mercury	P,G	HNO_3 to pH<2	100	28 days
Metals, Dissolved (Including Ca, Mg, K, Na)	P,G	Filter on site; HNO_3 to pH<2	200	6 months
Metals, Total (Including Ca, Mg, K, Na)	P,G	HNO_3 to pH<2	100	6 months
Phenols	P,G	Add H_2SO_4 pH<2, cool (4°C)	500	28 days
Hardness	P,G	HNO_3 to pH<2	100	6 months
Volatile Organic Compounds (VOC)	G, TFE-lined cap	Add HCL to pH<2; cool (4°C)	2 × 40 ml	14 days
Total Organic Carbon (TOC)	G, TFE-lined cap	Add H_2SO_4 or HCL to pH<2, cool (4°C)	40	28 days
Total Organic Halogen (TOH)	Amber glass, TFE-lined cap	H_2SO_4 to pH<2 and cool (4°C) for EPA 9020A; cool (4°C) for EPA 9022	250	28 days
Turbidity	P, borosilicate glass	Cool (4°C)	100	48 h

[A] P = Plastic (polyethylene or equivalent); G = Glass; G, TFE-lined cap = Glass screw-cap vials sealed with Teflon-faced silicone septa.

[B] Individual laboratories may request more than the minimum volume.

[C] ASAP = As soon as possible.

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