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WELL VENTING AND APPLICATION OF PASSIVE SOIL VAPOR EXTRACTION AT HANFORD AND SAVANNAH RIVER

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ABSTRACT

At the Hanford and Savannah River Sites, wells with open intervals in the unsaturated zone have been observed to "breathe", i.e., to inhale ambient air from the surface and to exhale soil gas to the atmosphere. This breathing results primarily from the difference in pressure that develops between the soil pressure near the open interval of a well and the barometric pressure. Volatile organic compounds (VOC) have been identified at both Hanford (carbon tetrachloride) and Savannah River (trichloroethylene and tetrachloroethylene). Passive vapor extraction (PVE) refers to the enhancement and application of this natural breathing phenomenon as a remediation method for increased VOC removal rates from the unsaturated zone.

Passive vapor extraction is proposed as a complementary technology to be used with active vapor extraction (AVE). The AVE system would be used to extract soil gas from the high VOC concentration, highly permeable zones. The enhanced PVE would be used to address those zones of lower VOC concentration and those zones where extraction is limited by mass transfer and diffusion. The primary advantages of PVE application are low capital costs and minimal operating costs. This combination allows for many small PVE systems to be placed on individual wells and for the systems to operate for the extended periods of time associated with remediation of sites in which soil-gas transport is diffusion limited.

PASSIVE VAPOR EXTRACTION CONCEPTUAL MODEL

Wells with open intervals into the unsaturated zone have been observed to "breathe", i.e., to inhale ambient air and exhale soil gas to the atmosphere. This passive breathing results primarily from the difference in pressure that develops between the barometric pressure and the soil pressure near the subsurface well openings (Fig. 1). The difference in pressure results from natural barometric pressure fluctuations and the delayed and damped response of the subsurface air to those fluctuations. Exhalation of soil gas through the wells is also referred to as well venting.

PLACE FIG. 1 HERE

Investigations to understand and quantify the well breathing phenomenon are being conducted at both the U.S. Department of Energy (DOE) Hanford and Savannah River Sites. Barometric and subsurface soil pressures from several different depths are measured at multiple locations to characterize the propagation of the pressure wave through the subsurface. Wellhead monitoring stations have been installed on multiple wells at both sites to measure temperatures, pressures, flows, humidity, and volatile organic compound (VOC) concentrations.

Passive vapor extraction (PVE) refers to the enhancement and application of this natural breathing process as a remediation method to create the potential for increased VOC removal rates from the unsaturated zone. Our initial PVE design enhances the pressure differential, which will increase the exhaled soil-gas flow rate and thus the mass flux of VOCs. The effectiveness of PVE is also enhanced by preventing ambient air flow into the extraction well. Modeled and observed effects of the developed enhancement methods are being used to evaluate the feasibility of various PVE designs.

Passive vapor extraction is proposed as a complementary technology with active vapor extraction (AVE). The AVE system would be used to extract soil gas from the high VOC concentration, highly permeable zones. The enhanced PVE would be used to address those zones of lower VOC concentration and those zones where extraction is limited by mass transfer and diffusion. The primary advantages of PVE application are low capital costs and minimal operating costs. This combination allows for many small PVE systems to be placed on individual wells and for the systems to operate for the extended periods of time associated with remediation of sites in which soil-gas transport is diffusion limited.

HANFORD AND SAVANNAH RIVER VOC CONTAMINATION

At the Hanford Site, a total of 363,000 to 580,000 L of liquid carbon tetrachloride, in mixtures with other organic and/or aqueous, actinide-bearing fluids, were discharged to the soil column at three primary disposal sites within a 120- by 520-m area between 1955 and 1973. Vapor phase VOC concentrations exceeding 10,000 ppm by volume are currently observed in one area of the resulting vapor plume. Dissolved carbon tetrachloride is also found within a groundwater plume extending over greater than 12 km^2. The local stratigraphy of the unsaturated zone consists of an upper 41 m of relatively permeable sand and gravel, a relatively impermeable interval consisting of 4 m of silt and sand and 3 m of carbonate-rich silt and sand ("caliche layer"), and a lower 28 m of permeable sandy gravel (Fig. 2). The majority of the carbon tetrachloride present in the vadose zone is concentrated in or near the low-permeable silt and sand layers 41 to 48 m below ground surface.

PLACE FIG. 2 HERE

As part of an expedited response action under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) to remove carbon tetrachloride vapor from the unsaturated zone at Hanford, AVE operations were initiated at one disposal site in February 1992 and are now underway at all three disposal sites. As part of the strategy to optimize the wellfield design, an evaluation of the feasibility of PVE using new or existing wells is being conducted. To support this study, collection of data using wellhead monitoring systems was initiated in June 1992.

At the Savannah River Site, approximately 600,000 L of waste solvents from metal degreasing facilities were released through a process sewer line to a settling basin between 1958 and 1985. The waste solvents consisted of trichloroethylene, tetrachloroethylene, and to a lesser extent, 1,1,1-trichloroethane. Television surveys of the process sewer line showed that it had cracks along its length. Dissolved solvents were identified in the groundwater below the sewer line and the settling basin in the early 1980's. Subsequent characterization studies show that the bulk of the contamination in the area is located in the 40-m-thick unsaturated zone, which consists mainly of interbedded sands and clayey sands but also contains three distinct clay and sandy layers (Fig. 2). The finer grained materials in the unsaturated zone tend to hold the contaminants to a greater extent than the coarser materials.

In 1990, an in situ air stripping experiment using horizontal wells was implemented as part of the DOE-sponsored Integrated Demonstration Program at Savannah River. In addition to monitoring the active air extraction processes, naturally produced pressure differentials between air in the subsurface and surface air have been monitored in the area.

PRESSURE WAVE PROPAGATION

Changes in the barometric pressure are propagated through the soil in waves. Initial indications are that the depth and permeability of the soil through which the pressure waves must move influence the pressure attenuation and delay experienced by the wave. This will result in positive and negative pressure differentials, depending on the relative magnitude and rate of change of the barometric pressure, soil depth, and soil properties. The magnitude of the generated air flow at a given location is proportional to the magnitude of the pressure difference.

Subsurface monitoring points, consisting of porous metal filters connected to the surface by 3.2-mm-diameter tubing, were installed at the Hanford Site in 1993 using a cone penetrometer. Each monitoring point is surrounded by a sand pack and isolated from the other monitoring points with a bentonite seal. Depths of the monitoring points range from 4 to 28 m; up to five points are installed at different depths beneath a single location. Differential pressures are recorded at the surface and added to the barometric pressure to obtain absolute pressures. The barometric pressure data are received from the Hanford Meteorological Station and represent the atmospheric pressure at an elevation approximately 16 m above the Hanford carbon tetrachloride site.

Barometric and soil pressure data measured at monitoring points at four depths indicate that attenuation or delay of the pressure wave at the Hanford carbon tetrachloride site is minimal in the first 28 m of propagation, through relatively permeable gravels and sands (Fig. 3a). However, the dependency of the attenuation and delay of the soil pressure wave on the barometric pressure signal is evident.

At Savannah River, 2.5-cm-diameter vadose zone piezometers with 1.5-m-long screens at different stratigraphic intervals in the subsurface also exhibit a damped and lagging response to surface pressure fluctuations corresponding to depth and stratum permeability (Fig. 3b). The piezometer pressures were monitored at the wellhead through a short length of tubing attached to a gas-tight connector mounted on sealed piezometers. The tube length was less than 10 cm and the wellhead was covered to minimize pressure changes resulting from heating the air in the tubes. Similar to the Hanford Site, the piezometers at different depths were isolated from each other by sand pack and bentonite seals. At Savannah River, however, the surface barometric pressure data were taken at the individual wellhead.

PLACE FIG. 3 HERE

Differential pressure data were collected from above and below the relatively impermeable caliche layer within a single well, 299-W18-247, at the Hanford Site to investigate the effect of this layer on wave propagation. The well is sealed between the open intervals. The data show similar results between the upper interval (36 to 39 m depth) pressure and barometric pressure (Fig. 4a). The differential between the lower interval (49 to 52 m) pressure and barometric pressure shows a delay and strong attenuation. The attenuation is most likely the result of the intervening caliche layer, which can be considered partially opaque to the pressure wave. In the area of this well, the caliche layer is approximately 3 m thick.

A similar effect is shown within a single well, MHV1, at Savannah River. The soil-gas pressure at 13 m depth closely tracks the barometric pressure signal, whereas the pressures from below an intervening clay layer are strongly damped (Fig. 4b). The amount of damping and phase lag observed at the monitoring depth increases with the number and thickness of low-permeability layers penetrated by the monitoring point. In the area of MVC-3 (Fig. 3b), the clay zones are not as distinct as they are in the area of MHV-1 (Fig. 4b); therefore, a larger and more damped response is evident in the two lower piezometers of MHV-1.

PLACE FIG. 4 HERE

WELL VENTING

The principal driving force for air flow in a well that is open to the atmosphere and the subsurface is the difference in subsurface and barometric pressure. This pressure differential for well 299-W18-247 at Hanford's carbon tetrachloride site is shown in Fig. 5.

PLACE FIG. 5 HERE

Air flow data have been measured at well 299-W18-246, approximately 157 m away. Wells 299-W18-246 and -247 were installed in 1992 and are of similar construction and have screened open intervals at similar depths. The 299-W18-247 subsurface pressure overlaid on the 299-W18-246 air flow rates above and below the caliche layer are shown in Fig. 6a and 6b, respectively. In both cases there is a strong correlation between the sign and magnitude of the differential pressure and the direction and magnitude of the flow rate. The correlation above the caliche is a little more tenuous because the flow rates are more erratic than those from below the caliche.

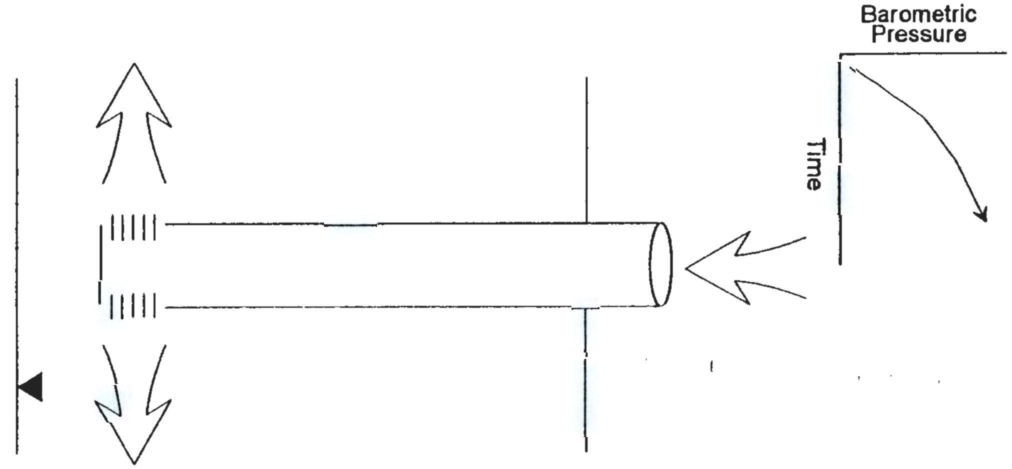
PLACE FIG. 6 HERE

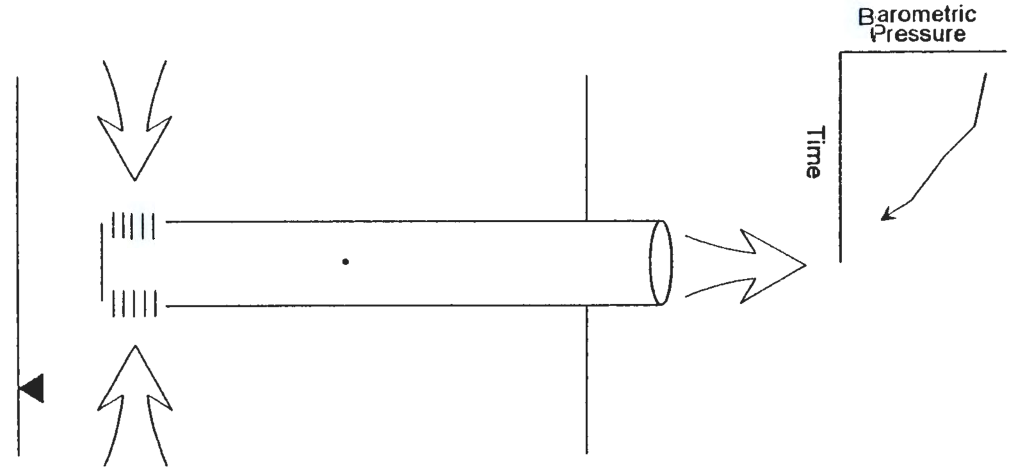
Preliminary results of wellhead monitoring at Hanford indicate that air flow rates out of wells may be as high as 1,700 L/min, but typically range from 60 to 140 L/min from 10- to 20-cm-diameter wells with variable amounts of open interval. On an annual basis, an estimated 35 million liters of air flow from the soil through each well to atmosphere.

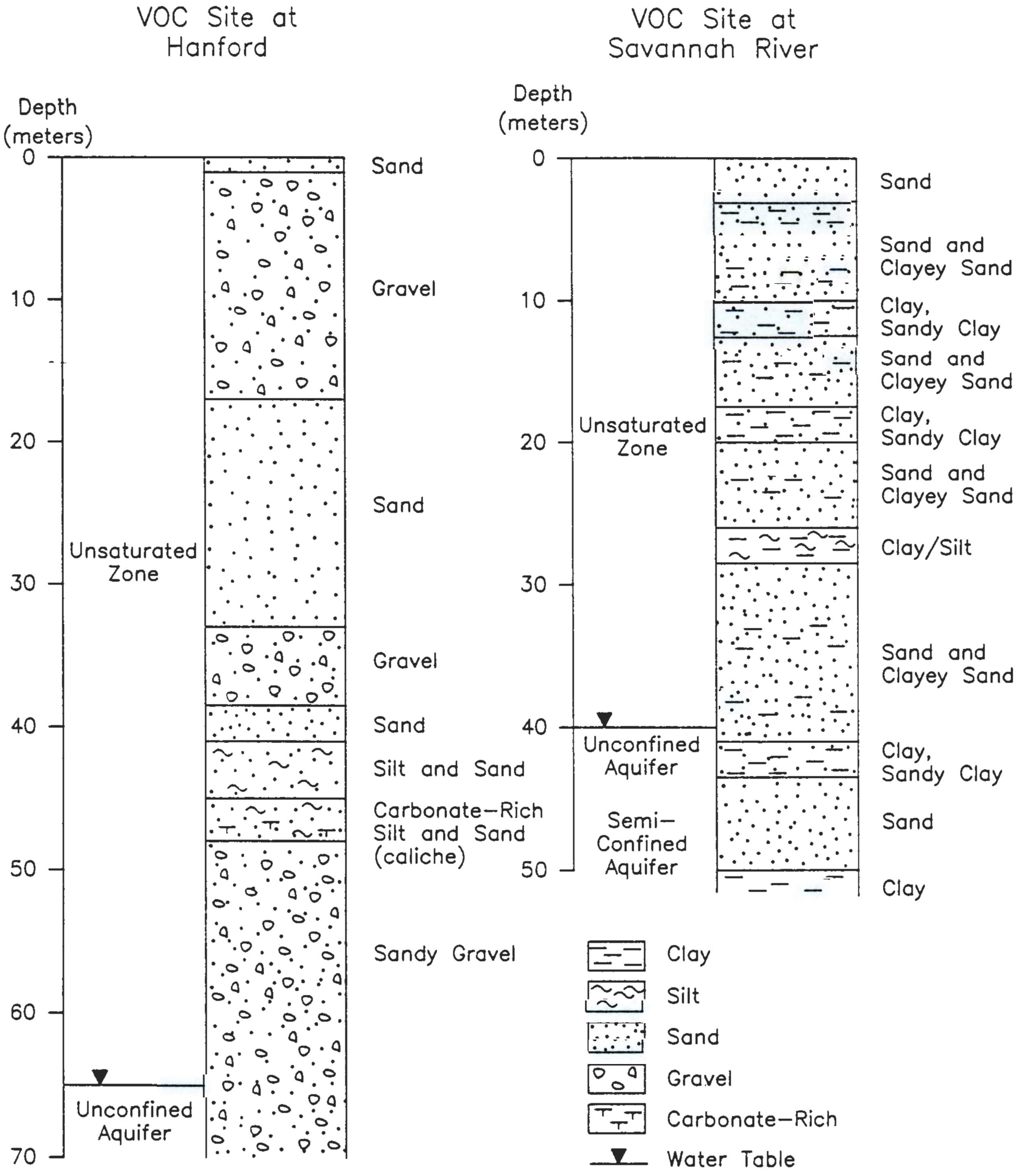
At Savannah River, flows produced as a result of naturally induced pressure differentials are typically about 10 L/min in

2.5-cm-diameter piezometer wells with 1.5-m-long screens. Contaminant concentrations of greater than 1,000 ppmv have also been measured, implying potential contaminant removal rates of 14 L/day in the gas phase. The rate of contaminant removal achievable using PVE depends on factors such as the magnitude and frequency of the natural barometric pressure fluctuation; the confining zones and permeabilities of the subsurface layers; and the nature and type of contaminant.

LIST OF FIGURES

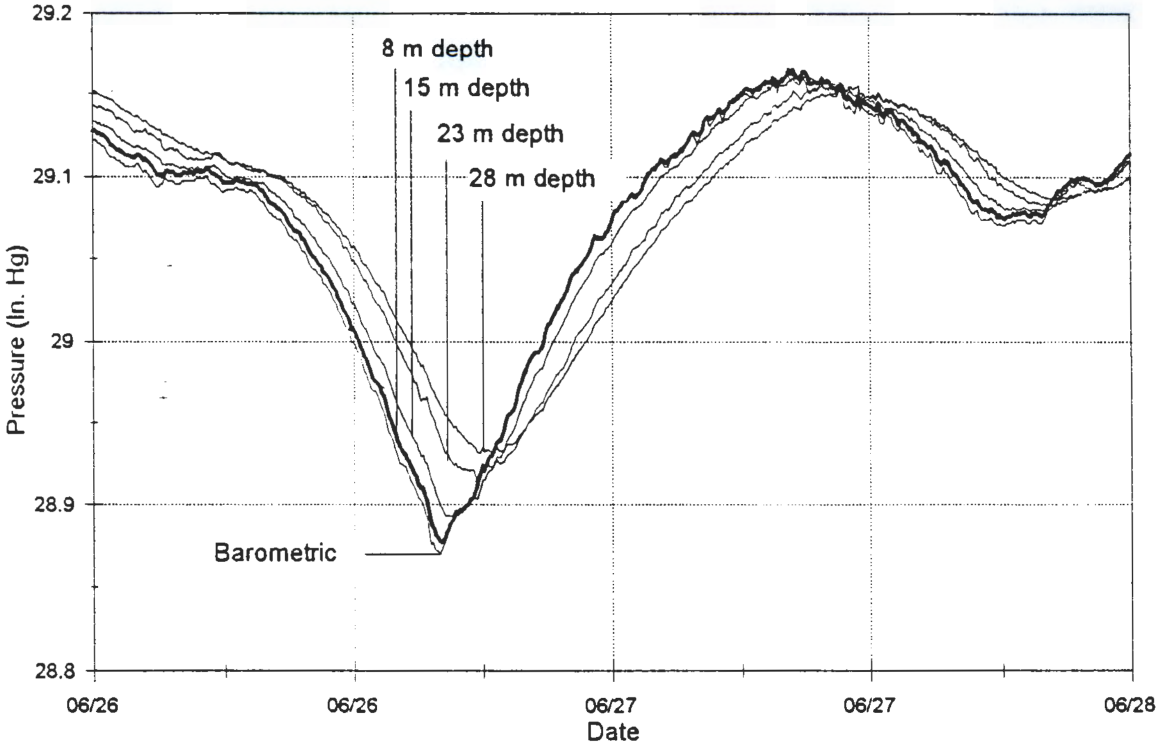

Barometric Pressure
Time


Barometric Pressure
Time


VOC Site at Hanford
Depth (meters)
0
10
20
30
40
50
60
70
Sand
Gravel
Sand
Unsaturated Zone
Gravel
Sand
Silt and Sand
Carbonate-Rich Silt and Sand (caliche)
Sandy Gravel
Unconfined Aquifer
VOC Site at Savannah River
Depth (meters)
0
10
20
30
40
50
Sand
Sand and Clayey Sand
Clay, Sandy Clay
Sand and Clayey Sand
Clay, Sandy Clay
Unsaturated Zone
Sand and Clayey Sand
Clay/Silt
Sand and Clayey Sand
Unconfined Aquifer
Clay, Sandy Clay
Semi-Confined Aquifer
Sand
Clay
Clay
Silt
Sand
Gravel
Carbonate-Rich
Water Table

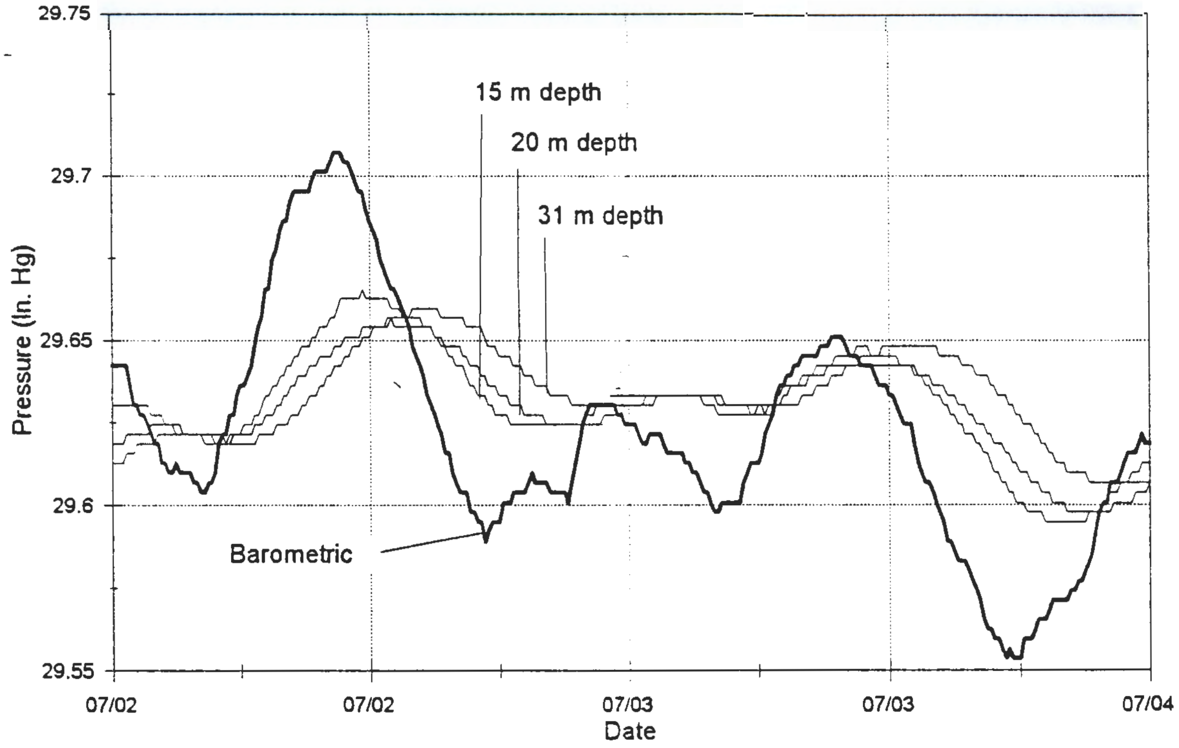
VJR\092893-A

3a

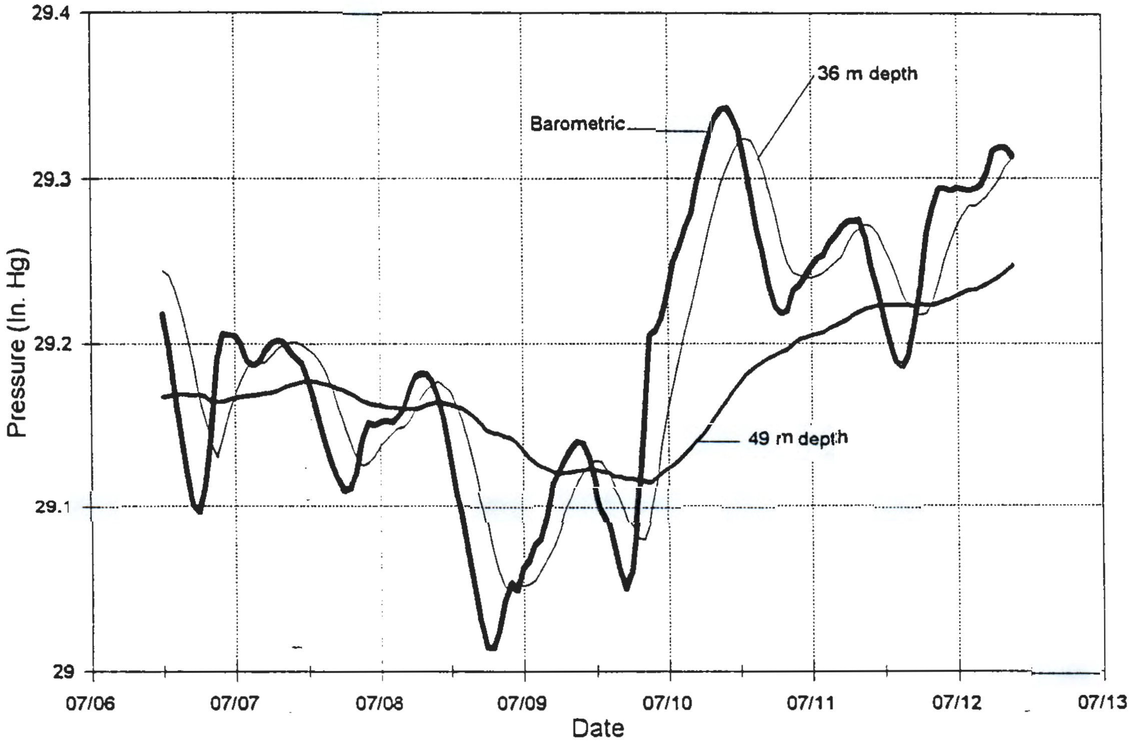


29.2
29.1
29
28.9
28.8
Pressure (In. Hg)
8 m depth
15 m depth
23 m depth
28 m depth
Barometric
06/26
06/26
06/27
06/27
06/28
Date

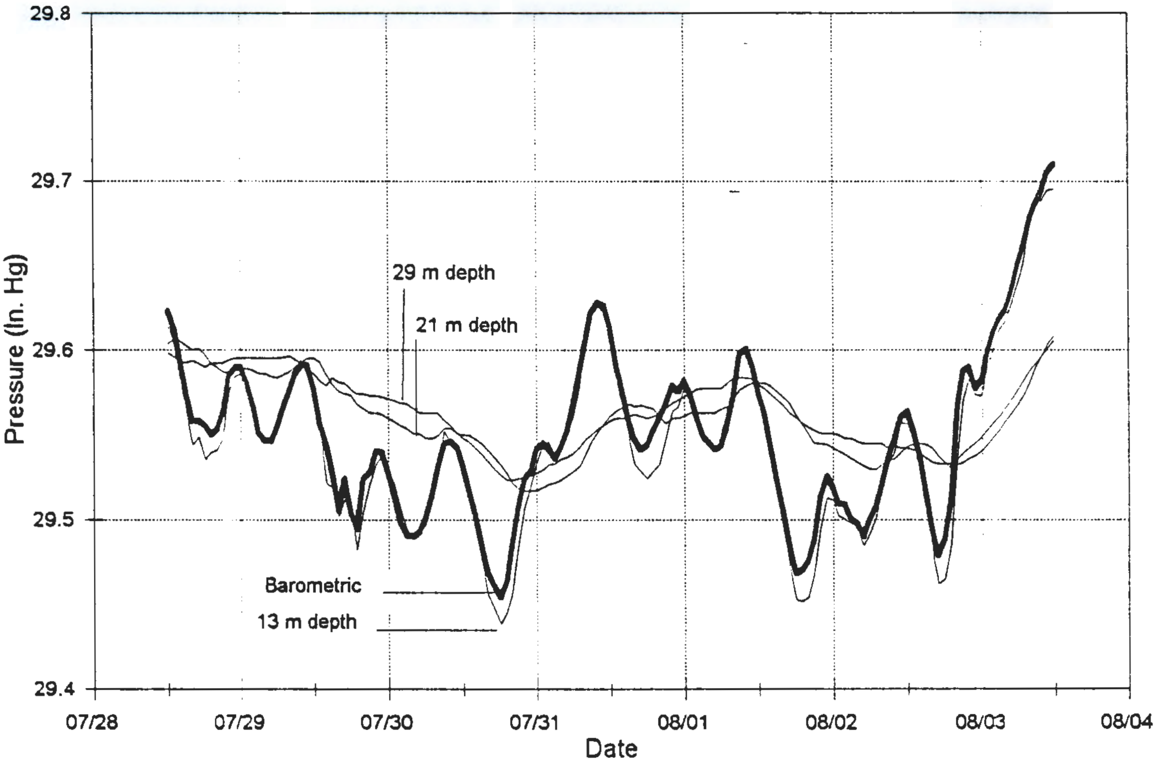
3b


29.75
29.7
29.65
29.6
29.55
Pressure (In. Hg)
15 m depth
20 m depth
31 m depth
Barometric
07/02
07/02
07/03
07/03
07/04
Date

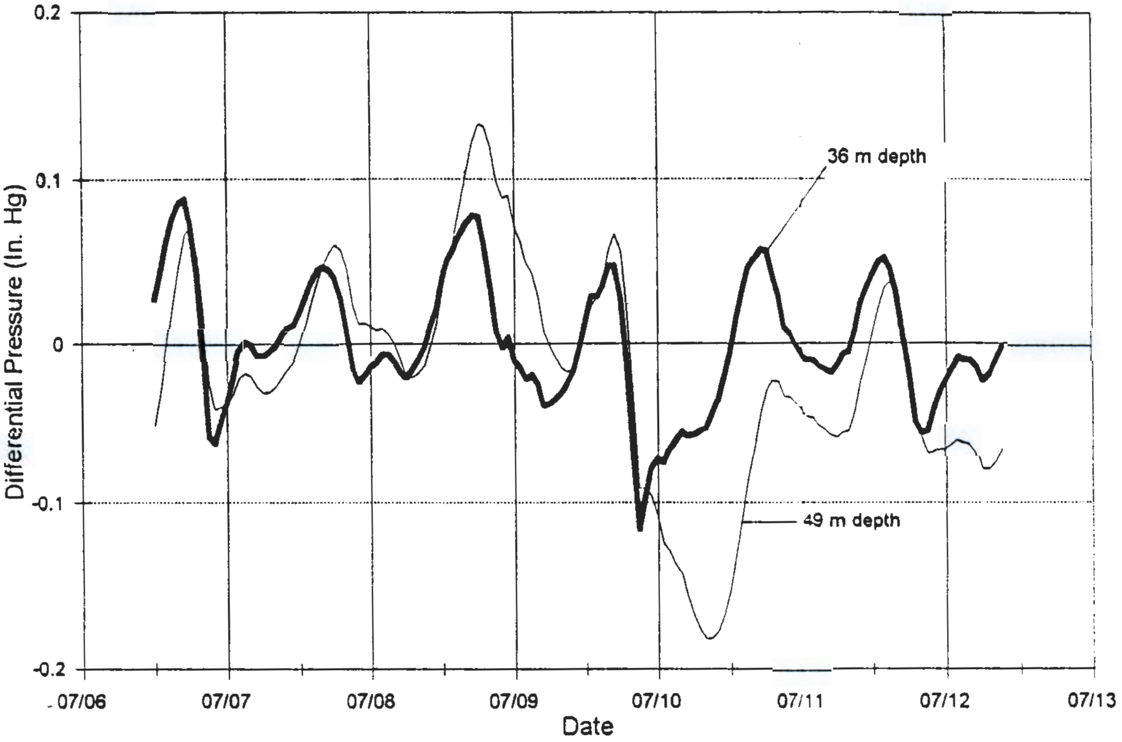
4a

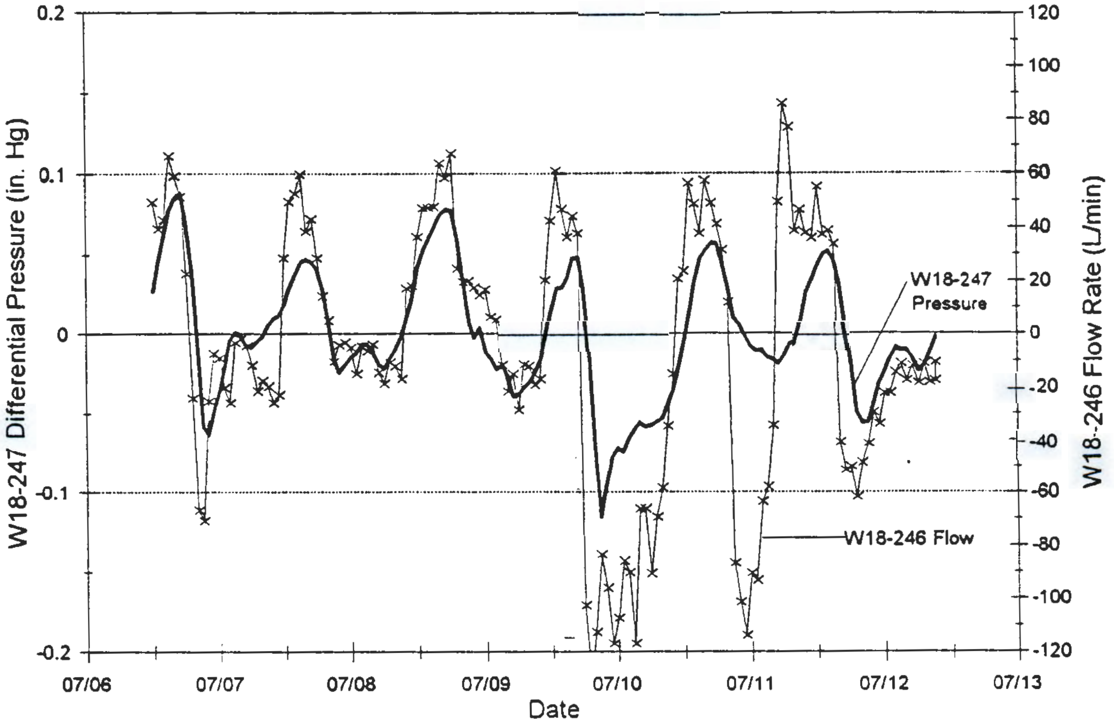

29.4
29.3
29.2
29.1
29
Pressure (In. Hg)
Barometric
36 m depth
49 m depth
07/06
07/07
07/08
07/09
07/10
07/11
07/12
07/13
Date

4b

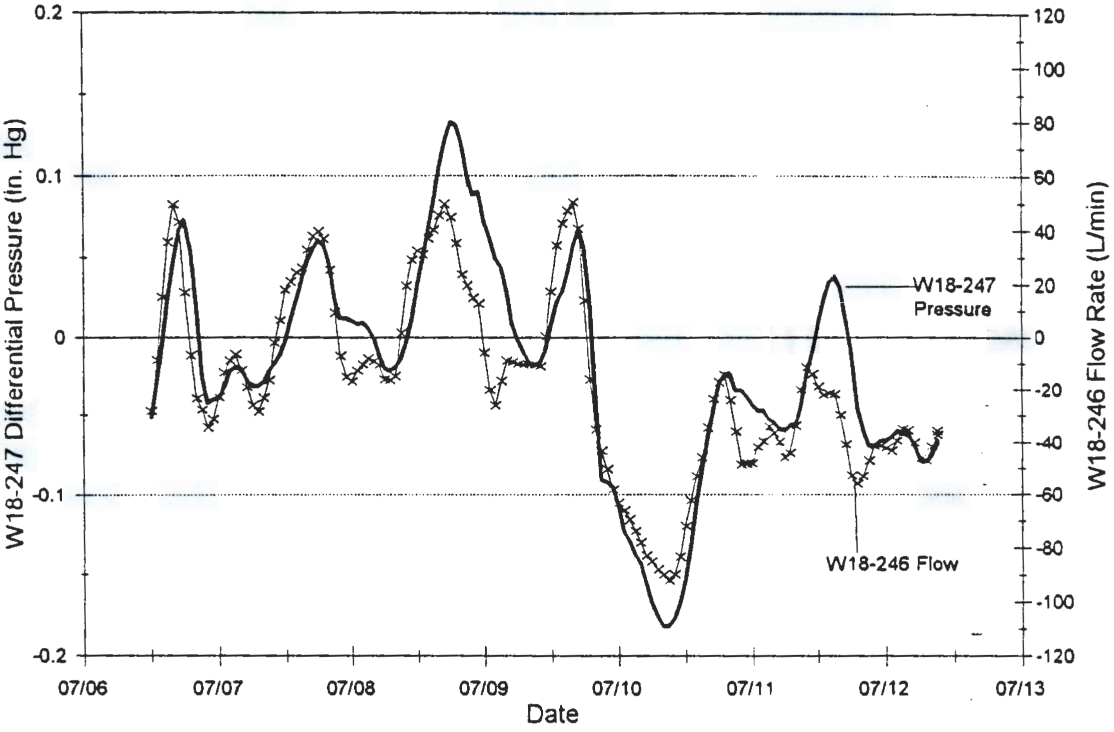


29.8
29.7
29.6
29.5
29.4
Pressure (In. Hg)
29 m depth
21 m depth
Barometric
13 m depth
07/28
07/29
07/30
07/31
08/01
08/02
08/03
08/04
Date


0.2
0.1
0
-0.1
-0.2
Differential Pressure (In. Hg)
36 m depth
49 m depth
07/06
07/07
07/08
07/09
07/10
07/11
07/12
07/13
Date


0.2
0.1
0
-0.1
-0.2
W18-247 Differential Pressure (in. Hg)
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
W18--246 Flow Rate (L/min)
W18-247 Pressure
W18-246 Flow
07/06
07/07
07/08
07/09
07/10
07/11
07/12
07/13
Date

6b


W18-247 Differential Pressure (In. Hg)
0.2
0.1
0
-0.1
-0.2
W18-246 Flow Rate (L/min)
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
W18-247 Pressure
W18-246 Flow
07/06
07/07
07/08
07/09
07/10
07/11
07/12
07/13
Date