HYDROFOCUS INC.

Solutions for Land and Water Resources

Geotechnical Analysis of Soil Sediments in Abandoned Irrigation Wells

Well number 8 looking east from Bay Road, August 10, 2004.

INTRODUCTION

The City of Palo Alto owns abandoned wells located in the East Palo Alto marshes. San Mateo County Health Department has notified the City of the need to permanently cap the wells to prevent downward migration of saline bay water into the underlying groundwater aquifer system. HydroFocus, Inc. sampled the sediments in two accessible wells and assessed whether the sediments in-place provide reasonable protection from the downward migration of saline baywater.

BACKGROUND

The abandoned wells, previously owned by the Spring Valley Water Company, are buried in East Palo Alto marshes. The marshes are habitat for the largest population of California Clapper Rails, a Federally-recognized endangered species, and the endangered Salt Marsh Harvest Mouse. In 2003, the U.S. Geological Survey utilized a ground magnetometer survey to approximately locate eight wells in the marsh[1]. Figure 1 shows the well locations based on the magnetometer data. Four of the eight wells were later physically located using a metal probe[2].

The abandoned wells were constructed in the early 1900's and are up to 250 feet deep[3]. The boreholes intercept an upper water-bearing zone (50- to 70-feet below land surface), underlain by an approximately 100-feet thick bed of fine-grained silt and clay (Figure 2). Beneath this clay bed, the wells intercept Niles Cone aquifers[4], which are fed primarily by recharge from the east in Alameda County. In the past, these wells exhibited year-round artesian conditions, and standing water levels were as much as 30 feet above land surface. Under present-day conditions, nearby wells are reportedly seasonally artesian[5]; water levels rise above land surface during the winter and spring, but decline below land surface during the summer and fall.

APPROACH

Site conditions and wildlife concerns limit well accessibility. We therefore utilized a hand-auger to sample two of the eight abandoned wells. Hand-auger sampling was advantageous because of its minimal disturbance to the marshland habitat and wildlife. We employed the hand auger to collect representative sediment

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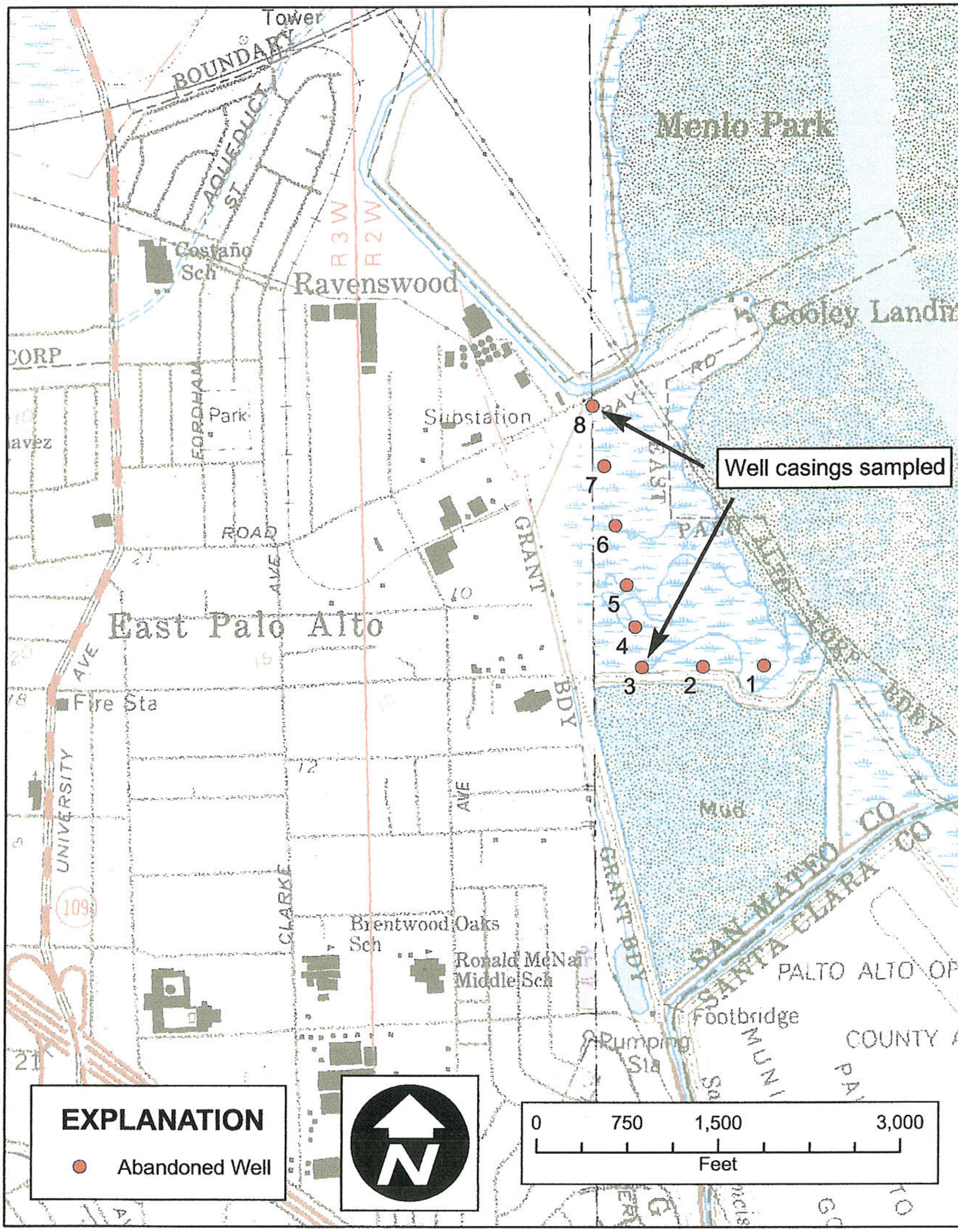
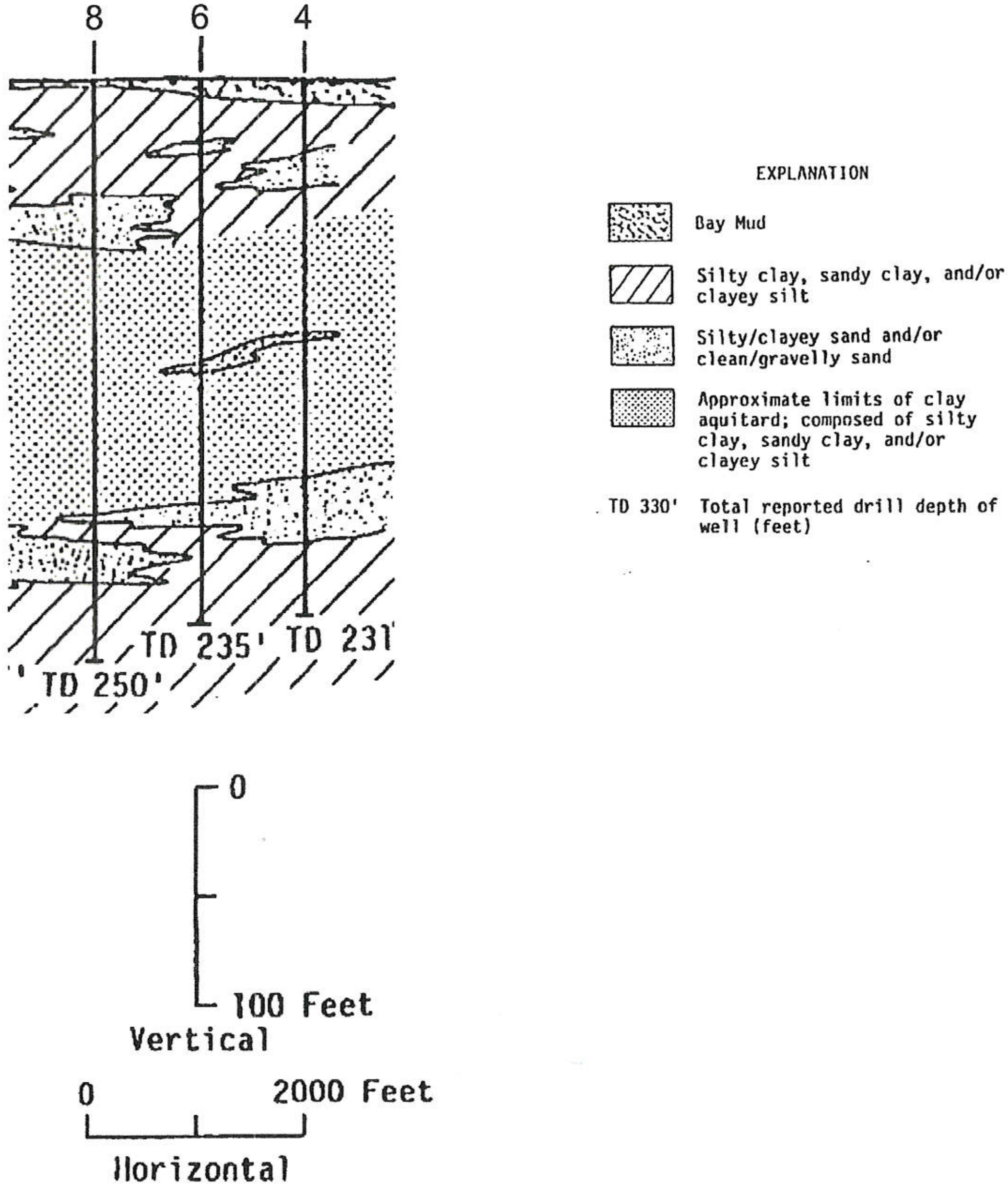
[1] "Abandoned Well Search", letter from Robert Jachens and Carter Roberts, U.S. Geological Survey, to Ana Ruiz, MidPeninsula Regional Open Space District, August 7, 2003.
[2] Darren Anderson, Senior Park Ranger, Palo Alto Baylands, Personal Communication, August 18, 2004.
[3] Geomatrix Consultants Inc., 1989, "Remedial Investigation Report, 1990 Bay Road Site and Vicinity East Palo Alto, California".
[4] Department of Water Resources, "Evaluation of Ground Water Resources: South Bay", 1967.
[5] Erdmann Rogge, San Mateo County Department of Public Health, personal communication, August 11, 2004.



HYDROFOCUS INC. Solutions for Land and Water Resources	Approximate abandoned well locations.	Figure 1
PROJECT: 5022	DATE: 3/1/2005	



Note: Well numbers correspond to well numbers shown on figure 1.
Adapted from Geomatrix Consultants, Inc., 1989, Final Remedial Investigation Report, Vol 1, 1990 Bay Road Site and Vicinity, East Palo Alto, CA, figure 7.

HYDROFOCUS INC. Solutions for Land and Water Resources	Geologic section along abandoned well locations.	Figure 2
PROJECT: 5022	DATE: 3/1/2005	

cores within the abandoned well casings. Select cores were submitted to a geotechnical laboratory for determination of hydraulic conductivity[6].

Field Activities

On October 21, 2004, HydroFocus, Inc. personnel sampled sediments in two of the abandoned well casings (3 and 8). We arrived first at well casing 8, which is located south of Bay Road (Figure 1). The well casing location was marked with a metal stake, and the soil had been previously excavated to expose the casing at a depth of about 18 inches below land surface. Our site measurements indicated an 8-inch diameter steel casing, surrounded by a 12-inch steel conductor casing (the space between the inner and outer casings is apparently filled with grout).

During the previous two days, more than an inch of rain fell in the area and the hole was filled with about 6 to 8 inches of water. We bailed the water using a bucket to expose the well casing. Water flowed into the hole from the walls of the excavation, and we continued bailing during sampling to keep the casing exposed. We utilized a 2-inch hand auger to bore into and sample the sediments within a depth interval of 0 to 137.5 inches below the top of casing (a total depth of almost 13 feet below land surface). We collected 5 cores to measure hydraulic conductivity (Figure 3). During our sampling activities we noted a strong odor of hydrogen sulfide gas, indicating anoxic chemically reducing conditions.

Figure 3. Intact soil core extracted from well-casing 8.

[6] Hydraulic conductivity is a property of water-bearing materials. Hydraulic conductivity relates groundwater movement to hydraulic gradient; the product of hydraulic conductivity, hydraulic gradient, and area normal to the flow direction is the volume of groundwater transmitted per unit time. The dimensions for hydraulic conductivity are length/time.

After completing our sampling, the open borehole was filled with about 35 pounds of bentonite chips. The chips were poured slowly into the borehole and then tamped into place with a metal rod. We continued this process until the chips completely filled the borehole. Sediments removed from the borehole were spread around the area.

Our second sampling was conducted at well-casing 3, located south of 8 and at the opposite end of the marsh (Figure 1). The well location was marked with a metal stake, but the casing was covered by a soft, saturated brown to gray organic mud. Soil penetrometer readings indicated no resistance. Using a magnetic locator and metal probe, we located the casing and then removed the surface sediments with a shovel. The casing was exposed about 29 inches below land surface. Similar to well-casing 8, water flowed into the hole from the walls of the excavation, however because the hole was deeper we could not bail the water. We therefore conducted our sampling from beneath standing water in the hole and casing.

We utilized the 2-inch diameter hand auger to bore into and sample the sediments inside the well casing from a depth of 0 to 103 inches below the top of casing (a total depth of 11 feet below land surface). We collected 3 cores to measure hydraulic conductivity. The sediments and water smelled strongly of hydrogen sulfide; bubbles were observed rising from the casing, which may have been out-gassing of hydrogen sulfide and methane.

After completing our sampling, the borehole in the casing was filled with 50 pounds of bentonite chips. A portion of the chips were poured slowly into the borehole, and then tamped into place with a metal rod. We continued this process until the chips completely filled the borehole. The metal stake was placed in the center of the casing, and the hole was backfilled with sediment.

Laboratory Methods

Hydraulic conductivity values were determined on eight core samples using a falling head permeameter test (ASTM D5084) by Cooper Testing Laboratories located in Mountain View, California. Appendix A contains the individual laboratory reports for each core. Our lithologic descriptions and the permeameter test results are summarized below in Tables 1 (well-casing 8) and 2 (well-casing 3), respectively.

Table 1. Borehole sampling intervals, lithologic descriptions, and measured hydraulic conductivity of sediment from within well-casing 8.					
Core Tube Number	*Depth Interval (inches below top of casing)*	*Symbol*	*Description*	*Hydraulic Conductivity*	
				(cm/s)	(ft/yr)
2	0 – 5.5	OH[1]	Soft, saturated black muck, clay, organics, dark gray sticky silty clay.	1.60E-07	0.17
	5.5 – 14.5	OH	Soft, saturated gray to dark gray organic clay.		
1	14.5 – 20.0	OH	Soft, saturated dark gray organic clay; black areas, some organic fibers.	7.80E-8	0.08
	20.0 – 29.0	OH	Soft, saturated gray organic clay; black areas.		
3	29.0 – 34.5	OH	Soft, saturated gray organic clay; black areas.	1.60E-07	0.17
	34.5 – 39.0	OH	Soft, saturated gray organic clay; black areas.		
	39.0 – 44.0	OH	Soft, saturated gray organic clay; black areas.		
	44.0 – 49.0	OH	Soft, saturated gray organic clay; black areas.		
	49.0 – 55.0	OH	Soft, saturated gray organic clay; black areas.		
5	55.0 – 60.0	OH	Soft, saturated gray organic clay; black areas.	2.40E-07	0.25
	60.0 – 65.0	OH	Soft, saturated gray organic clay; black areas.		
	65.0 – 113.0	OH	Soft, saturated gray organic clay; black areas; gray nodules – easily broken with fingers.		
	113.0 – 132.0	OH	Soft, saturated gray organic clay; black areas; organic fibers.		
6	132.0 – 137.5	OH	Soft, saturated gray organic clay; black areas; borehole caving in, core sample may be compacted and not representative of natural conditions.	2.90E-06	2.7

1: OH indicates organic clays of medium to high plasticity, organic silts.

Table 2. Borehole sampling intervals, lithologic descriptions, and measured hydraulic conductivity of sediment from within well-casing 3.					
Core Tube Number	*Depth Interval (inches below top of casing)*	*Symbol*	*Description*	*Hydraulic Conductivity*	
				(cm/s)	(ft/yr)
4	0 - 5.5	OH[1]	Soft, saturated dark gray to black organic clay.	4.10E-07	0.42
	5.5 - 53.0	OH	Soft, saturated dark gray to black organic clay.		
	53.0 – 75.0	OH	Soft, saturated gray and black organic clay.		
7	75.0 – 85.5	OH	Soft, saturated gray and black organic clay.	2.80E-07	0.29
	80.5 – 92.0	OH	Soft, saturated gray organic clay, abundance of plant fibres.		
	92.0 – 97.5	OH	Clay, dark gray and black, plant fibers. Sample is hard and brittle, and sediment may have been compressed causing the water to be squeezed out of the core.		
9	97.5 – 103.0	OH	Dark gray and black clay, hard, appears to have been compressed during sampling; sample may not represent natural conditions.	3.80E-06	3.9

1: OH indicates organic clays of medium to high plasticity, organic silts.

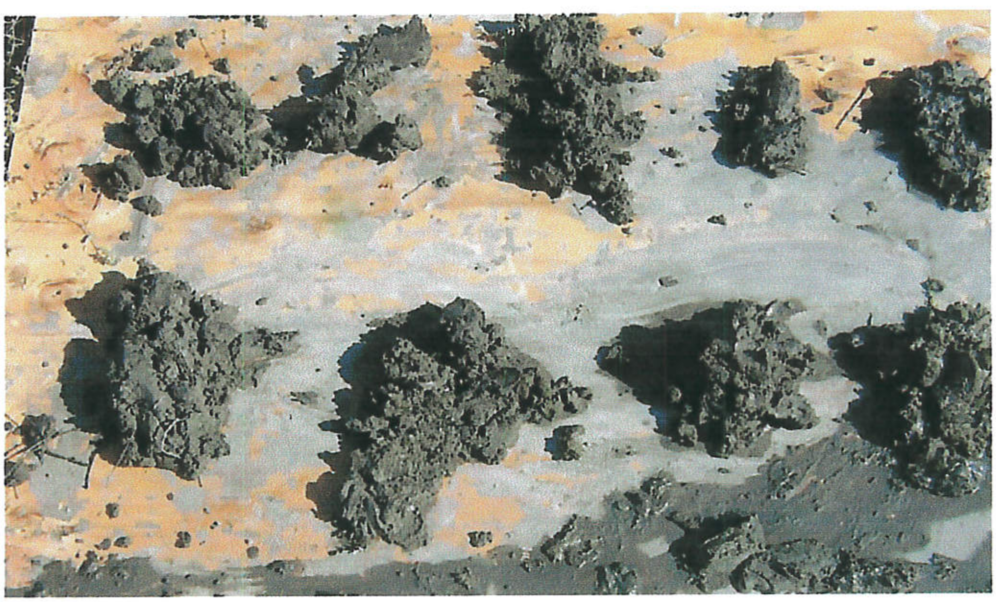


Figure 4. Representative sediments from casing 3.

RESULTS AND DISCUSSION

Our results indicate that at least 1.5 to 2.2 feet of low-permeability clay (bay mud) covers the abandoned wells. Within the well casings, at least 11 to 13 feet of bay mud is deposited within each casing. We observed black and dark gray sediments, smelled hydrogen sulfide gas, and observed possible out-gassing of hydrogen sulfide and/or methane, which all indicate an oxygen deficit environment and suggests a low rate of air and surface-water movement into the subsurface.

Laboratory analysis of sediment cores indicated the hydraulic conductivity of the clay materials deposited within the well casings ranges from 0.08 to 3.9 feet per year. The two highest conductivity values (2.7 and 3.9 feet per year) are associated with the deepest samples from each location, and may have been disturbed and therefore not representative of their actual permeability in-place within the casings[7]. If we discard the two deepest samples, the measured hydraulic conductivity values fall within a significantly narrower, and lower, hydraulic conductivity range (0.08 to 0.42 feet per year).

Table 3 below compares measured East Palo Alto marshland sediment conductivity values with reported values for clay and fine-grained beds mapped within the Niles Cone aquifers (aquitards). The range for measured conductivity values (0.08 to 0.42 feet per year) is similar to the reported range for the Niles Cone aquitards (0.10 to 1.0 feet per year). This is significant because the Niles Cone aquitards are comprised of similar bay muds, and form natural barriers between saline baywater and the Niles Cone aquifers beneath the marshland[8,9]. The sediments deposited above and within the abandoned well casings appear similar to the sediments that form natural barriers between the bay and deeper groundwater.

San Mateo County requires abandoned water wells to be destroyed in accordance with County Ordinances and by California law, including regulations and standards issued by the California Department of Water Resources. The principal objective of destroying and sealing abandoned wells is to restore, as far as possible, the original (natural) hydrogeologic conditions that protect groundwater. California water well standards define well sealing materials to include native soils that have a hydraulic conductivity of less than 10 feet per year[10]. Examples of cited native sealing materials include very fine sand with a large percentage of silt or clay, inorganic silts, mixtures of silt and clay, and clay.

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[7] The samples were questionable because we experienced difficulty maintaining an open borehole at the deeper depths, and the deeper cores may have contained disturbed sediments from the borehole walls.

[8] Department of Water Resources, "Evaluation of Ground Water Resources: South Bay", 1967.

[9] California Department of Water Resources, 1973, "Evaluation of Ground Water Resources: South San Francisco Bay. Volume II: Additional Fremont Area Study".

[10] California Department of Water Resources, "Water Well Standards: State of California", Bulletin 74-81, 1981; Section 23.D.1.

Since all of the well core sediments we sampled have measured hydraulic conductivities substantially less than 10 feet per year, these can be considered sealing materials in accordance with State standards.

Our investigation is limited by the depth of the hand auger samples, and information is lacking to confirm that the wells are sealed through the 150-feet thick upper water bearing zone and underlying clay aquitard. In layered aquifer systems, such as that found beneath the East Palo Alto marshlands, California water well standards require the well be sealed to prevent the interchange of water between zones. The well standards require that impervious material be placed a distance of 10 feet or more above and below the natural aquitards. In Appendix B, we summarize specifications from four drilling firms that estimated construction methods and costs to seal the well-casings. Our inquiries suggest the cost is substantial ($240,000 to $325,000), and even carefully planned and implemented construction activities can damage the protected habitat.

Table 3. Geologic materials and reported hydraulic conductivity.		
Material Description	*Hydraulic Conductivity* (ft/yr)	*Reference*
Granite	0.001	Neretnieks and others, 1990
Clay	0.002 to 0.24	Masch, and Denny, 1966; Morris and Johnson, 1967; Davis, 1969: Desauliers and others, 1981
East Palo Alto Marshland Bay Mud	0.08 to 3.9[a]	HydroFocus, Inc., 2005
Niles Cone Aquitards (beneath South San Francisco Bay)	0.10 to 1.0	Californaia Department of Water Resources, 1973
Clayey silt	3.1 to 8.3	Rehm and others, 1980; Martin and Frind, 1998.
Sand	3,300 to 56,000	Akindunni, and Gillham, 1992; Nwankor and others, 1992; Morris and Johnson, 1967; Masch, and Denny, 1966; Davis, 1969, Pickens and Grisak, 1981; Lee and others, 1980; Kreft and others, 1974

a: If we neglect the anomalous values associated with the compacted samples (tube 6 from well-casing 8 and tube 9 from well-casing 3), the range in hydraulic conductivity values decreases to 0.08 to 0.42 ft/yr, which is generally within the range of Clay and naturally occurring Niles Cone Aquitards.

<u>References cited in Table 3</u>

Akindunni, F.F. and R.W. Gillham, 1992, "Unsaturated and saturated flow in response to pumping of an unconfined aquifer: Numerical investigation of delayed drainage", Ground Water, 30(6), 873-884.

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Lee, D.R., J.A. Cherry, and J.F. Pickens, 1980, "Groundwater transport of salt tracer through a sandy lakebed", Limnol. Oceanogr., 25(1), 46-61.

Martin, P.J. and E.O. Frind, 1998, "Modeling a complex multi-aquifer system: The Waterloo Moraine", Groundwater, 36(4), 679-690.

Masch, F.E. and K.J. Denny, 1966, "Grain size distribution and its effect on the permeability of unconsolidated sands", Water Resour. Res. 2, 665-677.

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Neretnieks, I., H. Abelin, L. Birgersson, L. Moreno, H. Widen and T. Argen., 1990, "A large scale flow and tracer experiment in granite", in Hydrology of Low Permeability Environments, S.P. Neuman and I Neretnieks (Eds.), International Association of Hydrologists.

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Pickens, J.F., and G.E. Grisak, 1981, "Scale dependent dispersion in a stratified granular aquifer", Water Resour. Res., 17(4), 1191-1211.

Rehm, B.W., G.H. Groenewold and K.A. Morin, 1980, "Hydraulic properties of coal and related materials, Northern Great Plains", Ground Water, 18(6), 551-561.

APPENDIX A: Laboratory Reports for Soil Core Testing

Hydraulic Conductivity
ASTM D 5084
Method C: Falling Head Rising Tailwater

Job No:	556-001a	**Boring:**		**Date:**	11/08/04
Client:	HydroFocus, Inc.	**Sample:**	1	**By:**	MD/PJ
Project:	City of Palo Alto	**Depth'**		**Remolded:**	

Visual Classification: Gray CLAY (Bay Mud)

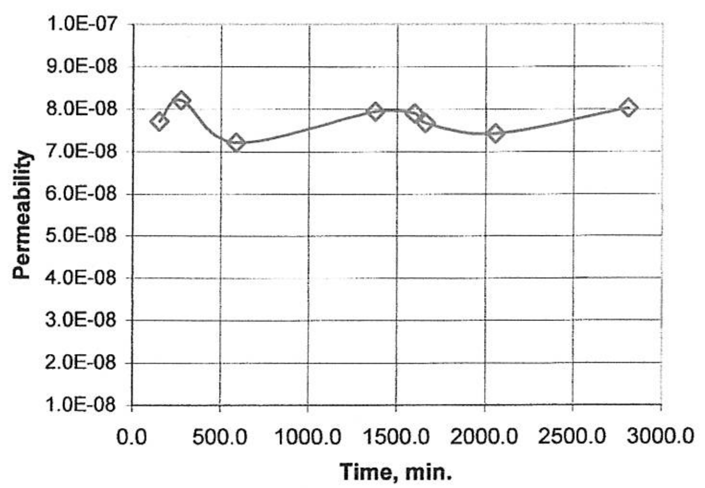
Max Sample Pressures, psi:

Cell:	Bottom	Top	Avg. Sigma 3
43	39	37	5

B: = >0.95 ("B" is an indication of saturation)

Max Hydraulic Gradient: = 40

Date	Minutes	Head, (in)	K,cm/sec
11/1/2004	0.00	79.38	Start of Test
11/1/2004	149.00	78.78	7.7E-08
11/1/2004	274.00	78.18	8.2E-08
11/1/2004	587.00	77.08	7.2E-08
11/2/2004	1376.00	73.98	7.9E-08
11/2/2004	1598.00	73.18	7.9E-08
11/2/2004	1660.00	72.98	7.7E-08
11/2/2004	2057.00	71.58	7.4E-08
11/3/2004	2807.00	68.88	8.0E-08



Average Permeability: 7.8E-08 cm/sec

Sample Data:	Initial		Final
Height, in	2.00		1.96
Diameter, in	1.97		1.92
Area, in2	3.05		2.90
Volume in3	6.10		5.68
Total Volume, cc	99.9		93.0
Volume Solids, cc	24.7		24.7
Volume Voids, cc	75.2		68.3
Void Ratio	3.0		2.8
Porosity, %	75.3		73.4
Saturation, %	98.5		98.5
Specific Gravity	2.70	Assumed	2.70
Wet Weight, gm	140.8		134.0
Dry Weight, gm	66.7		66.7
Tare, gm	0.00		0.00
Moisture, %	111.1		100.9
Dry Density, pcf	41.7		44.7

Remarks:

Hydraulic Conductivity
ASTM D 5084
Method C: Falling Head Rising Tailwater

COOPER

Job No:	556-001b	**Boring:**		**Date:**	11/08/04
Client:	HydroFocus, Inc.	**Sample:**	2	**By:**	MD/PJ
Project:	City of Palo Alto	**Depth'**		**Remolded:**	

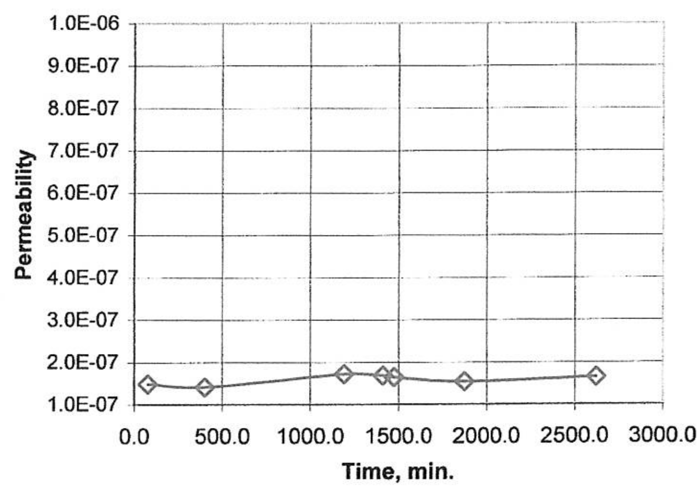
Visual Classification: Gray CLAY (Bay Mud)

B: = >0.95 ("B" is an indication of saturation)

Max Hydraulic Gradient: = 19

Max Sample Pressures, psi:			
Cell:	**Bottom**	**Top**	**Avg. Sigma 3**
53.5	49	48	5

Date	Minutes	Head, (in)	K,cm/sec
11/1/2004	0.00	98.33	Start of Test
11/1/2004	80.00	97.73	1.5E-07
11/1/2004	404.00	95.33	1.4E-07
11/2/2004	1193.00	89.13	1.7E-07
11/2/2004	1412.00	87.53	1.7E-07
11/2/2004	1476.00	87.03	1.6E-07
11/2/2004	1874.00	84.43	1.5E-07
11/3/2004	2622.00	79.83	1.7E-07



Average Permeability: 1.6E-07 cm/sec

Sample Data:	**Initial**		**Final**
Height, in	2.01		2.00
Diameter, in	1.96		1.93
Area, in2	3.02		2.91
Volume in3	6.06		5.82
Total Volume, cc	99.4		95.4
Volume Solids, cc	25.0		25.0
Volume Voids, cc	74.4		70.4
Void Ratio	3.0		2.8
Porosity, %	74.9		73.8
Saturation, %	99.2		99.3
Specific Gravity	2.70	Assumed	2.70
Wet Weight, gm	141.2		137.3
Dry Weight, gm	67.4		67.4
Tare, gm	0.00		0.00
Moisture, %	109.5		103.7
Dry Density, pcf	42.3		44.1

Remarks:

Hydraulic Conductivity
ASTM D 5084
Method C: Falling Head Rising Tailwater

Job No:	556-001c	**Boring:**		**Date:**	11/08/04
Client:	HydroFocus, Inc.	**Sample:**	3	**By:**	MD/PJ
Project:	City of Palo Alto	**Depth'**		**Remolded:**	

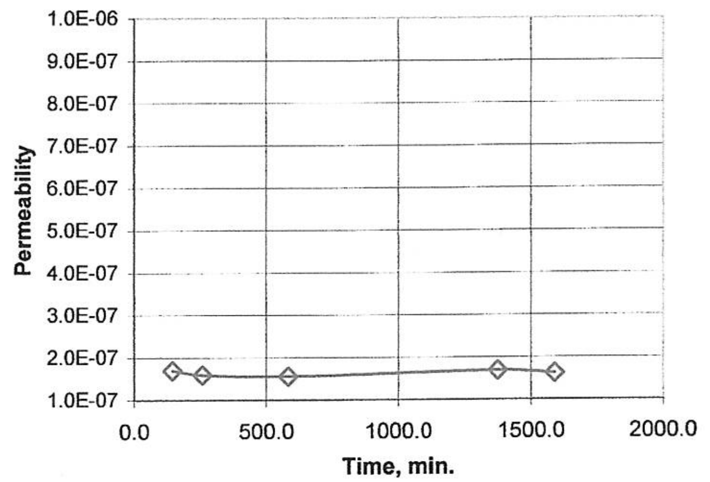
Visual Classification: Gray CLAY (Bay Mud)

B: = >0.95 **("B" is an indication of saturation)**

Max Hydraulic Gradient: = 34

Max Sample Pressures, psi:			
Cell:	**Bottom**	**Top**	**Avg. Sigma 3**
43	39	37	5

Date	Minutes	Head, (in)	K,cm/sec
11/1/2004	0.00	168.68	**Start of Test**
11/1/2004	146.00	166.56	1.7E-07
11/1/2004	261.00	165.06	1.6E-07
11/1/2004	585.00	160.66	1.6E-07
11/2/2004	1374.00	150.66	1.7E-07
11/2/2004	1591.00	148.26	1.6E-07
			1.6E-07



Average Permeability: **1.6E-07** **cm/sec**

Sample Data:	**Initial**		**Final**
Height, in	1.98		1.79
Diameter, in	1.96		1.90
Area, in2	3.02		2.84
Volume in3	5.97		5.08
Total Volume, cc	97.9		83.2
Volume Solids, cc	21.4		21.4
Volume Voids, cc	76.5		61.7
Void Ratio	3.6		2.9
Porosity, %	78.1		74.2
Saturation, %	98.8		98.8
Specific Gravity	2.70	Assumed	2.70
Wet Weight, gm	133.4		118.9
Dry Weight, gm	57.9		57.9
Tare, gm	0.00		0.00
Moisture, %	130.4		105.4
Dry Density, pcf	36.9		43.4

Remarks:

Hydraulic Conductivity

ASTM D 5084

Method C: Falling Head Rising Tailwater

Job No:	556-001d	**Boring:**		**Date:**	11/08/04
Client:	HydroFocus, Inc.	**Sample:**	4	**By:**	MD/PJ
Project:	City of Palo Alto	**Depth'**		**Remolded:**	

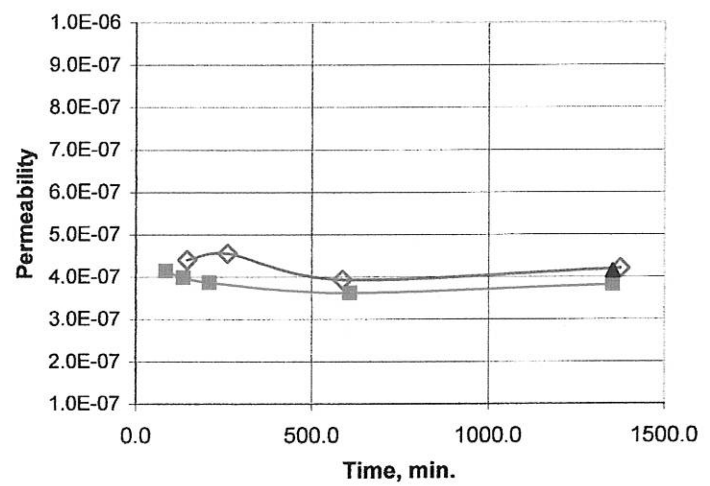
Visual Classification: Gray CLAY (Bay Mud)

B: = >0.95 ("B" is an indication of saturation)

Max Hydraulic Gradient: = 33

Max Sample Pressures, psi:			
Cell:	**Bottom**	**Top**	**Avg. Sigma 3**
43	39	37	5

Date	Minutes	Head, (in)	K,cm/sec
11/1/2004	0.00	168.68	Start of Test
11/1/2004	147.00	163.06	4.4E-07
11/1/2004	261.00	158.26	4.6E-07
11/1/2004	587.00	148.06	3.9E-07
11/2/2004	1375.00	125.46	4.2E-07
11/2/2004	86.00	165.56	4.1E-07
11/2/2004	136.00	163.96	4.0E-07
11/2/2004	210.00	161.66	3.9E-07
11/2/2004	608.00	149.46	3.6E-07
11/3/2004	1353.00	131.06	3.8E-07



Average Permeability: **4.1E-07** **cm/sec**

Sample Data:	**Initial**		**Final**
Height, in	2.01		1.91
Diameter, in	2.00		1.85
Area, in2	3.14		2.69
Volume in3	6.31		5.12
Total Volume, cc	103.5		84.0
Volume Solids, cc	19.4		19.4
Volume Voids, cc	84.1		64.5
Void Ratio	4.3		3.3
Porosity, %	81.2		76.9
Saturation, %	97.3		98.5
Specific Gravity	2.70	Assumed	2.70
Wet Weight, gm	134.2		116.0
Dry Weight, gm	52.4		52.4
Tare, gm	0.00		0.00
Moisture, %	156.1		121.4
Dry Density, pcf	31.6		38.9

Remarks:

Hydraulic Conductivity
ASTM D 5084
Method C: Falling Head Rising Tailwater

Job No:	556-001e	**Boring:**		**Date:**	11/08/04
Client:	HydroFocus, Inc.	**Sample:**	5	**By:**	MD/PJ
Project:	City of Palo Alto	**Depth'**		**Remolded:**	

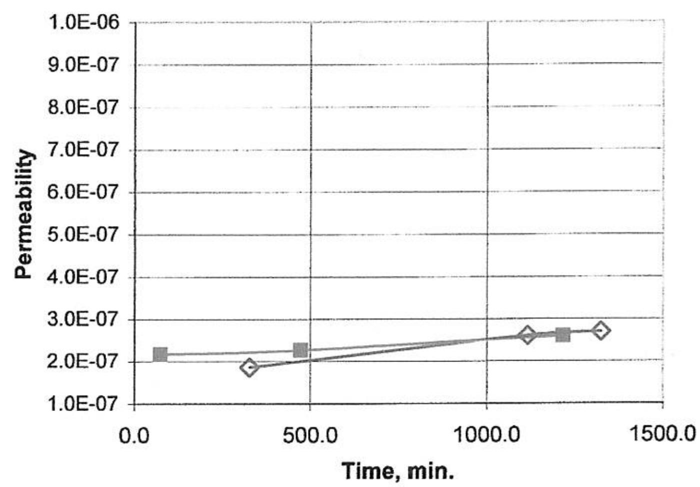
Visual Classification: Gray CLAY (Bay Mud)

B: = >0.95 ("B" is an indication of saturation)

Max Hydraulic Gradient: = 19

Max Sample Pressures, psi:			
Cell:	**Bottom**	**Top**	**Avg. Sigma 3**
53.5	49	48	5

Date	Minutes	Head, (in)	K,cm/sec
11/1/2004	0.00	98.33	Start of Test
11/1/2004	328.00	95.13	1.9E-07
11/2/2004	1116.00	85.53	2.6E-07
11/2/2004	1324.00	82.13	2.7E-07
11/2/2004	75.00	97.53	2.2E-07
11/2/2004	473.00	92.93	2.3E-07
11/3/2004	1217.00	84.53	2.6E-07



Average Permeability: **2.4E-07** **cm/sec**

Sample Data:	Initial		Final
Height, in	2.01		1.90
Diameter, in	1.96		1.92
Area, in2	3.02		2.91
Volume in3	6.06		5.51
Total Volume, cc	99.4		90.3
Volume Solids, cc	19.7		19.7
Volume Voids, cc	79.6		70.5
Void Ratio	4.0		3.6
Porosity, %	80.1		78.1
Saturation, %	99.2		99.5
Specific Gravity	2.70	Assumed	2.70
Wet Weight, gm	132.3		123.5
Dry Weight, gm	53.3		53.3
Tare, gm	0.00		0.00
Moisture, %	148.2		131.7
Dry Density, pcf	33.5		36.8

Remarks:

Hydraulic Conductivity
ASTM D 5084
Method C: Falling Head Rising Tailwater

Job No:	556-001f	**Boring:**		**Date:**	11/11/04
Client:	HydroFocus, Inc.	**Sample:**	6	**By:**	MD/PJ
Project:	City of Palo Alto	**Depth'**		**Remolded:**	

Visual Classification: Gray CLAY w/ organics (bay mud, very soft)

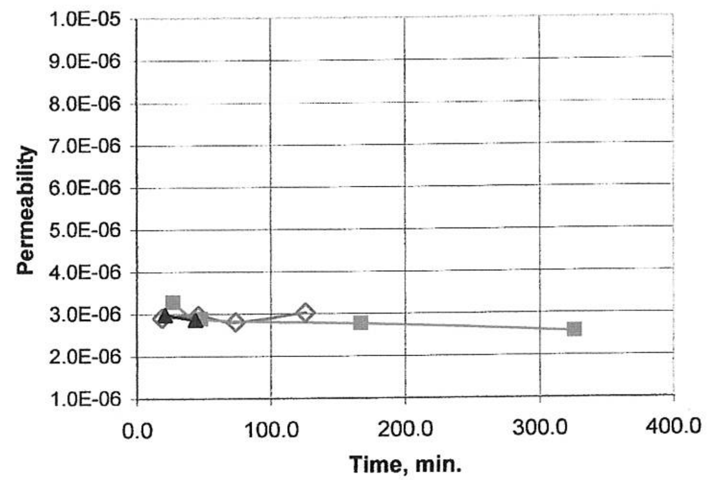
Max Sample Pressures, psi:

Cell:	Bottom	Top	Avg. Sigma 3
53.5	49	48	5

B: = >0.95 ("B" is an indication of saturation)

Max Hydraulic Gradient: = 20

Date	Minutes	Head, (in)	K,cm/sec
11/5/2004	0.00	98.33	Start of Test
11/5/2004	19.00	94.93	2.9E-06
11/5/2004	46.00	90.13	3.0E-06
11/5/2004	74.00	86.13	2.8E-06
11/5/2004	126.00	77.13	3.0E-06
11/5/2004	27.00	92.93	3.3E-06
11/5/2004	48.00	89.83	2.9E-06
11/5/2004	167.00	72.23	2.8E-06
11/5/2004	326.00	55.43	2.6E-06
11/6/2004	21.00	94.73	3.0E-06
11/6/2004	44.00	91.23	2.9E-06



Average Permeability: 2.9E-06 cm/sec

Sample Data:	Initial		Final
Height, in	1.96		1.78
Diameter, in	1.94		1.87
Area, in2	2.96		2.75
Volume in3	5.79		4.89
Total Volume, cc	94.9		80.1
Volume Solids, cc	19.3		19.3
Volume Voids, cc	75.7		60.9
Void Ratio	3.9		3.2
Porosity, %	79.7		76.0
Saturation, %	92.8		93.3
Specific Gravity	2.55	Assumed	2.55
Wet Weight, gm	119.3		105.9
Dry Weight, gm	49.1		49.1
Tare, gm	0.00		0.00
Moisture, %	143.0		115.7
Dry Density, pcf	32.3		38.2

Remarks: Dimensions, densities and related values reported are approximate due to the very soft nature of this material.

Hydraulic Conductivity
ASTM D 5084
Method C: Falling Head Rising Tailwater

Job No:	556-001g	**Boring:**		**Date:**	11/11/04
Client:	HydroFocus, Inc.	**Sample:**	7	**By:**	MD/PJ
Project:	City of Palo Alto	**Depth'**		**Remolded:**	

Visual Classification: Black Organic CLAY near Peat (soft)

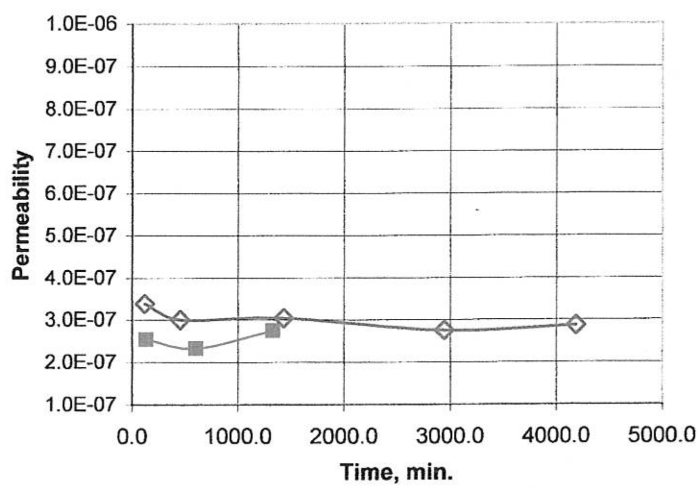
Max Sample Pressures, psi:

Cell:	Bottom	Top	Avg. Sigma 3
43.5	39	38	5

B: = >0.95 ("B" is an indication of saturation)

Max Hydraulic Gradient: = 26

Date	Minutes	Head, (in)	K,cm/sec
11/5/2004	0.00	51.69	Start of Test
11/5/2004	119.00	50.39	3.4E-07
11/5/2004	456.00	47.09	3.0E-07
11/6/2004	1431.00	39.99	3.0E-07
11/7/2004	2943.00	30.99	2.8E-07
11/8/2004	4186.00	24.99	2.9E-07
11/8/2004	131.00	50.59	2.5E-07
11/8/2004	605.00	47.19	2.3E-07
11/9/2004	1330.00	41.49	2.7E-07



Average Permeability: 2.8E-07 cm/sec

Sample Data:	Initial		Final
Height, in	2.02		1.81
Diameter, in	1.96		1.84
Area, in2	3.02		2.64
Volume in3	6.09		4.79
Total Volume, cc	99.9		78.5
Volume Solids, cc	16.2		16.2
Volume Voids, cc	83.7		62.4
Void Ratio	5.2		3.9
Porosity, %	83.8		79.4
Saturation, %	98.4		100
Specific Gravity	2.55	Assumed	2.55
Wet Weight, gm	123.6		103.8
Dry Weight, gm	41.2		41.2
Tare, gm	0.00		0.00
Moisture, %	200.0		151.9
Dry Density, pcf	25.7		32.7

Remarks: Dimensions, densities and related values reported are approximate due to the very soft nature of this material.

Hydraulic Conductivity

ASTM D 5084

Method C: Falling Head Rising Tailwater

Job No:	556-001h	**Boring:**		**Date:**	11/11/04
Client:	HydroFocus, Inc.	**Sample:**	9	**By:**	MD/PJ
Project:	City of Palo Alto	**Depth'**		**Remolded:**	

Visual Classification: Dark Gray CLAY w/ vertical peat strata

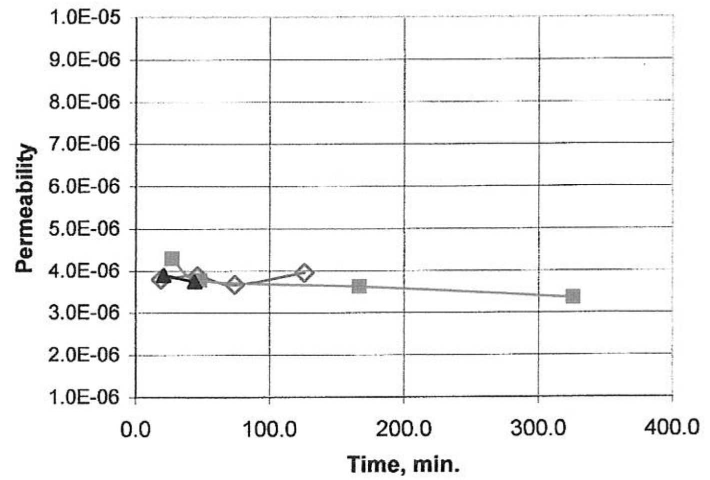
Max Sample Pressures, psi:

Cell:	Bottom	Top	Avg. Sigma 3
53.5	49	48	5

B: = >0.95 ("B" is an indication of saturation)

Max Hydraulic Gradient: = 19

Date	Minutes	Head, (in)	K,cm/sec
11/5/2004	0.00	98.33	Start of Test
11/5/2004	19.00	94.93	3.8E-06
11/5/2004	46.00	90.13	3.9E-06
11/5/2004	74.00	86.13	3.7E-06
11/5/2004	126.00	77.13	4.0E-06
11/5/2004	27.00	92.93	4.3E-06
11/5/2004	48.00	89.83	3.8E-06
11/5/2004	167.00	72.23	3.6E-06
11/5/2004	326.00	55.43	3.3E-06
11/6/2004	21.00	94.73	3.9E-06
11/6/2004	44.00	91.23	3.7E-06



Average Permeability: **3.8E-06** **cm/sec**

Sample Data:	**Initial**		**Final**
Height, in	2.01		1.99
Diameter, in	1.95		1.95
Area, in2	3.00		2.97
Volume in3	6.03		5.91
Total Volume, cc	98.8		96.9
Volume Solids, cc	21.5		21.5
Volume Voids, cc	77.3		75.4
Void Ratio	3.6		3.5
Porosity, %	78.2		77.8
Saturation, %	99.6		99.6
Specific Gravity	2.60	Assumed	2.60
Wet Weight, gm	132.9		131.0
Dry Weight, gm	55.9		55.9
Tare, gm	0.00		0.00
Moisture, %	137.7		134.3
Dry Density, pcf	35.3		36.0

Remarks:

APPENDIX B: Recommended Well-Casing Sealing Specifications

Background

The principal objective of destroying and sealing abandoned well casings is to restore, as far as possible, the original (natural) hydrogeologic conditions[1]. San Mateo County requires abandoned water wells to be destroyed in accordance with County Ordinances and by California law, including regulations and standards issued by the California Department of Water Resources[2].

In the East Palo Alto Marshlands, the abandoned well casings originally intercepted upper and lower water-bearing zones. The interchange of water between stratified zones can deteriorate groundwater quality or result in a loss of artesian pressure when well casings intercept multiple water-bearing zones (i.e., upper and lower zones). In these circumstances, the California water well standards require the well be sealed to prevent such interchange by placing impervious material a distance of 10 feet or more above and below the natural aquitards that separate the different zones[3].

We reviewed well-sealing proposals from four drilling firms, and combined the most reliable aspects to prepare a recommended approach and cost estimate. However, it is difficult for a contractor to prepare detailed scopes and provide firm cost estimates for conditions they have not inspected. Furthermore, method feasibility and costs can change as a result of actual field conditions encountered during construction activities. Hence, our cost estimate is for planning purposes only, and should be refined based on a detailed site inspection by the contractor doing the work. Our cost estimate includes resources for a contractor to visit the marsh and conduct a detailed assessment of site conditions for the purpose of verifying or modifying the work scope and improving the reliability of the cost estimate.

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[1] Hydrogeologic conditions beneath the East Palo Alto marsh consist of a shallow water-bearing zone overlying deeper semi-confined and confined water-bearing zones. The shallow and deep water-bearing zones are separated by aquitards formed by natural fine-grained silty clay deposits (bay mud). The upper water-bearing zone and underlying aquitard beneath the marsh is about 160 to 175-feet thick.

[2] San Mateo County: Ordinance No.04128; Chapter 4.68; San Mateo County Ordinance Code, 2001.

[3] California Department of Water Resources, "California Well Standards", Bulletin 74-90, 1990.

Recommended Specifications

Assumed Site Conditions

- All well casings (8) have been located and staked in the field.
- The assumed well casing characterization is: casings were approximately installed during the period 1910-1930 using cable-tool driven casing; 8-inch diameter steel casing; 250 feet maximum casing depth; 12-inch diameter, shallow conductor casing around each well; no artificial gravel pack or annular seal below conductor casing; the annulus between well-casing and conductor casing is filled with cement grout.
- The conductor casing does not need to be perforated or removed.
- Maximum artesian flow from the deep aquifer is 10 gpm.

Special Access Issues

- Surface vegetation consists of pickle grass and marshland plants and must be protected to the extent possible. The marshland is habitat for two endangered species: clapper rail and harvest mouse.
- Surface soils beneath the vegetation mat consist of saturated bay mud with some peat.
- Access to well casings 4 and 5 (Figure 1) will require crossing sloughs approximately 15 feet wide and more than 6 feet deep. Access to well casing 2 will require crossing a slough approximately 6 feet wide and at least 2 feet deep. Additional well casings may require crossing shallower sloughs about 2 feet wide. The area around well casing 1 may have shallow water less than 18" deep.

Special Construction Considerations

- Drilling equipment includes a low-ground-pressure track-mounted mud-rotary drill rig and track-mounted support vehicle.
- Plywood or landing mats will be used to protect the vegetation and wildlife habitat. However, the work will inevitably cause some surface damage to the marsh. Damage to pickle grass and marshland plants may result from the plywood or landing mats remaining in place for up to a week.
- Some leakage of drilling fluids or bentonite grout is possible.
- Flowing artesian water, if encountered, will discharge into the marsh while packers are being installed and removed. Artesian pressure may also discharge drilling fluids into the marsh.
- Temporary bridge construction required to cross sloughs. Bridge materials to include beams or girders and deck planking. Install temporary bridges using a heavy lift helicopter. Palo Alto airport operations may be affected when the helicopter is in use.

Recommended Sealing Strategy and Materials

- Obtain San Mateo County Department of Health Services (SMCDHS) well destruction permits and underground utility clearance.
- Remove sediment filling the inside of each well casing by mud-rotary and/or auger drilling to a maximum depth of 150 feet (through the entire expected thickness of the shallow aquifer and underlying regional aquitard).
- Drum cuttings and fluids either at the well head or on an adjacent shoreline. A discharge pump and hose will be used to pump fluids and drilling mud to the shoreline, if feasible.
- If encountered, utilize packers to control flowing artesian water.
- If necessary, a mills knife will be used to create 10-feet perforated intervals in the well casings at 30 foot intervals to promote sealing outside the well casing and reduce the potential interchange of water between stratified zones.
- Grout each well from the sounded bottom of the casing up through a tremie pipe with a high-solids bentonite grout.
- Each well is already cut off below land surface, and is now covered with several feet of bay mud. Once exposed, and after the casing has been grounted, the sealed casing will be covered with a concrete mushroom cap to a height of one foot above the ground surface. A non-corrosive plate shall be affixed to each concrete mushroom cap that documents the well destruction.
- Field notes will be submitted indicating the size and depth of each well, artesian rate of flow, amount of grout placed, and all other observations.
- Dispose of drilling muds and fluids at an approved waste disposal facility.

Engineer's Estimated Costs (based on available information)

- City to obtain San Mateo County Department of Health Services (SMCDHS) well destruction permits and provide underground utility clearance.
- Muds and fluids are assumed to be non-hazardous. Costs for hazardous mud and fluid disposal are not included.
- Table B.1 provides a summary of estimated costs.

TABLE B1. CONSTRUCTION COST ESTIMATE

Destruction of Eight Abandoned Water Wells

East Palo Alto Marshland Baylands Preserve, City of Palo Alto, CA

		Units	Unit Cost	Total Cost
TASK 1. Contractor's Site Inspection				
A	Site inspection	1	5000	$ 5,000
TASK 2. Destroy Five Wells Accessible Overland (Wells #1, 3, 6, 7, 8)				
A	Mobilize drilling equipment, lump sum	1	10000	$ 10,000
B	Destroy accessible wells, per well	5	9250	$ 46,250
C	Casing packers, per day	15	300	$ 4,500
D	Packer supplies, lump sum	1	500	$ 500
E	Water and drilling fluids discharge pump, per day	15	300	$ 4,500
F	55-gallon drums for drilling mud containment, per drum	55	50	$ 2,750
G	Drilling mud and fluids disposal, lump sum	1	10000	$ 10,000
		0	0	$ 0
TASK 2. SUBTOTAL				$ 78,500
TASK 3. Destroy Inaccessible Wells (Wells #2, 4, 5)				
A	Mobilize additional bridging materials, lump sum	1	15000	$ 15,000
B	Construct bridges over sloughs, per well	3	8000	$ 24,000
C	Destroy wells, per well	3	10000	$ 30,000
D	Casing packers, per day	18	300	$ 5,400
E	Packer supplies, lump sum	1	500	$ 500
F	Water and drilling fluids discharge pump, per day	18	300	$ 5,400
G	55-gallon drums for drilling mud containment, per drum	33	50	$ 1,650
H	Drilling mud and fluids disposal, lump sum	1	7000	$ 7,000
I	Mobilize heavy-lift helicopter, lump sum	1	20000	$ 20,000
J	Helicopter lifts, per lift	24	1500	$ 36,000
K	Helicopter crew per diem, per day	15	750	$ 11,250
		0	0	$ 0
		0	0	$ 0
TASK 3. SUBTOTAL				$ 156,200
CONSTRUCTION SUBTOTAL				$ 239,700
CONTINGENCY, 35%				$ 83,895
CONSTRUCTION TOTAL				$ 323,595