RECONDITIONING OF TEN MONITORING WELLS, ISLAND COUNTY, WA - 1987

by

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This Open File Technical Report presents the results of a monitor well rehabilitation project undertaken by the Water Resources Program, Department of Ecology. It is intended as a working document and has received internal review. This report may be circulated to other Agencies and the Public, but it is not a formal Ecology Publication.

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I. INTRODUCTION

In 1983, the Washington Department of Ecology (WDOE) and the United States Geological Survey (USGS) initiated a cooperative ground water investigation in Island County. Ten monitoring wells were drilled during 1983 and 1984 (eight on Whidbey Island and two on Camano Island - Figure 1.) in order to:

(1) document the surficial deposits above bedrock to a maximum depth of 1000 ft.,
(2) obtain information on the character of formations using borehole geophysical methods,
(3) determine the vertical distribution of hydrostatic head at each location, and
(4) install piezometers for periodic observation of static water level and water quality.

The wells were rotary drilled and cased to selected depths with 6 or 8 in. steel pipe. After casing, each well was equipped with either three or four piezometers (Table 1). Piezometers consist of two-inch nominal I.D. galvanized steel pipe joined with threaded couplings and fitted on the lower end with a three-foot stainless steel screen. The screens were set at depths adjacent to geologic formations of interest. Before setting the piezometers, the casing was slotted adjacent to the screen depth with a down-hole perforating knife to allow water entry and plugged below this depth with a cement grout seal. Once the casing was perforated, the bottom seal installed, and the piezometers set in place, the space between the casing and the screen was filled with washed pea-gravel before placing a top seal (Figure 2.).

A top seal was not usually installed above the shallowest piezometer. The gravel pack and casing were left open to atmospheric pressure. However, seals were installed above the screen levels of all piezometers in wells #9 and #10. Contrarily, a bottom seal was usually installed below the deepest piezometer. Exceptions are wells #6 and #7, whose deepest piezometers are open to the maximum depth of the borehole.

An organic polymer drilling fluid (Revert [Tm]) controlled sand heaving into the casing during the perforating and installation of the piezometers at all wells except wells #1 and #5. Following well completion, however, the piezometers were not properly cleansed of residual Revert. This precluded using these wells for monitoring water quality and raised some concern over plugged screens and the validity of measured water levels. To alleviate this concern and to prepare the wells for monitoring water quality, a contract was prepared to clean and rehabilitate the 33 piezometers.

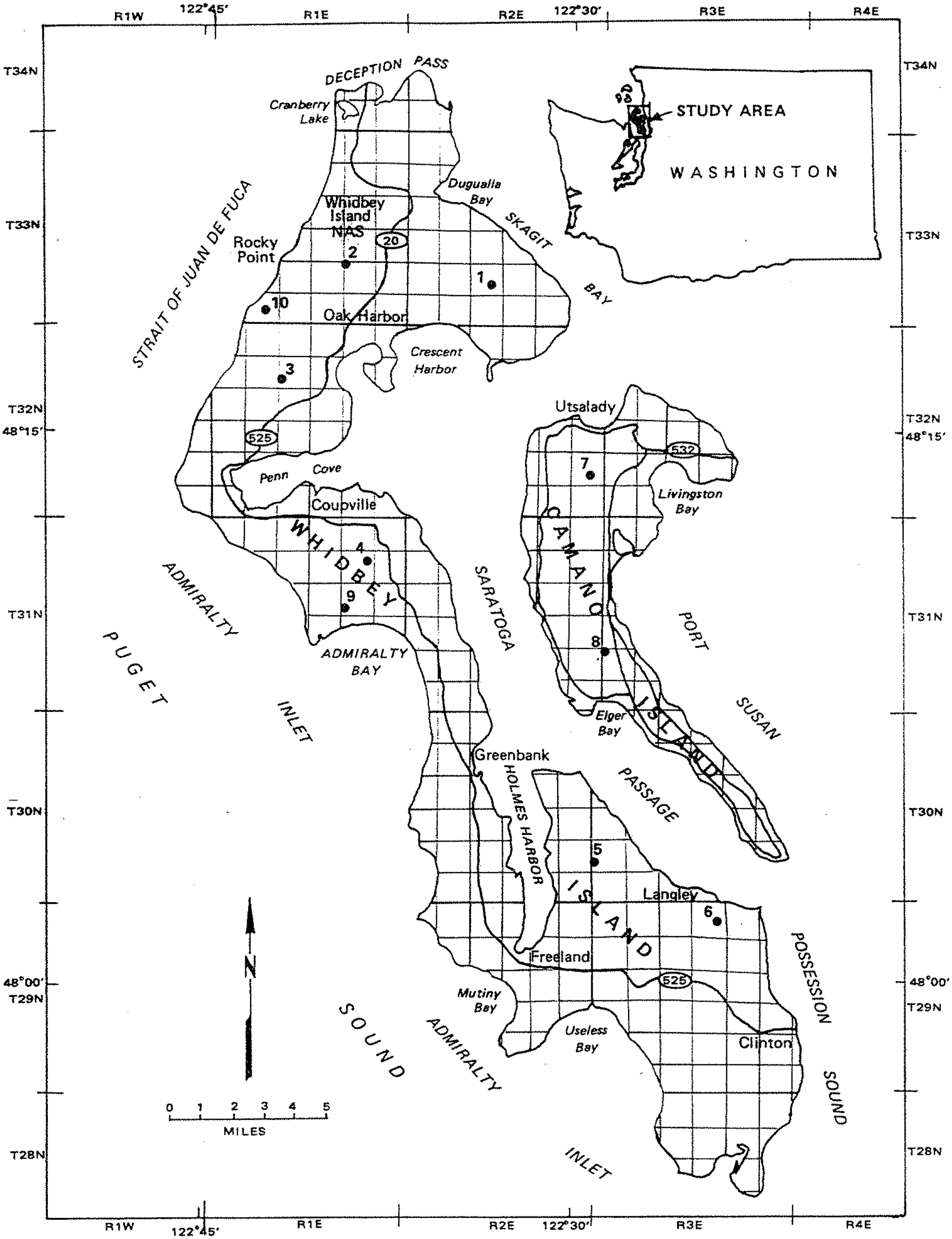
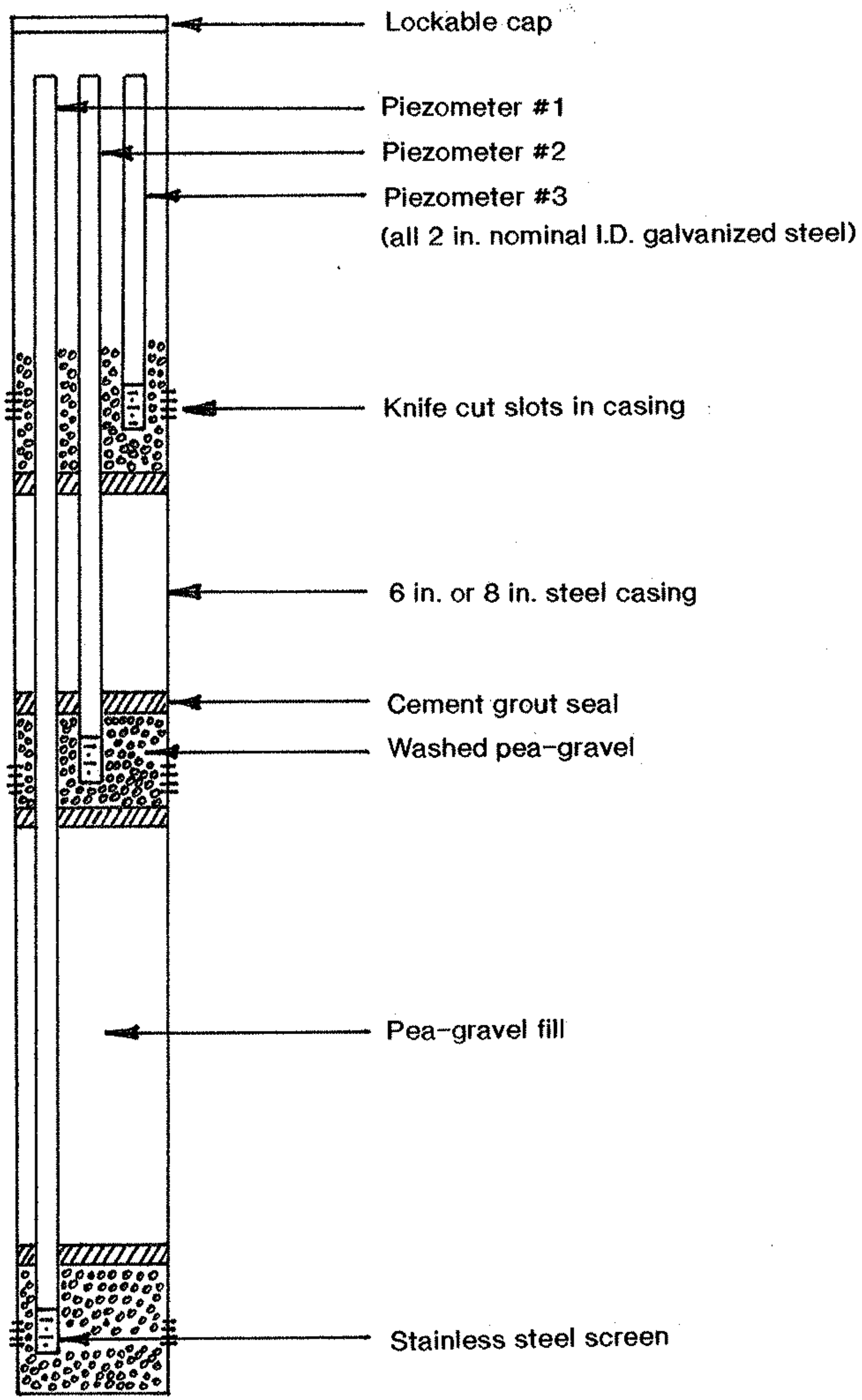


Figure 1. TEST/OBSERVATION WELLS, ISLAND COUNTY, WASHINGTON.

Table 1. Depths below land surface of boreholes and installed piezometers (ft.).

Well	Date Completed	Borehole Depth	Casing Dia.(in.)	# of Piezo's	Depth P1	P2	P3	P4
1	9/83	820	6	3	573	424	304	
2	10/83	682	8	4	583	439	342	159
3	11/83	1006	8	4	827	672	486	347
4	10/83	1000	6	3	530	372	170	
5	9/83	1000	6	3	935	494	304	
6	10/83	1006	8	4	831	606	444	211
7	11/83	1000	6	3	990	466	266	
8	11/83	1005	6	3	582	243	133	
9	7/84	1000	6	3	638	361	148	
10	10/84	1000	6	3	612	308	114	

FIGURE 2. Typical Construction Diagram – Island County Monitoring Wells.



II. INTERAGENCY AGREEMENT No. L0088030

In July 1987 WDOE signed an interagency agreement with the Water Well Technology Program at Edmonds Community College to recondition the ten monitoring wells. Work included:

(1) cleaning the piezometer pipes,
(2) oxidizing any remaining Revert using calcium hypochlorite,
(3) developing the piezometers to insure unrestricted flow between the screen and gravel pack, and
(4) removal of stagnant water in the piezometers and associated casing.

Work was performed by the college's well drilling instructor, Al Butler, and the author, a representative of WDOE. The project was initiated in August, and completed in October, 1987.

III. RECONDITIONING METHODS

The piezometers were reconditioned using a Bucyrus-Erie Model 22-W cable tool drilling rig equipped with a special surging-tool. The tool, designed to fit the two-inch diameter pipe, consisted of an 15 ft. x 1-1/2 in. diameter steel rod fitted on the lower end with replaceable rubber washers (Figure 3). The upper end of the tool connected swagged to the 5/8 in. drill cable for lowering into the piezometer. The length and weight (approximately 60 lbs.) of the steel rod allowed it to rapidly drop through the water without cocking and jamming. The tool was used to remove water from the piezometers, to surge water back and forth through the screen during chlorination, and to physically swab the interior of the piezometer.

The surging-tool was originally designed with rigid plastic seals. Slots, machined in the seals, passed water when the tool was lowered, but closed when the tool was raised. The variation in internal pipe diameter, the roughness of the galvanized coating, and the gap between pipe ends at couplings, however, quickly destroyed the rigid seals. The tool was redesigned to use flexible rubber washers. The washers were allowed to move up the shaft about one-inch and to flex upon lowering into the piezometer, thus bypassing the water. When rapidly raised, the washers would flare out, sealing against the sides of the pipe and lifting out the majority of water trapped above the tool.

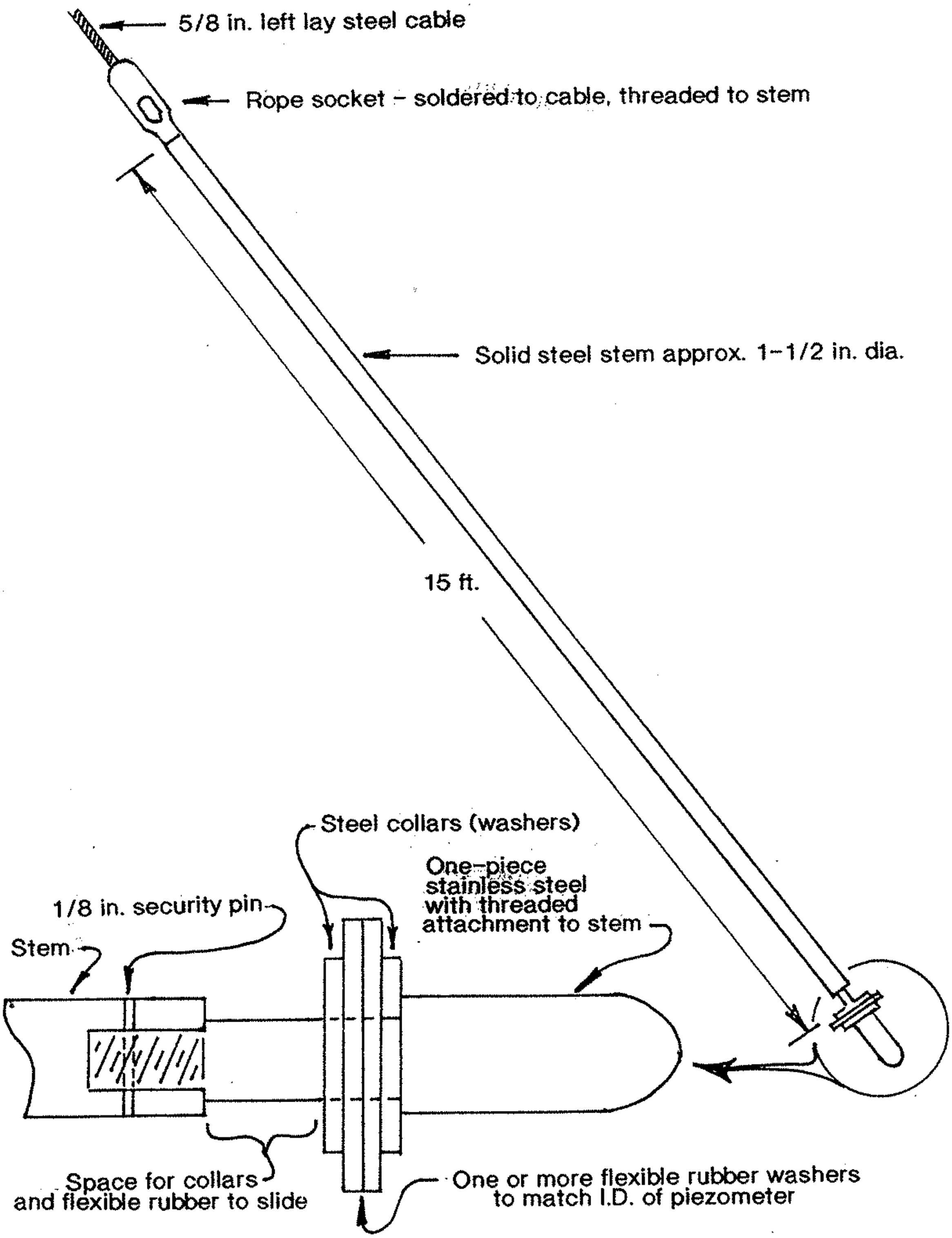
A. WATER REMOVAL

Water was removed from the piezometers by dropping the surging-tool to the bottom of the screen and then rapidly (3 ft./sec) lifting the tool and overlying water out of the piezometer. During these purging operations, the top of the piezometer was extended with a three-foot section of pipe fitted with a T-connector and a drain pipe. Water lifted from the well was passed out the drain pipe and measured in five-gallon buckets. The pipe extension was loosely connected with a threaded coupling and was pivoted from one bucket to another until the purge was complete. The tool lifted between 50 and 95 percent of the trapped water. Leakage was related to the wear on the rubber washers and the distance the water was lifted (depth of the piezometer).

The surging-tool was effective in removing water from the piezometers, occasionally purging 100 gallons in a single lift. In most cases, the piezometer was dried-up with only a few lifts. The limiting factor controlling the rate at which water was removed from any piezometer was always the time required for water level recovery (inflow through the screen and casing perforations) and not how rapidly the tool could be operated.

Lifting of the surging-tool also created a powerful suction on the piezometer screen and related gravel pack which helped to dislodge any blockage. In a few cases, a significant quantity of clay sized material was brought into the piezometer from the formation. When this occurred, the suction was reduced by starting the lift with the tool above screen level.

Figure 3. Piezometer cleaning tool.



B. CHLORINATION

After purging stagnant water, all piezometers were chlorinated (except those in Well #1) with a concentrated solution of calcium hypochlorite (commercial HTH). HTH, a strong oxidizing agent, was used to break down any remaining Revert and to destroy bacterial growth. A quantity of dry, granular HTH sufficient to produce a concentration of approximately 1000 mg/l chlorine was added to the water in each piezometer. The quantity of HTH added depended on the estimated volume of water in the piezometer and associated gravel pack. An additional volume of 1000 mg/l chlorine solution was then added to each piezometer to produce a positive head above the static water level and force the solution out into the gravel pack and formation.

Initial attempts were made to pump the chlorine solution into the piezometers under pressure (up to 200 psi). However, once the piezometer filled with solution it accepted little additional water even at high pressure. Because pumping was relatively ineffective and the effects of the high pressure on the formation were unknown, pumping was discontinued.

An increase in piezometer water level was relied on to force the solution into the gravel pack. The HTH solution was added to each piezometer until at least 50 gallons (equivalent to a 300 ft. increase in piezometer head) were accepted, or until the solution overflowed the piezometer (primarily piezometers less than 300 ft. deep).

After adding the HTH solution, the mixture was agitated by lowering the surging-tool (fitted with worn rubber washers) into the piezometer to a level just above the screen, engaging the spudding beam on the drill rig, and surging water back and forth though the screen. Piezometers were surged for about one hour and then left undisturbed for 20 to 48 hours to allow the chlorine to react. At the end of this time, the chlorinated water was purged from the piezometer. Purging was alternated among the piezometers at each well until the desired water volumes were removed. Alternating between piezometers allowed each to recover slightly before re-lowering the tool for another lift. Water was removed until the chlorine residual was no longer detectable using a chlorine indicator test (a standard test kit for swimming pools). Purging of most piezometers continued until at least the entire volume of water stored in the piezometer and casing (plus the volume of added HTH solution) had been removed (Table 2).

The complete purging of water stored within the casing of the shallowest piezometers was not always accomplished. Because a casing seal was not usually installed above the piezometer screen, the volume of water in the casing was relatively large. And, because the water in the casing was not confined by a top seal, lowering the tool into the piezometer tended to push water through the screen into the gravel pack raising the water level in the casing. It often took 20 minutes or longer for the water to drain back into the piezometer so that it could be lifted to the surface. Even when the water level in the piezometer had recovered, the quantity of water in the piezometer was often only a few gallons, making it a time consuming task to purge the larger volume stored in the casing.

Table 2. Approximate volume of water in piezometer (P) and casing (C) at static water level; volume of water purged before chlorination (BC); volume of water added as chlorine solution (HTH) or slug test (Slug); and volume of water purged after chlorination (AC) (volumes in gallons).

Well	#	P	C	P+C	BC	HTH	Slug	AC
1*	1	28	62	90	229			
	2	28	96	124	183			
	3	20	97	117	81			
2	1	78	36	114	101	60		332
	2	56	38	94	72	36		200
	3	39	45	84	65	62		145
	4	10	46	56	7	50		36
3	1	109	25	134	107	50		489
	2	84	33	117	90	100	90	194
	3	54	56	110	175	50		362
	4	31	158	189	50	50		126
4	1	62	66	128	142	50		232
	2	39	34	73	104	50		167
	3	8	51	59	32	50		106
5*	1	102	168	270	98	5		174
	2	29	147	176	19	5		205
	3	0	8	8			15	
6	1	110	93	203	267	88		263
	2	79	99	178	76	50	75	167
	3	47	33	80	81	37		281
	4	8	62	70	19	50		105
7	1	95	14	110	148	50		449
	2	39	19	58	106	50		198
	3	10	53	63	36	50		128
8	1	71	53	124	93	150		402
	2	20	40	60	44	50		111
	3	6	48	54	2	24		28
9	1	103	95	198	188	38		272
	2	56	38	94	159	21		483
	3	25	29	54	62	32		99
10	1	99	33	132	689	300		417
	2	50	28	78	145	55		228
	3	18	36	54	25	25		35

* Revert not used in construction.

Since costs for the cleaning operation exceeded $100/hr, we decided early in the project that if the screens were clean and residual chlorine levels reduced, the purging of remaining water within the casing of the shallow piezometers would be given a low priority. We anticipated that this water could be economically airlifted (blown out with compressed air) at a later date. Priority was given to purging deeper piezometers beyond the pressure limits of inexpensive airlifting.

C. MISCELLANEOUS

In addition to the removal of stagnant water and the HTH chlorination, several miscellaneous measurements were made to indicate the effectiveness of the rehabilitation. First, the depth of each piezometer was measured before and after cleaning to determine if any significant deposits were removed. Depths were measured by lowering the drill cable and tool into the piezometer until bottom was reached and recording the cable length to the nearest one-tenth foot.

Second, as each piezometer was purged, any measurable changes in the water level of adjacent piezometers were noted. Significant changes in water level would indicate leakage from one piezometer to another.

Finally, a few chemical analyses were run on the purged water (after chlorination) as an aid in determining whether the piezometers were adequately purged and recharged with fresh water from the formation. Water was tested for pH, specific conductance (YSI Model 33 conductivity meter), chloride (HACH digital titration Mohr Argentometric Method), and occasionally total hardness (HACH test kit HA-4P). The water was repeatedly analyzed during the purging operation, and fresh formation water was assumed present when the values approached a constant.

IV. RESULTS OF THE RECONDITIONING

The purpose of cleaning was to insure unrestricted water flow from the formation through the casing, gravel pack, and piezometer screen. Because we could not visually or physically inspect the piezometers, the determination of unrestricted flow was based on the volume of water purged and/or the rate of recovery of the dynamic water level.

If the water level within the piezometer recovered within 15 to 20 hours (i.e.., returned to its original level), the screen was assumed clean with unrestricted flow between the piezometer and outer formation. Directly related to a rapid recovery was the ability to purge large volumes of water. A good to excellent flow between the formation and piezometer was also assumed if the volume of water purged was greater than about 1.5 times the volume in the piezometer and casing.

A. CLEANING

A volume of water greater than 1.5 times the combined volume of the piezometer and casing was purged from 19 of the 23 deeper piezometers (Table 3). We assumed these were adequately cleaned. The four remaining deep piezometers having a low purged volume were:

#3-P2,
#5-P1 and P2, and
#6-P2.

Because of the low priority on purging shallow piezometers, five of the ten shallow piezometers had less water removed than 1.0 times the combined casing and piezometer volume. In most cases, this was a direct result of terminating the purging operation once purging of deeper piezometers was complete. For these shallow piezometers, the overnight (approximately 15 hrs.) recovery rate rather than the volume of purged water was used to indicate whether flow between the screen and gravel pack was adequate. In some cases, the flow between the screen and gravel pack of shallow piezometers was determined by measuring the rise and fall of water in the casing during purging.

Recovery was measured by comparing the water level within the piezometer, before purging, with the water level on following days. The volume of water purged minus the volume of water necessary to bring the water level back to its former level equals recovery:

Recovery Rate = [Volume Purged -
(Original Volume - Subsequent Volume)]/Days since purged

Recovery rates varied from a maximum of 417 gallons/day to a minimum of 5 gallons/day (Table 4). A recovery greater than 100 gallons/day was assumed to indicate excellent flow and a recovery between 50 and 100 gallons/day to indicate good flow.

Table 3. Volumes of water purged* from piezometers as a percentage of the water volume in the piezometer and casing at static water level (percent).

Well	Percent purged			
	P1	P2	P3	P4
1	254	148	69	
2	327	251	176	0
3	407	80	443	67
4	253	303	149	
5	99	124	Dry	
6	218	66	406	106
7	497	438	181	
8	278	175	11	
9	213	661	239	
10	611	408	65	

* Volumes of added chlorine solution and slug test water were subtracted before calculation.

Table 4. Maximum piezometer recovery measured over a 24 hr. period during cleaning operations (gallons/day).

Well	P1	P2	P3	P4
1	128	156	6	
2	182	76	62	R
3	238	16	231	60
4	138	61	R	
5	61	78	Dry	
6	72	9	54	R
7	301	145	R	
8	290	49	5	
9	155	159	62	
10	417	66	12	

R = Full recovery to static water level within 24 hours.

Piezometer screens capable of transmitting a minimum of 50 gallons of water per day have adequate capacity for monitoring static water level and for occasional water quality sampling. Fifty gallons is equal to a change in static water level of 300 ft. in the two-inch piezometers.

Seven of the ten shallow piezometers and 21 of the 23 deeper piezometers had good overnight recovery. Four of the shallow piezometers recovered to static water levels, as did 21 of the 23 deeper piezometers.

Only five of the 33 piezometers had recovery rates less than 50 gallons/day:

shallow piezometers	#1-P3,
	#8-P3,
	#10-P3,
deep piezometers	#3-P2,
	#6-P2.

The two deep piezometers, as previously mentioned, also had low purge volumes.

One shallow piezometer, #5-P3, was dry at the time of cleaning. However, the screen was determined to be clean by adding 15 gallons of water (about 90 ft. of head) to the piezometer. Within 15 minutes, the water level dropped by 84 feet indicating all but about one gallon of water had passed through the screen into the gravel pack and formation.

B. QUESTIONABLE PIEZOMETERS

Slow recovery and a low volume of purged water do not automatically indicate a plugged screen. Several of the piezometers were placed in formations of low hydraulic conductivity. The questionable piezometers from which only small volumes of water could be purged were cross checked against the drillers log to determine if the formation rather than a plugged screen was responsible for slow recovery (Table 5).

1. Deep Piezometers

Four deep piezometers had low purge volumes and/or slow recovery of the water level:

#3-P2,
#5-P1,
#5-P2, and
#6-P2

Piezometer #3-P2: This piezometer, according to the drillers log, is set in a gray silty, clay, sand formation. This formation has a potentially low conductivity. To test the screen, 90 gallons (540 ft.) of water were added to the nearly dry piezometer. The new dynamic water level in the piezometer dropped 90 ft. in 15 minutes as about 15 gallons of the

Table 5. Geologic information from drillers well logs.

Well	Piezometer	Formation
1	1	Gray silty clay, some gravel.
	2	Medium coarse
	3	Dry, compact gravel.
2	1	Gray silt with sand lenses, wood.
	2	Gray silty gravel.
	3	Gray silty clay, fine sand.
	4	Gray clean medium sand.
3	1	Gravel and silt.
	2	Gray silty, clay, sand with water.
	3	Gravel with trace of silt, sand.
	4	Medium to coarse gravel,sand,water.
4	1	Sandy gravel, water.
	2	Sandy clay, shells.
	3	Sandy clay.
5	1	Dark gray, silty clay.
	2	Gray, silty sand.
	3	Fine, gray, silty sand.
6	1	Gray clay.
	2	Gray clay.
	3	Gray sand, hard lens, wood.
	4	Medium sand.
7	1	Medium to fine gravel, sand, water.
	2	Gray siltstone, fractured sandstone.
	3	Blue, silty gravel.
8	1	Gray clay, sand lenses.
	2	Coarse gray gravel, sand.
	3	Coarse gray sand.
9	1	Sand and fine gravel, water.
	2	Gravel, 1-1/4", water.
	3	Sand, water.
10	1	Sand, gravel, boulders.
	2	Sand and silt, water.
	3	Clay

water moved out into the reduced pressure of the gravel pack. The remaining 75 gallons was purged, and in the first 19 days after cleaning, the piezometer recovered 275 ft. A slow recovery, but equivalent to about 45 gallons of water passing through the screen. We believe the slow rate of water movement into the piezometer is a result of low formation conductivity and not a plugged screen.

Piezometer #5-P1: This piezometer is set in a dark gray, silty clay. Although about 6 ft. of clay was measured in the bottom of the piezometer prior to cleaning, the volume of water purged during cleaning indicates the screen is not plugged even though recovery was slow. Almost 100 gallons/day of water passed through the screen during several days of purging. Although there is an unknown quantity of clay in the gravel pack, we believe the major impediment to water movement is the formation itself and not the piezometer.

Piezometer #5-P2: The drillers log indicates this piezometer is located in a gray, silty sand formation. This should transmit a reasonable volume of water. We believe the low purge volume is an artifact of the large volume of water in the casing when compared to the volume in the piezometer. The piezometer holds about 29 gallons while the casing holds an additional 147 gallons. We probably did not spend adequate time purging water from this piezometer. However, because one entire casing volume was drawn through the screen, and the 24 hr. recovery was about 78 gallons (Table 4), we believe the screen is clean.

Piezometer #6-P2: This piezometer was also set in a gray clay. After purging the majority of water in the piezometer, and getting little recovery overnight, 75 gallons of water were added to the piezometer. However, unlike piezometer #3-2, the water level did not drop rapidly. Water did not move into or out of the piezometer. Although not substantiated, we believe the clay formation is responsible for the slow recovery and not the screen. However, a measurement four months after cleaning found the water level still below its original level.

We concluded that, with the possible exception of #6-P2, the slow recovery of these piezometers was related to the low conductivity of their respective formations. Additional cleaning or purging of water would not result in significant improvement.

2. Shallow Piezometers

Three shallow piezometers had low purge volumes and/or slow recovery of the water level:

#1-P3,
#8-P3, and
#10-P3

Piezometer #10-P3: This piezometer is located in a clay formation. Because it is one of the few shallow piezometers with a top casing seal, measuring changes in the casing water level to check flow between the piezometer and gravel pack was not possible. However, the static water level has recovered since cleaning and is presently about three feet higher than before. This indicates improvement in the piezometers flow connection with the formation and an adequately clean screen.

The remaining two piezometers, #1-P3 and #8-P3, are believed to be non-functional. Either the screen or the casing perforations are plugged.

Piezometer #1-P3: Although this piezometer is set in a silty clay formation, unusual fluctuations in the casing water level indicated problems other than a "tight" formation. Because there was no casing seal above the piezometer screen, we were able to fill the casing with water and monitor the rise of water level in the piezometer. Water in the piezometer rose 100 feet in one hour, and reached within 0.5 ft. of the casing water level overnight. An excellent flow connection exists between the piezometer and gravel pack. However, the water level, now greater than static, dropped only slowly in the piezometer and casing. It dropped only three feet in the following 20 days, remaining about 120 feet above the original static water level. Either the formation has an extremely low hydraulic conductivity, or the casing perforations were cut at a lower elevation than recorded, and subsequently plugged during placement of the lower cement seal. We believe the latter case to be true.

Piezometer #8-P3: This piezometer reacted to purging differently than #1-P3. The water level in the casing fell only slightly after removal of all water in the piezometer. Only a limited flow connection exists between the piezometer screen and gravel pack. Because depth measurements indicated the piezometer itself was free of any blockage, we checked the casing for obstruction by lowering the surging-tool down alongside the piezometers. According to the piezometer construction notes, an upper cement seal was not installed and only loose pea gravel surrounds the piezometer screen. The tool dropped without resistance until about 9 ft. above the top of the screen. The tool was driven another 3 ft. before it was stopped by a major obstruction. Additional beating or driving with the tool failed to penetrate the barrier. Either cement was mixed with the gravel, or a top seal was incorrectly installed and not recorded. A normal 10-ft. cement seal located at the obstruction would completely plug the screen as well as the casing perforations.

C. MISCELLANEOUS FINDINGS

The cleaning changed the depth of four piezometers:

Well #5 -	P1	deeper by 6.0 ft.
Well #7 -	P1	shallower by 0.5 ft.
Well #9 -	P1	shallower by 0.1 ft.
	P2	deeper by 0.2 ft.

Only P1 at well #5 was significantly changed by cleaning. A large quantity of clay, brought up with the purged water, was cleaned from this piezometer.

In addition, piezometers at well #8 had anomalous changes in water level. The water level in #8-P1 fell as #8-P2 was purged. In one instance, it dropped 2 feet in 35 minutes. A leak apparently exists between P1 and P2, probably within the P2 gravel pack. Since the static water level of P1 is greater than that of P2, the leak is from P1 to P2. If the leak exists, P1 will not reach a true static water level since it continues to bleed off to P2. However, P2 may reach a true static water level if its formation conductivity and thus outflow into the formation is greater than the leakage in.

D. WATER QUALITY

Chemical analyses of the water were done only to indicate when purging was complete. No attempt was made to determine water quality for drinking or other purposes. The chemical values usually stabilized when slightly less than one casing plus one piezometer volume of water was removed. Mixing and dilution of water in the piezometer by incoming water from the formation was probably responsible for this early stabilization. Approximate chemical values, collected as cleaning of each piezometer was completed, are presented in Table 6. Specific conductance was the most useful parameter for indicating when sufficient water had been purged.

Table 6. Results of chemical analyses.

Well	Piezo.	pH	Cond. (umhos/cm)	Cl- (mg/l)	Hardness (as CaCO3)
1	1	11.5	1050	120	
	2	7.2	300	20	
	3	9.8	100	30	
2	1	8.0	9000	>1500	
	2	7.5	6000	>1200	
	3	9.0	4000	>1200	
	4	9.7	2500	750	
3	1	7.2	750	150	
	2	10.5	3000		
	3	10.8	1200	170	
	4	10.7	3000	>1000	
4	1	9.0	500	130	
	2	9.0	4000	>1000	
	3	8.5	400	200	
5	1	11.5	7000	>1200	
	2	9.5	1000	250	
	3	Dry			
6	1	7.7	12000	>1200	
	2				
	3	8.0	2000	850	
	4	9.7	180	75	
7	1	7.5	600	30	400
	2	7.7	175	30	140
	3	8.0	250	220	230
8	1	7.5	450	400	150
	2	9.5	160	60	130
	3				
9	1	11.2	650	160	
	2	10.5	3000	180	
	3	8.4	600	250	
10	1	8.2	550	100	
	2	11.5	1000	95	
	3	11.0	5000	400	

V. SUMMARY

I believe that all piezometers were adequately cleaned during this project. However, two piezometers, #1-P3 and #8-P3 are non-functional due to blockage of the screen or casing perforations. The blocking is probably a result of incorrect construction. Another piezometer, #6-P2 may also be blocked. A leak was found in piezometer #8-P2 between P1 and P2. The magnitude of the leak is unknown. The remaining 29 piezometers are functional for water level monitoring and occasional water quality testing.

One problem exists in using these wells for monitoring water quality. A common practice is to purge a water volume equal to 3 to 5 times the volume in the piezometer and casing before removing a sample for chemical analyses. As a minimum, at least one piezometer plus casing volume of water should be purged. This practice will be time consuming for many of these piezometers.

A comparison of the total water volume of each piezometer (Table 2) with their recovery rate (Table 4) indicates which piezometers will be difficult to purge. For instance, piezometer #7-1 contains 110 gallons of water at static water level, and recovers at a rate of 301 gallons/day. Thus it could be easily purged and sampled in a day. However, piezometer #6-1 contains 203 gallons but recovers at only 72 gallons/day. It would take three days to purge once. Table 7 presents similar calculations for the remaining piezometers.

The lowest estimated time for a single piezometer purge is about 0.3 days (piezometer #10-1), the highest estimate (piezometer #6-2) is nearly 20 days. About one-half of the piezometers require more than one day to produce a single purge volume of water. Remember, this is not controlled by how fast the water is pumped out, but by how rapidly the geologic formation will replace the water (recovery).

Purging and sampling one well at a time will be inefficient. Most of the time will be spent waiting for the piezometers to recover. An efficient sampling scheme will require selecting a well, pumping the available water, moving on to another well, pumping it, and then returning to the original well to pump more. The pumping would be rotated among several wells until adequate water volumes were purged. Water quality sampling would occur only after several wells had been purged.

Table 7. Number of days required to purge a volume of water equal to that contained in the piezometers and casing at static water level (based on Tables 2 & 3).

Well	P1	P2	P3	P4
1	0.7	0.8	NF	
2	0.6	1.2	1.4	<1
3	0.6	7.3	0.5	3.2
4	0.9	1.2	<1	
5	4.4	2.3	Dry	
6	2.8	19.8	1.5	<1
7	0.4	0.4	<1	
8	0.4	1.2	NF	
9	1.3	0.6	0.9	
10	0.3	1.2	4.5	

NF = non-functional.

Figure 3. Piezometer cleaning tool.

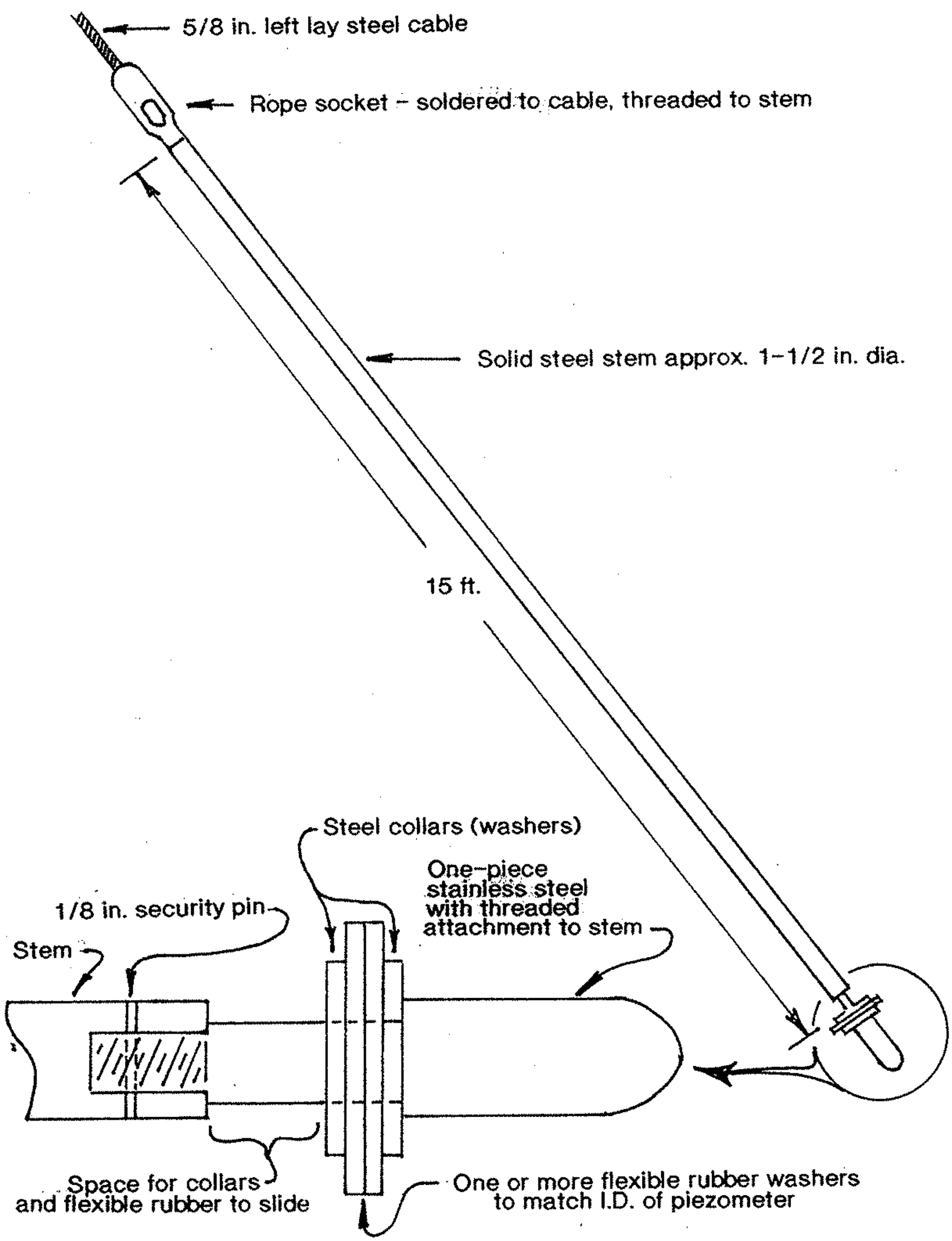
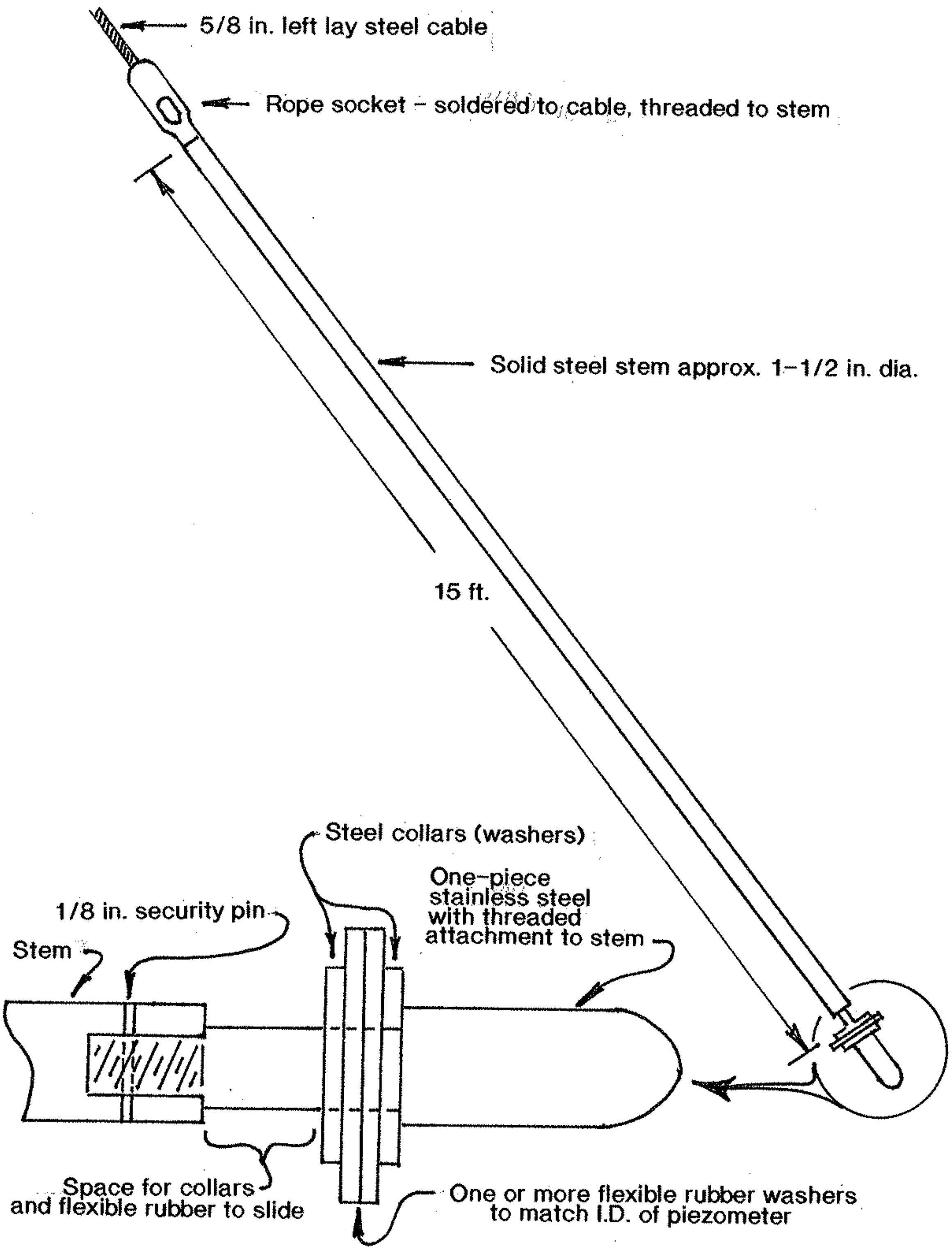


Figure 3. Piezometer cleaning tool.



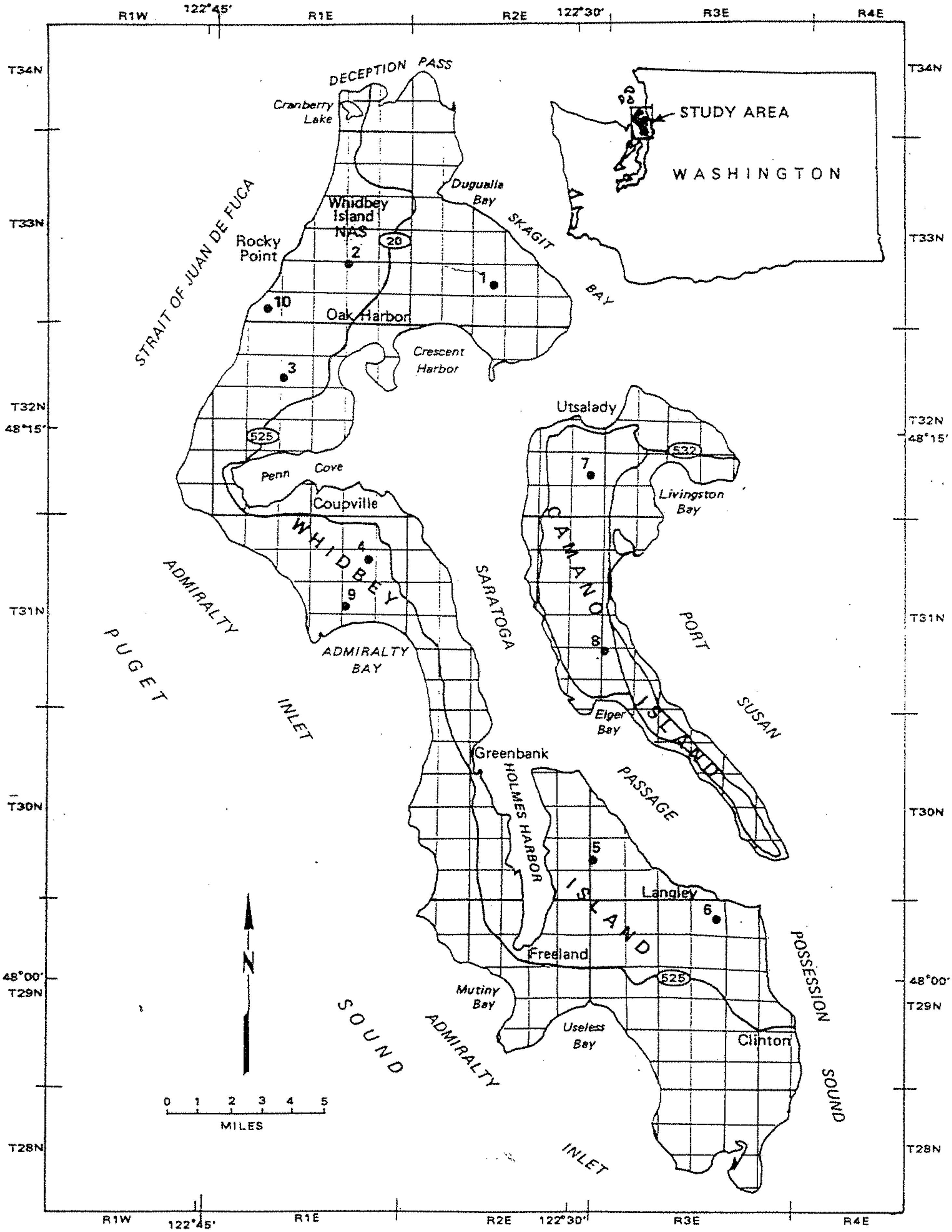


Figure 1. TEST/OBSERVATION WELLS, ISLAND COUNTY, WASHINGTON.