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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Federal Center, Lakewood, Colorado 80225

WATER INFLOW INTO HOLE UA-1,
AMCHITKA ISLAND, ALASKA

(Amchitka-34)

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ABSTRACT

Chemical composition of water samples, temperature of inflow water, and theoretical calculations were compared to evaluate the water-contributing intervals to the zone to be mined--1,782.8 to 1,798.6 meters (5,849 to 5,901 feet)--in hole UA-1, Amchitka Island, Alaska.

Chemical composition and temperature of inflow water indicated the contributing zones to have a mean depth of 1,670 meters (5,478 feet) and 1,726.7 meters (5,665 feet), respectively. An unrestricted inflow rate based on this data was calculated to be 380 cubic meters per day (70 gallons per minute) which compared well with the measured restricted-inflow rate of 164 cubic meters per day (30 gallons per minute) for hole UA-1 at the end of November 1970.

INTRODUCTION

Hole UA-1 was constructed by the U.S. Atomic Energy Commission (AEC) for the purpose of testing an underground nuclear device. The U.S. Geological Survey evaluated the geology and hydrology of the site under agreement with the AEC.

At a conference at the Nevada Operations Office in Las Vegas, Nevada, in November 1968, W. C. Ballance and W. W. Dudley presented their predictions on water inflow to a chamber 18.3 m (60 ft) high and 9.14 m (30 ft) in diameter to representatives of the U.S. Atomic Energy Commission, Lawrence Livermore Laboratory (LLL), and Fenix and Scisson (F&S). In their predictions, they assumed the center of the

chamber to be at 1,790.7 m (5,875 ft) below land surface. For the chamber configuration, they predicted an inflow to the chamber of 43.6 m³ per day (cubic meters per day) or 8 gpm (gallons per minute). In their calculations of water inflow to the chamber, the time-dependent discharge to a large-diameter well at constant drawdown was determined. Hantush (1959) derived equations that can be used for computing inflow to underground chambers using hydraulic-test data from deep wells and Walton (1962) prepared a set of type curves that are at a convenient scale for aquifer analysis. These equations and type curves can be used if certain physical assumptions are made concerning the construction procedure and the hydraulic characteristics of the rocks. These assumptions are: 1) that partial penetration in the center of a rock unit can be treated as a leaky-aquifer problem with vertical leakage from above and below; 2) that chamber excavation is sufficiently rapid to simulate instant drawdown; and 3) that construction includes a sealed sump that stores all inflow to the chamber or the inflow is removed by pumping, thus maintaining constant drawdown at the chamber.

The interval between 1,782.8 and 1,798.6 m (5,849 and 5,901 ft) was selected for mining a chamber for the nuclear explosive because of favorable rock features, including low permeability. A 228.6-cm (centimeter) or 90-in. (inch) hole was drilled to 1,873.0 m (6,145 ft) and cased with 137.2-cm (54-in.) pipe to 1,860.5 m (6,104 ft); the casing was then cemented from bottom to land surface in two stages.

Preparations were then made to remove the casing in the interval to be mined so that a chamber 15.8 m (52 ft) in diameter could be

excavated in the rock. A grout port in hole UA-1 was opened at a depth of 1,801.4 m (5,910 ft) below land surface by a miner. A hole was drilled through the cement surrounding the casing. A mixture of unhardened cement, drilling mud, and water flowed through the grout port into the interior of the casing at a reported rate of about 380 m³ per day (70 gpm).

One million gallons of fluid flowed into hole UA-1 through the grout port. The water was pumped out using two submersible pumps, water samples were collected for chemical analysis, and the water temperature at the grout port was measured. The water temperature at the grout port stabilized at 41.0°C (106°F). The static water level for the interval supplying the water was determined to be 43.0 m (141.1 ft) below land surface based on pressure-gage readings at the grout port. A grouting program to reduce water inflow was begun in July 1970. Tubing was lowered into the hole and attached to the grout port. About 68 m³ (cubic meters) or 2,400 ft³ (cubic feet) of cement slurry was forced through the grout port opening and behind the pipe. A radioactive tracer (molybdenum-99) was placed in the cement to determine the extent of cement movement. A tracer log detected tracer movement behind the pipe in the interval 1,819.4 m (5,969 ft) to 1,731.3 m (5,680 ft).

Time was allowed for the cement grout to harden and the grout port was again opened. Water flowed into hole UA-1 at a rate of about 65 m³ per day (12 gpm). The grout port was again connected with the grout tubing and an additional 28 m³ (1,000 ft³) of cement was forced through the grout port and behind the pipe. The tracer log reportedly indicated

that this cement penetrated downward to a depth of 1,822.4 m (5,979 ft), 3.0 m (10 ft) below the first grout penetration, and penetrated upward to 1,775.8 m (5,826 ft), 44.5 m (146 ft) short of the first grout penetration. Time was allowed for the cement grout to harden and the grout port was reopened. Grouting to reduce flow was done in five stages between June and September, 1970. On completion of these remedial actions, the inflow was less than 8.2 m³ per day (1.5 gpm).

Considerable mining had been accomplished by October 31, 1970, in the hole between 1,784.9 m (5,886 ft), and 1,806.9 m (5,928 ft). This interval was to have a 15.8-m (52-ft) cavity with a drift connecting the cavity to a dewatering hole at the lower limit of the cavity. Water inflow into the cavity and drift was reported to be about 8.2 m³ per day (1.5 gpm). Vertical/rock-bolt holes were then drilled about 1.8 m (6 ft) from the casing at the 1,785.2-m (5,857-ft) level. These holes were reported to be about 3.8 cm (1.5 in.) in diameter and 6.1 m (20 ft) in depth. Water flowed from one of these holes at a reported rate of about 22 m³ per day (4.0 gpm), and after a nearby blast for excavation, the inflow from the rock-bolt hole increased to about 60 m³ per day (11 gpm). Water samples were collected and analyzed for their chemical constituents. Inflow continued to increase as construction continued until the rate was approximately 164 m³ per day (30 gpm) by the end of November 1970.

This report provides documentation of the application of the hydro-geochemical techniques in attempting to assess the location of the zones that probably were contributing water to hole UA-1 during the construction phases of the chamber.

METHODS OF ANALYSIS

Three methods have been used to determine the probable source of water inflow to hole UA-1 since the grout port at a depth of 1,801.4 m (5,910 ft) was opened and the cement envelope was penetrated by drilling. These methods include: (1) analysis of chemical relationships of water from various depths in hole UAe-1, an exploratory hole 91.4 m (300 ft) southwest of hole UA-1, and from other sources on Amchitka Island; (2) comparison of the temperature of water flowing into hole UA-1 with the temperature gradient in hole UAe-1; and (3) computation of possible inflow based on the assumption that the cement in the interval from 1,706.9 to 1,828.8 m (5,600 to 6,000 ft) was not adequately bonded to the rock.

Chemical Analyses

Samples of water pumped from hole UA-1 between June 13-23, 1970, were analyzed. The first samples collected from hole UA-1 during this period were, by visual inspection, a mixture of water, drilling mud, and cement slurry. After several hundred thousand gallons of water were removed, the water still contained some cement and drilling mud. Additional samples collected from October 22 to November 24, 1970, after grouting, were also analyzed.

Table 1 is a summary of the chemical analyses of water samples from hole UA-1. The volume of water discharged prior to the time of collection for some water samples is given, although only approximate values are known by the authors. After about 1 million gallons were removed from the hole, the water was less contaminated with drilling mud and cement; analysis of water samples obtained during the latter part of the water-removal period showed the samples to compare more realistically with the analyses of samples obtained in test hole UAe-1.

The chemical characteristics expected of interstitial water in ancient submarine rocks, interstitial water in recent marine rocks, and present-day ocean water are not the same; however, certain similarities exist, particularly in shallow zones of recent marine rocks that have been subjected only to fresh-water circulation rather than to extreme hydrothermal alteration. Water analyses of ocean samples collected near Amchitka Island and some analyses from the geochemical literature are tabulated in table 2. Mean values from table 2 for these samples are sodium, 9,670 mg/l (milligrams per liter); magnesium, 1,180 mg/l; calcium, 370 mg/l; potassium, 340 mg/l; chloride, 17,400 mg/l; sulfate, 2,200 mg/l; and carbonate equivalent, 70 mg/l. These values show the chemical character to follow the series $\text{Na} > \text{Mg} > \text{Ca} > \text{K}$ and $\text{Cl} > \text{SO}_4 > \text{CO}_3$.

Table 1.--Chemical analyses of water samples collected from hole UA-1, Amchitka Island, Alaska

(Chemical analyses in milligrams per liter; <, less than)

Date	Time	Discharge (cumulative gallons)	Mag- ne- sium (Mg)	Cal- cium (Ca)	Sodium (Na)	Potas- sium (K)	Car- bonate (CO ₃)	Bicar- bonate (HCO ₃)	Chlo- ride (Cl)	Sul- fate (SO ₄)	Specific conduct- ance (micro- mhos/cm at 25°C)	pH
6-13-70	0900	200,000	<0.1	32	1,170	196	--	--	1,020	--	--	12.0
6-14-70	0800	250,000	<.1	190	1,030	61	--	--	1,540	--	6,220	11.5
6-14-70	1040	253,000	<.1	203	1,000	56	--	--	1,540	--	6,360	11.6
6-14-70	1430	265,000	<.1	211	1,060	48	--	--	1,650	--	6,490	11.5
6-14-70	1810	273,000	<.1	211	1,060	48	--	--	1,670	--	6,430	11.5
6-14-70	2140	280,000	<.1	205	1,060	47	--	--	1,650	--	6,450	11.5
6-15-70	0115	288,000	<.1	205	1,060	44	--	--	1,670	--	6,480	11.5
6-15-70	0445	302,000	<.1	217	1,060	43	--	--	1,690	--	6,440	11.5
6-15-70	1500	346,000	<.1	213	1,060	41	--	--	1,700	--	6,420	11.4
6-15-70	1900	368,000	<.1	218	1,090	40	--	--	1,720	--	6,380	11.4
6-15-70	2300	386,000	<.1	213	1,110	38	--	--	1,700	--	6,380	11.4
6-16-70	0100	395,000	<.1	222	1,080	34	--	--	1,760	--	6,440	11.4
6-16-70	0240	396,000	<.1	220	1,030	37	--	--	1,700	--	6,410	11.4
6-16-70	1040	439,000	<.1	218	1,080	33	--	--	1,740	--	6,450	11.4
6-16-70	1345	450,000	<.1	218	1,100	34	--	--	1,740	--	6,430	11.4
6-16-70	2130	480,000	.1	224	1,100	32	--	--	1,740	--	6,500	11.4
6-17-70	1040	505,000	.1	226	1,150	32	--	--	1,750	--	6,480	11.4
6-17-70	1430	510,000	<.1	226	1,130	31	--	--	1,760	--	6,490	11.4
6-17-70	1844	518,000	.1	226	1,100	30	--	--	1,770	--	6,440	11.4
6-18-70	0040	528,000	.2	248	1,130	30	--	--	1,770	--	6,490	11.4

Table 1.--Chemical analyses of water samples collected from hole UA-1, Amchitka Island, Alaska--Continued

(Chemical analyses in milligrams per liter; <, less than)

Date	Time	Discharge (cumulative gallons)	Mag- ne- sium (Mg)	Cal- cium (Ca)	Sodium (Na)	Potas- sium (K)	Car- bonate (CO ₃)	Bicar- bonate (HCO ₃)	Chlo- ride (Cl)	Sul- fate (SO ₄)	Specific conduct- ance (micro- mhos/cm at 25°C)	pH
6-18-70	0450	534,000	0.1	238	1,130	31	--	--	1,790	--	6,490	11.4
6-18-70	0900	542,000	.1	226	1,100	31	--	--	1,790	--	6,420	11.4
6-21-70	1315	680,000	<.1	220	1,100	47	32	0	1,700	280	6,400	11.3
6-22-70	1400	755,000	<.1	180	1,200	110	73	0	1,700	300	6,800	11.5
6-23-70	2050	862,000	.1	220	1,100	31	54	0	1,800	300	5,500	11.0
10-22-70	1830	1,334,312	.2	230	1,100	--	0	0	1,960	--	6,900	10.3
10-28-70	1945	1,347,116	.2	220	1,100	11	0	0	1,850	--	6,080	9.7
10-30-70	1130	1,368,586	.1	227	1,100	12	--	--	1,850	--	6,090	10.2
∞ 10-31-70	0830	1,386,248	.19	225	1,060	11	--	--	1,790	--	5,990	9.6
10-31-70	1900	1,391,351	.19	260	1,120	28	--	--	1,790	--	6,870	11.6
11-1-70	0230	1,392,100	.38	230	1,080	12	--	--	1,810	--	6,040	10.1
11-1-70	0840	1,395,850	.30	225	1,100	11	--	--	1,800	--	6,050	9.6
11-1-70	1400	1,398,600	.04	265	1,150	25	--	--	1,850	--	6,960	11.4
11-1-70	1900	1,402,374	.07	230	1,070	10	--	--	1,850	--	6,840	9.6
11-2-70	0230	1,406,400	.37	245	1,070	90	--	--	1,750	--	7,990	11.8
11-2-70	0450	1,410,400	.25	225	1,070	11	--	--	1,850	--	6,060	9.3
<u>1/</u> 11-2-70	1115	1,414,400	.07	225	1,040	10	--	--	1,850	--	6,090	9.4
11-2-70	1900	1,418,362	.08	225	1,040	10	--	--	1,850	--	6,080	9.8
11-3-70	0640	1,424,380	.08	230	1,150	11	--	--	1,850	--	6,080	9.4

Table 1.--Chemical analyses of water samples collected from hole UA-1, Amchitka Island, Alaska--Continued

(Chemical analyses in milligrams per liter; <, less than)

Date	Time	Discharge (cumulative gallons)	Magnesium (Mg)	Calcium (Ca)	Sodium (Na)	Potassium (K)	Carbonate (CO ₃)	Bicarbonate (HCO ₃)	Chloride (Cl)	Sulfate (SO ₄)	Specific conductance (micro- mhos/cm at 25°C)	pH
11-06-70	0045	1,485,038	0.1	222	1,180	11	--	--	1,820	--	6,130	7.6
11-17-70	1800	1,718,953	.1	230	1,100	11	--	--	1,820	--	6,200	9.0
11-19-70	1230	1,761,437	.3	250	1,000	8.1	11	0	1,700	370	6,000	8.9
11-19-70	1430	1,763,257	.1	220	1,100	8.2	23	0	1,900	280	5,900	9.0
11-24-70	1830	1,888,696	.1	230	1,060	11	--	--	1,840	--	6,270	8.9

^{1/} Sample had a deep yellow color.

Table 2.--Chemical analyses of selected water samples from oceans, streams, lakes, and springs from Amchitka Island, Alaska and geochemical literature

(Chemical analyses in milligrams per liter; <, less than)

Name	Date	Mag- ne- sium (Mg)	Cal- cium (Ca)	Sodium (Na)	Potas- sium- (K)	Car- bonate (CO ₃)	Bicar- bonate (HCO ₃)	Chlo- ride (Cl)	Sul- fate (SO ₄)	Specific conduct- ance (micro- mhos/cm at 25° C)	pH
Chukchi Sea	08-24-59	1,180	349	9,400	313	0	133	16,600	2,910	45,000	7.9
Do.	09-02-59	936	306	7,660	295	0	120	13,700	1,950	39,600	7.9
Bering Sea	10-28-65	1,170	375	9,380	361	0	137	18,000	1,990	49,900	7.9
Do.	02-22-68	1,210	393	10,000	--	0	153	18,200	1,500	47,400	7.2
Sea water ^{1/}	--	1,300	400	11,000	350	--	--	19,000	--	--	--
Do. ^{2/}	--	1,270	400	10,600	380	0	140	19,000	2,650	--	--
MEAN FOR OCEAN SAMPLES		1,180	370	9,670	340	0	137	17,400	2,200	45,500	^{3/} 7.9
White Alice Creek	08-25-67	0.6	19	33	1.4	0	68	43	8.0	256	7.8
Bridge Creek	09-26-67	4.0	19	33	1.2	0	60	49	16	267	7.3
Stream 00-46	09-27-67	3.6	13	40	1.7	0	84	39	10	245	7.7
Bridge Creek	12-10-67	4.3	5.8	28	1.6	0	26	46	10	216	6.8
Do.	02-20-68	5.1	6.6	36	2.6	0	45	50	7.0	260	7.4
Limpet Creek	02-20-68	3.8	4.0	27	1.5	0	22	41	6.5	198	7.2
Bridge Creek	02-23-68	6.7	6.6	54	3.2	0	85	58	11	357	7.3
Clevenger Creek	04-20-68	4.6	8.0	46	2.0	0	76	51	11	305	6.7
Stream 08-40	07-20-68	4.1	4.4	24	2.6	0	30	39	7.4	198	6.8
Andesite Creek	10-09-68	3.8	4.2	23	2.4	0	22	37	6.1	178	7.1

Table 2.--Chemical analyses of selected water samples from oceans, streams, lakes, and springs from Amchitka Island, Alaska and geochemical literature--Continued

(Chemical analyses in milligrams per liter; <, less than)

Name	Date	Magnesium (Mg)	Calcium (Ca)	Sodium (Na)	Potassium (K)	Carbonate (CO ₃)	Bicarbonate (HCO ₃)	Chloride (Cl)	Sulfate (SO ₄)	Specific conductance (micro-mhos/cm at 25°C)	pH
Mud Flow Creek	10-09-68	3.0	11	26	1.8	0	42	35	9.1	204	7.2
Stream 97-63	10-10-68	4.2	3.2	40	2.8	0	55	40	10	242	7.4
Stream 23-14	10-11-68	3.6	4.8	20	2.4	0	23	34	5.2	167	6.8
Stream 03-46	11-21-68	4.3	7.7	30	1.1	0	42	40	7.4	220	7.1
MEAN FOR STREAMS		4.0	8.4	33	2.0	0	49	43	8.9	237	^a /7.2
Lake 09-40	10-19-64	2.0	1.4	18	0.7	0	7	27	5.9	111	6.3
Lake 03-45	10-20-64	2.8	3.1	21	.7	0	15	31	5.9	140	6.9
Lake 00-52	10-19-65	4.0	3.7	32	1.7	0	45	40	5.0	219	7.0
Lake 11-36	02-22-68	3.8	7.6	35	2.3	0	35	44	23	574	7.2
Clevenger Lake	10-10-68	4.4	5.4	51	3.7	0	85	41	9.1	293	7.6
Jones Lake	10-10-68	2.4	2.6	73	3.0	0	119	52	8.3	372	7.4
Lake 18-26	10-11-68	1.8	1.2	13	.8	0	5	23	4.6	102	6.3
Pumphouse Lake Outlet	10-12-68	1.4	.8	63	3.6	0	84	41	13	309	7.6
Pumphouse Lake Inlet	10-12-68	1.0	.5	67	3.8	0	92	41	12	313	7.2
MEAN FOR LAKES		2.6	2.9	41	2.3	0	54	38	9.6	270	^a /7.2

Table 2.--Chemical analyses of selected water samples from oceans, streams, lakes, and springs from Amchitka Island, Alaska and geochemical literature--Continued

(Chemical analyses in milligrams per liter; <, less than)

Name	Date	Magnesium (Mg)	Calcium (Ca)	Sodium (Na)	Potassium (K)	Carbonate (CO ₃)	Bicarbonate (HCO ₃)	Chloride (Cl)	Sulfate (SO ₄)	Specific conductance (micro-mhos/cm at 25°C)	pH
Constantine Spring	10-21-64	2.9	2.4	56	5.2	0	93	40	9.8	297	7.7
Do.	02-21-68	3.5	2.4	52	5.1	0	93	40	7.0	294	7.8
Spring 08-40	07-20-68	6.9	8.0	30	3.3	0	46	40	16	249	6.8
Topside Spring	10-09-68	2.7	5.6	17	.8	0	19	27	5.2	145	7.0
CP Camp Spring	10-11-68	2.6	3.6	21	1.6	0	13	33	12	167	6.6
MEAN FOR SPRINGS		3.7	4.4	35	3.2	0	53	36	10	230	^a /7.0

¹/From Collins, 1970, p. 6.

²/From Sverdrup, Johnson, and Fleming, 1942, p. 173.

³/Median value.

Inland fresh water, where precipitation is not dominated by salt spray from the ocean, normally has a series of $\text{Ca} > \text{Na} > \text{Mg} > \text{K}$ and $\text{CO}_3 > \text{SO}_4 > \text{Cl}$. Chemical analyses of water from the leached marine rocks of Amchitka Island show a different series of $\text{Na} > \text{Ca} > \text{Mg} > \text{K}$. The mean analyses of cations are summarized below.

Class	Na	K	Mg	Ca
Ocean	9,670	340	1,180	370
Streams	33	2.0	4.0	8.4
Lakes	41	2.3	2.6	2.9
Springs	35	3.2	3.7	4.4

The Amchitka fresh water samples series of $\text{Na} > \text{Ca} > \text{Mg} > \text{K}$ rather than an inland series of $\text{Ca} > \text{Na} > \text{Mg} > \text{K}$ demonstrates the importance of salt spray introduced to the fresh water by wind action. This is also noted in the means of the anion series: ocean, $\text{Cl} > \text{SO}_4 > \text{CO}_3$; fresh water, $\text{Cl} > \text{CO}_3 > \text{SO}_4$; rather than $\text{CO}_3 > \text{SO}_4 > \text{Cl}$ as expected in inland fresh water.

Class	CO_3	Cl	SO_4
Ocean	70	17,400	2,200
Streams	25	43	8.9
Lakes	27	38	9.6
Springs	27	36	10

In analyses of ocean water the ratios of ions such as Na/Cl, Ca/Cl, Mg/Cl, or K/Cl are essentially constant. These ratios calculated from chemical analyses of water samples can change by mineralogic reactions between the rocks and the water. Until these reactions take place, one constituent provides a measure of the others.

Since the marine sediments of Amchitka Island were deposited and the island was formed, fresh water has been precipitated on the land surface and circulated slowly through the rocks. The ocean water in interstices at the time of deposition has been diluted by movement of fresh water downward, and the water has been subjected to possible mineralogic reactions between the rocks and the water. Table 3 is a summary of chemical analyses of water samples from test hole UAe-1. The pH values indicate that all samples were contaminated to some degree by drilling and by cementing of casing. Using the data in tables 2 and 3, figures 1 and 2 were constructed to note extent of change of ratios and summarize relationships between analyzed constituents.

In figure 1, the concentrations of different cations were plotted against the respective chloride concentration and compared to curves given by Collins, 1970. It is apparent that contamination of samples or possible chemical reactions had occurred for some cations as the curves showing the expected composition of a mixture of fresh water and ocean water are not followed. However, both sodium and calcium follow the expected relationship reasonably well.

Table 3.--Chemical analyses of selected water samples collected during hydraulic tests from test hole UAe-1, Amchitka Island, Alaska

(Chemical analyses in milligrams per liter, <, less than)

Zone sampled (meters)	Date	Time	Magnesium (Mg)	Calcium (Ca)	Sodium (Na)	Potassium (K)	Carbonate (CO ₃)	Bicarbonate (HCO ₃)	Chloride (Cl)	Sulfate (SO ₄)	Specific conductance (micro-mhos/cm at 25°C)	pH
^{1/} 487.3- 564.0	9-29-67	1830	0.9	120	420	6.0	3	0	620	110	3,190	11.8
^{1/} 759.2- 786.6	9-28-67	1400	1.2	53	310	5.0	39	0	520	150	2,190	11.0
951.2- 969.5	9-28-67	2130	1.7	68	530	5.0	37	0	690	220	2,560	10.3
^{1/} 1,356.7-1,387.2	9-29-67	0440	4.1	400	1,000	10	3	0	2,010	250	6,530	11.6
1,531.7-2,134.2	9-19-67	1400	<.1	310	940	10	1	0	1,790	280	5,860	11.1
^{1/} 1,643.9-1,655.5	8-13-67	0438	.3	293	1,080	10	48	21	1,850	320	6,340	10.0
1,646.3-1,725.0	8-11-67	2310	1.5	278	1,100	7.9	12	32	1,860	320	6,430	8.7
1,724.4-1,784.8	8-11-67	1200	.2	289	1,200	7.9	15	18	2,060	330	6,710	8.9
1,786.0-1,826.2	8-11-67	1605	1.6	268	1,140	7.9	11	19	2,040	310	6,350	8.7
1,802.4-1,862.2	8-28-67	0428	1.0	170	730	5.0	4	30	1,220	210	4,270	8.6
^{1/} 1,850.6-1,911.0	8-27-67	2106	5.2	280	940	7.0	14	0	1,740	290	5,970	10.3

^{1/}Bypass around packers indicated.

EXPLANATION	
•	U Ae-1
■	Ocean
△	Lake
○	Stream
×	Spring

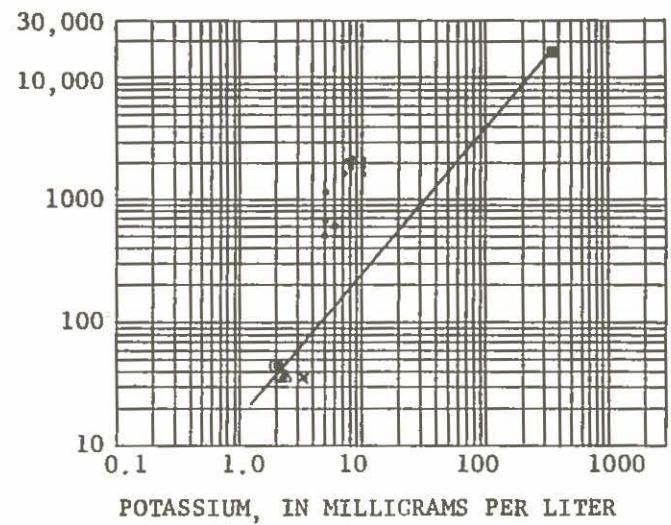
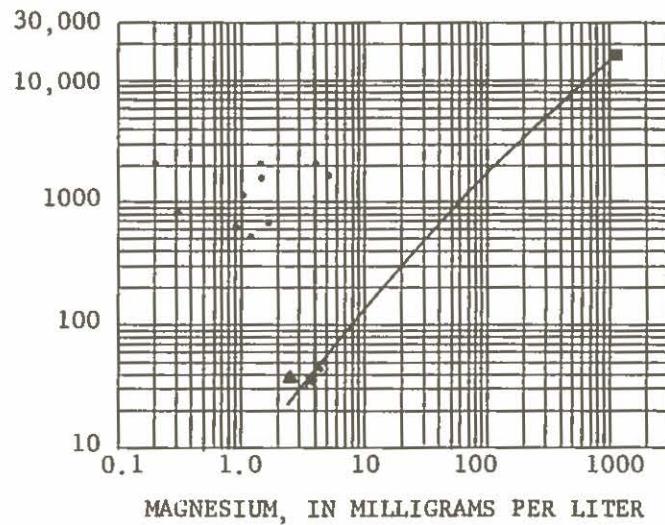
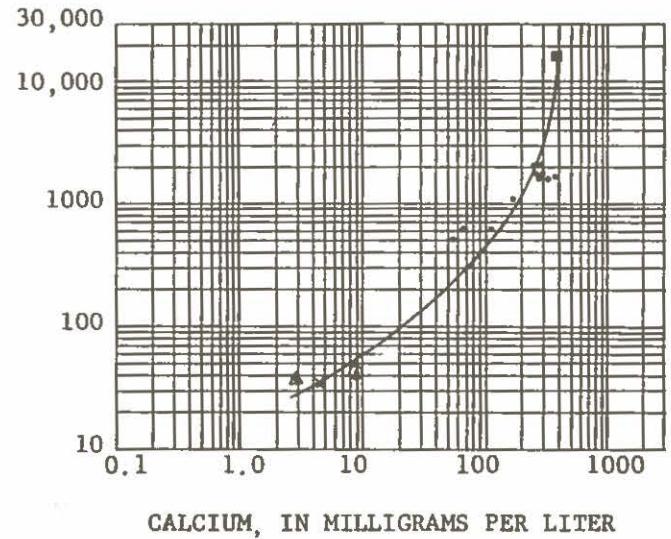
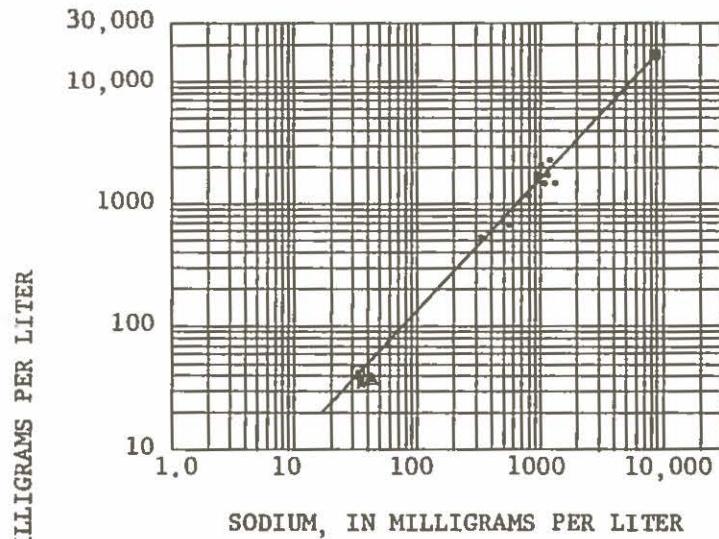


Figure 1.--Concentrations of chloride versus sodium, magnesium, calcium, and potassium for waters of Amchitka Island, Alaska.

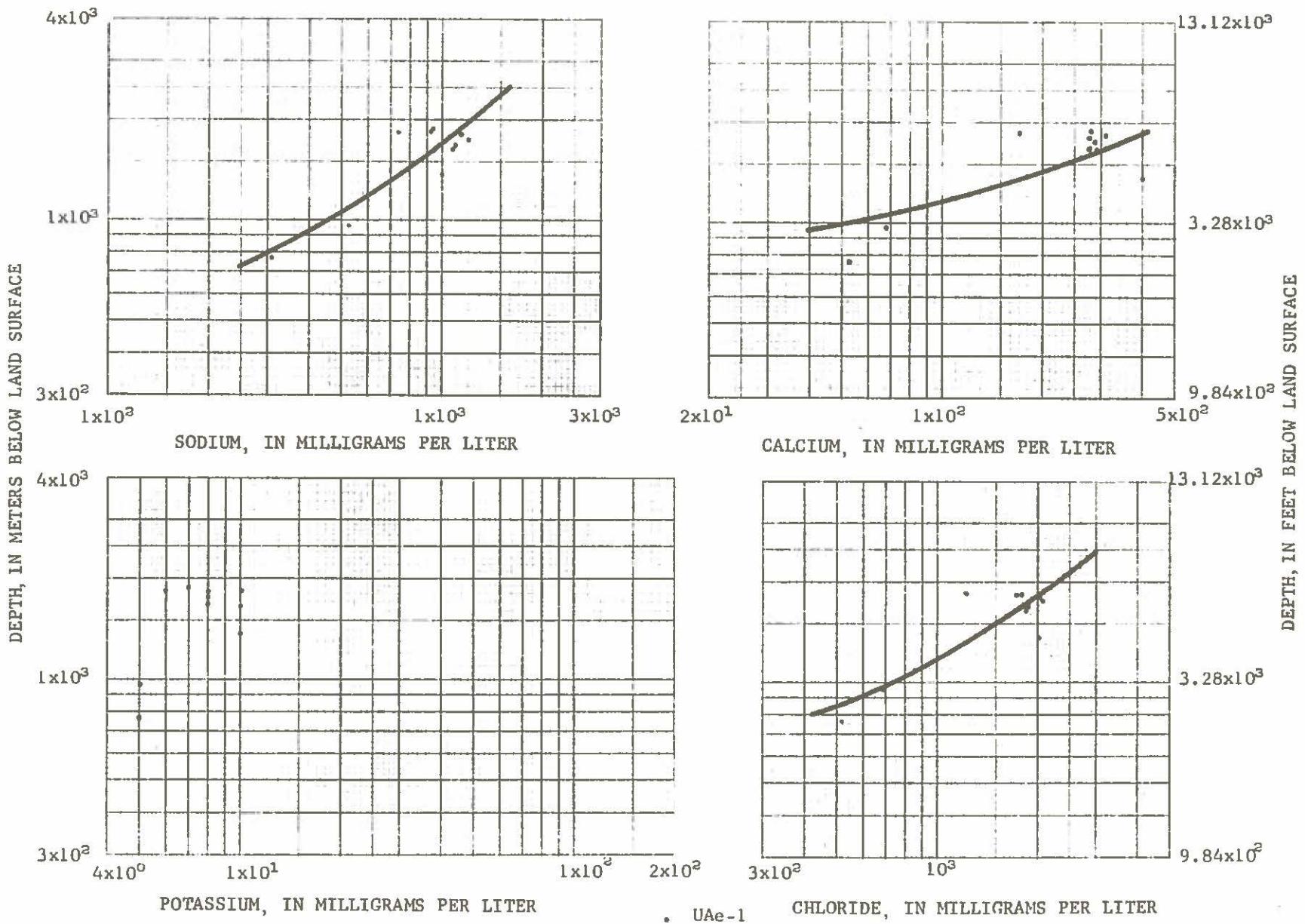


Figure 2.--Concentrations of sodium, calcium, potassium, and chloride versus depth below land surface for water samples from test hole UAe-1.

Figure 2 represents an attempt to correlate the concentrations of sodium, potassium, calcium, and chloride versus depth below land surface datum for water samples from test hole UAe-1. In figure 2, the curves were drawn by using least-square calculations from analyses of water samples (first sample in table 3 excluded).

The comparison of the chemical composition and concentration of constituents of water samples collected from test hole UA-1 with curves on figures 1 and 2 were made. Using the depth versus chloride relationship (fig. 2), the analyses of water samples obtained after several hundred thousand gallons indicate an inflow depth of 1,670 m (5,478 ft). Concentrations of sodium and calcium found in water samples from hole UA-1 for the same period of pumping, although not as reliable as chloride when considering contamination factors, indicate the water-contributing zones are at depths of 1,810 and 1,510 m (5,938 and 4,954 ft). In general, calcium, sodium, and chloride ions followed a definable pattern. Of these, chloride is considered the most reliable since it is least affected by drilling contamination, organic oxidation, or mineralogic reactions. Therefore, chloride was chosen as the best indicator for determining the location of the water-contributing zones.

Water samples collected from test hole UA-1 are not water expected opposite the grout port but are representative of water that would be encountered in a higher zone or a combination of higher zones. Therefore, definite determination of a single contributing zone cannot be made using this technique alone; however, the analyses indicate a water from contributing zones at a mean depth of 1,670 m (5,478 ft).

Temperature Analysis

Test hole UAe-1 was cased with 24.45-cm ($9\frac{5}{8}$ -in.) pipe from land surface to 1,531.3 m (5,024 ft) and the space behind the pipe cemented. In order to test selected zones for hydraulic parameters in the upper cased part of the hole, the pipe was perforated at six locations. The lowermost perforations were in the interval 1,356.4 to 1,386.8 m (4,450 to 4,550 ft). During the testing of the perforated intervals, large amounts of diluted and unhardened cement were pumped from the hole. Ground-water circulation behind the pipe, between areas of perforations, was observed during the hydraulic tests. Drilling and hydraulic testing of hole UAe-1 was completed in October 1967.

The borehole temperatures were measured by geophysical logging techniques in October 1968. Figure 3 shows a profile of ground-water temperatures versus depth below land-surface datum as measured in test hole UAe-1. From about 1,082.0 to 1,767.4 m (about 3,550 to 5,800 ft), a uniform temperature gradient is apparent. The average temperature gradient calculated for this interval is 0.92°C (1.65°F) per 30.5 m (100 ft). In the interval 1,356.4 to 1,524.0 m (4,450 to 5,000 ft), the curve deviates from the mean slope to a nearly vertical curve. This is an indication of downward water flow from rock fractures in the vicinity of the perforations at 1,356.4 m (4,450 ft) to 1,531.3 m (5,024 ft). Presumably the water moves through the perforations near 1,356.4 m (4,450 ft) into the casing and downward inside the casing to just below the bottom of the pipe at 1,531.3 m (5,024 ft) and moves outward into the formation at that point. Previous hydraulic tests on test hole UAe-1 had measured decreasing heads with depth.

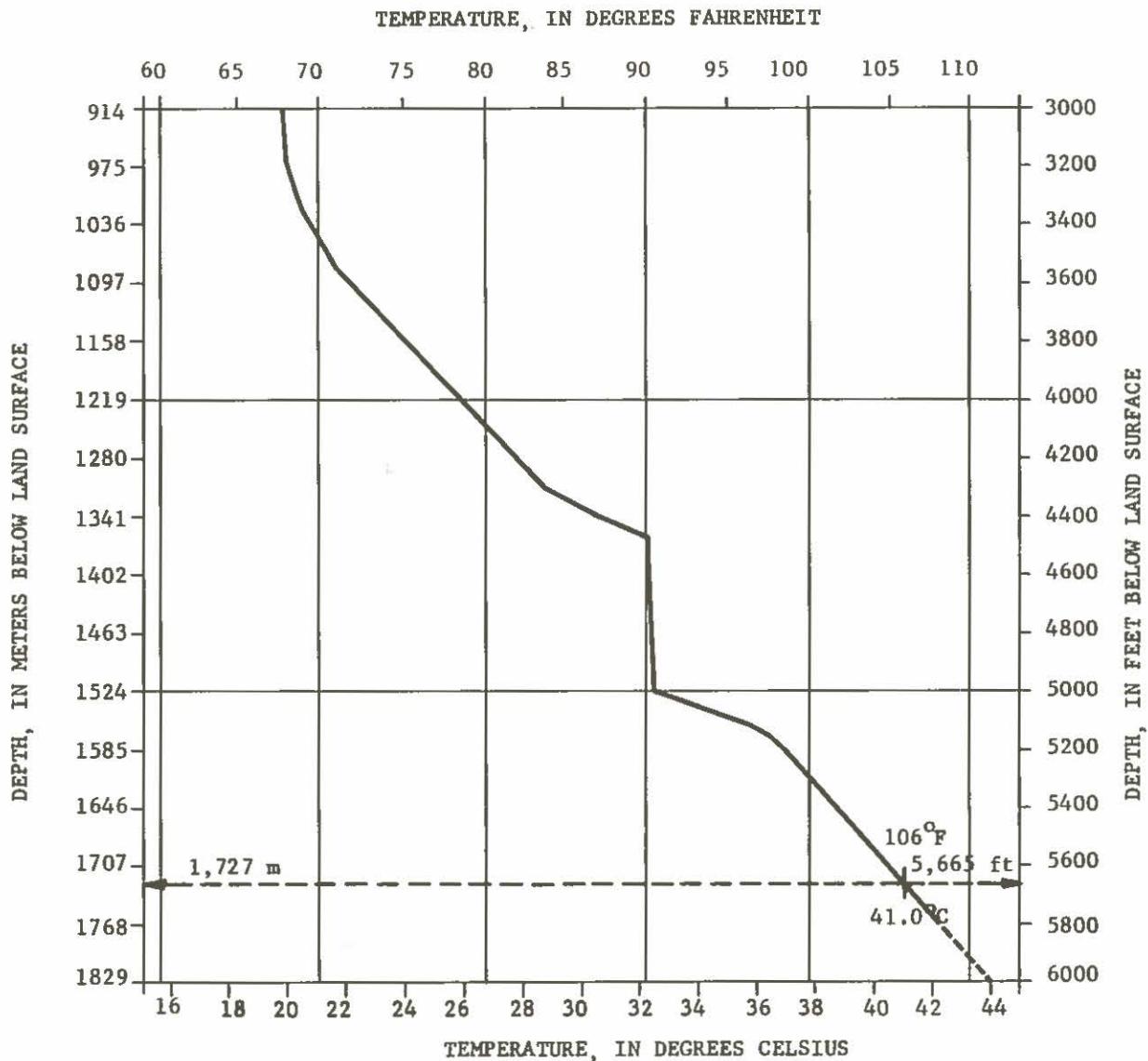


Figure 3.--Profile of temperature versus depth below land surface for test hole UAe-1, Amchitka Island, Alaska (after Sass, John H., and Moses, Thomas H. Jr., 1969).

Water temperature at the inflow port at 1,801.4 m (5,910 ft) in hole UA-1 was reported to be 41.0°C (106°F). This temperature is the same as the temperature measured at a depth of 1,726.7 m (5,665 ft) in test hole UAe-1. This is interpreted as an indication of water movement downward to the grout port. An interval of at least 152.4 m (500 ft) with a mean water temperature of 41.0°C (106°F) could have contributed the flow to the grout port.

Water-Inflow Analysis

In the calculation of water inflow, the problem was to determine the time-dependent discharge to a large-diameter well at constant drawdown. The same procedure was followed as for the original estimate of inflow prior to beginning the chambering. The assumptions are:

(1) that partial penetration in the center of a rock unit can be treated as a leaky-aquifer problem with vertical leakage from above and below; and (2) that construction includes a sealed sump that stores all inflow to the chamber, and that inflow is removed by pumping at intervals, thus maintaining constant drawdown at the chamber; and (3) calculation of the inflow was determined by assuming that horizontal and vertical permeability are equivalent.

In order to calculate the possible water inflow available in an uncemented section of hole UA-1, it was necessary to estimate the probable interval of the incompletely cemented section. The tracer log of the first remedial cement grouting of hole UA-1 indicated cement movement behind the pipe in the interval from 1,731.3 to 1,819.4 m (5,680 to 5,969 ft). It was reported that the tracer log of the

second cement grouting of hole UA-1 indicated cement penetration from 1,775.8 to 1,822.4 m (5,826 to 5,979 ft). During the two grouting operations cement penetrated behind the pipe in the interval 1,731.3 to 1,822.4 m (5,680 to 5,979 ft). Therefore, this 91.1 m (299 ft) of void space in the cement behind the pipe was the minimum length of the contributing zone.

Accordingly, it was assumed for the purpose of calculation that the composite of two previously tested intervals between 1,706.9 and 1,828.8 m (5,600 and 6,000 ft), an interval slightly thicker than the interval that was shown to have received cement through the grout port, contributes the water inflow to hole UA-1. Also, it was assumed that the annulus around the pipe was open or that there was extensive channeling in the cement in this interval before the two stages of grouting.

The hydraulic head of the inflow water built up to 43.0 m (141.1 ft) below land surface in the grouting pipe. This head corresponds to that of the interval from 1,724.3 to 1,859.3 m (5,657 to 6,100 ft), as measured in hole UAe-1.

Using hydraulic data obtained when testing hole UA-1 and assuming that the annulus around the pipe was either open or that there was considerable channelization in the cement in the 121.9-m (400-ft) interval, the inflow rate was calculated and indicated by a theoretical-inflow curve in figure 4. The inflow curve shows the rate to be:

<u>Time</u>	<u>Cubic meters per day</u>	<u>Gallons per minute</u>
1.4 minutes	1,580	290
14 minutes	790	145
144 minutes	518	95
1 day	425	78

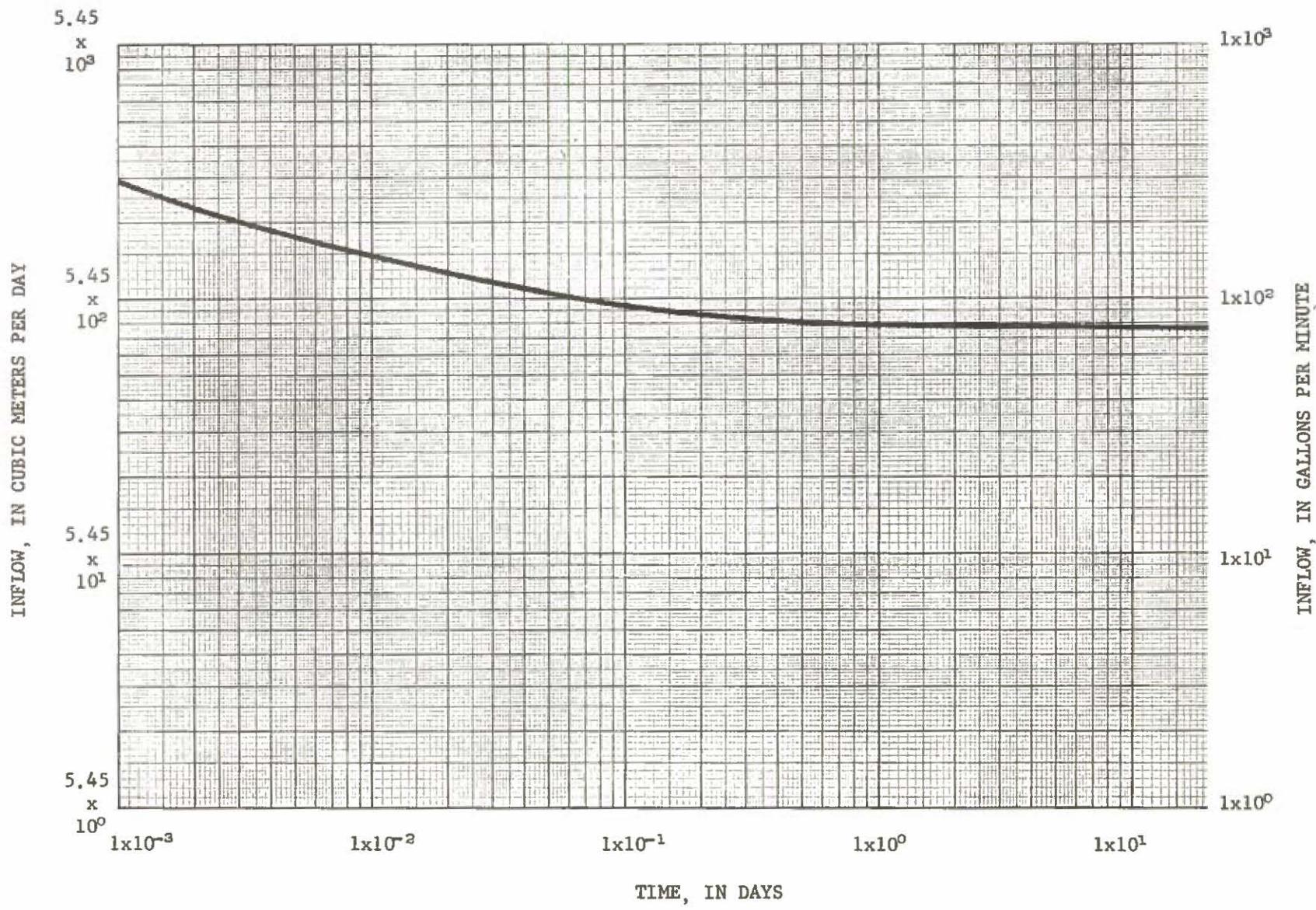


Figure 4.--Theoretical inflow through grout port as a function of time for hole UA-1, Amchitka Island, Alaska.

As time increases, water is taken from storage causing a reduction of gradient in the water-contributing zone, resulting in a reduction of inflow. Discharge stabilizes in about 10 days at about 75 gpm. These calculations show that all the inflow water could have been derived from the formation in the interval that accepted the cement grout.

The predicted inflow does not take into account any mechanical restrictions in the system. The steel casing and grout port, even when open to the annulus around the casing, presents some restriction to fluid flow. The opening in the grout port was reported to be 2.54 cm (1 in.) in diameter. When the grout port was closed, the water pressure behind the port was about $1.7 \times 10^8 \pm 3.4 \times 10^8$ dynes per cm^2 ($2,500 \pm 50$ psi). When the grout port was opened, the pressure dropped rapidly. Using the continuity equation of Bernoulli, the pressure required to produce 380 m^3 per day (70 gpm) of flow through a 2.54-cm (1-in.) diameter pipe, disregarding friction, was calculated to be 6.9×10^5 dynes per cm^2 (10 psi). Therefore, the size of the port opening did not significantly affect the rate of water inflow.

SUMMARY AND CONCLUSIONS

The first inflow water removed from hole UA-1 contained a large percentage of drilling mud and cement slurry. As removal of the water continued, the water became less contaminated, that is, a larger percentage of the water was formation fluid. Analyses of formation fluid without contamination could have been used to determine the water-contributing zone if the zones were isolated from each other,

as would have occurred if the cement job were perfect. Because of the low rate of inflow, considerable time is required before contamination in the water is eliminated sufficiently for the chemical analyses to be used in depth of water inflow determinations.

The lower pH of more recent samples indicates less contamination by cement than during any previous sampling.

Chloride under measurement conditions is the most reliable constituent to use as an indicator, as it is least affected by drilling-fluid contamination, organic oxidation, or mineralogic reactions. The concentration of 1,790 mg/l of chloride found in water samples from hole UA-1 at the conclusion of pumping indicates a mean water-contributing zone at a depth of approximately 1,670 m (5,478 ft), based on the depth versus chloride concentration curve developed for test hole UAe-1. The samples collected and analyzed during October and November show little change from earlier samples, which indicates the same source for the water flowing into the cavity.

The temperature of inflow water from hole UA-1, when compared with the profile of temperatures obtained from test hole UAe-1, indicates the water-contributing zone is in the vicinity of the 1,727-m (5,665-ft) level. However, if water enters the annulus at a higher level, it could be warmed to the measured temperature during slow, downward movement.

The hydraulic head of the contributing zone to hole UA-1, which was 43.0 m (141.1 ft) below land surface, when compared with the head measured for various zones tested in holes UAe-1 and UA-1, indicates the contributing interval is between 1,724.3 and 1,859.3 m (5,657 and 6,100 ft).

The void behind the pipe was grouted twice with cement slurry. A tracer placed in the cement indicated penetration during the grouting operations ranged from 1,731.3 to 1,822.4 m (5,680 to 5,979 ft), a distance of 91.1 m (299 ft). This distance represents the minimum thickness of the water-contributing zone, or the zone of open channels through which water from other zones could flow to the grouting port.

Calculation of water inflow for a 121.9-m (400-ft) section of exposed rock in the general area penetrated by the cement grout indicated transmissivity was sufficient to sustain the initial water inflow of 380 m³ per day (70 gpm) for an indefinite period.

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