The HYDRODYNAMICS Group
studies in mass and energy transport in the earth

INVESTIGATION of the ARROWHEAD COMPLEX 1 & 8 for FDA COMPLIANCE

prepared for: **PERRIER GROUP of AMERICA**

John Bredehoeft *PhD, NAE*
Michael King *CHG*

April, 1998

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1.0 INTRODUCTION

The HYDRODYNAMICS Group conducted a study to evaluate compliance of Arrowhead Springs 1 and 8 with recent FDA regulations.

The Arrowhead Springs 1 and 8 are currently licensed by the State of California Department of Health Services (DHS), Food and Drug Branch to operate as a Private Water Source (License No.'s 86066, 86067, and 86074—Appendix A). The United States Food and Drug Administration (FDA) was specific in its new regulations that cover spring water sources. The objective of this study was to conduct hydraulic and chemical testing of the Arrowhead Springs 1, and 8 and bore-hole 1A (collectively referred to as the Arrowhead Complex 1 & 8) to establish compliance with FDA regulations. Spring 4 was developed in the course of our compliance studies. This report describes Arrowhead Complex 1 and 8, and presents the results of our compliance evaluation.

1.1 FDA Regulations

FDA spring regulations are defined in the Federal Register—Department of Health and Human Services, Federal Food and Drug Administration, Volume 60, No. 218, (Monday November 13, 1995) 21CFR Part 103, 129, 165, and 184 Document No. 88P-0030, RIN 0910-AA11 Beverages-Bottled Water, Code 165.110(a)(2)(vi), Sections 48, 53, and 54.

1.2 Approach to Demonstrate FDA Compliance

Our approach was to inspect the springs at Arrowhead Complex 1 & 8 , and investigate the local hydrogeology. We reviewed historical data to confirm that the springs have flowed for a long period. Water samples were collected and analyzed to confirm the chemical similarity of water from the springs and bore-holes. As part of our investigation a catchment was constructed at Spring 4.

We performed hydraulic tests during which spring flows were monitored to demonstrate a hydraulic connection between springs 1 and 8 and bore-hole 1A, and another hydraulic test to investigate the hydraulic connection between 1, 1A, 8.and spring 4. The hydraulic tests were performed in March, and October to December, 1997.

1.3 Previous Site Studies

John F. Mann, Jr., consulting hydrogeologist, worked for the Arrowhead Drinking Water Company from 1964 to 1988. During this period he prepared reports describing the geology and hydrogeology of the Arrowhead Springs, that included Complex 1 & 8. The various springs are described in his report of April 1, 1988 entitled *The Arrowhead Springs*. Additional information, including bore-hole drilling reports, and spring site plans, was made available by Perrier.

2.0 SETTING

The Arrowhead Springs are historically well known springs that were developed in the 1930's. The original developments at Arrowhead consisted of collection galleries constructed at springs 2, 3, and 7. The galleries are tunnels driven through the decomposed granite into the hard granite at the site of the spring orifices. Springs 1 and 8 were developed by driving horizontal bore-holes into the spring orifices; this was the *standard-of-practice* for spring development at that time. Water from all of the Arrowhead springs and bore-holes drain by gravity into a pipeline that runs down the mountain to the Waterman Canyon storage tank and truck loading facilities. A chronology of the development at Complex 1 and 8 is provided in Table 1.

TABLE 1. Historical Summary of Development—Complex 1 & 8

Spring 1	Original Development		1930s
	Spring Clogged	no flow	1967-75
	New Borehole		1976
		shut in	1977-80
Spring 8	Developed		1950
	New Borehole		1993
Borehole 1A	Drilled		1993
	Combined Flow of 1 & 1A		1993

2.1 Spring Locations

The Arrowhead Complex 1 & 8 is situated in Township 2 North, Range 3 West, in the southwest ¼, of the northeast ¼, of the southeast ¼, of Section 30, in San Bernardino County, California—Plate 1. The land is located within the boundaries of the San Bernardino National Forest, which is under the jurisdiction of the U.S. Forest Service. Site access is by a primitive service trail off of "Rim of the World Drive" (State Route 18). The Complex 1 & 8 springs are in close proximity to one another.

2.2 Physiography

The Arrowhead Springs are located in the San Bernadino Mountains. The upper springs, including Complex 1 & 8, are on a steep southern slope (64% slope) of Strawberry Peak near the community of Twin Peaks. Arrowhead Complex 1 & 8 is at an elevation of approximately 5,200 feet, and is located in a tributary ravine of Strawberry Creek at the head of Coldwater Canyon (Plate 1). Complex 1 & 8 is located approximately 1,100 feet down slope from State Route 18, and is about 800 feet lower in elevation.

Springs 1 and 8 and bore-hole 1A are housed in a concrete block structure located about 60 feet down slope from the original spring 1 and 8 orifices, at an elevation approximately 20 feet lower,. The mountain drops off on a steep slope below the bore-hole structure. The vegetation is largely shrub oak in the vicinity of the site. Another natural spring, designated spring 4, is located approximately 125 down slope from the concrete block structure, and is about 60 feet lower in elevation.

2.3 Geology

The San Bernardino Mountains in the vicinity of Arrowhead Complex 1 & 8 are composed entirely of crystalline rock, mainly granite and metamorphic rock of the so-called *"basement complex."* The San Andreas Fault runs along the base of the San Bernardino Mountains, approximately 5 miles to the southwest; the fault in this area trends west-northwest/east-southeast.

Driller's logs of bore-holes at Complex 1 & 8 indicate the site is underlain by decomposed granite to a depth of about 100 feet; beneath that is highly fractured granite with clay grus. There is almost no residual or colluvial soils at the site; however, the granite near the surface is decomposed.

2.3 Hydrostratigraphy

The primary water-bearing materials are the decomposed granite and the fractured crystalline granite. The water-bearing characteristics of these materials are dependent on the degree of weathering and the presence of fractures; the matrix permeability is so small as to be insignificant. Springs 1, 4 and 8 are situated in the decomposed granite. Bore-hole 1A produces water from both the decomposed and highly fractured granite.

3.0 SPRINGS

Springs 1 and 8 were developed according to the *standard-of-practice* for developing springs from the 1930's to 1993. At the Arrowhead property, springs were developed during this period by either 1) constructing a tunnel into the mountain horizontally at the spring orifice; or 2) drilling a horizontal bore-hole into the orifice. The development of springs by these methods obliterated the original spring orifice. Spring flows were captured totally by the spring development. Typically if the original bore-hole clogged, a new off-set bore-hole was drilled at an angle to intercept the original bore-hole. Once a new borehole was drilled, the original spring bore-hole was capped at the surface; this resulted in diverting the spring flow to the new bore-hole.

Spring 1 was developed in the 1930's by drilling a horizontal bore-hole into the spring orifice. Similarly, spring 8 was also developed in the 1950s by drilling a horizontal bore-hole into the spring orifice.

The discharge from the spring 1 bore-hole declined from 1966 to 1975. A new spring 1 bore-hole was slant drilled from a lower elevation to intercept the original bore-hole in June, 1976. Similarly, the discharge from the spring 8 bore-hole also declined from 1988 to 1992. A new spring 8 bore-hole was slant drilled from a lower elevation into the original spring 8 bore-hole spring in August, 1993.

The natural spring orifices at both 1 and 8 were destroyed during development of the second set of bore-holes. There is still visual evidence of the original bore-holes.

A summary of the spring 1 and 8 developments is provided in Table 1. The new bore-holes at the 1 & 8 complex both have similar construction; they consist of 2 7/8-inch diameter bore-holes drilled into the mountain at an elevation below the spring. The bore-holes were lined with 2-inch diameter, schedule 40, galvanized blank casing, with a 2-inch diameter, 3/16-inch slot, schedule 40, galvanized, screen attached to the end of the casing. Each bore-hole was pressure grout sealed along the entire length of the blank casing.

The bore-hole development, especially when the new slant bore-holes that were drilled later, while it was *state-of-practice,* resulted in plugging the original bore-hole orifice. The new FDA regulations require that where a bore-hole is used to capture spring flow, the natural spring orifice must continue to flow. It is a matter of interpretation whether the second bore-holes meet the new FDA qualifications as a natural orifice. It is our opinion that this is highly questionable; we believe Perrier is vulnerable at springs 1 and 8.. There is no natural orifice that continues to flow; the only orifices at springs 1 and 8 that continue to flow are the new bore-holes, slant drilled, in 1976 and 1993, at a lower elevation than the original orifices. In our opinion, bore-holes 1 and 8 are not natural springs and do not comply with the new FDA regulations.

Spring No. 4 is located near the 1 and 8 complex. It discharges from a natural orifice that is a nearly vertical fracture in an isolated granite outcrop in a ravine down slope from 1 and 8. A rock catchment was constructed at the base of the rock outcrop. A discharge pipe was installed at the base of the catchment basin to allow for flow measurements. A summary of spring design at Complex 1 & 8 is provided in Table 2.

TABLE 2. Bore-hole Construction.

Spring/Borehole	Date Developed	Bore-hole Length	Seal Length	Status
Original Spring 1	1930s	unknown	unknown	abandoned
New Spring 1	6/14/76	290	126	in use
Original Spring 8	1966	52	unknown	abandoned
New Spring 8	8/20/93	120	100	in use
Bore-hole 1A	8/29/93	130	66	in use

The history of spring flow is presented in Table 3, and plotted as Figure 1. Prior to 1945, flows were not recorded. We measured flow rates from 1, 4 and 8 from March to December of 1997. The flow at 1, 8, and 4 averaged 23, 42, and 1 gallons per minute (gpm), respectively. The flow measurements were interrupted occasionally due to clogging of the flow meters. Flow measurements from the spring 4 catchment were also interrupted when the flow rate dropped below the accuracy of the flow meter.

TABLE 3. Summary of Flow at Arrowhead Spring Complex 1 & 8.

Annual Spring and Bore-Hole Flow Volumes
(Acre-Feet Per Year)

Year	Original Spring NO. 1	New Spring Bore-hole NO. 1	Combined Bore-holes NO. 1 & 1A	Original Spring NO. 8	New Spring Bore-hole NO. 8
1947	ND				
1948	3.30				
1949	13.44				
1950	12.32			8.23	
1951	5.60			16.80	
1052	17.92			56.00	
1953	7.86			26.95	
1954	8.96			38.08	
1955	7.24			34.72	
1956	5.60			33.60	
1957	5.48			34.72	
1958	7.64			51.36	
1959	5.27			31.57	
1960	3.61			18.40	
1961	1.96			10.22	
1962	1.91			6.69	
1963	1.51			5.73	
1964	5.86			5.48	
1965	1.07			33.82	
1966	0.69			88.62	
1967	0.00			67.20	
1968	0.00			80.88	
1969	0.00			90.78	
1970	0.00			64.65	
1971	0.00			20.98	
1972	0.00			20.98	
1973	0.00			11.51	
1974	0.00			18.90	
1975	0.00			14.40	
1976		9.37		20.57	
1977		0.00		18.90	
1978		0.00		14.08	
1979		0.00		21.46	
1980		0.00		15.10	
1981		10.02		26.10	
1982		13.60		23.30	
1983		0.00		11.70	
1984		25.09		29.10	
1985		28.09		18.65	
1986		20.03		0.81	
1987		18.18		10.00	
1988		19.64		9.18	
1989		0.62		0.28	
1990		14.48		5.80	
1991		16.19		10.24	
1992		26.90		27.50	
1993			37.70		19.70
1994			52.30		59.70
1995			38.60		55.30
1996			55.80		54.30

ND = No Data Available

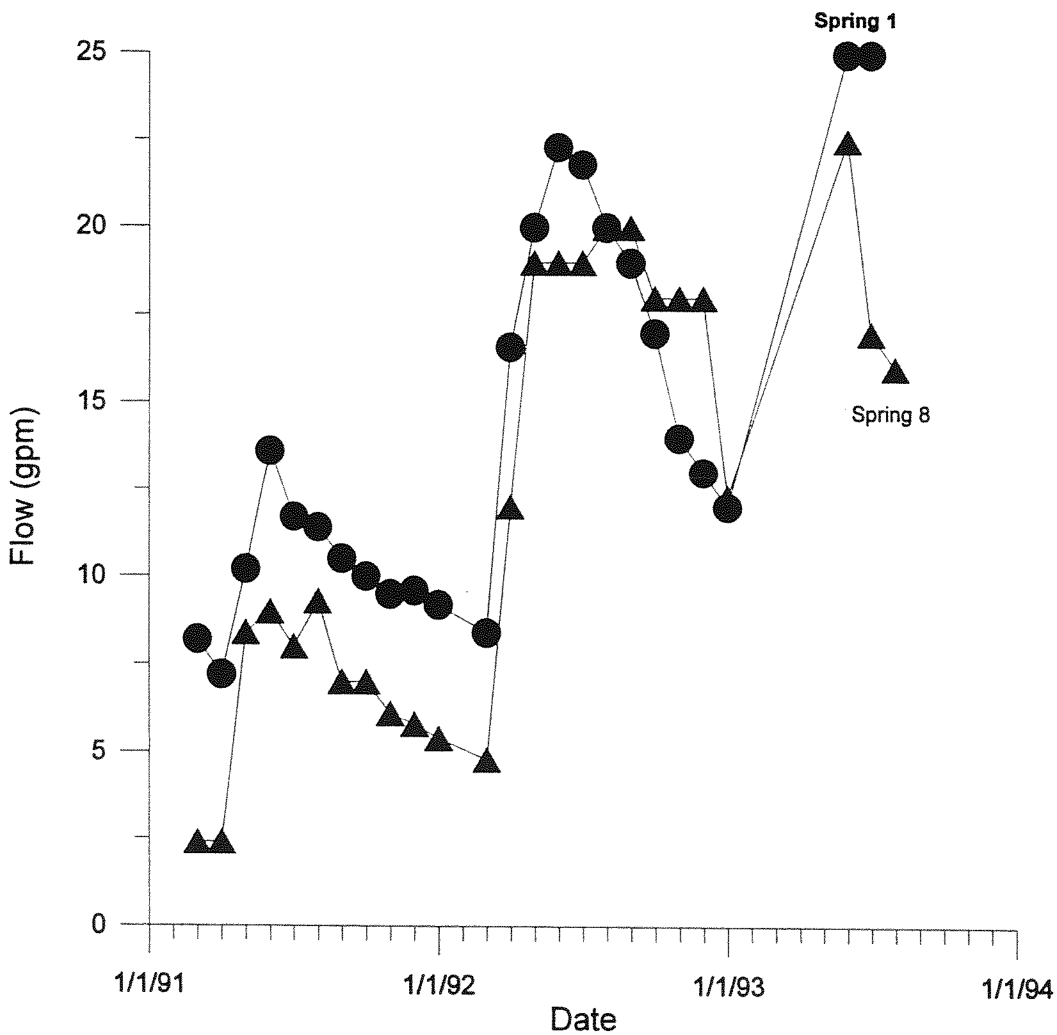

Figure 1. Plot of monthly flow during 1991, 1992, and 1993 at Arrowhead Springs 1 & 8.

4.0 SPRING AND BORE-HOLE HYDRAULIC CONNECTION

Hydraulic tests were performed on bore-holes 8 and 1A to demonstrate a hydraulic connection. The tests involved shutting off bore-hole 8 and reopening it while observing changes in the flow of bore-hole 1A. A full description of test monitoring and results is provided below.

4.1 Bore-Hole 1A

Bore-hole 1A was drilled between 1 and 8 in August, 1993. A summary of bore-hole 1A construction is provided in Table 3. The driller's log for bore-hole 1A is provided in the Appendix. The construction is similar to bore-holes 1 and 8—described above.

4.2 Spring and Bore-hole Monitoring

Spring and bore-hole flow rates were monitored from March to December of 1997, as previously discussed. During this period the flow of spring 4 was measured using a 1/2 inch diameter Signet flow meter. The flow of bore-holes 1, 8, and 1A were also measured using 2 inch diameter Signet flow meters. Data was recorded at 15 minute intervals on a Unidata Data Logger. Data was monitored on-site; the data logger was also accessed using a cellular phone and computer modem.

4.3 Testing

The purpose of testing 8 and 1A from October 17 to 25, and November 25 to December 5, 1997, was to demonstrate a hydraulic connection between spring (bore-hole) 8 and bore-hole 1A. The tests showed that they are hydraulically connected. The flow of bore-hole 1A was observed to decrease and increase as a result of regulating the flow from 8. Bore-hole 1A flow rates increased from an average of approximately 7.5 to 10.25 gpm from October 17 to 21, 1997 when 8 was shut-in—Figure 2. Bore-hole 1A flow rates increased from an average of about 6.5 to 9.25 gpm from November 26 to December 2, 1997 when 8 was again shut-in—Figure 3. Following each test, when 8 was subsequently reopened the flow of 1A declined to approximately the same rate observed prior to the test.

The hydraulic tests demonstrated number 8 is hydraulically connected to bore-hole 1A. Four hydraulic tests were conducted; the results of two are displayed on Figures 2 and 3:

4.3 Spring 4

Spring 4 is a natural spring located down-slope in the ravine below the bore-holes. The spring is approximately 60 feet lower in elevation than the block house that contains bore-holes 1, 1A, and 8. The riparian vegetation in the vicinity of the spring indicates there is some flow year round. Our intent was to establish a hydraulic connection between spring 4 and the other bore-holes. Making this connection establishes spring 4 as the natural orifice for the spring associated with the bore-holes, and would meet the FDA criteria.

Unfortunately none of our experiments was conclusive in demonstrating this connection. Figure 4 is a plot of flow for spring 4 during March 16 and 17, 1997. Bore-holes 1, 1A and 8 were shut off at approximately 1 PM on March 17. Although it is small, there appears to be an associated change in the flow of the spring. The change in flow rate is less than 1 %; the change approaches the resolution of the flow meter. At approximately 10 AM on March 18 the bore-holes were turned back on. Again there is a change in flow of approximately 1 %. Both changes are in the direction we expect—the flow increases as the bore-holes are turned off, the flow decreases as the bore-holes are turned back on.

Spring 4 also shows the impact of riparian evapotranspiration (ET) on the flow of the spring. In March 1997 the change in daily flow caused by transpiration of the local riparian vegetation is about twice that might be attributable to the change caused by opening and closing the bore-holes—approximately 2 %. By carefully experimenting—observing flow in spring 4 while selectively regulating flow—one may be able to establish a clearer hydraulic connection. One possibility might be to run the experiments in the late fall when the flow in spring 4 is low, and when the riparian ET is also low. One might also turn off the wells during the dead of night when there is no transpiration. In view of the importance of the bore-holes at complex 1 & 8 to the productivity of the Arrowhead property, further careful testing involving spring 4 seems warranted.

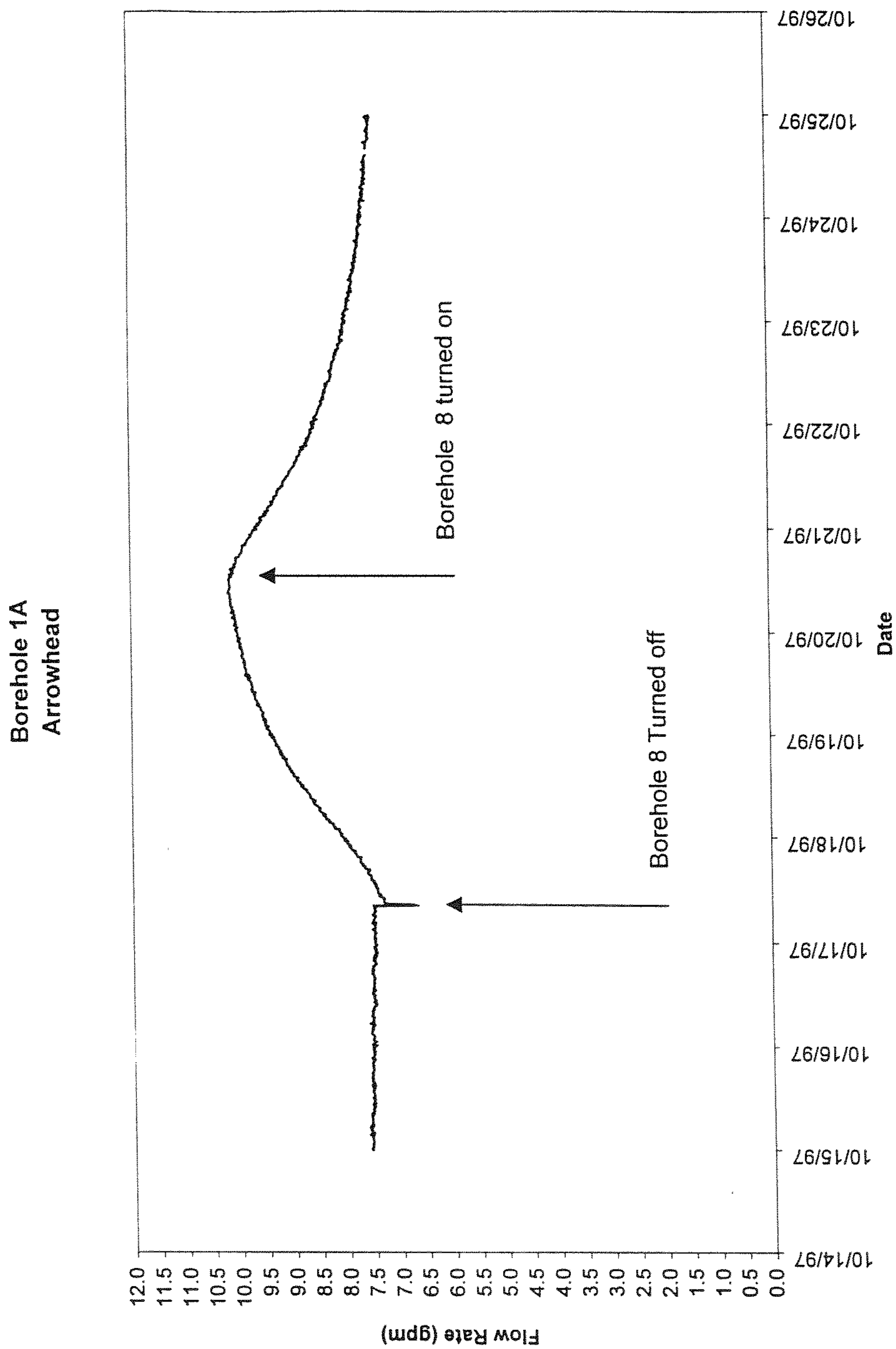

Figure 2. **Flow of bore-holes 8 and 1A during test—October 17 to 25, 1997.**

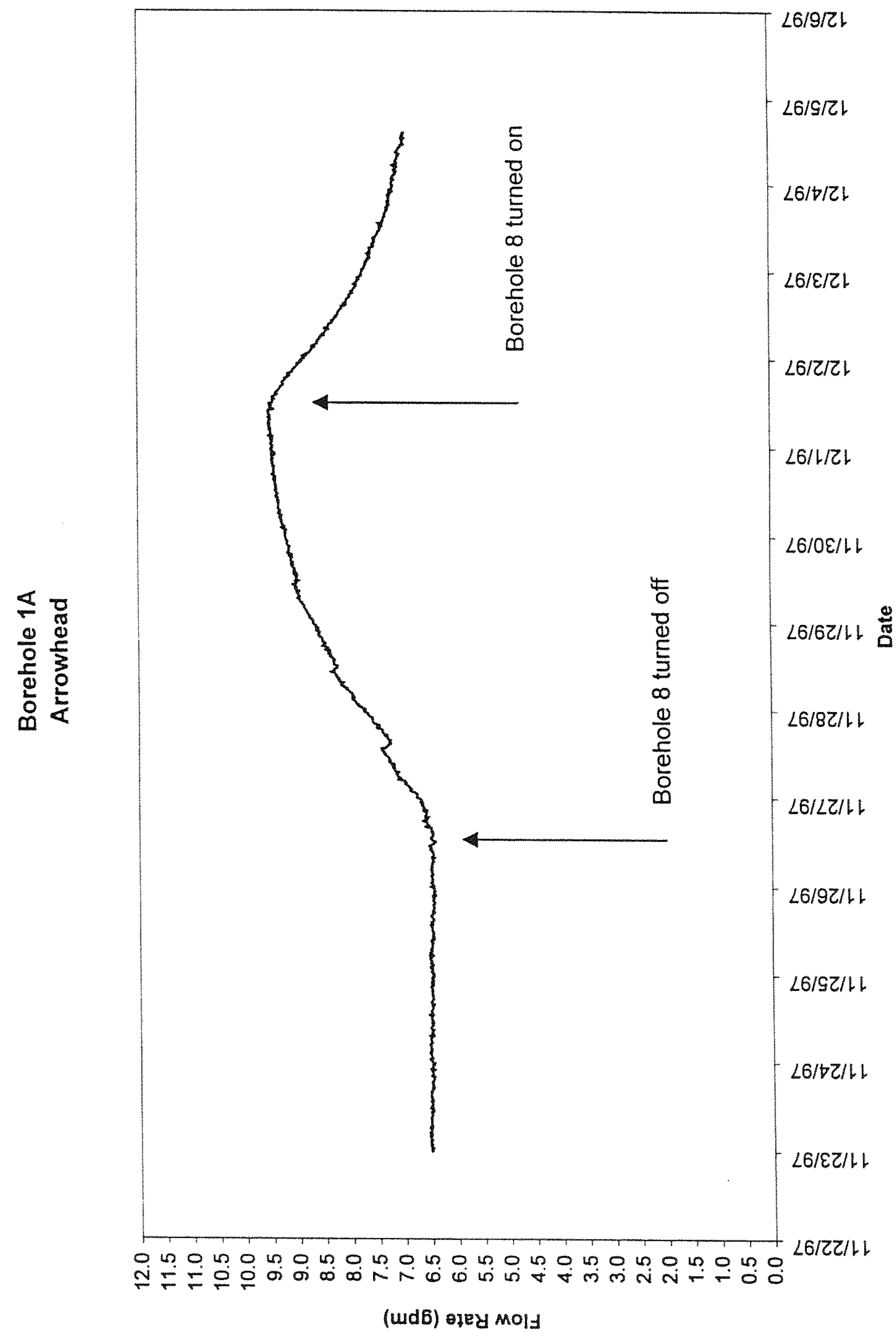

Figure 3. **Flow of bore-holes 8 and 1A during test November 25 to December 5, 1997**

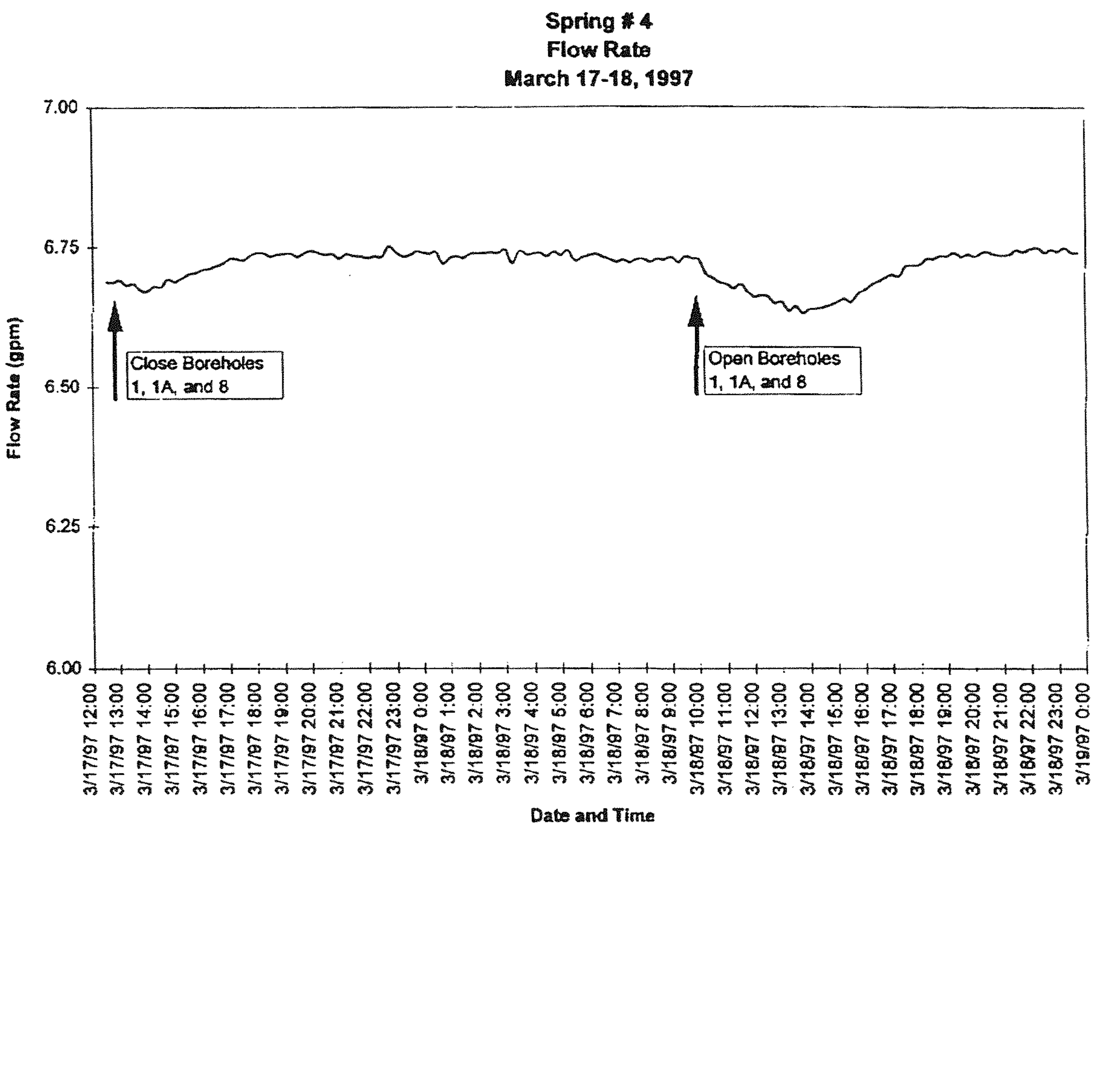

Figure 4. Flow of spring 4 during hydraulic testing in March 1997.

5.0 SPRING & BORE-HOLE CHEMISTRY

Water quality samples were collected from the Arrowhead bore-holes 1, 1A, 8, and spring 4. The samples were collected in accordance with state-of-the-practice protocols. Samples were submitted to California certified laboratories for analysis. Results of analysis are summarized in the Appendix. The quality of the water from Arrowhead Complex 1 & 8 is within the Federal FDA and California DHS drinking water standards for a public water supply (Table 4); the total dissolved solids are quite low.

For the purposes of comparison, the major ion content of the water is plotted on a Piper Diagram—Figure 5. The Piper Diagram shows that the waters have similar chemical composition. The similarity of chemical composition from numbers 1, 1A, 8, and spring 4 indicate the same ground-water source.

TABLE 4. Summary of chemical analyses for bore-holes 1, 1A, 8, and spring 4.

	Spring 1 10/08/97	Spring 8 10/08/97	Bore-hole 1A 10/08/97	Spring 4 03/17/97
Bicarbonate	70.0 mg/l	76.0 mg/l	91.0 mg/l	68.7 mg/l
Carbonate	nd	nd	nd	-
Chloride	18.0	6.0	6.2	5.2
Fluoride	0.1	0.1	0.1	0.1
Nitrate	1.6	nd	nd	nd
Phosphate	nd	nd	nd	nd
Silica	33.0	23.0	23.0	24.2
Sulfate	1.4	3.4	2.6	2.6
Nitrite	nd	nd	nd	nd
Bromide	nd	nd	nd	nd
Aluminum	nd	nd	nd	nd
Arsenic	nd	nd	nd	nd
Barium	0.010	nd	nd	nd
Cadmium	nd	nd	nd	nd
Calcium	16.0	17.0	21.0	13.7
Chromium	nd	nd	nd	nd
Copper	0.060	nd	nd	nd
Iron	nd	nd	nd	nd
Lead	nd	nd	nd	nd
Magnesium	5.0	2.0	3.0	2.4
Manganese	nd	nd	nd	nd
Mercury	nd	nd	nd	nd
Potassium	2.0	2.0	2.0	1.2
Selenium	nd	nd	nd	nd
Silver	nd	nd	nd	nd
Sodium	11.0	8.0	8.0	7.3
Zinc	nd	nd	nd	nd
Beryllium	nd	nd	nd	nd
Antimony	nd	nd	nd	nd
Nickel	nd	nd	nd	nd
Thallium	nd	nd	nd	nd
Coliform	nd	nd	nd	-
Conductivity	182 uS/cm	150 uS/cm	173 uS/cm	129 uS/cm
TDS	125 mg/l	101 mg/l	111 mg/l	91 mg/l
Total Alkalinity	58	62	75	56
Total hardness	58	51	65	44
Turbidity	nd	nd	nd	nd
pH	6.0	6.3	6.3	7.4

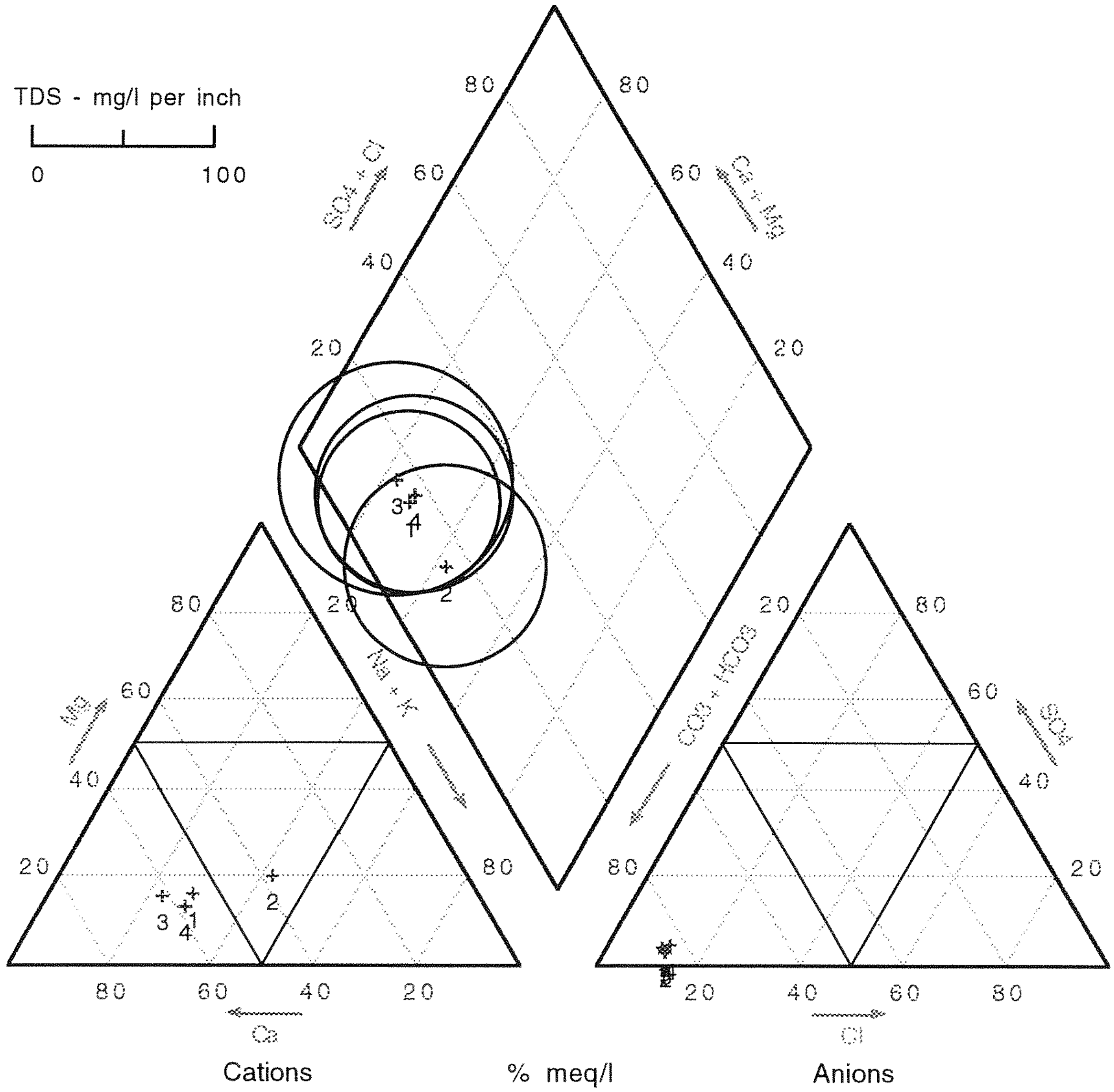

Figure 5. Arrowhead 1 &8 Complex Piper Diagram					
No.	TDS	Sample	No.	TDS	Sample
1	101	Spring #4			
2	110	Spring #1			
3	127	Bore-hole 1A			
4	109	Spring #8			

Figure 5. **Piper Diagram for water from Arrowhead Complex 1 and 8.**

6.0 POTENTIAL INFLUENCE of SURFACE WATER

EPA suggested that rapid shifts in spring water chemistry associated with periods of heavy rainfall, or heavy surface water runoff could indicate an undo impact on the spring by local surface water. We examined the time history of the available water quality data from the Arrowhead Complex 1 & 8 to see if there were rapid shifts in 1) spring flow, 2) total dissolved solids (TDS), or 3) turbidity.

In order to be fully convincing that there is no significant surface water influence, both water conductivity (a measure of total dissolved solids) and turbidity should be continuously monitored. Quarterly sampling does not necessarily capture the more immediate impacts of major storm, or runoff events. In California, MPA samples need to be collected during periods of recharge in the late winter and early spring when the potential of surface water impacts are the greatest.

6.1 Spring Flow

The flow rates of 1 and 8 are plotted in Figure 1 (above) for the period 1991 through 1993. The flow is high in the late winter and early spring and then declines during the remainder of the year.

6.2 Time Trends of Water Chemistry

EPA suggested examining changes in several parameters as indicators of surface water influence—1) conductivity/TDS, 2) pH, and 3) turbidity. There are difficulties with measuring pH other than directly in the field; it can change between the field and the laboratory. We examined historical measurements of TDS in an attempt to see if there were changes that indicated a significant surface water influence on the springs.

We plotted the available TDS data for three principal Complex 1 & 8 sources of water in Figure 6. We have data from quarterly samples taken from 1995 through 1997. The water is very low in TDS ranging from a high of 140 to a low of 90 mg/l. There is only a slight change in quality during the period—approximately 10 %. There is no strong seasonal trend. The temporal stability of the spring water chemistry indicates no influence of surface water.

6.3 Microscopic Particulate Analyses

EPA also suggested that the presence of *'microscopic particulate'* materials could also indicate the impact of surface water. EPA codified these into a test procedure for microscopic particulate material—the so-called *Microscopic Particulate Analysis* (MPA). We have no MPA samples from Complex 1 & 8.

6.4 Summary—Surface Water Influence

The only relevant data Complex 1 & 8 are the quarterly samples of water chemistry. These data indicate no surface water influence on the Complex 1 & 8

We recommend continuous monitoring of TDS and turbidity, along with periodic sampling for chemical analyses and MPAs. We suggest MPAs be done in the late winter or early spring when the spring flow is highest. Such a program of data collection should provide early warning of an undo influence of surface water on the springs or other problems, and allow for corrective action.

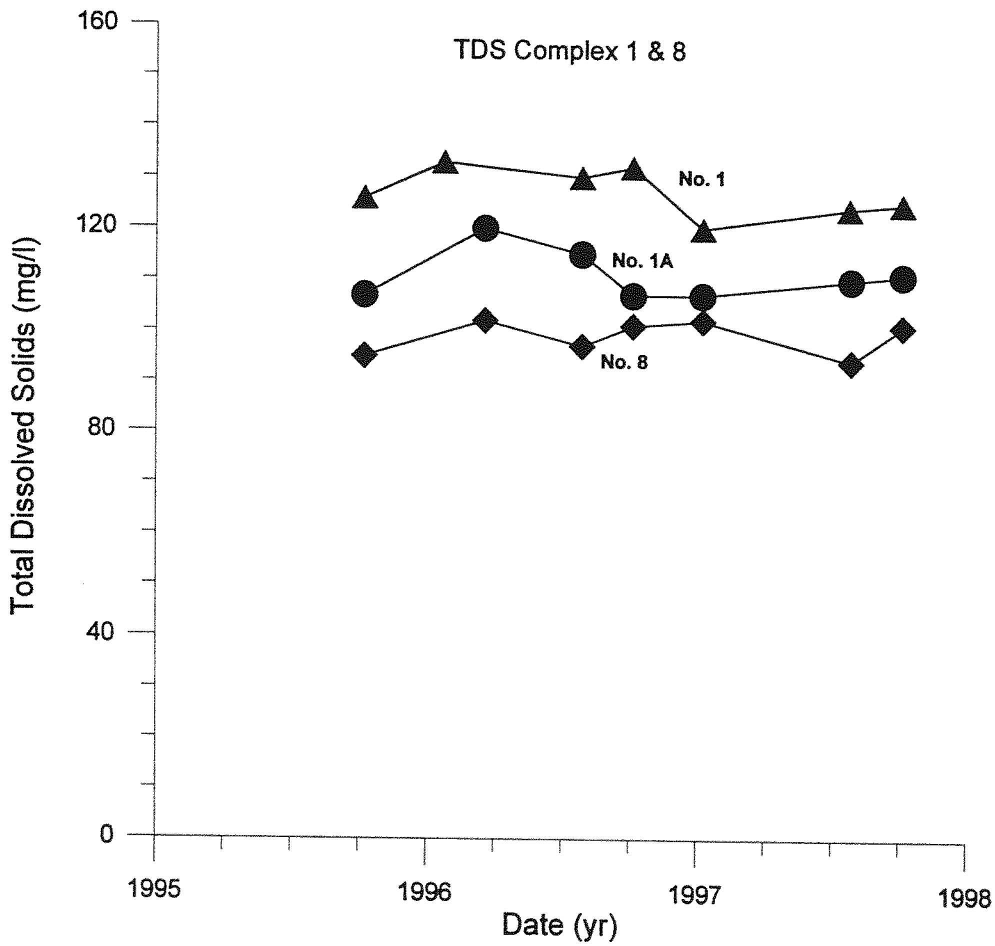

Figure 6. Time series of TDS for the Complex 1 & 8 sources.

16 April, 1998

7.0 FDA COMPLIANCE

As a result of our investigation of Arrowhead complex 1 & 8, we reached the following conclusions :

1. Spring 1 and 8 appear to have been natural springs that were developed by drilling bore-holes horizontally into the mountain at the spring orifices. This was *standard state of practice* in the 1930s and 1950s when this was done. Later when flow at the original bore-holes declined significantly, slant holes were drilled at a lower elevation to intercept the original bore-holes. Once the slant holes were completed the original bore-holes (the original spring orifices) were plugged. The spring flow is now through the slant bore-holes. It is a matter of interpretation as to whether the original spring orifices (or orifice) exist and continue to flow, as required by the new FDA regulations. We believe Perrier is not in compliance with the new FDA regulations at springs (bore-holes) 1 and 8; these are bore-holes not springs. No natural orifice continues to flow as required by the FDA regulations.

2. There is a long history of flow at bore-holes 1, and 8; it has been recorded since 1947, and 1951, respectively.

3. Tests demonstrated that number 8 is in hydraulic connection with bore-hole 1A.

4. The chemical similarity of the waters, as shown by the Piper Diagram, indicates the same ground-water source for Numbers 1, 1A, 8, and spring 4.

5. Further careful testing at the site may qualify spring 4 as a natural orifice that is in hydraulic connection with the bore-holes. Our testing, while not conclusive, is highly suggestive that this is the case. If it can be established that spring 4 is in hydraulic connection with the bore-holes it would meet the FDA criteria that an associated natural spring orifice continues to flow.

6. Preliminary analysis of the quarterly chemical samples for complex 1 & 8 indicates there is no influence of surface water at the site. Further monitoring, including sampling for MPAs, should be done to fully demonstrate no surface water influence on the springs.

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