B. ARTESIAN WELL HYDROLOGY

The artesian well hydrology of Big Bertha has been logically divided into 5 phases of monitoring, analysis, and investigation as outlined below:

Sample Station Locations and
Descriptions Definition of Recharge
Systems
Establishment of Continuous Flow Rcording Station
Physical and Chemical Analysis of Flowing Artesian Well Data
Summary of Impact Assessment of Flowing Artesian Well

I. Sample Station Locations and Descriptions

Eight well zone water sampling stations were developed to serve as monitoring points. Each well zone water sampling station was sampled weekly (when open) and measured the following:

specific conductance
field pH
laboratory pH
alkalinity (mg/l - 4.5.ph)
acidity (mg/l - 8.2 pH)
sulphates (mg/l)
total iron (mg/l)
ferrous iron (mg/l)

The eight well zone water sampling stations are described below

Station 13 - 72' (below surface)
Station 14 - 80' (below surface)
Station 15 - 90' (below surface)
Station 16 - 110' (below surface)
Station 17 - 120' (below surface)
Station 18 - 165' (below surface)
Station 19 - 180' (below surface)
Station 20 - 210' (below surface)

The locations of each sampling station in relation to the stratigraphic features of the flowing artesian well are shown on sheets 7 and 8 of the plans.

When reviewing the analyses on the following pages, refer to the following sheets which show the data plotted on a time relationship basis for the period of monitoring:

Sheet 19 - Sample Zone 20
Sheet 20 - Sample Zone 19
Sheet 21 - Sample Zone 18
Sheet 22 - Sample Zone 17
Sheet 23 - Sample Zone 16
Sheet 24 - Sample Zone 15
Sheet 25 - Sample Zone 14
Sheet 26 - Sample Zone 13

2. Definition of Recharge Systems

Six recharge systems were confirmed to exist in the artesian well as shown on Sheet 8 and labelled B1-B6.

During installation and grouting of the cased well, gate valve, and pressure gauge system, recharge systems B1 and B2 were isolated and could no longer be sampled from the artesian well. Additionally, a packer which was lost during construction subsequently became lodged at 210'± and further isolated the bottom zones and eliminated lower zones from sampling. Thus, when the sampling program began, only recharge zones B3, B4, B5, and B6 could be effectively sampled at the artesian well.

Prior to construction, the magnitude of contribution from each recharge system was determined and confirmed by multiple tracer tests. The procedure for conducting tracer tests to determine recharge is comparatively simple, as outlined below:

a. Determine the diameter of the well hole (we used a caliper and obtained a continuous record).

b. Select tracer(s) which can be readily spotted when it appears at the surface. [We used red and green FDC #5 dye and Rodamine WT (20%) dye.]

c. Inject the tracer at a known (initially shallow) depth. The tracer can be injected by using tubing and a pump; or a closed cylinder which can be triggered from the surface to open at a given depth.

d. Record the length of time required for the dye to reach the surface. For example; if the dye was injected at a 50' depth and it took 5 minutes for the dye to reach the surface, then the velocity can be calculated as:

50' depth = 10 ft./min. 5 minutes

The quantity can be calculated if the diameter of the hole is known. For example; assume we measured an 8" hole, then: each foot of an 8" hole contains 2.61 gallons where:

10 ft./min. x 2.61 gal./ft. = 26.1 gal./minute.

5. Move the injection apparatus deeper in the well and record the time required to reach the surface. Now, the velocity of the added zone is calculated as the difference between the initial (or last) tie of travel to the surface and the current time of travel (t) which is divided into the additional distance travelled (d). Referring to the previous example, assume that we

injected dye at 60' and it took 7 minutes to surface. Then for an additional 10' depth, 2 (Tore minutes were required. The velocity from 0 50' remains the same. The velocity from 50'-60' is calculated as:

$$\frac{d}{t} = \frac{10 \text{ ft.}}{2 \text{ min.}} = 5 \text{ ft./min.}$$

Again the quantity can be calculated as:

5 ft./min. x 2.61 gal./ft. = 13.05 gal.

6. The process and calculations above are repeated at regular intervals throughout the depth of the well until a depth/velocity/ quantity profile is produced.

7. The testing should be repeated fully to confirm the initial results.

The results of our testing are shown on the following page.

The reviewer should be aware that salinity tracer tests were also attempted at the artesian well; however, due to the naturally occurring high specific conductance of the well water(s), we (the author and Bill Roth, USGS) were unable to measure or distinguish with downhole instruments (fluid resistivity geophysical probe) the salinity slug against the background.

8. The reviewer should be aware that due to averaging of results, differences in dye injection methods, differences in estimating occurrence, etc.; the results will occasionally show a zone with less magnitude of flow above a zone which apparently has more flow. This is due to unavoidable human sampling and estimation error. (Comparison between zone 177'-184' and zone 184'210').

9. Trial #1 - conducted on 10/12/84
   Trial #2 - conducted on 10/13/84
   Trial #3 - conducted on 10/26/84

ZONE (Depth)	(ft)	TRIAL 1 (min)*	TRIAL 2 (min)*	TRIAL 3 (min)*	AVERAGE (min)	(ft/min)	VELOCITY (ft/min)	ZONE FLOW (gal/min)	CUMULATIVE FLOW (gal/min)
0-72	72'	4.37	4.33	4.35	4.35	72/4.35	16.55	36.8	44.2
72-76	4'	--	4.93	4.97	4.95	4/.60	6.66	6.8	17.4
76-80	4'	5.24	5.85	5.56	5.55	4/.60	6.66	6.8	17.4
80-90	10'	6.90	7.15	7.10	7.05	10/1.50	6.66	6.8	17.4
90-100	10'	9.33	9.66	9.51	9.50	10/2.45	4.08	3.4	10.6
100-105	5'	--	10.70	10.80	10.75	5/1.25	4.00	3.2	10.4
105-110	5'	--	12.00	12.00	12.00	5/1.25	4.00	3.2	10.4
110-120	10'	15.50	15.80	15.65	15.65	10/3.65	2.74	4.4	7.2
120-140	20'	22.16	23.48	22.84	22.83	20/7.18	2.78	4.4	7.2
140-150	10'	--	26.35	26.45	26.40	10/3.60	2.77	4.4	7.2
150-170	20'	33.40	34.00	33.70	33.70	20/7.30	2.74	4.4	7.2
170-177	7'	--	40.35	40.25	40.30	7/6.60	1.06	2.8	2.8
177-184	7'	46.60	48.80	48.00	47.80	7/7.50	0.94	2.5	2.5
184-210	26'	71.50	74.00	73.50	73.00	26/25.2	1.03	2.7	2.7

* TRIAL 1 - Used FDC #5 Red and Closed Cylinder Insertion

* TRIAL 2 - Used FDC #5 Green and Open Tube/Pump Insertion

* TRIAL 3 - Used Rotamine WT 20% and Closed Cylinder Insertion

FLOW SYSTEM BREAKDOWN	ZONE	
B-1	0 - 35	Casing Restricts trials above 72'
B-2	35 - 72	B-1 and B-2 differentiated by lithology - assumed.
B-3	72 - 90	
B-4	90 - 110	
B-5	110 - 170	
B-6	170 - 210	
B-7	Below 210 -	(Assumed - packer blocking hole)

3. Establishment of Continuous Flow Recording Station

An Isco bubbler was established to allow "instantaneous" and continuous stage and discharge measurements to be made on the artesian well discharge.

The bubbler was placed in a locked steel box adjacent to the well head assembly. Since this area was also very open, the continuous recording rain gauge was placed at this location.

The bubbler was outfitted with heavy duty 12 V.D.C. batteries which would permit accurate operation up to 15 days during reasonable weather. These batteries were switched weekly and recharged for later use.

This site was the subject of repeated, excessive vandalism. Following six or seven encounters, the locked steel box was fastened by size chains to the well head assembly and secured with several locks.

The bubbler tube was buried in the ground and routed from the steel box to a weir placed approximately 20' from the well head assembly. Both the bubbler tube and the weir were repeatedly vandalized.

The author was forced to make some adjustments to the data and some assumptions with regard to unnatural occurrences which have been attributed to the vandals. For example:

Several periods (usually on a weekend, particularly Saturday evening) showed rainfall amounts in excess of 20 inches/hour. Given no antecedent rainfall conditions, and no observed major peaks in the stream hydrograph (which would be expected if a 20inch store would occur), the author assumed the rain gauge was being used as a urinal, and those "events" were filtered out of the data.

On two occasions, the steel box was tipped over; fortunately, only minor damages were incurred. Short-term (two-four days) of data were lost on at least four instances wizen the bubbler line was uprooted and. cut or tore or when the weir (and associated pool) were disturbed. Twice the weir served as firewood during some social gathering. FORTUNATELY, the flowing well exhibited steadystate discharge tendencies such that no valuable data was lost.

4. Physical /Chemical Analysis of Artesian Well Water Data

The physical and chemical analysis of the artesian well water sampling points will rely heavily on the use of three statistical measures:

a. Regression analysis - this statistical procedure will be the principle method in which we will describe relationships between parameters and infer trends for each given parameter of concern. A principle measure of importance will be the multiple correlation coefficient which will be used to gauge the strength of the relationship (or trend).

b. Standard deviation - this statistical measure quantifies the variance. Remember that the standard deviation given on the analysis sheets in the appendices represents the magnitude of one standard deviation. As previously discussed, we will model the field of variation as two standard deviations (approxilmately 95% level of significance).

c. Analysis of variance - this procedure was used by the author to evaluate the regression analysis results and select that analysis which statistically is the most significant, by utilizing the F-test procedure when appropriate.

The relationships we will examine for the artesian well water sampling points are:

Specific Conductance vs. pH
Specific Conductance vs.
Alkalinity Specific Conductance vs.
Acidity Specific Conductance vs.
Total Iron Specific Conductance
vs. Ferrous Iron Specific
Conductance vs. Ferric Iron

A graph accompanies each chemical specie relationship to allow the reviewer to visually assess the relationship. Additionally, sheets 19, 20, 21, 22, 23, 24, 25, and 26 show the data plotted on a time relationship basis for the monitoring period. Due to the extensive amount of data and analysis (approximately 20 sheets per sample station), the physical and chemical analyses will be presented as appendices 13, 14, 15, 16, 17, 18, 19, and 20 (corresponding to the sample number) contained in the back of the report. The summary of this section of the report will be divided into four phases of examination:

Pre-construction summary
Pre-closure (background)
summary Closure summary
Post closure summary

SUMMARY

Pre-Construction Summary

Prior to construction, seven flow systems were identified as contributing to the artesian well discharge as described below:

Flow System	Zone Depth	Recharge, gpm (by zone)	Recharge, gpm (cumulative)
B-1	Surface-35	0 - 3.7	43.3 - 47.0
B-2	35- 72	25.9	43.3
B-3	72- 90	6.9	17.4
B-4	90-110	3.3	10.5
B-5	110-170	4.6	7.2
B-6	170-210	2.6	2.7
B-7	210 and below	0.1	0.1

Previous investigations indicated that the cumulative recharge could reach 200+ gpm due to precipitation effects. This author believes the increased flow would be present in flow system B-l, since this is the first aquifer below regional drainage and would receive the majority of recharge during events. Physical and chemical conditions which existed prior to construction have been documented previously in this report. The monitoring program, as developed for the artesian well, involved two samples for each accessible flow system (bottom of flow system and top of flow system) to show the effects of the water entering the artesian system at that zone and for comparison with other zones.

The monitoring program was then implemented to examine the flow systems as a three-phase operation:

Phase I - Development of Background Data

This involved sampling of the well to determine the characteristics of the flow system's prior to temporary closure of the well.

Phase II - Closure of Gate Valve

This involved the physical interruption of artesian flow by closing the gate valve at the well and observing the pressurization of the system.

Phase III - Post Closure Analysis

This involved the restoration of artesian flow by opening the gate valve and observing the change in characteristics of the system and each of the respective flow systems.

Pre-Closure (Background) Summary

Construction activities included installation of casing to 72' depth and grouting of annular space around casing to surface. Construction activities isolated flow systems B1 and B2 as a result of casing/grouting activities; and B7 was isolated due to an abandoned packer which became wedged at 210'.

This resulted in a steady-state discharge from the well, with regional aquifers B3-B6 recharging the well and causing a 17 gpm (.04 cfs) discharge to persist.

Reconnaissance of the accessible flow systems prior to closure of the artesian well for the purposes of describing background conditions yielded the following summarized results for the period from 2/17/83 - 5/04/85.

pH System

Zone	Sample	Depth (ft.)	Flow(gpm) (cumulative)	No. of Samples	Mean (St.Units)	Range (mg/l)
B3	13	72	17.4	9	5.83	5.63 - 5.99
B3	14	80	17.4	7	5.88	5.82 - 5.95
B4	15	90	10.6	7	6.30	6.20 - 6.37
B4	16	110	10.4	8	6.37	6.32 - 6.43
B5	17	120	7.2	7	6.37	6.32 - 6.41
B5	18	165	7.2	7	6.39	6.31 - 6.53
B6	19	185	2.5	8	6.54	6.41 - 6.72
B6	20	210	2.7	5	6.44	6.34 - 6.49

Specific Conductance

Zone	Sample	Depth (ft.)	Flow(gpm) (cumulative)	No. of Samples	Mean (mg/l)	Range (mg/l)
B3	13	72	17.4	9	1472	1400 - 1600
B3	14	80	17.4	7	1464	1400 - 1550
B4	15	90	10.6	7	1285	1200 - 1300
B4	16	110	10.4	8	1294	1250 - 1350
B5	17	120	7.2	7	1271	1200 - 1300
B5	18	165	7.2	7	1758	1600 - 2000
B6	19	185	2.5	8	2044	1950 - 2150
B6	20	210	2.7	5	2050	2000 - 2150

Alkalinity

Zone	Sample	Depth (ft.)	Flow(gpm) (cumulative)	No. of Samples	Mean (mg/l)	Range (mg/l)
B3	13	72	17.4	9	40	25 - 51
B3	14	80	17.4	7	46	38 - 50
B4	15	90	10.6	7	105	73 - 132
B4	16	110	10.4	8	117	81 - 131
B5	17	120	7.2	7	116	84 - 133
B5	18	165	7.2	7	146	117 - 198
B6	19	185	2.5	8	184	142 - 235
B6	20	210	2.7	5	163	139 - 176

Acidity

Zone	Sample	Depth (ft.)	Flow(gpm) (cumulative)	No. of Samples	Mean (mg/l)	Range (mg/l)
B3	13	72	17.4	9	247	222 - 290
B3	14	80	17.4	7	233	215 - 271
B4	15	90	10.6	7	.71	0 - 5
B4	16	110	10.4	8	0	0
B5	17	120	7.2	7	0	0
B5	18	165	7.2	7	0	0
B6	19	185	2.5	8	0	0
B6	20	210	2.7	5	0	0

Sulphates

Zone	Sample	Depth (ft.)	Flow(gpm) (cumulative)	No. of Samples	Mean (mg/l)	Range (mg/l)
B3	13	72	17.4	9	975	607 - 1084
B3	14	80	17.4	7	831	634 - 1039
B4	15	90	10.6	7	458	315 - 629
B4	16	110	10.4	8	403	302 - 466
B5	17	120	7.2	7	376	307 - 416
B5	18	165	7.2	7	509	440 - 543
B6	19	185	2.5	8	437	343 - 493
B6	20	210	2.7	5	412	354 - 466

Total Iron

Zone	Sample	Depth (ft.)	Flow(gpm) (cumulative)	No. of Samples	Mean (mg/l)	Range (mg/l)
B3	13	72	17.4	9	146	110 - 160
B3	14	80	17.4	7	142	129 - 151
B4	15	90	10.6	7	64	31 - 96
B4	16	110	10.4	8	36	29 - 41
B5	17	120	7.2	7	36	30 - 41
B5	18	165	7.2	7	60	57 - 65
B6	19	185	2.5	8	61	51 - 75
B6	20	210	2.7	5	201	56 - 550

Ferrous Iron

Zone	Sample	Depth (ft.)	Flow(gpm) (cumulative)	No. of Samples	Mean (mg/l)	Range (mg/l)
B3	13	72	17.4	9	139	104 - 156
B3	14	80	17.4	7	134	121 - 146
B4	15	90	10.6	7	61	30 - 94
B4	16	110	10.4	8	34	28 - 40
B5	17	120	7.2	7	34	29 - 40
B5	18	165	7.2	7	58	55 - 65
B6	19	185	2.5	8	58	46 - 73
B6	20	210	2.7	5	196	55 - 238

Ferric Iron

Zone	Sample	Depth (ft.)	Flow(gpm) (cumulative)	No. of Samples	Mean (mg/l)	Range (mg/l)
B3	13	72	17.4	9	7	3.0 - 13.0
B3	14	80	17.4	7	8	3.0 - 12.0
B4	15	90	10.6	7	3	0.2 - 8.0
B4	16	110	10.4	8	2	0.1 - 5.5
B5	17	120	7.2	7	2	0.4 - 3.5
B5	18	165	7.2	7	2	0.1 - 3.5
B6	19	185	2.5	8	2	0.1 - 4.9
B6	20	210	2.7	5	5	0.1 - 12.0

Review of the background conditions for the artesian well indicates a dramatic degradation in the mean chemical parameters occurs between flow system B3 (sample 13) and B4 (sample 15) as shown below:

Parameter	Flow System B4	Flow System B3	% of Change
pH	6.30	5.83	--
Specific Conductance	1285	1472	--
Alkalinity	105	40	-163
Acidity	.71	247	+34688
Sulphate	458	975	+ 213
Total Iron	64	146	+ 128
Ferrous Iron	61	139	+ 128
Ferric Iron	3	7	+ 133
Cumulative Flow	10.6	17.4	+ 64

From the standpoint of loadings, a 64% change in flow multiplied by the various % changes in concentrations will allow an assessment of the man change in loadings magnitude, that is the contribution from the degraded (B3) flow system.

Alkalinity - 104% decrease in loadings.
Acidity - 22000% increase in loadings.
Sulphates - 136% increase in loadings.
Total Iron - 82% increase in loadings.
Ferrous Iron - 82% increase in loadings.
Ferric Iron - 85% increase in loadings.

Restated, flow system B3 degrades the water quality of the artesian well such that the pH drops and conductance rises; the well 'becomes dominantly acidic where almost no acidity was present in the lower zones; a significant rise in both concentrations and loadings of sulphates, total iron, ferrous iron, and ferric iron occurs and a significant decrease in the concentrations and loadings of alkalinity occurs.

Conversely, if the recharge from the upper flow zone (B3) could be excluded then the discharge a the artesian well would exhibit chemical concentrations similar to flow system B4. While this would result in a definite improvement in the discharge characteristics, this would entail additional expenditures. Further, evaluation of complete closure would be necessary to document interaction between flow systems.

Closure Summary

Closure of the flowing artesian well was performed to observe what physical and chemical changes might occur at the well and in the adjacent areas of the site.

Closure was effected at the gate valve on May 4, 1983. Records of the pressure head observed at the gauge are displayed below:

Reference Time/ Date	Pressure Head (psi)	Change (psi)
Start (noon - 5/4/83)	0	0
15 seconds	2	2.0
1 minute	2.5	0.5
3 minutes	3.0	0.5
12 minutes	4.0	1.0
1 hour	4.3	0.3
6 hours	4.5	0.2
5/11/83	6.0	1.5
5/19/83	6.0	--
5/25/83	6.5	--
6/01/83	6.5	1.0
6/07/83	7.0	--
6/12/83	7.0	--

Opened on 6/12/83 @ 11:00 A.M.

The ultimate pressure head observed was 7.0 psi or the equivalent of 16.1 feet of head. The elevation of the pressure gauge at the well was 1223. Adding the head to elevation of the gauge yield an elevation of 1239. This elevation corresponds very well with the ultimate elevations observed in the mine pool (1240) and monitoring wells 10, 11, and 12 (1244, 1236, and 1236 respectively) during closure.

Post Closure Summary

Post closure data indicated the following trends:

1. When the well was reopened, discharge at the weir was initially measured at 36 gpm (.08 cfs). However, within 2 hours the discharge had returned to 17 gpm (.04 cfs) and maintained that level of flow for the remainder of the project.

2. Mixing had occurred throughout the well, as the analysis for each zone was functionally identical, as shown below:

Sample	pH	Acidity	Alkalinity	Sulphate	T. Iron	Iron II
B3 (13)	5.62	315	18	1349	193	184
B3 (14)	5.63	322	15	1374	177	172
B4 (15)	5.56	309	21	1340	182	174
B4 (16)	5.56	336	21	1489	190	185
B5 (17)	5.57	341	22	395	189	188
B5 (18)	5.58	340	22	572	186	183
B6 (19)	5.59	320	20	275	193	191
B6 (20)	5.54	202	22	831	227	200

3. Within two to three weeks, the lower zones (15-20) were exhibiting quality characteristics similar to those which existed prior to closure, indicating only short term (localized) modification had occurred in this flow system.

4. The upper zones (13 and 14) which represent conditions in the flow system B3, were much slower to recover. This is attributed to the similarity of the quality characteristics of this zone during closure to that which existed prior to closure (that is, this zone showed little effect due to closure and probably was the dominant zone during closure causing a moderation of quality in the lower zones). Additionally, as the lower zones recovered, the flushed water would bend to accumulate near the bop inhibiting flushing of that zone.