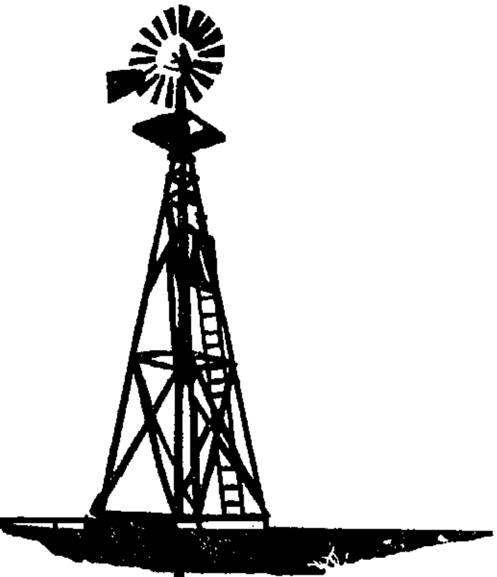

TEXAS WATER DEVELOPMENT BOARD

Ground-Water Quality and Availability In and Around Bruni, Webb County, Texas

LP-209

March, 1991

Texas Water Development Board

LP-209

Ground-Water Quality and Availability In and Around Bruni, Webb County, Texas

by

Eric O. Adidas

March 1991

Texas Water Development Board

G. E. (Sonny) Kretzschmar, Executive Administrator

Published and Distributed
by the
Texas Water Development Board
P. O. Box 13231, Capitol Station
Austin, Texas 78711-3231

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INTRODUCTION

Purpose

This report has been prepared in an attempt to address the existing water-quality problems in the area in and around Bruni, Texas.

Historical data from shallow aquifers which provide water to municipal wells and private domestic wells in Bruni indicate that ground water in this area contains certain trace metal elements such as arsenic, selenium, molybdenum, iron, manganese and some radioactive minerals (uranium, thorium and their daughter products) which occur naturally and in concentrations that are generally above the Texas Department of Health's (TDH) recommended limits for public drinking water standards. In fact, uranium ore is being mined by injection leaching from mines located near Bruni.

Despite this, some individuals question whether the uranium concentration in the ground-water occurs naturally or whether the uranium and other elements detected in the ground water occur because of the mining processes at the Total Minerals and Westinghouse uranium mines.

As a result, the Texas Water Development Board was requested to evaluate the water-quality problems of the ground water produced by the Bruni Water Works. The inquiries were from the Texas Department of Health and Mr. William C. Layton, owner/operator of the Bruni Water Works. Both inquiries requested that the Board determine:

1. If the ground-water contamination in the water-bearing aquifers underlying Bruni is being caused by the uranium mining operations at Total Minerals and Westinghouse;

2. If the aquifers underlying Bruni are being dewatered by the uranium mining operations;

3. If there are any aquifers underlying Bruni which contain ground water which is not contaminated with arsenic and uranium compounds;

4. If there are any intervals which contain good quality ground water; and at what depths they occur;

5. If the Texas Water Development Board can assist in locating sufficient good quality ground water to meet the areas needs; and

6. If the Board can provide any financial assistance to help upgrade the Bruni Water Works water supply and treatment plant.

Location

The unincorporated town of Bruni is located in southeastern Webb County at the junction of State Highway 359 and Farm to Market Road 2050. Figures 1 shows the location of the study area in Webb

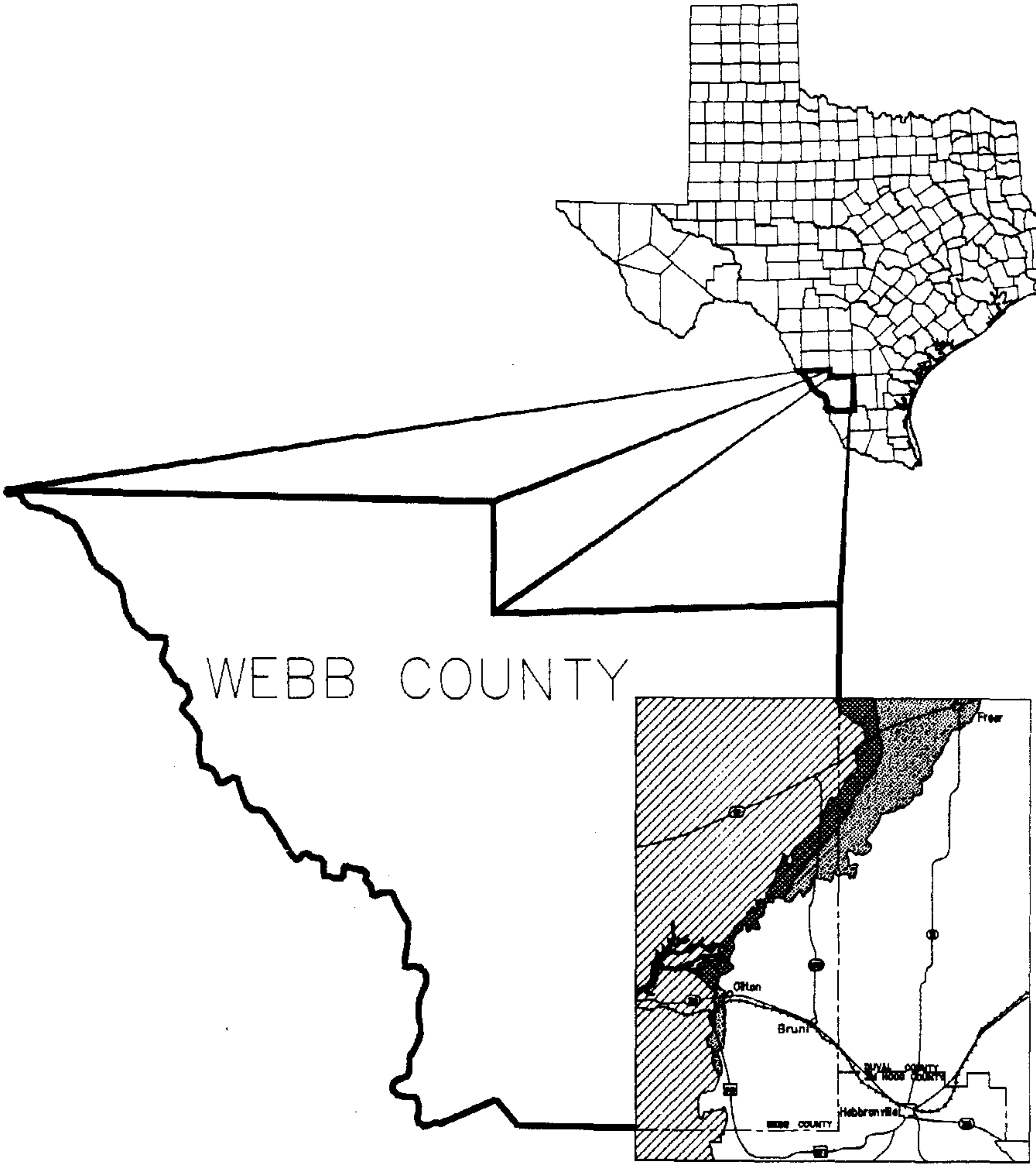


Figure 1

LOCATION OF STUDY AREA

Population and Economy

Population of Bruni is approximately 698, based on 1980 population census and extrapolated to the present.

The economy of Bruni is supported by nearby ranching, uranium mining operations, oil and natural gas drilling/production and related industries, commercial water supply services, and the electric utility corporation located less than a mile north of Bruni. There are no industries within the town of Bruni itself.

The active uranium mines are: Total Uranium Leaching Mine plant located one mile north of Bruni immediately west of Highway 2050, and Malapai-Ohern Uranium Mine located east of Bruni. The inactive uranium mines are: The Westinghouse (formerly Wyoming Minerals) Uranium Mine located 7 miles north of Bruni and immediately west of Highway 2050; the Longoria Uranium Mine located 2 miles east of Bruni and just south of Highway 359; and Mobil-Ohern Uranium Mine, all of which are undergoing ground-water restoration. These mines are shown on Figure 2.

There are two water supply companies which produce and sell raw water commercially for road construction, oil drilling development, and hydrofrac and secondary recovery. These companies are Bruni Water Works and Lowe's Commercial Water Supply.

The people living in the town of Bruni are employed in the oil field operations (production, servicing, and drilling), uranium mining, ranching, retail food stores, teaching-education, and water supply.

Domestic Water Supply and Waste Disposal

There are about 29 residences with private domestic supply wells in Bruni. The wastewater from these residences consists of chlorinated and detergent concentrated laundry water and raw sewage that is disposed of in individual septic and cesspool systems operated and maintained by each resident. These systems can release high sulfates, ammonia, nitrates, phosphates, boron, organic matter, carbon dioxide, and sodium into the shallow aquifers. In some households, these septic tanks and cesspools are hydraulically upgradient of the domestic water supply well(s) and create a potential for contamination of ground water.

Public Water Supply

The majority of the inhabitants of Bruni obtain their domestic water supply needs from the Bruni Water Works Inc., owned and operated by Mr. William C. Layton. Mr. Layton has two producing wells which supply about 100 home connections. The two wells tap a ground water between depths of 300 and 360 feet. The Bruni Water Works also owns two additional wells which are used exclusively for commercial water supply purposes. These two wells are completed at depths of 403 feet and 407 feet respectively. The pressure in the

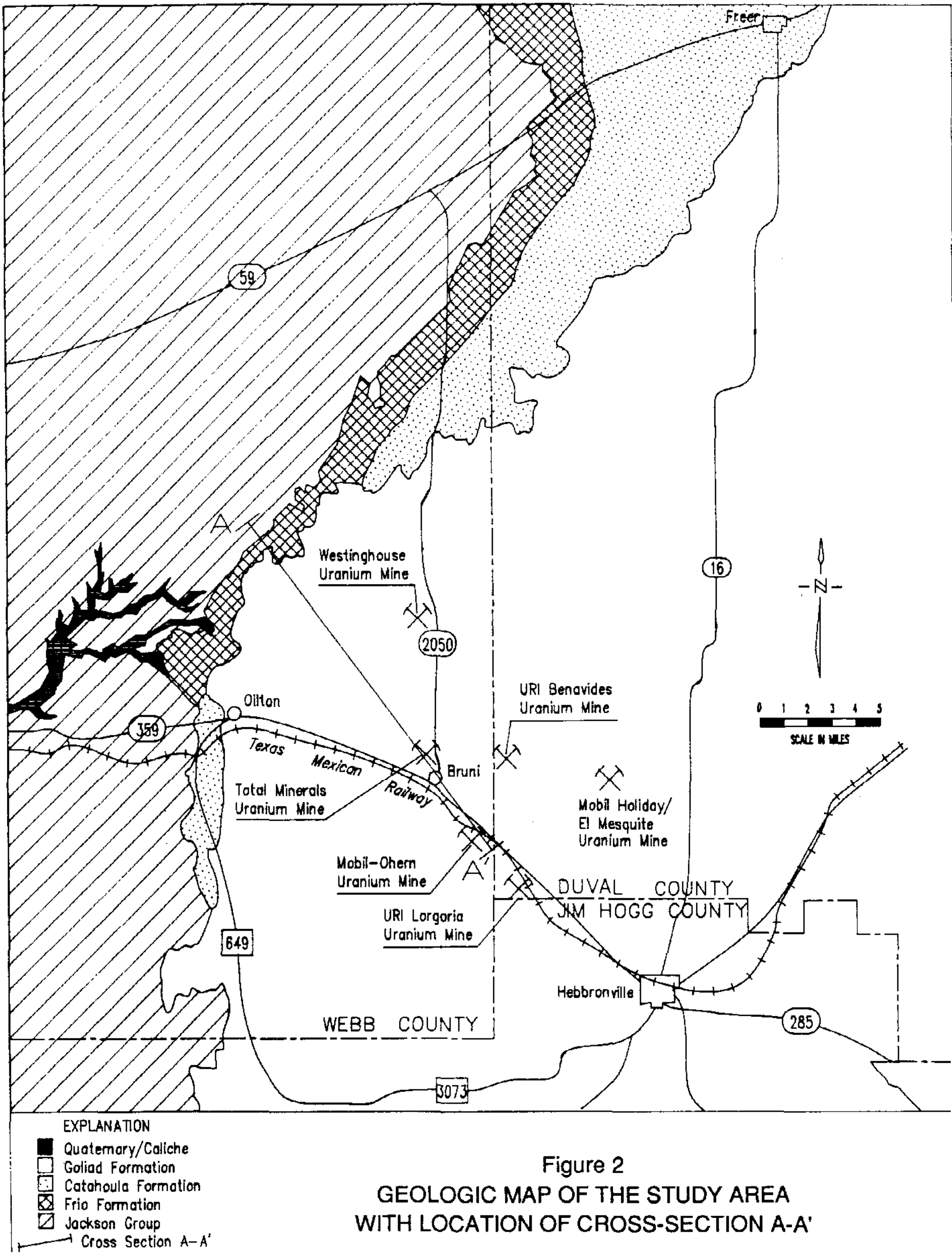


Figure 2
GEOLOGIC MAP OF THE STUDY AREA
WITH LOCATION OF CROSS-SECTION A-A'

water supply lines is generally very low between the well head and the individual home connections. Figure 3A shows how these wells are completed. Sometimes the customers experience complete interruption in supply during regular domestic use. Some of the customers furthest from the Bruni Water Works have been very dissatisfied with this constant in-line low water supply pressure and periodic interruptions. Consequently, many have had their own wells drilled. Figure 3B shows how these wells are generally completed. The Bruni school administration owns and operates two wells which are completed to depths of 389 feet and 530 feet respectively. These wells supply water to the school and to the teachers' residences. Water from the well supplying the school buildings has been reported to have a sulfur odor. It is therefore assumed that this deeper well has a significant hydrogen sulfide concentration. Figure 3C also shows how these wells are completed. Well design and completion methods have a tremendous influence on ground-water chemistry.

Ground water of usable quality for domestic, commercial, and mining injection-recovery processes occur within the area of investigation in rocks of the Frio, Catahula, and Goliad Formations. These rocks subcrop or crop out in an area which strikes in a northeasterly-southwesterly direction and they dip gently in the east-southeast direction at a gradient of 30 feet per mile. They outcrop approximately 11 miles northwest of Bruni and comprise the recharge area for the aquifers (Figure 2). The stratigraphic relationships of the individual lithologies and their water bearing potential are discussed in Table 1 and illustrated in the cross section A-A' (Figure 4). The areal extent of the cross section is shown on Figure 2.

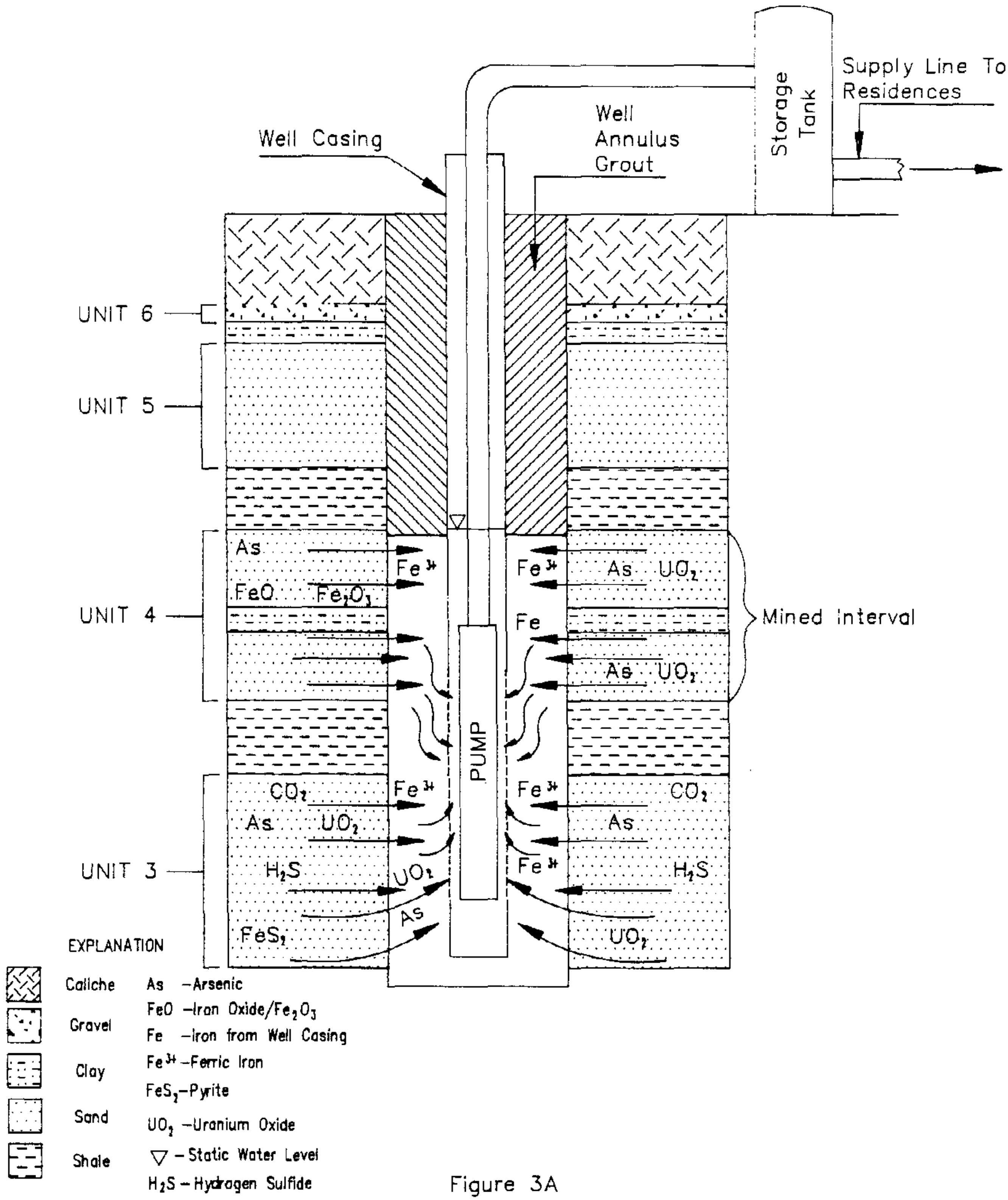
The Westinghouse mine site is located 7 miles north of Bruni. At this mine, uranium was mined from an ore zone extending from 110 feet to 240 feet below land surface. Figure 5 shows the location of water wells at the mine site, and Table 2 portrays the information concerning each well.

The Total Minerals mine site located 5.5 miles south of the Westinghouse mine and 1.5 miles north of Bruni has a uranium production zone extending from 190 feet to 270 feet below land surface. This production ore zone is believed to be the same geologic unit as the one mined by Westinghouse. Figure 6 shows the permit area for the Total Uranium Leaching Mine site.

Since the Total Minerals mine site boundary is only 1.5 mile north of Bruni, the subsurface geologic stratigraphy at Bruni is assumed to be similar. This is supported by drillers records and geophysical logs and shown on geologic cross section B-B's. The areal extent of the cross section is shown on Figure 7.

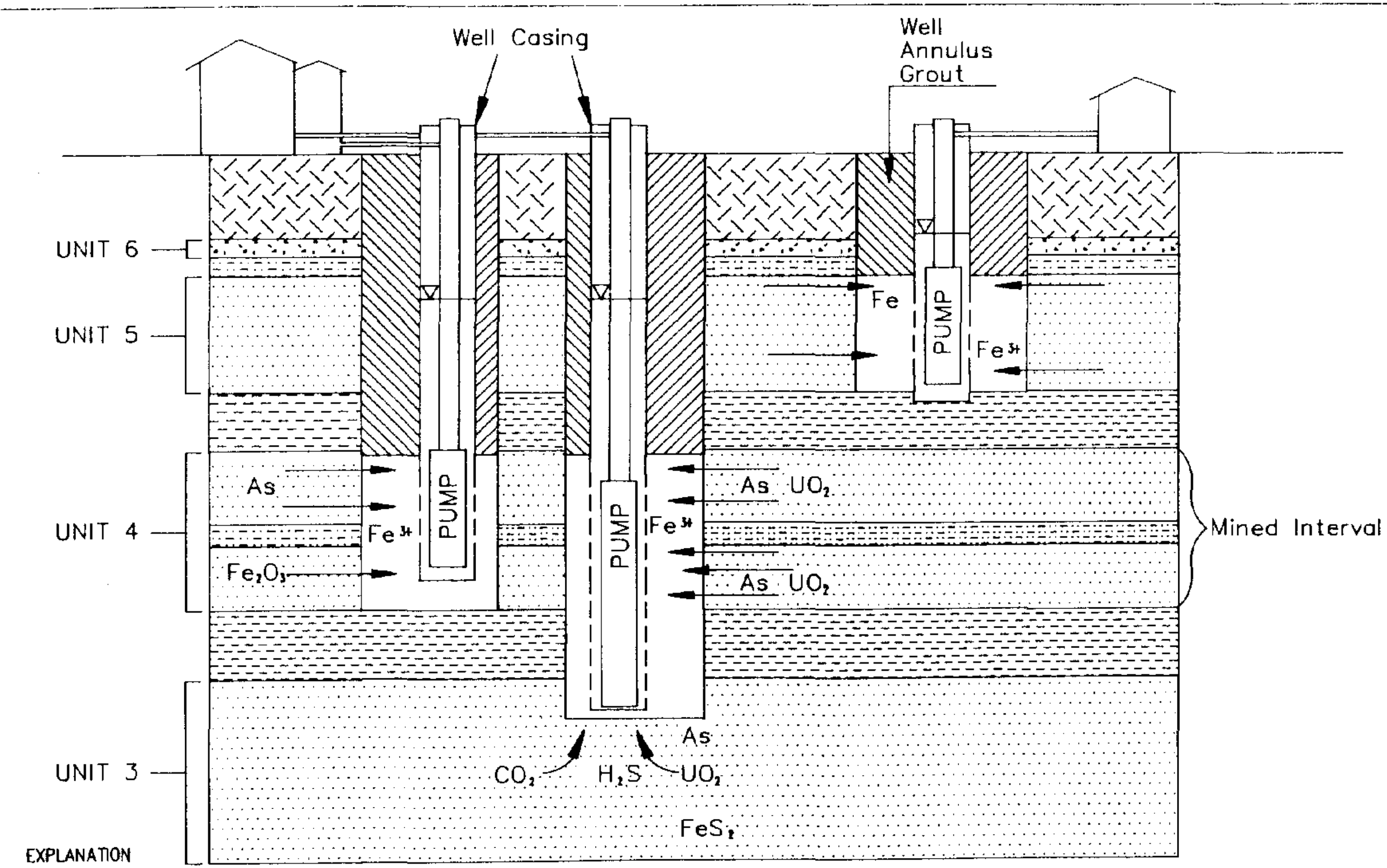
Previous Investigations

The Texas Water Development Board, U. S. Geological Survey, and other governmental entities, as well as private consultants, have gathered ground-water data in parts of Webb and adjacent counties. The more detailed investigations dealing with hydrogeology and



Supply Line To Residences
Storage Tank
Well Casing
Well Annulus Grout
UNIT 6
UNIT 5
UNIT 4
UNIT 3
Mined interval
PUMP
As
Fe 3+
FeO
Fe2O3
As UO2
Fe
CO2
H2S
FeS2
EXPLANATION
Caliche
Gravel
Clay
Sand
Shale
As —Arsenic
FeO —Iron Oxide/Fe2O3
Fe —Iron from Well Casing
Fe 3+ —Ferric Iron
FeS2—Pyrite
UO2 —Uranium Oxide
▽ — Static Water Level
H2S — Hydrogen Sulfide
CO2 — Carbon Dioxide

Figure 3A



EXPLANATION

Caliche

Gravel

Clay

Sand

Shale

As —Arsenic
FeO/Fe_2O_3 —Iron Oxide
Fe —Iron from Well Casing
Fe^{3+} —Ferric Iron
FeS_2—Pyrite
UO_2 —Uranium Oxide
H_2S—Hydrogen Sulfide
CO_2 —Carbon Dioxide
▽ Static Water Level

Figure 3B

WELL COMPLETION DIAGRAM—DOMESTIC SUPPLY WELLS

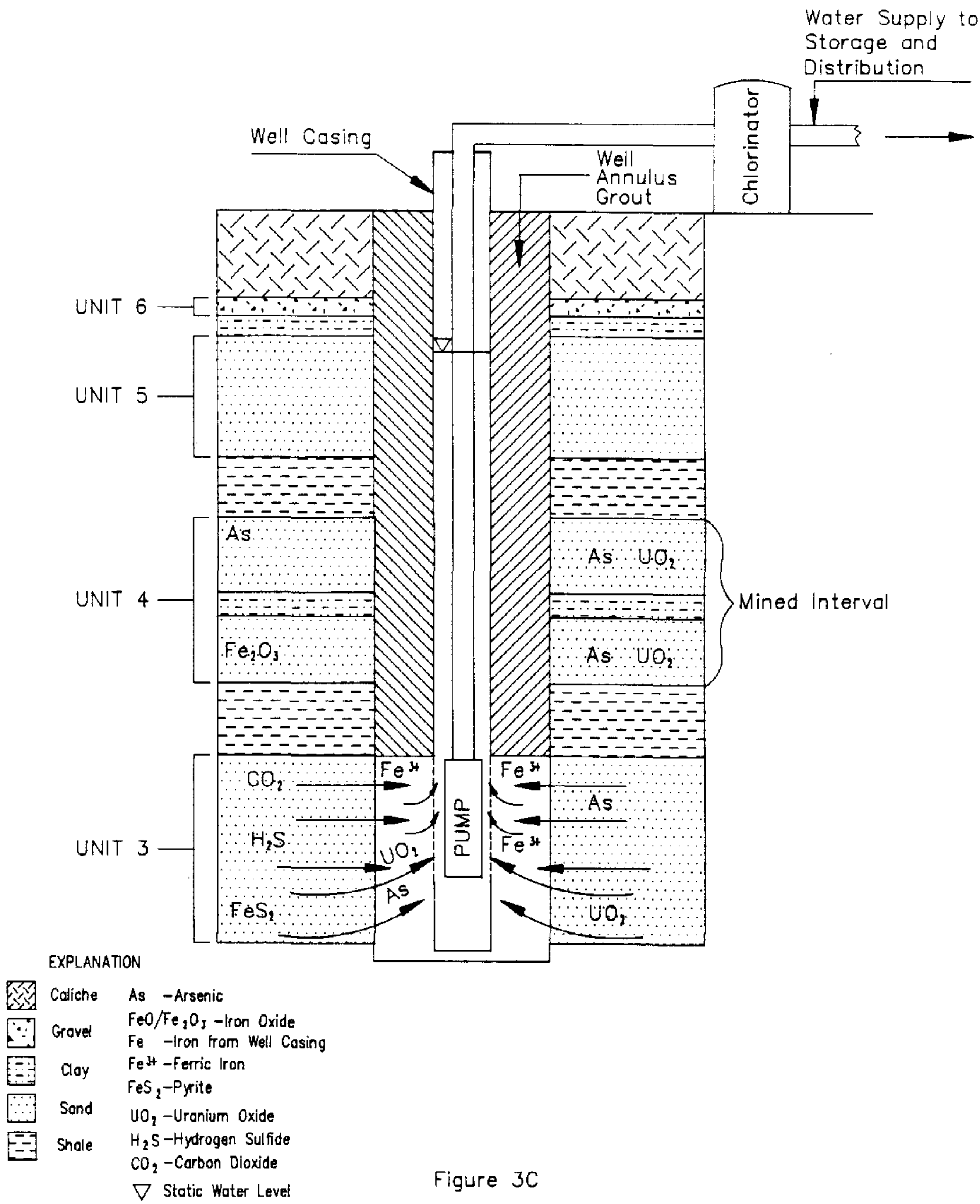


Figure 3C

WELL COMPLETION DIAGRAM—BRUNI SCHOOL SYSTEM WELL

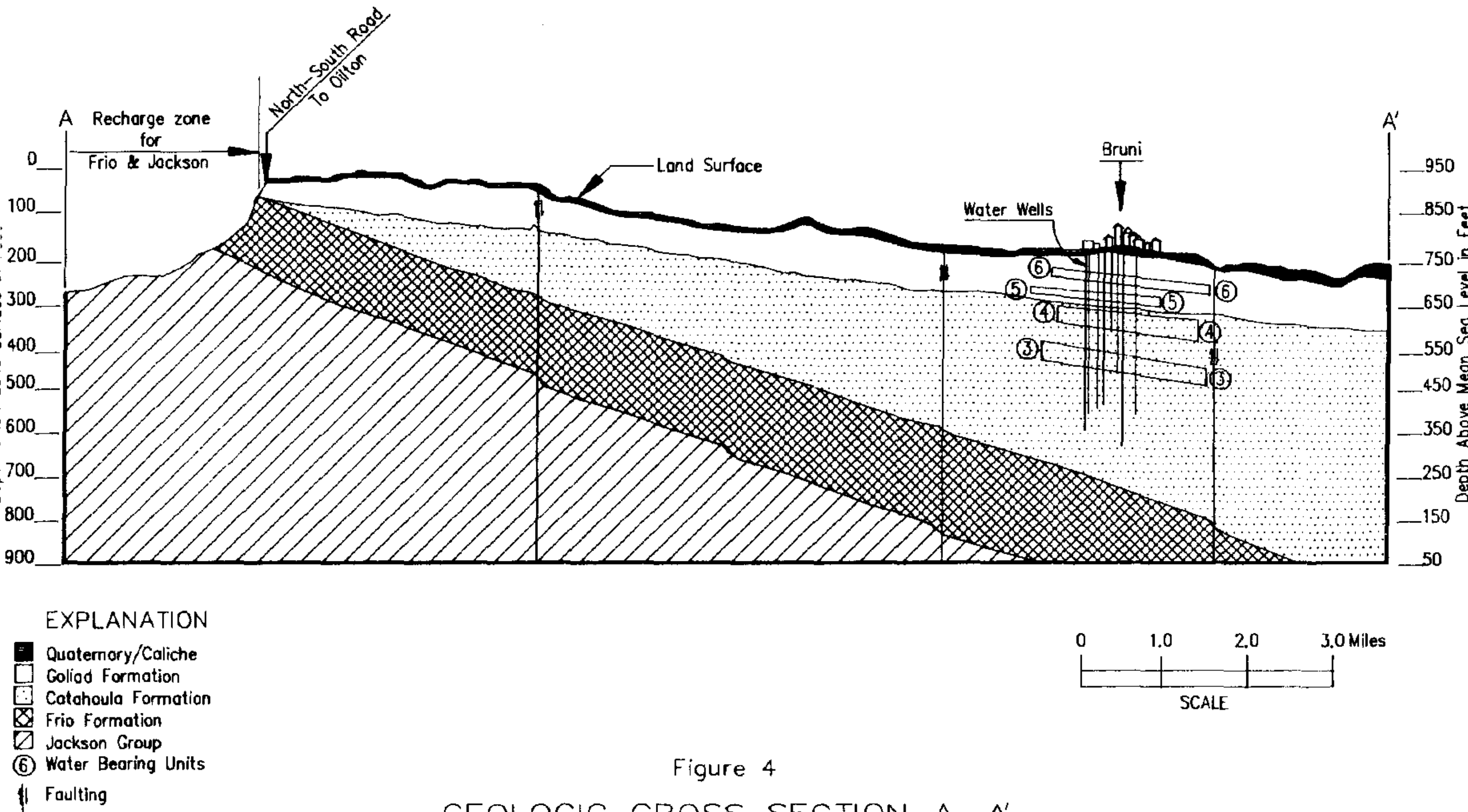


Figure 4

GEOLOGIC CROSS-SECTION A-A'

Table 1.
Geologic Units and Their Water-Bearing Properties

System	Series	Stratigraphic Units		Maximum Thickness (feet)		Lithologic Character	Ground-Water Conditions
aternary	Recent	Alluvium		50		Stream-deposited sand, gravel, and silt.	Alluvium along streams yield variable amounts of water. Quality varies, but in some places the water is suitable for domestic use.
		Unconformity					
rtiary (?)	Pliocene (?)	Uvalde Gravel		25		Gravel, conglomerate and sand.	Not known to yield water.
ertiary	Pliocene	Goliad Formation		75		Reddish sand, caliche, and conglomerate with minor amounts of clay. Sand and conglomerate may be indurated to quartzitic.	Sand and conglomerate yield variable amounts of water at shallow depths in the southeastern part of the county. Quality variable; usually suitable for domestic use.
		Unconformity					
	Miocene (?)	Catahoula Formation	Chusa Tuff Member	675	160–200	Predominantly pyroclastic rocks; tuffaceous sandstone and conglomerate, whitish tuff, grayish and pinkish silicified tuff, purplish and greenish bentonitic clay. Minor amounts on nonvolcanic sandstone and clay are present. Sandstone beds up to 20 feet thick.	Outcrop areas yield very little and in general, highly mineralized water. In the southeastern part of the county wells 150 to 400 feet yield considerable quantities of water, some highly mintities of water, some highly mineralized but some suitable for domestic use and irrigation. Flowing wells occur near Bruni.
			Soledad Volcanic Conglomerate Member		75		
			Font Tuff Member		600		
	Oligocene (?)	Frio Formation		200		Greenish and grayish clay and sandy clay.	Not known to yield water.
	Eocene	Jackson Group		360		Grayish, green, and buff clay, gray to buff sandy clay, buff to light- grayish sandstone, light to white ashy sandstone, and light-gray to white volcanic ash. Ashy beds contain plant and scanty invertibrate fauna fossils.	Yields variable amounts of highly mineralized water.
		Units older than the Jackson Group					

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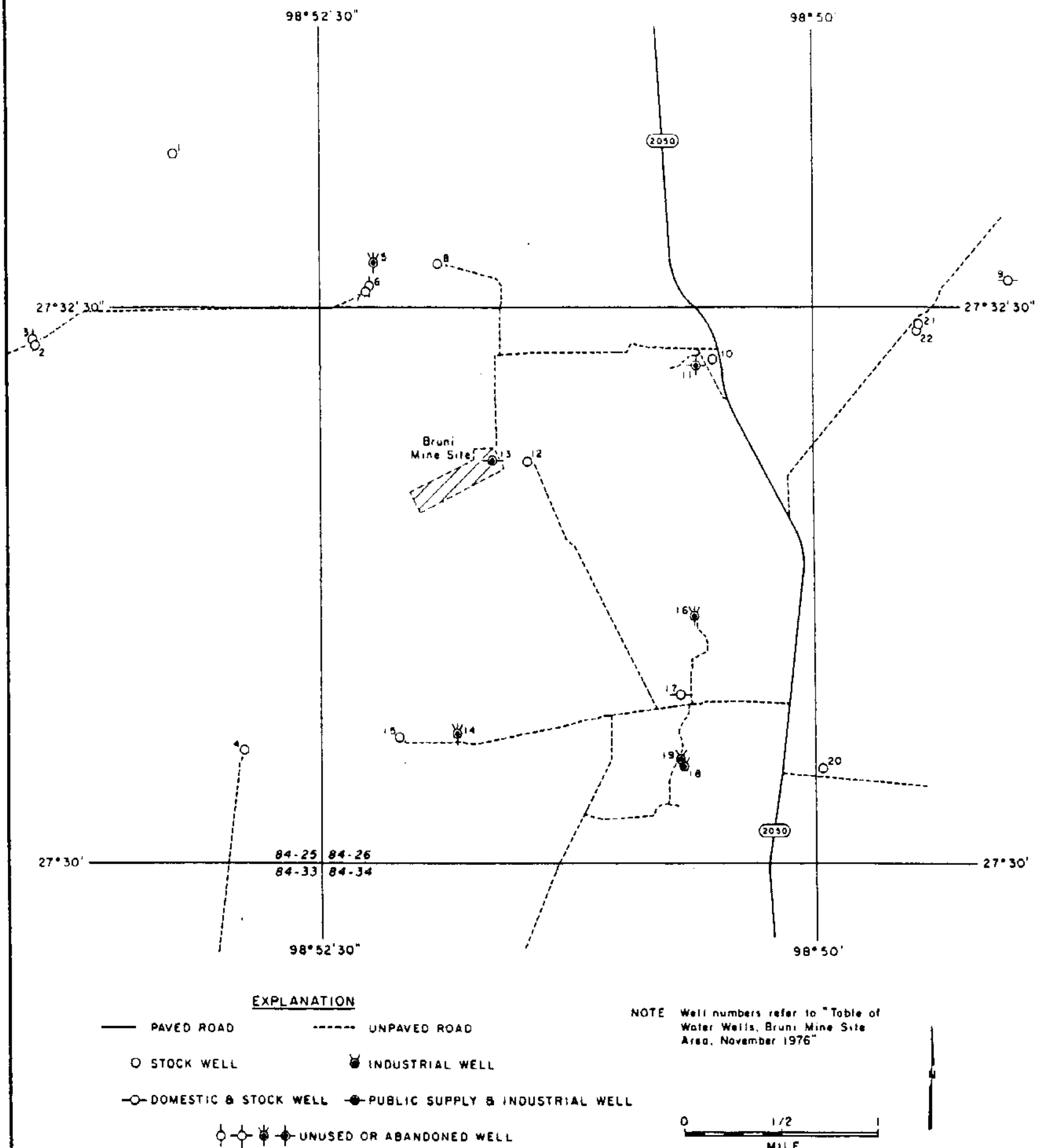


Figure 5

LOCATIONS OF WATER WELLS NEAR WESTINGHOUSE

Table 2
Records of Water Wells in the Study Area

Texas Water Development Board
Ground Water Data System

WELL	OWNER	DRILLER	DATE COM-PLETED	DEPTH OF WELL (FT.)	CASING AND SCREEN DATA: CASING OR SCREEN	DIAM-ETER (IN.)	TOP DEPTH (FT.)	BOT DEPTH (FT.)	WATER BEARING UNIT	ALTITUDE OF LAND SURFACE (FT.)	WATER LEVEL: MEASURE-MENT FROM LSD (FT.)	DATE	METHOD OF LIFT AND POWER	USE OF WATER	REMARKS
4-25-601	Robert Marshall	Dillard Wied	1971	109	C	5	0	76	121GOLD	850	-65.00	06-29-1971	P W	S	
					S	5	76	109			-56.50	12-14-1989			
4-25-701	Armando Benavides	Williamson Drilling	1971	510					122CJCK	930		- -	N	U	
		Company										- -			
4-25-702	Armando Benavides	Molina	1973	440	C	5			122CJCK	930		- -	S E	S	
												- -			
4-26-401	Robert Marshall	Welty Water Wells	1976	167	C	5	0	114	122CTHL	821	-58.00	11-17-1976	P W	S	
					S	5	114	125			-53.50	12-14-1989			
					C	5	125	145							
					S	5	145	158							
4-26-701	Westinghouse Electric	Huerta Water Well	1975	560	C	6	0	343	122CTHL	830	-70.00	04-25-1975	S E	N	
	Corporation	Drilling										- -	10		
4-26-702	Westinghouse Electric			385					122CJCK	820	-109.75	12-10-1985	S E	U	
	Corporation										-159.00	12-11-1989	7.5		
4-26-703	Westinghouse Electric			391					122CJCK	821	-170.00	04-04-1988	S E	U	
	Corporation											- -			
4-33-101	Olton Rural W.S.C.	Wied Drilling	1973	340	C	5	0	178	124JCKS	857	-176.00	08-14-1973	N	U	Measured yield 6.3 GPM with 70 feet
		Company			S	5	178	213			-167.85	07-08-1981			drawdown in 1981.
					C	5	213	242							
					S	5	242	256							
					C	5	256	289							
					S	5	289	340							
4-33-102	Olton Rural W.S.C.	David Morales	1975	300	C		0	198	124JCKS	857	-155.00	08-11-1975	N	U	
					S		198	245				- -			
					O		245	300							
4-33-103				330					124JCKS			- -			
												- -			
4-33-104	Mrs. Gusmaro Garcia								122CTHL	857		- -	S E	U	
												- -			

Table 2 - continued
Records of Water Wells in the Study Area

					CASING AND SCREEN DATA						WATER LEVEL				
WELL	OWNER	DRILLER	DATE COM-PLETED	DEPTH OF WELL '(FT.)	CASING OR SCREEN	DIAM-ETER (IN.)	TOP DEPTH (FT.)	BOT DEPTH (FT.)	WATER BEARING UNIT	ALTITUDE OF LAND SURFACE (FT.)	MEASURE-MENT FROM LSD (FT.)	DATE	METHOD OF LIFT AND POWER	USE OF WATER	REMARKS
1-33-201	Allen Black	Killam Oil	1935	300	C	5			122CTHL	853	-180.00	12-14-1989	S E	H	
												- -	.50		
1-33-202	Allen Black	Killam Oil	1935	100	C	5			121COLD	853	-45.40	12-14-1989	N	U	
												- -			
1-33-601	Robert Marshall	Wied Drilling	1966	258	C	6	0	208	122CTHL	823	-64.00	11-23-1966	S W	S H	
		Company			S	6	208	258			-67.30	12-13-1989			
1-34-401	William A. Layton	Long Brothers	1953	400	C	6			122CTHL	775	-80.20	12-13-1989	S E	P	
	Burni Water Works	Drilling										- -	7.50		
1-34-402	William Layton	Wied Water Well	1967	300	C	6	0	0	122CTHL	776		- -	S E	P	
	City of Bruni #2	Service										- -	7.50		
1-34-403	William Layton	Molina	1969	400	C	6	0	0	122CTHL	776		- -	S E	P	
	City of Bruni #3											- -			
1-34-404	William A. Layton	Howell Water Well	1985	320	C	6	0	230	122CTHL	775	-98.00	06-22-1985	S E	C	
	Bruni Water Works	Drilling			S	6	230	315			-84.25	12-13-1989	7.50		
					C	6	315	320							
1-34-405	Bruni Public Schools	Wied Drilling Co.	1967	345	C	11	0	27	122CTHL	773	-68.00	08-10-1967	S E	T	
					C	7	0	236			-74.85	12-13-1989	7.50		
					S	7	236	345							
1-34-406	Bruni Schools	Wied Drilling	1966	340	C	6	0	237	122CTHL	770	-36.00	09-26-1966	S E	I	
		Company			S	6	237	340			-71.00	12-13-1989	3		
1-34-407	Larry Lowe	Sam Howell Water	1977	210	C	5	0	140	122CTHL	765	-45.00	11-21-1977	S E	H	
		Well Water Drilling			S	5	140	204				- -			
					O		204	210							
1-34-408	Total Minerals	Young	1984	280	C	5	0	202	122CTHL	780	-74.20	08-15-1989	N	U	
	Corporation				S	5	202	217				- -			
1-34-409	Total Minerals	Young	1984	125	C	5	0	102	122CTHL	780	-42.50	08-15-1989	N	U	
	Corporation				S	5	102	117				- -			
1-34-410	Total Minerals	Young	1984	280	C	5	0	259	122CTHL	776	-114.30	06-04-1989	N	U	
	Corporation				S	5	259	274			-88.20	12-11-1989			

Table 2 - continued
Records of Water Wells in the Study Area

WELL	OWNER	DRILLER	DATE COM-PLETED	DEPTH OF WELL (FT.)	CASING AND SCREEN DATA: CASING OR SCREEN	DIAM-ETER (IN.)	TOP DEPTH (FT.)	BOT DEPTH (FT.)	WATER BEARING UNIT	ALTITUDE OF LAND SURFACE (FT.)	WATER LEVEL: MEASURE-MENT FROM LSD (FT.)	DATE	METHOD OF LIFT AND POWER	USE OF WATER	REMARKS
-34-411	Total Minerals Corporations		1987	213	C	5	0	188	122CTHL	769	-106.60	06-04-1989	N	U	
					S	4	188	203			-72.30	12-08-1989			
-34-501	Arturo Benavides		1935	150	C	4			122CTHL	763	-79.30	12-12-1989	S E	H	
												- -	.50		
-34-502	Arturo T. Benavides	Sam Howell Water Well Drilling	1979	326	C	5	0	295	122CTHL	763	-68.00	08-06-1979	S E	H	
					S	5	295	326				- -			
-34-801	Lowes Water Sales	Sam Howell Water Well Drilling	1978	320					122CTHL	742	-32.50	05-07-1978	S E	C	
												- -	3		
-34-802	Lowes Water Sales	Frank Huerta	1981	320	C	6	0	320	122CTHL	742	-80.00	03-09-1981	S E	C	
											-33.30	12-13-1989	3		
-34-803	Lowes Water Sales	D. D. Davis	1981	440	C	6	0	320	122CTHL	748	-80.00	08-20-1981	S E	C	
					S	6	320	350				- -	5		
					C	6	350	370							
-34-804	Lowes Water Sales	Frank Huerta	1982	740	C	6	0	540	122CJCK	747		- -	S E	C	
					S	6	540	620				- -	7.50		
					C	6	620	640							
-34-805	Lowes Water Sales	Howell Water Well Drilling	1985	500	C	6	0	320	122CTHL	747		- -	S E	C	
					S	6	320	340				- -	5		
					C	6	340	440							
					S	6	440	490							
					C	6	490	500							
-41-101	Roberta Garcia		1930		C	5			122CJCK	898		- -	S E	S	
												- -			
-41-201	John Puig		1922	100					121GOLD	896	-67.40	12-14-1989	S E	S	
												- -	.75		

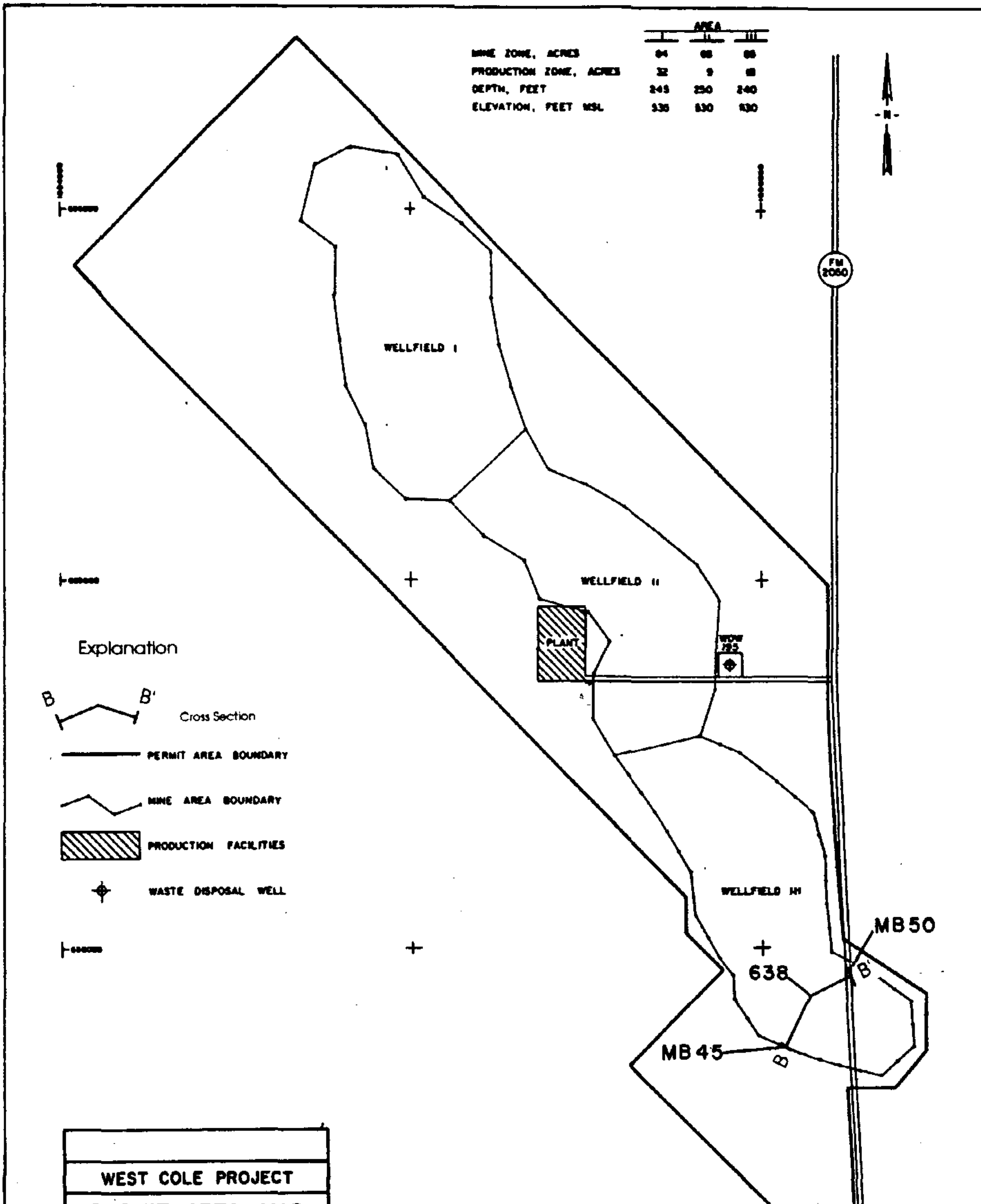


Figure 6
PERMIT AREA FOR THE
TOTAL URANIUM MINE WITH
LOCATION OF CROSS SECTION B-B'

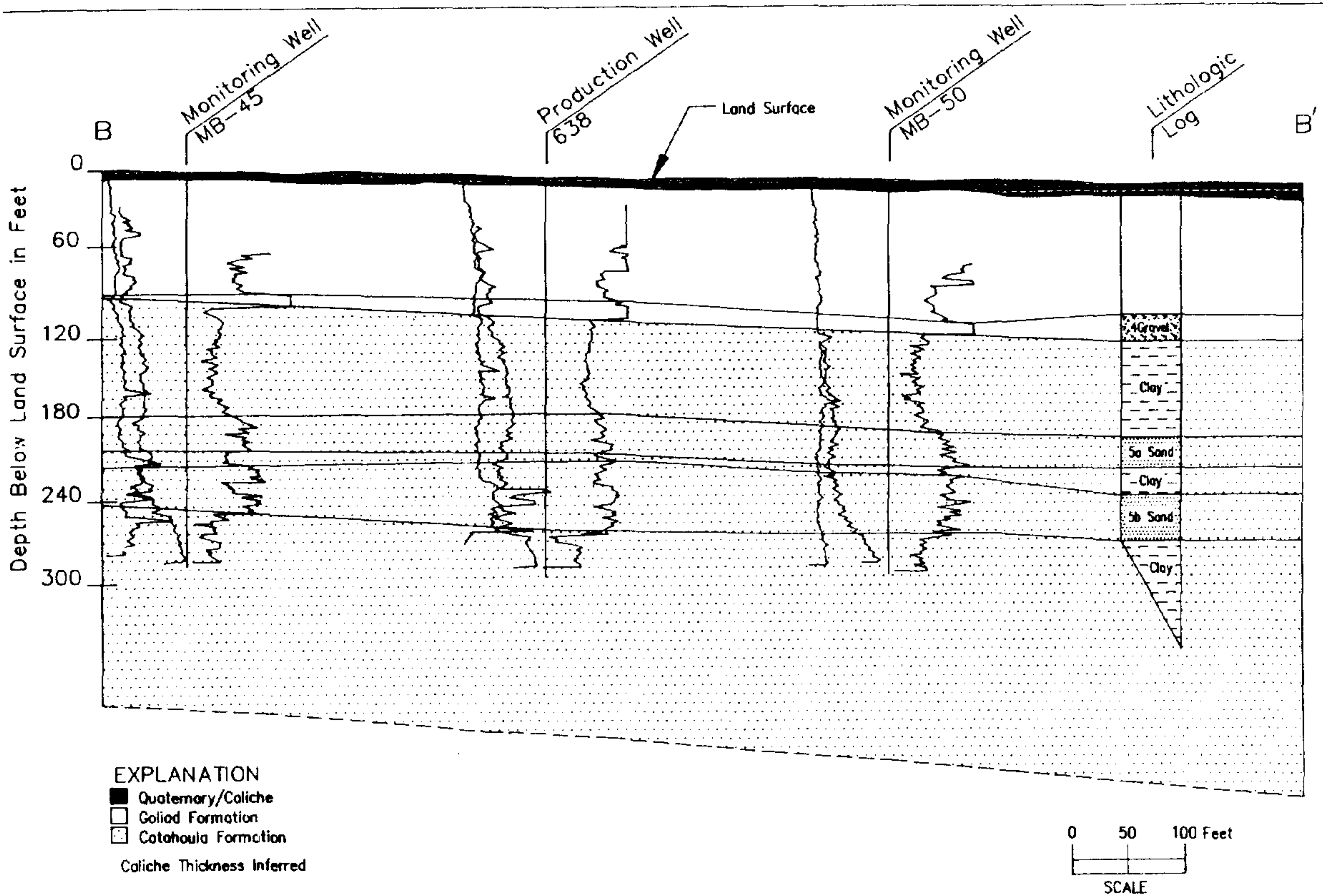


Figure 7
GEOLOGIC CROSS-SECTION B-B'

Source: Total Minerals Corp.
Permit Application, 1987

Personnel

This investigation was conducted by personnel of the Planning Division of the Texas Water Devleopment Board, under the general direction of Dr. Tommy Knowles (P.E.), Division Director, Henry Alvarez, Chief of the Ground Water Section, and Phil Nordstrom of the Ground Water Monitoring Unit.

The author conducted the field and site hydrogeologic investigation, water quality data interpretation, and literature research. Quality assurance of the report review and management was provided by Robert Flores who conducted substantial editing of the draft, and John B. Ashworth, both geologists with the Ground Water Section. Finally, many thanks go to Steve Gifford who drafted the illustrations, Wanda Cooper who typed the text, and Zelphia Bloodworth of Electronic Publishing Services for her typescripting efforts.

Acknowledgements

The detailed account of the potential water-quality problems and uranium leaching mining methods was provided by Dr. Steve Etter and Tony Bennet of the Texas Department of Health; Mr. David Benavides, Mr. William C. Layton, and Mr. Larry Lowe all of Bruni, Texas; Dale Kohler and Charles Greene of the Texas Water Commission.

The author would like to thank the many property and well owners and drillers for providing additional well information in the area.

HYDROGEOLOGIC SETTING

The hydrogeologic setting of the shallow water bearing units is discussed briefly under their appropriate headings in Table 1. Figure 4 is a cross section which shows the outcrop of the hydrogeologic units and their relative depth beneath Bruni.

Geology and Stratigraphy

The rocks which form the Jackson Group are the youngest formation of Eocene Age. The Jackson Group consists of sandstone and clay lithic units with sandstone being predominant. The texture of the sandstone unit is fine to coarse grained, friable to quartzitic, laminated and cross-bedded, fossiliferous, and appears to be white to gray, greenish-brown, light-brown to yellow in color. The sandstone has been reported to yield some water. The clay unit appears to be sandy, calcareous, greenish-gray, pink, red and contains abundant silicified wood. Some beds of white volcanic ash are also found in this formation. Large dark limestone concentrations composed of calcite crystals are common. The maximum thickness of the Jackson Group is up to 360 feet.

The Frio Formation consists of a dark-greenish, gray clay that is massive, and contains some gypsum and calcareous concretions with a thickness of up to 200 feet. It outcrops just about 11 miles west of Bruni in a northeast to south trend extending between Highway 359 near Oilton and FM Road 2050. The length of this outcrop belt is about 19.5 miles.

The Catahoula Formation consists of three Members. In ascending order they are the Fant Tuff Member, the Soledad Volcanic Conglomerate Member, and the Chusa Tuff Member.

The Fant Tuff Member of the Catahoula Formation directly and conformably overlies the Frio Formation and consists of volcanic tuff, claystone, and sandstone. The tuff is grayish white, massively bedded, moderately well indurated, and with lumpy pisolitic texture. The claystone is silty and pale olive to brown in color. The sandstone has multicolored grains and in some parts is interlaminated with pale-brown clay. The Fant Tuff Member reaches a maximum thickness of 600 feet east of Webb County.

Soledad Volcanic Conglomerate Member of the Catahoula is made up of abundant pebbles, cobbles, and boulders which may be up to one foot in diameter of ryholitic, trachytic, and trachyandesitic composition, and are loosely to moderately cemented. It is generally mottled gray and may reach a thickness of 75 feet.

Finally, the Chusa Tuff Member of the Catahoula does not appear to be present in the study area due to past erosion; but where it does occur, in northwest Duval County, it consists of tuffaceous mudstone and clay balls up to 1/2 inch in diameter. It is massive to irregular bedded and is light gray to pink in color. Where present, it may attain a thickness of 160 to 200 feet.

The Goliad unconformably overlies the Soledad Volcanic Conglomerate Member in the study area. It consists of clay, sand, sandstone, mud, caliche, limestone, and conglomerate. Commonly, the clay has light shades of pink and green, and contains calcareous concretions. The sand and sandstone is medium to very coarse grained, in part crossbedded, and mostly made of quartz with some black and red chert. The conglomerate consists of black chert and dark siliceous granules and pebbles in a calcareous (caliche) matrix. The sandstone and conglomerate are locally well bedded while the marl and limestone are poorly bedded and sometimes massive. Tertiary vertebrate and reworked Cretaceous invertebrate fossils are fairly common. It attains a thickness up to 300 feet, but is 75 feet thick near Bruni. It is overlain by very thin caliche soils.

This zone constitutes the recharge area for the Frio, Catahoula and Goliad Formations.

Hydrogeology

In the area between the recharge zone, the town of Bruni, and the Westinghouse (formerly Wyoming Minerals) Uranium Mining Company there are numerous wells which have been completed at various depths producing water either from individual zones or from a combination of zones in the Catahoula and Goliad Formations, some of which contain uranium and trace elements such as arsenic. For purpose of this report, the water-bearing zones have been identified from the deepest to the shallowest as the Aquifer Units 1, 2, 3, 4, 5, and 6, all of which occur in the two formations. Unit 1 occurs at depths of between 550 to 750 feet, Unit 2 between 410 to 520 feet, Unit 3 between 300 to 410 feet, Unit 4 between 190 to 290 feet, Unit 5 between 150 to 170 feet, and Unit 6 between 35 to 90 feet below the surface; and is believed to be in the Goliad Formation. Units 4, 5, and 6 are shown in Figure 4.

The rocks identified in the first five units were deposited from sediments derived from aeolian volcanic tuffaceous materials; fluvial silts, clays, clastics sands, and conglomerates from the Catahoula Formation. The water quality of the connate water within these aquifers derive their characteristics from the chemical constituents (trace metals, rare earth and non-metallic minerals) of the original sediments which after deposition, formed the individual aquifers. The provenance of these sediments were the metaigneous rocks which were fragmented, cindered, and then transported by wind fluvial processes as pyroclastics during the active volcanic events in Mexico and New Mexico. After deposition, these beds underwent hydrodynamic structural settlement and adjustments due to the incipient overburden stresses thereby resulting in several growth faults common in the area (Adams et al., 1981). These faults have influenced the horizontal and vertical ground water flow characteristics within individual aquifers in this area between the outcrop-subcrop at the Bordas Escarpment and Bruni.

The meteoric water which has historically recharged these aquifers has a definite water-quality characteristic which reflects its mixing with minerals which comprise the aquifer matrix. As the meteoric water enters the aquifer outcrop or subcrop area during recharge, it infiltrates the aquifer units vertically and then moves horizontally and hydraulically down gradient. As the recharge water moves down gradient it flushes the aquifer through mass dilution, mixes and reacts in transit with the connate water. It also transports oxygen and carbon dioxide away from the recharge area. The mixing process results in the precipitation and/ or dissolution of certain chemical species, some of which form chemical complexes. The resulting mixture of water may exchange chemical species due to the natural processes of: sorption-adsorption, desorption, ionic exchange, and reduction-oxidation (redox). It may also be influenced by the attendant insitu biochemical reactions from sulfide, iron, nitrogen bacteria and other microorganisms which further reduce or oxidize organic compounds and certain specific minerals. The sulfide, iron, and nitrogen fixing bacteria are the major microorganisms which can be expected to be present in some of these aquifers. The natural chemical changes resulting from these chemical processes are continuous and adjust themselves to flushing from natural recharge, recharge from man's activities, seepage from secondary flooding, and ground-water withdrawal for commercial, municipal and private domestic ground-water use in the study area.

Hydraulic Properties

Ground-water flow through the Catahoula and Goliad Formations is slow. The parameters needed to use Darcy's Law to characterize the rate of ground-water flow are: transmissivity (T), hydraulic gradient (i), hydraulic conductivity (κ), and aquifer thickness (b). The hydraulic conductivity for the Catahoula Formation aquifers (Units 1, 2, 3, and 4) is assumed to be on the order of 18.7 feet per day. The storage coefficient is about 0.0008, while the hydraulic gradient in Units 3 and 4 have been reported to be 0.004 and 0.006, respectively. Using Darcy's Law the ground-water flow velocity in these aquifers can be determined as follows:

$$i = \frac{h_1 - h_2}{L}$$

$$Q = kiA$$

$$q = \frac{Q}{hA} = ki$$

$$q = V = \text{average linear velocity}$$

(i) $$V_4 = (21.7 \times 10^{-5}\ ft/sec \times 35.6\ 10^{-6}\ sec/yr)$$

$$V_4 = 30.9\ ft/yr \text{ in Unit 4}$$

(ii) $$V_3 = (21.7 \times 10^{-5}\ ft/sec \times 35.6\ 10^{-6}\ sec/yr)$$

$$V_3 = 13.02 \times ft/yr \text{ in Unit 3}$$

$$T = kb\ 505\ gpd/ft \text{ (range is 297 to) in Unit 4 per Total Minerals Company, 1987 permit.}$$

where h_1, h_2 = water level between any two points
L = horizontal, linear distance between any two points, of water levels
Q = aquifer discharge or yield
A = surface area of aquifer perpendicular to the direction of flow
q = specified discharge, linear velocity
η = porosity, assuming .25
V = linear velocity

The ground water flow has been reported to range between 5 feet to 30 feet per year in Units 3 and 4 and is toward the east-southeast direction. The results of the aquifer test conducted by Total Minerals Uranium Company are shown on Table 3.

Hydraulics of Ground Water Near the Mines and Bruni

The flow of ground water occurs because of the existing hydrostatic pressure or potential energy gradient. Consequently, ground water will flow from a high to low gradient between any two points along the flow path. Ideally the flow path is supposed to be perpendicular to the equipotential contour lines creating a rectangular mesh as shown in Figure 8. This assumes that the aquifer rock matrix and the geometry of the porous zone forms a uniform physical characteristic between any two points regardless of the distance. Practical field examples of ground-water flow characteristics show that the flow field vector is generally distorted because the aquifer rock matrix is composed of zones of both low and high permeabilities which results in a preferential flow path with the energy gradient as the driving and controlling force of ground-water flow. The aquifers in the Catahoula Formation are considered to have preferential flow paths.

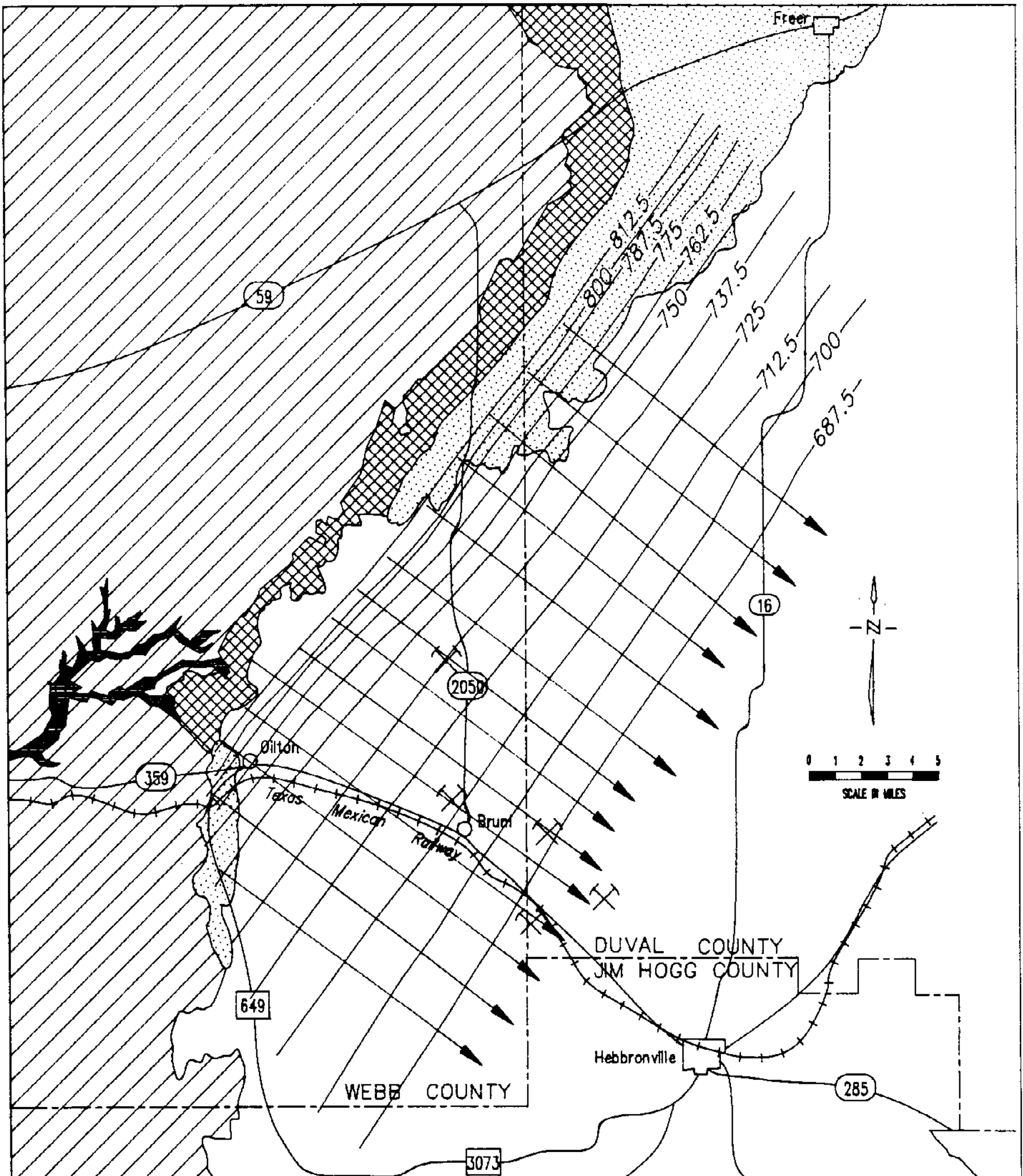
Apart from these natural influences, the ground-water flow pattern can be further distorted by recharge basins, earth impoundments (tanks), recharge/injection wells, industrial production (recovery) wells, any dewatering wells, and municipal/domestic water wells. Figure 9 shows the distorted flow field modified from that of Figure 8 by recharge, recovery and water-supply wells.

The ground-water flow direction between the recharge zone and Bruni should appear similar to the flow net shown on Figure 8. However, ground-water pumpage by Bruni Water Works and other nearby wells will slightly distort the natural flow direction within a one mile radius of Bruni (Figure 9). Total Mineral's mining operation is located 1.5 miles north of Bruni and consists of ground-water recharge (injection) wells and recovery (withdrawal) wells. These wells distort local ground-water flow in the aquifer as the ore is mined. Because the water producing unit in which the uranium mine wells are completed (Unit 4) is separated by a 15 foot thick aquitard, the ground-water recharge/withdrawal operations at the mine site should have no significant influence upon ground-water flow direction in Unit 3, where BWW wells are completed. Consequently, the ground-water flow net created by the pumpage of BWW wells should show a different configuration in Unit 3, and should rarely affect Unit 4 which supplies the mining operations.

At the Westinghouse Uranium Mining Company site located 7 miles north of Bruni, the uranium has been mined in the aquifer zone

Table 3
Results of Aquifer Tests, Total Minerals Uranium Mine

Sand Unit	Pump Test	Well	Hours Pumped	Flow (gpm)	Results Well/Drawdown (ft)	
5a	1	605	26.00	12.0	SO-14	0.23
					SO-15	3.09
					SO-16	5.35
					SO-17	5.08
					SO-18	3.00
					SO-19	1.60
5a	2	605	40.32	16.3	MA-38	—
					MA-39	0.43
					MA-40	1.35
					MA-41	2.27
					MA-42	—
					MA-43	7.43
					MA-44	4.25
					MA-45	3.99
					MA-46	3.24
					MA-47	2.26
					MA.48	2.00
					MA-49	2.95
					MA-50	4.07
					MA-51	5.45
					MA-52	4.49
					MA-53	—
					MA-54	2.36
					MA-55	0.60
					MA-56	0.98
					MA-29	0.21
					SO-14	1.58
					SO-15	5.10
					SO-16	9.29
					SO-17	10.15
					SO-18	6.23
					SO-19	3.84
5a	3	605	22.25	16.4	MA-42	4.43
					MA-53	1.73
5a	4	SO-14	14.43	2.5	MA-38	1.66
					MA-29	5.15
5b	1	605	26	12.0	M-27	0.88
					MB-38	1.56
					MB-39	3.66
					MB-40	5.60
					MB-41	6.74
					MB-42	6.43
					MB-43	3.33
					MB-44	1.84
					MB-45	1.47
					MB-46	1.18
					MB-47	0.95
					MB-48	1.06
					MB-49	1.44
					MB-50	2.25
					MB-51	3.84
					MB-52	5.27
					MB-53	5.89
					MB-54	4.06
					MB-55	3.37
					MB-56	2.57
					M-29	1.78



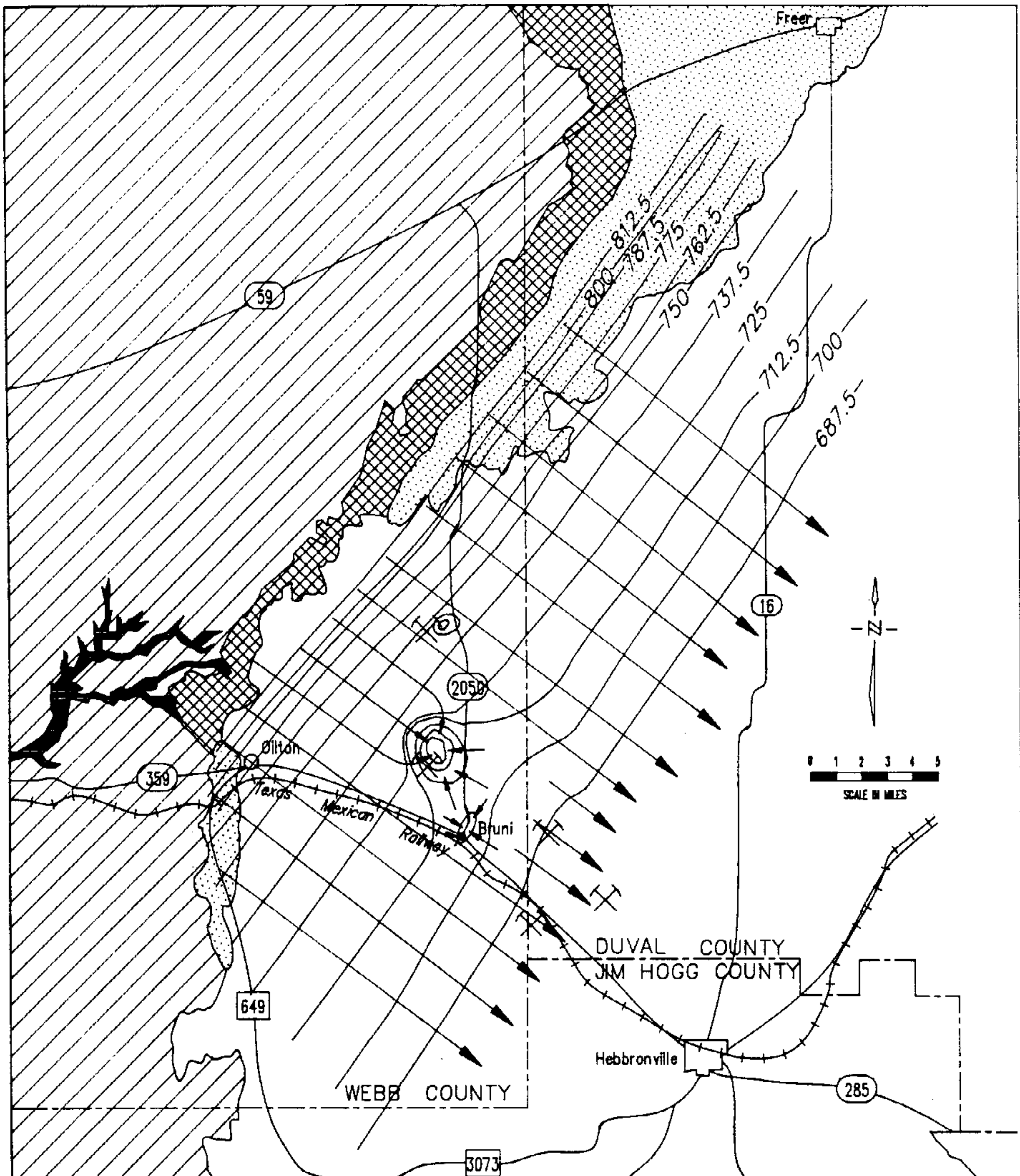
EXPLANATION

- Quaternary/Caliche
- Goliad Formation
- Catahoula Formation
- Frio Formation

Flow Net and Direction, Elevations in Feet Above Mean Sea Level 12.5 Foot Intervals

Figure 8

MAP SHOWING THE NORMAL



EXPLANATION

- Quaternary/Caliche
- Goliad Formation
- Catahoula Formation
- Frio Formation

Flow Net and Direction, Elevations in Feet Above Mean Sea Level 12.5 Foot Intervals

Figure 9

MAP SHOWING THE DISTORTED

the same zone in which uranium is being mined by the Total Minerals Uranium Mining Company near Bruni (Unit 4). The Westinghouse Uranium Mining Company uses state of the art mining methods, incorporating the barren lixiviant injection leaching process with the recovery of "pregnant" leached solutions by wells working in tandem (Greene, 1983; TDMI, 1979; Total, 1987). Initially Westinghouse had used ammonium bicarbonate (NH_4HCO_3) instead of sodium bicarbonate ($NaHCO_3$) as a uranium complexing agent. This created some difficulty because the ammonium (NH4+) ion from the complexing agent adsorbed strongly on clay particles within the aquifer making ground-water restoration of ammonia and nitrate difficult (Henry et al., 1982). Consequently, Westinghouse switched to $NaHCO_3$ as the complexing agent and retained oxygen and hydrogen peroxide as the oxidants.

Based on the available hydrologic information and considering 7 miles of lateral distance from the Westinghouse mine to Bruni; it is felt that any cone of depression and it's radius of influence, resulting from the current ground-water restoration/remediation work at the Westinghouse Mine, does not reasonably have any significant hydrodynamic influence on the ground-water flow pattern in the uranium bearing aquifer at Total Minerals Uranium Mine Phase III field site; or underneath the town of Bruni, the Bruni Water Works (Unit 3) and local domestic supply wells (Unit 4) at Bruni.

Water Quantity

There are six major water bearing units whose combined storage should be sufficient to sustain public water supply, livestock ranching supply and normal mining related water supply needs. Most aquifers have been reported to yield between 5 to 30 gallons per minute (gpm) and have transmissivities ranging from 200 to 900 gallons per day (gpd) per square foot. Pumpage of ground water from domestic water wells and mining in Unit 4 is not expected to create a critical depletion to the aquifer's storage since the duration of pumpage for mining is dictated by the usually short active life of the mine coupled with the economic yield of the aquifer. Although a mine will initially produce significant quantities of water from Unit 4 during the active operations, this impact will be limited to the duration of active mining. Prior to 1937, several wells completed in the Catahoula Formation aquifers in and near Bruni were drilled to depths ranging from 273 to 277. They were reported to flow and were pumped up to 336,000 gpd. By 1937, however, the artesian head in some of these wells was reported to have declined to 5 feet below land surface. A well owned by the Texas-Mexican Railway in Bruni was completed to a depth of 271 feet and flowed 8 gpm. By 1937, however, its hydraulic head had declined 44 feet below land surface. In the Goliad Formation, windmills yielded 2 to 20 gpm while industrial supply wells yielded 35 gpm. A ranch located southwest of Bruni had seven wells reported to have yielded 120,000 gpd by 1937. (Lonsdale and Day, 1937). One of the wells belonging to Lowe's Commercial Water Supply still flows. The estimated total volume of water in storage, per unit, is shown on Table 4. The table also shows the parameters used to determine the availability of water in the individual units.

Table 4
Estimates of Ground Water Availability

ifer it	Aquifer Area (acres)	Aquifer Thickness (ft)	Porosity (28%)*	Volume of Water in Storage (ac-ft)	Storage Coefficient or Specific Yield (gpm/ft)	Available Ground Water (ac-ft)
	140,800	12.0	0.28	473,088	0.25	118,272.0
	142,720	65.0	0.28	2,597,504	$5x10^{-4}$	1,298.0
	142,720	105.0	0.28	4,195,968	$5x10^{-4}$	2,098.0
	142,720	100.0	0.28	3,996,160	$5x10^{-4}$	1,998.0

med

Water Quality

Historical and recent water-quality data is listed in Table 5 by state well numbers, which can be cross-referenced for ownership with the record of wells (Table 2).

The quality of the water in Unit 1 is highly brackish, contains excess chloride, sodium, hydrogen and other sulfide compounds, and has a dissolved solids content in excess of 3,000 milligrams per liter (mg/l). This water is of $NaCl$-$NaHCO_3$ type and contains trace elements such as arsenic, selenium, molybdenum and uranium. The water quality is believed to be influenced by the combined natural organic and inorganic compounds and chemical reactions resulting from the interaction of the aquifer matrix, local seepage of brackish water from underlying water bearing units, probable seepage of oil field saline waters through geologic faults, poorly cased wells, deteriorating casing, casing seals and water wells which were improperly converted from gas or oil wells near Bruni.

The ground-water quality in Unit 2 is of marginal to poor quality. There are two wells completed in this unit, one of which provides water for ranch and livestock supply about one mile west of Bruni. The other, located at the school, supplies water for domestic and other daily school use. Water quality data for this aquifer is not available, but at its depth of completion, it is anticipated that the water quality should be highly mineralized, brackish, and contain hydrogen sulfide. Westinghouse drilled and completed two wells in this unit at their mine 7 miles north of Bruni, and screened them to depths of 400 and 500 feet to supply drinking water to the mine plant.

Unit 3 is the aquifer in which the Bruni Water Works (BWW) water supply wells are completed. The water quality in this unit is marginally acceptable to fair and is of predominantly $NaHC0_3$-Na_2S0_4 type. It contains arsenic at concentration levels ranging from 0.03 to 0.2 mg/l. The TDH's acceptable arsenic range is below .05 mg/l. The dissolved solids in this unit ranges from 774 to 1500 mg/l. Uranium and certain radioactive decay daughter products have also been identified in the ground water of this unit (Table 6). Since the BWW wells are screened across units 3 and 4, the arsenic and radioactive element concentration levels are expected to be the composite of its concentration in the two separate water bodies. Individually, Unit 4 is expected to have a relatively higher arsenic and uranium concentration than Unit 3, since it generally contains uranium and other trace elements such as arsenic, molybdenum, pyrite, selenium, iron, manganese, zinc, chromium, barium and copper. These were part of the fine rock particles and sediments which comprise the volcanic tuff which were transported by the aeolian and fluvial processes. Having been originally deposited in a chemically oxidizing environment and later exposed to a chemically reducing environment such as sulfides and organic matter, they resulted in the formation of FeS_2, MoS_2, As_2S_5, As_2S_3, Cu_2S, and H_2S (Adams et al., 1981). However, with the continuous biochemical process and intrinsic chemical reactions that have taken place over the years, coupled with the fresh flushing of oxygen-bearing recharge waters, chemical changes resulting from the ongoing oxidation-

Table 5
Results of Water Analyses, Bruni Waterworks Inc. and Other Wells in and Near Bruni

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Texas Water Development Board
Ground Water Data System

Ground Water Quality Samples
County – Webb

Aquifer	Well Depth (Feet)	Date of Collection	pH	Silica (SiO2) MG/L	Calcium (Ca) MG/L	Magnesium (Mg) MG/L	Sodium (Na) MG/L	Potassium (K) MG/L	Carbonate (CO3) MG/L	Bicarb. (HCO3) MG/L	Sulfate (SO4) MG/L	Chloride (Cl) MG/L	Fluoride (F) MG/L	Nitrate (NO3) MG/L	Dissolved Solids MG/L	Spec. Cond. (micromhos)	Hardness as CaCO3 MG/L	Percent Sodium	SAR	RSC
122CTHL		08/06/1966 U	8.7		3		181		12	268	41	87	0.8	0.4	602		8			
122CTHL		01/26/1971	8.7		6	2	219		10	261	42	168	0.8	0.4	720	1112	21	95	19.8	4.1
122CTHL		01/15/1973	8.9		2	2	200		19	303	37	98	0.9	0.4	679	973	11	97	23.9	5.3
122CTHL		07/10/1974	8.8		1	1	212		12	318	32	118	0.9	0.6	702	1015	5	98	35.9	5.5
122CTHL	400	03/25/1986	7.2		7	2	289		0	356	112	182	0.7	3.8	771	1463	25	96		5.3
122CTHL	320	04/20/1989	8.4	44	7	2	299	7	5	362	107	172	0.7	10.5	832	1450	26	96	25.5	5.6

lue here reflects the bottom of the SAMPLED INTERVAL which was different from the completed well depth

Table 5–continued
Results of Water Analyses,
Bruni Waterworks Inc. and Other Wells In and Near Bruni

INFREQUENT CONSTITUENT REPORT   COUNTY - Webb

STATE WELL NUMBER	DATE	SAMPLE #	STORET CODE	DESCRIPTION	FLAG	VALUE	CONFIDENCE +OR-
8434404	04/20/1989	1	00610	NITROGEN, AMMONIA, TOTAL (MG/L AS N)	<	0.02	
8434401	12/18/1987	1	01000	ARSENIC, DISSOLVED (UG/L AS AS)		76	
8434402	12/18/1987	1	01000	ARSENIC, DISSOLVED (UG/L AS AS)		197	
8434403	03/25/1986	1	01000	ARSENIC, DISSOLVED (UG/L AS AS)		88	
8434403	12/18/1987	1	01000	ARSENIC, DISSOLVED (UG/L AS AS)		71	
8434404	04/20/1989	1	01000	ARSENIC, DISSOLVED (UG/L AS AS)		100	
8434404	06/07/1989	1	01000	ARSENIC, DISSOLVED (UG/L AS AS)		102	
8434401	12/18/1987	1	01005	BARIUM, DISSOLVED (UG/L AS BA)	<	50	
8434402	12/18/1987	1	01005	BARIUM, DISSOLVED (UG/L AS BA)	<	50	
8434404	04/20/1989	1	01005	BARIUM, DISSOLVED (UG/L AS BA)		50	
8434401	12/18/1987	1	01025	CADMIUM, DISSOLVED (UG/L AS CD)	<	5	
8434402	12/18/1987	1	01025	CADMIUM, DISSOLVED (UG/L AS CD)	<	5	
8434404	04/20/1989	1	01025	CADMIUM, DISSOLVED (UG/L AS CD)	<	10	
8434401	12/18/1987	1	01030	CHROMIUM, DISSOLVED (UG/L AS CR)	<	20	
8434402	12/18/1987	1	01030	CHROMIUM, DISSOLVED (UG/L AS CR)	<	20	
8434403	03/25/1986	1	01030	CHROMIUM, DISSOLVED (UG/L AS CR)	<	20	
8434404	04/20/1989	1	01030	CHROMIUM, DISSOLVED (UG/L AS CR)	<	20	
8434401	12/18/1987	1	01040	COPPER, DISSOLVED (UG/L AS CU)	<	20	
8434402	12/18/1987	1	01040	COPPER, DISSOLVED (UG/L AS CU)	<	20	
8434403	03/25/1986	1	01040	COPPER, DISSOLVED (UG/L AS CU)	<	20	
8434404	04/20/1989	1	01040	COPPER, DISSOLVED (UG/L AS CU)	<	20	
8433101	09/24/1973	1	01045	IRON, TOTAL (UG/L AS FE)		130.	
8433101	07/02/1975	1	01045	IRON, TOTAL (UG/L AS FE)		200.	
8433103	10/24/1979	1	01045	IRON, TOTAL (UG/L AS FE)		200.	
8433103	09/18/1980	1	01045	IRON, TOTAL (UG/L AS FE)		300.	
8433104	08/06/1966	1	01045	IRON, TOTAL (UG/L AS FE)		0.	
8433104	01/15/1973	1	01045	IRON, TOTAL (UG/L AS FE)		200.	
8433104	07/10/1974	1	01045	IRON, TOTAL (UG/L AS FE)		200.	
8434401	12/18/1987	1	01045	IRON, TOTAL (UG/L AS FE)		40	

Table 5–continued
Results of Water Analyses,
Bruni Waterworks Inc. and Other Wells In and Near Bruni

INFREQUENT CONSTITUENT REPORT   COUNTY - Webb

STATE WELL NUMBER	DATE	SAMPLE #	STORET CODE	DESCRIPTION	FLAG	VALUE	CONFIDENCE +OR-
8434403	03/25/1986	1	01045	IRON, TOTAL (UG/L AS FE)	<	20	
8434403	12/18/1987	1	01045	IRON, TOTAL (UG/L AS FE)		180	
8434404	04/20/1989	1	01045	IRON, TOTAL (UG/L AS FE)		69	
8434401	12/18/1987	1	01049	LEAD, DISSOLVED (UG/L AS PB)	<	20	
8434402	12/18/1987	1	01049	LEAD, DISSOLVED (UG/L AS PB)	<	20	
8434404	04/20/1989	1	01049	LEAD, DISSOLVED (UG/L AS PB)	<	50	
8433101	09/24/1973	1	01055	MANGANESE, TOTAL (UG/L AS MN)		50.	
8433101	07/02/1975	1	01055	MANGANESE, TOTAL (UG/L AS MN)		0.	
8433103	10/24/1979	1	01055	MANGANESE, TOTAL (UG/L AS MN)		0.	
8433103	09/18/1980	1	01055	MANGANESE, TOTAL (UG/L AS MN)		0.	
8433104	08/06/1966	1	01055	MANGANESE, TOTAL (UG/L AS MN)		0.	
8433104	07/10/1974	1	01055	MANGANESE, TOTAL (UG/L AS MN)		100.	
8434401	12/18/1987	1	01055	MANGANESE, TOTAL (UG/L AS MN)	<	20	
8434402	12/18/1987	1	01055	MANGANESE, TOTAL (UG/L AS MN)		1130	
8434402	12/18/1987	1	01055	MANGANESE, TOTAL (UG/L AS MN)		60	
8434403	03/25/1986	1	01055	MANGANESE, TOTAL (UG/L AS MN)	<	20	
8434403	12/18/1987	1	01055	MANGANESE, TOTAL (UG/L AS MN)	<	20	
8434404	04/20/1989	1	01055	MANGANESE, TOTAL (UG/L AS MN)	<	20	
8434404	04/20/1989	1	01062	MOLYBDENUM, TOTAL (UG/L AS MO)		47	
8434401	12/18/1987	1	01075	SILVER, DISSOLVED (UG/L AS AG)	<	10	
8434403	03/25/1986	1	01075	SILVER, DISSOLVED (UG/L AS AG)	<	10	
8434404	04/20/1989	1	01075	SILVER, DISSOLVED (UG/L AS AG)	<	10	
8434404	04/20/1989	1	01085	VANADIUM, DISSOLVED (UG/L AS V)	<	20	
8434401	12/18/1987	1	01090	ZINC, DISSOLVED (UG/L AS ZN)	<	20	
8434402	12/18/1987	1	01090	ZINC, DISSOLVED (UG/L AS ZN)		100	
8434403	03/25/1986	1	01090	ZINC, DISSOLVED (UG/L AS ZN)	<	20	
8434403	12/18/1987	1	01090	ZINC, DISSOLVED (UG/L AS ZN)		30	
8434404	04/20/1989	1	01090	ZINC, DISSOLVED (UG/L AS ZN)		20	

Table 5–continued
Results of Water Analyses,
Bruni Waterworks Inc. and Other Wells In and Near Bruni

INFREQUENT CONSTITUENT REPORT   COUNTY - Webb

STATE WELL NUMBER	DATE	SAMPLE #	STORET CODE	DESCRIPTION	FLAG	VALUE	CONFIDENCE +OR-
8434401	12/18/1987	1	01145	SELENIUM, DISSOLVED (UG/L AS SE)		10	
8434402	12/18/1987	1	01145	SELENIUM, DISSOLVED (UG/L AS SE)	<	2	
8434403	03/25/1986	1	01145	SELENIUM, DISSOLVED (UG/L AS SE)		8	
8434403	12/18/1987	1	01145	SELENIUM, DISSOLVED (UG/L AS SE)		8	
8434404	04/20/1989	1	01145	SELENIUM, DISSOLVED (UG/L AS SE)		9	
8434403	02/29/1988	1	01503	ALPHA DISSOLVED		25	6.0
8434404	04/20/1989	1	01503	ALPHA DISSOLVED		19	5.0
8434403	02/29/1988	1	03503	BETA, DISSOLVED, (PC/L)		0.8	0.1
8434404	04/20/1989	1	03503	BETA, DISSOLVED, (PC/L)		12	5.0
8434403	02/29/1988	1	09503	RADIUM 226, DISSOLVED		9.3	4.5
8434404	04/20/1989	1	09503	RADIUM 226, DISSOLVED		0.4	0.2
8434403	02/29/1988	1	11500	RADIUM 226 + RADIUM 228 DISSOLVED PC/L		0.7	0.3
8434404	04/20/1989	1	11500	RADIUM 226 + RADIUM 228 DISSOLVED PC/L		0.3	0.2
8434403	02/29/1988	1	22703	URANIUM, NATURAL, DISSOLVED (UG/L)		25	3.0
8434404	04/20/1989	1	22703	URANIUM, NATURAL, DISSOLVED (UG/L)		22	3.0
8434401	12/18/1987	1	71890	MERCURY, DISSOLVED (UG/L AS HG)	<	.2	
8434403	03/25/1986	1	71890	MERCURY, DISSOLVED (UG/L AS HG)		0.4	
8434404	04/20/1989	1	71890	MERCURY, DISSOLVED (UG/L AS HG)	<	0.2	
8434403	02/29/1988	1	81366	RADIUM 228, DISSOLVED (PC/L AS RA-228)	<	1.00	
8434404	04/20/1989	1	81366	RADIUM 228, DISSOLVED (PC/L AS RA-228)	<	1.0	

Table 6
Ground-Water Analysis Summary Report for Units 4 and 5, Total Minerals Corp.

TEXAS DEPARTMENT OF WATER RESOURCES

GROUND WATER ANALYSIS REPORT SUMMARY And BASELINE WATER QUALITY – In Situ Mining

GRAVEL UNIT 4

Company: Total Minerals Corporation
Mine Name: West Cole
Mine Area: Wellfield III
Date Summarized:

	PARAMETER	UNIT		NON PRODUCTION ZONE**			PRODUCTION ZONE						WELL I.D. BY AREA*		
							MINE AREA**			PRODUCTION AREA			NON PROD. ZONE	PROD. ZONE	
				Low	Average	High	Low	Average	High	Low	Average	High		Mine	Product.
1	Calcium	mg/l		178	189	200							SSM-7		
2	Magnesium	mg/l		62	65	70							SSM-8		
3	Sodium	mg/l		400	427	472							SSM-9		
4	Potassium	mg/l		23	25	27									
5	Carbonate	mg/l		0	0	0									
6	Bicarbonate	mg/l		157	205	235									
7	Sulfate	mg/l		247	253	257									
8	Chloride	mg/l		853	894	967									
9	Fluoride	mg/l		0.62	0.72	0.80									
10	Nitrate - N	mg/l		2.9	4.4	5.8									
11	Silica	mg/l		76	88	98									
12	pH	Std. unit		7.73	7.84	8.03									
13	TDS	mg/l		2070	2130	2210									
14	Conductivity	µmhos		3380	3450	3560									
15	Alkalinity	Std. unit		129	168	193									
16	Arsenic	mg/l		0.003	0.006	0.009									
17	Cadmium	mg/l		0.0001	0.0003	0.0005									
18	Iron	mg/l		0.08	0.31	0.70									
19	Lead	mg/l		<0.001	0.002	0.004									
20	Manganese	mg/l		0.016	0.033	0.064									
21	Mercury	mg/l		<0.0001	<0.0001	<0.0001									
22	Selenium	mg/l		<0.001	0.001	0.002									
23	Ammonia	mg/l		0.13	0.15	0.17									
24	Uranium	mg/l		0.004	0.008	0.016									
25	Molybdenum	mg/l		0.01	0.01	0.01									
26	Radium 226	mg/l		0.5	0.53	0.6									

* LIST THE IDENTIFICATION NUMBERS OF WELLS USED TO OBTAIN THE LOW, AVERAGE AND HIGH VALUES. **MONITOR WELLS

Table 6–continued
Ground-Water Analysis Summary Report for Units 4 and 5, Total Minerals Corp

TEXAS DEPARTMENT OF WATER RESOURCES

GROUND WATER ANALYSIS REPORT SUMMARY And
BASELINE WATER QUALITY – In Situ Mining

COMPARISON OF MINE AREA
5a and 5b Sand

Company: Total Minerals Corporation
Mine Name: West Cole
Mine Area: Wellfield III
Date Summarized:

	PARAMETER	UNIT		NON PRODUCTION ZONE**			MINE AREA						WELL I.D. BY AREA*		
							5a Sand			5b Sand			5a Sand	5b Sand	
				Low	Average	High	Low	Average	High	Low	Average	High			
1	Calcium	mg/l					3	30.6	98	5.8	16.2	35	SO-14	514	MB-50
2	Magnesium	mg/l					0.2	8.2	23	2.9	6.4	8.9	SO-15	523	MB-51
3	Sodium	mg/l					344	391	418	351	398	439	SO-16	530	MB-52
4	Potassium	mg/l					18	54	105	12	17.8	43	SO-17	551	MB-53
5	Carbonate	mg/l					0	11.7	99	7	16.8	32	SO-18	567	MB-54
6	Bicarbonate	mg/l					161	233	282	328	366	484	SO-19	572	MB-55
7	Sulfate	mg/l					153	216	265	126	196	251	MA-29	594	MB-56
8	Chloride	mg/l					298	430	554	269	297	346	MA-38	605	
9	Fluoride	mg/l					0.39	0.56	0.82	0.42	1.03	1.2	MA-39	606	
10	Nitrate - N	mg/l					<0.01	0.01	0.06	0.01	1.7	4.3	MA-40	626	
11	Silica	mg/l					25	60.5	150	43	50.9	66	MA-41	627	
12	pH	Std. unit					8.11	8.44	9.20	8.39	8.61	8.99	MA-42A	638	
13	TDS	mg/l					1180	1385	1600	1110	1232	1360	MA-43	643	
14	Conductivity	µmhos					1930	2206	2540	1690	1919	2180	MA-44	MB-47A	
15	Alkalinity	Std. unit					140	211	339	294	328	429	MA-45	MB-38	
16	Arsenic	mg/l					<0.001	.008	0.023	0.014	0.030	0.051	MA-46	MB-39	
17	Cadmium	mg/l					<0.0001	0.0003	0.0015	<0.0001	0.0001	0.0003	MA-47	MB-40	
18	Iron	mg/l					0.03	0.51	3.00	0.04	0.56	2.9	MA-48	MB-41	
19	Lead	mg/l					<0.001	0.007	0.089	<0.001	0.002	0.009	MA-49	MB-42	
20	Manganese	mg/l					<0.01	0.15	2.10	0.002	0.040	0.210	MA-50	MB-43	
21	Mercury	mg/l					<0.0001	0.0001	0.0001	<0.0001	<0.0001	<0.0001	MA-51	MB-44	
22	Selenium	mg/l					<0.001	0.001	0.001	<0.001	<0.001	<0.001	MA-52	MB-45	
23	Ammonia	mg/l					0.03	0.09	0.19	0.01	0.06	0.25	MA-53A	MB-46	
24	Uranium	mg/l					0.001	0.003	0.012	<0.001	0.74	6.78	MA-54	MB-47	
25	Molybdenum	mg/l					<0.01	0.01	0.03	<0.01	0.01	0.03	MA-55	MB-48	
26	Radium 226	mg/l					0.3	2.3	36	0.3	21.2	137	MA-56	MB-49	

* LIST THE IDENTIFICATION NUMBERS OF WELLS USED TO OBTAIN THE LOW, AVERAGE AND HIGH VALUES. **MONITOR WELLS

Table 6–continued
Ground-Water Analysis Summary Report for Units 4 and 5, Total Minerals Corp

TEXAS WATER COMMISSION

GROUND-WATER ANALYSIS REPORT SUMMARY
BASELINE WATER QUALITY—Solution Mining

5a Sand

Company: Total Minerals Corporation
Mine Name: West Cole
Mine Area: Wellfield III
Date Summarized:

	PARAMETER	UNIT		NON PRODUCTION ZONE**			PRODUCTION ZONE: MINE AREA**			PRODUCTION ZONE: PRODUCTION AREA			WELL I.D. BY AREA*: NON PROD. ZONE	WELL I.D. BY AREA*: PROD. ZONE	
				Low	Average	High	Low	Average	High	Low	Average	High		Mine	Product.
1	Calcium	mg/l					3	33.7	98					MA-29	SO-14
2	Magnesium	mg/l					0.2	7.7	23					MA-38	SO-15
3	Sodium	mg/l					344	390	411					MA-39	SO-16
4	Potassium	mg/l					18	60.2	105					MA-40	SO-17
5	Carbonate	mg/l					0	12.4	90					MA-41	SO-18
6	Bicarbonate	mg/l					196	238.6	282					MA-42A	SO-19
7	Sulfate	mg/l					153	214.3	265					MA-43	
8	Chloride	mg/l					298	436	554					MA-44	
9	Fluoride	mg/l					0.39	0.59	0.82					MA-45	
10	Nitrate - N	mg/l					0.01	0.01	0.06					MA-46	
11	Silica	mg/l					25	65.3	150					MA-47	
12	pH	Std. unit					8.11	8.41	9.20					MA-48	
13	TDS	mg/l					1230	1411.5	1600					MA-49	
14	Conductivity	μmhos					1930	2236	2540					MA-50	
15	Alkalinity	Std. unit					161	216.3	339					MA-51	
16	Arsenic	mg/l					<0.001	0.007	0.023					MA-52	
17	Cadmium	mg/l					<0.0001	0.0003	0.0015					MA-53A	
18	Iron	mg/l					0.03	0.48	3.0					MA-54	
19	Lead	mg/l					<0.001	0.009	0.089					MA-55	
20	Manganese	mg/l					<0.01	0.17	2.1					MA-56	
21	Mercury	mg/l					<0.0001	0.0001	0.0001						
22	Selenium	mg/l					<0.001	0.001	0.001						
23	Ammonia	mg/l					0.05	0.10	0.17						
24	Uranium	mg/l					0.001	0.002	0.005						
25	Molybdenum	mg/l					<0.01	0.01	0.02						
26	Radium 226	pCi/l					0.3	2.5	36						

* LIST THE IDENTIFICATION NUMBERS OF WELLS USED TO OBTAIN THE LOW, AVERAGE AND HIGH VALUES. **MONITOR WELLS

Table 6–continued
Ground-Water Analysis Summary Report for Units 4 and 5, Total Minerals Corp

TEXAS WATER COMMISSION

GROUND-WATER ANALYSIS REPORT SUMMARY
BASELINE WATER QUALITY—Solution Mining

5b Sand

Company: Total Minerals Corporation
Mine Name: West Cole
Mine Area: Wellfield III
Date Summarized:

	PARAMETER	UNIT		NON PRODUCTION ZONE**			PRODUCTION ZONE: MINE AREA**			PRODUCTION ZONE: PRODUCTION AREA			WELL I.D. BY AREA*: NON PROD. ZONE	WELL I.D. BY AREA*: PROD. ZONE	
				Low	Average	High	Low	Average	High	Low	Average	High		Mine	Product.
1	Calcium	mg/l					5.8	15.8	26	11	16.8	35		MB-38	514
2	Magnesium	mg/l					3.8	6.5	8.4	2.9	6.1	8.9		MB-39	523
3	Sodium	mg/l					351	398	439	360	397	438		MB-40	530
4	Potassium	mg/l					12	18.6	43	12	16.7	27		MB-41	551
5	Carbonate	mg/l					10	16.1	32	7	17	32		MB-42	567
6	Bicarbonate	mg/l					328	357	376	307	378	484		MB-43	572
7	Sulfate	mg/l					126	197	248	149	194	251		MB-44	594
8	Chloride	mg/l					269	301	346	270	293	341		MB-45	605
9	Fluoride	mg/l					.42	1.01	1.2	1.0	1.06	1.2		MB-46	606
10	Nitrate - N	mg/l					<0.001	2.1	4.3	0.01	1.1	2.5		MB-47	626
11	Silica	mg/l					45	50.1	66	43	52	60		MB-48	627
12	pH	Std. unit					8.45	8.60	8.99	8.39	8.63	8.85		MB-49	638
13	TDS	mg/l					1110	1231	1360	1130	1234	1350		MB-50	643
14	Conductivity	µmhos					1690	1938	2180	1800	1894	2070		MB-51	MB-47A
15	Alkalinity	Std. unit					299	320	343	294	339	429		MB-52	
16	Arsenic	mg/l					0.014	0.027	0.051	0.021	0.028	0.041		MB-53	
17	Cadmium	mg/l					<0.0001	0.00008	0.0003	<0.0001	<0.0001	<0.0001		MB-54	
18	Iron	mg/l					0.12	0.54	2.6	0.04	0.58	2.9		MB-55	
19	Lead	mg/l					<0.001	0.0014	0.011	<0.001	0.0017	0.009		MB-56	
20	Manganese	mg/l					0.002	0.038	0.150	0.004	0.041	0.21			
21	Mercury	mg/l					<0.0001	0.0001	0.0001	<0.0001	<0.0001	<0.0001			
22	Selenium	mg/l					<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			
23	Ammonia	mg/l					0.03	0.09	0.25	0.01	0.032	0.04			
24	Uranium	mg/l					<0.001	0.069	0.297	0.17	1.66	6.78			
25	Molybdenum	mg/l					<0.01	0.011	0.02	<0.01	0.011	0.03			
26	Radium 226	pCi/l					0.3	2.8	11	6.3	46	137			

* LIST THE IDENTIFICATION NUMBERS OF WELLS USED TO OBTAIN THE LOW, AVERAGE AND HIGH VALUES. **MONITOR WELLS

oxidation, and ground water pumpage processes have resulted in localized water quality changes due to the ground water flow and diffusion of carbon dioxide and oxygen gases. The arsenic compounds of As^{3+} and As^{5+} can be precipitated from ground water by hydrogen sulfide (H_2S).

Unit 4 is generally divided into two separate aquifers by a thin clay bed which is 15 to 30 feet thick. The two aquifers occur at depths of between 135 feet and 190 feet and 200 to 270 feet respectively and contain uranium in concentrations that are economically being mined. In some places where the clay bed is absent, it may form one major aquifer. The Total Minerals Company has completed production wells in a zone of Unit 4 which occurs between depths of 195 feet and 270 feet. Table 5 provides water-quality data summaries for their wells. In Bruni, about 25 residences have their domestic water supply wells completed in this aquifer. The ground water quality of Unit 4 has other heavy metals which are associated with uranium ore. The uranium, arsenic, molybdenum, and selenium are partially dissolved between the ground water, and adsorbed in the aquifer's matrix under reducing conditions. The Total Minerals Uranium Company is mining only the lower portion of unit 4. Whenever the equilibrium state of the chemically reducing environment is disturbed such as by mining, well drilling or water supply well pumpage, the pH and equilibrium conditions change and more oxidation occurs. The uranium, arsenic, molybdenum, copper, selenium, manganese and iron will then continue to desorb and dissolve in the ground water until another equilibrium or saturation point is reached. This dissolution may simultaneously take place with ion-exchange process and precipitation of certain chemical constituents. The net effect of these chemical processes will be to increase or decrease certain chemical constituents in the ground water. Most of those chemical processes are controlled by the pH, Eh (oxidation-reduction) potential, and mass transport (advection, diffusion) processes. The mobilization of the chemical species released into the ground water occurs as a result of ground water flow velocity or by spontaneous chemical gradient diffusion. Table 7 shows the chemical water quality in one of the Westinghouse Uranium Mines public drinking water-supply well completed in the same aquifer as for Bruni Water Works wells.

Unit 5 occurs at a depth of between 90 feet and 135 feet. It is not known as to whether this zone is the same one in which uranium leaching operations and post mining ground-water restoration has occurred 7 miles north of Bruni at Westinghouse Mine. In Bruni, there is one domestic ground-water supply well completed in this unit. The ground water quality of this unit is of sodium-bicarbonate, sodium sulfate and sodium chloride mixture types with a pH of 7.2 and contains 0.052 to 0.195 mg/l of arsenic, 0.58 mg/l iron, up to 10.0 mg/l uranium, 0.046 mg/l molybdenum, and a dissolved solids content of between 1100 and 1800 mg/l. In the mine area, the pH of the water is about 8.9, and the water contains an arsenic level of 0.03 mg/l, molybdenum of 0.001 mg/l, uranium of between 0.001 mg/l and 11 mg/l, and a dissolved solids content of between 1200 and 2300 mg/l.

Aquifer 6 occurs at a depth of between 35 to 90 feet in a sandy conglomerate which is found in a broad zone underlying Bruni and

Table 7
Water-Quality Data from Westinghouse Uranium Mine's Public Supply Well

TEL. 512-884-0371 PO BOX 2552 78403

JORDAN LABORATORIES, INC.
CHEMISTS AND ENGINEERS
CORPUS CHRISTI, TEXAS
JULY 7, 1988

WESTINGHOUSE ELECTRIC CORP.
P.O. BOX 187
BRUNI, TEXAS 78344

REPORT OF ANALYSIS

IDENTIFICATION: BRUNI SITE
FRESHWATER SAMPLE *Well #1*
6-3-88

		ANALYSIS DATE
PH	8.39	06-22-88
COLOR, PT-CO UNITS	1	06-23-88
CORROSION RATE, MILS/YR	10.3	06-27-88
	MG/L	
FLUORIDE	1.1	06-06-88
NITRATE NITROGEN	<0.01	06-06-88
TOTAL PHOSPHORUS	0.02	07-03-88
CHLORIDE	125	06-22-88
SULFATE	98	06-21-88
ARSENIC	<0.001	06-13-88
BARIUM	0.11	06-21-88
CADMIUM	<0.0001	06-24-88
CHROMIUM	<0.01	06-22-88
COPPER	0.01	06-22-88
IRON	0.01	06-21-88
LEAD	<0.001	06-24-88
MERCURY	<0.0001	06-15-88
MOLYBDENUM	0.01	06-21-88
SELENIUM	<0.001	06-13-88
SILVER	<0.01	06-21-88
URANIUM	0.001	07-06-88
GROSS ALPHA ACTIVITY, PCI/L	-2.4 +/- 3.4	07-07-88
RADIUM 226, PCI/L	0.1 +/- 0.1	06-29-88

LAB. NO. M26-3569

RESPECTFULLY SUBMITTED,

CARL F. CROWNOVER

base of Goliad Formation. The water quality in this zone is generally considered poor to brackish. In Bruni, the water in this aquifer is considered unusable because residents believe that all residential septic tanks and cesspools including that of the school have been leaking waste water and raw sewage into this aquifer; consequently, no water wells have been completed in this unit.

Staff concludes that in the Bruni area, domestic wells are completed in Units 3, 4 and 5, whereas the Bruni Water Works wells, which supply water for commercial and domestic use, are completed only in Unit 3.

Another commercial water supply company (Lowe's Water Supply) located 2 miles east of Bruni and south of Highway 359 has three sets of wells completed in Unit 1 at 690 to 750 feet and whose waters are high in dissolved solids and hydrogen sulfide, Unit 2 at 550 feet also has high dissolved solids and hydrogen sulfide, and Unit 3 at 375 feet, the same zone in which the Bruni Water Works municipal supply well is completed.

Arsenic is a trace metal which occurs naturally in weathered sedimentary, metaigneous rocks, and deposits of volcanic origin and always coexists with uranium, molybdenum, selenium and iron in the sedimentary uranium ores. In Bruni, and the surrounding areas, extending westward to the outcrop of rocks of Miocene Age (Catahoula and Frio Formations) and Pliocene Age (Goliad Formation), the sedimentary geologic units were deposited as derivatives of metaigneous and volcanic origins. Consequently, uranium, arsenic, pyrite, marcasite, selenium, and manganese, have formed a significant percentage of such sediments, and are naturally deposited and constitute the natural primordial components of such geologic layers which formed the current water-bearing units in the Bruni area. This area lies in the faulted South Texas uranium depositional belt zone. The natural, seasonal, regional and local changes in the quality of ground-water around Bruni occur spontaneously and are due to mixing, hydrolysis, dissolution, oxidation, reduction, biochemical bacterial and fungi biodegradation, adsorption and desorption, and pumpage of ground water. These processes control the fate and transport of the various inorganic and organic chemical elements and naturally dictate which chemical species will appear or disappear with time anywhere in the ground water. These natural processes have been taking place in the ground water beneath Bruni since the aquifer came into being, and could be responsible for the presence of high arsenic levels reported in the Bruni Water Works municipal water supply wells. The arsenic dissolved in the ground water at the ambient pH and Eh exists at the concentration level that occurs under the equilibrium state between arsenic compounds and other trace metal compounds. Also, bad water quality could evolve near fault zones that restrict movement. Bruni is found between two faults which lie within a distance of two miles east and west of Bruni.

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Arsenic chemical ionic species exist as arsenite (As^{3+}) in ground water in the reducing environment and as arsenate (As^{5+}) in an oxidizing environment (Buchanan 1962). In ground water with a pH of 5 and 9, the dominant arsenic species is arsenate acid, H_3AsO_3. At a pH of 7, arsenite is approximately equally distributed. In the mine area, pH of ground water in Unit 4 is expected to be between pH 7 and 9, while under the town of Bruni the pH of ground water in Units 3 and 4 is expected to lie between pH 7.0 and 7.9 (Henry et al., 1982).

Under oxidizing conditions and with a pH range between 6.5 and 9, its unlikely for arsenate or arsenite minerals to precipitate with the exception of barium arsenate [$Ba_3(AsO_4)_2$] which is much less soluble than the other species. Consequently, if arsenic occurs in Units 3 and 4 beneath Bruni it will be found naturally in solution.

Under mild reducing conditions, arsenic is likely to occur as soluble arsenious acid species. Orpiment (As_2S_3) and realgar (AsS) chemical species are likely to be stable at low to moderate pH. The partition between the dissolved and precipitated adsorbed arsenic species is such that solid arsenic occurs at a pH below 5 while at pH of 7 or less dissolved arsenic sulfite found in solution can occur in equilibrium with the solid species orpiment in small concentration in the order of $2x10^{-7}$ mg/l. It has been reported by Gulens, et al (1979) that in neutral pH oxidation environment, arsenate is absorbed more readily by ferric hydroxide than arsenite. Arsenic also occurs as a colloidal complex species known as arsenious sol which may be mobilized as suspended matter in ground water. Most arsenious sols are very stable and may travel freely with ground water and will move from the well intake to the well head or the point of use in the ground-water delivery system without being filtered or precipitated out. At the well, unfiltered ground water should precipitate arsenate with ferric hydroxide leaving arsenite in solution.

Ground water which exists under oxiding conditions in a uranium bearing aquifer contains the oxidized uranium ion U^{6+} as UO_2^{2+}, which is complexed with some organic chemical compounds that are subject to the pH and Eh control of the environment. Uranium may also predominantly occur complexed with phosphate and carbonate species if they are present in ground water whose pH ranges from 4 to 7. The ground water in the aquifer tapped by the water supply used by the Bruni Water Works is believed to be in a reducing environment. When well pumps are turned on, this water is subjected to oxidation conditions in the well bore, the uranium is oxidized in that zone and forms minerals commonly found in oxidizing uranium deposits. Examples of such minerals which may be found in Units 3 and 4 are: $Ca(UO_2)_2(PO_4)_2 \cdot 10\text{-}12H_2O$ (autunite), $Cu(UO_2)_2(PO_4)2 \cdot 8\text{-}12H_2O$ (torbernite) and $Ca(UO_2)_2Si_2O_7 \cdot 6H_2O$ (uranophane), all of which have been reported to be highly soluble and common in South Texas uranium bearing aquifers; and the carnotite $K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$ (carnotite), and $Ca(UO_2)_2(VO_4)_2 \cdot 5\text{-}7H_2O$ (tyuyamunite) which occur as secondary uranium minerals formed due to the reaction of meteoric waters with the uranium and vanadium minerals. They are normally found disseminated or concentrated locally near organic matter in the aquifers.

In ground water reducing environments uranium (U^{6+}) minerals are reduced to uranium (U^{4+}) minerals such as uraninite (UO_2) or coffinite ($USiO_4$); consequently, the amount of silica concentration in ground water will dictate which one of the two uranium compounds becomes dominant. When (U^{6+}) comes into contact with dissolved sulfide minerals, ferrous iron ($FeSO_4 \cdot nH_2O$), or some organic matter, it may be reduced to the divalent (U^{2+}) and tetravalent (U^{4+}) uranium minerals. When the tetravalent (U^{4+}) minerals come into contact with the trivalent iron (Fe^{3+}) it will be oxidized to (U^{6+}). In the absence of phosphate and carbonate ions, such reduced divalent and tetravalent uranium species become almost *insoluble and undetectable in solution* in ground water. The ground water in the uranium bearing aquifer supplying the Bruni Water Works wells contains iron, carbonate, and some phosphate ions in significant concentrations to participate in these reactions; hence, uranium is expected to dissolve and remain in solution both in the reducing and oxidizing environments, and to occur naturally in the well water during pumpage. Arsenic can also be found complexed in the colloidal sols. These, among other factors, may explain why arsenic and uranium have persistently occurred, with fluctuating concentration levels, in the Bruni Water Works wells.

Movement of Arsenic and Uranium from the Uranium Mines

The dissolved ionic and molecular chemical species of uranium, uranium decay daughter products, arsenic, molybdenum, selenium, manganese, zinc, iron and copper can be transported from the uranium mining site (source) to another place down gradient by several mechanisms found within the aquifer between any two points, and are dictated by the concentration gradient of the chemical species, availability of oxygen and carbon dioxide, and how fast ground water is moving through the uranium ore bearing aquifer. The transport of these species can take place by any one of these processes:

(i) The dominant mechanism of transport of a chemical contaminant will be by the natural ground-water mass flow velocity (advection/convection) method. It is a function of the velocity, mass change of chemical material concentration, chemical reactivity and dimunition with distance during transport. This will only occur if the ground water velocity is above the critical flow velocity. Due to the geometry of the ambient flow field in Unit 4, and the trajectory of the ground-water particle passing through the Total Minerals and Westinghouse uranium mines, it is evident that uranium and arsenic from these mines will not travel towards Bruni by the advection mechanism.

(ii) However during the same time the advection transport mechanism causes the chemical contaminant to move with the natural ground-water body velocity, the chemical material itself is also moved by a process of vertical and horizontal spreading due to the textural and depositional characteristic of the aquifer porous medium. Tis process which is also influenced by the bulk flow of a ground water body is known as the hydrodynamic dispersion and will only occur if ground water velocity is not static. It is believed that if any contaminant chemical enters ground water in Units 3 or 4 at Total Minerals uranium mine site, it will not move under it's own hydrodynamic dispersion and advection processes to the town of Bruni because the pumpage in Unit 4 is much heavier at the mine than in Bruni water wells. This is likely to induce limited ground water flow from Bruni to Total Minerals Uranium mine in Unit 4. At the same time, if there is vertical leakage in the equitard between Units 3 and 4, there will be ground water flow from Unit 3 to Unit 4 rather than from the mine into Unit 3 underneath the mine or toward Bruni.

When the ground-water flow velocity is so slow that it is almost static, the mechanism of transport will no longer be by hydrodynamic advection or hydrodynamic dispersion but instead will be by the mechanism of Fickian (chemical concentration gradient) molecular induced flow. This mechanism of transport is known as molecular diffusion and depends on the characteristic diffusion rate of arsenic and uranium which are considered to be very low compared to the ground-water velocity. The molecular diffusion may take place locally but the range of the prevalent distance and the attenuation/decay of the transported chemical species will not support their travel from Total Minerals or Westinghouse uranium mine to the aquifer(s) underneath Bruni through the transport mechanisms considered. The molecular diffusion transport flux (q), for arsenic can be determined by the following numerical model:

$$q = Dx\left(\frac{\partial^2 C}{\partial x^2}\right)_\tau + Dy\left(\frac{\partial^2 C}{\partial y^2}\right)_\tau = \left(\frac{\partial C}{\partial t}\right)_\eta$$

(modified from Farringtron et. al., Crank, 1975, and Javandel, 1984)

$$D = \left(\frac{RT}{6\chi\Omega rN}\right) = \left(\frac{RT}{F/Z}\right)_\tau \text{(Equivalent conductance of Arsenic)}$$

$$D = 7.94\times10^{-10}\left(\frac{meter}{\text{sec}}\right) = \text{Diffusion coefficient}$$

$$D = 7.38 \times 10^{-11}\, ft^2/\text{sec} \quad as\ \ in\ \ air$$

where C = Concentration
∂ = Change
τ = Time
x = Distance
R and T = Thermodynamic gas constant and temperature respectively
Ω = Coefficient of viscosity
N = avogadros number of the atom $\left(\frac{6.022 \times 10^{23}}{\text{mole}}\right)$
F = Faraday's constant
Z = Ionic change of the constituent

$$C_A = \left(\frac{100 \ mg/l}{4(3.14159)(9 \ yrs.)\left(31.56m^2/yr \times 10.8ft^2 \ /m^2\right)} \right)$$

$$C_A = 0.0026$$

The concentration of arsenic (C_A) above shows that in Unit 4 underneath Bruni, the wells should show concentration levels of 0.0026 mg/l, which is below the maximum primary drinking water standards.

On the other hand, if arsenic migrates conservatively with a ground water chemical transport velocity of 30 feet per year, it would take the leading edge of the arsenic plume

$$\left(1.5 \text{ miles} \left(\frac{5{,}280 \ ft}{miles} \right) \left(\frac{1 \ yr}{30 \ ft} \right) \right)$$

264 years to reach Bruni from Total Minerals mine or 1320 years from Westinghouse's mine, assuming ground water flow direction is due south of these mines, which is not the case.

(iii) During the chemical transport, some of the chemical constituents may leave (precipitate out of) or come into (dissolve) the solution of moving ground water. This mechanism of chemical behavior during transport will result either in a net increase or decrease of chemical contamination or pollution. The processes that may control the presence or absence of arsenic, uranium, molybdenum, copper, and manganese are hydrolysis, oxidation-reduction potential, biodegradation (biochemical) and the pumpage of wells. These processes may occur at a particular spot or may occur along the entire transit distance as a result of ground water coming into contact with aquifer matrix materials, oxygen, and/or organic carbon along its flow path. If a release of a "pregnant" uranium solution were to occur in the mine field at any time, the concentration level of the developing plume of contamination from that release would spread radially with corresponding radial attenuation due to chemical reduction, adsorption, precipitation and dilution during its transport away from the mining field and because of the complex pumpage hydrology may not be detected near the Bruni Water Works wells. The precipitation of arsenic and uranium will occur because the oxidized "pregnant solution" will be mixing with ground water in a more reduced phase in the immediate periphery of the mine field.

(iv) The uranium and its daughter products may undergo further intrinsic reduction in concentration by radioactive decay during its transport, generating other isotopes including radium and radon gas. To estimate the concentration of arsenic and uranium's primary radioactivity decay mechanism the following chemical transport and mass balance expressions were used:

$$\frac{\partial C}{\partial t} = \frac{D}{R}\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} - V\frac{\partial c}{\partial x} - \lambda C\right)$$

The solution of which is:

$$C = \frac{C_0}{4\kappa t\sqrt{(Dx\ \ Dy)}} \times e^{-\lambda\tau-\beta}$$

$$C_A = \frac{(\text{massive arsenic / liter})}{4\kappa t\sqrt{(Dx\ \ Dy)}} \times Qe^{\beta}$$

where

	C_A or C	=	original concentration of arsenic and uranium radioactive chemical constituent now, respectively
	C_o	=	initial mass concentration of the radioactive constituent during sedimentation or some other known earlier time
	D	=	dispersivity
	y	=	distance in y-direction
	x	=	distance in x-direction
	e	=	2.7182
	λ	=	chemical decay constant
	Q	=	specific discharge

$$\beta = \left(\frac{\left(x-vt^2\right)(y)^2}{4Dt \qquad 4Dt}\right)$$

$$R = \text{retardation factor}\left(\frac{1+Density Kd}{porosity}\right) = \frac{V}{V_c}$$

V = average groundwater linear velocity

V_c = velocity of contaminant of $C/C_o = 0.5$ point

To properly model the solute transport using these simulations would require that the background concentration of both arsenic and uranium were accurately known in Bruni and at the mine site prior to the beginning of the mining operations, otherwise the number obtained would be an estimated guess.

WATER QUALITY PROBLEMS

According to the Texas Department of Health (TDH), Division of Water Hygiene, the ground-water quality analyses data collected and compiled from the Bruni water supply wells (Table 5) have consistently yielded water with high arsenic concentrations. The two domestic water supply wells (numbers 2 and 3) and the two commercial-industrial water supply wells (numbers 1 and 4) have all reported arsenic concentration two to three times above the acceptable primary drinking water standards of the TDH and EPA. In some of the wells the high arsenic concentrations have been identified and reported since 1939. A recent test of ground water samples from wells 2 and 3 conducted by the Texas Water Development Board have also shown the presence of arsenic, uranium and its daughter products in ground water produced from Unit 3. Water samples of domestic and school wells in Bruni have also shown high levels of radium, radon gas, and arsenic.

The concern for the presence of uranium and arsenic was raised and brought to the attention of the Texas Water Development Board in April of 1989 by an inquiry from the TDH and Mr. Layton who owns the Bruni Water Works. This inquiry prompted our attention concerning Bruni's ground-water quality problems and formed the basis for this investigation. An attempt has therefore been made to determine the source of arsenic and uranium contamination and to recommend possible solutions to alleviate the water quality problem.

Are The Chemical Contaminants Introduced Into The Ground Water By Uranium Mines Traceable to Bruni?

The process of uranium mining by a well designed and engineered injection leaching and recovery process results in the hydrodynamically controlled movement of "pregnant" solution containing uranium and trace arsenic, molybdenum, selenium, iron and manganese leached from the absorbed precipitate reduced-ore environment. This is accomplished by injecting ground water in which sodium hydroxide, carbon dioxide and oxygen have been mixed in a predetermined proportion to produce barren lixiviant solution which upon reaching the uranium ore body in the aquifer oxidizes and complexes the uranium and the associated chemical trace element suite. The uranium concentration level is increased several times in ground water creating a "pregnant" lixiviant solution which is then recovered by pumping through ground water recovery wells. The volume of the solution pumped is deliberately made slightly higher than the volume of barren lixiviant solution going into the aquifer. The difference is the bleed off volume which maintains a hydrodynamic sink/source balance that effectively supports a local cone of depression near the recovery wells within the mine field. The wells particular network design in the uranium mine leaching field physically induces local ground-water movement toward the recovery wells in the mine field and not away from them in the direction of Bruni. This prevents the escape of plumes of high uranium concentrated fluid from the mine itself to peripheral areas such as Bruni.

Apart from this design, there is a network of ground-water monitoring wells installed in the periphery of the mine field to immediately detect any release or escape of uranium "pregnant" fluids.

Based on this careful design of the uranium mine field, the characteristic ground-water flow net, detection monitoring wells, and with contingency plans for quick "pull back" remediation of any runaway fluids, it can reasonably be assumed that the Total Minerals Uranium Mine site is not expected to cause detectable uranium contamination in the aquifer underneath Bruni. In addition, the ground-water flow direction appears to be to the east of southeast and not in the southerly direction toward the town of Bruni as has been thought. The ground-water flow maps (Figures 8 and 9) illustrate this observation.

Where Do Arsenic And Uranium Concentrations in the Bruni Water Works Wells Come From?

Under reducing conditions, the tetravalent (U^{+4}) ions or minerals uraninite and coffinite, present in the ground water and in contact with the uranium ore, are normally insoluble. However, when they come into contact with a reactive oxidant such as hydrogen peroxide (H_2O_2) and oxygen, they will dissolve into the ground water. In the underground uranium leaching process any one of these oxidants (salt solutions of sulfate bicarbonate, carbonate and ammonium) is normally injected down the well at the well head under controlled hydraulic pressure in the presence of barren lixiviant or, if suitable subsurface geologic conditions exist, the oxidant can be generated naturally in situ due to the chemical reaction between the barren lixiviant and the other heavy metals found together with the uranium in the ore-body. As an example, when the hydrogen peroxide (H_2O_2) oxidant is injected in presence of the lixiviant sodium bicarbonate ion reactions proceed as;

$$UO_2 + H_2O_2 + 2HCO_3 \rightarrow UO_2(CO_3)_2^{2-} + 2H_2O$$

(Uraninite+Peroxide+Bicarbonate ions→ Uranyl Carbonate ion + water)

but the oxidant may also react with other heavy metals in the ore and generate other chemical constituents. One such constituent is the iron, which exists as ferrous (Fe^{2+}) in the reducing state but is oxidized to a ferric (Fe^{3+}) state. The ferric ion is capable of oxidizing the tetravalent uranium (U^{4+}) to a hexavalent uranium (U^{6+}) state. It has been reported that ferric iron may be the mechanism by which the Uranium (U^{6+}) is actually oxidized. The ferrous iron exists in ground water as $FeSO_4 \cdot H_2O$ or in the reducing ore environment as pyrite (FeS_2, or iron disulfide). The ferrous iron can be oxidized by inorganic chemical reaction with the oxidants oxygen, chlorine compound (chlorate ClO_3^-) ion, and iron bacteria such as Theobacillus Ferroxidans.

(a) In the presence of the chlorate ion, ferrous (Fe^{2+}) ion is oxidized to ferric (Fe^{3+}) ion which in turn oxidizes the tetravalent uranium (U^{4+}) to hexavalent U^{6+} state;

(i) $6Fe^{2+} + ClO_3^- + 6H^+ \rightarrow 6Fe^{3+} + Cl^- + 3H_2O$

(ii) Oxidation by oxygen proceeds as follows:

$$FeS_2 + 6O_2 + 4H_2O \rightarrow 2Fe^{3+} + 4H_2SO_4$$

$2FeS_2 + H_2O$ + Bacterial Enzyme $\rightarrow$ $Fe^{3+} + SO4^{2-}$ + More Bacteria + E

where E = a particular enzyme

(b) then, the ferric ion (Fe^{3+}) reacts with the uranium as follows:

$$UO_2 + 2Fe^{3+} \rightarrow UO_2^{2+} + 2Fe^{2+}$$

generating more ferrous ion and the cycle continues.

(c) Arsenic which has four valences (-3, 0, +3, +5) can react as follows:

$$NH_3 + H_2S + H_2O \rightarrow NH^{4+} + H_2S + OH$$

$$As_2S_3 + 12OH^- + 14H_2O_2 \rightarrow 2[AsO_4]^{3-} + 3SO_4^{2-} + 20H_2O$$

where arsenic is adsorbed when it comes into contact with a reducing aqueous environment.

Once the uranium is oxidized, it is easily leached into ground water by the available sulfate, bicarbonate or carbonate solutions and is produced by the mine wells. In addition to uranium, calcite ($CaCO_3$) in the aquifer can also be dissolved and release calcium ions into solution. The dissolution proceeds as follows:

$$CaCO_3 + 2HCO_3^- + \rightarrow Ca^{2+} + H_2O + CO_2$$

The dissolution of uranium by iron (ferric state) will take place anywhere at the uranium underground injection leaching mine field and naturally in any part of the aquifer remote from the mine and can also be enhanced near the domestic ground-water supply well field where iron bacteria, iron compounds, iron well casing pumps, sulfur, sulfate, sulfur bacteria/microorganisms, carbonate, bicarbonate and chlorides are present, and where the steel well casing is undergoing corrosion. The mixture of the two water bodies from Units 3 and 4 are therefore expected to create conditions for these types of chemical reactions and may lead to a rise in arsenic concentration levels in the Bruni Water Works wells. In addition to this situation, several domestic water wells are drilled and completed such that each well penetrates, is screened across and produces water from both Units 3 and 4.

In comparing the ground-water chemical data obtained from private wells near Bruni in 1937, the BWW wells in 1987, 1988 and 1989, and

Total Minerals Uranium Leaching Mine in 1988, there does not appear to be a general increase in some of the anions, cations and dissolved solids in the BWW wells to support the feeling that a contamination plume from Total Minerals uranium mine has seeped from Unit 4 into Unit 3 and significantly affected the municipal water wells at Bruni. There does not appear to be a trend or a chemical signature to help support the claim that the arsenic elevated levels in Bruni are from the Total Minerals uranium mine.

Results of ground water samples (Table 5) collected from several wells completed in Units 3 and 4 in and around Bruni show uranium, thorium, radium, and radon gas concentrations to be naturally high. Their distribution and concentration characteristics do not exhibit a definite plume of contamination from Total Minerals uranium mine.

The highest radon gas concentration of 6,600 piC/l was detected in Unit 4 in one domestic well located between FM 2050 and Bruni's school. The next highest radon gas concentration of 3,240 piC/l was detected a short distance north of the Post Office. Three other wells showed radon gas concentrations of 1,050, 1,600, and 2,270 piC/l. The remaining eleven wells showed radon gas concentrations ranging from 192 piC/l to 691 piC/l with a median of 304 piC/l. The distribution of radon gas in Unit 4 tends to reflect a local condition underneath Bruni and as such may not be an indication of a runaway plume from Total Minerals uranium mine.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. There are about 6 ground-water bearing aquifer units underlying Bruni. Of the six, only Units 3 and 5 contain water of relatively better quality. The base of economically usable quality water occurs at a depth of about 530 feet beneath Bruni.

2. Uranium and arsenic occur naturally within Units 3 and 4 but the concentration is highest in Unit 4, which is also the interval that contains the uranium ore that is being mined by Total Minerals Company at a distance of 1.5 miles north of Bruni. As uranium and thorium constantly undergo radiochemical changes, yielding daughter products, it is normal to find other radioactive chemical constituents such as radium, radon gas, and bismuth in ground water.

3. About 25 individuals own private domestic wells which are completed in this uranium bearing Unit 4. However, the extent and the exact concentration of uranium in Unit 4 in the vicinity of Bruni is not known. Nonetheless, it is likely to have some arsenic and uranium minerals areally disseminated throughout its entire horizontal and vertical extent.

4. Unit 3 is not hydraulically connected to Unit 4 except as a result of poor well drilling, construction, and completions, such as in the two wells owned by the Bruni Water Works. Both wells are completed in the two aquifers, thereby allowing water from the overlying arsenic and uranium bearing Unit 4 to mix with water from the underlying Unit 3. This mixing can be expected to result in the release of significant arsenic concentrations into the Bruni Water Works wells (BWW).

Since the aquifers in which the BWW wells are completed contain naturally occurring arsenic and uranium, the occurrence of these elements in the ground water is understandable. Any increase of uranium and/or arsenic in the ground water is also understandable because of the natural oxidation/reduction reactions taking place. The hydrologic and hydrodynamic ground-water flow field conditions developed between BWW wells, and the Total Minerals and Westinghouse mine well fields, and the distance involved, fails to support the contention that the arsenic concentration levels increased in BWW wells as a result of the uranium mining operations.

While the oxidant (oxygen or peroxide) used in the mining process could diffuse laterally away from the mine fields, the lateral and vertical migration distances of the oxidants would be limited by the inorganic and bio-chemical reactions in which oxygen or peroxide is consumed along the diffusion path.

Recommendations

The Texas Water Development Board recommends that:

1. (a) Bruni Water Works should isolate Unit 4 from 3 by plugging off the lower zone of 4 which is now connected in the annulus of the two municipal water supply wells; or,

   (b) Bruni Water Works should: (1) install a corrosion inhibitor such as a cathodic protection system to reduce the iron supply around the well screen intake area and open casing surface areas exposed to the uranium and arsenic bearing fluids, or, (2) if new wells are drilled, plastic (pvc) casing should be used instead of steel or steel alloy casings; and,

   (c) Bruni Water Works should install a working chlorinator unit to control harmful bacteria; and an ion exchanger or reverse osmosis unit to reduce the concentration of arsenic and other undesirable trace metals from this water; and,

   (d) The Bruni Water Works should drill a third well to be completed in the sand units between 130 feet and 190 feet in Unit 5 and blend this water in a predetermined ratio with ground water from Unit 3. The exact blend ratio can only be determined after the well waters from the separate zones are tested, and a wet chemical analyses of cores from Units 3 and 5 is performed.

   (e) Drilling of any well should be conducted by a well qualified driller with an emphasis on minimizing contamination to an aquifer by undesirable chemical constituents due to improper grouting and screen placement.

   (f) The wells which are completed in water bearing units 3 and 5, and which show high radium and radon gas concentrations, should install a small aerator outside the building between the well head and the storage tank to bleed off the radon gas.

2. Exploratory holes should be drilled near Bruni covering the area of this investigation as part of a detailed water quality and availability assessment. Rock cores should be collected from some of the strata of Units 2 thru 6. In addition to this type of data, all wells between the outcrop and Highway 16 in Duval County and as far south as the Jim Hogg-Webb County boundary line should be inventoried and water levels measured in selected wells. The combined data should then be used to develop a final report on the status of ground-water quality and availability in southern Webb County.

3. Since the town of Bruni is not an incorporated governmental community, and it does not constitute a political entity, it has been determined that Texas Water Development Board loan funds cannot be made available to the privately owned and owner operated Bruni Water Works Company; and the Board's efforts to locate funds from other sources administered by the agencies such as the Federal Emergency Management Administration (FEMA) and administered by the TDH-DWH and by the Hone Owners Federal Assistance Program were not successful. No other sources of financial assistance have been considered apart from those identified here.

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