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NUCLEAR EXPLOSIONS—PEACEFUL APPLICATIONS (TID-4500)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

HYDROLOGY OF PROJECT GASBUGGY SITE,

RIO ARRIBA COUNTY, NEW MEXICO

By

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ABSTRACT

The Project Gasbuggy nuclear experiment of 26 kilotons design yield was detonated at 4,240 feet below ground surface at the Gasbuggy site in the SW¼ sec. 36, T. 29 N., R. 4 W., Rio Arriba County, New Mexico, on Sunday, December 10, 1967, 1230 mountain standard time. The experiment was designed to increase the permeability of a low-yield natural gas formation.

The Ojo Alamo Sandstone reportedly was the only aquifer within probable range of fracturing at the site. Thus, hydrologic testing in the exploratory holes was in that sandstone between approximate depths of 3,475 and 3,650 feet.

Data from packer tests determined that the average transmissivity of the Ojo Alamo Sandstone is less than 3 gallons per day per foot and that relative specific capacities are less than 0.03 gallon per minute per foot of drawdown. Tests also showed that the hydraulic pressure in the Ojo Alamo Sandstone is greater than the gas pressure in the Pictured Cliffs Sandstone. These data indicated that if the nuclear detonation fractured the Ojo Alamo Sandstone, water from this sandstone would fill the chimney or detonation chamber at an estimated rate of less than half a foot per day. The low transmissivity of the sandstone aquifer would hinder the transport of radioactive contaminants in water in the aquifer, even if momentary overpressure in the explosion cavity caused contaminants to reach the Ojo Alamo Sandstone.

Observation of water levels in wells and measurements of yields of springs preshot, at shot time, and postshot indicate that the detonation did not significantly or permanently disturb nearby water wells or springs.

ACKNOWLEDGMENTS

Personnel of El Paso Natural Gas Co., U.S. Bureau of Indian Affairs, U.S. Forest Service, and U.S. Bureau of Land Management supplied data on wells and springs in the Project Gasbuggy area and, in some instances, assisted in the field. The author gratefully acknowledges their help. Wells GB-1 and GB-2 were hydraulically tested by W. C. Ballance, F. C. Koopman, and J. D. Hudson, U.S. Geological Survey.

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INTRODUCTION

Historical Description of the Gasbuggy Event [1/]

The Project Gasbuggy nuclear explosive of 26 kilotons design yield was detonated on Sunday, December 10, 1967, at 1230:00 mountain standard time.

The explosive was emplaced at 4,240 feet below ground surface, 1,770 feet from the West line and 1,218 feet from the South line in Section 36 of Township 29 North, Range 4 West, in Rio Arriba County, New Mexico, about 55 air miles east of the city of Farmington, New Mexico. The geodetic coordinates are: Latitude -- 36°40'40.4" North; and longitude -- 107°12'30.3" West. The elevation of surface ground zero was 7,204 feet above mean sea level.

The detonation occurred in the Lewis Shale Formation of the San Juan Basin about 40 feet below its contact with the gas-bearing Pictured Cliffs Sandstone.

Early indications are that the explosive performed satisfactorily.

[1/] This statement is the official description provided by the U.S. Atomic Energy Commission after the event.

Objectives

Where underground nuclear devices are detonated, ground- and surface-water contamination is a possibility if radioactivity escapes through fractures radiating upward from the detonation chamber and intersecting water-bearing formations. In addition, water inflow through the fractures could fill the chimney.

To provide data useful in evaluating hydrologic problems at and near the Project Gasbuggy site, the U.S. Atomic Energy Commission asked the U.S. Geological Survey to (1) provide preshot hydrologic data from exploratory holes at Project Gasbuggy site; (2) inventory and examine wells and springs within a 10-mile radius of ground zero before the detonation; and (3) monitor fluctuations of water levels in wells and discharge of springs during and immediately following the detonation.

Background

Two exploratory holes, GB-1 and GB-2, were drilled to 4,308 and 4,247 feet, respectively, at the Gasbuggy site (fig. 1). Order of penetration into the various formations was: San Jose, Nacimiento, and Ojo Alamo Formations of Tertiary age (Baltz, Ash, and Anderson, 1966), and Kirtland Shale, Fruitland Formation, Pictured Cliffs Sandstone, and Lewis Shale of Late Cretaceous age. The Pictured Cliffs Sandstone was of primary importance because within this formation the chimney was formed by block-caving and (or) collapse activity after detonation of the nuclear device in the underlying Lewis Shale.

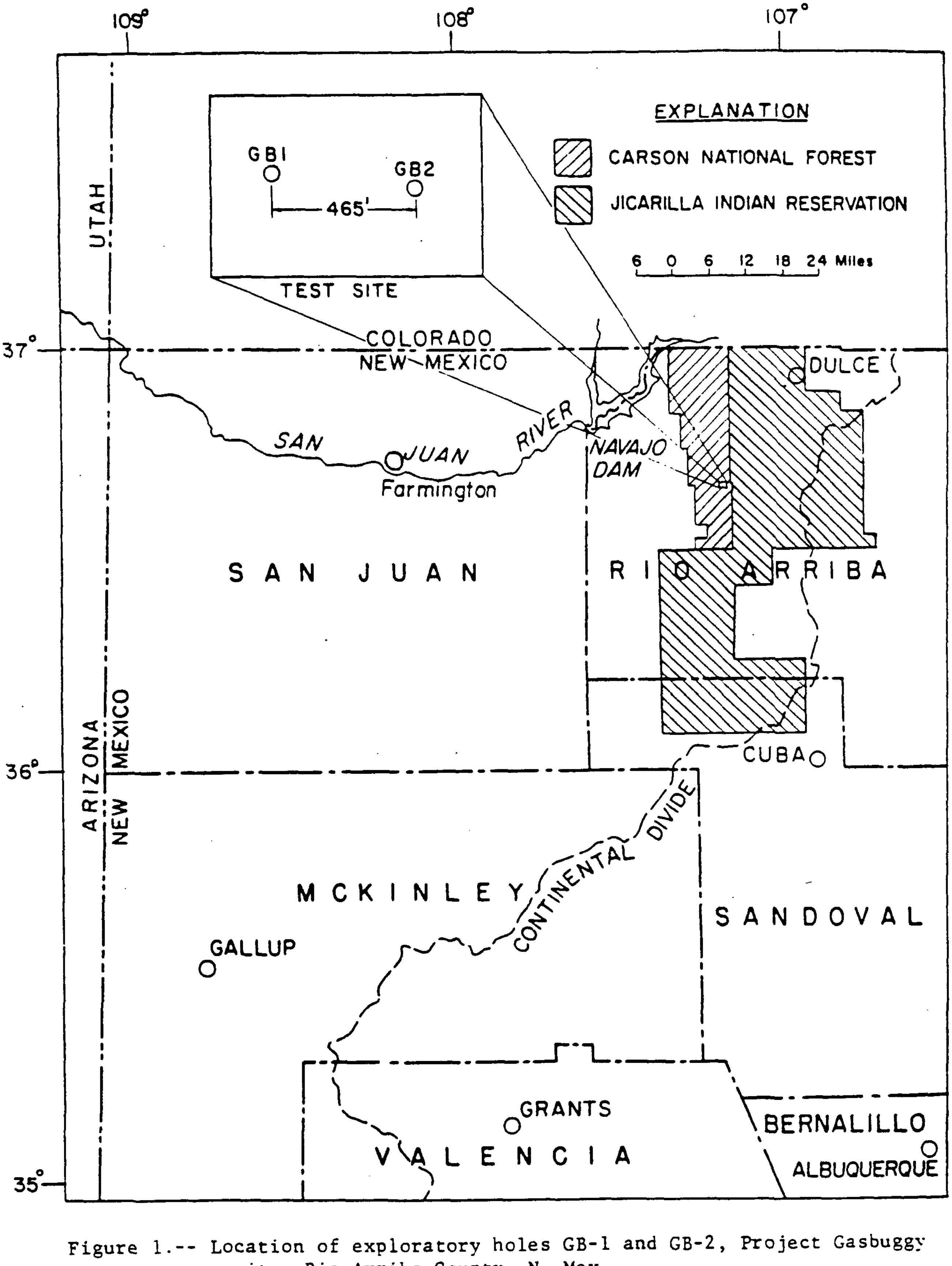

Figure 1.-- Location of exploratory holes GB-1 and GB-2, Project Gasbuggy site, Rio Arriba County, N. Mex.

Topography

Project Gasbuggy site (fig. 2) lies in the eastern part of the San Juan Basin, a structural feature in the eastern part of the Navajo physiographic section of the Colorado Plateau Province. Structural elements of the basin (fig. 2) were named and described by Kelley (1950, p. 101-104). The roughly circular basin is about 180 miles long and 135 miles wide. Except for badland surfaces in areas of sedimentary rocks of Tertiary age, young plateaus with moderate to strong relief characterize the central part of the basin. The Gasbuggy site is within the Central Basin structural element.

The central part of the San Juan Basin drains mostly northwest to the San Juan River. However, tributaries of the Little Colorado River drain most of the south and west sides of the basin; and the extreme southeastern part lies in the Rio Grande drainage basin.

Lithology

Rocks in and around the San Juan Basin range in age from Precambrian to Holocene. Nonmarine sedimentary rocks of early Tertiary age blanket the central part of the basin. Marine and nonmarine strata of Late Cretaceous age surround the Tertiary sedimentary rocks. Older Mesozoic and Paleozoic sedimentary rocks encircle the Cretaceous rocks and mark the outer limits of the depressed part of the basin. Facies changes and intertonguing of marine and nonmarine strata are common throughout the area. The sedimentary rocks in the center of the basin range in thickness from 10,000 to 15,000 feet. Small intrusive plugs, dikes, and flows of basalt occur along the margins of the basin.

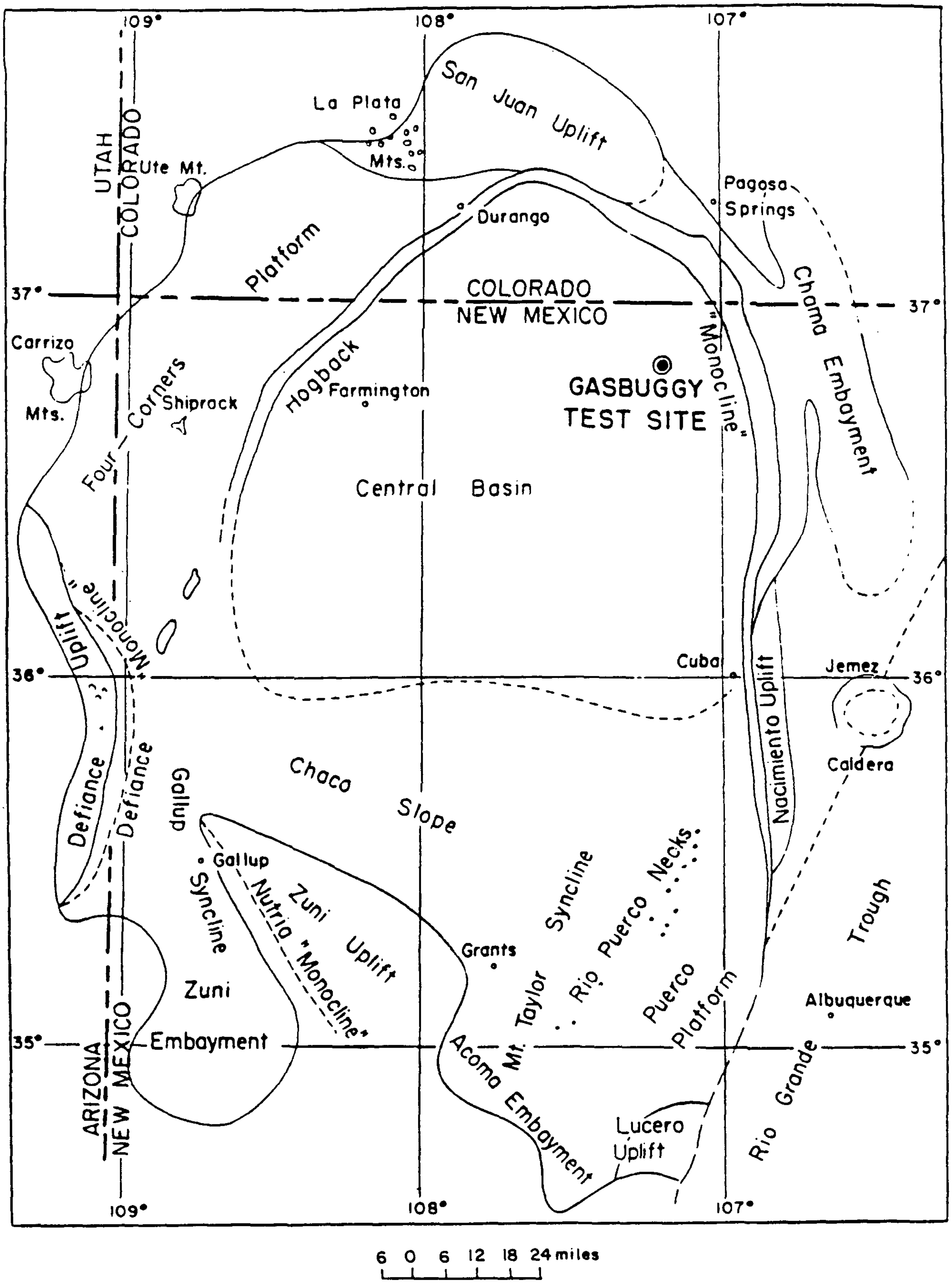

Figure 2.--Major structural elements of the San Juan Basin, New Mexico (from Kelley, 1950).

Nacimiento and San Jose Formations.--The Nacimiento and the San Jose Formations are continental flood plain deposits and are the predominant surface formations in the Project Gasbuggy area. At the test site, they compose a 3,500-foot sequence of fine- to medium-grained, locally conglomeratic sandstone, interbedded with claystone and sandy variegated shale. The thick beds of sandstone in these formations commonly contain water throughout the central part of the San Juan Basin.

Ojo Alamo Sandstone.--The Ojo Alamo Sandstone overlies the Kirtland Shale; it is about 180 feet thick at Project Gasbuggy test site. The formation consists primarily of a light-gray, fine- to medium-grained, clayey sandstone but also contains a few minor beds of shale. The Ojo Alamo Sandstone is water bearing and yields water to domestic wells along the San Juan River 50 miles west of the test site where the formation is 1,700 feet higher than it is at the Gasbuggy site. At the test site, the formation yields minor amounts of water.

Fruitland Formation and Kirtland Shale.--The Fruitland Formation and the Kirtland Shale overlie the Pictured Cliffs Sandstone in ascending stratigraphic order. These formations compose a 260-foot interval of gray to dark-green shale and siltstone interbedded with thin, very fine- to medium-grained sandstone. Abundant carbonaceous material and coal generally are associated with the beds of shale. Coal stringers in the Fruitland Formation yield small amounts of water in some parts of the basin. Exploratory hole GB-1 was drilled with gas as the circulating fluid through the lower part of the Kirtland Shale and through the Fruitland Formation. The cuttings recovered during this drilling were dry, and there were no other indications of water yield from these formations.

Pictured Cliffs Sandstone.--The Pictured Cliffs Sandstone is predominantly a marine sandstone, underlain by the Lewis Shale and overlain by the Fruitland Formation. At the Gasbuggy site, the Pictured Cliffs Sandstone is about 290 feet thick and is chiefly a light-gray, fine- to very fine-grained sandstone interbedded with dark, sandy shales. The sandstone beds bear natural gas and contain minor coal fragments, carbonaceous layers, and traces of oil. The formation yields only small amounts of water in the San Juan Basin. Exploratory hole GB-1 was drilled through the Pictured Cliffs Sandstone with gas as the circulating fluid without noticeable indications of water yield. After the hole was completed, water filled only the lower 10 feet of hole in 18 hours of observation.

Well- and spring-numbering system

All wells and springs discussed in this report are identified by a location number used by the Geological Survey and the New Mexico State Engineer's office for numbering water wells in New Mexico. The location numbers are based on townships, ranges, sections, and tracts within a section. The first three parts of the number, separated by decimal points, represent the township north, range west, and section number, respectively. For convenience, the quarters of a section are numbered 1, 2, 3, and 4. The first digit of the last part of the number gives the quarter section, the second digit gives the quarter of that quarter and the third digit designates the 10-acre tract. Letters a, b, c, and so on are added to the last part of the number to designate the second, third, fourth, and succeeding wells or springs listed in

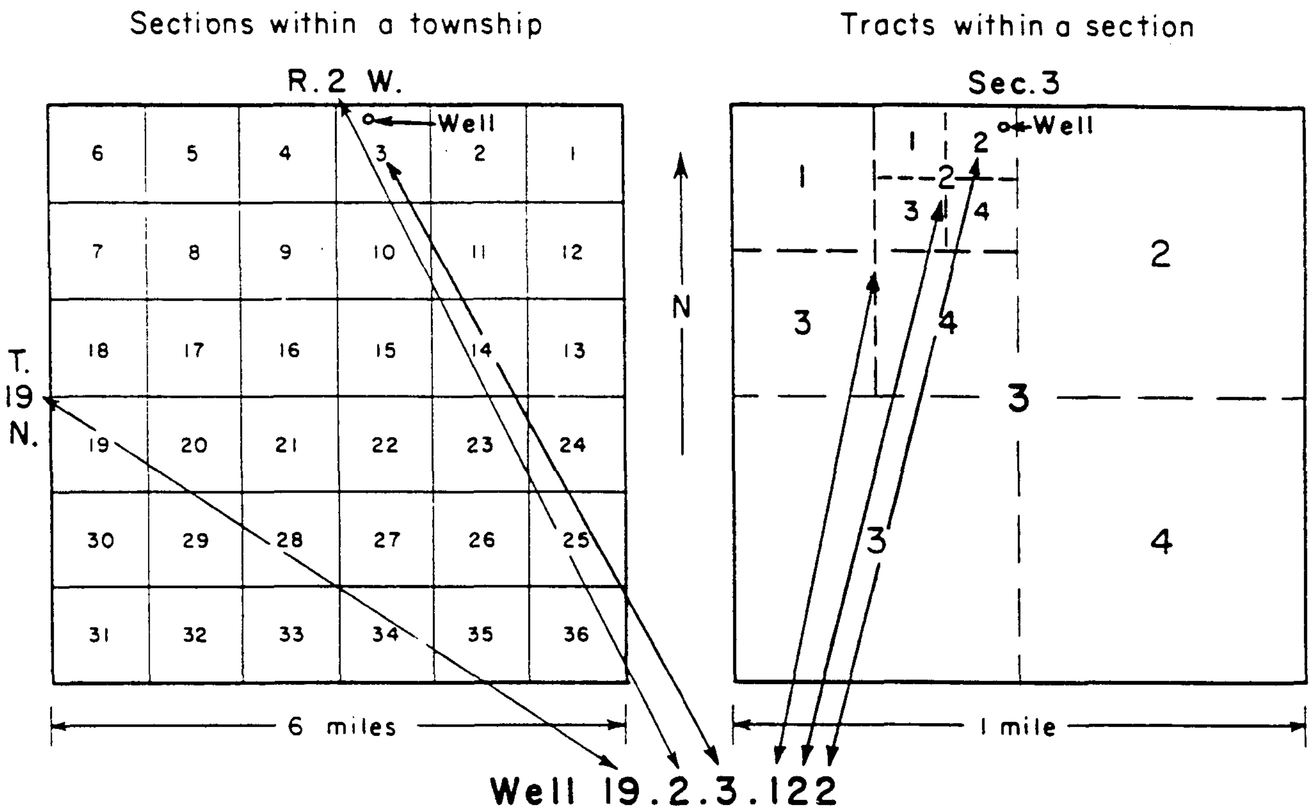

Figure 3.--System of numbering wells and springs in New Mexico.

the same 10-acre tract. For example, the location of well 19.2.3.122 in Rio Arriba County is the NE¼NE¼NW¼ of sec. 3, T. 19 N., R. 2 W. Springs are numbered in the same manner, except that the letter "S" precedes the number.

Theory

Underground nuclear explosions generally fracture the surrounding rocks. The volume of broken rock and the distance that fractures extend from the shot point depend on the yield of the device and the properties of the rock. The design yield of 26 kilotons was not expected to create continuous fractures from the point of explosion to water-bearing sandstones higher in the stratigraphic section (El Paso Natural Gas Company, and others, 1965). Should the fractures have extended upward to the Ojo Alamo Sandstone, or higher beds of water-bearing sandstone, the rubble chimney could be flooded with water and, conversely, radioactive contaminants could momentarily move into the beds of water-bearing sandstone, while the gas overpressure due to the explosion still existed.

PROCEDURE

Hydraulic Test and Sampling

Hydraulic testing was designed to determine how much water might enter the chimney if the Ojo Alamo Sandstone were ruptured by fractures extending upward from the chimney. Testing was not scheduled in the San Jose and Nacimiento Formations above the Ojo Alamo Sandstone, because these formations are well above the expected position of the top of the chimney and zone of radial fractures and because previous drilling and testing in the area indicates that hydrostatic head decreases with depth.

Procedures for testing selected zones in the Ojo Alamo Sandstone in holes GB-1 and GB-2 were similar. With deepening of the holes, test intervals were isolated with a Lynes packer attached to the drill stem and were then tested. Tubing was then inserted into the drill stem to a depth of about 3,000 feet and a swab was run in the tubing to remove fluid from the hole. All measurements during testing are referenced to lsd (land-surface datum). Land surface altitude at GB-1 is 7,198 feet and at GB-2 is 7,198.6 feet above mean sea level.

Hole GB-1

The upper test zone (3,463-3,563 feet) in the Ojo Alamo Sandstone was swabbed twice (fig. 4). On February 23, 1967, fluid was swabbed from a depth of 3,000 feet for 146 minutes at an estimated rate of 5.3 gpm (gallons per minute) (fig. 5). After swabbing, the fluid level was approximately 2,700 feet below lsd. The specific conductance of the fluid removed from the test zone during the latter part of the swabbing period was 9,000 micromhos per cm at 25°C. Water samples for chemical analysis were collected immediately before the end of swabbing. During 349 minutes of water-level recovery measurements after swabbing, the water level recovered to 1,685 feet.

During the second swab test in the upper test zone, on February 24, 1967 (fig. 6), fluid was swabbed from a depth of 3,300 feet for 217 minutes at an estimated rate of 5.3 gpm. After swabbing, the

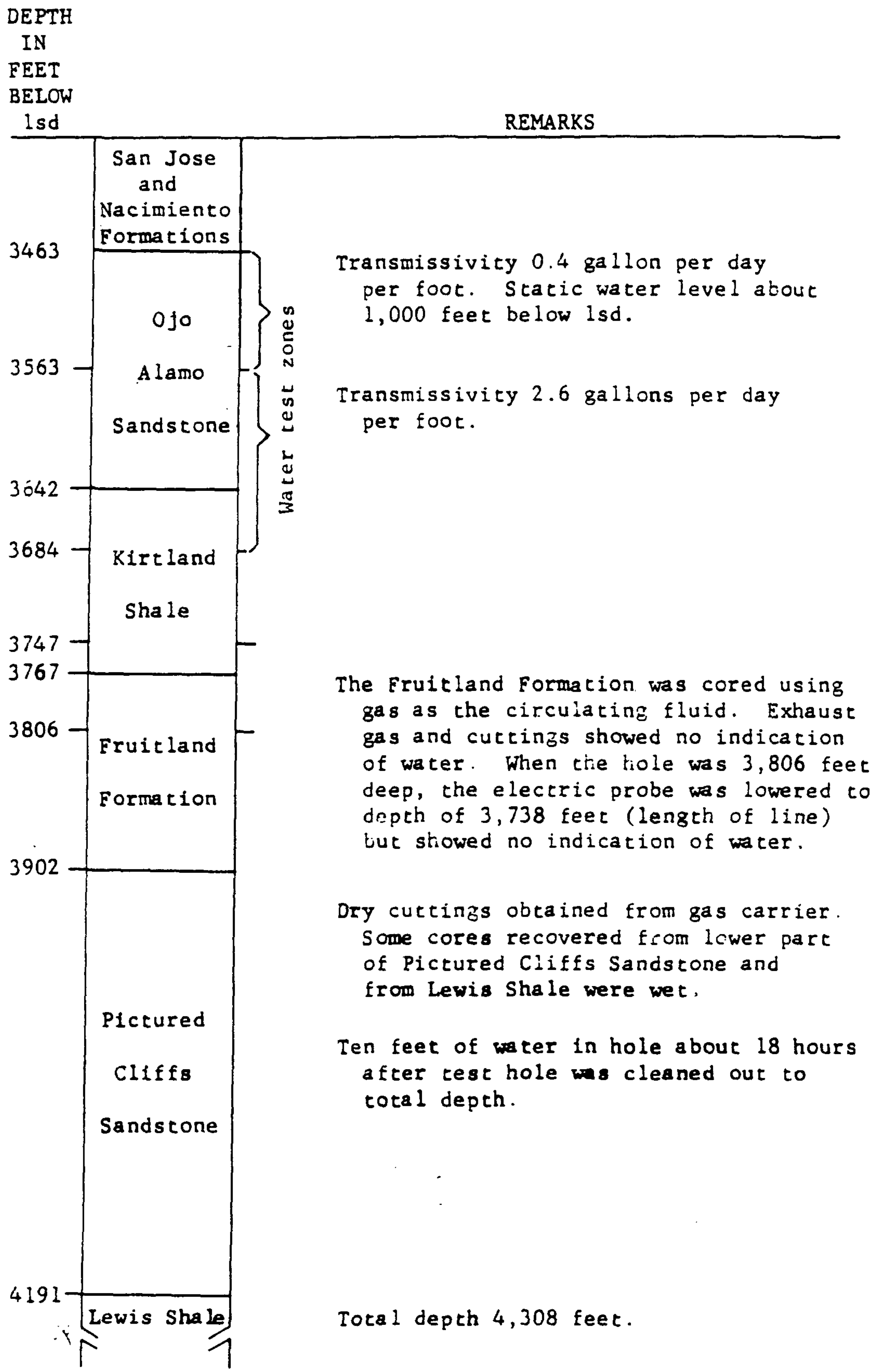

Figure 4.--Formations tested and remarks on hydrologic conditions in hole GB-1, February 23, 1967.

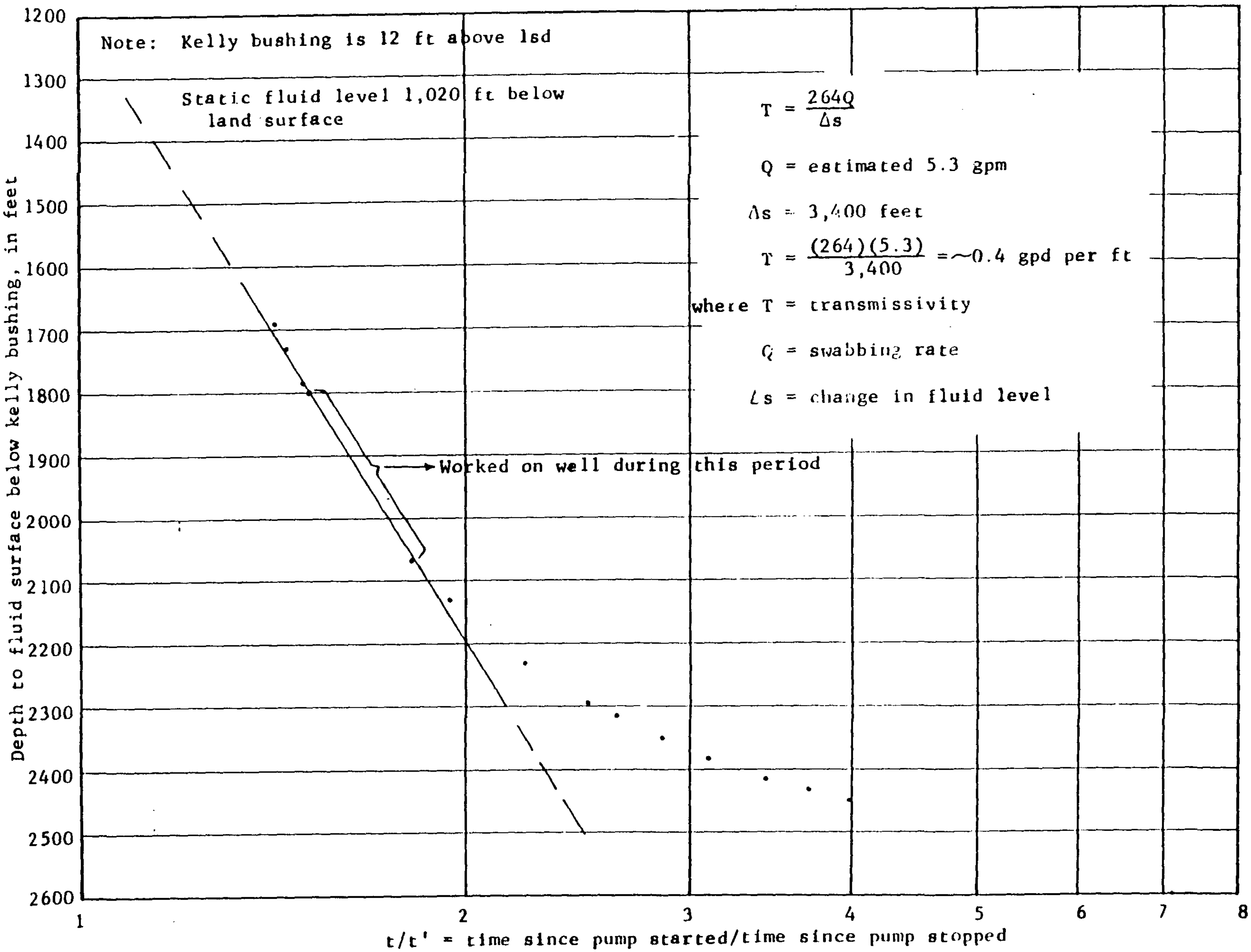

Figure 5 --Recovery of water level in hole GB-1 after first swabbing test of upper zone of Ojo Alamo Sandstone, February 23, 1967.

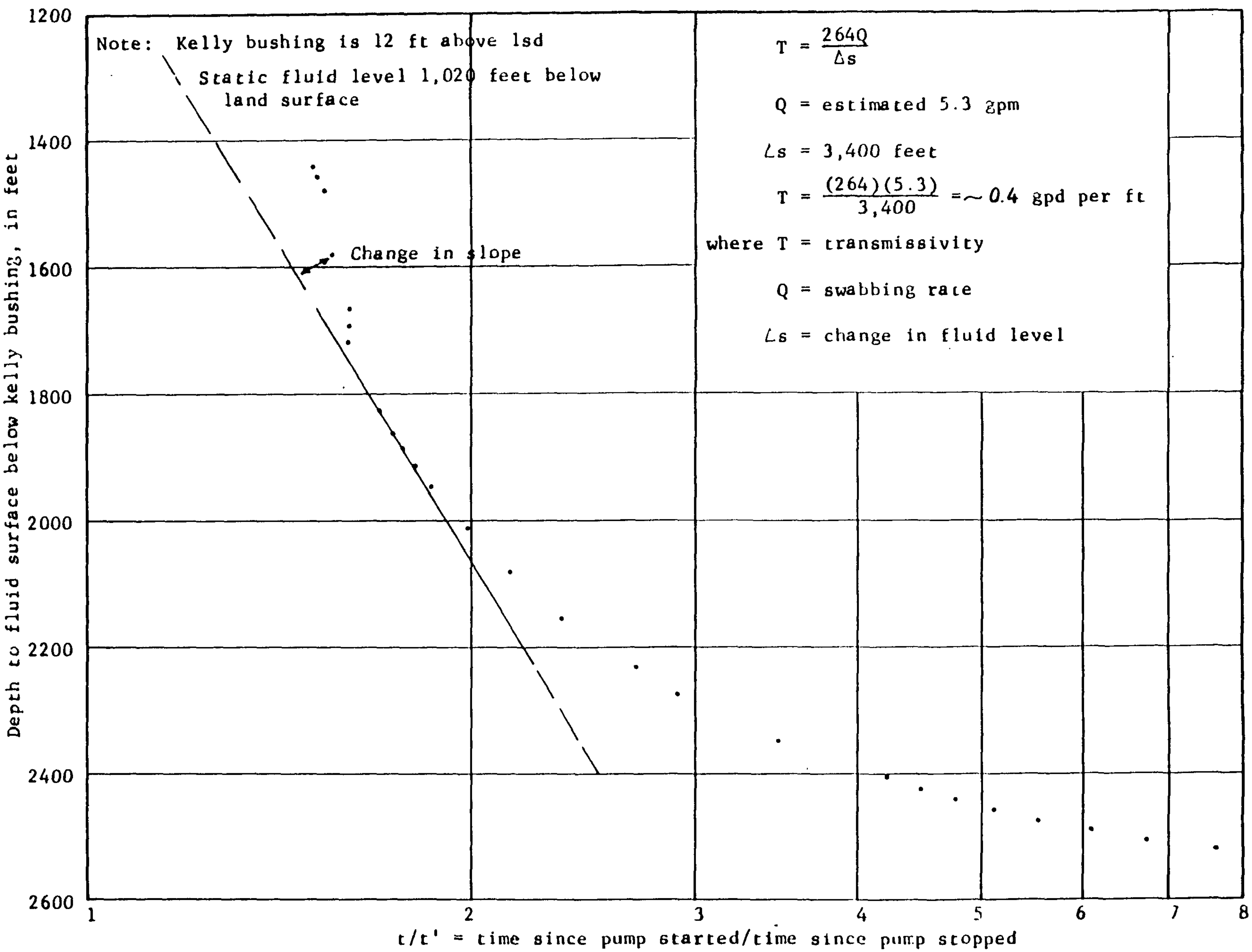

Figure 6.--Recovery of water level in hole GB-1 after second swabbing test of upper zone of Ojo Alamo Sandstone, February 24, 1967.

fluid level was approximately 3,000 feet below lsd. Specific conductance of the fluid removed from the test zone was 9,000 micromhos per cm at 25°C. During 436 minutes of water-level recovery measurements after swabbing, the water level recovered to 1,434 feet. To expedite recovery of the fluid to static level, water was injected into the tubing for 1 hour at a rate of 2.5 gpm.

The lower test zone (3,563-3,642 feet) of hole GB-1 in the Ojo Alamo Sandstone was swabbed twice. On February 26, 1967, fluid was swabbed from a depth of 3,000 feet for 179 minutes at an estimated rate of 14 gpm (fig. 7). After swabbing, the fluid level was approximately 2,300 feet. Specific conductance of the fluid removed from the test zone during the latter part of the swabbing was 9,000 micromhos per cm at 25°C. Water samples for chemical analysis were collected immediately before the end of swabbing. During 470 minutes of water-level recovery measurements after swabbing, the water level recovered to 1,032 feet.

On February 27, 1967, fluid in hole GB-1 was swabbed from a depth of 3,000 feet for 213 minutes at an estimated rate of 13 gpm. After swabbing, the fluid level was approximately 2,350 feet. Water-level recovery measurements were not made after swabbing.

Hole GB-2

On April 17, 1967, the Ojo Alamo Sandstone in hole GB-2 was hydraulically tested in the depth interval 3,465 to 3,649 feet (fig. 8). Fluid was swabbed from a depth of 3,000 feet for 225 minutes at an estimated rate of 9.5 gpm (fig. 9). After swabbing, the fluid level

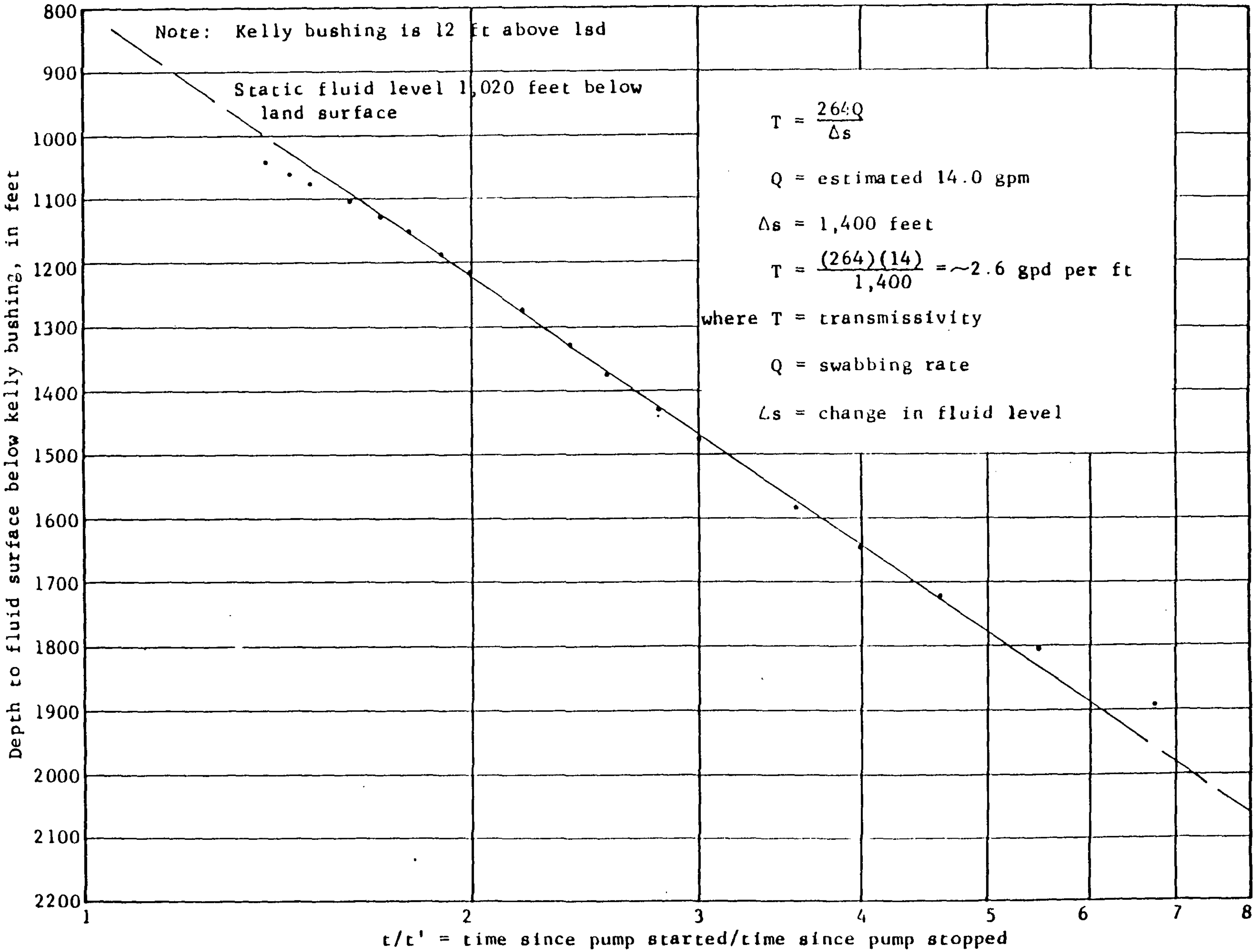

Figure 7.--Recovery of water level in hole GB-1 after first swabbing test of lower zone of Ojo Alamo Sandstone, February 26, 1967.

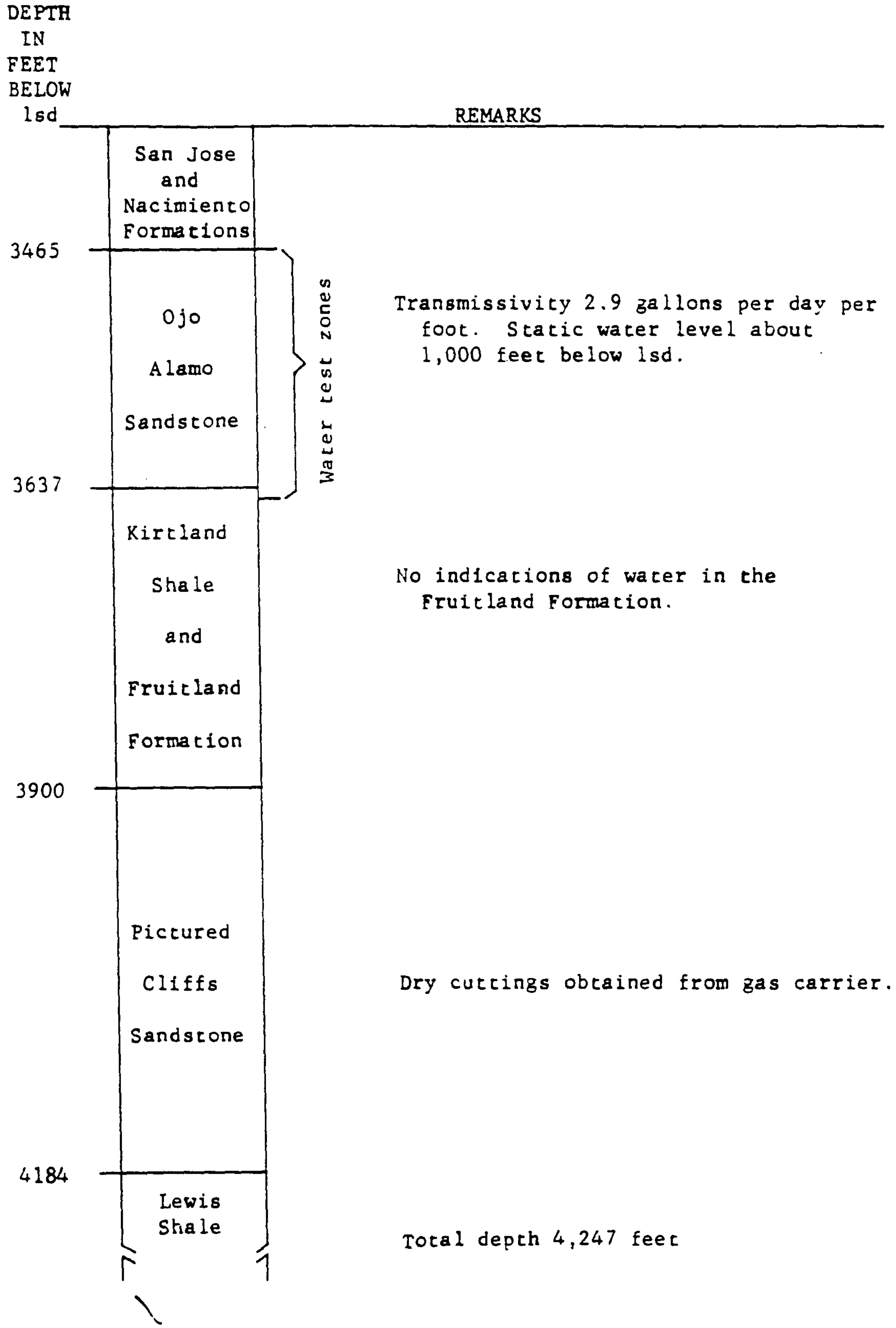

Figure 8 --Formations tested and remarks on hydrologic conditions in hole GB-2, April 17, 1967.

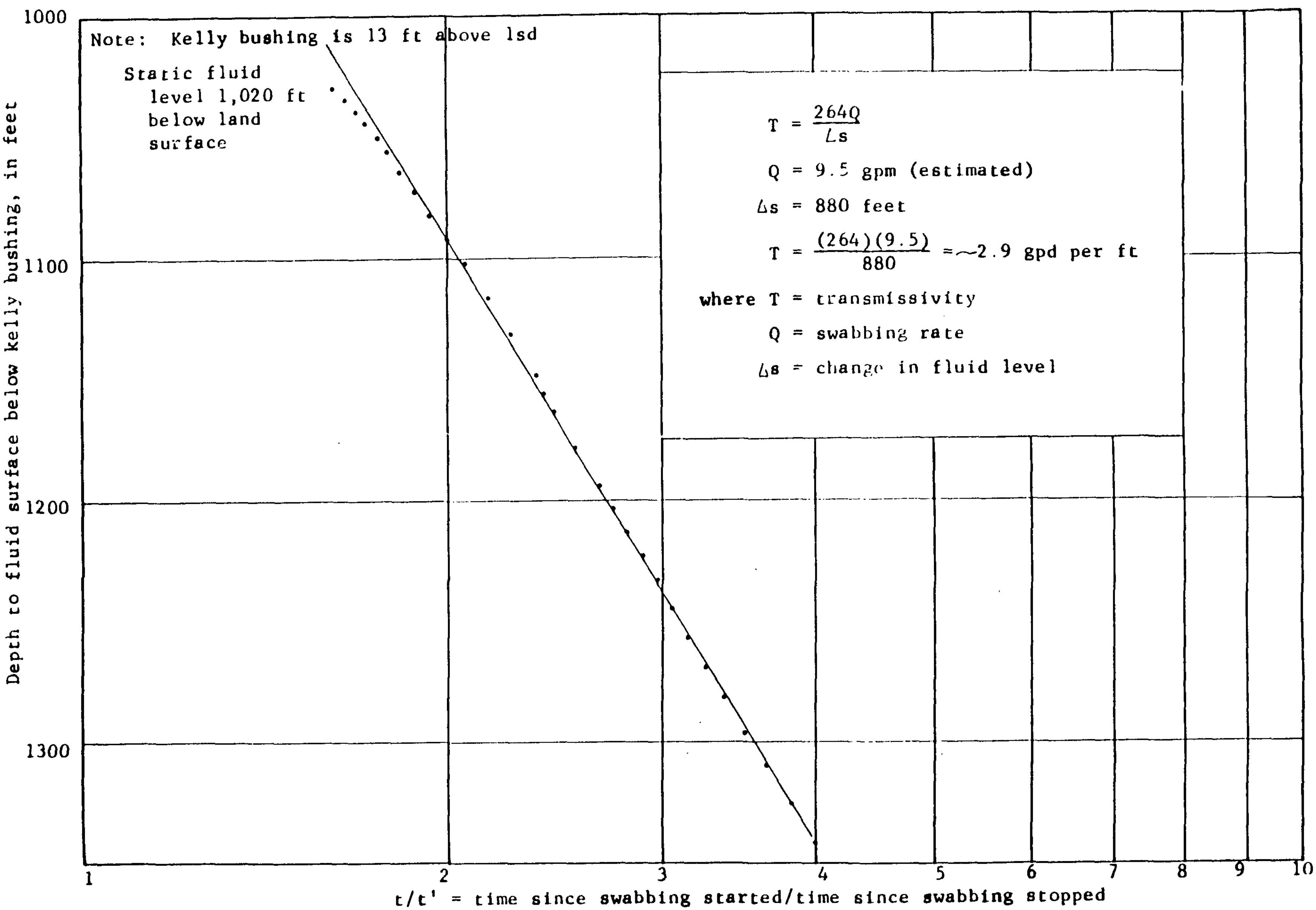

Figure 9.--Recovery of water level in hole GB-2 after swabbing test of Ojo Alamo Sandstone, April 17, 1967.

was approximately 1,600 feet. Specific conductance of the fluid removed from the test zone during the latter part of the swabbing period was 9,000 micromhos per cm at 25°C. Water samples for chemical analysis were collected immediately before the end of swabbing. During 360 minutes of water-level recovery measurements, the water level recovered to 1,018 feet.

Water samples for determination of chemical constituents, physical properties, gross alpha, gross beta, and tritium were collected from the Ojo Alamo Sandstone during swabbing tests in holes GB-1 and GB-2.

Calculations

Analysis of recovery curves

Equation 1 was used for analyzing the recovery properties of the hydrologic tests.

$$T = \frac{264Q}{s} \log_{10} \frac{t}{t'} \qquad (1)$$

T = Transmissivity in gallons per day per foot

s = Residual drawdown in feet

t = Time since swabbing began

t' = Time since swabbing stopped

Q = Swabbing rate in gallons per minute

Time may be in any unit, as the term t/t' becomes dimensionless by cancellation of units. However, time in minutes is recorded in the data tables. Over one log cycle, $\log_{10}$ t/t' becomes unity; s equals Δs or change in s: and then

$$T = \frac{264Q}{\Delta s} \qquad (2)$$

The recovery data were also used to compute the relative specific capacity of the interval tested, a common practice for estimating water inflow to mined chambers at the Nevada Test Site. The equation used to compute specific capacity is as follows:

$$\text{Relative specific capacity} = \frac{Q}{(h' - h)} \qquad (3)$$

where: Q = Gallons of water accepted by an interval isolated with straddle packers during 1-minute time span. The time span 3-4 minutes after the tool is opened is commonly used.

h = Static water level of the hole, or interval tested, in feet below land surface.

h'= Average water level in the tubing, in feet below land surface, in 1-minute time span used for determining Q. The water level at 3.5 minutes is used.

Estimated water flow into chimney

Equations 4 and 5 (Jacobs and Lohman, 1952) were used to estimate rates of water flow into the rubble chimney should the rubble chimney for some unpredictable reason extend upward to the Ojo Alamo Sandstone:

$$Q = \frac{TsG(\alpha)}{229} \qquad (4)$$

$$\alpha = \frac{0.134\ Tt}{r_e^2\ S} \qquad (5)$$

where: Q = Discharge of well, in gallons per minute

T = Transmissivity, in gallons per day per foot

s = Constant drawdown in the discharging well, in feet

t = Time since pumping began, in days

r_e = Effective radius of the discharging well, in feet

S = Storage coefficient, a decimal

and values of $G(\alpha)$ have been tabulated by Jacobs and Lohman (1952). The calculation proceeds on the following assumptions which represent the worst conceivable situation: The chimney intercepts the entire aquifer; water is released to atmospheric pressure.[2/] Values of α (equation 5) for a particular time are then calculated from assumed values of transmissivity, effective radius of the rubble chimney, and storage coefficient. $G(\alpha)$ can then be obtained from the reference and flow rate into the chimney for the time calculated. If the porosity and the radius of the chimney are known, one can compute the rate of rise of water level in the chimney as a function of time.

In computing potential flow of water into a rubble chimney extending through the Ojo Alamo Sandstone, the following values of variables were used in equations 4 and 5:

Transmissivity = 3.0 gallons per day per foot

Constant drawdown = 2,654 feet (bottom of aquifer, 3,654 feet, minus static water level, 1,000 feet)

[2/] Although the gas pressure in the Pictured Cliffs Sandstone is less than the hydrostatic pressure in the Ojo Alamo Sandstone, the pressure in the chimney would not approach atmospheric except during uncontrolled flow of gas from the chimney.

Storage coefficient = 1×10^{-4}

Radius of rubble chimney = 160 feet

Porosity = 20 percent.

In 5 days after detonation of the Project Gasbuggy nuclear explosive, the water level in the chimney would rise 2.3 feet; in 10 days after the detonation it would rise 4.0 feet. If the assumed values of the variables are correct and if equations 4 and 5 apply to the assumed conditions, the water-level rise in the chimney will be less than half a foot per day.

Preshot Investigation of Wells and Springs

All known wells and springs within a 5-mile radius of ground zero were investigated during June 1967 as were all accessible wells and springs between the 5- and 10-mile radius. Locations of these wells and springs are plotted on figure 10 and listed in tables 2 (wells) and 3 (springs). The 13 wells investigated range in depth from 54 to 229 feet and are completed in alluvium. Well yields in the range 1 to 3 gpm are considered good. Specific conductance of the water ranges from 700 to 2,600 micromhos per cm at 25°C.

Twenty-three springs of the contact type were investigated. The springs discharge from sandstones in the San Jose Formation of Eocene age. Some of the springs are seeps with little or no visible flow; others are characterized by yields generally ranging from 1 to 8 gpm. Specific conductance of spring water ranges from 370 to 2,300 micromhos per cm at 25°C.

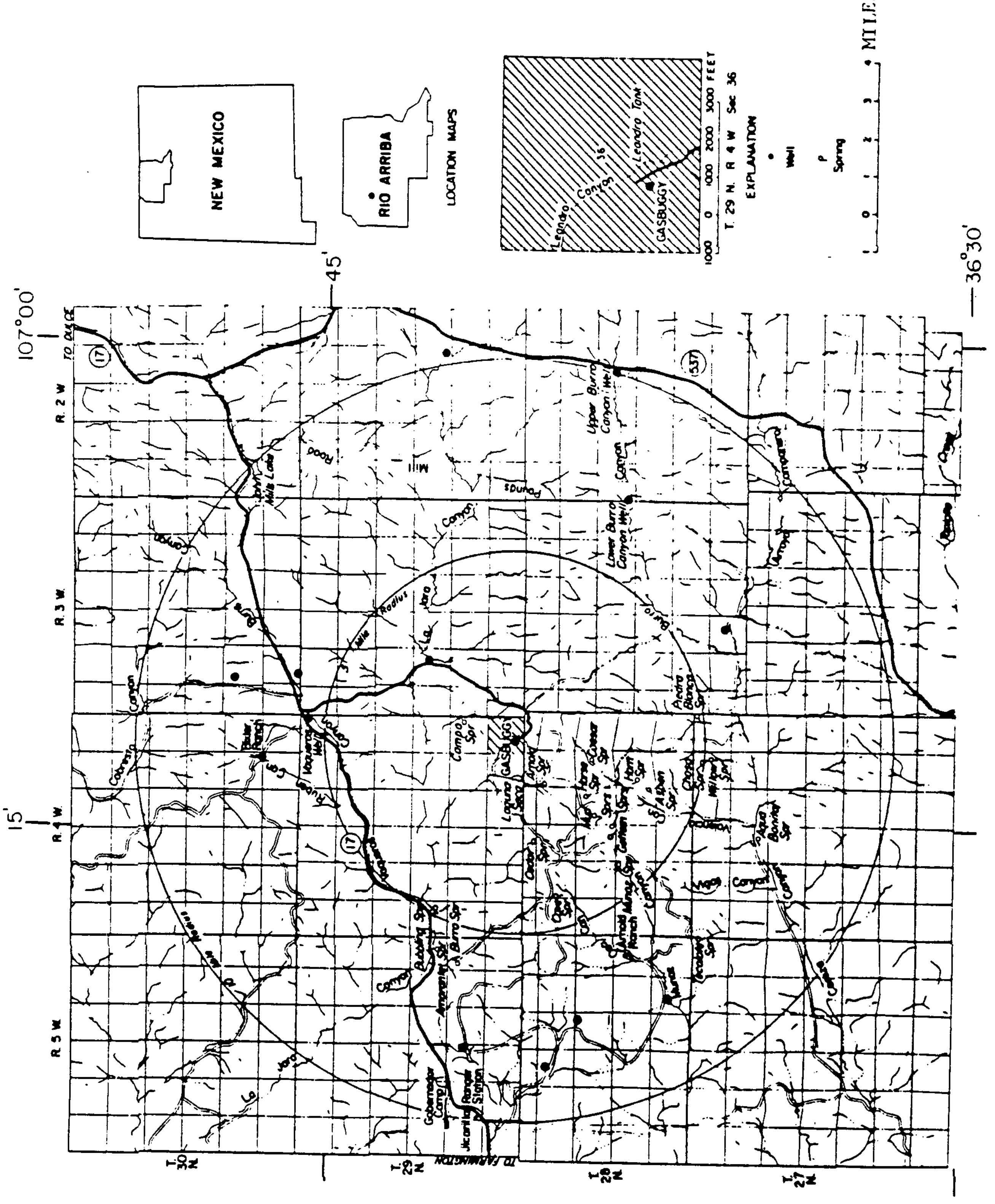

Figure 10.--Location of wells and springs within a 10-mile radius of Project Gasbuggy site.

Table 1.--Records of wells inventoried within a 10-mile radius of Project Gasbuggy Site, Rio Arriba County, N. Mex.

Location number: See text for explanation of well-numbering system.
Depth: Depths listed are measured depths to the nearest foot.
Diameter: Diameter of the casing to the nearest inch.
Altitude: Altitude of land surface at well. Altitude interpolated from U.S.G.S. topographic maps, scale 1:24,000 and contour interval 20 feet.
Water level: Measured depths below land surface, to nearest tenths of a foot.
Stratigraphic unit: Qal - Alluvium.
Type of pump: P - plunger or cylinder; N - none.
Type of power: W - wind; I - internal combustion.
Use of water: D - domestic; S - stock.
Note: Unless specified, all wells are drilled and cased to total depth.

Location no.	Owner or name	Year completed	Depth (feet)	Diameter (inches)	Altitude (feet)	Water level: Depth below land surface (feet)	Water level: Date	Stratigraphic unit	Pump	Power	Use of water	Distance from ground-zero (miles)	Specific conductance (micromhos per cm at 25°C)	Remarks
28.2.15.144	Jicarilla Apache Reservation	-	152	6	7,234	110.2	6-29-67	Qal	P	W	S	10.2	2,100	Upper Burro Canyon well.
28.2.18.331	do	-	229	6	7,089	72.2	6-29-67	Qal	P	W	S	7.1	3,000	Lower Burro Canyon well.
28.3.33.233	do	-	81	6	6,920	51.8	6-29-67	Qal	P	I	S	6.3	-	--
28.5.16.213	U.S. Bur. Land Management	-	95	6	6,580	57.5	6-30-67	Qal	P	I	S	8.6	-	--
28.5.22.221	do	-	-	-	6,698	-	-	-	P	W	S	7.5	700	Yield 1 gpm; temp 50°F.
28.5.35.144	Russell Arnold	1950	-	6	6,630	-	-	Qal	P	I	D,S	7.9	-	Reported yield 11 gpm; reported depth 54 ft.
29.2.22.441	Jicarilla Apache Reservation	1962	198	6	7,150	174.1	6-29-67	Qal	P	W	S	10.2	1,500	Yield 1 gpm; temp 44°F.
29.3.20.234	do	-	75	7	6,875	22.2	6-29-67	Qal	P	W	S	3.1	2,600	Yield 3 gpm; temp 43°F.
29.4. 1.223	U.S. Forest Service	1953	115	7	6,680	29.9	6-30-67	Qal	N	N	N	5.6	-	Vaqueros well old ranger station.
29.5.28.422	U.S. Bur. Land Management	-	130(?)	7	6,650	122.4	6-30-67	Qal	P	W	S	8.2	-	--
30.3.29.132	Jicarilla Apache Reservation	-	-	7	7,235	-	-	-	P	W	S	7.5	850	Yield 2 gpm; temp 47°F.
30.3.32.343	do	-	200	7	7,038	64.1	6-29-67	Qal	P	W	S	5.9	-	--
30.4.35.221	Fred Bixler	-	175	6	7,140	52.7	6-29-67	Qal	P	W	D	6.6	-	Reported yield 3 gpm.

Table 2.--Records of springs inventoried within a 10-mile radius of Project Gasbuggy Site, Rio Arriba County, N. Mex.

Location number: Number preceded by S designates spring location (see text for explanation of well-numbering system).
Altitude: Altitude of land surface at spring, altitude interpolated from U.S.G.S. topographic map, scale 1:24,000 and contour interval 20 feet.
Stratigraphic unit: Qal - Alluvium; Tsj - San Jose Formation.
Yield: Measured unless specified.
Use: N - none; S - stock.

Location no.	Owner	Name	Topographic situation	Altitude (feet)	Strati-graphic unit	Yield (gpm)	Date	Use of water	Temper-ature (°F)	Distance from ground-zero (miles)	Specific conduct-ance (micro-mhos per cm at 25°C)	Remarks
S27. 4. 1.222	U.S. Forest Service	Piedra Blanca	Stream channel	6,960	Tsj	0.2	6-29-67	S	-	4.9	-	Temp 55°F at discharge point, developed spring.
S27. 4. 2.232	do	Chosa	do	7,095	Tsj	.1	6-27-67	N	46	5.0	1,400	Discharge from S6 above SH.
S27. 4. 2.234	do	Willow	do	7,050	Tsj	.1	6-27-67	N	43	5.2	2,200	--
S27. 4. 9.414	do	Agua Bonita	Hillside	6,730	Tsj	8.6	6-26-67	S	49	7.1	1,500	Good spring, developed.
S27. 5. 1.224	do	Tecolote	Stream channel	7,190	Tsj	-	6-30-67	S	48	7.0	850	Dammed; yield not measured.
S28. 4. 9.342	do	Cedar	Hillside	7,350	Tsj	<.1	6-21-67	S	47	2.6	470	Partially developed.
S28. 4.14.113	do	Arnold	do	7,200	Tsj	<.1	6-23-67	N	47	1.3	950	--
S28. 4.17.311	do	Cave	do	7,410	Tsj	.1	6-21-67	S	48	4.2	370	Partially developed, stock tank.
S28. 4.21.444	do	Gotten	Stream channel	7,200	Tsj	.2	6-28-67	S	44	3.4	1,400	--
S28. 4.21.444a	do	-	do	7,200	Tsj	<.1	6-28-67	N	43	3.4	-	--
S28. 4.22.134	do	Mud	do	7,210	Tsj	-	6-27-67	S	52	2.9	-	Series of seeps. Called Hungry by U.S. Forest Service.
S28. 4.22.241	do	Horse	do	7,260	Tsj	-	6-23-67	N	43	2.4	-	Seep.
S28. 4.23.234	do	Caesar	do	7,130	Qal	~.6	6-23-67	S	-	2.1	1,950	Developed, stock tank seepage in excess of measured flow.
S28. 4.26.312	do	Horn	do	7,180	Tsj	.1	6-27-67	N	48	3.4	2,300	Called Aspen by U.S. Forest Service.
S28. 4.27.444	do	Aspen	do	7,135	Tsj	.1	6-27-67	N	54	3.8	-	Seep, called Horn by U.S. Forest Service.
S28. 4.29.221	do	Munoz	Hillside	7,080	Tsj	.5	6-21-67	S	43	4.3	-	--
S28. 5.25.142	Arnold Ranch	-	Valley flat	6,780	Tsj(?)	-	6-30-67	S	48	6.4	-	Seep.
S28. 5.25.142a	do	-	do	6,790	Tsj(?)	-	6-30-67	S	47	6.4	-	Seep.
S29. 4.19.412	do	Bubbling	do	6,555	Tsj	4.3	6-23-67	S	45	5.1	1,290	Developed.
S29. 4.19.421	do	-	do	6,570	Tsj	4.0	6-23-67	N	45	4.9	900	--
S29. 4.25.241	do	Campo	Stream channel	6,920	Tsj	-	6-22-67	N	45	1.5	-	Seep.
S29. 5.24.413	do	Amarante	Hillside	6,570	Tsj	.6	6-23-67	N	44	5.8	515	--
S29. 5.25.132	do	Burro	do	6,580	Tsj	~.3	6-23-67	S	50	6.0	740	Developed, stock tank.

Measurements of Wells and Springs

Water levels in five wells and discharges in five springs were measured on December 8, 1967. On December 10, a few hours after the nuclear shot, repeat measurements were made in these same wells and springs. During the shot, recording instruments were in operation in one well and in two springs. The well (29.3.20.234), 3.1 miles from ground zero, was monitored by an electro-mechanical recorder with a chart time drive of 2 inches per minute and a water-level magnified response ratio of about 2:1. The pressure-sensing unit (strain-gage transducer) was installed 65 feet below the water level in the well. Mechanical recorders were installed on springs 5.1 miles northwest (S29.4.19.412) and 7.1 miles southwest (S27.4.9.414) of ground zero. Table 3 lists the wells and springs observed at, or near shot time, and the observations made in them.

Table 3.--Wells and springs observed at, or near, shot time, Project Gasbuggy, Rio Arriba County, N. Mex.

Location no.: See text for explanation of numbering system.

Location no.	Owner	Name	Water level, depth below land surface (feet)		Yield (gpm)		Remarks
			Date		Date		
			12-8-67	12-10-67	12-8-67	12-10-67	
28.5.16.213	U.S. Bur. Land Management	--	58.80	58.84	--	--	--
29.3.20.234	Jicarilla Apache Reservation	--	21.30	20.41	--	--	Instrumented.
29.4.1.223	U.S. Forest Service	Old Vaqueros well	37.37	37.84	--	--	--
30.3.32.343	Jicarilla Apache Reservation	--	61.76	62.42	--	--	--
30.4.35.221	Fred Bixler	--	56.31	57.93	--	--	Well had been pumped shortly before measurement of 12-10-67.
S27.4.9.414	U.S. Forest Service	Agua Bonita	--	--	8.75	8.87	Instrumented.
S28.4.17.311	do	Cave	--	--	.08	.12	--
S29.4.19.412	Arnold Ranch	Bubbling	--	--	4.23	4.35	Instrumented.
S29.4.19.421	do	--	--	--	9.30	10.00	--
S29.5.24.413	do	Amarante	--	--	.50	.35	--

RESULTS

In hole GB-1, the transmissivity of the Ojo Alamo Sandstone is about 0.4 gpd per ft in the upper 100 feet and 2.6 gpd per ft in the lower 70 feet. In hole GB-2, the transmissivity of the sandstone is 2.9 gpd per ft. Calculated relative specific capacities are 0.003 gpm per ft in the upper zone and 0.016 gpm per ft in the lower zone of hole GB-1 and 0.026 gpm per ft in hole GB-2.

Temperature of the formation fluid at the well head (GB-1) during swabbing was 112°F.

The hydraulic conductivity of the Ojo Alamo Sandstone is about 0.017 gpd per sq ft. This value was derived by using a transmissivity of 3 gpd per ft and an effective aquifer thickness of 180 feet. The average porosity, determined by Core Laboratories, Inc., is 13 percent. Calculations based on this average value and a hydraulic gradient of 30 feet per mile (the average gradient from the Gasbuggy site to the nearest discharge points at outcrops along the San Juan River) indicate that the rate of movement of ground water in the Ojo Alamo Sandstone is about 0.0001 foot per day or 0.04 foot per year.

Seismic effects of the Project Gasbuggy nuclear shot caused a hydrostatic pressure pulse in the monitored well (fig. 11). An initial water-level rise of 0.75 foot was followed by a decline of water level to within 0.1 foot of the original static level after 1 second and an oscillation due to seismic arrivals of 0.2 foot magnitude that continued for 3 seconds. About 6 seconds after the first pulse, the water level returned to the preshot static level.

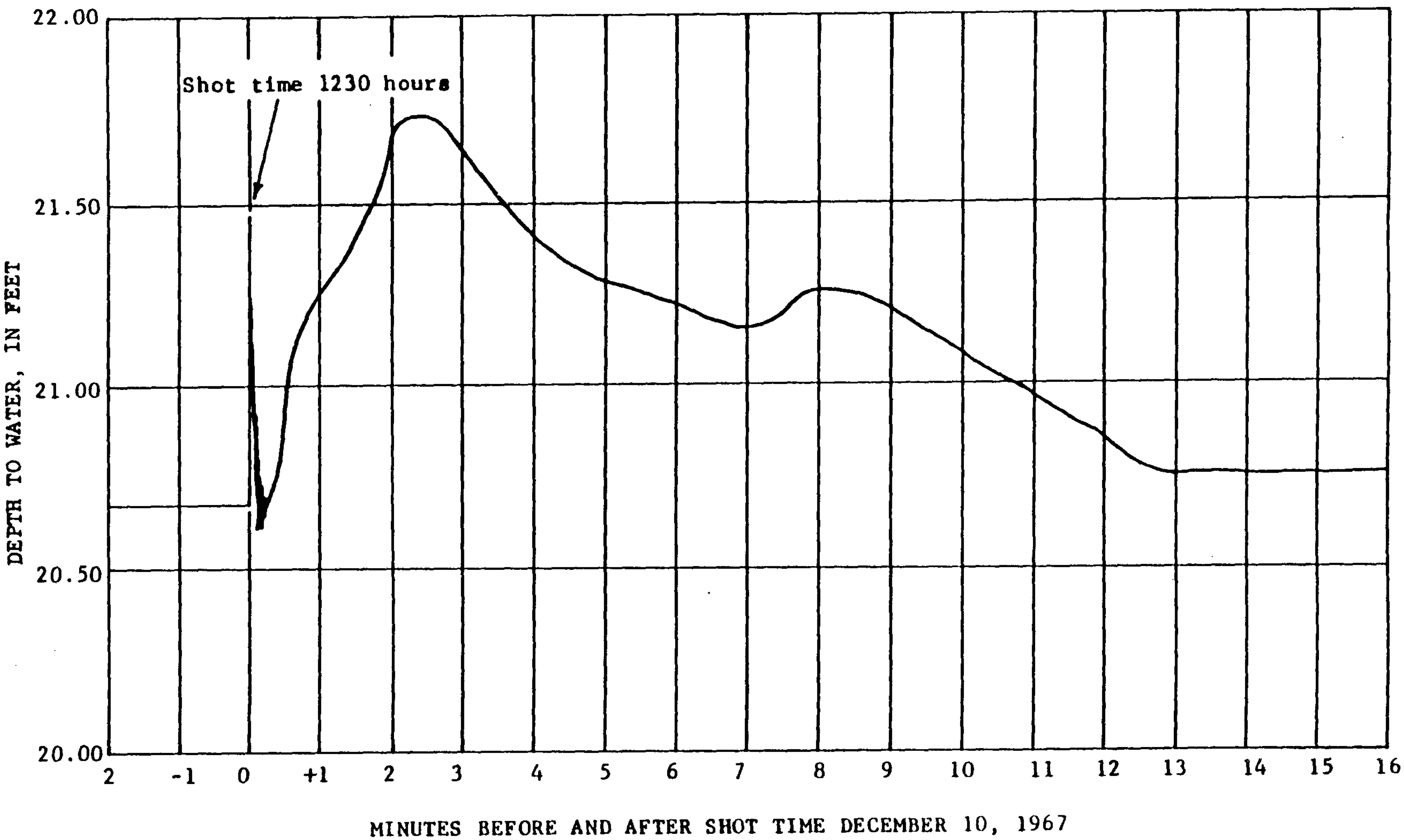

Figure 11.--Hydrograph of well 29.3.20.234 during time of Project Gasbuggy nuclear shot, December 10, 1967.

Twelve seconds after the first pressure pulse, the water level rose steadily for 35 seconds to 0.5 foot above static level. It then continued to rise at a lesser rate for 80 seconds to 1.05 feet above static level where it held steady for 24 seconds before starting a steady decline that continued for 13 minutes after the first pulse. About 40 minutes after the first pulse, the fluid level was 0.1 foot above static level. The ink in the recorder pen ceased to flow 40 minutes after the first pulse; several hours later when the recorder station was attended, the pen position indicated the water level in the well was near static level.

In response to the Project Gasbuggy nuclear shot, the pen of the recorder on a spring 5.1 miles northwest of ground zero moved slightly upward (fig. 12). This rise suggests an increased rate of flow of only a small fraction of a gallon per minute. The increase continued for 4 days after the shot. The recorder on a spring 7.1 miles southwest of ground zero did not respond to the shot. Preshot and postshot measurements in 5 wells and 5 springs showed only slight differences of water level and yield. These differences are attributed to normal daily variations and are probably unrelated to the nuclear shot.

Examination of table 4 reveals the quality of ground water at Project Gasbuggy site. Table 4 shows that water in both holes GB-1 and GB-2 is sodium sulfate type, hard (hardness as calcium carbonate exceeds 600 ppm), and moderately saline (dissolved solids range from 6,060 to 7,370 ppm). This salinity indicates poor circulation of ground water in the Ojo Alamo Sandstone in the vicinity of the Project Gasbuggy site.

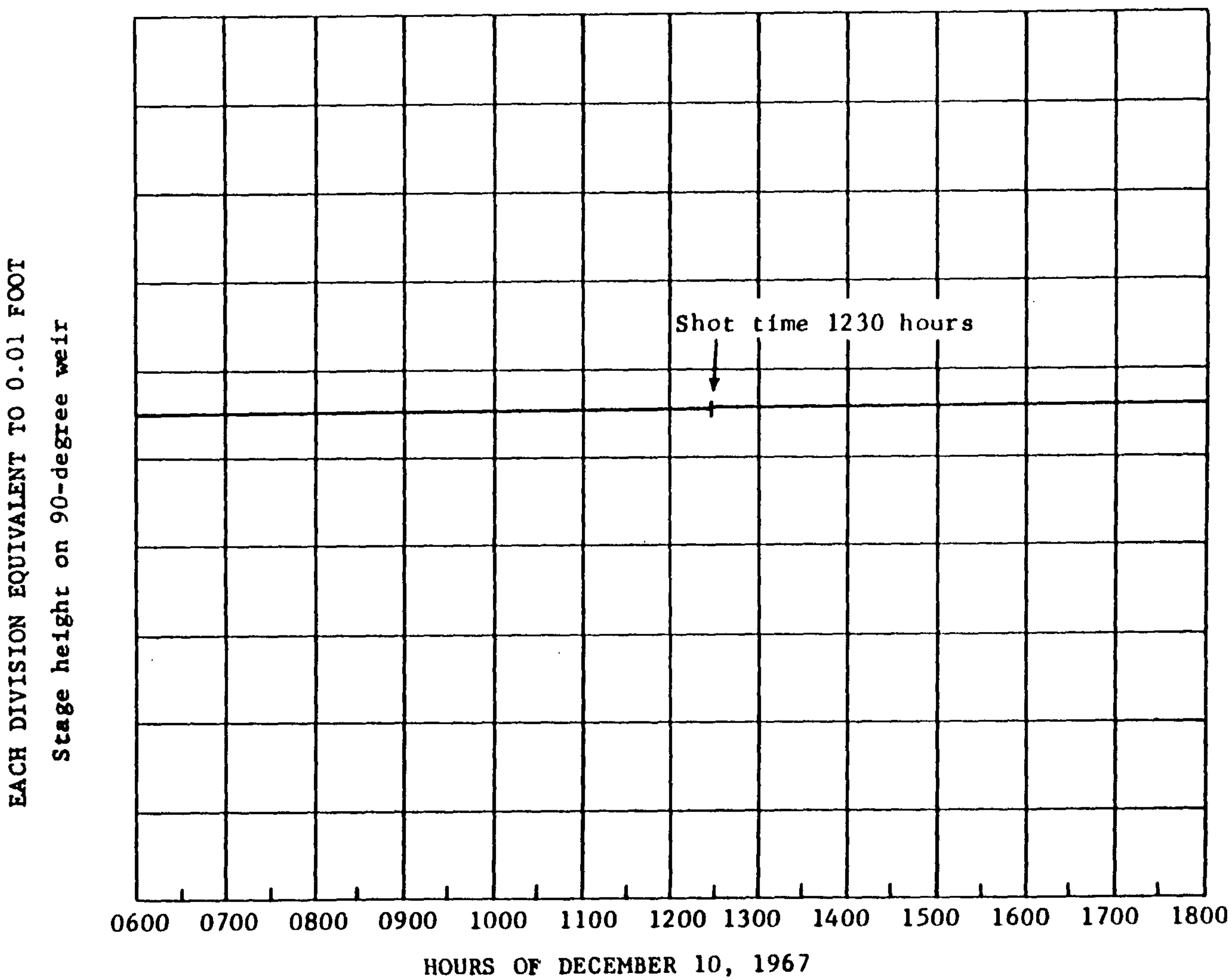

Figure 12.--Stage height of water level at weir on spring S29.4.19.412 (Bubbling Spring) during time of Project Gasbuggy nuclear shot, December 10, 1967.

Table 4.--Analyses of water samples from holes GB-1 and GB-2, Project Gasbuggy, Rio Arriba County, N. Mex.

Water samples analyzed by G. F. Scarbro and R. K. Glanzman (chemical); P. K. Roscio and R. S. Dewar (gross beta and gross alpha); and W. A. Tarrant (tritium).

(Chemical components are in parts per million)

Hole no.	GB-1	GB-1	GB-2
Zone sampled (ft below land-surface datum)	(3,463-3,563)	(3,563-3,642)	(3,465-3,649)
Date of collection	2-23-67	2-26-67	4-17-67
Silica (SiO_2)	8.0	16	10
Iron (Fe)	.49	.69	1.4
Aluminum (Al)	.02	.02	.4
Manganese (Mn)	1.5	.08	.33
Arsenic (As)	<.01	<.01	--
Strontium (Sr)	4.6	5.3	4.7
Calcium (Ca)	218	242	251
Magnesium (Mg)	14	14	12
Lithium (Li)	.28	.28	.28
Sodium (Na)	2,160	1,880	2,220
Potassium (K)	14	12	1.6
Copper (Cu)	.01	.01	--
Zinc (Zn)	.01	.01	.03
Bicarbonate (HCO_3)	223	86	306
Carbonate (CO_3)	0	0	0
Boron (B)	.40	.25	.86
Sulfate (SO_4)	4,060	3,630	4,440
Phosphate (PO_4)	.00	.00	.00
Selenium (Se)	<.01	<.01	.02
Chloride (Cl)	272	221	282
Fluoride (F)	1.4	1.4	2.3
Nitrate (NO_3)	.0	.0	.0
Dissolves solids, calculated	6,860	6,060	7,370
Hardness as $CaCO_3$			
Total	607	668	682
Non-carbonate	424	598	430
Specific conductance (micromhos per cm at 25°C)	8,210	7,450	9,350
pH	7.7	6.9	7.2
Percent sodium	88	86	88
SAR	38	32	37
Tritium (T. U.)	<400[1]	<400[1]	<400[2]
Gross beta as Sr^{90}-Y^{90} (pc per l)	14[3,4]	13[3,4]	--
Gross alpha as U equivalent (μg per l)	3.1[3]	1.5[3]	--

[1] Determined on 4-24-67.

[2] Determined on 5-10-67.

[3] Determined on 5-18-67.

[4] Includes activity due to K^{40}

CONCLUSIONS

The alluvium, the San Jose and Nacimiento Formations, and the Ojo Alamo Sandstone are the aquifers in the Project Gasbuggy area. The San Jose and Nacimiento Formations at the Gasbuggy site were considered to be far above the expected position of the top of the chimney and fracture zone. The Ojo Alamo Sandstone was considered to be within the unlikely but remotely possible range of fracturing. Thus, hydrologic testing in the exploratory holes was limited to the Ojo Alamo Sandstone.

The low transmissivities and the specific capacities determined for the Ojo Alamo Sandstone indicate that should fracturing reach the formation the entry of water into the chimney would cause filling of the chimney at an estimated rate of about half a foot per day. The low transmissivity of the aquifer and the decreasing hydrostatic head with depth would prevent extensive radioactive contamination of water in the aquifer.

The major discharge point for water moving in the Ojo Alamo Sandstone is probably the San Juan River, 50 miles northwest of the Project Gasbuggy site. The computed average rate of ground-water movement is about 0.0001 foot per day or 0.04 foot per year.

Thirteen wells and 23 springs within a 10-mile radius of the Project Gasbuggy site were investigated before the nuclear shot. These wells and springs tap either alluvium or the San Jose Formation; no wells in the area are known to tap deeper aquifers.

The effects of the nuclear shot were minimal to those springs and wells observed within a 5- to 6-mile radius of ground zero. These temporary effects could be detected only by delicate recording instruments; flow of the springs and change in water levels in wells affected by the shot were discernible for about 5 days. These disturbances to the ground-water regime caused by the shock of the detonation were only of short duration and possibly were due to mechanical adjustments of the aquifer material. Water levels in wells and the flow of springs over a period of a few months are more significantly affected by natural hydrologic influences than they were by the nuclear shot.

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TECHNICAL AND SAFETY PROGRAM REPORTS
PROJECT GASBUGGY

A. TECHNICAL REPORTS - (already issued)

Authoring Organization	Report No.	Report Title
EPNG/AEC/USBM/LRL	PNE-1000	Project Gasbuggy (Feas. Study Rpt.)
LRL	PNE-1001	Pre-Shot Summary
LRL	PNE-1003	Preliminary Post-Shot Summary
EPNG	PNE-G-9	Drilling & Testing Operations
LRL	PNE-G-10	Gas Quality Investigation Program Status Rpt.
LRL	PNE-G-11	Post-Shot Geologic Investigation
USBM/EPNG	PNE-G-13	Status of Reservoir Evaluation

B. TECHNICAL REPORTS - (to be prepared)

SL	PNE-1002	Free-Field & Surface Ground Motions
LRL	--	Prediction & Results of Dynamic Effects
LRL	--	Analysis & Interpretation of Gaseous Radioactivities
LRL	--	The Gasbuggy Seismic Source
LRL	--	Response of the Navajo and El Vado Dams
EPNG/USBM/LRL	--	Reservoir Geology
EPNG/USBM	--	Post-Shot Flow Tests
EPNG/USBM	--	Reservoir Analysis

C. SAFETY REPORTS - (already issued)

ERC	PNE-1010	Analysis of Ground Motions and Close-in Physical Effects
USBM (BuMines)	PNE-1011	Gasfield and Mine Survey
JAB	PNE-1012	Final Report on Structural Responce
USGS	PNE-1013	Hydrology of Project Gasbuggy Site, Rio Arriba County, New Mexico
USC&GS	PNE-1014	Seismic Measurements
NV	PNE-G-12	Operational Safety Aspects

D. SAFETY REPORTS - (to be prepared)

EIC	PNE-1006	On-Site Radiological Safety
USPHS	PNE-1007	Off-Site Radiological Surveillance
ESSA/ARFRO	PNE-1008	Weather and Radiation Predictions
II	PNE-1009	Ground Water Safety Evaluation

E. ABBREVIATIONS OF ORGANIZATIONS

EIC	Eberline Instruments Corp., Santa Fe, N.M.
EPNG	El Paso Natural Gas Co., El Paso, Texas
ERC	Environmental Research Corp., Alexandria, Va.
ESSA/ARFRO	Environmental Science Services Administration/ Air Resources Field Research Office, Las Vegas, Nev.
II	Isotopes, Inc., Palo Alto, California
JAB	John A. Blume & Associates, San Francisco, Calif.
LRL	Lawrence Radiation Laboratory, Livermore, Calif.
NV	USAEC Nevada Operations Office, Las Vegas, Nevada
SL	Sandia Laboratory, Albuquerque, N.M.
USAEC	U. S. Atomic Energy Commission
USBM	Bureau of Mines, U. S. Department of the Interior
USC&GS	U. S. Coast & Geodedic Survey, Las Vegas, Nev.
USGS	U. S. Geological Survey, Denver, Colo.
USPHS	U. S. Public Health Service, Las Vegas, Nev.

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SECTION 3.7

COVER SHEET

NAME OF SITE: Gasbuggy Site, New Mexico

LOCATION: The site is located in north central New Mexico in Rio Arriba County, 55 miles east of Farmington.

DISPOSITION: The Gasbuggy test was conducted on U.S. Forest Service land under lease to El Paso Natural Gas Co. T29N R4W Section 36 was withdrawn from the BLM for use by AEC (now DOE) as well as subsequent surface and subsurface rights. Radionuclides were released to the subsurface environment at the time of the shot. Surface release of radionuclides (to the atmosphere) occurred during gas production testing in 1968, 1969, and 1973.

PRELIMINARY ASSESSMENT REPORT
GASBUGGY SITE, NEW MEXICO

INTRODUCTION

The Gasbuggy site is located in Rio Arriba County, New Mexico, approximately 55 air miles east of Farmington, New Mexico. The Gasbuggy device was the first U.S. underground nuclear experiment for the stimulation of low-productive natural gas reservoirs.

Project Gasbuggy (Plowshare Series) was sponsored by the Division of Peaceful Nuclear Explosives (DPNE). The Gasbuggy site is on an El Paso Natural Gas (EPNG) Company lease in the San Juan Basin and is surrounded by other EPNG lease holdings.

The primary purpose of the Gasbuggy experiment was to determine if nuclear stimulation could economically release gas that could not be economically produced from underground reservoirs by conventional methods. The experiment involved the detonation of a nuclear device designed to have a 29 kt yield. The nuclear explosive was emplaced at a depth of 4,240 ft below the land surface in the Lewis Shale just below the natural gas-producing Pictured Cliffs sandstone formation. The Gasbuggy device was detonated on December 10, 1967.[1]

OVERALL FACILITY DESCRIPTION

In the case of Gasbuggy, a single detonation occurred followed by several testing phases. The underground ground zero (GZ) and the surface facilities are treated in this report as a single facility site.

The Project Gasbuggy site is located in the southwest quarter of Section 36, T29N, R4W, New Mexico Principal Meridian. It is located on the eastern side of the San Juan Basin, a structural feature of the Colorado Plateau Province located in northwestern New Mexico and southwestern Colorado (see Figure 3.7.1). The nearest large town is Farmington, New Mexico, with a population of 23,000. The nearest community is Dulce, New Mexico, 20 miles to the northeast with a population of about 500. There were no habitations within a five-mile radius at the time the Gasbuggy experiment was conducted. The population remains the same at the date of 1986.[1] The test site was within the Carson National Forest and adjacent to the Jicarilla Apache Indian Reservation. The existing oil and gas leases for the

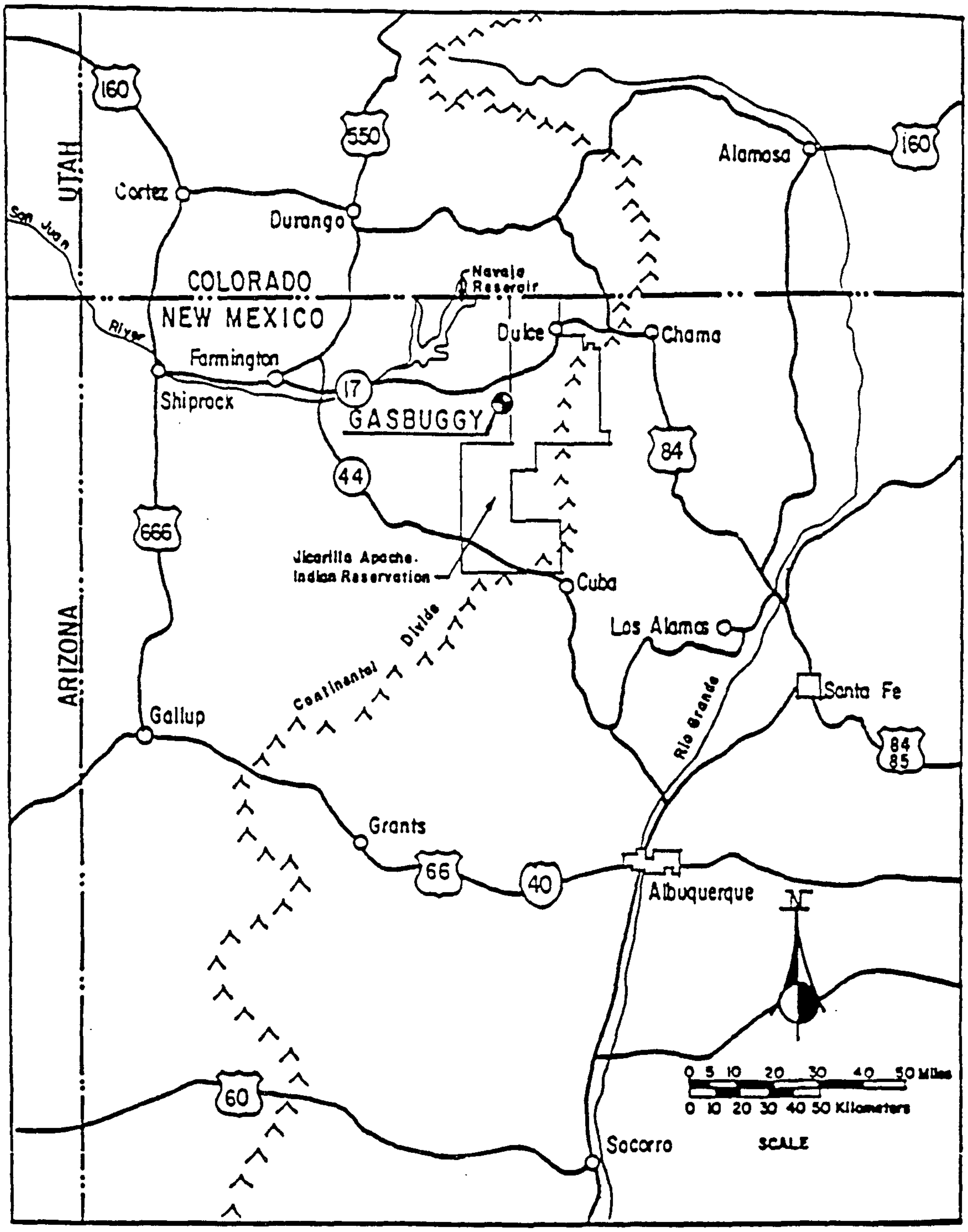

FIGURE 3.7.1. Location Map for Gasbuggy Site.

lands in the immediate area of the test location are held by EPNG (see Figures 3.7.2 and 3.7.3).[2]

The project installations, consisting of the GZ area, the recording trailer park (RTP), the control point (CP), and the helicopter pad were located on lands within the Carson National Forest. The use of these lands for the Gasbuggy Project was established in a Memorandum of Understanding between the U.S. Forest Service and the U.S. Atomic Energy Commission. Additionally, by land withdrawal action of Public Land Order 4232, dated June 22, 1967, the Bureau of Land Management withdrew from all forms of appropriation, including mining and mineral leasing laws, and reserved for the use of the Atomic Energy Commission the surface and subsurface of lands within Section 36, T29N, R4W, New Mexico Principal Meridian. Surface and subsurface operating rights to lands within the southwest one-fourth of the described section were reserved for the use of the AEC under stipulations of Contract AT(04-3)-711. Access to the project site was by a road traversing the Jicarilla Apache Indian Reservation. Upgrading and extending this roadway was accomplished by the New Mexico State Highway Department through EPNG under stipulations in Contract AT(04-3)-711. This road was provided for Project Gasbuggy use, but the project did not acquire control or responsibility for its maintenance.[3]

ENVIRONMENTAL SETTING

The test location is surrounded by typical canyon and plateau topography of the Colorado Plateau Province. Elevations range from 6,800 to 7,500 ft in the surrounding area and from 7,000 to 7,300 ft in the immediate test area. The San Juan River, at its nearest point, is 20 miles away. Navajo Dam, which was completed in 1963, is located some 23 miles distant.[1] There are believed to be no critical habitats at the site. Land use is primarily cattle grazing.

HYDROGEOLOGIC SETTING

Project Gasbuggy is located on the eastern side of the San Juan Basin. This structural feature is about 180 miles long and 135 miles wide. It covers the eastern part of the Navajo physiographic section of the Colorado Plateau Province. Rocks in and around the test site range in age from pre-Cambrian to recent. Total thickness of sedimentary rocks in the Central Basin ranges from 10,000 to 15,000 ft. The formations penetrated by drilling at the Gasbuggy site are in descending

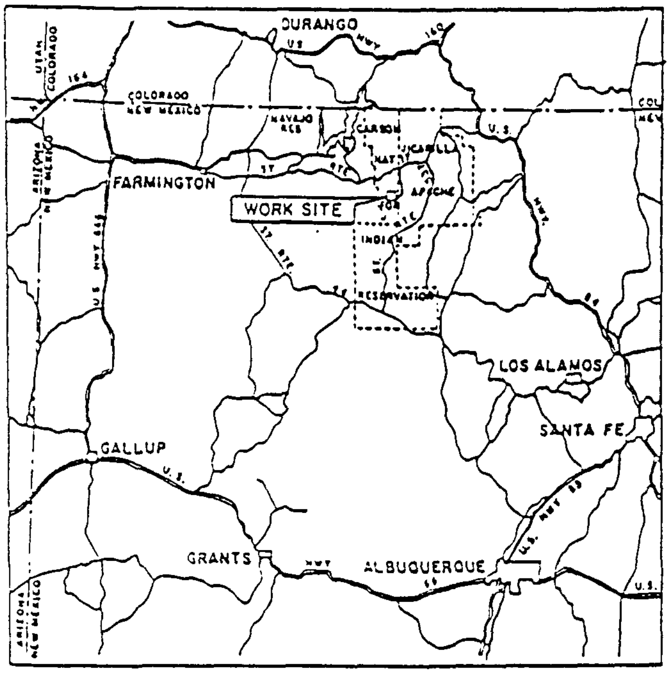

FIGURE 3.7.2. Project Gasbuggy Area Map.

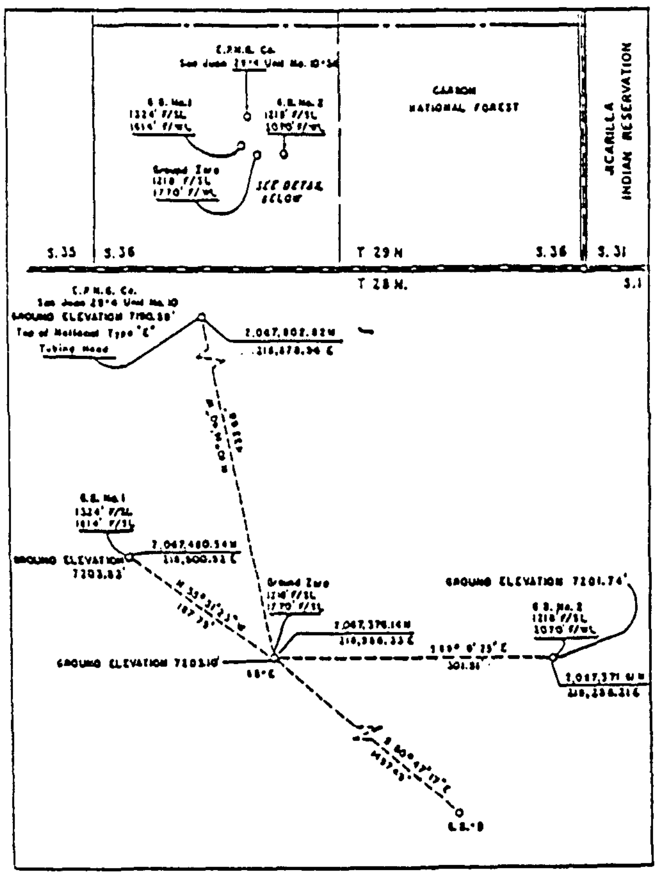

FIGURE 3.7.3. Project Gasbuggy Ground Zero Plot Plan.

order: Surficial alluvium (recent); San Jose formation; Nacimiento formation; the Ojo Alamo sandstone formation all of Tertiary age; the Kirtland Shale formation; the Fruitland formation; Pictured Cliffs sandstone formation; and Lewis Shale formation all of late Cretaceous age. The Pictured Cliffs sandstone is of primary importance because it was within this formation that the Gasbuggy chimney was formed by the detonation in the underlying Lewis Shale. See Figures 3.7.4, 3.7.5, and 3.7.6 for stratigraphic section and geologic cross section.[1]

1. Pictured Cliffs Sandstone

   The Pictured Cliffs sandstone is predominantly a marine sandstone. It is underlain by the Lewis Shale. At the Gasbuggy test site, the Pictured Cliffs sandstone is about 290 ft thick and is chiefly a light-gray, fine- to very fine-grained sandstone interbedded with dark, sandy shales. The sandstone beds bear natural gas and contain minor coal fragments, carbonaceous layers, and traces of oil. The formation is not known to yield substantial amounts of water and is not a water producer at the Gasbuggy site.

2. Fruitland Formation and Kirtland Shale

   The Fruitland formation and the Kirtland Shale overlie the Pictured Cliffs sandstone in ascending stratigraphic order. These formations comprise a 260-ft interval of gray to dark-green shale and siltstone. Abundant carbonaceous material and coal generally are associated with beds of shale. Coal stringers in the Fruitland formation yield small amounts of water in some parts of the basin. The Kirtland Shale lacks aquifer characteristics and probably does not release water to wells in the Gasbuggy area.

3. Ojo Alamo Sandstone

   The Ojo Alamo sandstone overlies the Kirtland Shale and is about 180 ft thick at the Gasbuggy site. The formation consists primarily of a light-gray, fine- to medium-grained, clayey sandstone, but also contains a few minor beds of shale. The Ojo Alamo sandstone generally is water bearing, and it yields water to domestic wells along the San Juan River 50 miles west of the test site where the formation is 1,700 ft higher than it is at the Gasbuggy site. At the test site, the formation yields minor amounts of water.

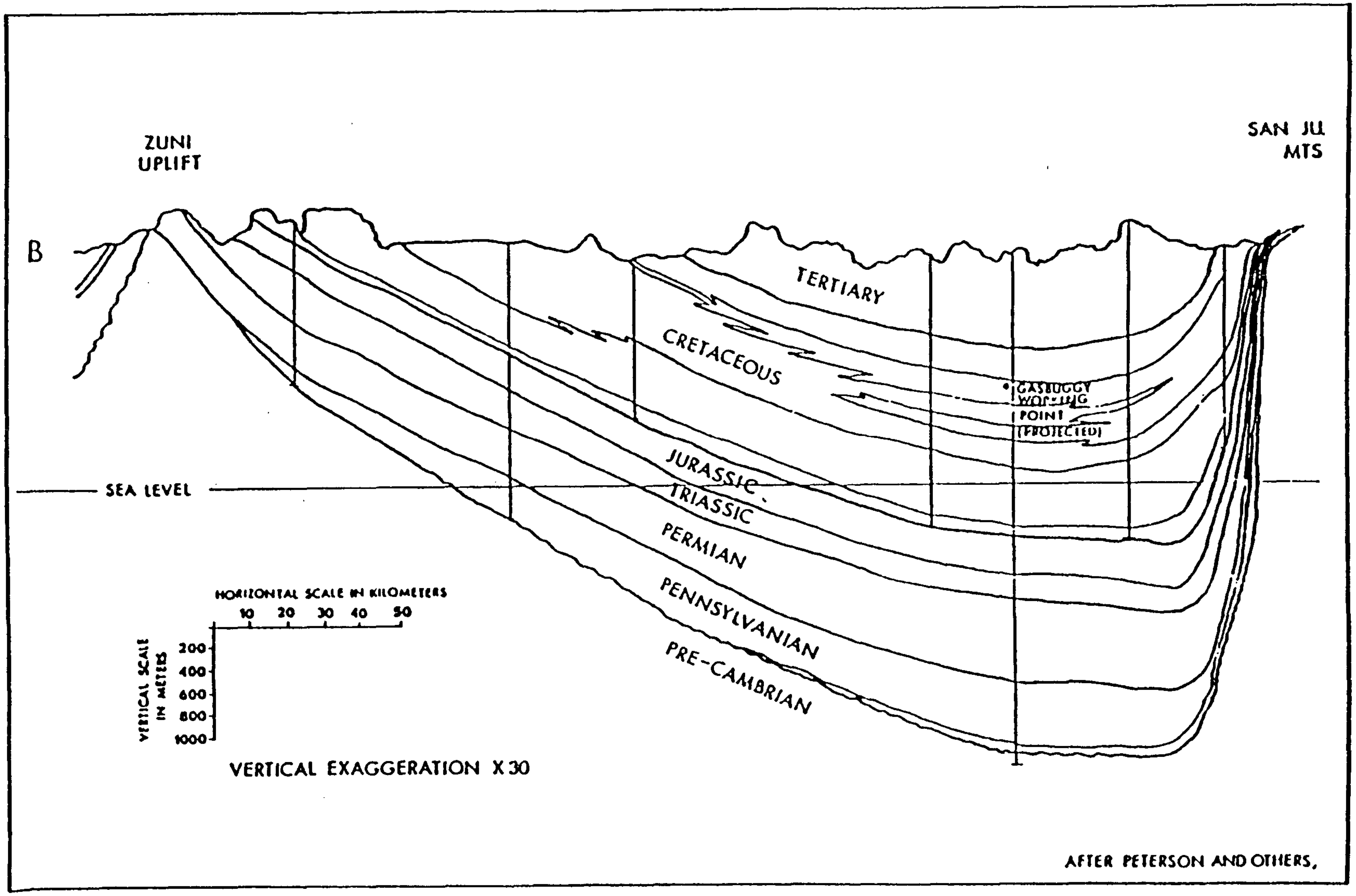

FIGURE 3.7.4. . South-North Geologic Cross Section Across the San Juan Basin.

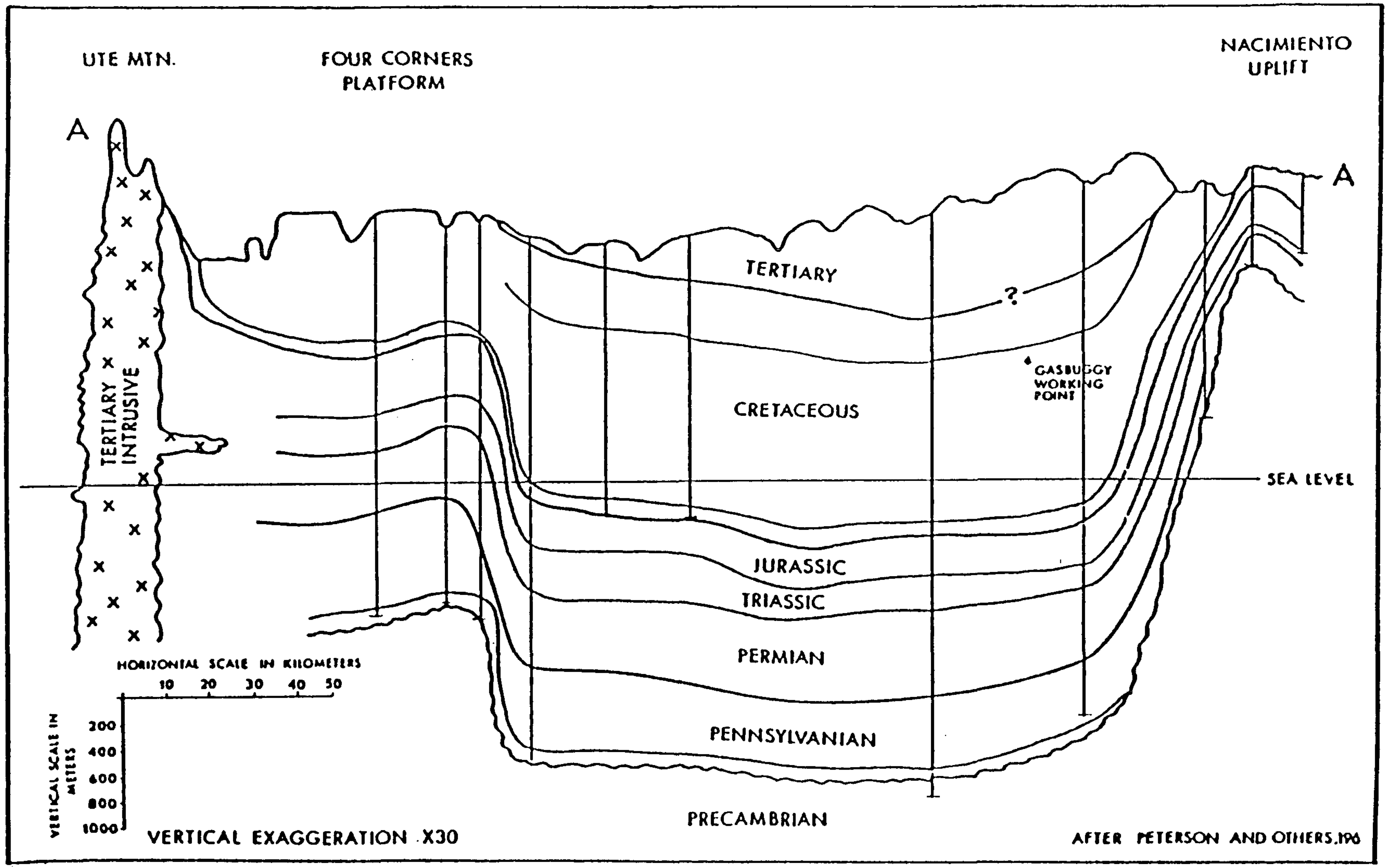

FIGURE 3.7.5. West–East Geologic Cross Section Across the San Juan Basin.

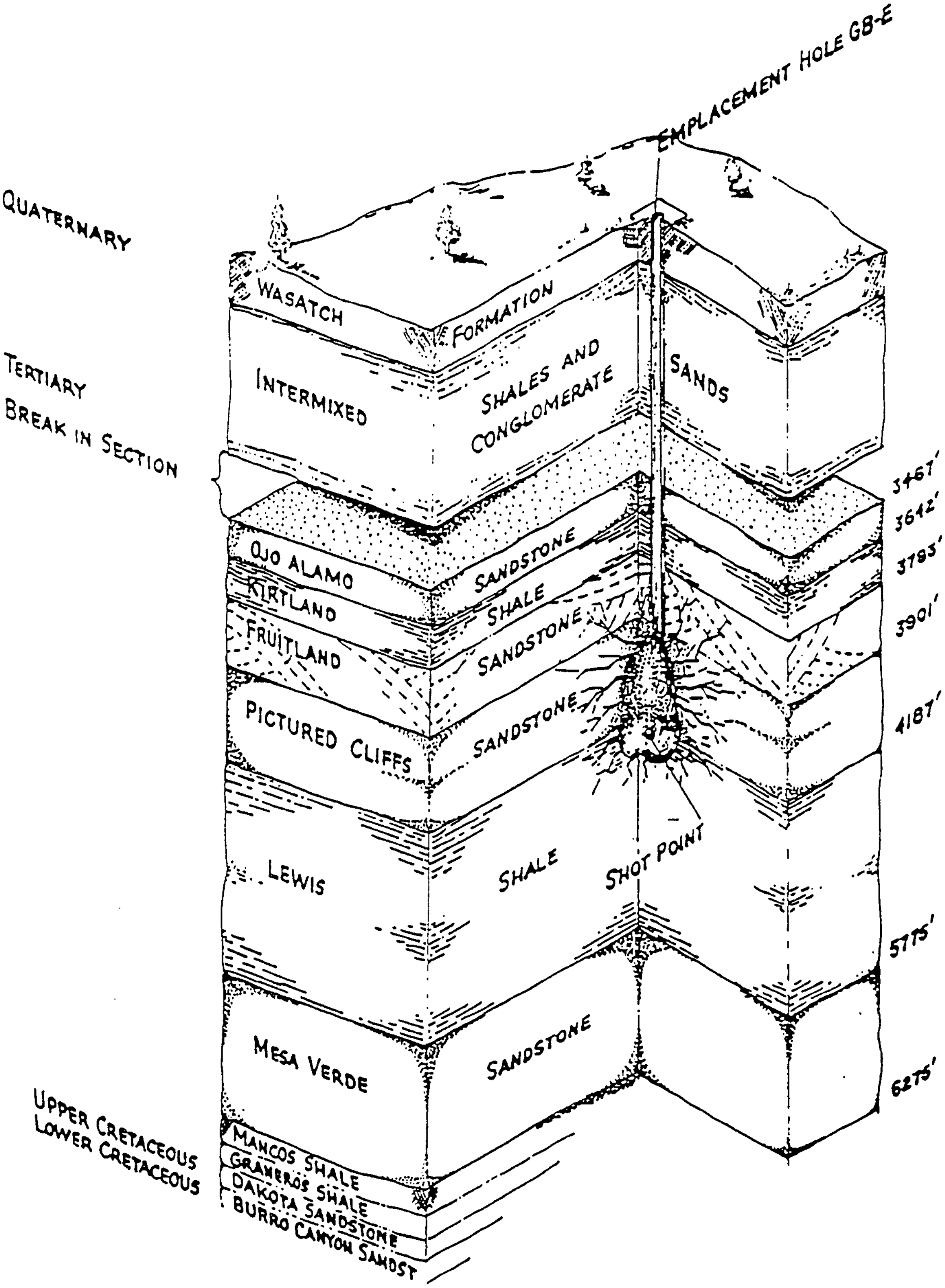

FIGURE 3.7.6. Project Gasbuggy Generalized Geologic Cross Section.

4. Nacimiento and San Jose Formations

   The Nacimiento and San Jose formations are continental flood-plain deposits and are the predominant surface formations in the Gasbuggy area. At the test site, they comprise a 3,500-ft sequence of fine- to medium-grained, locally conglomeratic sandstone, interbedded with claystone and sandy, variegated shale. The beds of sandstone in the San Jose and Nacimiento formations commonly contain water, but these water-bearing zones probably are far enough above the explosion point at the test site to be unaffected by the nuclear event.

The surficial alluvium, the San Jose formation, the Nacimiento formation, and the Ojo Alamo sandstone are the principal aquifers in the Gasbuggy area.[1]

The Ojo Alamo sandstone was the only water-producing formation considered to be within the "unlikely but remotely possible" range of fracturing from the nuclear detonation. Hydrologic testing was limited to the Ojo Alamo sandstone.[6]

The direction of the ground-water movement in the San Juan Basin is not well known. The major discharge point for water moving in the Ojo Alamo sandstone probably is the San Juan River, 50 miles northwest of the test site. An estimate of the rate of ground-water movement was computed by using known, or assumed, values for the permeability and porosity of the aquifer and for the hydraulic gradient of the water in the aquifer.[1]

The coefficient of permeability of the Ojo Alamo sandstone was determined to be approximately 0.017 gal/day/ft^2. This value was derived by using a coefficient of transmissivity of 3 gal/day/ft and an effective aquifer thickness of 180 ft as determined from data collected from holes GB-1 and GB-2. A hydraulic gradient of 30 ft/mi across the central basin was assumed. An average porosity of 13 percent was determined from core samples analyzed by Core Laboratories, Inc. Calculations based upon these values indicate that the average rate of ground-water movement in the Ojo Alamo sandstone across the basin is about 0.0001 ft/day, or 0.04 ft/yr.[1]

High total dissolved solids make water from this aquifer unsuitable for irrigation or domestic use.[1]

All known wells and springs within a five-mile radius of GZ were investigated during June 1967 as were all accessible wells and springs between the five- and ten-mile radius. Locations of these wells and springs are plotted on Figure 3.7.7 and listed in Tables 3.7.1 (wells) and 3.7.2 (springs). The 13 wells investigated range in depth from 54 to 229 ft and are completed in alluvium. Well yields in the range of 1 to 3 gpm are considered good. Specific conductance of the water ranges from 700 to 2,600 micromhos/cm at 25°C.[8] No wells in the area are known to tap the deeper Ojo Alamo aquifer.[8]

Twenty-three springs of the contact type were investigated. The springs discharge from sandstones in the San Jose formation of Eocene age. Some of the springs are seeps with little or no visible flow; others are characterized by yields generally ranging from 1 to 8 gpm. Specific conductance of spring water ranges from 370 to 2,300 micromhos/cm at 25°C.[6]

No springs or wells within a five-mile radius from the site are used for human consumption. Springs and some wells that likely serve for stock watering are within a three-mile radius from GZ. With the exception of well EPNG 10-36, these are believed to intersect the shallow alluvial/San Jose aquifer system only. Selected wells and springs are sampled yearly as part of a long-term hydrologic monitoring program.[6,1]

Surface water is present in La Jara Creek approximately 2.5 miles from the surface facilities. The Creek is ephemeral and is sampled yearly when water is flowing (personal communication, EPA-EMSL). La Jara Creek has shown no tritium contamination above background precipitation.[7] The Creek is not believed to be used for human consumption, but is likely used by stock for watering.

Climatological data for the Gasbuggy area have been collected at Governador, New Mexico (El Paso Camp) for a 20-year period of record. This station, located about 10 miles from GZ, is considered representative of the Gasbuggy area. Data presented in NVO-277 incorrectly presents the average precipitation. Data from the HRS document suggests that the average annual precipitation is approximately 10 in/yr.[8] The average annual lake evaporation is 48 in.[8] Temperatures range from the lower 70°'s F in July and August to the upper 20°'s F in December. Recorded extremes are +105°F in August to -28°F in February.[1] The 2 year, 24 hr precipitation value is 1.6 in.

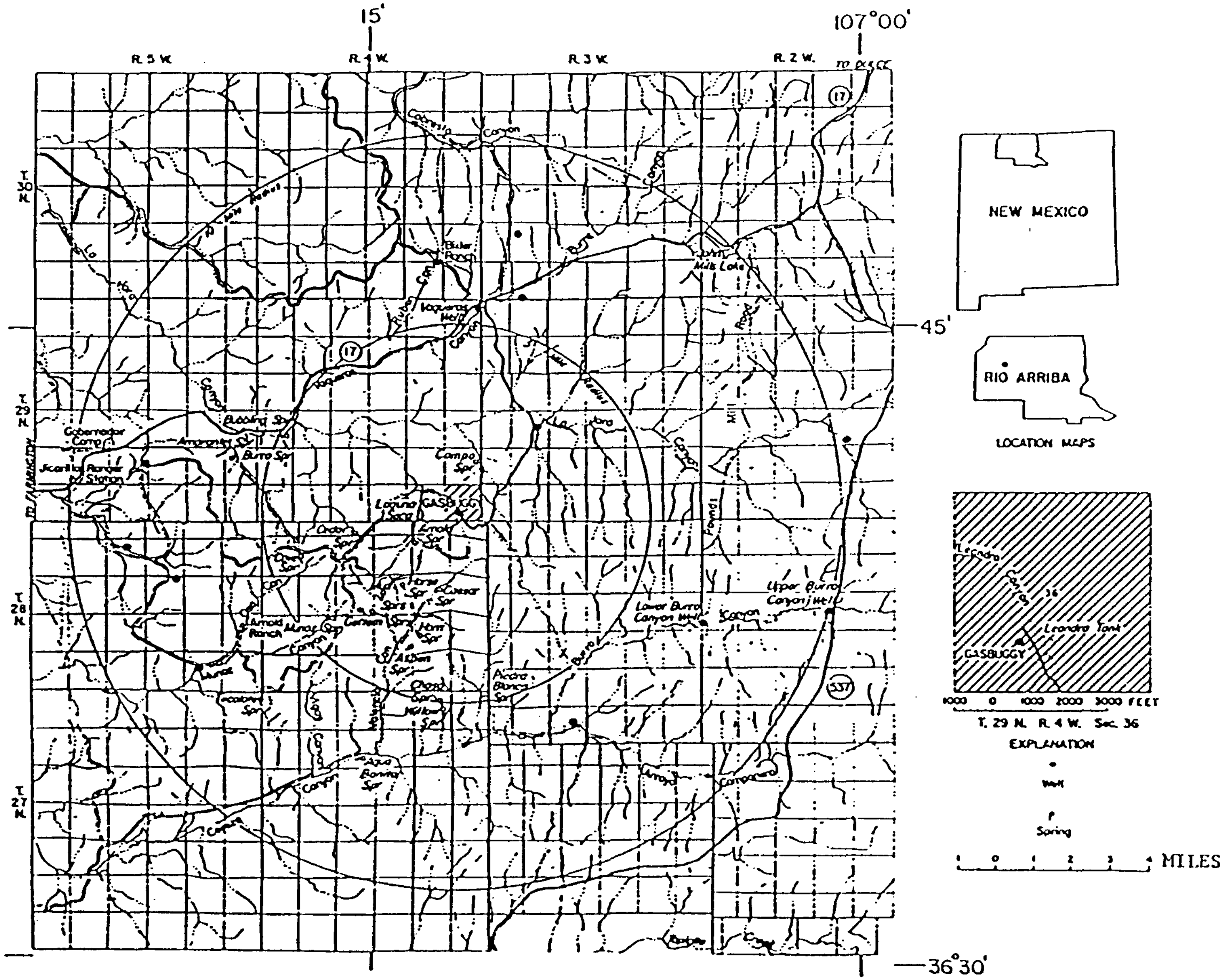

FIGURE 3.7.7. Location of Wells and Springs Within a 10-Mile Radius of Project Gasbuggy Site.

TABLE 3.7.1. RECORDS OF WELLS INVENTORIED WITHIN A 10-MILE RADIUS OF PROJECT GASBUGGY SITE, RIO ARRIBA COUNTY, NEW MEXICO.

Location Number	Owner or Name	Year Completed	Depth (feet)	Diameter (inches)	Altitude (feet)	Water Level: Depth Below Land Surface (feet)	Water Level: Date	Strati-graphic Unit	Pump	Power	Use of Water	Distance from ground zero (miles)	Specific conductance (micromhos per cm at 25°C)	Remarks
28.2.15.144	Jicarilla Apache Reservation	-	152	6	7,234	110.2	6-29-67	Qal	P	W	S	10.2	2,100	Upper Burro Canyon Well
28.2.18.331	do	-	229	6	7,089	72.2	6-29-67	Qal	P	W	S	7.1	3,000	Lower Burro Canyon Well
28.3.33.233	do	-	81	6	6,920	51.8	6-29-67	Qal	P	I	S	6.3	-	--
28.5.16.213	U.S. Bur. Land Management	-	95	6	6,580	57.5	6-30-67	Qal	P	I	S	8.6	-	--
28.5.22.221	do	-	-	-	6,698	-	-	-	P	W	S	7.5	700	Yield 1 gpm; temp. 50°F
28.5.35.144	Russell Arnold	1950	-	6	6,630	-	-	Qal	P	I	D,S	7.9	-	Reported yield 11 gpm; reported depth 54 ft.
29.2.22.441	Jicarilla Apache Reservation	1962	198	6	7,150	174.1	6-29-67	Qal	P	W	S	10.2	1,500	Yield 1 gpm; temp. 44°F
29.3.20.234	do	-	75	7	6,875	22.2	6-29-67	Qal	P	W	S	3.1	2,600	Yield 3 gpm; temp. 43°F
29.4. 1.223	U.S. Forest Service	1953	115	7	6,680	29.9	6-30-67	Qal	N	N	N	5.6	-	Vaqueros well old ranger station
29.5.28.422	U.S. Bur. Land Management	-	130(?)	7	6,650	122.4	6-30-67	Qal	P	W	S	8.2	-	--
30.3.29.132	Jicarilla Apache Reservation	-	-	7	7,235	-	-	-	P	W	S	7.5	850	Yield 2 gpm; temp. 47°F
30.3.32.343	do	-	200	7	7,038	64.1	6-29-67	Qal	P	W	S	5.9	-	--
30.4.35.221	Fred Bixler	-	175	6	7,140	52.7	6-29-67	Qal	P	W	D	6.6	-	Reported yield 3 gpm

Location Number: See text for explanation of well-numbering system.
Depth: Depths listed are measured depths to the nearest foot.
Diameter: Diameter of the casing to the nearest inch.
Altitude: Altitude of land surface at well. Altitude interpolated from U.S.G.S. topographic maps, scale 1:24,000 and contour interval 20 feet.
Water Level: Measured depths below land surface, to nearest tenths of a foot.
Stratigraphic Unit: Qal - Alluvium.
Type of Pump: P - plunger or cylinder; N - none.
Type of Power: W - wind; I - internal combustion.
Use of Water: S - stock; D - domestic.
Note: Unless specified, all wells are drilled and cased to total depth.

TABLE 3.7.2. RECORDS OF SPRINGS INVENTORIED WITHIN A 10-MILE RADIUS OF PROJECT GASBUGGY SITE, RIO ARRIBA COUNTY, NEW MEXICO.

Location Number	Owner	Name	Topographic situation	Altitude (feet)	Strati-graphic Unit	Yield (gpm)	Date	Use of Water	Temper-ature (°F)	Distance from ground zero (miles)	Specific conductance (micromhos per cm at 25°C)	Remarks
S27. 4. 1.222	U.S. Forest Service	Piedra Blanca	Stream Channel	6,960	Tsj	0.2	6-29-67	S	-	4.9	-	Temp. 55°F at discharge point, developed spring
S27. 4. 2.232	do	Chosa	do	7,095	Tsj	.1	6-27-67	N	46	5.0	1,400	Discharge from SS above SH
S27. 4. 2.234	do	Willow	do	7,050	Tsj	.1	6-27-67	N	43	5.2	2,200	--
S27. 4. 9.414	do	Agua Bonita	Hillside	6,730	Tsj	8.6	6-26-67	S	49	7.1	1,500	Good spring, developed
S27. 5. 1.224	do	Tecolota	Stream Channel	7,190	Tsj	-	6-30-67	S	48	7.0	850	Dammed; yield not measured
S28. 4. 9.342	do	Cedar	Hillside	7,350	Tsj	<.1	6-21-67	S	47	2.6	470	Partially developed
S28. 4.14.113	do	Arnold	do	7,200	Tsj	<.1	6-23-67	N	47	1.3	950	--
S28. 4.17.311	do	Cave	do	7,410	Tsj	.1	6-21-67	S	48	4.2	370	Partially developed, stock tank
S28. 4.21.444	do	Gettem	Stream Channel	7,200	Tsj	.2	6-28-67	S	44	3.4	1,400	--
S28. 4.21.444a	do	-	do	7,200	Tsj	<.1	6-28-67	N	43	3.4	-	--
S28. 4.22.134	do	Mud	do	7,210	Tsj	-	6-27-67	S	52	2.9	-	Series of seeps. Called Hungry by U.S. Forest Service
S28. 4.22.241	do	Horse	do	7,260	Tsj	-	6-23-67	N	43	2.4	-	Seep
S28. 4.23.234	do	Caesar	do	7,130	Qal	~.6	6-23-67	S	-	2.1	1,950	Developed, stock tank seepage in excess of measured flow
S28. 4.26.312	do	Horn	do	7,180	Tsj	.1	6-27-67	N	48	3.4	2,300	Called Aspen by U.S. Forest Service
S28. 4.27.444	do	Aspen	do	7,135	Tsj	.1	6-27-67	N	54	3.8	-	Seep, called Horn by U.S. Forest Service
S28. 4.29.221	do	Munoz	Hillside	7,080	Tsj	.5	6-21-67	S	43	4.3	-	--
S28. 5.25.142	Arnold Ranch	-	Valley flat	6,780	Tsj(?)	-	6-30-67	S	48	6.4	-	Seep
S28. 5.25.142a	do	-	do	6,790	Tsj(?)	-	6-30-67	S	47	6.4	-	Seep
S29. 4.19.412	do	Bubbling	do	6,555	Tsj	4.3	6-23-67	S	45	5.1	1,290	Developed
S29. 4.19.421	do	-	do	6,570	Tsj	4.0	6-23-67	N	45	4.9	900	--
S29. 4.25.241	do	Campo	Stream Channel	6,920	Tsj	-	6-22-67	N	45	1.5	-	Seep
S29. 5.24.413	do	Amarante	Hillside	6,570	Tsj	.6	6-23-67	N	44	5.8	815	--
S29. 5.25.132	do	Burro	do	6,580	Tsj	~.3	6-23-67	S	50	6.0	740	Developed, stock tank

Location Number: Number preceded by S designates spring location (see text for explanation of well-numbering system).
Altitude: Altitude of land surface at spring. Altitude interpolated from U.S.G.S. topographic map, scale 1:24,000 and contour interval 20 feet.
Stratigraphic Unit: Tsj - San Jose Formation; Qal - Alluvium.
Yield: *Measured unless specified.*
Use: S - stock; N - none.

HUMAN RECEPTORS

The site is both remote and uninhabited, yet readily accessible by paved highway. The nearest sizable town was Farmington, New Mexico, 55 air miles to the west of the site, with a population of 23,000. The nearest community was Dulce, New Mexico, approximately 20 miles to the northeast, with a population of about 500. There were no houses or buildings within a five-mile radius of the site at the time of the test.[2] These conditions are believed to be accurate today. Two residences, based upon the water supply data in Table 3.7.1, are located approximately 7 miles from the site (Arnold Ranch and Bixler Ranch).

ENVIRONMENTAL RECEPTORS

The Gasbuggy site is currently used for grazing and also is expected to support a wide variety of flora and fauna typical of northern New Mexico. Based upon discussions with Carson National Forest personnel, the site and its surroundings are not considered critical habitat for any currently federally listed threatened or endangered species. Bald Eagles and Peregrine Falcons are found to the south at Navajo Lake, however, nesting sites are not believed to be present near the Gasbuggy site (personal communication, USFS). This site is not fenced.

SITE HISTORY

As early as 1958, El Paso Natural Gas Company (EPNG) investigated the application of nuclear explosive stimulation to a gas reservoir by initiating correspondence with the University of California, Lawrence Radiation Laboratory (LRL), Livermore, in connection with the Pinedale Unit Area, covering approximately 92,000 acres in Sublette County, Wyoming. However, EPNG did not propose a field test at that time.

A study was initiated by the AEC San Francisco Operations Office (SAN), EPNG, and the U.S. Bureau of Mines (USBM), utilizing accepted technology of the industry, performing the necessary calculations, and making the engineering evaluations for such a project. EPNG furnished the geologic data and ownership and location information, while LRL provided consulting service pertaining to effects of nuclear explosions and to resulting radioactivity in the gas.

On June 17, 1965, Mr. Howard Boyd, Chairman of the Board, EPNG, presented the feasibility study dated May 14, 1965 to the AEC suggesting nuclear explosive stimulation of a natural gas reservoir and proposing that the experiment be jointly conducted.

On June 24, 1965, the Division of Peaceful Nuclear Explosives, USAEC, requested a comprehensive review and evaluation of the proposed project. This review was undertaken in the summer of 1965 by LRL. A report on the review was distributed on July 30, 1965 to EPNG, USBM, and the AEC recommending that Gasbuggy be conducted.

Following a 6-month period of relative inactivity, the Gasbuggy concept was re-examined. An updated Technical Concept was distributed on October 17, 1966. EPNG proposed to make available to the AEC the EPNG gas lease on Federal land for use as a site for a nuclear experiment and offered technical assistance in the design and execution of an experiment.

On January 31, 1967, Contract No. AT(04-3)-711 was signed by AEC/HQ, the Department of the Interior, and EPNG. On February 9, 1967, the Manager, NVOO, was authorized by the General Manager, AEC, to act as the authorized representative of the Contracting Officer for the administration of the contract.

On February 11, 1967, EPNG began drilling the first pre-shot test well, GB-1, which was completed on March 17 to a total depth of 4,306 ft. On April 9, EPNG began drilling the second test well, GB-2, which was completed on May 5 to a total depth of 4,248 ft. Gas reservoir tests in conjunction with GB-1 and EPNG Well 10-36 were conducted.

On April 5, 1967, the AEC accepted the site for the execution of Project Gasbuggy based on the recommendations of: a) the NVOO staff as to the acceptability of the site from overall safety and operational considerations, and b) LRL, EPNG, and USBM as to site suitability for conduct of project technical programs.

On June 25, 1967, drilling was begun on emplacement hole GB-E.

Authorization for the execution of the Gasbuggy detonation was received from DPNE on November 29, 1967.

The original readiness date of October 18, 1967 was delayed by construction difficulties with the emplacement hole. A new readiness date of December 6, 1967 was established, but later delayed to December 10, 1967 due to technical difficulties. The device was fired on December 10, 1967.

Re-entry drilling in hole GB-ER ("R" indicating the same hole has been re-entered) was begun on December 13, 1967. On January 10, 1968, at a depth of 3,907 ft (333 ft above the detonation point), communication with the chimney was established.

The Gasbuggy site initial re-entry was completed by January 31, 1968 and the site placed on a standby status with gas sampling continuing at monthly intervals. Production testing and reservoir evaluation were tentatively planned to begin within 6 to 9 months, depending upon results of the radiochemistry analysis and the availability of funds.

A 15-day production test was begun June 28, 1968. This test was conducted to determine bottom-hole temperatures and pressures and to determine build-up times after flowing the well at 5 million cu ft/day (5 MMcf/D). Following this test, the well was shut in and remained so until long-term production testing was initiated in November 1968.

On November 4, 1968, a long-term production testing program of Well GB-ER was begun. The test program consisted of three 30-day production tests at successively lower (and constant) chimney pressures followed by a 7-month production test at a still lower pressure. A final pressure blowdown was begun October 28, 1969, and terminated on November 14, 1969. At this time, GB-ER was shut in for long-term pressure build-up.

Other field activities during the above time interval included the following:

1. Re-entry of Pre-shot Test Well GB-2

   During June 1968, GB-2R was completed to 4,224 ft with production tubing landed at that depth in open hole. The open hole apparently collapsed, pinched the tubing, and prevented the use of the hole for production testing.

2. Re-entry of Well 10-36 (Pre-shot Production Well)

   During October 1968, stemming material was removed from the 5.5-in. casing to a depth of 3,612 ft where casing damage prevented further penetration. The well was then completed in the Ojo Alamo sandstone formation as an aquifer monitor well.

3. Well GB–3

During August and September 1969, GB–3 was drilled to a depth of 4,800 ft to investigate changes in the Ojo Alamo and Pictured Cliffs formations and in the underlying shale. An extensive coring program utilizing logs and natural flow gauges was used in defining reservoir characteristics.[2]

In 1973, another gas flaring program was initiated. The program ran from May 15, 1973 to November 6, 1973 (personal communication, EPA–EMSL, 1988).

WASTE GENERATION AND DISPOSAL

Waste generated at the site primarily consists of radioactive contaminants. No non–radioactive wastes were found on the site in 1985.[5]

Radionuclides were produced as a result of detonation of the nuclear explosive. These nuclides consists of both gaseous, liquid, and solid isotopes. The total radioactivity produced at shot time plus 1 min/kt of yield is estimated to be 3 x 10^{10} Ci. For the yield of Gasbuggy (29 kt), this yields an estimate of 87 x 10^{10} Ci at 1 minute after detonation. Much of this radiation is from short–lived radioisotopes however, and quickly decays.

A sample of water collected from the 3,000–ft depth in GB–ER well above the shot cavity on January 2, 1968 contained tritium at a concentration of $(1.6 \pm 0.3)10^{-4}$ µCi/ml (1.6 x 10^5 pci/l). Another sample collected from the same location on January 6, 1968 contained $(6.0 \pm 0.4)10^{-4}$ µCi/ml (6.0 x 10^5 pci/l). Water collected directly from the drill stem on January 10, 1968 contained $(30 \pm 1)10^{-4}$ µCi/ml (3.0 x 10^6 pci/l). Ice removed from the top of GB–ER on January 16, 1968 contained $(25 \pm 0.7)10^{-4}$ µCi/ml. None of the water samples from GB–ER contained detectable amounts of other beta emitters except ^{133}Xe.[2] These results show tritium levels above drinking water standards in the fluids in the shot cavity.

Fluids produced during the gas flaring and production phases were contaminated with waste produced from the nuclear explosion. Tritium and ^{85}Kr were the primary radionuclides from the detonation that were found in the gas or liquids during production tests in June and July 1968, and the series of tests which began in November 1968. This was also true of the tests in 1973.

Water and some oil were carried up the tubing with the gas in the emplacement re–entry well (GB–ER) when the velocity of the gas was sufficient to carry up the water. Most of this liquid was removed by two bulk liquid separators and was stored in a metal tank until analyzed for radioactive material.

The limited tests in June and July 1968 produced 1,440 gallons of water. This water was placed in 36 55-gallon drums, gelled, and sent to the Nevada Test Site (NTS) for disposal. These 36 drums contained a total of 7.2 Ci of tritium. Five 55-gallon drums with HTO in dirt containing a total of 0.1 Ci of tritium and one 55-gallon drum with 0.03 Ci of tritium in assorted wastes were also shipped to NTS. For the subsequent series of tests, 118,440 gallons of water were separated. The bulk of this water was produced during three rapid drawdown periods at high flow rates designed to reduce the downhole pressure.[2]

The disposal of this quantity of water by forming a gel in barrels and transporting the barrels to a waste disposal site would have been too costly. The water produced would have required approximately 2,725 barrels to be prepared and shipped. The tritium contained in the separated water also constituted only about 5 to 10 percent of the tritium released by burning the gas.

A steam/spray system was designed to vaporize the water into the flame at the top of the flare stack. Two pipes with nozzles were attached at the top of the flare stack and the liquids were sprayed directly into the gas being flared. When the flow rate of the gas was approximately 2 MMcf/D or greater, the water was completely vaporized. With lower flow rates, the water was first passed through a steam generator and then introduced into the gas flare as steam. The objective in both cases was to completely vaporize the water.

EPNG conducted, on a variable schedule, downhole pressure and temperature bomb runs on the GB-ER well. The bomb was lowered to 3,790 ft for the measurements. Liquid (water and oil) and sludge entered the bomb through a small hole. The composition of the liquid varied from day to day. The amount of liquid collected was highly variable.

The liquid was removed from the bomb and assayed for tritium by liquid scintillation spectrometry. In some cases, much less than a milliliter of liquid was obtained and the samples were not analyzed. Many of the samples were so highly colored by sludge that extreme quenching precluded accurate analysis without extensive sample pre-treatment. Centrifuging and distillation were performed when sample volume permitted.[2]

The first rapid decrease in pressure from 870 psi to 700 psi lasted 6 days at a flow rate of 5 MMcf/D. During this period, 5,172 gallons of water were produced. The next reduction, a month later at the same flow rate, from 700 psi to 500 psi downhole pressure, lasted 9 days and 18,500 gallons of water were produced. The third reduction of downhole pressure, from 500 psi to 260 psi, lasted 24 days and 76,441 gallons of water were produced. During this period, the well was flared wide open and flow rates gradually decreased from 3.42 MMcf/D on February 18, 1969 to 0.95 MMcf/D on March 14, 1969. Water production reached 220 gal/hr during portions of this period and the well was shut in several times because water production exceeded maximum disposal capability with existing equipment and storage facilities. A 6-month production test, maintaining a constant downhole pressure of 260 psi, commenced March 14, 1969. The flow rate decreased gradually to a flow rate of 300 Mcf/D. A total of 119,880 gallons of liquid waste were handled, including the 1,440 gallons sent to NTS.[3]

KNOWN RELEASES

A System to Analyze Low Levels of Krypton and Tritium (STALLKAT) was designed and built by LRL. This system was designed so that the gas flowed through two chambers at a flow rate of approximately 1.8 liter/min. The tritium chamber had a volume of 15.9 cm^3 and contained a CaF_2(Eu) scintillation detector 0.010 in. thick x 1.75 in. in diameter. The krypton chamber had a volume of 3,665 cm^3 and contained a CaF_2(Eu) scintillation detector 0.030 in. thick x 1.75 in. in diameter. The signals from the detectors were amplified and pulse height selected by single channel analyzers. The tritium detector was kept at a temperature of −10°C by a refrigeration system. A scaler and a count rate meter were driven by the analyzer output. The scaler output drove a printer. The entire system was calibrated using standard krypton and tritium gas supplied by LRL. Frequent gas samples taken to LRL for analysis verified the calibration of this on-line system. The limit of detection for the STALLKAT was 2×10^{-5} µCi/cc for tritium and 1.3×10^{-7} µCi/cc for ^{85}Kr.

The STALLKAT employed a bulk liquid trap, a particulate filter, and a desiccant moisture trap before the detectors. Although the pre-filter and traps had no effect upon the monitoring of krypton, these traps remove tritiated distillate (oil and water) from the gas prior to the gas flowing to the detectors. In order to determine the tritium content of the vapor which was not seen by the on-line detectors, freeze-out samples were collected and analyzed for tritium.

The STALLKAT was used during all production tests through November 1969.

The total tritium released during the June and July 1968 tests were based on the analysis of gas samples by LRL. The total ^{85}Kr released during this period was based on STALLKAT readings.

The tritium released during the tests that began in November 1968 was composed of three parts: 1) tritium in the gas monitored by the STALLKAT; 2) tritium in the wastewater monitored by liquid scintillation spectrometry of water samples taken during the steam/spray operations; and 3) the tritium in the vapor phase as monitored by liquid scintillation spectrometry of freeze-out samples collected after the bulk liquid separation. The ^{85}Kr results for this period are based on STALLKAT readings. Through November 1969, 2,432 Ci of tritium and 364 Ci of ^{85}Kr were released to the environment.[2] During the tests of 1973, 127 Ci of tritium and 7.7 Ci of krypton-85 were released into the air (personal communication, EPA-EMSL, 1988).

Surveillance provided during the flaring operations of the production testing phase consisted of monthly trips to the site by three or four SWRHL personnel to collect environmental samples. The surveillance consisted of:

1. Collecting special air samples for tritium in atmospheric moisture.
2. Collecting snow, vegetation, and soil samples on three trips.
3. Collecting cryogenic samples with an aircraft during September and October 1969.

There were 86 atmospheric moisture samples collected during the production flaring, and 31 of these samples collected from within 13 miles of the site showed tritium levels greater than background. The highest level of atmospheric tritium was found in the samples collected within 0.3 miles from the site in November 1968, just after production flaring was begun. One of these samples contained tritium levels of 116 pCi/ml H_2O, or 500 pCi/m^3 air. This is less than one percent of the off-site RCG. Levels of tritium in the atmospheric continued to decrease after mid-1969, only occasional atmospheric samples contained levels of tritium above background.

Four cryogenic air samples were collected in the flaring plume with an aircraft in September and October 1969. These samples contained tritium from 10 to 17 pCi/m^3 air. None of these samples contained radioisotopes of xenon. The September samples contained no radioisotopes of krypton, while the October samples indicated levels of 350 and 450 pCi/m^3 air for radioisotopes of krypton.

Twelve snow samples were collected from 0.3 to 1.3 miles from the flare during January and February 1969. All of these samples contained tritium at or near background levels. Several vegetation and soil samples were collected within 2.2 miles of the site in November 1968 which contained tritium above background levels.

Tritium concentrations in vegetation ranged from 4.1 to 36 pCi/ml H_2O and soil ranged from <0.8 to 7.1 pCi/ml H_2O. A second set of vegetation and soil samples was collected in July 1969 from the same area. The levels in these samples were lower, with vegetation ranging from 3.4 to 8.4 pCi/ml H_2O and soil from 0.9 to 2.0 pCi/ml H_2O. The last set of vegetation and soil samples was collected in October 1969, with tritium levels in all samples at background.[2]

No levels of tritium or other isotopes were detected which were reported to present a hazard to people or livestock in the off-site area.[2]

During cleanup and decommissioning operation in 1978, 175 barrels of low level tritium contaminated water from the steam decontamination operation accumulated in the "Red Tank" after the GB-ER wellbore was sealed. The water was subsequently disposed of by vaporization to the atmosphere using the steam generator. The tritium level in this water ranged from 14.7 pCi/ml to 43.7 pCi/ml, and a total of 1.31 mCi was released to the atmosphere over a period of 25 days in September 1978. During the water vaporization and steam decontamination activities, air moisture samples were collected by molecular sieve units around the site. All of the moisture samples thus collected were less than the lower limit of detection (LLD) for tritium air moisture.

Approximately 60.5 barrels of tritium contaminated water and sludge at an average of 1439 pCi/ml, and 7.3 barrels of tritium contaminated water and sludge at an average of 350 pCi/ml were pumped from the produced water storage tank which is referred to throughout this document as the "Red Tank" and decon sump, respectively, and injected into the GB-ER cavity before the re-entry well was plugged. The tubing and annulus were then flushed with 3 annulus volumes of H_2O. The total tritium content of the injected fluid was 18.7 mCi. The water did not contain other radioactive isotopes above detection limits except naturally occurring radioactive elements.[4] The total volume of fluid injected was approximately 27,000 gallons.

POTENTIAL FOR DIRECT CONTACT OR FIRE/EXPLOSION HAZARD

As a result of site cleanup in 1978, only low levels of tritium remain at the Gasbuggy site. The maximum soil water concentration of tritium found in 1973 was 11,200 pCi/ml (11,200,000 pCi/l) at a depth of 4 ft near the gas flare stack. In 1978, a sample collected very near this site yielded 1,303 pCi/ml. Table 3.7.3 shows the results of soil samples collected during the 1978 cleanup.

The site clearance criteria are given below[1]:

Surface Water	
Tritium	300 pCi/ml
Buildings, Equipment, & Materials	
Tritium (non-removable)	5,000 pCi/100 cm^2
Tritium (removable)	1,000 pCi/100 cm^2
Soil	
Tritium in Soil Moisture	30,000 pCi/ml
Beta-Gamma (including worldwide fallout) (measured at 1 cm)	0.05 mrad/hr

The cleanup operation (reported in PNE-G-89) indicates that the potential for direct contact with wastes at the Gasbuggy site is small but significant, although most soil water levels of tritium were below drinking water standards. Uptake of tritium by plants or volatilization poses a potential pathway for direct contact.

A survey was made in 1985 to determine if non-radioactive wastes were located at the surface facilities of Gasbuggy. The historical records search indicated no potential hazardous waste release sites at Gasbuggy, either radioactive or non-radioactive. There was no documented burial of hazardous material at this installation. All decontamination operations were performed by steam cleaning. The installation contained a concrete decontamination pad and plastic-lined sump which were never used. Due to a lack of first-hand information, nine "operational

TABLE 3.7.3. POST OPERATIONAL SURFACE SOIL SAMPLES.[4]

Sample Number	Collection Date	Site Location	Soil Moisture ^3H pCi/ml
1	9/23/78	Near Red Tank and Pump Shack	< LLD
2	"	"	3.3
3	"	"	< LLD
4	"	"	< LLD
5	"	"	< LLD
6	"	"	< LLD
7	"	Along waterline from Red Tank	< LLD
8	"	"	< LLD
9	"	Along gas lines	< LLD
10	"	"	< LLD
11	"	"	< LLD
12	"	"	< LLD
23	"	Along old flare line	< LLD
24	"	"	< LLD
25	"	"	< LLD
26	"	"	< LLD
27	"	"	< LLD
28	"	"	< LLD
29	"	Around new operational location of Red Tank and Decon Pan	< LLD
30	"	"	3.0
31	"	"	< LLD
32	"	"	< LLD
33	"	"	1.7
34	"	"	10.5
35	"	"	4.0
36	"	"	3.9
37	"	"	2.6
38	"	"	2.4
39	"	"	1.8
40	"	Around Steamer Shack	5.9
41	"	"	6.6
42	"	"	2.9
43	9/25/78	Around Steamer Shack	63.1
44	"	Under Steamer Sump	60.7
13	"	Where the separators sat	< LLD
14	"	"	< LLD
15	"	"	< LLD
16	"	"	2.5
17	"	"	< LLD

TABLE 3.7.3. (continued)

Sample Number	Collection Date	Site Location	Soil Moisture ^3H pCi/ml
18	9/25/78	"	< LLD
19	"	6'N from GB-ER	< LLD
20	"	6'E from GB-ER	17.3
21	"	6'S from GB-ER	2.1
22	"	6'W from GB-ER	< LLD
46	"	At GB-ER	7.8
45	"	2.5' Under Steamer Sump	280

(LLD 2pCi/ml @ 3σ counting error for Tritium)

areas" were sampled. These sites are listed in Table 3.7.4. The location of the sites are shown on Figure 3.7.8. There were no hazardous substances detected in the sample collected at the Gasbuggy Test Site.[5]

Mud reserve pits were filled-in during site restoration.[3] It is unknown if these pits contained any hazardous constituents associated with drilling mud. They did not however, contain radioactive contamination.[1] The drilling muds should pose no hazard from fire and explosion.

POTENTIAL FOR GROUND-WATER RELEASE

Teledyne Isotopes, Palo Alto Laboratory, prepared a ground-water contamination prediction for Project Gasbuggy. This prediction is based, in part, on hydrologic data gathered and interpreted by the U.S. Geological Survey (USGS). Teledyne Isotopes determined that it was most unlikely that fractures or radioactive contamination from the detonation would even reach the Ojo Alamo sandstone formation. In the exceedingly unlikely event that they did reach Ojo Alamo sandstone, it would be the only viable route for radionuclide transport away from the Gasbuggy site. Ground water in Ojo Alamo flows in a generally westward direction. Its most probable discharge point is the San Juan River, some 50 miles northwest of the Gasbuggy site. Hydraulic tests on the Ojo Alamo sandstone by the USGS showed it to have low transmissivity. Ground water moving away from the site is estimated to have a velocity of 0.04 ft/yr. The low transmissivity and the decreasing head with depth preclude any significant areal contamination of the aquifer. Tritium, strontium-90, and cesium-137 will decay to concentrations well

TABLE 3.7.4. OPERATIONAL AREAS INVESTIGATED AT GASBUGGY TEST SITE.

Site	Site Number	Site Location	Depth of Soil Samples
Red Tank	1	90′ from GZ @ 355 degrees	Surface
"Drip Pan Decon Area"	2	115′ from GZ @ 16 degrees	Composite – Surface to 6′
"Drip Pan Decon Area"	2	110′ from GZ @ 31 degrees	Composite – Surface to 6′
"Mud Pit Burial Area"	3	195′ from GZ @ 37 degrees	3′
"Steamer" Area	4	178′ from GZ @ 31 degrees	3′
Flare Stack	5	200′ from GZ @ 41 degrees	Composite – Surface to 0.5′
Flare Stack	5	200′ from GZ @ 41 degrees	Composite – 21″ to 27″
East of GZ	6	6′ from GZ @ 90 degrees	Surface
Mud Pit D	7	40′ from GZ @ 318 degrees	5′
Mud Pit C	8	223′ from GZ @ 347 degrees	3′
Mud Pit A	9	282′ from GZ @ 85 degrees	2.5′

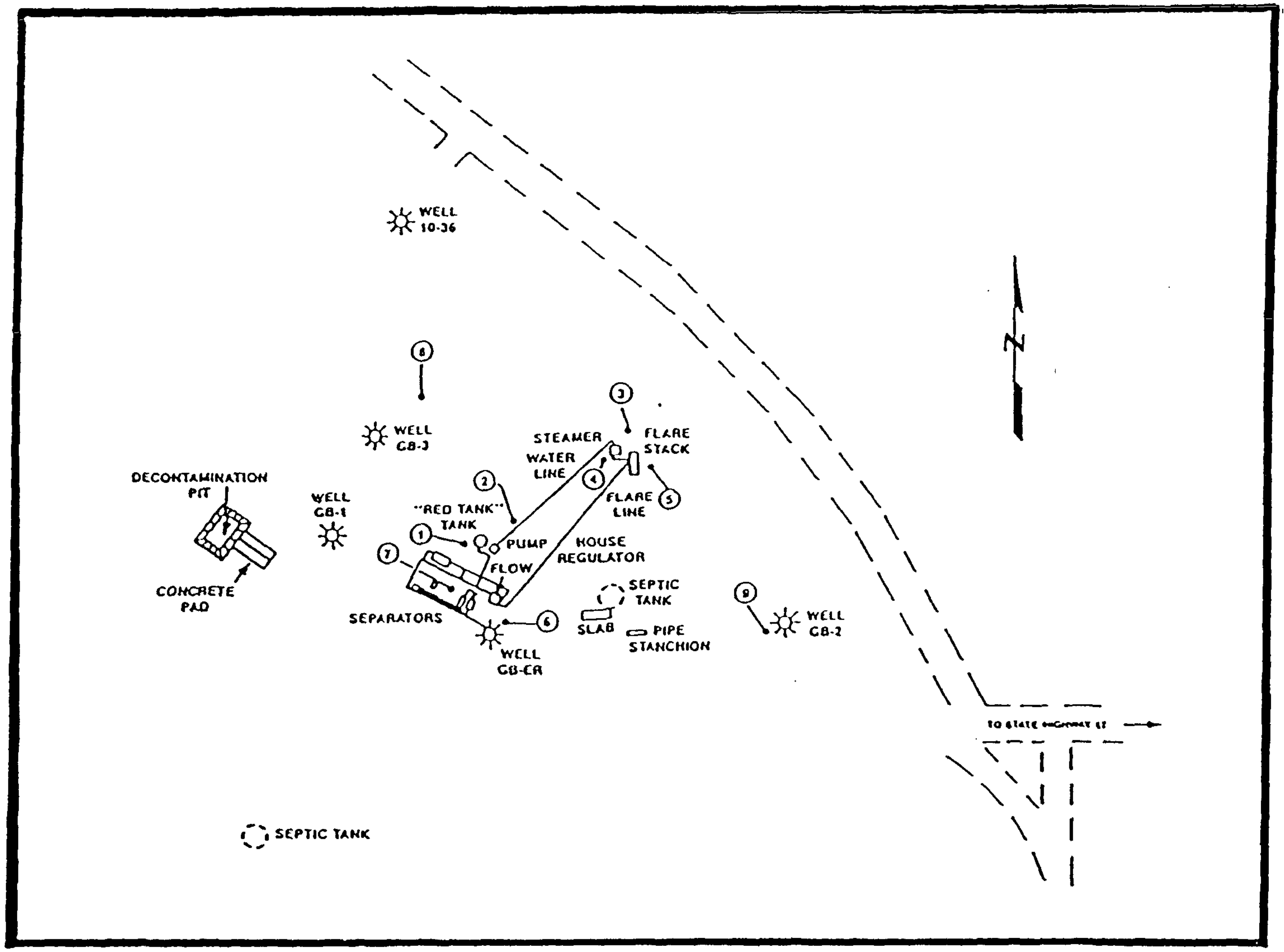

FIGURE 3.7.8. Potential Hazardous Waste Release Sites Investigated at the Gasbuggy Test Site. A Description of Each Site Identified is Given in Table 4.

below concentration guides before moving even a small fraction of the 50-mile distance. High total dissolved solids make water from this aquifer unsuitable for irrigation or domestic use.[1]

A long-term hydrologic monitoring program is on-going to determine any ground-water migration of wastes for the shot cavity. The monitoring locations are given in Table 3.7.5 and shown in Figure 3.7.9.[1]

Yearly samples are collected and analyzed by EPA-Las Vegas. The results are given in Table 3.7.6.

TABLE 3.7.5. LONG-TERM HYDROLOGIC MONITORING LOCATIONS.

Wells	Depth (ft) (Meters)	Aquifer	Location
1. EPNG Well 10-36	3,620 (1,103.7)	Ojo Alamo	436 feet NNW of Gasbuggy GZ. In unsurveyed T29N, R4W
2. *Jicarilla Apache Reservation North Well	Unknown		28.3.33.233 (6.5 miles)
3. *Jicarilla Apache Reservation North Well	200 (60.9)	Wasatch	30.3.33.343 (6.0 miles)
4. Lower Burro Canyon Well	Unknown		28.2.18.331 (7.0 miles)
5. Fred Bixler Ranch Well	175 (53.4)	Wasatch	30.4.34.221 (7.0 miles)
6. Windmill Well No. 2	Unknown		30.4.34.221 (3 miles)
7. Jicarilla Well No. 1	Unknown		(7.5 miles)

*Sample points no longer monitored because pumps are inoperative.

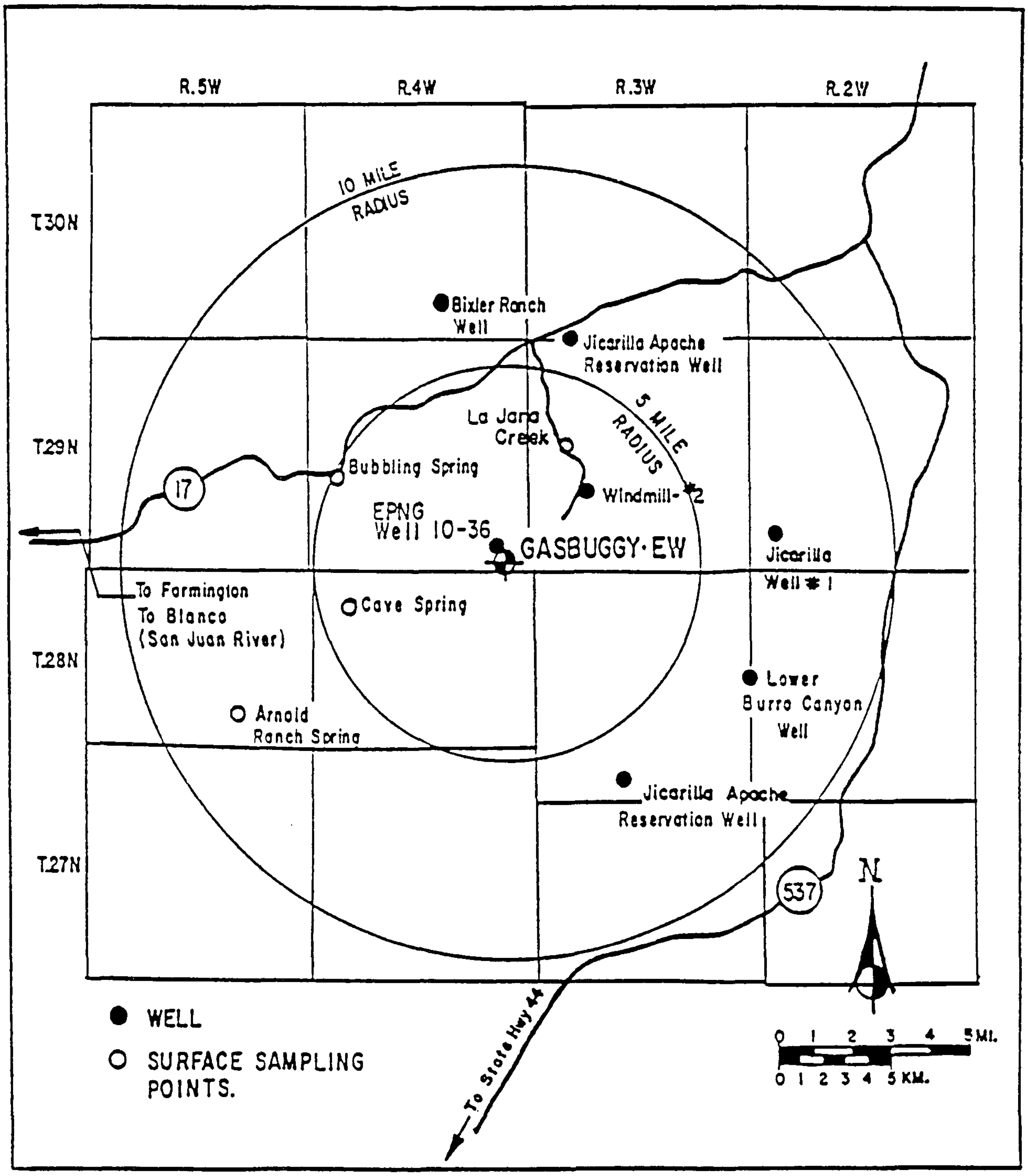

FIGURE 3.7.9. Long-Term Hydrologic Monitoring Program Sampling Points.

TABLE 3.7.6. TRITIUM RESULTS FROM LONG-TERM MONITORING PROGRAM AT GASBUGGY SITE* (pCi/l).

Sample Location	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
San Juan River	830	420	420	510	270											
La Jara Lake	740	260	350	280	220											
Arnold Ranch	<240	<250	28	<10	<8	<8	<20	<10	63	35	<9	<9	5.4	1.6	54	9.5
Bixler Ranch	<240	<250	21	13	8	11	<20	19	30	26	13	18	13	21	20	23
Bubbling Spring	310	<240	240	<13	140	110	120	8.5	86	110	87	110	54	75	120	82
Cave Spring	<210	<240	27	9	12	12	<220	<10	<10	49	57	100	68	80	120	38
Cedar Spring																73
La Jara Creek						110	70	72	120	78	81	100	64	90	69	62
Lower Burro Canyon	<210	<250	<8	<8	6	<9	<20	<20	94	20	<9	<11	4.1	63	120	
EPNG Well 10-36	<210	<250	38	13	<7	17	16	<20	<10	46	20	18	300,400**	390	320	35
Well 28.3.33.333S	<210					93	67									73
Jicarilla No.1													11	7.2	69	-0.96
Well 30.3.32.343N	230													54	96	59
Windmill No. 2			<22	8	27	<24	<20	<20	26	24						8
Ducle City Supply	510	<250	380	260	230											

*Tritium enrichment procedures used on most samples after 1973.

Data compiled from EPA/EMSL yearly monitoring reports. 1987 data from Personal Communication EPA/EMSL.

**Duplicate Samples.

The results indicate that tritium levels in all shallow wells, springs, and surface waters are low and likely reflect tritium levels in recent precipitation. Well EPNG-10-36, completed at a depth of 3,620 ft, showed an increase in tritium in the 1980's. These levels, still well below drinking water standards, are not typical of a deep aquifer system. The proximity of the well to the cavity (436 ft) may indicate that some migration of shot-related tritium has occurred into the Ojo Alamo aquifer. The disposal of wastewater into the cavity during site cleanup in 1978 may have resulted in these elevated levels in well EPNG 10-36. No drinking water wells are completed in this aquifer within 4 miles of the site.[6]

The potential for migration of waste from the cavity to drinking water wells is slight based upon the low transmissivity of the Ojo Alamo aquifer. In addition, all wells used during the testing have been sealed and abandoned (see PNE-G-89 for abandonment procedure used). The migration potential of tritium in soil to the ground water and shallow wells and springs is also low due to the low levels of tritium in the soil and the affects of dilution.

Surface and Municipal Supplies	Location Distance From SGZ
1. Arnold Ranch Spring	8 miles
2. Cave Springs	4 miles
3. Bubbling Spring (SE side Highway 17)	5 miles
4. La Jara Creek	3.5 miles

POTENTIAL FOR SURFACE WATER RELEASE

As a result of surface cleanup and well abandonment, the potential for surface water release appears insignificant. Releases from tritium in the soil also appear negligible due to dilution by precipitation. Release from the cavity is also believed to be impossible.

Surface water sampling of La Jara Lake Creek has shown no anomalous or above background tritium levels.

The land surrounding the GZ is described as relatively flat to gently rolling. Natural revegetation, as well as seeding during site restoration, has significantly reduced the possibility of surface erosion.[3]

POTENTIAL FOR AIR RELEASE

With the abandonment of all wells completed in the shot cavity, there is insignificant potential for air release. Volatilization of tritium remaining in soil water is also believed to be negligible.

THREATS TO FOOD CHAIN AND ENVIRONMENT

Uptake of soil water tritium by on-site vegetation and subsequent introduction into the food chain is likely. Samples of vegetation collected in 1978 are given below in Table 3.7.7 and shows plant water in excess of drinking water standards.[4] It is believed that the area is used for grazing and as such, uptake may pose a hazard.

TABLE 3.7.7. ENVIRONMENTAL VEGETATION SAMPLE RESULTS.

Collection Date	Vegetation Samples Location	Total Tritium* pCi/ml Water
9/20/78	S. Side of Road	2.8 ± 0.5
9/20/78	N. Side of Road	<3.2 ± 0.5
9/21/78	Red Tank Area	10.4 ± 0.3
9/21/78	Separator Area	7.7 ± 0.3
9/21/78	Stack Area	470 ± 2.6
9/21/78	Profile Hole #16	7.2 ± 0.6

*Free water and organically bound.

CONCLUSION AND RECOMMENDATIONS

A preliminary hazard score of the Gasbuggy site (based upon the old HRS) is presented in Appendix 3.7.A. The resulting score of 5.24 indicates that the site poses little hazard. Long-term hydrologic monitoring should continue to determine if significant migration of cavity wastes or soil water tritium is occurring.

The anomalous rise in tritium levels in EPNG-10-36 between 1984 and 1986 should be reviewed in detail to determine its cause. Such data is useful in interpreting the migration potential from the cavity. It is also recommended that further studies be conducted to determine the extent of and impacts of tritium uptake by plants and animals in the area since the area is believed to be used for cattle grazing.

REFERENCES

1. Long-Term Hydrologic Monitoring Program, Project Gasbuggy, Rio Arriba County, New Mexico. 1986. NVO-277, 26 pp.

2. Project Gasbuggy: Manager's Report. 1971. NVO-37, 163 pp.

3. Project Gasbuggy: Site Restoration Final Report. 1983. NVO-211, 70 pp.

4. Project Gasbuggy: Radiation Contamination Clearance Report. 1979. PNE-G-89, 41 pp.

5. Draft Phase I Installation Report. 1986. Department of Energy, Nevada Operations Office, 66 pp.

6. Hydrology of Project Gasbuggy Site, Rio Arriba, County, New Mexico. 1969. PNE-G-60, 45 pp.

7. Off-site Environmental Monitoring Report, 1987. EPA/600/4-87/017.

8. Uncontrolled Hazardous Waste Site Ranking System: A Users Manual, 1984. EPA/HW-10, 60 pp.

APPENDIX 3.7.A
HRS WORKSHEETS
GASBUGGY SITE

FIRE AND EXPLOSION WORK SHEET

Rating Factor	Assigned Value (circle one)	Multi-plier	Score	Max. Score	Ref. (Section)
1 Containment	1 3	1	1	3	7.1
2 Waste Characteristics					7.2
Direct Evidence	0 3	1	0	3	
Ignitability	0 1 2 3	1	0	3	
Reactivity	0 1 2 3	1	0	3	
Incompatibility	0 1 2 3	1	0	3	
Hazardous Waste Quantity	0 1 2 3 4 5 6 7 8	1	8	8	
Total Waste Characteristics Score			8	20	
3 Targets					7.3
Distance to Nearest Population	0 1 2 3 4 5	1	0	5	
Distance to Nearest Building	0 1 2 3	1	0	3	
Distance to Sensitive Environment	0 1 2 3	1	0	3	
Land Use	0 1 2 3	1	3	3	
Population Within 2-Mile Radius	0 1 2 3 4 5	1	0	5	
Buildings Within 2-Mile Radius	0 1 2 3 4 5	1	0	5	
Total Targets Score			3	24	
4 Multiply 1 x 2 x 3			24	1,440	
5 Divide line 4 by 1,440 and multiply by 100			S_{FE} = 1.67		

DIRECT CONTACT WORK SHEET

Rating Factor	Assigned Value (circle one)	Multi-plier	Score	Max. Score	Ref. (Section)
1 Observed Release	0 45	1	0	45	8.1

If observed release is given a score of 45, proceed to line 4.

If observed release is given a score of 0, proceed to line 2.

Rating Factor	Assigned Value (circle one)	Multi-plier	Score	Max. Score	Ref. (Section)
2 Accessibility	0 1 2 3	1	3	3	8.2
3 Containment	0 15	1	15	15	8.3
4 Waste Characteristics					8.4
Toxicity	0 1 2 3	5	15	15	
5 Targets					8.5
Population Within a 1-Mile Radius	0 1 2 3 4 5	4	0	20	
Distance to a Critical Habitat	0 1 2 3	4	0	12	
Total Targets Score			0	32	
6 If line 1 is 45, multiply 1 x 4 x 5					
If line 1 is 0, multiply 2 x 3 x 4 x 5			0	21,600	
7 Divide line 6 by 21,600 and multiply by 100			S_{DC} = 0		

GROUND WATER ROUTE WORK SHEET

Rating Factor	Assigned Value (circle one)	Multi- plier	Score	Max. Score	Ref. (Section)
1 Observed Release	0 45	1	45	45	3.1
If observed release is given a score of 45, proceed to line 4. If observed release is given a score of 0, proceed to line 2.					
2 Route Characteristics					3.2
Depth to Aquifer of Concern	0 1 2 3	2		6	
Net Precipitation	0 1 2 3	1		3	
Permeability of the Unsaturated Zone	0 1 2 3	1		3	
Physical State	0 1 2 3	1		3	
Total Route Characteristics Score				15	
3 Containment	0 1 2 3	1		3	3.3
4 Waste Characteristics					3.4
Toxicity/Persistence	0 3 6 9 12 15 18	1		18	
Hazardous Waste Quantity	0 1 2 3 4 5 6 7 8	1		8	
Total Waste Characteristics Score			26		
5 Targets					3.5
Ground Water Use	0 1 2 3	3	3	9	
Distance to Nearest Well/Population Served	0 4 6 8 10 12 16 18 20 24 30 32 35 40	1	0	40	
Total Targets Score			3	49	
6 If line 1 is 45, multiply 1 x 4 x 5 If line 1 is 0, multiply 2 x 3 x 4 x 5			3,510	57,330	
7 Divide line 6 by 57,330 and multiply by 100			S_{gw} = 6.12		

SURFACE WATER ROUTE WORK SHEET

Rating Factor	Assigned Value (circle one)	Multi-plier	Score	Max. Score	Ref. (Section)
1 Observed Release	0 45	1	0	45	4.1

If observed release is given a score of 45, proceed to line 4.

If observed release is given a score of 0, proceed to line 2.

Rating Factor	Assigned Value (circle one)	Multi-plier	Score	Max. Score	Ref. (Section)
2 Route Characteristics					4.2
Facility Slope and Intervening Terrain	0 1 2 3	1	0	3	
1-yr. 24-hr. Rainfall	0 1 2 3	1	1	3	
Distance to Nearest Surface Water	0 1 2 3	2	0	6	
Physical State	0 1 2 3	1	3	3	
	Total Route Characteristics Score		4	15	
3 Containment	0 1 2 3	1	3	3	4.3
4 Waste Characteristics					4.4
Toxicity/Persistence	0 3 6 9 12 15 18	1		18	
Hazardous Waste Quantity	0 1 2 3 4 5 6 7 8	1		8	
	Total Waste Characteristics Score		26	26	
5 Targets					4.5
Surface Water Use	0 1 2 3	3	3	9	
Distance to a Sensitive Environment	0 1 2 3	2	0	6	
Population Served/ Distance to Water Intake Downstream	0 4 6 8 10 12 16 18 20 24 30 32 35 40	1	0	40	
	Total Targets Score		3	55	
6 If line 1 is 45, multiply 1 x 4 x 5					
If line 1 is 0, multiply 2 x 3 x 4 x 5			936	64,350	
7 Divide line 6 by 64,350 and multiply by 100			S_{SW} = 1.45		

AIR ROUTE WORK SHEET

Rating Factor	Assigned Value (circle one)	Multi-plier	Score	Max. Score	Ref. (Section)
1 Observed Release	0 45	1	45	45	5.1

Date and Location: 1968, 1973

Sampling Protocol:

If line 1 is 0, the S_a = 0. Enter on line 5.

If line 1 is 45, then proceed to line 2.

Rating Factor	Assigned Value (circle one)	Multi-plier	Score	Max. Score	Ref. (Section)
2 Waste Characteristics					5.2
Reactivity and Incompatibility	0 1 2 3	1	0	3	
Toxicity	0 1 2 3	3	9	9	
Hazardous Waste Quantity	0 1 2 3 4 5 6 7 8	1	8	8	
Total Waste Characteristics Score			17	20	
3 Targets					5.3
Population Within 4-Mile Radius	0 9 12 15 18 21 24 27 30	1	0	30	
Distance to Sensitive Environment	0 1 2 3	2	0	6	
Land Use	0 1 2 3	1	3	3	
Total Targets Score			3	39	
4 Multiply 1 x 2 x 3			1,890	35,100	
5 Divide line 4 by 35,100 and multiply by 100			S_a = 6.53		

HRS SCORE FOR
GASBUGGY SITE

$S_{gw} = 6.12$

$S_{sw} = 1.45$

$S_a = 6.53$

$$S_m = \frac{1}{1.73} \sqrt{S_{gw}^2 + S_{sw}^2 + S_a^2}$$

$$S_m = 5.24$$

$S_{FE} = 1.67$

$S_{DC} = 0$