POLICY AND GUIDELINES FOR PETROLEUM-BASED PRODUCT

STORAGE AND CLEAN-UP

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Because of the high incidence of problems related to the storage and handling of petroleum-based products, these guidelines have been prepared to assist the Mining and Minerals Division (MMD), Energy and Minerals Department and coal-mining operators in the assessment and clean-up of incidents. It is a fundamental assumption of this document that policy and guidelines are a technical interpretation of regulatory intent. Guidelines can thereby avoid costly and pointless legal discussion in the resolution of purely technical problems. In this spirit, it is anticipated that these guidelines will evolve through field application. Technical comments and/or suggestions from New Mexico coal-mining operators are an expected and encouraged part of this evolutionary process.

The New Mexico State Coal Surface Mining Regulations (NMCSMR) rule 80-1 states: "Surface coal mining operations shall be planned and conducted to minimize changes to the prevailing hydrologic balance in both the permit and adjacent areas..." (NMCSMR 80-1, 20-41 (a)) and "Non-coal wastes.....shall be placed and stored in a controlled manner in a designated portion of the permit area. Placement and storage shall ensure that the leachate and surface runoff do not degrade surface or ground water, fires are prevented, and that the area remains stable and suitable for reclamation..." (NMCSMR 80-1, 20-89 (a)) and "Support facilities...shall be designed, and constructed or reconstructed, maintained and used in a manner which prevents to the extent possible using the best technology currently available.... Damage to fish, wildlife, and related environmental values...." (NMCSMR 80-1, 20-181 (a)(1)). The New Mexico Mining and Minerals Division, Energy and Minerals Department (MMD) interprets these regulations as controlling the use, storage, disposal, and clean-up of petroleum-based products (products). Citation 20-89 (a) specifically addresses waste oils and greases, other lubricants, and product fuels (gasoline, diesel, kerosene, etc.). "Non-coal wastes" also includes product-contaminated waters and accidental spills or seepage. Citation 20-181 (a)(1) applies to storage facilities, corporation yards, distribution sites, pipelines, shops, tank farms, and drums. These regulations require that MMD regulate all operators to prevent and mitigate pollution of soils and water by petroleum-based products.

It is acknowledged that the proper storage and handling of petroleum-based products such as to prevent any pollution is a troubling and difficult subject. It is further acknowledged that the expertise and finances of the operator are strained by a comprehensive program to treat these products. These guidelines were written to address the expertise question. They are an attempt to accumulate "best technology currently available" and to suggest possible sources of further information to assist operators in meeting their obligations towards product pollution control. As such, these guidelines will be an evolving format for dealing with this problem.

As to the financial question, every attempt has been made to suggest mining practices that will prevent the costly spectre of aquifer restoration. A brief survey of product incidents throughout New Mexico and nation-wide

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will convince any rational operator that the job of aquifer restoration is enormously expensive, time-consuming, and frustrating. On the other hand, these guidelines have attempted to recommend design and operating procedures which will prevent product pollution and are based on sound engineering practice. The implementation of these guidelines should provide no problems to the average professional engineer, from either an expertise or ethical standpoint. These guidelines should also challenge operators to develop their own, possibly more economic, answers to these problems. Responsible alternatives to specific parts of these guidelines are both solicited and encouraged by MMD.

The bottom line is that while environmental degradation is a consequence of any mining operation, certain types of degradation are simply unacceptable. A poorly-designed and maintained petroleum-product facility that contaminates soil and water is unacceptable. Under the Federal Hazardous and Solid-Waste Amendments of 1984, Subtitle 1, Regulation of Underground Storage Tanks, the State of New Mexico will be required to regulate underground petroleum-product storage tanks within its jurisdiction. The Environmental Improvement Division, Health and Environment Department (NMEID) is currently preparing a program for promulgation of these regulations. While these guidelines address a broader concern, this document has been prepared with he close cooperation of NMEID staff. Note however, that these guidelines and policy derive their regulatory justification form the previously-cited New Mexico State Coal Surface-Mining Regulations and are therefore not legally dependant upon any EPA, EID, or other definitions, regulations, guidelines, and/or policy.

PREVENTION

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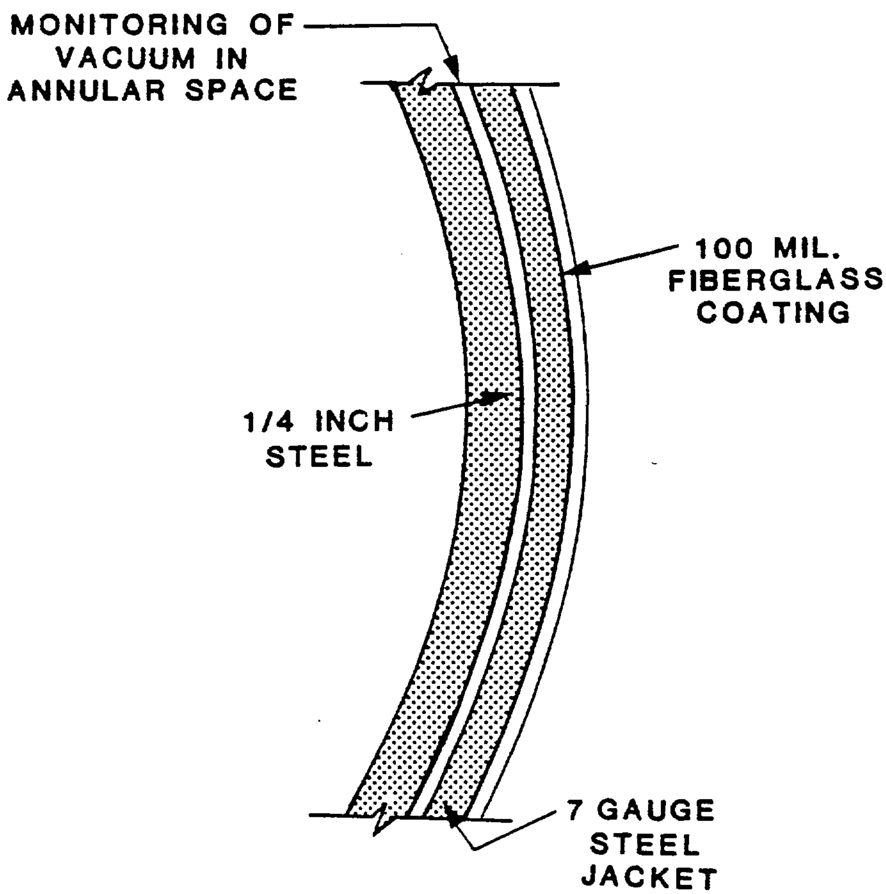
Prevention of petroleum-based product incidents is best achieved by proper isolation of storage and handling facilities from the hydrologic system. The Environmental Improvement Division, New Mexico Department of Health and Environment (NMEID) has assembled a program to specify petroleum product handling and storage requirements that will protect the hydrologic environment from product contamination. This program has assembled data and conclusion from the American Petroleum Institute (API), Underwriters Laboratory (UL), National Fire Prevention Association (NFPA), and many other sources. These guidelines have been written using these sources. A bibliography follows these guidelines which lists several very good references to petroleum-product storage and handling.

Underground Tanks-

This section of guidelines addresses underground tank installation, operation and inspection. All tanks installed after the adoption of these guide lines shall conform to the following. Tanks shall be constructed according to Underwriter Laboratory (UL) specifications listed in <u>Standards for Safety for Steel Underground Tanks for Flammable or Combustible Liquids</u>, or the equivalent. These specifications detail factory pressure testing, capacity, dimensions, nominal wall thickness, and materials types. Steel tanks shall be coated with a suitable corrosion protective material such as epoxy. Alternatively, cathodic protection shall be installed. Tanks shall include proper labeling at the surface, striker plates, and manholes (tanks greater than 64" diameters).

FIGURE 1

DOUBLE-WALLED STEEL TANK WITH BONDED FIBERGLASS COATING



CROSS SECTIONAL VIEW
(DRAWN TO APPROXIMATE SCALE)

All tanks shall be installed with an automatic leak-detection system. It should be noted that the inspection procedure outlined below is tied to the type of leak-detection system installed. Thus, significant long-term savings are possible dependant upon the leak detection system. Double-walled tanks are the monitoring system recommended by MMD. These tanks include (Figure 1) an annular vacuum between two epoxy-coated steel walls. The annular vacuum is monitored for pressure gains. A secondary containment structure with monitoring well, is also acceptable. The containment structure could involve, liners, vaults, or a U-tube system. The minimal alternative would be a monitoring well alone. This option may be the only one suitable in retrofit situations. Other retrofit options include the lining the interiors of existing tanks, see API (1983). Details on design can be found in the previously cited UL publication.

All underground tanks in current use must be tightness-tested prior to 80-1 permit approval. All operators with 80-1 permits must test all underground tanks for leakage within six (6) months of the adoption of these guidelines. MMD must approve all tank-testing projects before acceptance of the test results. MMD will also require future tank-testing according to the following criteria:

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doubled-walled steel tanks, or contained fiberglass-reinforced plastic (FRP) tanks, FRP-or epoxy-coated, or cathodic-protected steel tanks

-no testing required

FRP tanks, FRP-coated, epoxy-coated or cathodic-protected steel tanks, uncontained

-testing ten (10) years after installation and every ten (10) years after unprotected steel tanks with monitoring well

-testing ten (10) years after installation and every five (5) years thereafter

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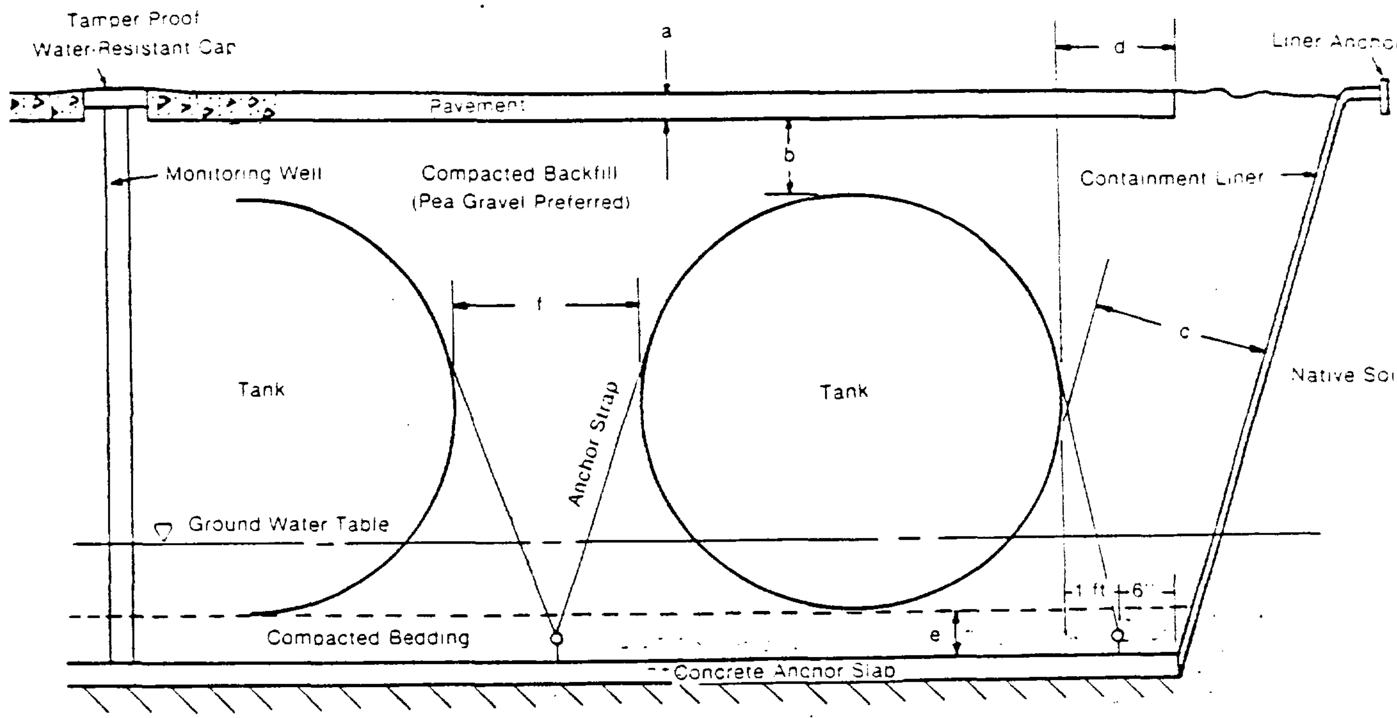
All tank installations shall be designed according to proper engineering practice. Plans shall be submitted and approved by a registered professional engineer. Installation planning and completion shall consider the following aspects, site preparation, excavation size and depth, depth to ground water, pre-installation testing, care in handling, proper bedding and backfilling, ground anchoring, pavement openings, distribution line connections, venting, filling and access opening, proper cover and/or pavement. Tightness testing shall follow completion of the installation procedure. A typical tank installation is shown in Figure 2 and Table 1. Inventories of all existant tanks, in use or abandoned, shall be submitted to MMD prior to 80-1 permit approval. All other operators shall submit a tank inventory with location map to MMD within three (3) months of the adoption of these guidelines. Daily inventories of tank delivery and dispensing shall be kept by the operator for a period of five (5) years. The operator shall notify MMD of any abnormal (greater than 1.0%) gains or losses in product.

The purchase and re-use by operators of tanks removed from service stations and other third-party facilities is discouraged. This is due to the generally inferior quality of these tanks and the common lack of a complete performance record. If an operator wishes to installed a used storage tank, a comprehensive service history for the tank will be required and

FIGURE 2

DIMENSIONS FOR UNDERGROUND TANK INSTALLATION



Key

a-pavement thickness
b-depth of compacted backfill cover
c-distance between tank and excavation wall
d-pavement extension
e-depth of bedding
f-distance between adjacent tanks

TABLE 1
RECOMMENDED DIMENSIONS FOR UNDERGROUND TANK INSTALLATIONS

TYPE OF TANK	MINIMUM REQUIREMENT*
All Tanks	
Pavement Extensions(d)	12 inches
Distance Between Adjacent Tanks(f)	24 inches
Distance Between Tank and Bank of Excavation(c)	24 inches
Thickness of Compacted Bedding(e)	12 inches
Steel Tanks	
With Traffic Loads	
Reinforced Concrete Pavement(a)	6 inches
Plus Compacted Backfill Cover(b)	18 inches
or	
Asphaltic Concrete Pavement(a)	8 inches
Plus Compacted Backfill Cover(b)	18 inches
Without Traffic Loads	
Reinforced Concrete Pavement(a)	4 inches
Plus Compacted Backfill Cover(b)	12 inches

TYPE OF TANK	MINIMUM REQUIREMENT*
Fiberglass Reinforced Plastic Tanks (20,000 Gallons and Under)	
Maximum Burial Depth(b)	84 inches
With Traffic Load	
Reinforced Concrete Pavement(a)	6 inches
Plus Compacted Backfill Cover(b)	18 inches**
or	
Asphaltic Concrete Pavement(a)	6 inches
Plus Compacted Backfill Cover(b)	30 inches**
Without Traffic Loads	
Reinforced Concrete Pavement(a)	4 inches
Plus Compacted Backfill Cover(b)	12 inches**
Fiberglass Reinforced Plastic Tanks (Over 20,000 gallons)	
Maximum Burial Depth(b)	84 inches
With Traffic Loads	
Reinforced Concrete Pavement(a)	6 inches
Plus Compacted Backfill Cover (b)	36 inches
or	
Asphaltic Concrete Pavement(a)	6 inches
Plus Compacted Backfill Cover(b)	42 inches
Without Traffic Loads	
Reinforced Concrete Pavement(a)	6 inches
Plus Compacted Backfill Cover(b)	24 inches

**Unless Otherwise Noted*
***In Wet Hole Installations, the Minimum Depth of Compacted Cover Is 36 Inches*

complete tank-tightness testing will be necessary prior to approval. In addition, the tank will be re-tested on a five (5) year schedule throughout its service life.

Abandoned tanks shall be removed prior to 80-1 permit approval. All other abandoned tanks shall be removed within six (6) months of the adoption of these guidelines. If the tank can not be removed due subsequent construction in the area or any other reason, a variance may be issued by MMD following review of the circumstances. If the tank is abandoned in place, MMD will require that the tank and all lines be completely emptied of all product, all lines be permanently capped and sealed, all openings be permanently plugged and sealed, the tank filled with an inert, solid material, and the location of the tank registered on all permanent legal documents. If the abandoned tank is removed from the location, care and safety should be exercised to avoid spillage or ignition of vapors. Proper engineering practice should be followed. API, Recommended Practice for Abandonment or Removal of Used Underground Service Tanks is a good reference to these procedures.

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Aboveground Tanks-

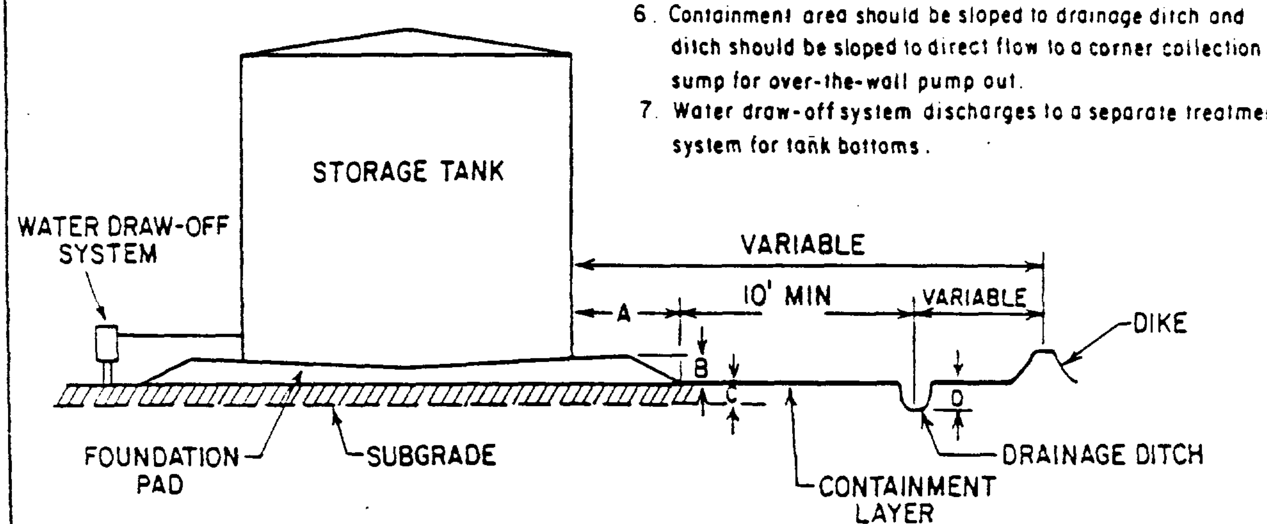
Above ground tanks are defined by having 100% volume above the ground surface, thus if any portion of the tank exists below the ground surface the tank will be considered underground. Aboveground tanks shall be constructed of proper material and should be structurally-sound. Tanks must be designed and constructed under the direction of a registered professional engineer. The tank foundation must be stable, impermeable, and non-corrosive. Tanks should be constructed to include proper venting,

FIGURE 3

Bulk Plant Layout

NOTES:

1. Dimension A is 1/25 of tank diameter plus one foot.
2. Dimension B is 1 1/2' minimum.
3. Dimension C is 1' minimum.
4. Dimension D is 1 1/2' minimum.
5. Containment volume must equal 110% of tank volume.
6. Containment area should be sloped to drainage ditch and ditch should be sloped to direct flow to a corner collection sump for over-the-wall pump out.
7. Water draw-off system discharges to a separate treatment system for tank bottoms.



overfill protection, and clean-out access. Wet wells must be installed in the subgrade to monitor leakage. All tanks must meet API specifications, UL specifications or the equivalent.

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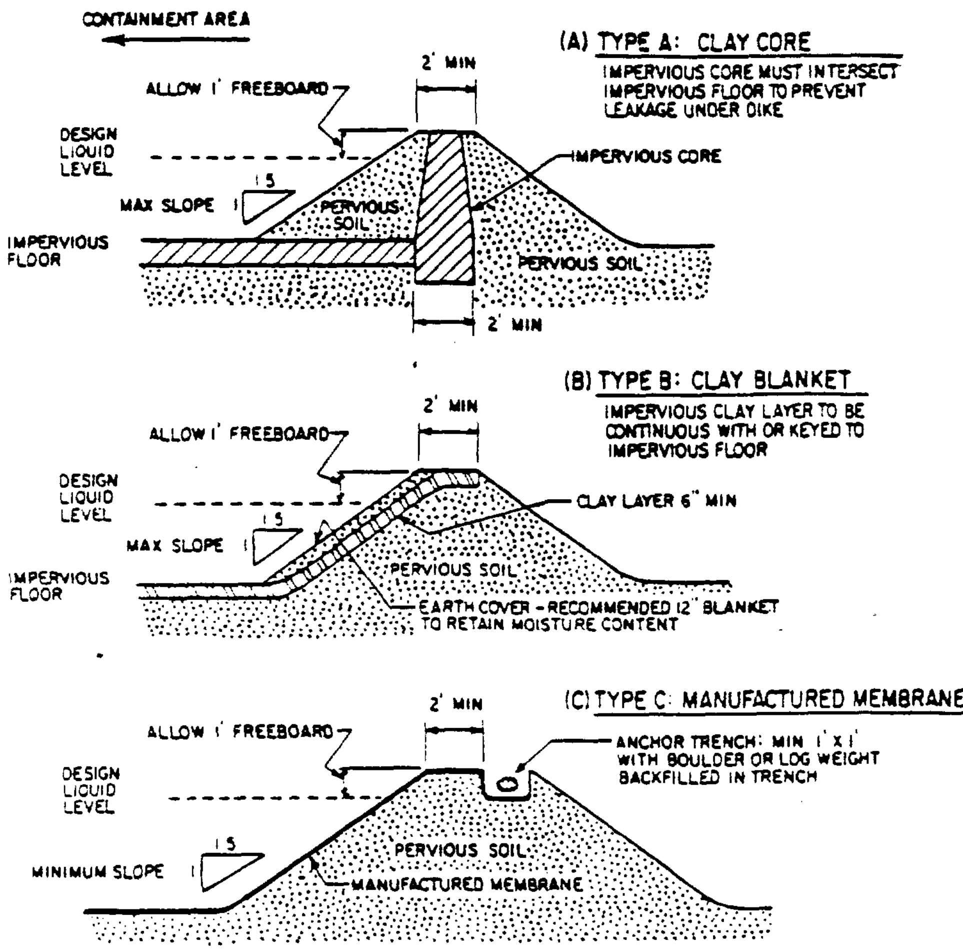
Tank distribution facilities shall be designed by a registered professional engineer. A typical bulk plant layout is sketched in Figure 3. Piping must be constructed of proper material, compatible with the product delivered. Corrosion protection shall be required for carbon steel piping. All distribution systems shall include automatic backfill and overfill protection valves. A remote shut-off valve shall also be included and all automatic valves shall be constructed to prevent manual override if inoperative. Leak-detection devices shall be installed in all underground distribution systems. All hoses and connecting equipment shall be of proper material and design. Connections shall be dry-disconnect to prevent draining during disconnection. All permanent pipes and hoses shall be properly supported and covered if underground. Pumps and fuel islands shall be designed to insure minimal spills during delivery. All valve seals, stuffing boxes, etc shall of appropriate material. In general API or ASTM specifications and recommendation or the equivalent should be followed in distribution system design.

Aboveground facilities shall be located with proper attention to surface water sources and erosion control. Facilities shall be underlain by impermeable material and surrounded by an impermeable berm (Figure 4) which will contain 110% of the capacity of the largest tank or other storage unit in the facility. Outdoor facilities must also be designed to contain any surface runoff. Underground sumps or other containment systems are also permissible providing that they are designed to isolate the materials from

FIGURE 4

Typical Earth Dikes



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the subsurface and will allow detection of leaks. In general, underground secondary containment facilities must meet the requirements of underground storage tanks. Gravity drains should not be used within the berm. Pumps or siphons shall be used to drain the bermed area. All runoff and spilled product should be diverted to a lined and/or sealed pond or other containment structure and the product separated for disposal.

All facilities shall be inspected on a regular monthly basis. Routine tank testing will not normally be required. Visual inspection should be sufficient. MMD may require testing if a problem is discovered.

Bulk Storage Facilities

Drums or small tanks, mobile tanks, and in-use containers shall be stored in an area designated on mine plans. Up-to-date inventories of all petroleum-based products shall be maintained for inspection. The area shall be underlain by an impervious material and enclosed or otherwise protected from surface runoff. Drums and other containers must be in good repair with no leaks or weeps. All openings must have adequate seals. Bulk storage facilities should be located with proper attention to surface drainage courses.

Mobile tanks which are transported throughout the permit area deserve special attention. These devices should be leak-proof with properly-designed distribution, refilling and ventilation devices. Mobile tanks shall be constructed of suitable materials according to API, UL, and/or NFPA specifications. Job-site temporary locations for tanks should be selected with care and temporary berms or other spill containment structures should be considered. Despite the difficulty in designing adequate but temporary job-site locations, the operator must anticipate and prepare for accidental spills and will be held accountable for any product contamination from mobile tanks.

Waste Petroleum-Product Disposal

All waste oil and petroleum product, oil sludge, grease, spent lube oil, drained motor oil, washed oil, and any other petroleum product removed from service must be disposed of according to methodology approved by MMD. Equipment crankcases shall not be drained in to the pit but instead collected and recycled, transported off of the permit area, or otherwise disposed of in a manner approved by MMD. Shop and truck wash water should be directed into a sealed collection sump or pit. The product received by the pit shall be separated and properly disposed of. Disposal on site will not be disallowed, per se, however, any on-site disposal plan must receive prior approval from MMD.

CLEAN UP

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Cleanup of petroleum-based product spills is difficult and often only partially successful. Petrochemicals are commonly absorbed by soil particles, slowing down migration to the water table but resulting in an continuous, long-term pollution source (Figure 5 a & b). Thus, it is extremely important that leaks or spills are discovered quickly and remedial action begins at once. When petrochemicals enter the aquifer system, remedial costs increase rapidly and the potential for a successful clean-up decreases.

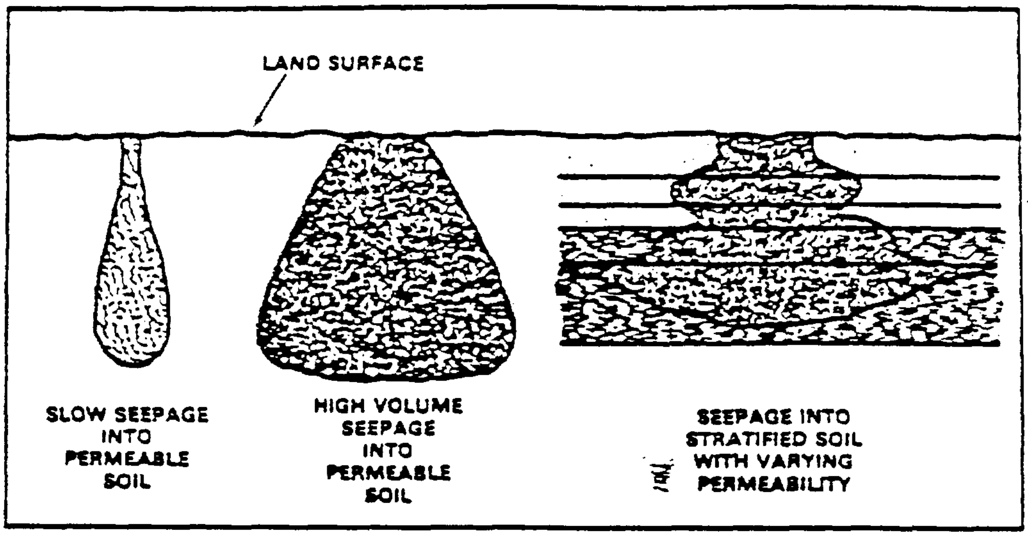

FIGURE 5a Product seepage in the unsaturated zone (API, 1980).

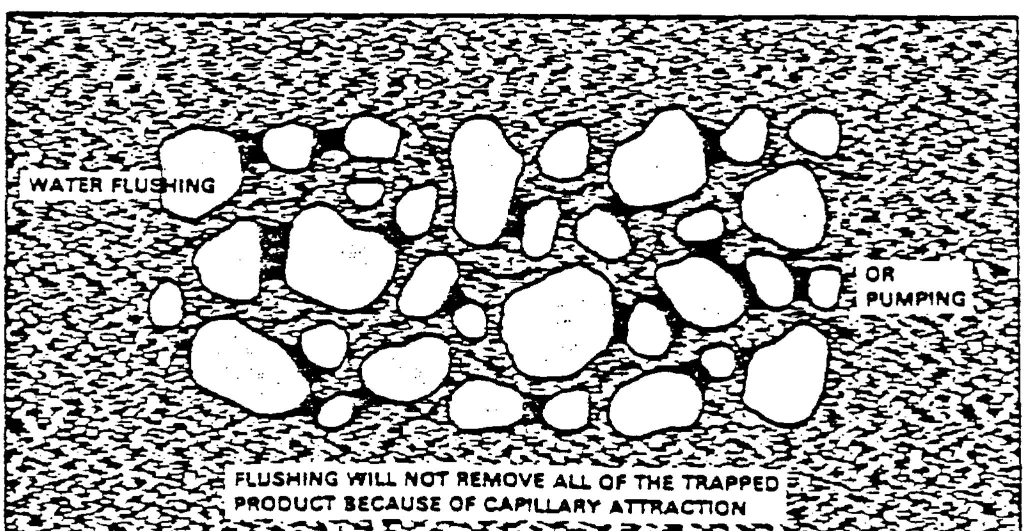

FIGURE 5b Residual product saturation in the soil profile (API, 1980).

An excellent clean-up manual can be obtained from API, Underground Spill Cleanup Manual. Copies are on-file at MMD. Several other API publications deal with specific aspects of product spills and clean-up.

The emergency response recommended by MMD is based on a common-sense approach. Prompt action is high priority. Promptness will be best facilitated by an adequately prepared staff. Operators should consider emergency-response planning and staff training. API regularly schedules workshops to train personnel in the rapid and appropriate response to product spills. At least one supervisor at each mine should be considered for this kind of training, either at these workshops or in-house by company personnel. API or NMEID can supply more information on training programs.

In a general way, any emergency response should involve several aeas of immediate concern. The following scenario is one possible course of action:

(1) Stop the leak. Isolate the pipeline. Contain the faulty container(s). Throw up a temporary berm or otherwise contain the surface spill. Cease operations in the area, other than emergency action. Protect water courses and if the product has already entered surface water try to contain it.

(2) Determine the kind of product spilled. Flammability is, of course, a major concern with volatile substances like gasoline.

(3) Estimate the surface area impacted and the duration of the incident. For example, was it a single surface spill, long-term leak, pipeline rupture, etc.? Determine volume lost from inventory records.

(4) Inventory facilities which might be impacted. These might include, shallow wells, soils, lakes or streams, underground excavations or buildings, agricultural facilities, and/or wildlife habitats.

(5) Alert MMD and report the above activities and observations. These steps should be carried out within hours of the discovery of the incident. Based on this data MMD will determine the seriousness of the situation and whether the incident requires the alerting of other agencies, (fire department, hazardous materials bureau, etc.). The operator, though, will basically be on his own for the first four steps of the response. It will be up to him to mitigate the damage and hopefully the cost of remedial action. It is the operator's responsibility to be aware of and prepared for proper emergency action in petroleum product accidents.

Following this initial response, MMD will assist the operator in any follow-up emergency action. In the case of a surface spill it is important to quickly assess the depth of the product plume. In the case of a single spill incident it is helpful to get a rough estimate at the outset. API (1972) suggests a formula to estimate the potential for ground water contact by a descending plume of petroleum-based fluids. The formula calculates the volume of soil needed to absorb or immobilize a given volume of oil. This volume represents the volume of the pollutant plume at the eventual point of saturation and immobilization.

OR:

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(1) Cubic Yards of Soil Required to Attain Immobility, $V_s = \frac{(0.20)V}{P\ (Sr)}$

WHERE: V = Volume of oil spilled in barrels (1 barrel = 42 gallons)
P = porosity of soil
Sr = Residual Saturation

AND: 0.10 = Sr for light oil and gasoline
0.15 = Sr for diesel, light fuel oil
0.20 = Sr for lube, heavy fuel oil

If the soil is unstratified, the spill plume will not migrate laterally. Thus, the depth of the plume will be proportional to the volume and the surface area of impact. Assuming a roughly cylindrical plume:

(2) Depth of Plume = $Vs/\pi R^2$

WHERE: Vs = the volume to soil needed to attain immobility (from 1)
R = the surface radius of the spill area in yards

Given a 10 barrel oil spill over 10-yard radius circular area underlain by soil of 30% porosity the volume of the plume will be:

$$Vs = \frac{(0.20)10}{.30(0.10)}$$

$$Vs = 66.7 \text{ cubic yards}$$

And the depth of the plume will be:

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$$D = 66.7/\pi(10)^2$$

$$= 0.21 \text{ Yards}$$

$$= 7\tfrac{1}{2} \text{ inches}$$

Thus, 66.7 cubic yards of oil-saturated soil must be removed or about 8 inches of soil over a 10-yard radius of impact.

With a larger volume spill the depth of the plume can be compared to the depth of the water table and the potential for ground water contamination evaluated. For example, if the above spill was 1000 barrels over a 20-yard radius the plume would reach 15 feet below the surface. If the water table was 10 feet below the surface, it could be assumed that the ground water was contaminated.

If the product has entered a surface water body, floating berms or plastic should be used to isolate the slick from the rest of the water body. Skimmer pumps, oil/water separators, or sorbants (straw, sawdust, synthetic petroleum sorbants) should be used to separate and remove the product from the surface of the water. The area should be isolated if a flammibility hazard exists. If it is practical, isolate the water body from surface drainage courses with temporary dams or diversions.

In addition to the estimated depth of impact, a field measurement of depth should also be made. Hand augers or soil sampling tubes should be used to measure the depth of impact and obtain a sample of the saturated soil. If these methods are insufficient, other shallow drilling and sampling techniques should be considered. Samples of the spilled product and any affected water should be taken. Samples from near-by wells and surface water should be taken if applicable. All fluid and soil samples should be preserved in a method recommended by Jercinovic (1984) (Table 2). In general, samples for organic-consistent analysis should be stored in glass containers, should not be filtered, and not acidified. Other parameters (trace metals, major dissolved species, etc.) required different procedures (Table 3) (see USGS, EPA, or other manuals on file at MMD). It is clear that an accurate inventory of petroleum products on hand must be made <u>before</u> <u>and</u> <u>in</u> <u>anticipation</u> of an incident.

The above actions should be completed within a short period of time (about a week). Following data collection and analysis, MMD will suggest an emergency clean-up procedure in consultation with other agencies and the operator. For a spill which has not contacted the water table or surface waters, this action may be limited to simply stripping the saturated soil and proper off-site or on-site disposal. Soil washing and biodegradation methods are also available and and are described in several publications. If the product has contacted the water table, more elaborate methods are needed. These methods can be broken down into, in-situ methods, in which

TABLE 2 Summary of water sample containers and treatment for laboratory analyses. (from Jercinovic 1984)

Analyses	Container	Treatment
Major Ions and Total Dissolved Solids (TDS)	One-liter plastic cubitainer	Unfiltered, non-acidified, and chilled
Nitrogen Species and Total Organic Carbon (TOC)	One-liter plastic cubitainer	Filtered, 2 ml concentrated H_2SO_4, and chilled
Trace Elements and Heavy Metals	One-liter plastic cubitainer	Filtered, 5 ml concentrated HNO_3, and chilled
Purgeable Organics	40-ml glass septum vial with teflon-lined disc	Unfiltered, non-acidified (3 mg $Na_2O_3S_2$ if chlorinated), and chilled
Extractable Organics	2000-ml amber glass bottle with teflon-lined disc	Unfiltered, non-acidified, and chilled

Summary of field measurements and equipment/method.

Parameter	Equipment/Method
Specific Conductance and Temperature	YSI Model 33 Salinity-Conductivty-Temperature Meter
pH	Corning Model 3D Meter (electrometric) or Hellige Comparator (colormetric)
Odor	Collector's Observation
Color	Collector's Observation

TABLE 3 Recommended methods for analysis (from Jercinovic 1984)

INORGANICS - GENERAL CHEMISTRY

Parameter(s)	Method(s)
Ca, Mg	EPA Test Method 215.2; titration
Na, K	Corning Flame Photometer and 800 Diluter; Flame photometric
Br	EPA Test Method 320.1; titration
F	EPA Test Method 340.2; specific electrode
HCO_3, CO_3	EPA Test Method 310.1; titration
Cl	EPA Test Method 325.2; colormetric-automated ferricyanide
SO_4	EPA Test Method 375.2; automated/methyl thymol blue
TOC (total organic carbon)	Oceanographic Institute 500 Flame Ionization Detector; flame ionization
NO_3, NO_2	EPA Test Method 353.2; autoanalyzer cadmium reduction
NH_3	EPA Test Method 350.1; automated phenate
SiO_2	EPA Test Method 370.1; colormetric
TDS (total filterable residue)	EPA Test Method 160.1; evaporation in tared beakers

INORGANICS - METALS

Parameter(s)	Method(s)
Al, Ba, Be, B, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Mo, Ni, Si, Ag, Sr, Sn, V, Y, and Zn	*Jarrell Ash 965 Atom Comp Inductively-Coupled Plasma Spectrometer (ICP)

*Soil samples first extracted using EP toxicity test procedures (USEPA, 1980) or total recoverables by not nitric acid extraction (USEPA, 1979).

TABLE 3 (continued)

As	EPA Test Method 206.2; graphite furnace atomic absorption matrix modified
Se	EPA Test Method 270.2; graphite furnace atomic absorption matrix modified
Hg	EPA Test Method 245.1; cold vapor atomic absorption

(The detection limits for metals analyses are provided in Appendix J)

ORGANICS - PURGEABLES

Parameter(s)	Method(s)
Aromatic and Halogenated Compounds (i.e., benzene, 1,2-dichloroethane)	EPA Test Methods 601 and 602; purge and trap on Tekmar LSC-2 and ALS autosampler; gas chromatography on Tracor 570 with photoionization detector in series with electrolytic conductivity (Hall) detector, columns include (a) 5% SP-1200 + 1.75% Bentone 34 on 100/120 Supelcoport (55°C for 3 minutes then to 140°C at a rate of 5°C/minute), (b) 1% SP-1000 on 60/80 Carbopack-B (50°C for 4 minutes, then to 220° at 8°C/minute), and (c) 10% SP-2100 on 80/100 Supelcoport (50°C for 4 minutes then to 220°C at 8°C/minute); internal standards 2-bromo-1-chloropropane and p-bromo fluorobenzene. Other detectors include Finnigan 4000 Mass Spectrometer and Tracor 200 Flame Ionization Detector and Tracor 220 Electron Capture. Any positive purgeables batch is cross-checked with one sample on Mass Spectrometer using EPA Test Method 623 , except for trihalomethanes (THM's)
Aromatic and Halogenated Compounds (soil samples)	James Montgomery Laboratory, Analysis by Gas Chromatography/Mass Spectrometry using the Finnigan 4000 GC/MS and approved EPA Test Methods

ORGANICS - EXTRACTABLES

Parameters	Method(s)
Polychlorinated Biphenyls (PCB's)	EPA Test Method 608; gas chromatography on Tracor 570 with Tracor 220 Electron Capture detector; column is 1½% SP-2250 80/100 Supelcoport + 1.95% SP-2401

TABLE 3 (continued)

Polynuclear Aromatic Hydrocarbons (PNA's)	James Montgomery Laboratory, Analysis by High Performance Liquid Chromatography (HPLC) using the Varian Vista 56 automated HPLC system and Vista 401 data system and approved EPA Test Methods
General Base/Neutral and Acid Priority Pollutant Scan (soil samples)	James Montgomery Laboratory, Analysis by Gas Chromatography/Mass Spectrometry using the Finnigan 4000 GC/MS and approved EPA Test Methods

REFERENCES

PEI, 1983, Tightness-testing systems for underground tanks, proceedings from the 33rd annual convention of the Petroleum Equipment Institute, Las Vegas: Petroleum Equipment Institute, manual 83-1, 124 p.

USEPA, 1979, Methods for chemical analysis of water and wastes, method 4.1.3.: Methods Development and Quality Assurance Research Center, Cincinnati, 298 p.

USEPA, 1980, Test methods for the evaluation of solid waste, physical/ chemical methods: USEPA pub. no. SW-846, Cincinnati, Ohio.

USEPA, 1984, Guidelines establishing test procedures for the analysis of pollutants under the Clean Water Act; Final Rule and Interim Final Rule and Proposed Rule: Federal Register, v. 49 (October 26, 1984), Part 136, p. 43234-43442.

biochemical and chemical agents are introduced into the aquifer, and purgative methods, in which the ground water is removed through interceptor trenches or wells and the product separated. The obvious complexity of these methods and the long-term effects of aquifer degradation point to the need for a well conceived plan.

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During emergency procedures and following accumulation of reconnaissance data, the operator should begin assembling a plan and report. The scope and detail of this plan will be incident specific. For example, a surface spill that has not contacted the water table may indicate a relatively short statement on the cause of the incident, the nature of the discovery, the emergency response, and the recommendations for prevention of further incidents. A major aquifer degradation will involve more detail, including for example, a geological and/or engineering appraisal, regional impact, time table for aquifer restoration, a description of restoration methodology, etc. The evaluation of the plan, its detail, and specific deadlines for reporting, will be made by MMD and will certainly be part of the abatement process.

While there is no acceptable level of product concentration in ground or surface water, zero or detection-limit concentration is rarely achieved. The policy adopted by MMD is therefore, that of EID, "Action until technological infeasibility". During approval of the plan, MMD will set a target level for product-derived pollutants based on Water Quality Control Commission regulations and the restoration technology used. Progress towards that goal will be required until it is achieved or MMD determines that it is technologically unfeasible to attempt further reduction of the pollutant. MMD will not require the operator to implement a new technique, if the operator has made a genuine attempt to achieve the target level.

Only a moderate amount of imagination is required to see that the above scenario is an operating and regulatory nightmare. Aquifer restoration is an extremely costly and frustrating procedure. This does, not, however, diminish the concern of both MMD and the public over ground water pollution. Thus, a policy of prevention and early detection is the only sane response to the problem. MMD will be delighted to work with any and all operators who wish to improve their facilities in this regard.

DRAFT

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May 2, 1985

Jeff Taylor, Esq.
Oil Conservation Division
P. O. Box 2088
Santa Fe, New Mexico 87504

"Hand Delivered"

Re: NMOCC Case 8224

Dear Mr. Taylor:

On behalf of Tenneco Oil Company, I am requesting that the OCD Staff provide to us the following post hearing documents concerning its ground water study of the Flora Vista site:

1. All field notes and data;

2. Schematic of site, with all monitoring wells or pit locations, including the direction of gradient and survey points;

3. All chemical analysis reports from all laboratories and for any and all samples taken;

4. Copies of all correspondence, documents, notes, and data concerning the Flora Vista site, including but not limited to, the Manana Mary Wheeler No. 1 well from the date of first reported contamination, and of any Flora Vista well.

Very truly yours,

Original signed by
W. THOMAS KELLAHIN

W. Thomas Kellahin

WTK:ca

cc: Mr. Richard L. Stamets
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Influence of Microbial Adaption on the Fate of Organic Pollutants in Ground Water.

Date Received______________________________

Date Received______________________________

John T. Wilson, James F. McNabb, and Jack W. Cochran

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The authors are participants in the National Center for Ground Water Research.

Correspondence regarding biotransformations should be sent to Dr. Wilson, regarding analytical environmental chemistry to Dr. Tomson, and regarding hydrology and computer modelling to Dr. Bedient.

Although the research described in this article has been funded in part by the United States Environmental Protection Agency through Cooperative Agreement No. CR806931-02 to the National Center for Ground Water Research, it has not been subject to Agency review, and therefore does not necessarily reflect the views of the Agency, and no official endorsement should be inferred.

Abstract - A plume of contaminated ground water originating from an abandoned disposal pit for wood-creosoting waste was characterized. The important organic contaminants in the plume include naphthalene, 1-methylnaphthalene, 2-methylnaphthalene, Dibenzofuran, and Fluorene at individual concentrations of 1,000 to 100 μg/liter. Core material from the site was studied to determine whether organisms in the subsurface could adapt to this waste, and whether biological activity influenced the disposition of the plume. Biodegradation of these organic pollutants in subsurface material from the margin of the plume was rapid. No biodegradation of these pollutants was detected in pristine subsurface material from the same geological structure. As a result of this adaption, the disposition of the plume was not controlled by the rate of utilization of the pollutants by the microorganisms, but by the extent of utilization allowed by the supply of oxygen.

Key words - Adaption, Adaptation, Acclimation, Ground Water, Organic Pollutants.

INTRODUCTION

The Nation is becoming acutely aware that inappropriate disposal of hazardous waste is a threat to our ground-water resources. A clear understanding of the behavior of these wastes in the subsurface environment is required to properly assess the environmental damage from existing waste disposal sites, and to identify the most appropriate approaches for containment or clean up of the waste.

At any particular site, the behavior of a waste is influenced by the hydrogeology of the site, by sorption to the particular subsurface materials, and by biological and non-biological transformations. The relative influence of these processes and conditions on the behavior of a waste can vary from compound to compound, between sites, and on occasion within sites. If an important process or condition is ignored in a projection of environmental fate, either through indifference or from absence of the appropriate information, the projection can be seriously misleading.

Hydrocarbons derived from petroleum or other fossil fuels are important pollutants of ground water. Sources include gasoline from spills or leaky storage tanks, waste from abandoned illuminating-gas plants, industrial impoundments, and land fills. The behavior of these compounds is subject to all the conditions and processes mentioned above. They should provide a good test of our capacity to characterize the behavior of an organic waste in the subsurface environment.

This report is a preliminary attempt at a comprehensive assessment of the behavior of pollution from creosote waste at a site in the Gulf Coast region of Texas. It emphasizes the importance of microbial adaption in determining the behavior of the waste.

Adaption of subsurface microbes to components in creosote wastes has been documented previously by Ehrlich et al. (1 , 2); however, activity at this site was under strictly anaerobic conditions and was restricted to the methanogenic degradation of phenolic compounds. There was no adaption to or activity against naphthalene or other polynuclear aromatic compounds under anaerobic conditions. Ogawa et al. (3) reported the aerobic degradation of a number of polynuclear aromatic compounds in water from a contaminated well. There was no degradation in water from an uncontaminated well in the same aquifer, indicating that adaption had occurred, at least in the environment of the contaminated well. The well may have allowed organisms from the surface to colonize the bore hole and the region of the formation around the well. There was no evidence that the aquifer at large was adapted to the waste. This study examines the prospects for adaption by indigenous subsurface microbes to the aerobic degradation of simple polynuclear hydrocarbons originating from a waste disposal site.

MATERIALS AND METHODS

Analysis of water from monitoring wells

Oxygen was determined by flushing the bore hole with nitrogen or argon, pumping the well to produce fresh water from the formation, then lowering a YSI oxygen electrode into the well. Chloride was determined by the Hach Kit method for total chloride. Organic compounds were sampled by pumping 100 to 1,000 ml of well water (depending on the extent of contamination) through a C-18 reverse phase Sep-Pak trap (Waters Assoc.). The compounds were eluted in 4.0 ml of methylene chloride. The extract was concentrated under nitrogen and analyzed by gas chromatography using a fused-silica capillary column and an FID detector.

Biotransformation studies

Authentic subsurface material was used to construct small 45-ml static, batch microcosms as has been described previously (4 ,5). Organic compounds were extracted from the subsurface material by shaking in a chloroform-methanol azeotrophe for 18 hours. The extract was separated from the aqueous phase and solids, dried through sodium sulfate, concentrated by Kuderna-Danish distillation and analyzed by gas chromatography using a fused-silica capillary column and an FID detector.

Computer modelling

Simulations were done using a one-dimensional analytical solution to the universal solute transport equation. Sorption was assumed to be linear, degradation was assumed to be first order with respect to concentration of the compound.

RESULTS

Geological setting and history of the site

The abandoned pits that are the source of pollution received wastes from a wood-creosoting process from 1952 to 1975. They have now been filled and the land developed for other purposes.

The waste pits and plume of contamination are contained in unconsolidated material deposited by an egressing river delta. From the present surface to a depth of 5 to 6 m is a complex pattern of interlayered sands and clays that probably were deposited as meander belts by a stream. From 5 to 6 m down to 8 to 9 m is a layer of poorly-sorted sand that was probably deposited in a near-shore environment. Below 8 to 9 m is a layer of clay that was probably deposited in an off-shore environment.

The lower layer of clay seems to be uniformly distributed across the entire site; its transmissivity is low, 10^{-9} to 10^{-10} cm/sec. The sand is somewhat variable over the site; its transmissivity near the waste pit is much higher than the clay, 10^{-3} to 10^{-4} cm/sec. The present water table is 7.6 to 8.5 m deep. A plume of contaminated water is moving laterally through the sand away from the disposal pit. All of the monitoring wells are screened in the relatively shallow zone of water-saturated sand situated above the clay. The present flow velocity in the sand is estimated to be 10 m/year.

Characterization of the plume

When the concentrations of organic pollutants, oxygen, and electrolytes in the monitoring wells are compared, the wells fall into four categories (Table 1, see also Fig. 1). Wells #3 and #14 were constructed at locations 85 and 330 m from the pits in areas that are removed from the hydrological influence of the waste pit. These areas were pristine; none of the organic pollutants were detected in these wells, oxygen was present, and chlorides and conductivity were low.

Wells #30, #9, #2, and #27 penetrated the plume of contamination. The concentration of the organic pollutants was high, and the concentration of individual compounds was remarkably uniform. Oxygen was greatly depleted and the concentration of chloride and the conductivity of the water was higher, probably reflecting salts that were in the creosote wastes.

Wells #28, #29, and #8 were in a region of active treatment. Oxygen concentrations were depressed and chloride and conductivity were elevated, indicating the arrival of the plume. However, the concentration of each organic pollutant was reduced roughly an order of magnitude. Wells #26 and #5A were in a treated zone. The concentrations of the organic pollutants were much reduced, and in the case of well #26, the concentration of oxygen was close to that expected for pristine conditions. These wells had elevated concentrations of chloride and higher conductivity than pristine water, indicating that these wells sampled renovated water from the plume.

Well #5J was anomalous; it produced water containing appreciable concentrations of the organic pollutants, as well as high concentrations of oxygen. The simplest explanation is that this well straddled the zone of active treatment, either vertically or horizontally, and produced oxygenated water from one region and water polluted with organics from another.

The locations of the monitoring wells is presented in Fig. 1. The direction of ground-water flow is down and to the left of the figure. Wells #30, #9, and #2 intercept the plume as it leaves the waste pit. The water probably has received little renovation due to sorption or degradation of the organics. Well #27 shows that the plume extends at least 60 m down-gradient without appreciable renovation.

The wells in the zone of active treatment and in the treated zone are scattered along the margin of the plume. In several cases, wells with intense pollution are very close to wells with considerable treatment. (Compare wells #2 and #8 or #27 and #28) This indicates that the zone of treatment can be very narrow, perhaps as little as 10 m in horizontal extent.

Biological activity in subsurface material

The water-saturated sands from two sites within the zone of treatment (#5 and #16) and from a pristine site (#14) were examined for biological activity against the organic pollutants. The samples were acquired in a manner that precluded contamination by surface microorganisms (4). Oxygen was added to the pore water of the subsurface material to a final concentration of at least 1.0 µg/liter. Because material from site #16 contained appreciable quantities of the organic contaminants it was not further amended. Material from sites #5 and #14 was essentially free of organic pollutants, and was amended with the organic compounds listed in Table 1 to a final concentration of 20 to 120 ng/gm dry subsurface material. Because acenaphthene was present in the material from site #16, it was also added to the other subsurface material.

There was no detectable biological activity in the material from the pristine site (Table 2). In fact, the disappearance of the compounds was somewhat more rapid in the autoclaved material. However, there was a rapid biotransformation of the organic compounds in the material from the zone of treatment. Material from site #5 was particularly active against all of the organic compounds.

Material from site #6 was examined for activity against a series of alkyl benzenes. The results will be presented elsewhere; however, biodegradation occurred in material from site #6 but was not detected in material from a pristine site. Additionally, material from sites #6 and #15 is presently being characterized by participants in the National Center for Ground Water Research to further elucidate the non-biological interactions between the organic pollutants and the subsurface material.

Site-specific interpretation of rates of degradation

The specific concentration of any one of the organic pollutants in the plume is simultaneously controlled by several processes, including dilution due to dispersion, sorption to subsurface solids, and biological and non-biological degradation. The contribution of any one of these processes can only be evaluated in the context of the other processes.

Fig. 2 depicts the influence of degradation on the fate of naphthalene under conditions that are appropriate to the Conroe creosote-waste site. Transport of nathphalene was simulated for the following conditions: The initial concentration was 1,000 μg/liter, the dispersion coefficient D was 100 m, the flow velocity was 10 m/year, and the retardation due to sorption was 3 as determined by the behavior of naphthalene in core material in the laboratory. A radius of 200 m was selected as an arbitrary boundary between a site scale and a regional scale of concern. Fig. 2 projects the influence of degradation on the concentration of naphthalene that can be expected to reach that boundary over the next 70 years. A rate of degradation as low as 5%/year should have a substantial influence on the breakthrough of naphthalene, while a rate of 50%/year should depress the breakthrough of naphthalene three orders of magnitude. A rate of 50%/year is close to the detection limit of the biodegradation assay, approximately 2%/week. Rates of degradation in subsurface material from the zone of treatment were one to two orders of magnitude greater, and could easily account for the extensive renovation of ground water in the zone of treatment over relatively short distances between monitoring wells.

DISCUSSION

Occurrence of adaption

Adaption is a phenomenon rather than a mechanism or process. The term simply refers to an increase in the rate of biotransformation of a substance resulting from exposure to that substance. Clearly, microbes in the water-saturated sand at the Conroe creosote-waste site adapted to the six organic pollutants considered in this study. This adaption results in rates of biotransformation of at least one to two orders of magnitude greater than could be detected in material that was not exposed to the pollutants. This result is similar to experience with surface sediments. Herbes and Schwall (6) found that the rate of degradation of naphthalene in oil contaminated stream sediment was 2,350%/week, while the rate of degradation in uncontaminated sediments was less than 7%/week. Additionally, Herbes (7) found that the rate of naphthalene degradation in stream sediments downstream of a coal-coking plant was 1,300%/week.

Significance of adaption

Once adaption occurs, biotransformation is so rapid that it can be considered instantaneous with the context of slow ground-water flow. As a result, the quantitative prediction of the effect of biological activity or the fate of a pollutant shifts from a consideration of the kinetics of utilization of the substrate by the microorganisms to consideration of the extent of utilization allowed by geochemical constraints on metabolism, and the rate of supply of that limiting requisite for metabolism to the subsurface environment. In the case of the Conroe creosote-waste site, the disposition of the plume is controlled by the supply of oxygen to its margins, either by diffusion from the unsaturated zone or by admixture of oxygenated ground water through dispersion.

As a result, predicting the behavior of a plume of contamination is greatly simplified--there is no need to characterize the biological activity. However, there is need for tools to quickly and cheaply recognize whether adaption has occurred in a particular subsurface environment. Also needed is a delineation of the conditions for which adaption can be expected in the subsurface, and methods to predict the time required for adaption.

Significance of the absence of adaption

If adaption fails to occur, predictions of the influence of biological activity and the fate of a pollutant will be difficult. As demonstrated in Fig. 1 rates of biotransformation that are much below the present detection limit can have considerable environmental significance. Work is under way within the National Center for Ground Water Research to lower the detection limit through the use of radiolabelled substrates.

CONCLUSIONS

1. Microbes in the subsurface environment adapted to degrade a series of polynuclear aromatic hydrocarbons in a plume of pollution originating from wood-creosoting waste.
2. Following adaption, the supply of oxygen controlled the disposition of the plume.
3. Slow rates of degradation in unadapted material can have profound effects on the fate of compounds in the subsurface environment on a regional scale.

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TABLE 1. Distribution of organic pollutants, oxygen, and electrolytes in monitoring wells at the Conroe, TX creosote-waste site.

Parameter	Unit	Location of Monitoring Wells											
		Pristine Zone (almost)		Plume of Contamination				Zone of Active Treatment				Treated Zone	
		3	4	30	9	2	27	28	29	8	5J	26	5A
Cl^-	mg/l	8	16	22	21	50	29	47	40	49	28	34	48
Conductivity	μmhos/cm	88	110	112	125	282	139	250	240	252	230	220	241
O_2	mg/l	1.4	no data	0.1	0.2	<0.1	0.3	0.3	<0.1	0.2	1.6	1.7	0.3
Naphthalene	μg/l	<0.1	<0.1	1200	1600	650	3500	49	67	90	65	1.4	14
1-methyl naphthalene	μg/l	<0.1	<0.1	470	370	220	610	3.5	8.8	15	22	2.2	1.5
2-methyl naphthalene	μg/l	<0.1	<0.1	650	710	390	1300	5.7	12	26	37	2.1	2.5
Dibenzofuran	μg/l	<0.1	<0.1	420	250	140	290	2.3	3.7	11	20	5.1	<0.1
Fluorene	μg/l	<0.1	<0.1	300	230	120	290	2.0	2.8	13	11	7.9	1.1

See Fig. 1 for the location of the monitoring wells.

TABLE 2. Biological activity against organic pollutants as inferred from the decrease in the quantity of compound extracted from subsurface material from Conroe, TX after incubation at 25°C.

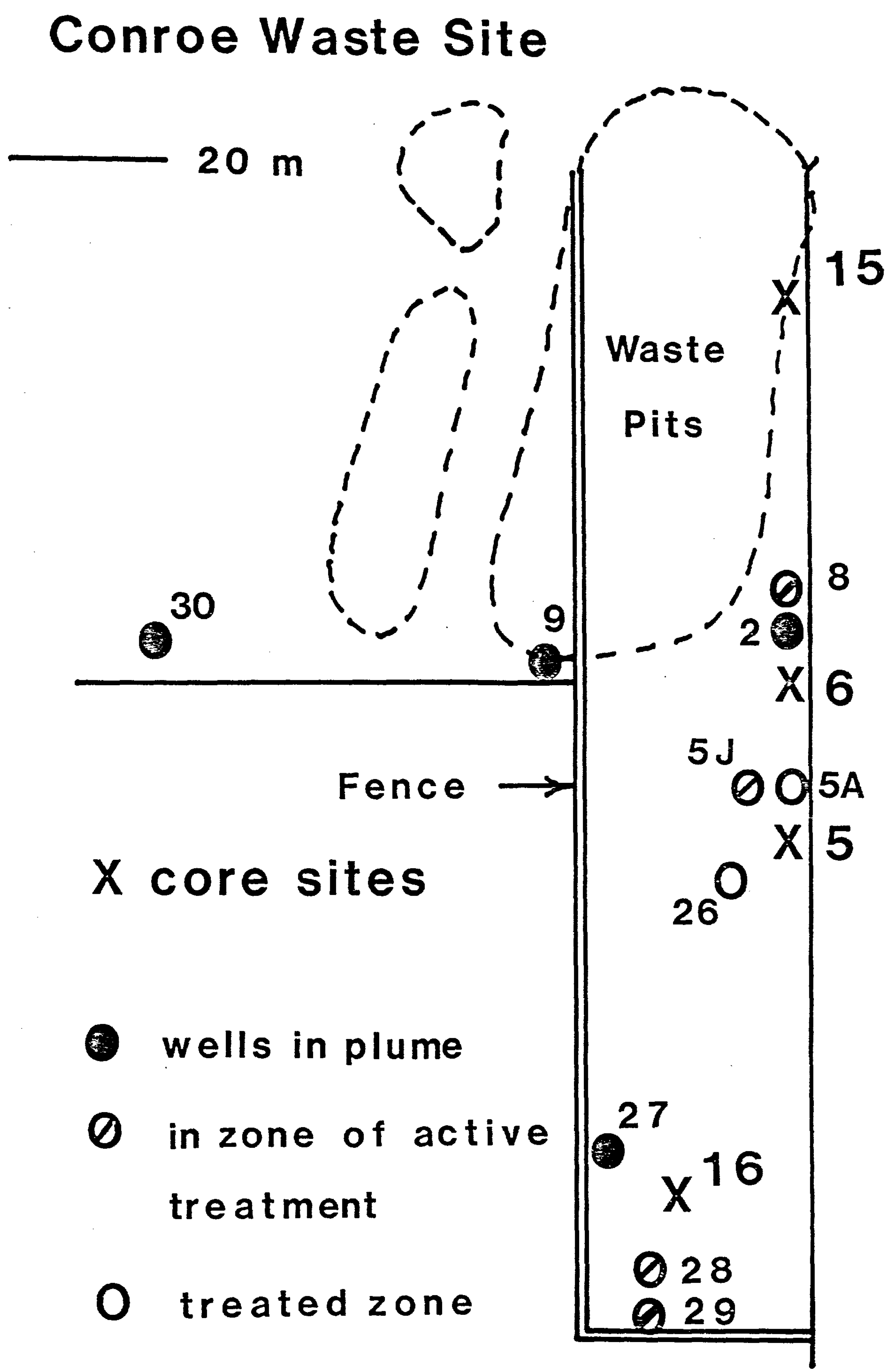
Sampling Site	Naphthalene	2-methylnaphthalene	Dibenzofuran	Fluorene	Acenaphthene	1-Methylnaphthalene
Contaminated Sites			-% per week-			
#5	>160[a]	>160[a]	>180[a]	>92[a]	>130	>160[a]
#5 Autoclaved	8.2 ± 6.3[b]	6.5 ± 4.6	4.9 ± 3.6	3.4 ± 4.0	5.0 ± 3.1	5.6 ± 4.6
#16	>257[a]	8.0 ± 2.5	No data	No data	32.5 ± 11.8	No data
#16 Autoclaved	7.7 ± 2.7	6.1 ± 2.9	4.9 ± 3.3	11.1 ± 6.9	7.9 ± 3.2	5.9 ± 3.2
Pristine Site						
#14	3.7 ± 4.0	3.5 ± 2.9	3.9 ± 3.6	6.4 ± 4.7	6.6 ± 2.1	3.6 ± 3.0
#14 Autoclaved	11.3 ± 6.2	11.1 ± 5.7	9.9 ± 6.2	9.4 ± 6.5	9.2 ± 6.9	10.9 ± 5.2

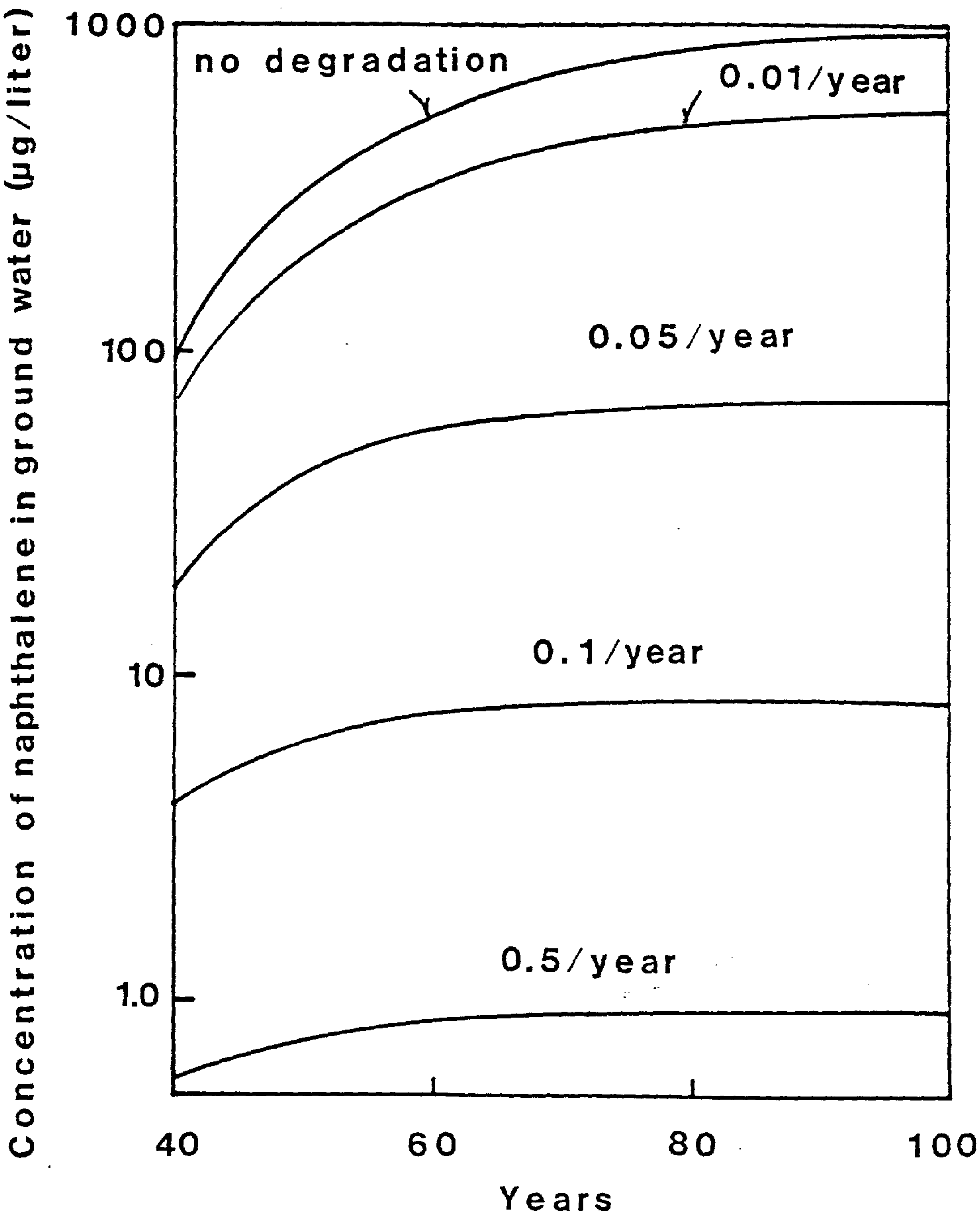
[a]below detection limit (1 ng/g) before first sampling interval.

[b]95% confidence interval ($s_b\ t_{0.05}$)

Fig. 1 Location of monitoring wells and sampling sites for core material at a disposal site for wood-creosote waste at Conroe, Texas.

Fig. 2 A computer simulation of the effect of degradation on the concentration of naphthalene that can reach an arbitrary boundary 200 m from the waste disposal pits.


Conroe Waste Site
20 m
Waste
Pits
15
8
30
9
2
6
5J
5A
5
Fence
X core sites
26
wells in plume
27
in zone of active
treatment
16
28
treated zone
29



Concentration of naphthalene in ground water (µg/liter)
1000
100
10
1.0
no degradation
0.01/year
0.05/year
0.1/year
0.5/year
40
60
80
100
Years

STATE OF NEW MEXICO
DEPARTMENT OF ENERGY AND MINERALS
OIL CONSERVATION DIVISION

IN THE MATTER OF THE HEARING
CALLED BY THE OIL CONSERVATION
COMMISSION OF NEW MEXICO FOR
THE PURPOSE OF CONSIDERING:

CASE No. 8224

APPLICATION OF THE OIL CONSERVATION
COMMISSION UPON ITS OWN MOTION TO
DEFINE THE VERTICAL AND AREAL EXTENT OF
AQUIFERS POTENTIALLY VULNERABLE TO
CONTAMINATION BY THE SURFACE DISPOSAL
OF PRODUCED WATER, McKINLEY, RIO ARRIBA,
SANDOVAL, AND SAN JUAN COUNTIES,
NEW MEXICO.

SUMMARY MEMORANDUM OF OCD STAFF

INTRODUCTION

This case was called by the Commission on its own motion to determine whether fresh water resources in the San Juan Basin of New Mexico are vulnerable to contamination by the surface disposal of produced water from oil and gas operations. If such threats of contamination are found to exist, the Commission has the duty to take action to regulate such disposal.

This hearing process was convened under the mandate contained in the Commission's "Enumeration of Powers" found at NMSA 70-2-12(15) (1978), which provides that the Commission is authorized to "... direct surface or subsurface disposal of [produced] water in a manner that will afford reasonable protection against contamination of fresh water supplies..." While some of the testimony and other evidence presented at the hearing of this case relates to regulations and standards promulgated pursuant to the Water Quality Act, NMSA 74-6-1 et. seq. (1978), it was emphasized in testimony that in this particular situation the requirements set forth in the regulations of the New Mexico Water Quality Control Commission are referred to only as standards and the hearing was not called pursuant to any authority contained in the Water Quality Act.

It is clear from the evidence introduced at the hearing on this matter that some of the components of produced water are toxic, (Boyer, Tr. 2/20/85, P. 58-60), while others, if introduced into ground water, will result in its degradation. No witness disputed this evidence. Moreover, the introduction of these substances into ground water designated by the State Engineer as "fresh water resources" in quantities that would cause the ground water to exceed water quality standards is strictly prohibited in other situations. Sections 3-101 and 3-103 (A) and (B), Water Quality Control Commission Regulations. So even though this hearing was not called pursuant to the OCC's delegated power to enforce Water Quality Control Regulations, any contemplated action should be viewed in light of these regulations and the water quality standards contained therein.

The evidence is also clear that much of the produced water that is dumped into unlined pits in Northwest New Mexico necessarily goes directly into the ground. (Boyer, Tr. 2/20/85, P. 69-71, Baca, Tr. 2/20/85, P. 148). And because of the shallow depth to ground water and the alluvial, unconsolidated nature of the soils in the San Juan Basin, most of the water that is absorbed into the ground eventually reaches the ground water.

Given this essentially uncontroverted evidence, the primary question to be addressed by the Commission prior to entering an order in this case concerns the final disposition of organic hydrocarbons and dissolved minerals (TDS) contained in this produced water. Testimony by the opponents of a "no-pit" rule that disposal of produced water onto the ground will have no adverse consequences to ground water is simply not credible. Although several industry witnesses were produced in an attempt to disarm the concern expressed by the Commission in initiating this case, none of them controverted the evidence produced by the Division that produced water contains toxic substances and that such water, if put into unlined pits, enters the ground and mixes with ground water. And in spite of the fact that industry representatives testified that because of the action of various mechanisms of attenuation, deleterious substances in the produced water do not contaminate ground water supplies, their own studies clearly showed high levels of benzene, a constituent of produced water that does not occur naturally in ground water, contaminating areas under produced water pits (Geoscience Exhibit 3, see especially results of monitoring Tenneco's Eaton A-1E).

Following is a brief synopsis of the relevant evidence. It demonstrates conclusively that the unregulated disposal of produced water should cease.

I. SUBSTANTIAL EVIDENCE WAS PRESENTED REGARDING THE POTENTIAL FOR GROUND WATER CONTAMINATION BY ORGANIC CONTAMINANTS

Modeling using acceptable hydrologic methods has shown the potential for ground water pollution by organic contaminants. In particular, "Random Walk" simulations which include a retardation factor for sorption show levels of benzene exceeding standards at a distance from the source. Standards are exceeded at all discharges of five barrels per day and at most intermediate values of discharge down to one-half barrel per day. Other than dilution, the mechanisms of attenuation (volatilization, sorption, evaporation and biodegradation) have not been shown to be effective at all places under all circumstances. This is especially true for biodegradation which requires the presence of oxygen or long adaptation times to be effective. Therefore, the potential for ground water contamination by volatile organic hydrocarbons cannot be discounted. Given the toxicity of the contaminants and health concerns related thereto, and the concommitant potential for ground water contamination, the Commission should protect ground water by limiting discharges of produced water into unlined pits to no more than one-half barrel per day. Since ancillary pits receive similar fluids, especially in the event of separator malfunction, or where separators are not present, discharges to such pits should also be limited to one-half barrel per day.

II. TESTIMONY IS CLEAR AS TO THE IMPORTANCE OF THE VADOSE ZONE AS AN ATTENUATION MECHANISM

Witnesses for both sides testified as to the importance of the vadose zone in preventing contamination of ground water from organics in the produced water discharge. Mr. Boyer mentioned in his direct testimony that the likelihood of volatilization is greater in the vadose zone than in the ground water (Boyer, Tr. 2/20/85, p. 84).

In their direct testimony, industry representatives also referred frequently to the importance of the vadose zone as a major attenuation mechanism. Dr. Schultz discussed the importance to organic volatilization of partially saturated flow and the air space in the pores. He testified that aromatics are volatilized into the soil gas and transferred to the atmosphere. This is one of the removal mechanisms of attenuation (Schultz, Tr. 4/3/85, p. 152-155). To have soil gas aid in volatilization, unsaturated or partially saturated flow must occur in the vadose zone (Schultz, Tr. 4/3/85, p. 169, 180-182).

Dr. Miller's testimony also emphasized the importance of the vadose zone. The percentage rate of aromatic hydrocarbon degradation in the unsaturated zone is eight times greater than in saturated material (Miller, Tr. 4/22/85, p. 23). Miller felt that there was concern if the pit was in ground water since degradation processes that occur in the unsaturated zone would not be present to provide adequate safety to ground water quality (Miller, Tr. 4/22/85, p. 68).

Since benzene and toluene are most rapidly degraded under aerobic conditions (Miller, Tr. 4/22/85, p.22) and these conditions are most always prevalent in the vadose zone, this zone must be maintained. Miller also stated that recent studies indicate that toluene and possibly benzene degrade in anaerobic conditions (Miller, Tr. 4/22/85, p. 26). Nevertheless, the OCD staff maintains that aerobic conditions must be maintained to ensure maximum possible benzene mineralization.

The most active zone of degradation is immediately beneath the pit for a depth of about one foot, but that thickness has to be protected from ground water interception of the pit bottom (Miller, Tr. 4/22/85, Tr. p. 69). Under cross-examination, Dr. Miller stressed the importance of preserving the vadose zone between the pit and the water table, and stated that direct introduction of produced water into ground water utilized as drinking water would take away the safety margin and be the worst case (Miller, Tr. 4/22/85, Tr. pp. 94, 104-105).

Since pits are commonly five to eight feet in depth at well sites, depth to ground water would have to be deeper to provide the necessary vadose zone protection advocated by both OCD and industry witnesses. Seasonal ground water variations due to the rise in river levels, or percolating irrigation waters, can cause ground water levels to move up or down several feet during a year. Frequent large discharges can move unsaturated or partially saturated conditions toward saturation and cause ground water mounding. Therefore, to provide the necessary vadose zone protection, unlined pits in areas where the depth to ground water is less than ten feet should be prohibited. Since pits and trenches dug to bury piping require use of mechanical equipment, the presence of water at depths up to ten feet can be easily ascertained. Therefore this determination will not pose any additional burden on industry.

III. RESULTS OF TDS STUDY

Values of total dissolved solids (TDS) found in produced water in the San Juan Basin are generally less than in Southeast New Mexico. Modeling using the Random Walk program shows that discharges of 10,000 mg/l salts do not significantly increase TDS levels at low discharge volumes (OCD post hearing submittal 5/23/85). Discharge volumes of one-half bbl/day did not cause large increases for any of the simulations using the range of hydraulic conductivities found in alluvium in the area (25-2500 ft/day). Discharges of five barrels per day, however, caused unacceptable increases at all hydraulic conductivity ranges. The increases were judged unacceptable because the discharges would cause the NM WQCC ground water standard of 1000 mg/l TDS to be exceeded when added to existing concentrations in the vulnerable area. Intermediate discharge volumes at 10,000 mg/l TDS may or may not pose a problem depending on the availability of sufficient ground water flow to allow mixing and dilution.

Since the affect on ground water quality cannot be determined with sufficient accuracy without site specific hydrogeological information being available, the Commission should allow a maximum blanket discharge of up to one-half barrel per day to provide necessary ground water protection.

Since TDS is a composite of individual contaminants, some of which can cause health or other problems, limiting TDS discharges should also mitigate most problems caused by individual contaminants (i.e. chloride, sulfate, and others).

IV. THE VALIDITY OF THE HYDROLOGIC INVESTIGATION PERFORMED ON THREE PITS IN THE VULNERABLE AREA IS QUESTIONABLE

In his testimony, Mr. Hicks asserts that his studies of three well sites show that small volume discharges are not a threat to ground water. Even if the drilling and sampling results of the site investigations are assumed correct, these results should not be interpreted as being representative of the entire vulnerable area population of 1300 wells, or of the sample of 300 wells of Amoco and Tenneco. The reason is that these three locations were evaluated and chosen from a list of 21 sites. The 21 sites were chosen separately and apparently prior to the selection of the 50 to 60 wells chosen at random from the Amoco/Tenneco population of 300. Even though some of the 21 sites were also listed in the random selection of 50-60 wells, the selection of the 21 apparently was not random and cannot be considered a representative random sample (Hicks, Tr. 4/22/85, pp. 127, 130).

At the three monitoring sites selected, volumes of water produced were stated by Mr. Hicks as being three and four barrels per day for the Tenneco wells and one-fourth barrel per day for the Amoco well. Official OCD records (Form C-115) show, however, that the Tenneco sites in question <u>never</u> have produced water from any of Dakota, Mesaverde, and Chacra completion intervals. The Amoco well has OCD-reported volumes similar to the one-fourth barrel per day shown in the report. Therefore, if the volumes of water produced by the Tenneco wells and utilized in the Geoscience study are high and not representative of actual site discharges, this could explain the low values of benzene found in the pits and ground water. If this is the case, the modeling and conclusions presented by Mr. Hicks that wells discharging three to four bbls/day do not represent a hazard to ground water are completely invalid.

Mr. Hicks stated that Pictured Cliffs wells do not have produced water pits or separator pits since no water is produced (Hicks, Tr. 4/22/85, p. 136, and Exhibit 3). Review of OCD records show, however, that such wells represent about one-third of the 45 wells in the vulnerable area with production of five bbls/day or more of produced water. Therefore, they are an important factor contributing to water discharges in the vulnerable areas and cannot be ignored.

OCD SUMMARY

The following conclusions can be drawn from the testimony:

1. Certain aromatic organic contaminants (especially benzene) have high potential to contaminate ground water when discharged even in small volume quantities with produced water. The mechanisms of attenuation, especially biodegradation, cannot be counted on to provide protection at all times and in all locations and situations. Therefore blanket small volume discharges not exceeding one-half barrel per day should not be allowed to unlined produced water and ancillary pits.

2. Both OCD and industry testimony stressed the importance of the vadose zone in attenuation of the organic contaminants. Especially necessary is the presence of air in pore spaces to allow volatilization and biodegradation to occur. To provide the necessary buffer zone, and because pit depths are on the order of five to eight feet, discharges to unlined pits should be prohibited where ground water is at a depth of ten feet or less.

3. From the standpoint of total dissolved solids, discharges of five barrels per day at concentrations of

10,000 mg/l TDS also cause the New Mexico Water Quality standard to be exceeded. Limiting the discharge to unlined pits to one-half barrel per day will provide the necessary TDS protection and mitigate deleterious effects of other contaminants which are TDS components.

4. The study conducted by GeoScience Consultants is inconclusive because the three sites chosen for intensive study cannot be considered representative of vulnerable area conditions, and because of discrepancies in the volumes of water actually discharged at two of the sites.

Since the Oil and Gas Act requires the reasonable protection of fresh water from contamination by such activities, the limits recommended by the Division in its proposed order will provide such protection and are necessary and prudent.

CONCLUSION

The opponents to regulation of produced water disposal have made much of the fact that no water wells have been proven to have been contaminated by produced water. Tenneco, in its Memorandum of Law filed herein even goes so far as to assert that "...we have yet to experience the first confirmed case of contamination of ground water by the use of unlined surface production pits" (at p.24). Clearly, the facts in this case contradict this statement. Tenneco's own witnesses showed concentrations of benzene in ground water underlying surface pits. (Geoscience Exhibit 3). In fact, one of Mr. Hick's own samples exceeded ground water standards for benzene as set by the New Mexico Water Quality Control Commission (Geoscience, Exhibit 3, relating to Tenneco's Eaton A-1E well).

The mandate of the Commission is not to protect only existing water wells. It is to protect all fresh water resources with potential for future use. Other states have not been so reticent or tardy in protecting water resources. Both Oklahoma and Texas have had "no-pit" rules for many years. Yet the opponents of regulation of produced water in New Mexico vow a fight to the finish. Do they really believe that New Mexico regulators are so uninformed and intimidated as to continue to permit such an obviously outdated practice as totally unregulated surface disposal of produced water? Oklahoma has had a "no-pit" order since 1969. Disposal in unlined pits is allowed only upon a conclusive showing that surface or subsurface water will not be polluted (See Oklahoma regulations attached hereto). Such a burden is almost impossible to meet. Consequently, surface disposal is almost non-existent. Texas has a similar rule. (See Texas Railroad Commission Regulations attached hereto).

The producers make many arguments as to why no rule should be adopted. Tenneco claims that imposition of a "no-pit" rule would entail an unconstitutional taking of private property because in the past it has operated its wells without having to line pits and no regulation to date has referenced the possibility that at some future time pits might be required to be lined. (Tenneco Oil Company's Memorandum of Law and Arguments, p. 18). This argument is patently ridiculous. Simply because an entity has not been required to take preventative measures in the past does not mandate that, given proper notice and due process, it cannot be required to take those measures at a future time. If Tenneco's position were the law, virtually no advance in human health and safety or environmental regulation would be possible because government would be required to absorb the entire cost of such improvements through legal proceedings claiming unconstitutional takings.

The water resources of New Mexico are a scarce and valuable natural resource, much like petroleum. And while the cost of the two is not now comparable, if fresh water resources are not protected for future use, water may eventually come too expensive for many uses.

In New Mexico, approximately 95% of water used for domestic purposes is ground water. This is due primarily to the fact that such little surface water exists in comparison to other areas of the country. Because we are so dependent upon ground water, it is necessary that adequate measures be taken to protect existing supplies. The staff of the OCD believes that its recommendations regarding disposal of produced water are best suited to guarantee protection of these fresh water resources. We have presented a case which demonstrates that produced water, which contains toxic contaminants, is now disposed of in Northwest New Mexico by being dumped into unlined surface pits. Much of this water is absorbed into the ground where it eventually reaches and combines with ground water. In small quantities, this degrades existing fresh water supplies. In larger quantities, it leads to contamination.

The Commission has an obligation to protect fresh water resources. In order to carry out this duty, the Commission must prohibit unregulated disposal of produced water except in quantities of less than one-half barrel. Any other action would be to ignore the evidence produced at the hearings in this matter, including that of the opponents to regulations.

JEFF TAYLOR
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RECOMMENDATIONS OF THE WATER STUDY COMMITTEE

Before the Oil Conservation Division (OCD) of the Energy and Minerals Department of the State of New Mexico.

The following is presented in the matter of the hearing called on June 7, 1984 by the OCD to consider case No. 8224, the Prohibition of Disposal of Produced Water on the Surface of the Ground, in Any Water Course, or in Any Body of Water in McKinley, Rio Arriba, Sandoval, and San Juan Counties, New Mexico; which hearing was continued to an indefinite date.

Background

A meeting was held in Santa Fe, New Mexico on July 18, 1984 by OCD to allow all parties interested in case No. 8224 to discuss the case and provide a forum for directing any studies which would be conducted. A committee was subsequently appointed by R. L. Stamets to evaluate the impact of oil and gas operations on the ground and surface waters in the northwest New Mexico area. The committee was divided into short-term and long-term groups.

The short-term committee goals were specified as:

1. Determine what constitutes a vulnerable aquifer;
2. map the vulnerable aquifer;
3. attempt to determine the probability unlined pits may have in contaminating the vulnerable aquifers; and
4. prepare a recommendation to the OCD for an order which will address the problems identified by the committee.

Meetings were held on August 2, October 17, November 29, and January 9 of the short-term committee with other task group mapping sessions and field tours held as needed. The meetings provided discussion of the goals, preparation of a definition of the problem and the preparation of a map and various recommendations to the OCD.

Report of Short-Term Water Study Committee

It has been determined that in San Juan, Rio Arriba, McKinley and Sandoval Counties in the State of New Mexico, there are areas where ground or surface water may be vulnerable to contamination by oil and gas production operations. Those vulnerable areas include areas where the depth to ground water is less than 50 feet, the aquifer containing the ground water consists of unconsolidated alluvial fill, and the water is presently used for or could reasonably be presumed to be used for municipal, domestic, industrial, agricultural or stock watering purposes.

Areas were excluded from the short-term committee's concern because of one or more of the following factors:

1. There are few if any oil or gas operations in the area;
2. there are few if any water wells in the area; and/or
3. water is non-existent or deeper than 400 feet.

The vulnerable area as defined below was delineated using available water well data, 100 yr. flood hazard maps, topographic maps. The vulnerable area was defined as that area which lies over or adjacent to a vulnerable aquifer and includes those portions of the San Juan, Animas, and La Plata River valleys which are bounded by the topographic line on either side of the river that is 100 vertical feet above the river channel measured perpendicularly to the river channel. Special areas were also identified which fell outside of the "vulnerable area". These areas were listed because water well records indicated water production from less than 50'.

RECOMMENDATIONS

It is hereby recommended that the NMOCD consider the following in promulgating an order for the regulation of the use of pits in the vulnerable areas of northwestern New Mexico.

A. DEFINITIONS:

1. Aquifer: An aquifer is a saturated permeable geologic unit (a geological formation, group of formations, or part of a formation) that can transmit significant quantitites of water under ordinary hydraulic gradients.

   For purposes of this definition, the word significant means that the water from the aquifer is used for or may reasonably be presumed to be usable for municipal, industrial, domestic, agricultural, or stock watering purposes.

2. Vulnerable Aquifer: For the purpose of this order the following are defined as vulnerable aquifers:

   a) Unconfined aquifers that are less than 50 feet from the surface, or

   b) Unconfined aquifers in floodplain areas, or

   c) Aquifers in unconsolidated materials.

3. Vulnerable Area: An area which lies over or adjacent to a vulnerable aquifer and is defined as an area within the river valleys of the San Juan, Animas, and La Plata Rivers which is bounded by the topographic line on either side of the river that is 100 vertical feet above the river channel measured perpendicularly to the river channel.

4. Special Areas: Areas outside of the vulnerable area in which ground water is subsequently found to be within 50' of the ground surface. Special areas presently identified are listed below:

   a) Sections

T28N-R 8W, Section 17	T30N-R12W, Section 13
T28N-R11W, Section 18	T30N-R12W, Section 15
T28N-R15W, Section 26	T30N-R12W, Section 27
T29N-R10W, Section 16	T30N-R12W, Section 33
T29N-R12W, Section 24	T30N-R13W, Section 1
T29N-R18W, Section 17	T30N-R15W, Section 6
T29N-R19W, Section 23	T30N-R15W, Section 16
T29N-R19W, Section 30	T30N-R15W, Section 21
T30N-R10W, Section 5	T30N-R16W, Section 29
T30N-R11W, Section 3	T30N-R19W, Section 34
T30N-R11W, Section 7	T31N-R10W, Section 13
T30N-R11W, Section 8	T31N-R11W, Section 35
T30N-R11W, Section 10	T32N-R10W, Section 10
T30N-R11W, Section 19	T32N-R11W, Section 23
	T32N-R12W, Section 25

   b) Areas that lie between the rivers and the ditches mentioned below are also special areas:

      Highland Park Ditch
      Hillside Thomas Ditch
      Cunningham Ditch
      Farmers Ditch
      Halford Independent Ditch
      Citizens Ditch
      Hammond Ditch

5. Produced Water Pit: That pit which receives water produced from primary separation in conjunction with the production of crude oil and/or natural gas whether or not such pit is located at the site of production.

6 Ancillary Pit: Those pits not receiving fluids from primary separation including but not limited to dehydrator pits, tank drain pits, pipeline drip collector pits, blowdown pits, and compressor scrubber pits. Examples are listed below:

   a) Dehydrator Pit: Those pits which normally receive produced water only from the dehydration unit.

   b) Blowdown Pit: Those pits which receive liquid only when a well is blown down.

   (c) Tank Drain Pit: Those pits which receive water that is drained from a production storage tank.

d) Pipeline Drip Collector Pit: Those pits which receive liquids which accumulate in gas pipelines.

e) Compressor Scrubber Pit: Those pits which receive liquids at the compressor suction in event of primary separator failure.

B. PROHIBITIONS AND EXEMPTIONS

Disposal of produced water or fluids produced in connection with the production of oil and natural gas, or both, in unlined pits is prohibited, except for disposal of produced water as described herein:

1. Pits lying outside vulnerable or special areas are exempt from this order.

2. Ancillary pits within vulnerable or special areas to which the volume of water discharged is no greater than ___*___ barrel per day are exempted from this order except where the depth to ground water is less than ___*___ feet in which case all unlined pits are prohibited.

3. Any pits, ponds, lagoons, or impoundments resulting from activities regulated by a discharge plan approved and permit issued by NMOCD or NMEID under Water Quality Control Commission Regulations authorized under the New Mexico Water Quality Act.

4. Any pits, ponds, lagoons or impoundments resulting from activities regulated by a RCRA or NPDES permit issued by NMEID or EPA under RCRA or NPDES regulations authorized under the Resource Conservation and Recovery Act, New Mexico Hazardous Waste Act, Clean Water Act or Safe Drinking Water Act.

5. Any pits, ponds, lagoons or impoundments resulting from activities regulated by a mining plan approved and permit issued by the New Mexico Coal Surface Mining Commission under the authority of the Surface Mined Lands Reclamation Act.

C. PERMITS

The purpose of this subsection is to allow for the disposal of ___*___ barrel per day or less of produced water into unlined pits, based on the depth to ground water beneath such pits and provided that such pits meet the quality and soil characteristics criteria as set forth below.

Upon application to and approval by the NMOCD, unlined produced water pits and those ancillary pits which receive greater than ___*___ bbl./day that are within the vulnerable area may be permitted under this order based on the following criteria and after satisfying either a. or b. below.

Depth to Groundwater	Maximum Volume For an Unlined Pit
*	*

---

* The committee could not reach an agreement on allowing the continued use of unlined pits (in the vulnerable area) for small volumes of produced water. All references to water volume or depth to groundwater have intentionally been left blank.

---

a) Quality Permit: If the operator can demonstrate that the quality of either existing uncontaminated ground water, or produced water is such that the introduction of produced water will not cause degradation of the ground water, the unlined pit may be permitted upon application to the NMOCD. The demonstration must include analysis for organic and inorganic parameters as required by the Division.

b) Soil and Geologic Characteristics Permit: If the operator can demonstrate through the use of standard soil analysis parameters (e.g. percolation tests, infiltration rates, particle size/distribution, etc.) that the existing soil and/or underlying geologic stratum exhibit low permeabilities such that the produced water will not cause degradation of the ground water, the unlined pit may be permitted upon application to the NMOCD. This can be accomplished on an areal or site specific basis.

D. COMPLIANCE SCHEDULE

After 18 months of the date of this order, the use of unlined pits for the treatment, storage or disposal of produced water within vulnerable or special areas defined herein is prohibited except by permit as defined above. Partially or fully buried tanks and lined pits installed shall be to NMOCD specifications.

CONCLUSION:

The committee feels that these recommendations will provide the basic structure for an order from the OCD which will provide some immediate protection to vulnerable ground and surface waters in northwest New Mexico. It should be understood that the committee worked essentially with limited data available in the records of various agencies, and that to date only limited evidence of contamination of these waters was found. Hydrologic mechanisms exist for transporting contaminants into the ground water. These mechanisms also provide some attenuation of such contaminants before reaching the ground water. The ultimate disposition of various liquids deposited into unlined pits and a determination of the probability an unlined pit may have in contaminating vulnerable aquifers depend on the hydrological, geological, soil and geochemical conditions at the individual pit sites. Shallow ground water conditions and permeable surface materials present in these vulnerable areas provide a contamination risk from discharges of produced water. Until and unless quantification of such risks becomes possible, protection of ground water for uses defined herein must be based on a rational but conservative methodology, keeping in mind the need to apply limited resources to address the potential serious problems first.

1/18/85:1410a

NMOCD CASE #8224

GIANT INDUSTRIES, INC. STATEMENT

Giant Industries, Inc. has been participating in the process of developing recommendations for a draft order and establishing the criteria which should be considered in the development of such an order. Giant has been represented on the committee by Geoscience Consultants, Ltd., a professional hydrogeologic and engineering firm specializing in ground water quality assessment and waste management. During the meetings that have taken place over the last 8-10 months, regulatory agencies, industry and environmental groups have attempted to arrive at a consensus that protects ground water and does not place an undue burden on the regulated industry.

Giant Industries, Inc. strongly supports the January 18, 1985 recommendations of the short-term study group on all of the points on which the committee was in agreement. This includes the definitions and prohibitions and exemptions on which the committee agreed and which are listed below:

PROHIBITIONS AND EXEMPTIONS

Disposal of produced water or fluids produced in connection with the production of oil and natural gas, or both, in unlined pits is prohibited, except for disposal of produced water as described herein:

1. Pits lying outside vulnerable or special areas are exempt from this order.

2. Any pits, ponds, lagoons, or impoundments resulting from activities regulated by a discharge plan approved and permit issued by NMOCD or NMEID under Water Quality Control Commission Regulations authorized under the New Mexico Water Quality Act.

3. Any pits, ponds, lagoons or impoundments resulting from activities regulated by a RCRA or NPDES permit issued by NMEID or EPA under RCRA or NPDES regulations authorized under the Resource Conservation and Recovery Act, New Mexico Hazardous Waste Act, Clean Water Act or Safe Drinking Water Act.

4. Any pits, ponds, lagoons or impoundments resulting from activities regulated by a mining plan approved and permit issued by the New Mexico Coal Surface Mining Commission under the authority of the Surface Mined Lands Reclamation Act.

In addition, based on an analysis of the available data, it is the professional opinion of hydrogeologists, chemists and engineers at Geoscience that a low volume exemption within the vulnerable area of approximately 5 bbls/day should be permitted at the present time. This opinion is based on existing Federal practices and an analysis of the available data on produced water quality, site conditions at produced water pits, soils data, ground water hydrology and the data presented at the initial hearing.

The long-term committee will examine this question in greater detail and attempt to more accurately determine the volume of produced water which could be discharged without presenting a threat to ground water quality in the vulnerable area. This work by the long-term committee could be used to modify the amount of a low volume exemption without the unnecessary and costly burden on industry that a total ban would cause. In addition, Giant strongly supports the establishment of a mechanism by which producers could permit an unlined pit where produced water quality or site-specific conditions preclude a threat to ground water.

Giant looks forward to continuing participation on the long-term committee and congratulates NMOCD on their foresight in involving all the interested parties in the regulatory development process.

CASE NUMBER 8224
POST HEARING DOCUMENTS
REQUESTED BY
NMEID AND NMOCD

May 1985

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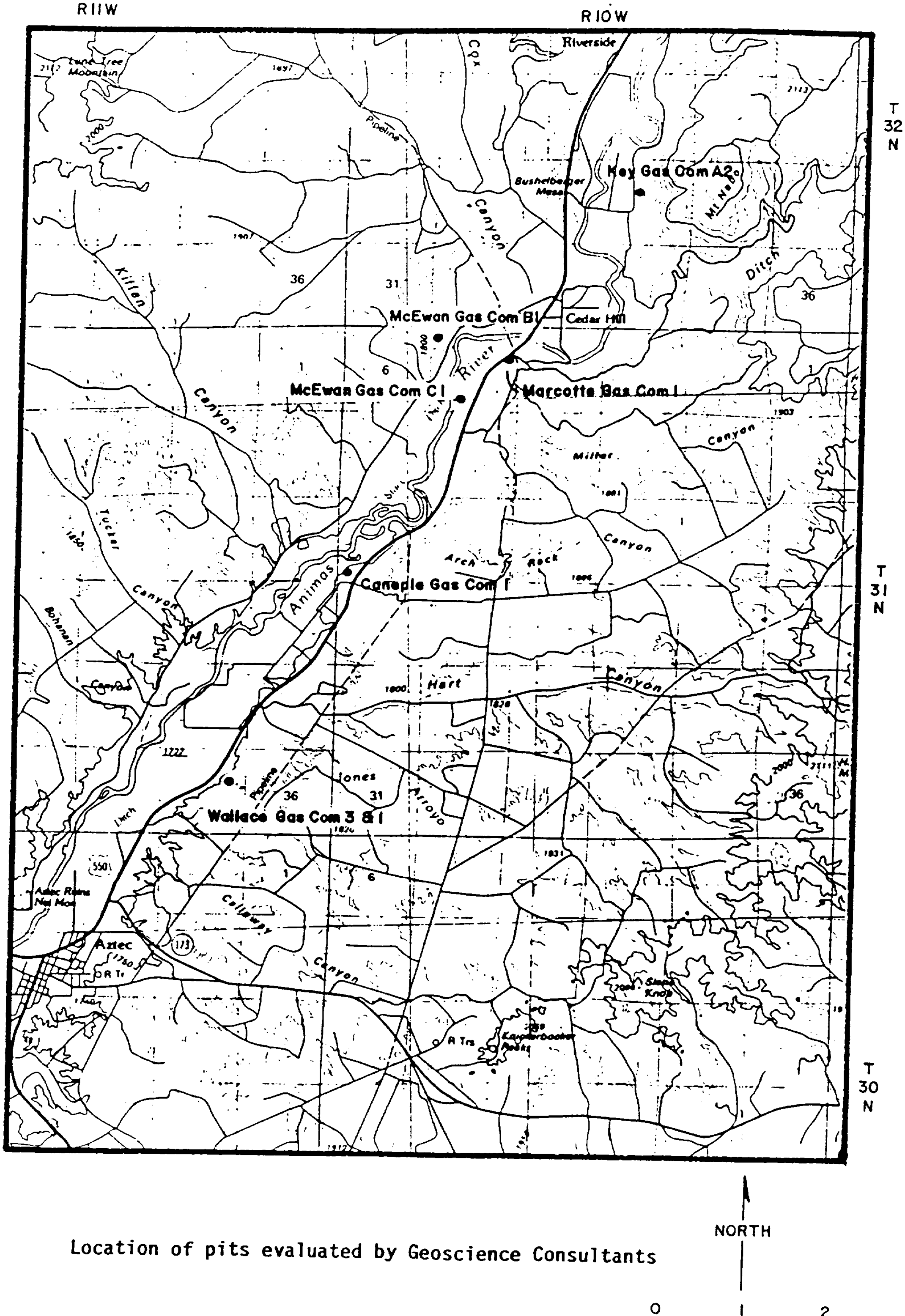
TABLE OF CONTENTS

Section 1.0

1.0 FIELD DATA FORMS, PHOTOGRAPHS AND HYDROGEOLOGIC NOTES

All field forms and accompanying photographs for the well sites visited in the random study of the vulnerable area are enclosed. The visual inspection employed the grain-sized versus hydraulic conductivity graph from Freeze and Cherry, 1979 Table 1-1. This section enclosed all of the field notes from the random study of well sites in the vulnerable area.



Location of pits evaluated by Geoscience Consultants

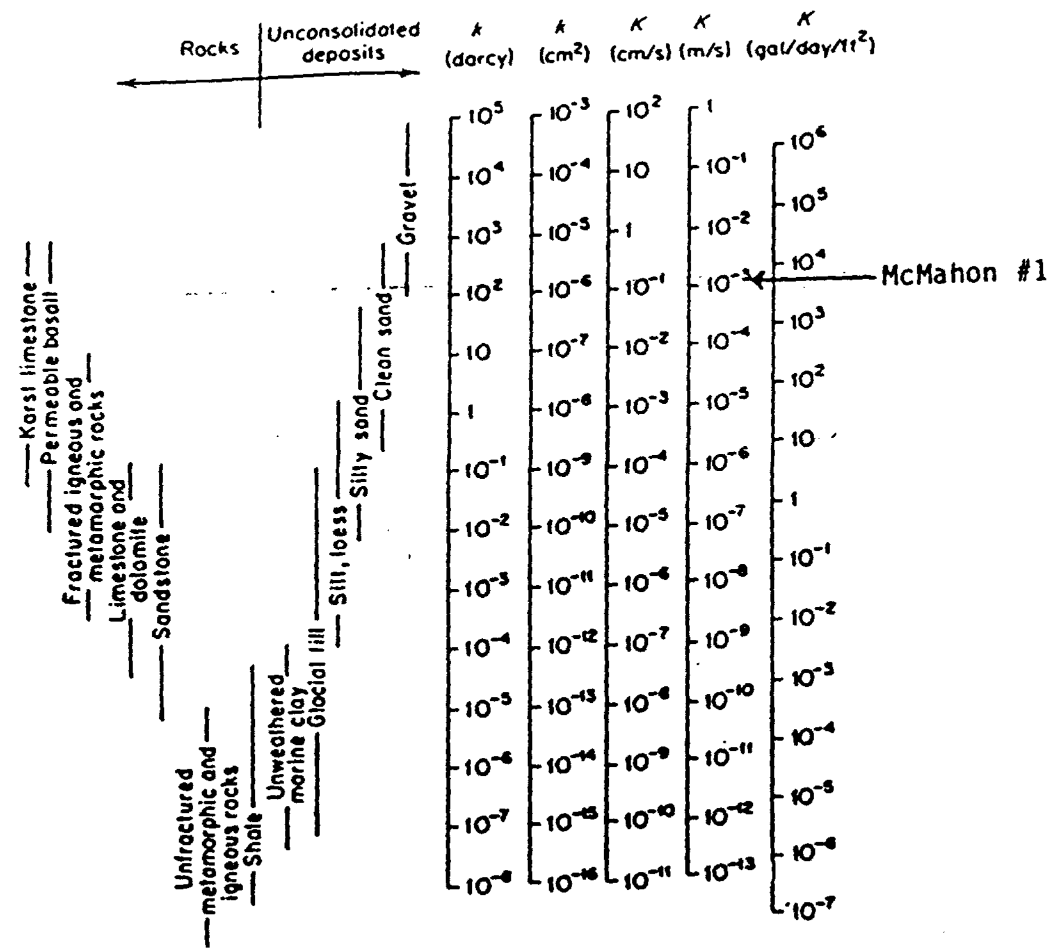


TABLE 1-1

RANGE OF VALUES OF HYDRAULIC CONDUCTIVITY AND PERMEABILITY (Freeze and Cherry, 1979)

WELL SITES INVESTIGATED IN GEOSCIENCE CONSULTANTS, LTD FIELD STUDY

DETAILED FIELD STUDY SITES

McCoy "D" 1
Eaton A-1E
Payne 1

RANDOM SAMPLING FIELD INVESTIGATION OF PRODUCED WATER PITS

1.1 SAN JUAN RIVER dh/dl = 0.002 - 0.003

HIGH HYDRAULIC CONDUCTIVITY CASES (10,000 gpd/ft^2)

- GCU 202 Roll 1 - Frame # 1, 3, 4
- Totah Vista 1 Roll 2 - Frame # 1, 2
- GCU 170 E Roll 3 - Frame # 17, 18
- GCU "I" 181 E Roll 3 - Frame # 15, 16

MEDIUM HYDRAULIC CONDUCTIVITY CASES (1,000 - 5,000 gpd/ft^2)

- Gerk B 1 M Roll 4 - Frame # 1, 2
- Archuleta A3 No Photo Available
- Madsen 1 Roll 1 - # 8, 9
- Armenta F1 Roll 4 - Frame 6, 7, 8
- Abrams L1 Roll 4 - Frame 5
- Sullivan A1 Roll 4 - Frame # 13, 14, 15
- GCU 153 E Roll 3 - Frame # 10, 11
- GCU 179 E Roll 1 - Frame # 5, 6, 7

LOW HYDRAULIC CONDUCTIVITY CASES (10 - 100 gpd/ft^2)

- GCU 169 E Roll 3 - Frame # 19, 20
- Romero A1 Roll 4 - # 9
- Ulibarri 1A Roll 5 - # 1, 2

1.2 ANIMAS RIVER dh/dl = 0.004

HIGH HYDRAULIC CONDUCTIVITY CASES (10,000 gpd/ft^2)

- Marcotte 1 Roll 2 - Frame # 17

MEDIUM HYDRAULIC CONDUCTIVITY CASES (1,000 - 5,000 gpd/ft^2)

No cases observed

LOW HYDRAULIC CONDUCTIVITY CASES (10 - 100 gpd/ft^2)

No cases observed

1.3 VALLEY SIDE SLOPES AND TRIBUTARIES dh/dl = 0.01

HIGH HYDRAULIC CONDUCTIVITY CASES

- McCoy D 1 E Roll 2 - Frame # 5, 6, 7

MEDIUM HYDRAULIC CONDUCTIVITY CASES

- Key A2 Roll 2 - Frame # 18, 19, 21
- o Florence 124 (630 days) No photo available
- o Florence 124 (1080 days) No photo available
- Florence 9 Roll 6 - Frame # 16, 17
- GCU 169 Roll 3 - Frame # 20
- Caneple 1 Roll 2 - Frame # 9, 10, 11, 12

LOW HYDRAULIC CONDUCTIVITY CASES

- GCU 150 Roll 3 - Frame # 13, 14
- Martinez F1 Roll 1 - Frame # 10, 11
- o Valdez AIE No photo available
- Pollock E1 Roll 4 - Frame # 10
- Black 1 Roll 4 - Frame # 12
- Irwin 1E Roll 2 - Frame # 3
- Heath G 1 Roll 5 - Frame # 15

1.4 BEDROCK MESAS CASES - Produced water can not enter ground water

- Howell 2A Roll 3 - Frame # 5, 6
- McEwen B1 No Photo Available
- Heath WD A 3X Roll 5 - Frame # 17
- Linda Nye 1 Roll 5 - Frame # 7, 8
- Heath Gas COM H 1 Roll 5 - Frame # 14
- Nye Gas COM B 1E Roll 1 - Frame # 12, 13, 14
- Heath WD A 10 Roll 5 - Frame # 16
- Heath WD A5 Roll 5 - Frame # 18, 19
- Florence 32 Roll 3 - Frame # 7, 8, 9
- Florence 111 Roll 3 - Frame 2, 3, 4
- Jacquez 1A Roll 5 - Frame # 9, 10
- Sandoval A 1 R Roll 5 - Frame # 5, 6
- Pritchard 1A Roll 3 - Frame # 1

1.5 PICTURED CLIFFS CASES - No water produced, no production equipment

- McEwen Gas COM C 1 Roll 2 - Frame # 14, 15, 16
- Wallace Gas COM 3 and 1 Roll 2 - Frame # 8
- o Hamner 9 No photo available
- o Sullivan, Bruce 1 No photo available
- o Sullivan, Earl B, 2 No photo available
- o Ulibarri Gas COM 2
- Likins Gas COM B 1 Roll 4 - Frame # 3
- o Heath Gas COM F 1 No photo available
- Elliott Gas COM N 1
- Jacquez Gas COM C 1 Roll 1 - Frame # 15

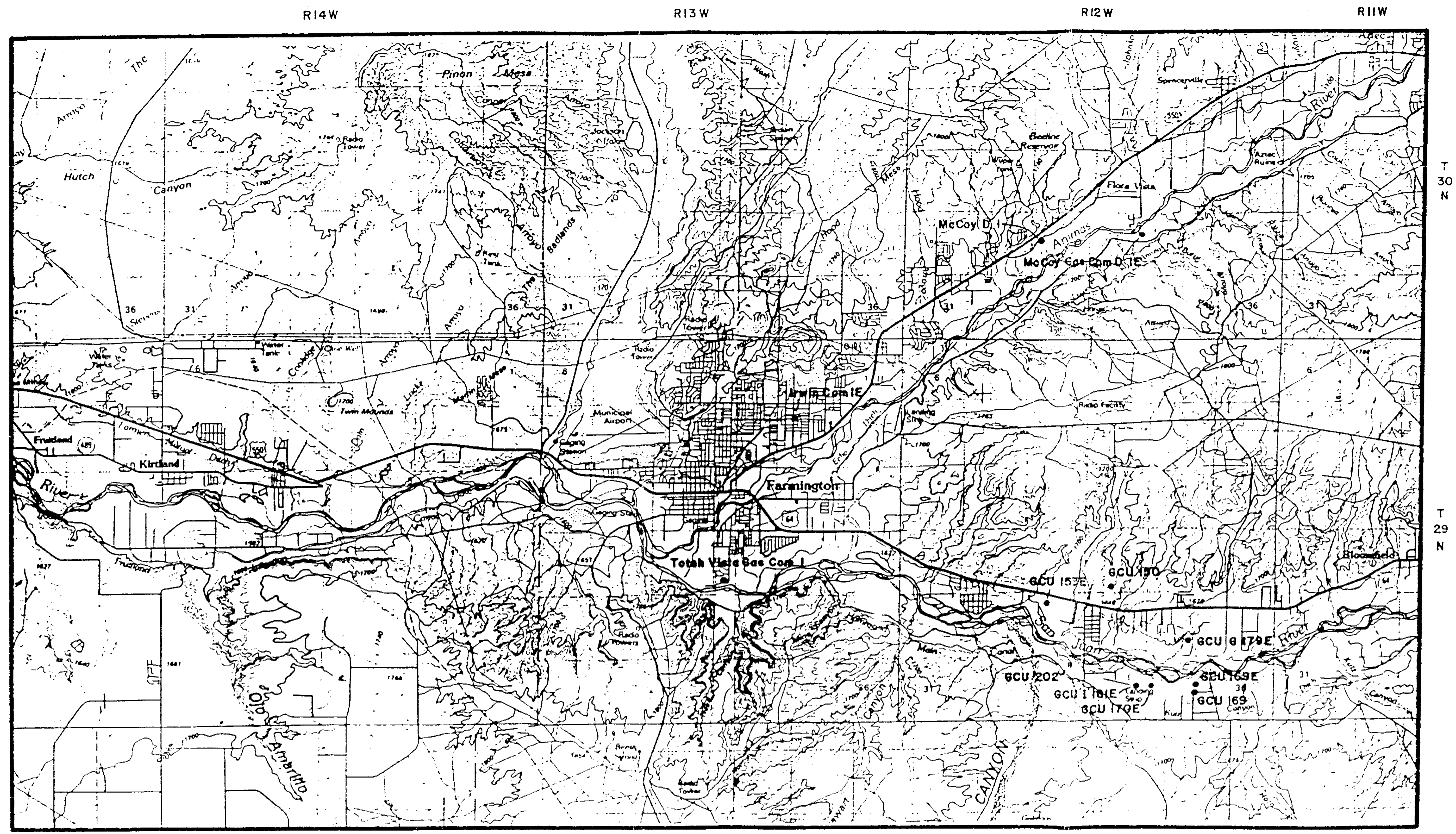
WELL SITES VISITED WHICH WERE NOT PART OF
RANDOM SAMPLE

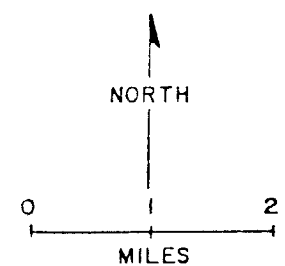
Sullivan Frame A1
Linda Nye 1
Sullivan Frame AIE
Jacquez 2A
Sullivan B1
Valdez B1

Linda Nye 1A
Archuleta 1
Jacquez 2
Jacquez 1M
Jacquez 3

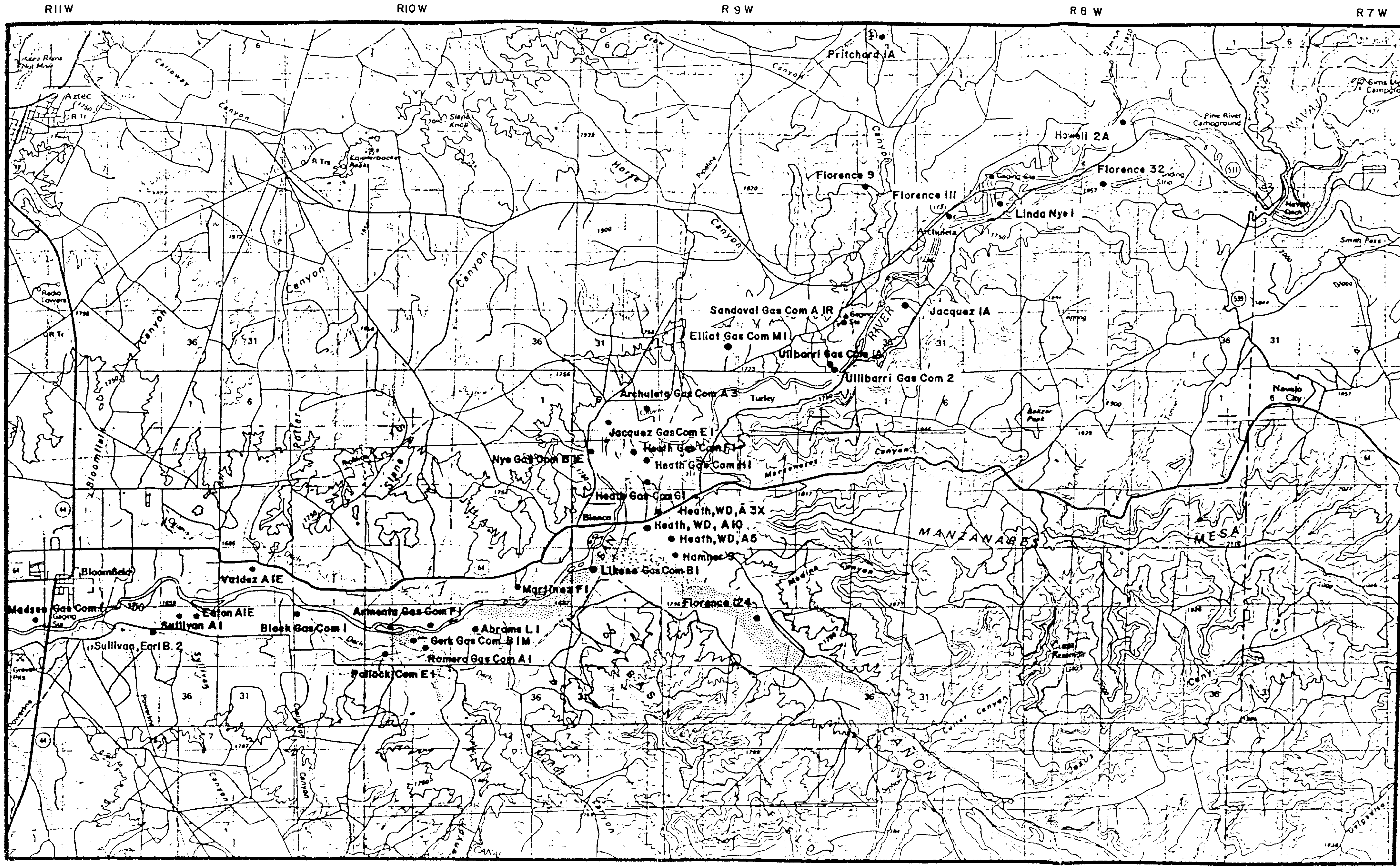
SAN JUAN RIVER

HIGH HYDRAULIC CONDUCTIVITY CASES





Location of pits evaluated by Geoscience Consultants



Location of pits evaluated by Geoscience Consultants

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	NWNE 33	29N	12W

WELL NAME GCU #202

Drainage Basin:

San Juan La Plata Animas other:

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other:

Barrels Water/Day Produced: 0.1

Estimated Hydraulic Gradient: 0.003

Estimated Hydraulic Conductivity: 10^3 - 10^4

Formation/Grain Size of Unsaturated Zone:

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: 6-10

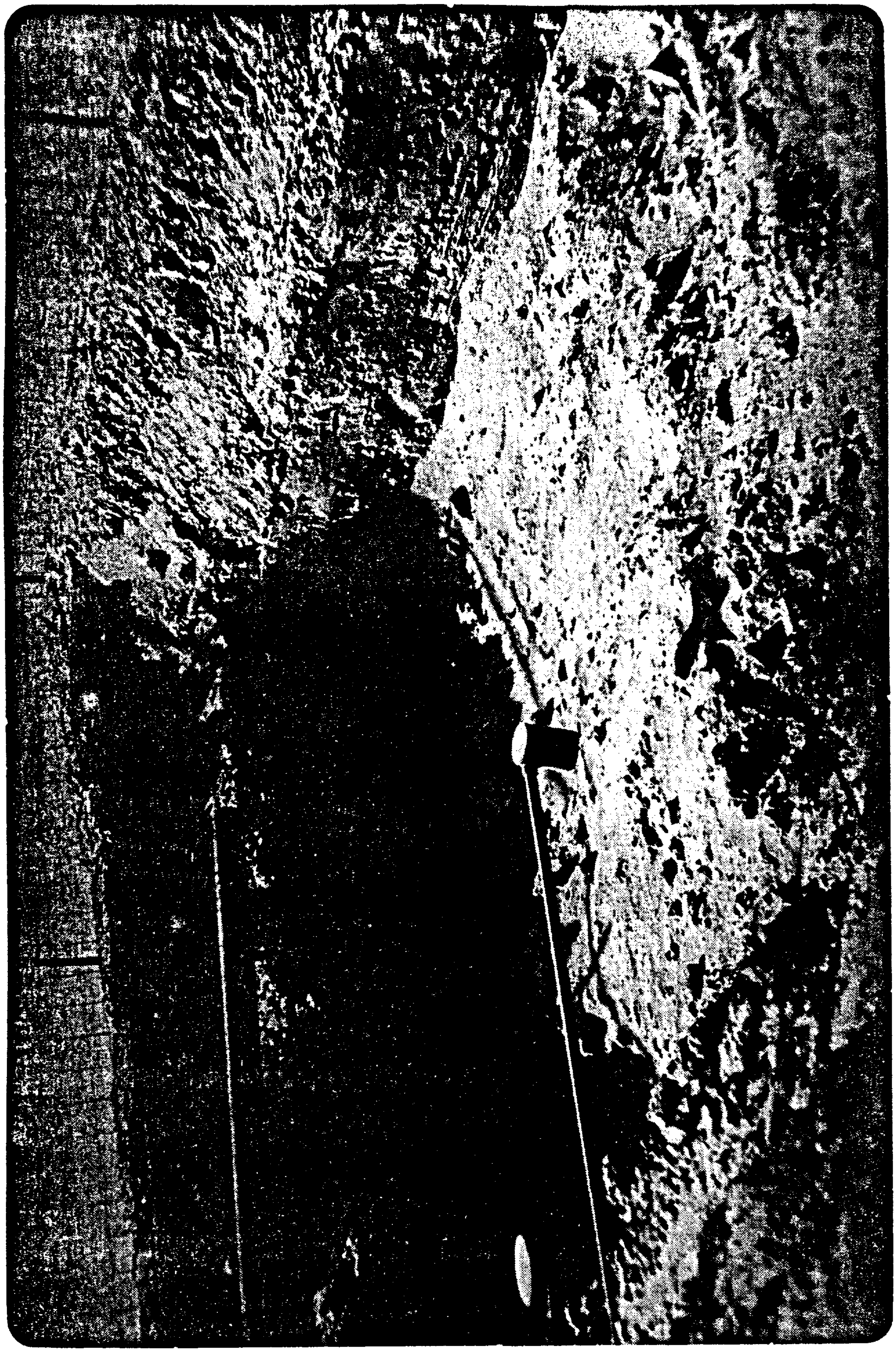
Pit Description Dry

Standing Water Estimated Depth: 0.25

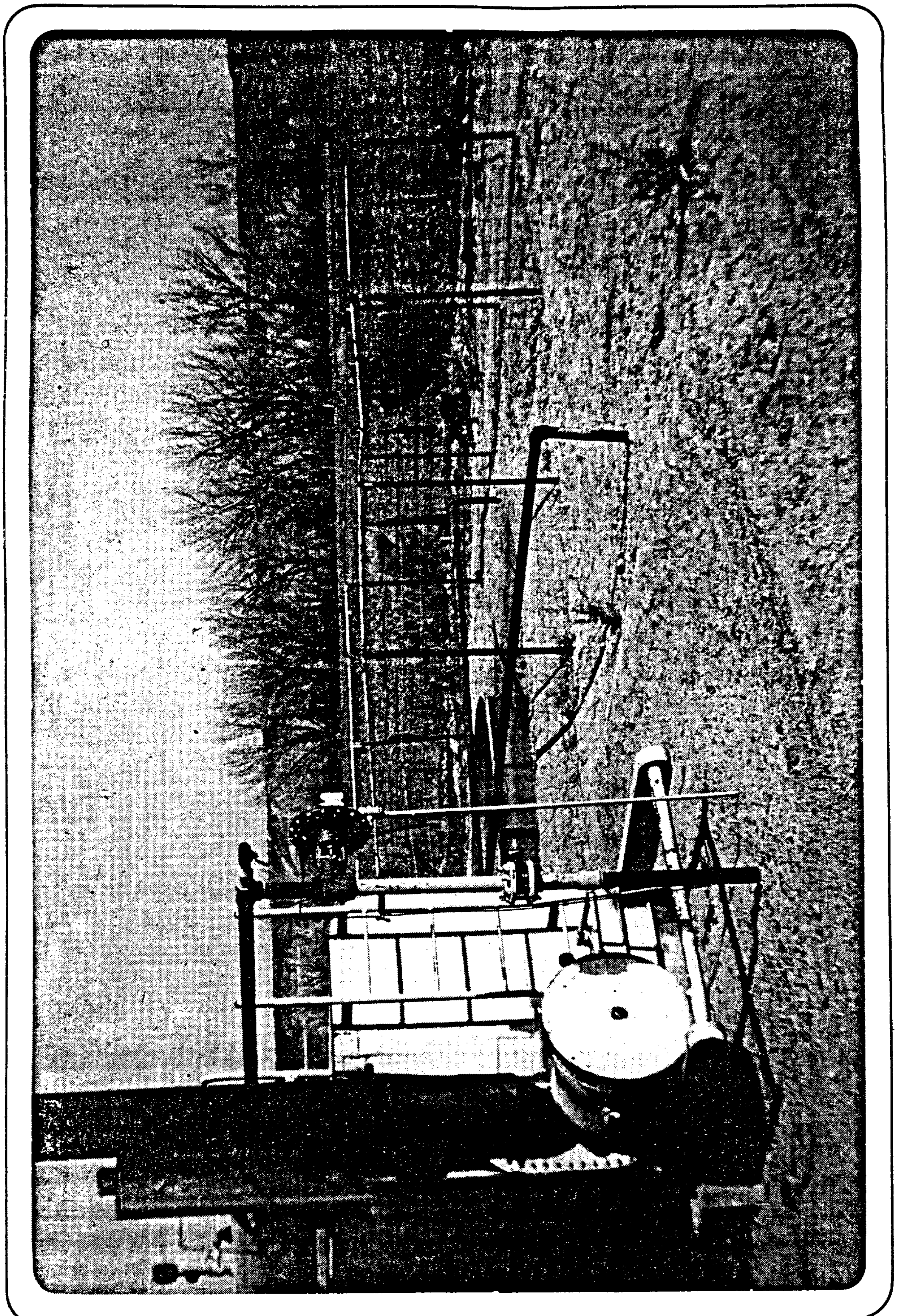
Photographs of Site: 0-4 EPNG EARTH PIT SHOWING FORMATION, LINED PIT

Producing Formation: BASIN DAKOTA

Comments: LINED PIT N SIDE RIVER



GCU 202 Roll #1 Slide 1



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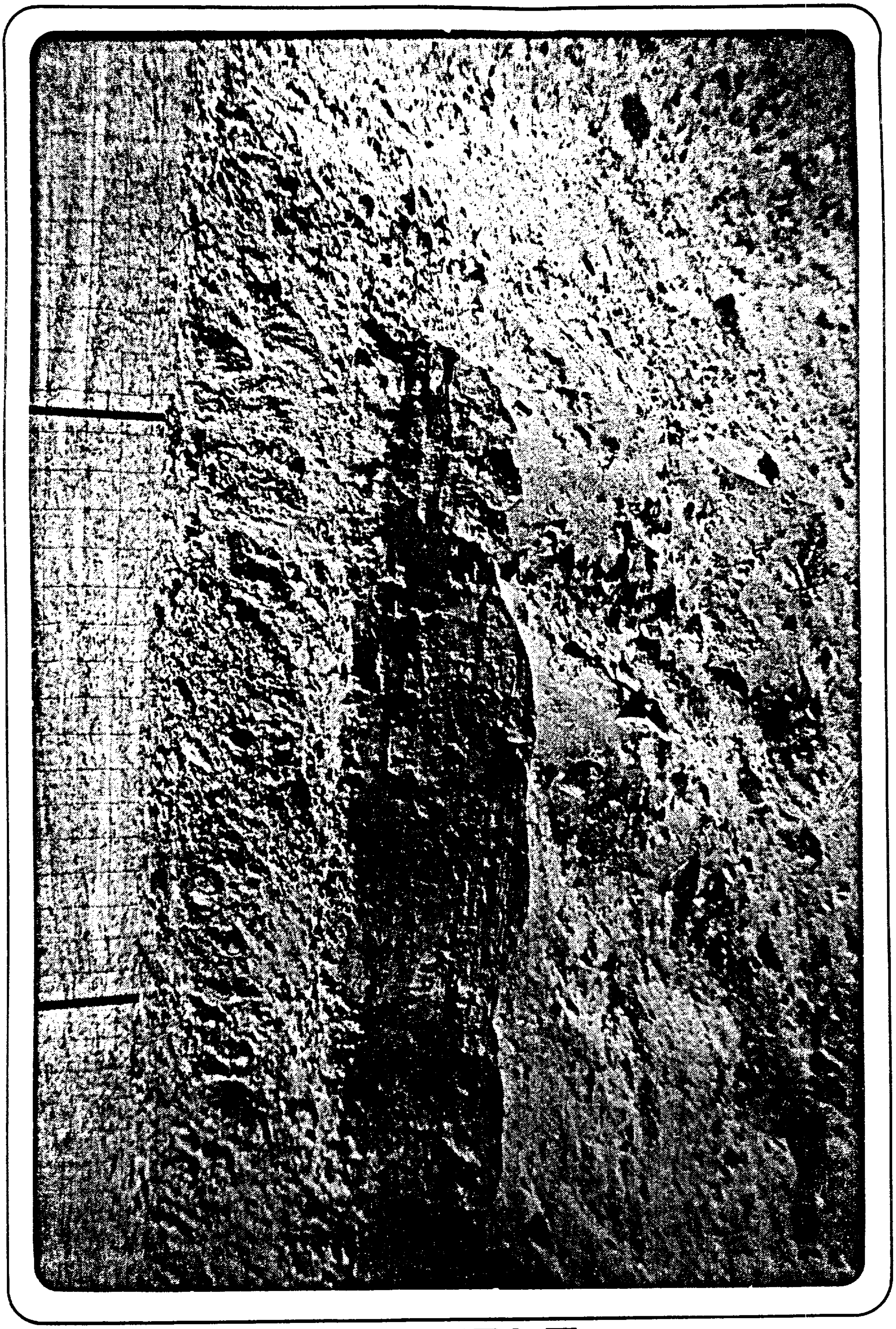

GCU 202 Roll #1 Slide 4

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Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	SW SW 22	29N	R13W

WELL NAME TOTAH VISTA GAS COM #1

Drainage Basin:

San Juan La Plata Animas other: ______

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other: ______

Barrels Water/Day Produced: — — PIT IS FULL OF GROUND WATER 0.02

Estimated Hydraulic Gradient: RIVER GRADIENT 0.003

Estimated Hydraulic Conductivity: 10^4 GPD/FT^2

Formation/Grain Size of Unsaturated Zone:

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: 1 1/2'

Pit Description Dry

Standing Water Estimated Depth: 1'

Photographs of Site: #1 PIT #2 EDGE OF PIT WELL SITE & RIVER IN BACK

Producing Formation: BASIN DAKOTA

Comments: ~~#~~ GRAVEL QUARRY 100' AWAY. BLOW SAND/OVERBANK SANDS AND VERY COARSE 3/4' GRAVEL AQUIFER.

4/10/85 PTM

TOTAH VISTA 1 Roll #2 Slide 1

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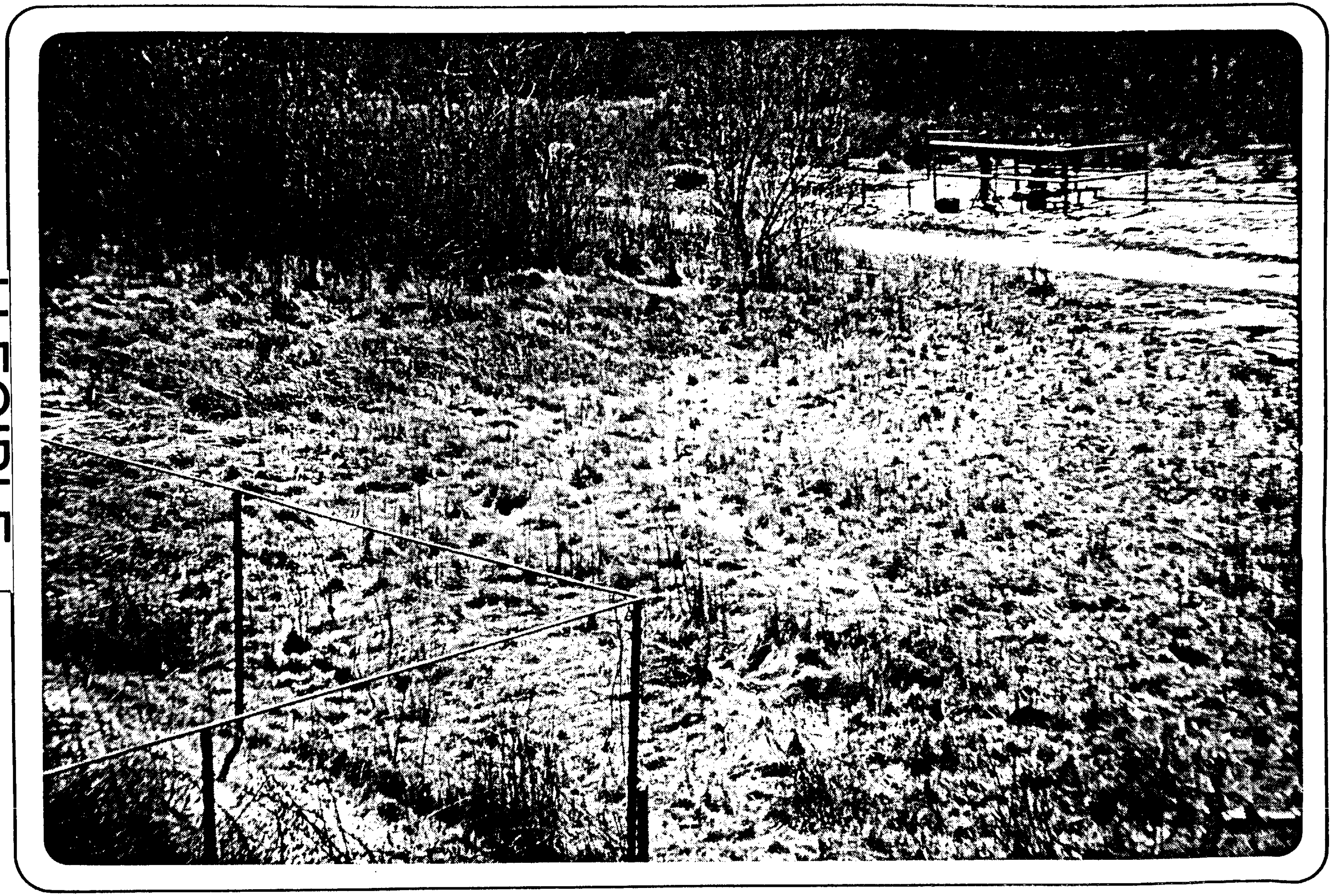

TOTAH VISTA 1 Roll #2 Slide 2

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Geoscience
Consultants, Ltd.

	Section	TWP	RNG
Location	SWNW 35	29N	12W

WELL NAME GCU #170E ✓

Drainage Basin:

San Juan   La Plata   Animas   other: ________

Description of Location:

River Bottom   Valley Slope   Dry Tributary   Mesa   Other: ________

Barrels Water/Day Produced: 0.13

Estimated Hydraulic Gradient: 0.003

Estimated Hydraulic Conductivity: 10^4 GPD/FT

Formation/Grain Size of Unsaturated Zone:

Very Fine   Fine   Med   Coarse   Very Coarse

Sorting: Poor   Fair   Good

Estimated Depth to Ground Water: 10'

Pit Description   Dry

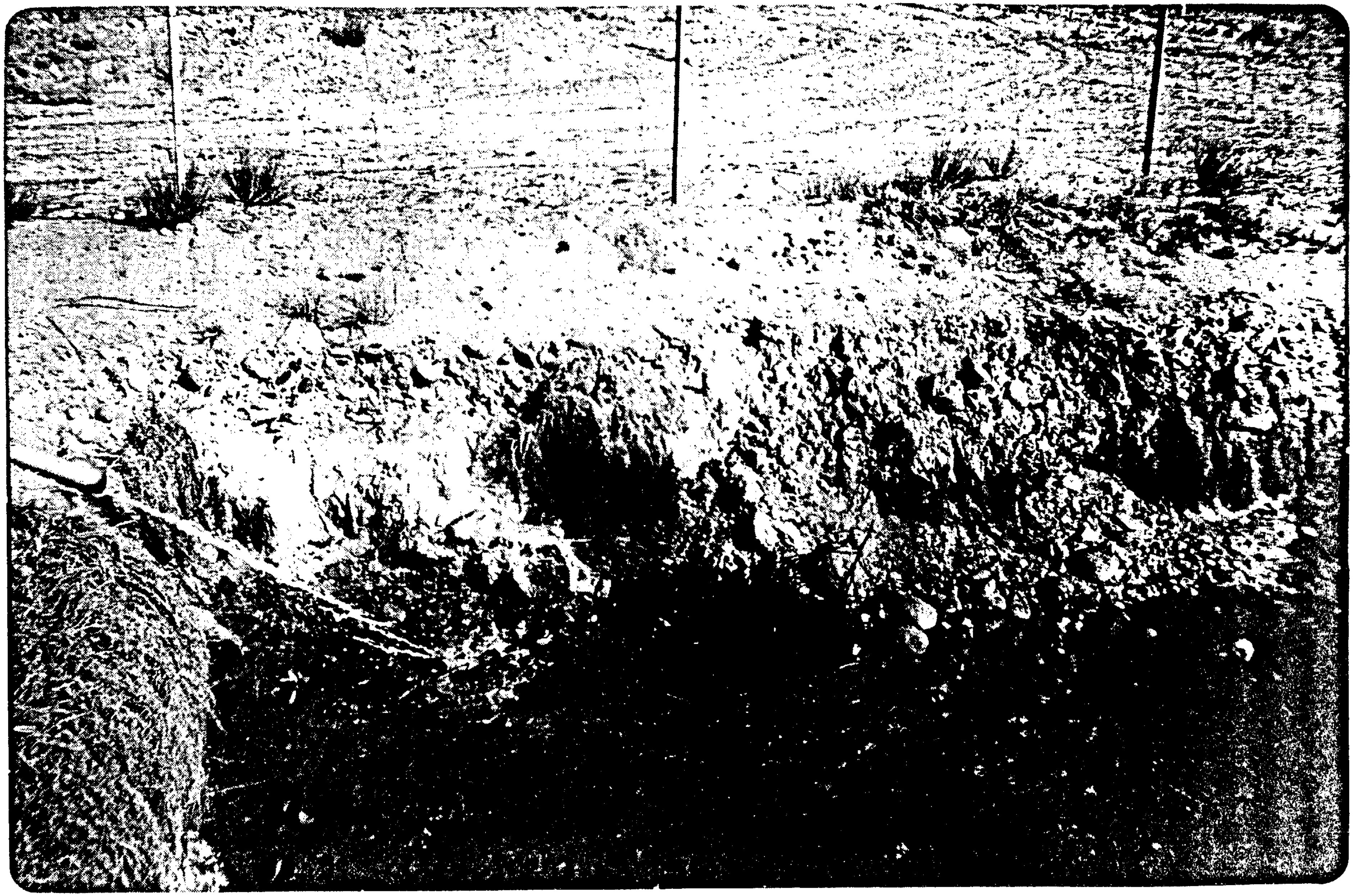
Standing Water   Estimated Depth: 0.25'

Photographs of Site: 17 18 NOTE RIVER IN BKGRND

Producing Formation: BASIN DAKOTA

Comments: GOOD SOIL OVER COARSE GRAVEL

LLEGIBLE I



GCU 170E Roll #3 Slide 17

GCU 170E Roll #3 Slide 18

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	SENE 34	29N	12W

WELL NAME GCU "I" #181E

Drainage Basin:

San Juan   La Plata   Animas   other: ______

Description of Location:

River Bottom   Valley Slope   Dry Tributary   Mesa   Other: ______

Barrels Water/Day Produced: 0.07

Estimated Hydraulic Gradient: 0.002

Estimated Hydraulic Conductivity: 10^4 GPD/FT

Formation/Grain Size of Unsaturated Zone:

Very Fine   Fine   Med   Coarse   Very Coarse

Sorting: Poor   Fair   Good

Estimated Depth to Ground Water: 4'

Pit Description   Dry

Standing Water   Estimated Depth: 0.2'

Photographs of Site: #15 #16 PIT w/ RIVER IN BACK

Producing Formation: BASIN DAKOTA

Comments: SOME BLOW SAND AND PARRIFIN FORM LINER

GCU "I" 181E Roll #3 Slide 15

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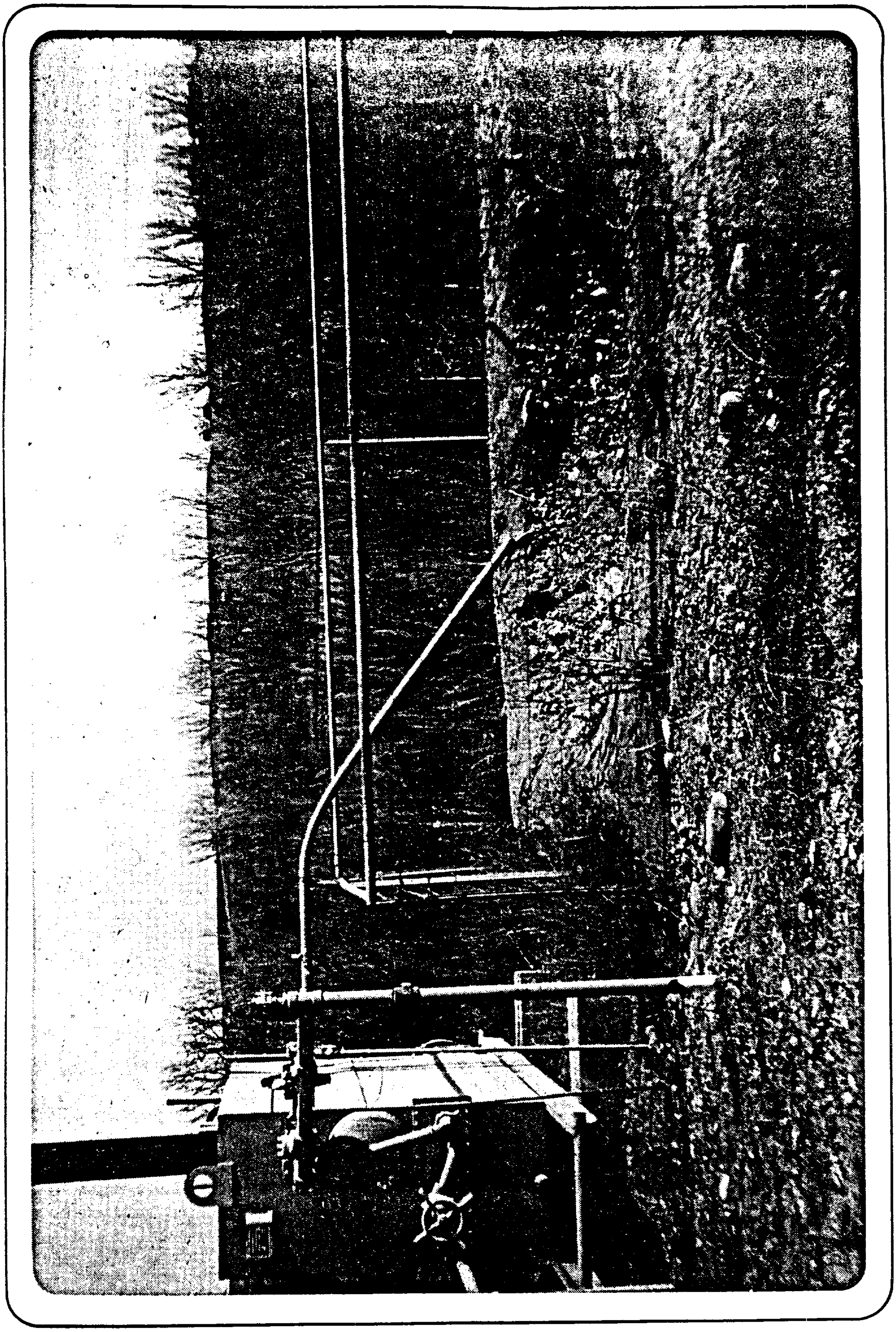

GCU "I" 181E Roll #3 Slide 16

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SAN JUAN RIVER

MEDIUM HYDRAULIC CONDUCTIVITY CASES

Geoscience Consultants, Ltd.

	Section	TWP	RNG
Location	27	29N	10W

WELL NAME GERK GAS COM B #1M

Drainage Basin:

San Juan 0.023 La Plata Animas other:

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other:

Barrels Water/Day Produced: 0.13

Estimated Hydraulic Gradient: 0.003

Estimated Hydraulic Conductivity: 10^3 GPD/FT^2

Formation/Grain Size of Unsaturated Zone: River Alluvium

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: 10-15 ft

Pit Description Dry

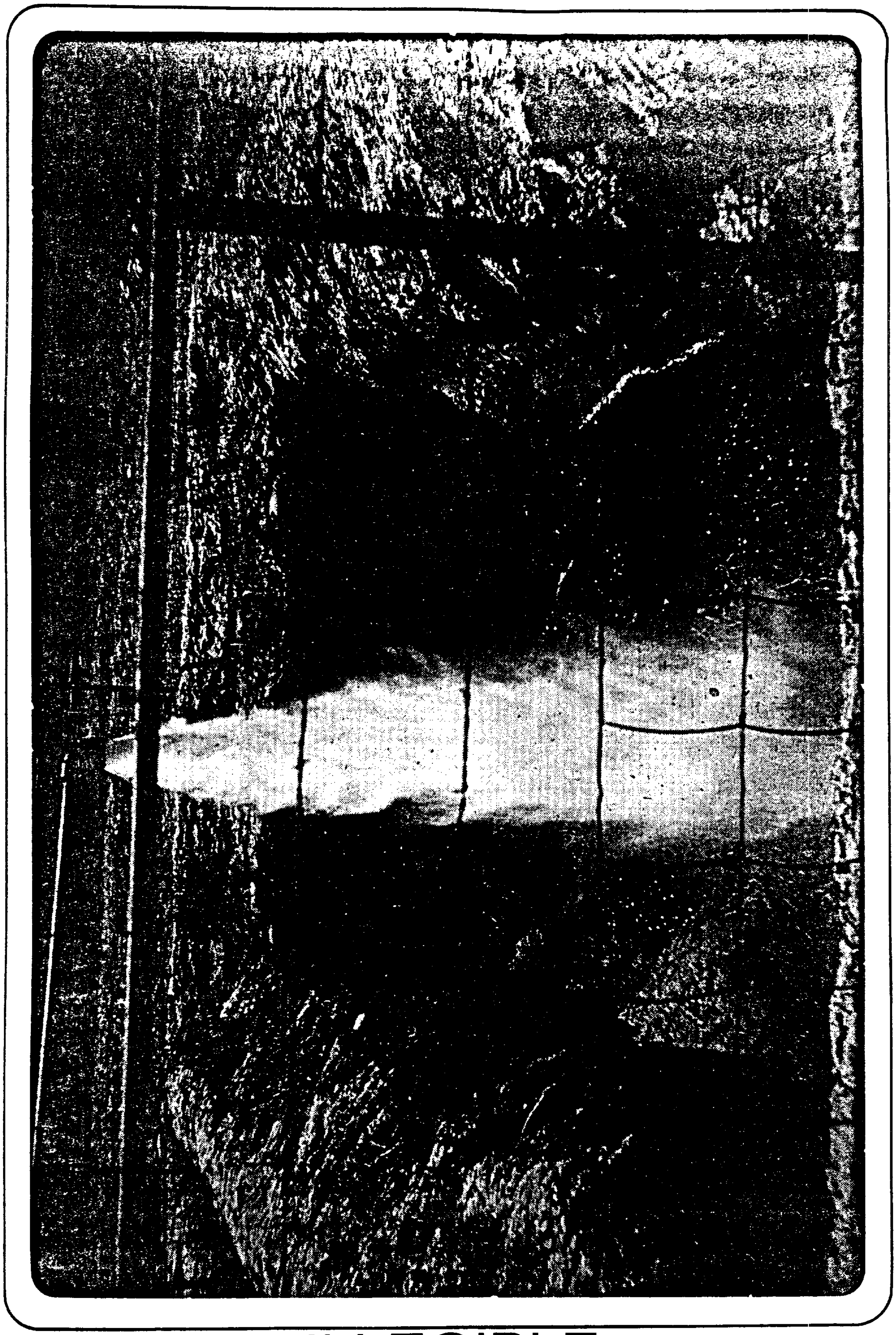
Standing Water Estimated Depth: 0.75

Photographs of Site: 1,2-~~3~~ PIT

Producing Formation: BASIN DAKOTA

Comments: SOME MAT/LINER CONSTANT DRIP OF CONDENSATE

4/11/85 BAH



GERK B 1 M Roll #4 Slide 1

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GERK B 1 M Roll #4 Slide 2

ILLEGIBLE

Geoscience
Consultants, Ltd.

	Section	TWP	RNG
Location	NESW5	29N	9W

WELL NAME ARCHULETA GAS COM A #3

Drainage Basin:

San Juan La Plata Animas other: ______

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other: ______

Barrels Water/Day Produced: — — 0.02

Estimated Hydraulic Gradient: 0.003

Estimated Hydraulic Conductivity: 10^2 - 10^3 GPD/FT

Formation/Grain Size of Unsaturated Zone: SOIL/SAND

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: 6'

Pit Description Dry

Standing Water Estimated Depth: 1'

Photographs of Site: 15 DISCHARGE OF A #3 PIT River Bkgrnd

Producing Formation: BASIN DAKOTA

Comments: FINE SAND H-C LINER

NO PHOTOGRAPHS AVAILABLE

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	NENE 28	29N	11W

WELL NAME MASDEN GAS COM #1

Drainage Basin:

San Juan La Plata Animas other: ______

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other: ______

Barrels Water/Day Produced: 0.23

Estimated Hydraulic Gradient: 0.003

Estimated Hydraulic Conductivity: 10^3 GPD / FT

Formation/Grain Size of Unsaturated Zone: SOIL AND ALLUVIUM

Very Fine Fine ~~Medium~~ Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: 2'

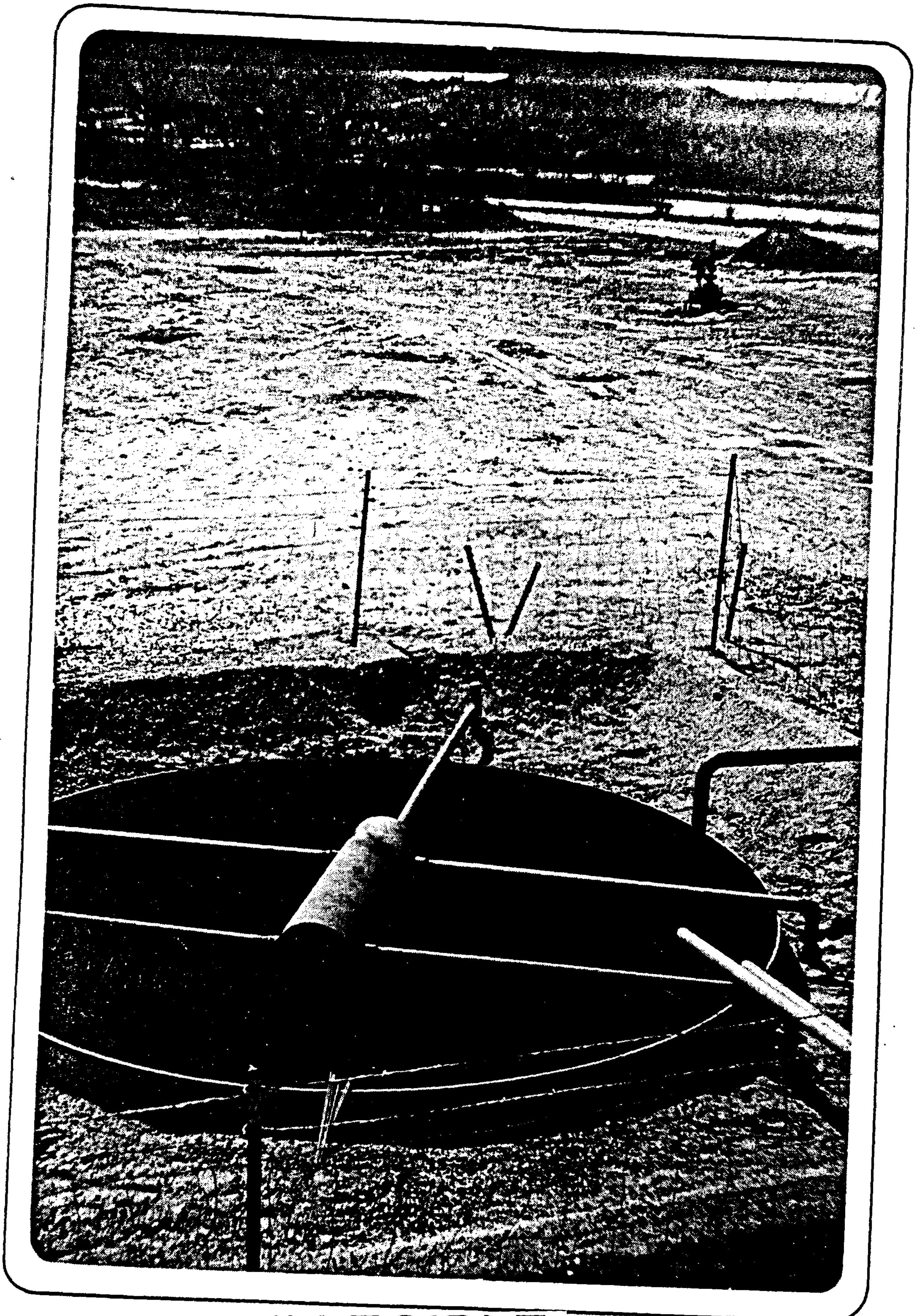
Pit Description Dry

Standing Water Estimated Depth: 0.1'

Photographs of Site: #9 #8 LINED PIT W/ RIVER BACKGRND

Producing Formation: BASIN DAKOTA

Comments: NEXT TO STP



MADSEN 1 Roll #1 Slide 8

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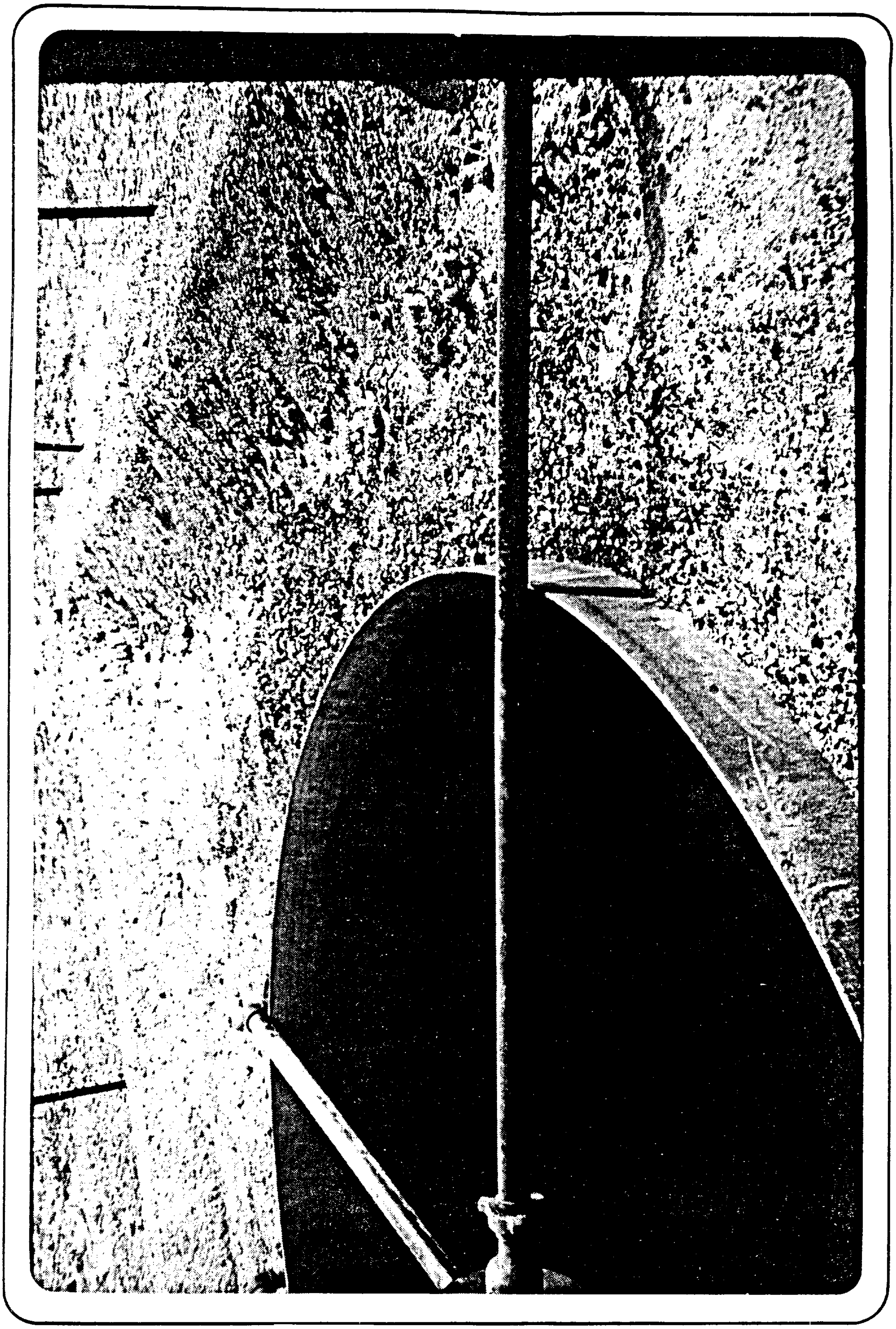

MADSEN 1 Roll #1 Slide 9

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Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	SENE 27	25 N	10 W

WELL NAME ARMENTA GAS COM F #1

Drainage Basin:

San Juan   La Plata   Animas   other: ______

Description of Location:

River Bottom   Valley Slope   Dry Tributary   Mesa   Other: ______

Barrels Water/Day Produced: — —   0.02

Estimated Hydraulic Gradient: 0.003

Estimated Hydraulic Conductivity: 10^3 or 10^2 BPD/FT^2

Formation/Grain Size of Unsaturated Zone:

Very Fine   Fine   Med   Coarse   Very Coarse

Sorting: Poor   Fair   Good

Estimated Depth to Ground Water: COULD BE LOOKING AT IT ~ 5-10'

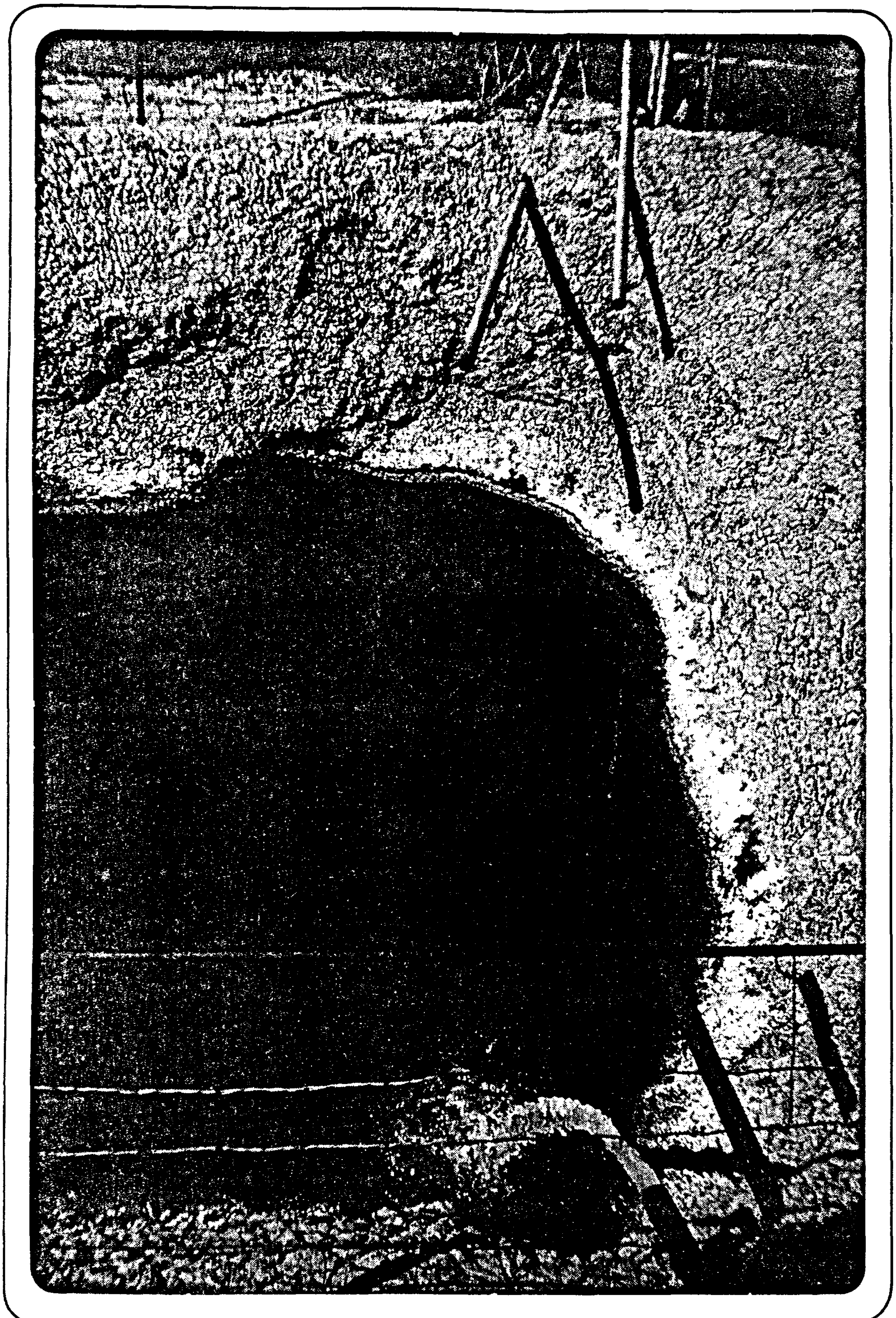
Pit Description   Dry

Standing Water   Estimated Depth: 1' ±

Photographs of Site: 5-6-7-8 PIT DISCHRGE RIVER FINE SEDS

Producing Formation: ARMENTA GALLUP

Comments: SEVERAL WELLS INTO ONE PIT



ARMENTA F1 Roll #4 Slide 6

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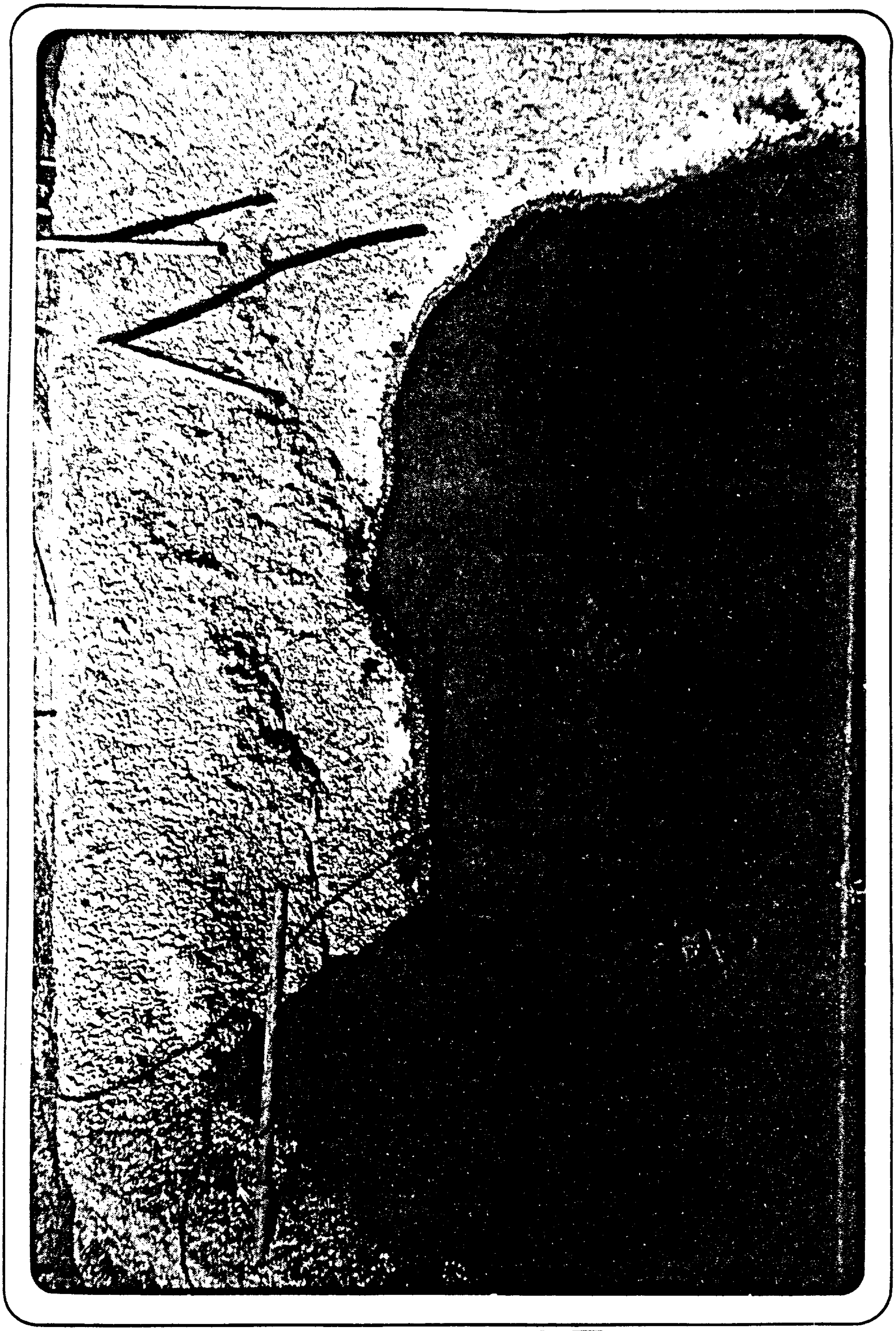

ARMENTA F1 Roll #4 Slide 7

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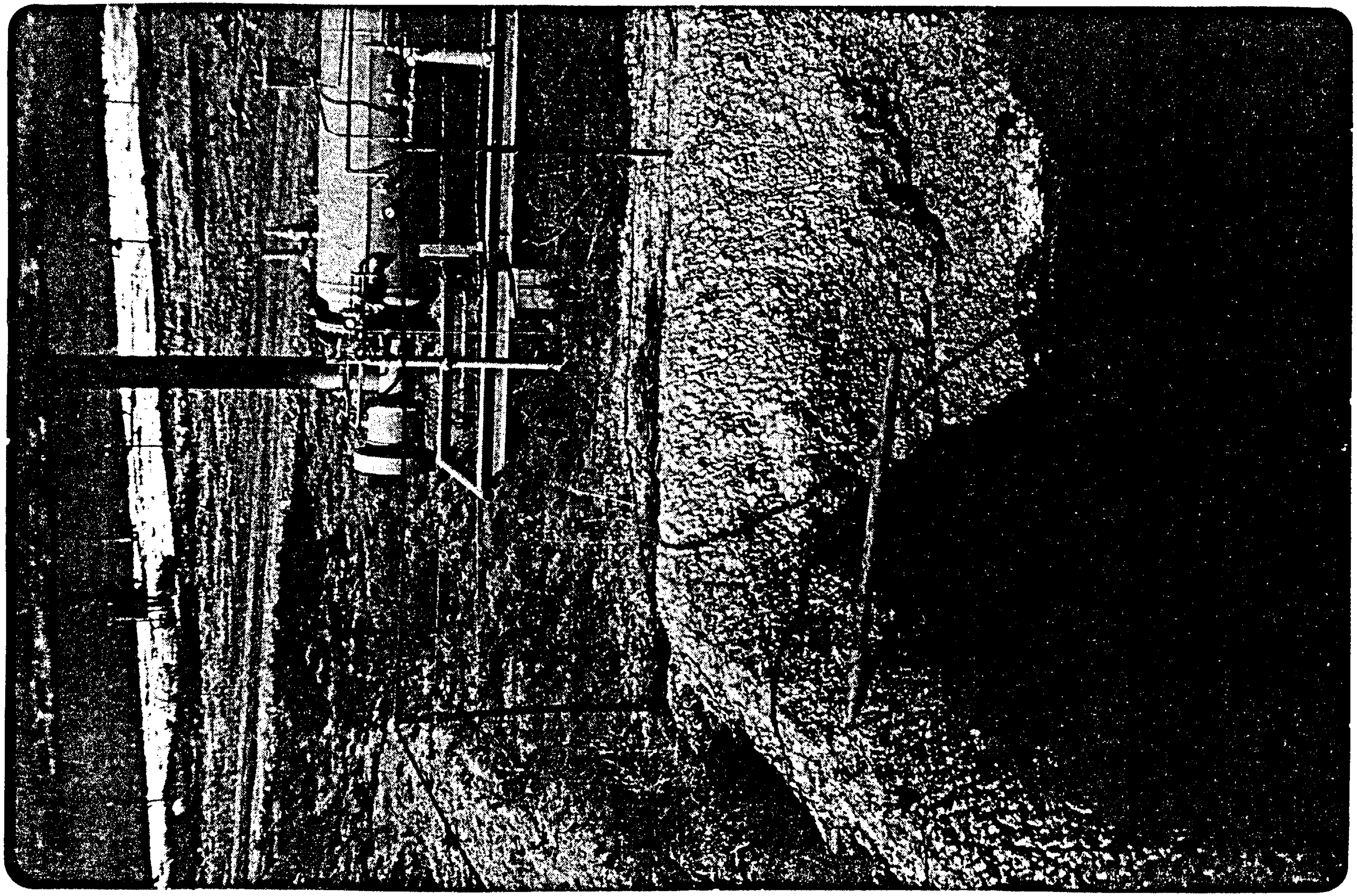

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ARMENTA F1 Roll #4 Slide 8

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	26	29 N	10W

10 PARTS
25 DAYS

1
1
2

WELL NAME ABRAMS L #1

Drainage Basin:

San Juan La Plata Animas other: ______

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other: ______

Barrels Water/Day Produced: — — 0.02

Estimated Hydraulic Gradient: 0.003

Estimated Hydraulic Conductivity: 10^3 GPD/FT^2

Formation/Grain Size of Unsaturated Zone:

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: 10-15'

Pit Description Dry

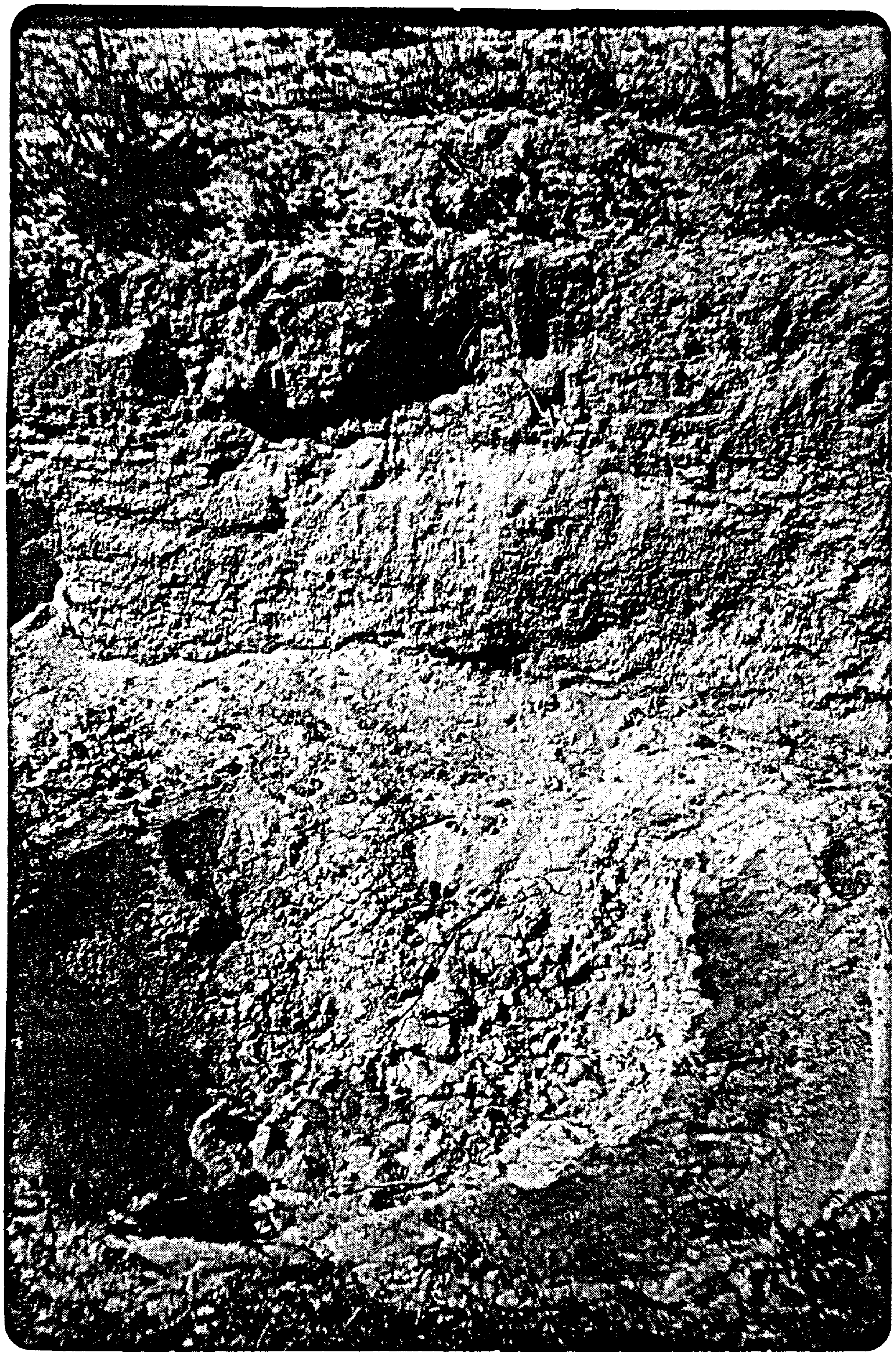
Standing Water Estimated Depth: ______

Photographs of Site: #5 PIT

Producing Formation: ARMENTA GALLUP NOW MV?

Comments: SHUT IN — NEVER PRODUCED?

$$\frac{0.02\ \text{bbls}}{\text{day}} \times \frac{42\ \text{gal}}{\text{bbl}} \times \frac{3.785\ \ell}{\text{gal}} \times \frac{\overset{\text{Source}}{3.5\ \text{mg}}}{\ell} = \frac{11.1\ \text{mg}}{\text{day}} \times \frac{25\ \text{days}}{10\ \text{part}} * \frac{1}{111000\ \ell} = \frac{0.00025\ \text{mg}/\ell}{\text{part}}$$



ABRAMS L1 Roll #4 Slide 5

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Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	NE/NW 25	29N	11W

WELL NAME SULLIVAN A1

Drainage Basin:

San Juan   La Plata   Animas   other: ______

Description of Location:

River Bottom   Valley Slope   Dry Tributary   Mesa   Other: ______

Barrels Water/Day Produced: ~~0~~ 0.02

Estimated Hydraulic Gradient: 0.003

Estimated Hydraulic Conductivity: 10^3

Formation/Grain Size of Unsaturated Zone:

Very Fine   Fine   Med   Coarse   Very Coarse

Sorting: Poor   Fair   Good

Estimated Depth to Ground Water: 10

Pit Description   Dry

Standing Water   Estimated Depth: 0.25

Photographs of Site: 13, 14 15

Producing Formation: DK

Comments: ______

SULLIVAN A1 Roll #4 Slide 13

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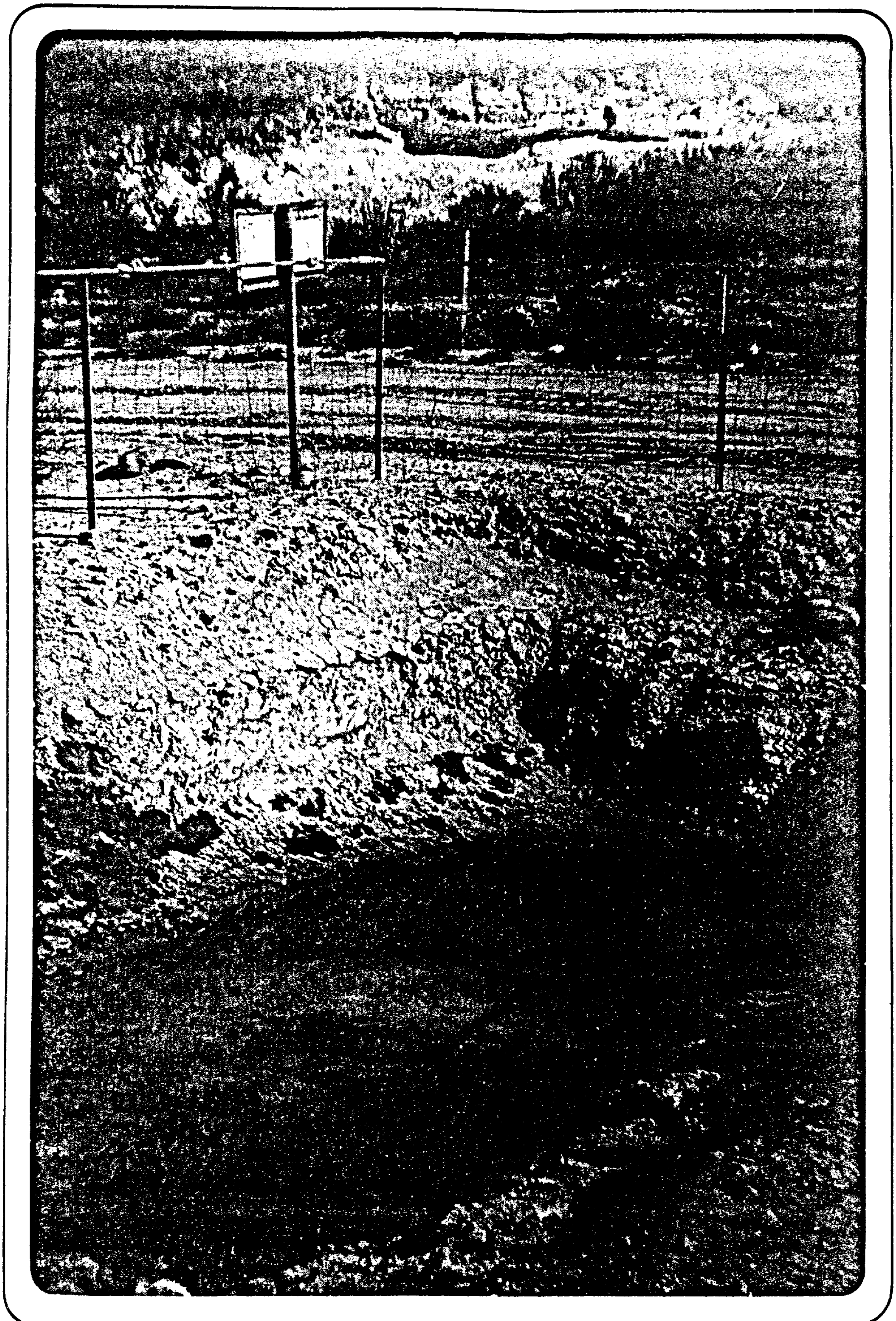

SULLIVAN A1 Roll #4 Slide 14

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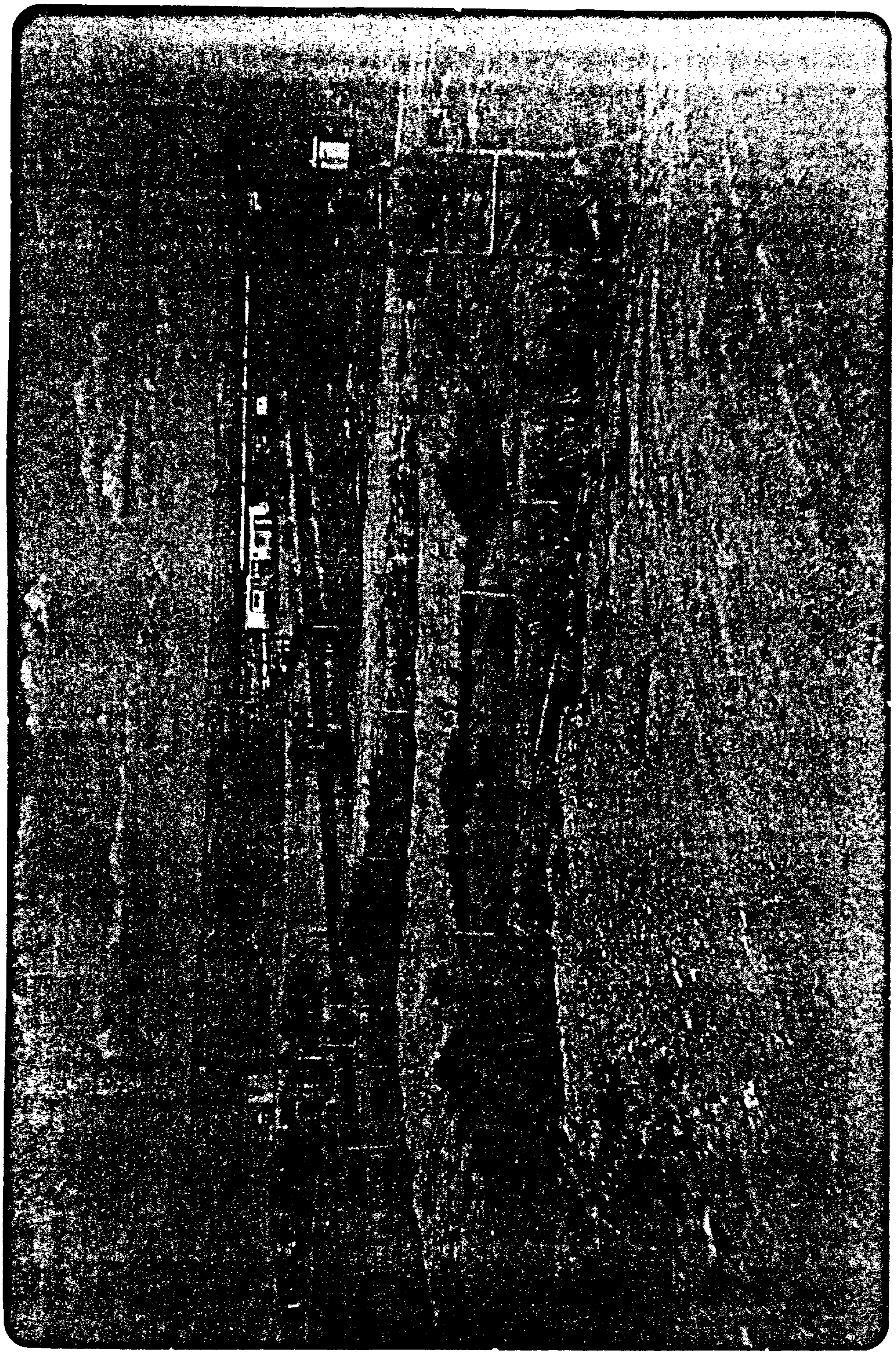

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SULLIVAN A1 Roll #4 Slide 15

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	NENW 28	29N	12W

WELL NAME GCU #153E

Drainage Basin:

San Juan La Plata Animas other:

Description of Location:

River Bottom * Valley Slope Dry Tributary Mesa Other:

Barrels Water/Day Produced: 0.33

Estimated Hydraulic Gradient: .003

Estimated Hydraulic Conductivity: $10^3 - 10^4$ GPD/FT^2

Formation/Grain Size of Unsaturated Zone:

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: BASED UPON POND 20'

Pit Description Dry

Standing Water Estimated Depth: 2'

Photographs of Site: #10 #11 Pit #12 SANDSTONE BENCH BEHIND WELL SITE

Producing Formation: BASIN DAKOTA

Comments: RIVER 200' * 1ST RIVER TERRACE

LOTS OF PARAFIN

ILLEGIBLE

GCU 153E Roll #3 Slide 10

GCU 153E Roll #3 Slide 11

ILLEGIBLE

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	NWSE 26	29N	12W

WELL NAME GCU G #179E ✓

Drainage Basin:

San Juan   La Plata   Animas   other: ____

Description of Location:

River Bottom   Valley Slope   Dry Tributary   Mesa   Other: ____

Barrels Water/Day Produced: -- ~~0.02~~ 0.016 ✓

Estimated Hydraulic Gradient: 0.002

Estimated Hydraulic Conductivity: 10^3

Formation/Grain Size of Unsaturated Zone:

Very Fine   Fine   Med   Coarse   Very Coarse

Sorting: Poor   Fair   Good

Estimated Depth to Ground Water: 57'

Pit Description   Dry

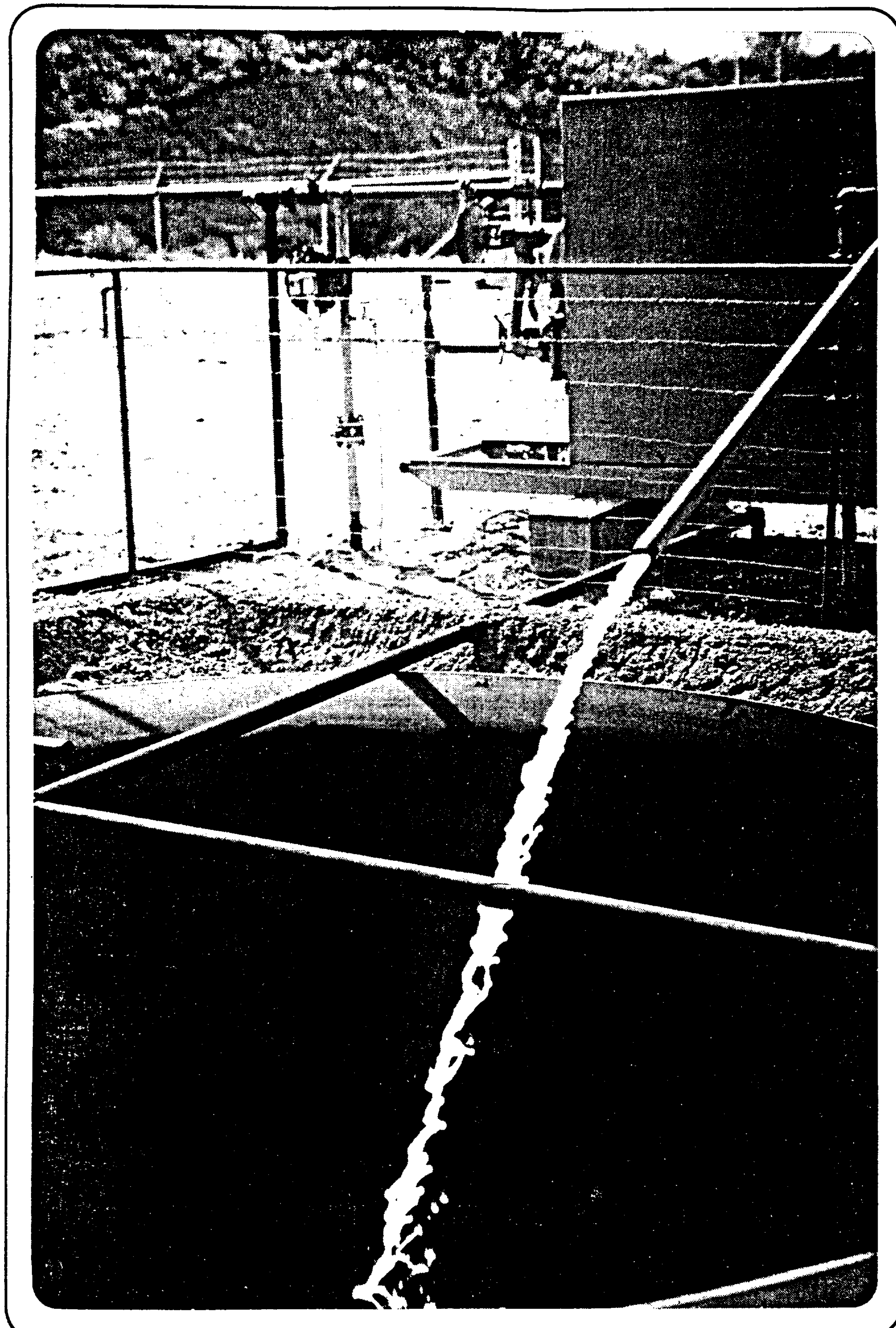
Standing Water   Estimated Depth: 0.75'

Photographs of Site: #4, #5 LINED PIT + BLOWDOWN SHOWS LITH

Producing Formation: BASIN DAKOTA

Comments: PIT LINED   LOTS OF PARAFIN

#6 SANDSTONE AT EDGE OF SITE SEEP AT BASE OF SS.



GCU 179E Roll #1 Slide 5

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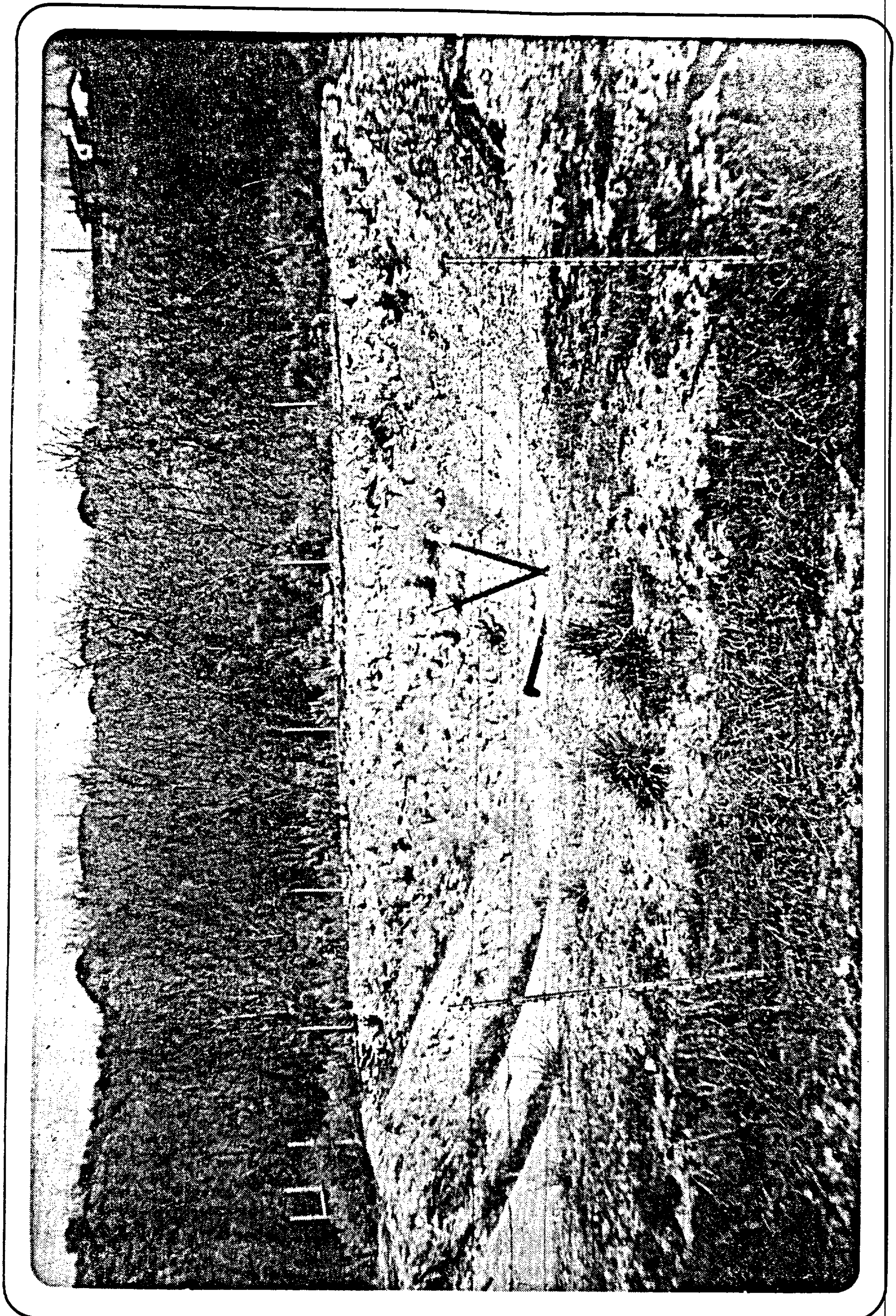

GCU 179E Roll #1 Slide 6

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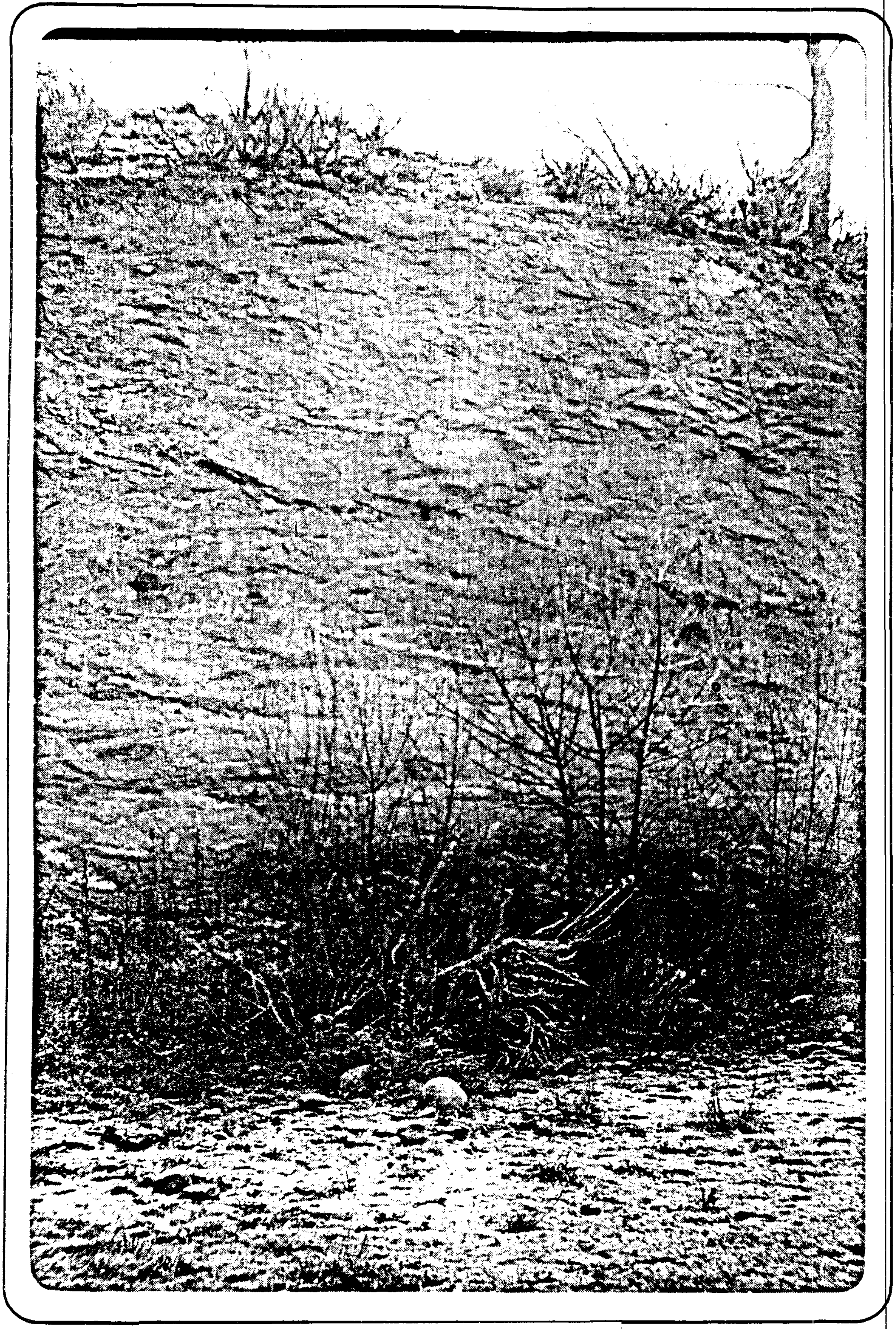
GCU 179E Roll #1 Slide 7



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SAN JUAN RIVER

LOW HYDRAULIC CONDUCTIVITY CASES

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	SENE 35	29N	12W

WELL NAME GCU #169E ✓

Drainage Basin:

San Juan La Plata Animas other:

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other:

Barrels Water/Day Produced: 0.06

Estimated Hydraulic Gradient: 0.003

Estimated Hydraulic Conductivity: 10^2 *

Formation/Grain Size of Unsaturated Zone:

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: 6-10'

Pit Description Dry

Standing Water Estimated Depth: 0.25

Photographs of Site: PIT BUILT IN FILL GRAVEL 19, 20

Producing Formation: BASIN DAKOTA

Comments: BUILT ON FILL

NOTE SALT CRUST ON GROUND

* 10^3 MAYBE UNDER SOIL - RIVER SEDS FROM SANDSTONE HERE

GCU 169E Roll #3 Slide 19

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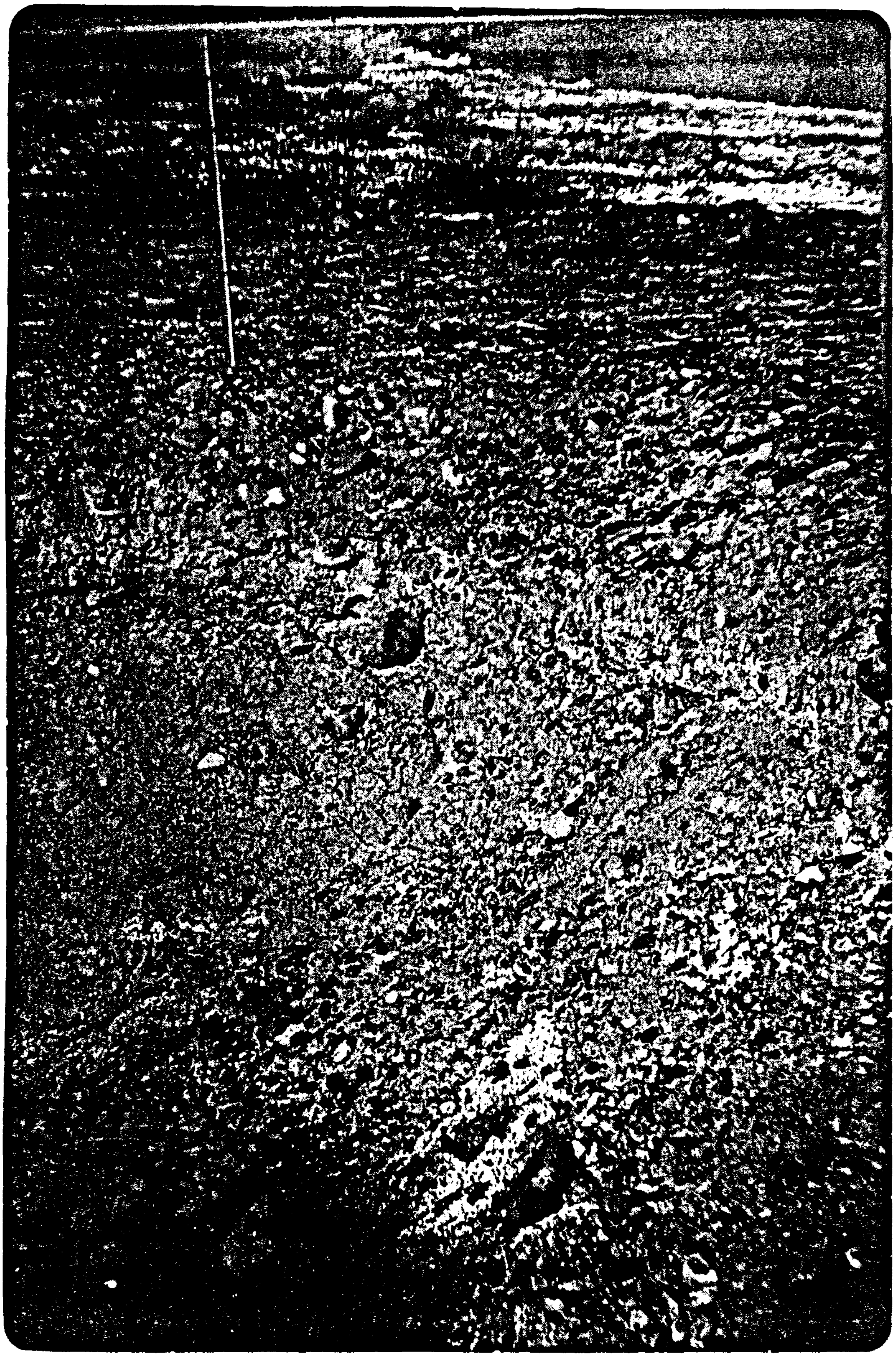


GCU 169E Roll #3 Slide 20

ILLEGIBLE

Geoscience
Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	NESW 27	29N	10W

WELL NAME ROMERO GAS COM A #1

Drainage Basin:

San Juan La Plata Animas other: ______

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other: ______

Barrels Water/Day Produced: — — 0.02

Estimated Hydraulic Gradient: 0.003

Estimated Hydraulic Conductivity: 10 GPD/FT

Formation/Grain Size of Unsaturated Zone: SiH

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: 9' ±

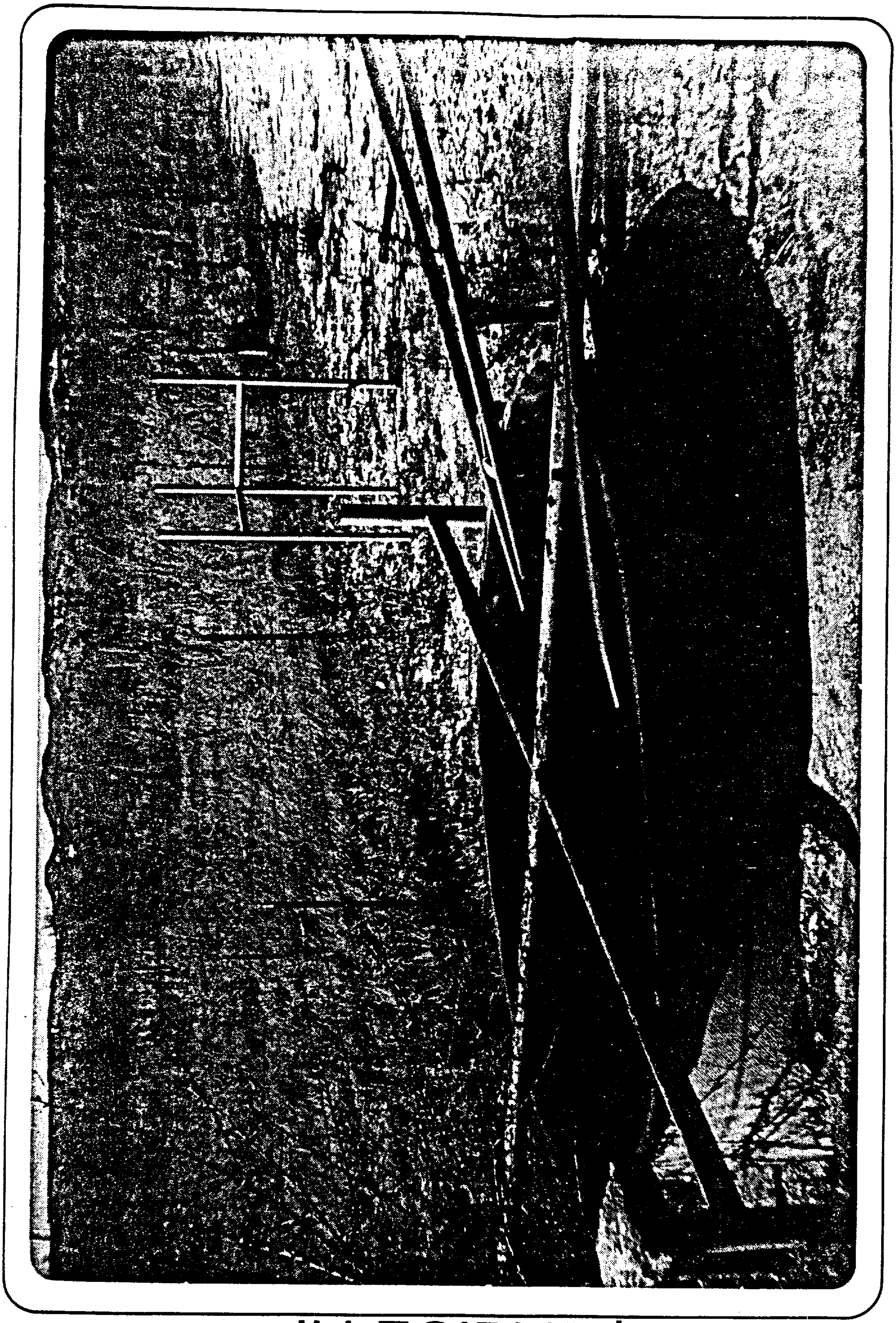
Pit Description Dry FIBREGLASS

Standing Water Estimated Depth: 0.1'

Photographs of Site: 9 — FIBERGLASS PIT

Producing Formation: BLANCO MESA VERDE

Comments: ______



ROMERO A1 Roll #4 Slide 9

ILLEGIBLE I

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	SWSE 35	30N	9W

WELL NAME ULIBARRI GAS COM #1A

Drainage Basin:

San Juan La Plata Animas other: ____

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other: ____

Barrels Water/Day Produced: 0.03

Estimated Hydraulic Gradient: ____

Estimated Hydraulic Conductivity: 10 @ SURFACE 10^2 SATURATED ZONE

Formation/Grain Size of Unsaturated Zone: Soil

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: 4'

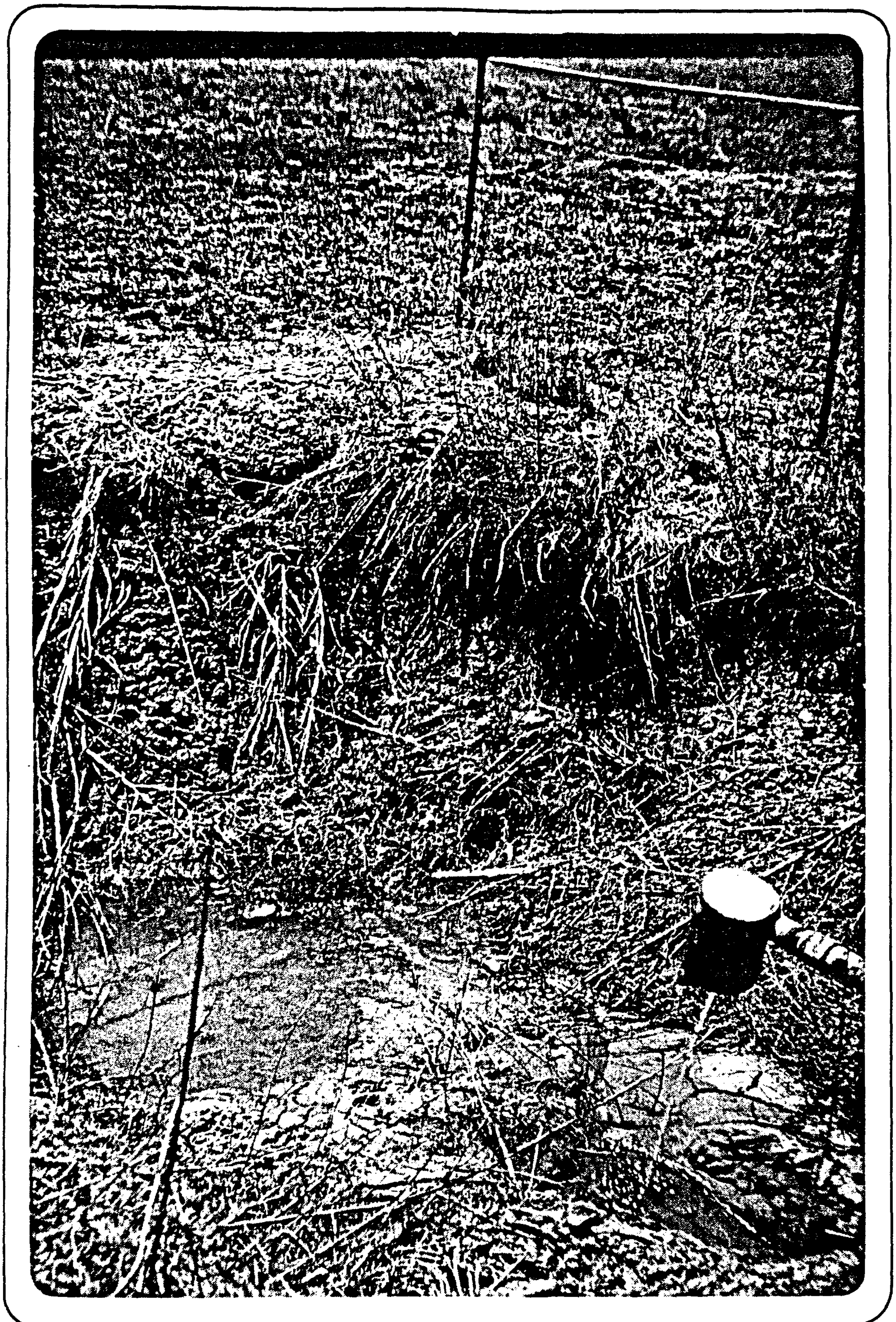
Pit Description Dry

Standing Water Estimated Depth: 0.2 ft

Photographs of Site: 2, 3 DISCHARGE River in Bkgrnd

Producing Formation: BLANCO - MESAVERDE

Comments: ALL AROUND HERE POOR SORTING FINE/COARSE ALLUVIUM



ULIBARRI 1A Roll #5 Slide 1

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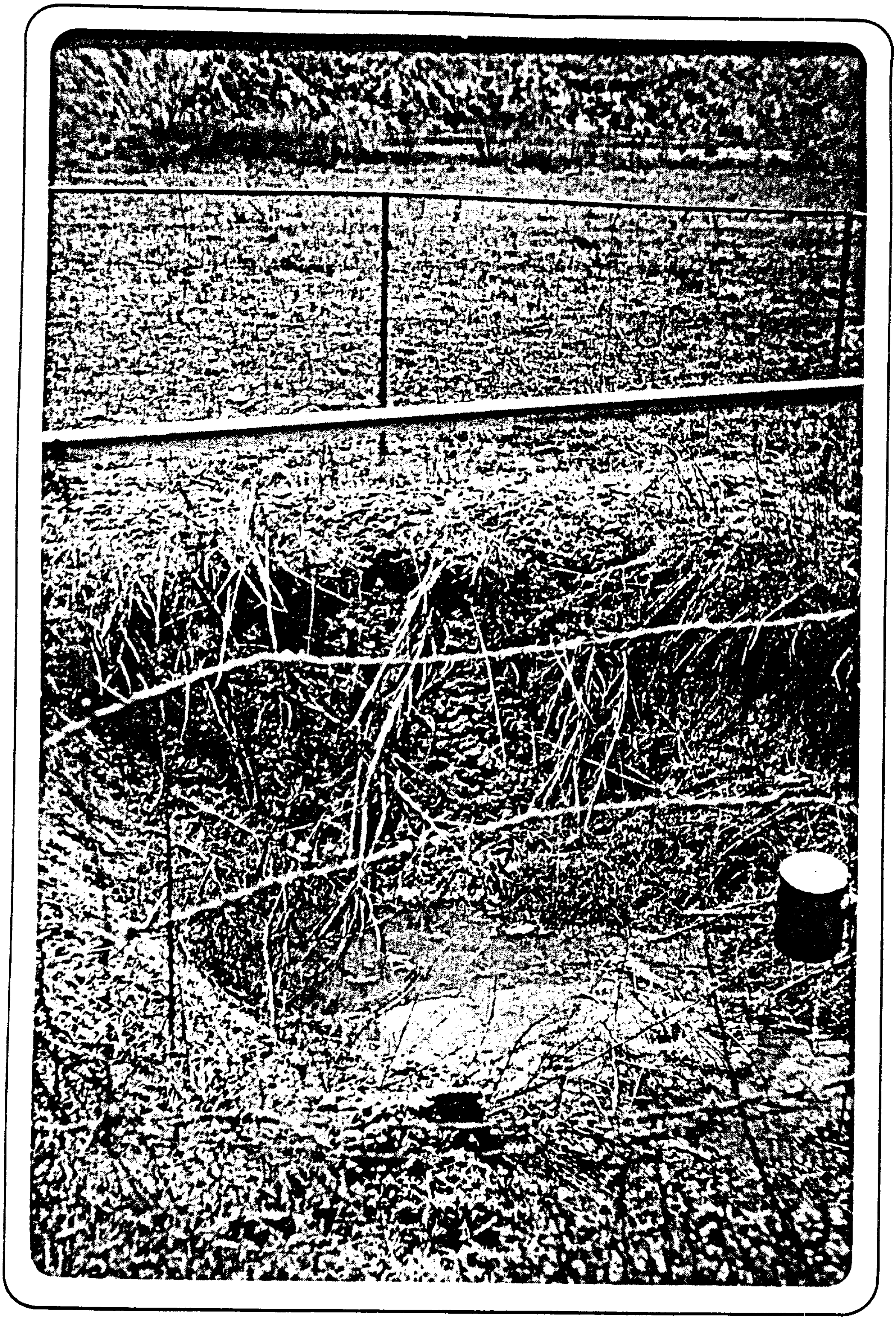


ULIBARRI 1A Roll #5 Slide 2

ILLEGIBLE

ANIMAS RIVER

HIGH HYDRAULIC CONDUCTIVITY CASES

Geoscience
Consultants, Ltd.

	Section	TWP	RNG
Location	SE NE 5	31N	10W

WELL NAME MARCOTTE GAS COM #1

Drainage Basin:

San Juan La Plata Animas other: ____________

Description of Location:

River Bottom* Valley Slope Dry Tributary Mesa Other: ________

Barrels Water/Day Produced: 0.33

Estimated Hydraulic Gradient: .004

Estimated Hydraulic Conductivity: 10^4 GPD/FT^2

Formation/Grain Size of Unsaturated Zone: SOME BLOWSAND AT SURFACE

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: ____________

Pit Description Dry

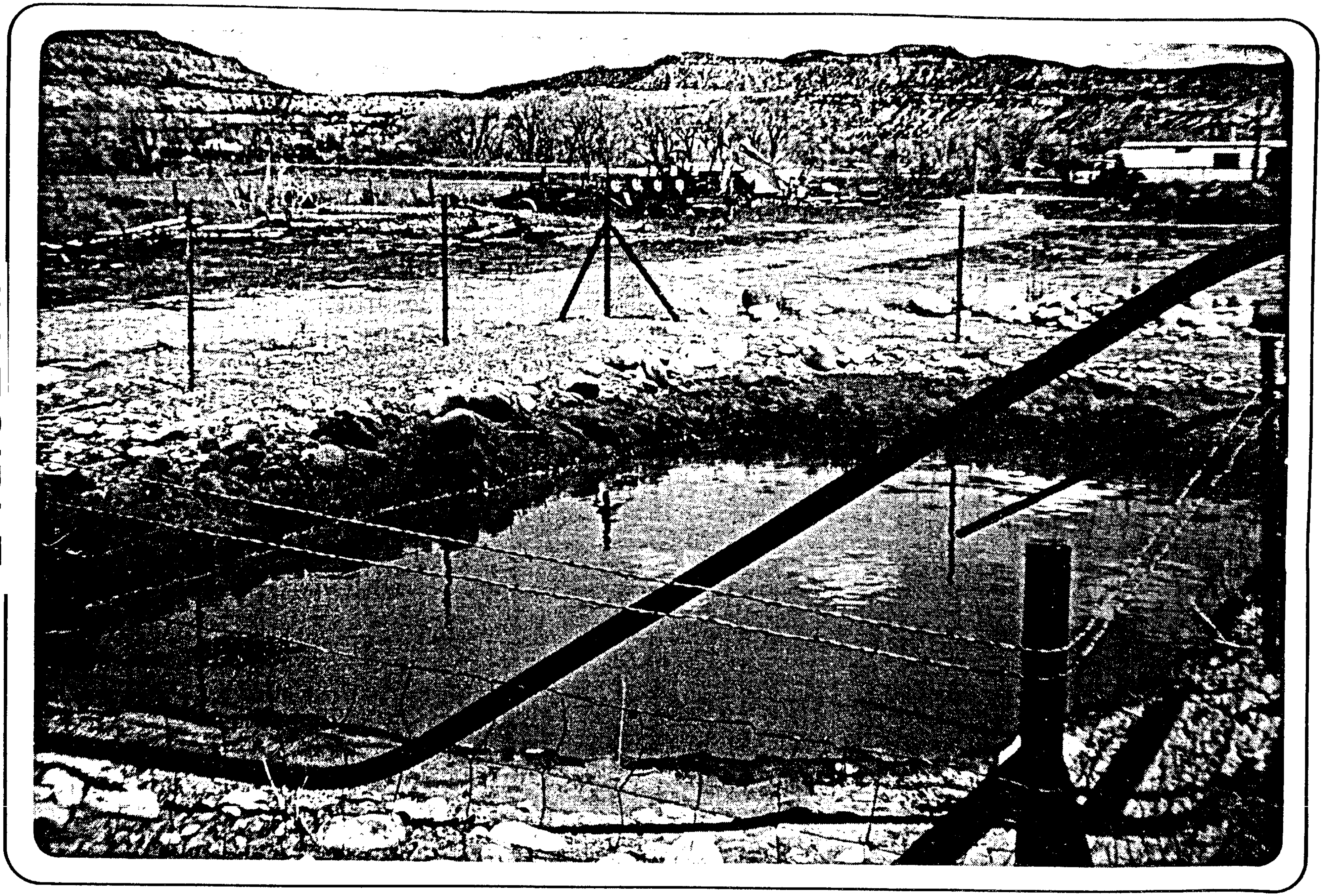
Standing Water Estimated Depth: 2"

Photographs of Site: #17 PIT SHOWING MAT/LINER

Producing Formation: BLANCO MESAVERDE

Comments: * Terrace 20-40 ABOVE RIVER
ASPHALTIC MAT PRECLUDES EXCESS PERC.

4/10/85 BAH



ILLEGIBLE

MARCOTTE 1 Roll #2 Slide 17

ANIMAS RIVER

MEDIUM HYDRAULIC CONDUCTIVITY CASES

NO CASES OBSERVED

ANIMAS RIVER

LOW HYDRAULIC CONDUCTIVITY CASES

NO CASES OBSERVED

1.3

VALLEY SIDE SLOPES AND TRIBUTARIES

HIGH HYDRAULIC CONDUCTIVITY CASES

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	SW NW 28	30N	12W

WELL NAME McCOY GAS COM D #1E

Drainage Basin:

San Juan   La Plata   Animas   other:

Description of Location:

River Bottom   Valley Slope   Dry Tributary   Mesa   Other:

Barrels Water/Day Produced: 0.2

Estimated Hydraulic Gradient: ~~.001~~ 0.01

Estimated Hydraulic Conductivity: 10^4 GPD/FT^2

Formation/Grain Size of Unsaturated Zone:

Very Fine   Fine   Med   Coarse   Very Coarse — SOME FINES MATRIX

Sorting: Poor   Fair   Good

Estimated Depth to Ground Water:

Pit Description   Dry

Standing Water   Estimated Depth: 1.5'

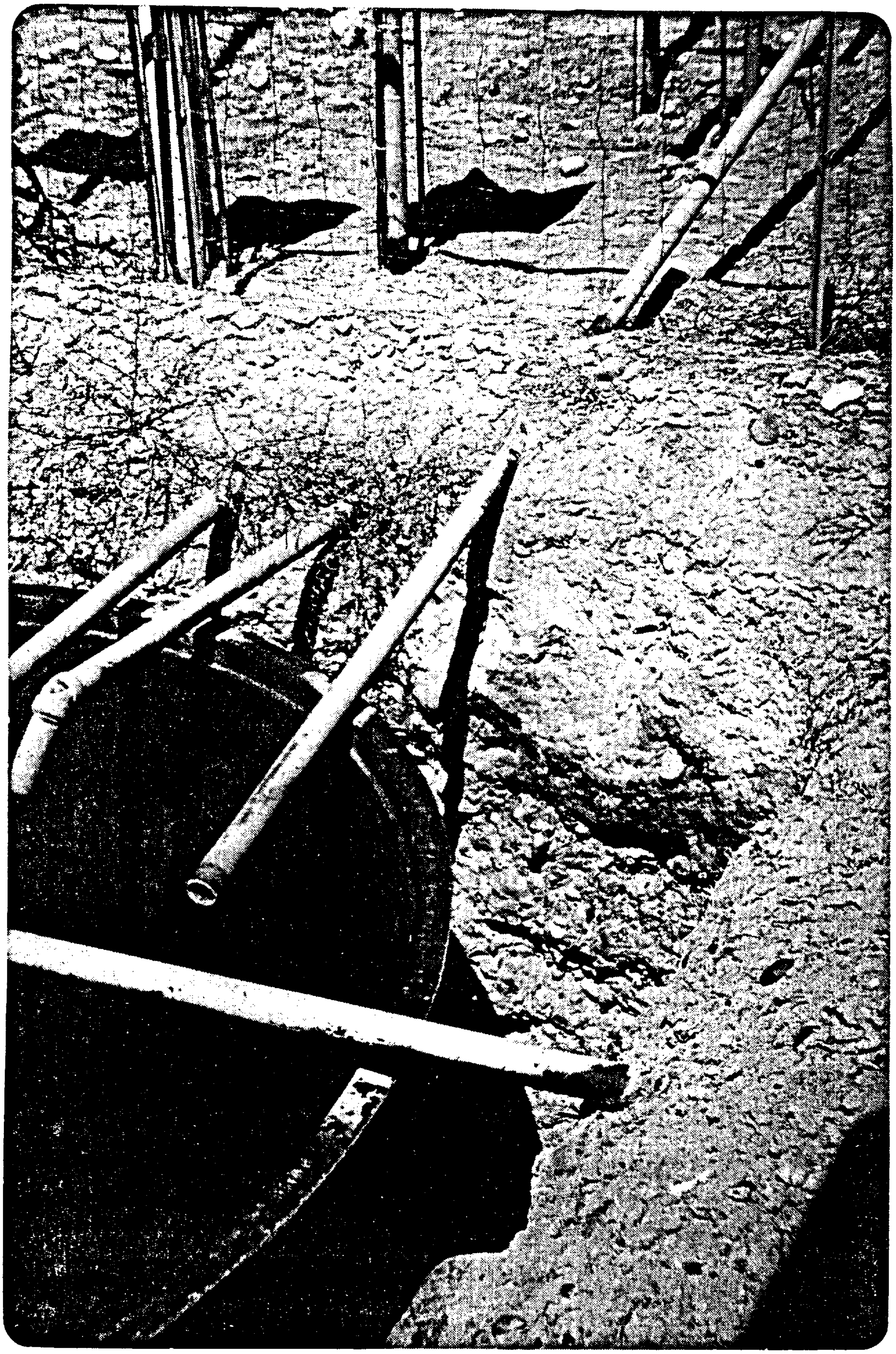
Photographs of Site: #5 TANK IN GRAVEL #6 TOWARD ANIMAS #7 Road cut AT SITE

Producing Formation: BASIN DAKOTA

Comments: FIBERGLASS TANK FILLED W OIL CARRIED OVER FROM SEPARATOR IN PHOTO 7 NOTE BEDROCK AT BASE OF CUT - SANDSTONE

4/10/85 RTH

$\frac{0.01\,\text{lbs}}{2} \times \frac{30\ \text{DAYS}}{10\ \text{PART}} \times$



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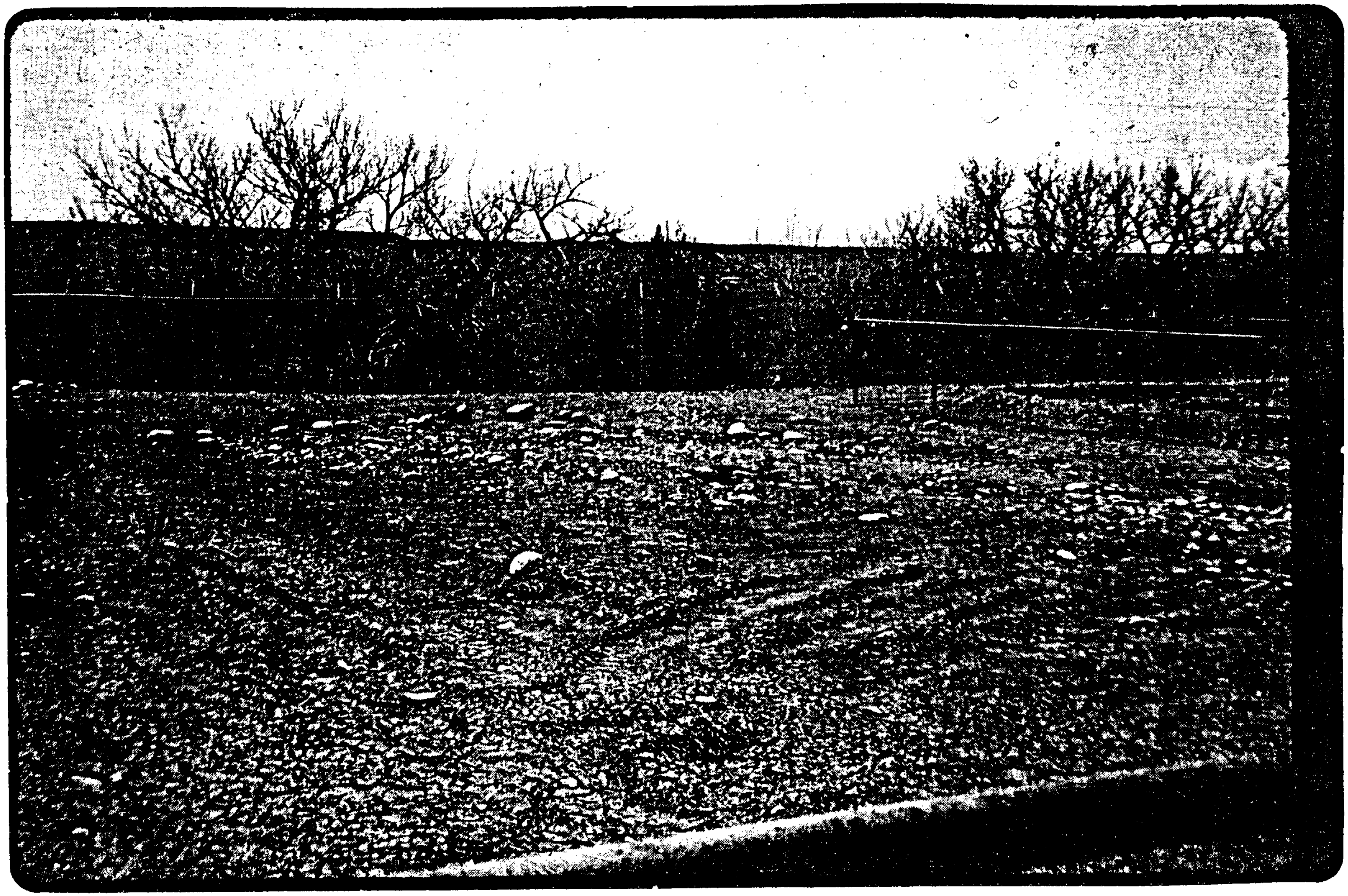
McCOY D1E Roll #2 Slide 5



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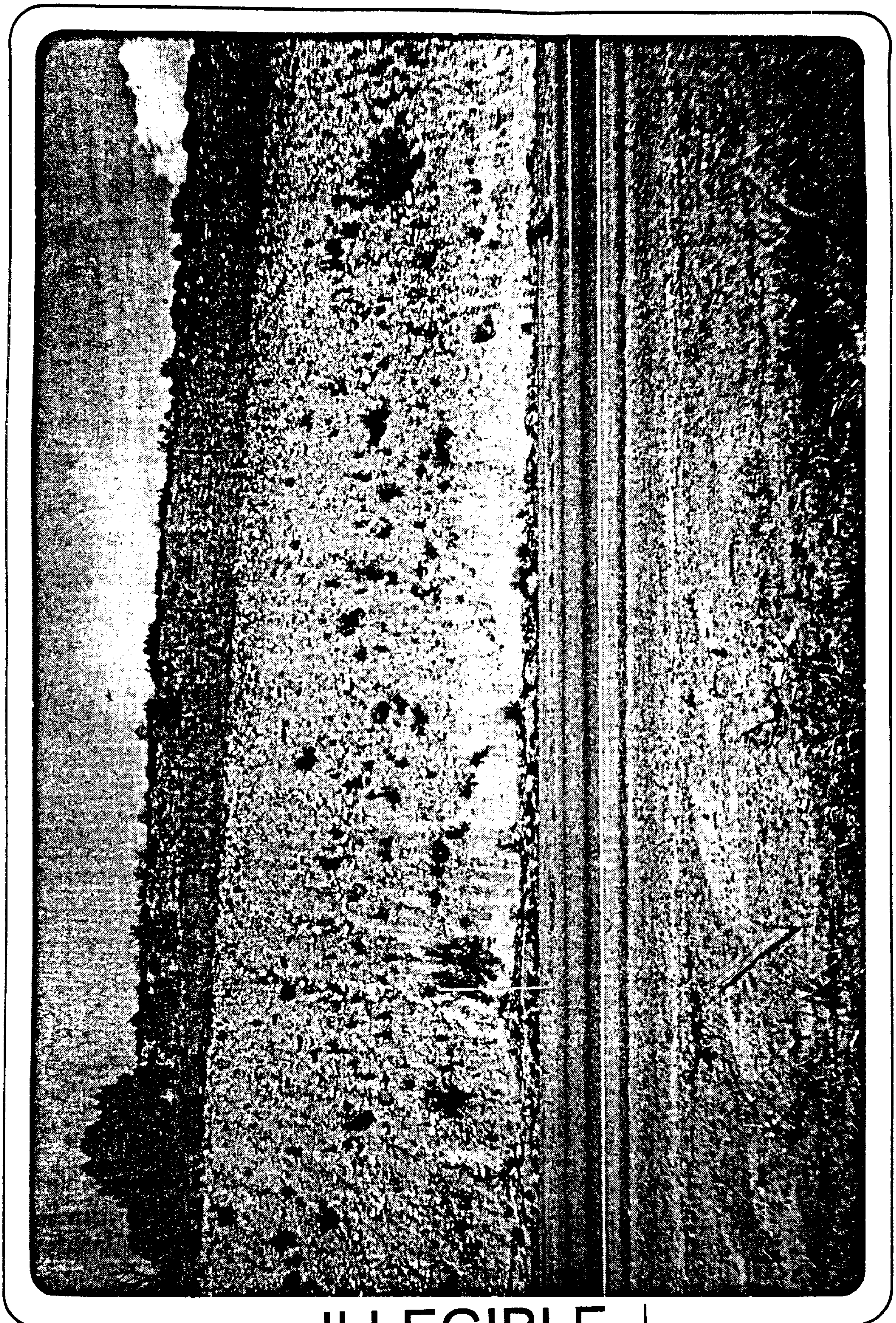


McCOY D1E Roll #2 Slide 7

ILLEGIBLE

VALLEY SIDE SLOPES AND TRIBUTARIES

MEDIUM HYDRAULIC CONDUCTIVITY CASES

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	SENW 27	32N	10W

WELL NAME KEYS GAS COM A #2

Drainage Basin:

San Juan La Plata Animas other:

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other:

Barrels Water/Day Produced: — — 0.02

Estimated Hydraulic Gradient:

Estimated Hydraulic Conductivity: 10^2 10^3 → 10^4 BELOW *

Formation/Grain Size of Unsaturated Zone:

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water:

Pit Description Dry

Standing Water Estimated Depth: 0.3 ft

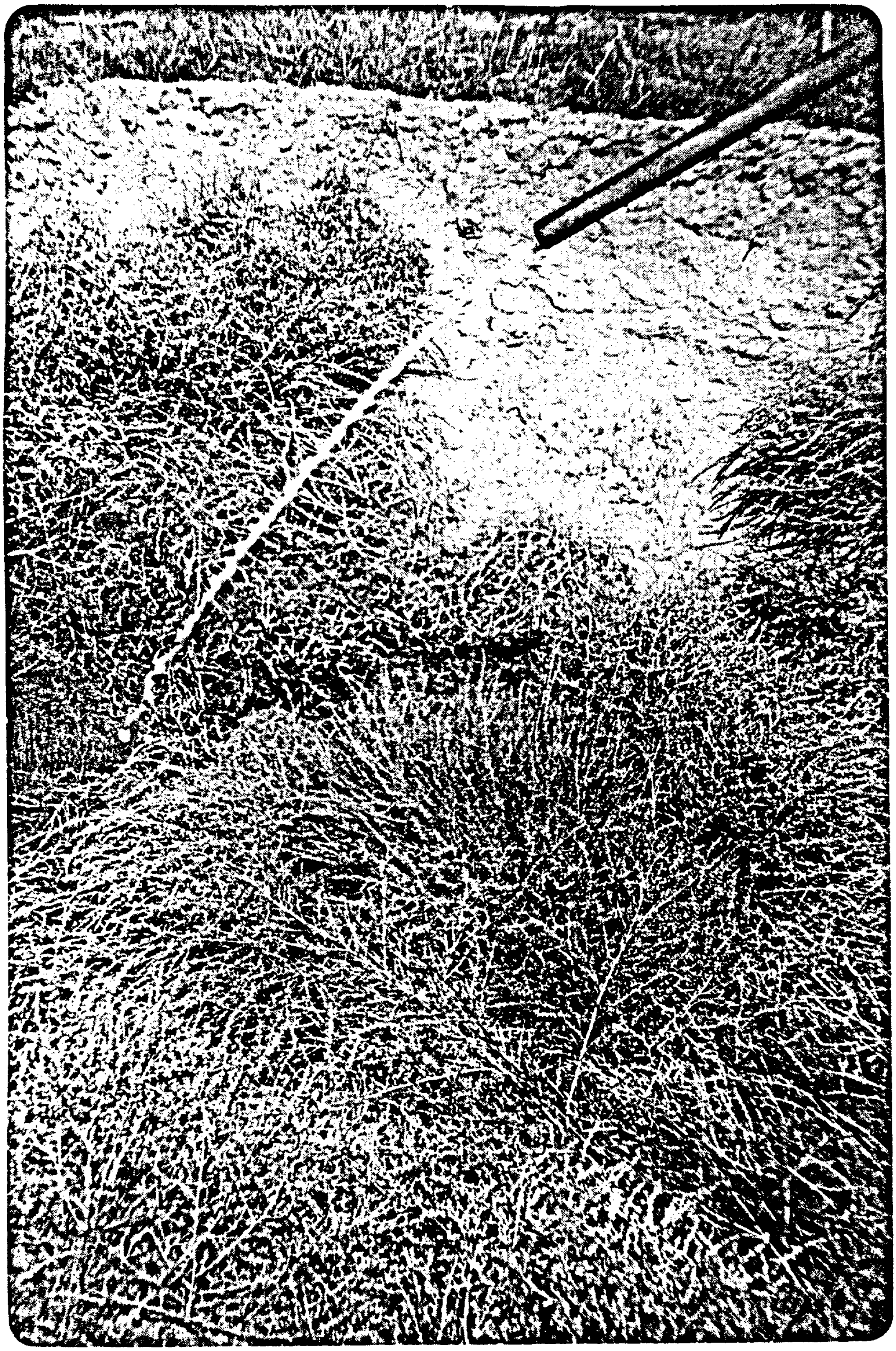
Photographs of Site: #18 PIT DUMP, #19 BOTTOM OF PIT, #20 FROM PIT TO RIVER

Producing Formation: BASIN DAKOTA

Comments: ABSOLUTE EDGE OF VALLEY FLOOR

* ARROYO NEAR PIT SHOWS LARGE BOULDERS AND MED SAND

4/10/85 CTH



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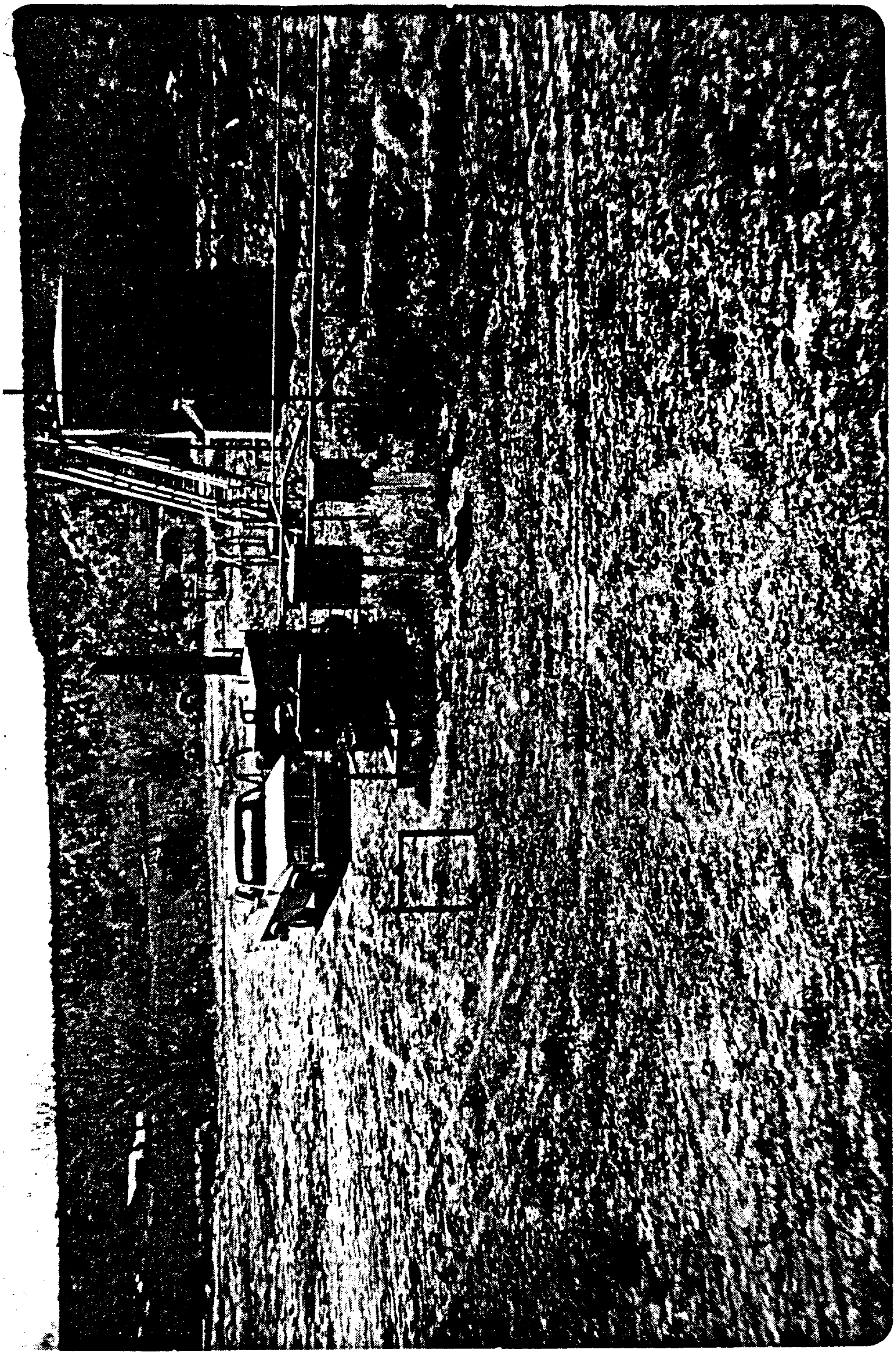
KEY A2 Roll #2 Slide 18

KEY A2 Roll #2 Slide 19

ILLEGIBLE



KEY A2 Roll #2 Slide 21

ILLEGIBLE

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	NE/NW 27	29N	9W

WELL NAME FLORANCE 124

Drainage Basin:

San Juan La Plata Animas other: LARGO

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other: ________

Barrels Water/Day Produced: 1

Estimated Hydraulic Gradient: ________

Estimated Hydraulic Conductivity: 1000

Formation/Grain Size of Unsaturated Zone:

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: ________

Pit Description Dry

Standing Water Estimated Depth: ________

Photographs of Site: ________

Producing Formation: DK/MV

Comments: LARGO

FLORANCE 4/2 SHOT # 20

NO PHOTOGRAPHS AVAILABLE

Geoscience
Consultants, Ltd.

	Section	TWP	RNG
Location	SW SW/3	30N	9W

WELL NAME FLORENCE 9

Drainage Basin:

San Juan La Plata Animas other: PUMP WASH

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other: ______

Barrels Water/Day Produced: 0.5

Estimated Hydraulic Gradient: 0.01

Estimated Hydraulic Conductivity: 10^3 10^2 GPD/FT^2

Formation/Grain Size of Unsaturated Zone:

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: ______

Pit Description Dry

~~Standing Water~~ Estimated Depth: 0.5 ft

Photographs of Site: 16, 17 18 PIT NOTE HC FILM AND MESA IN BACK

Producing Formation: MESA VERDE

Comments: WATER LOOKS PRETTY BAD

IT HAS BEEN HIGHER - VERY LITTLE ASPHALT MAT

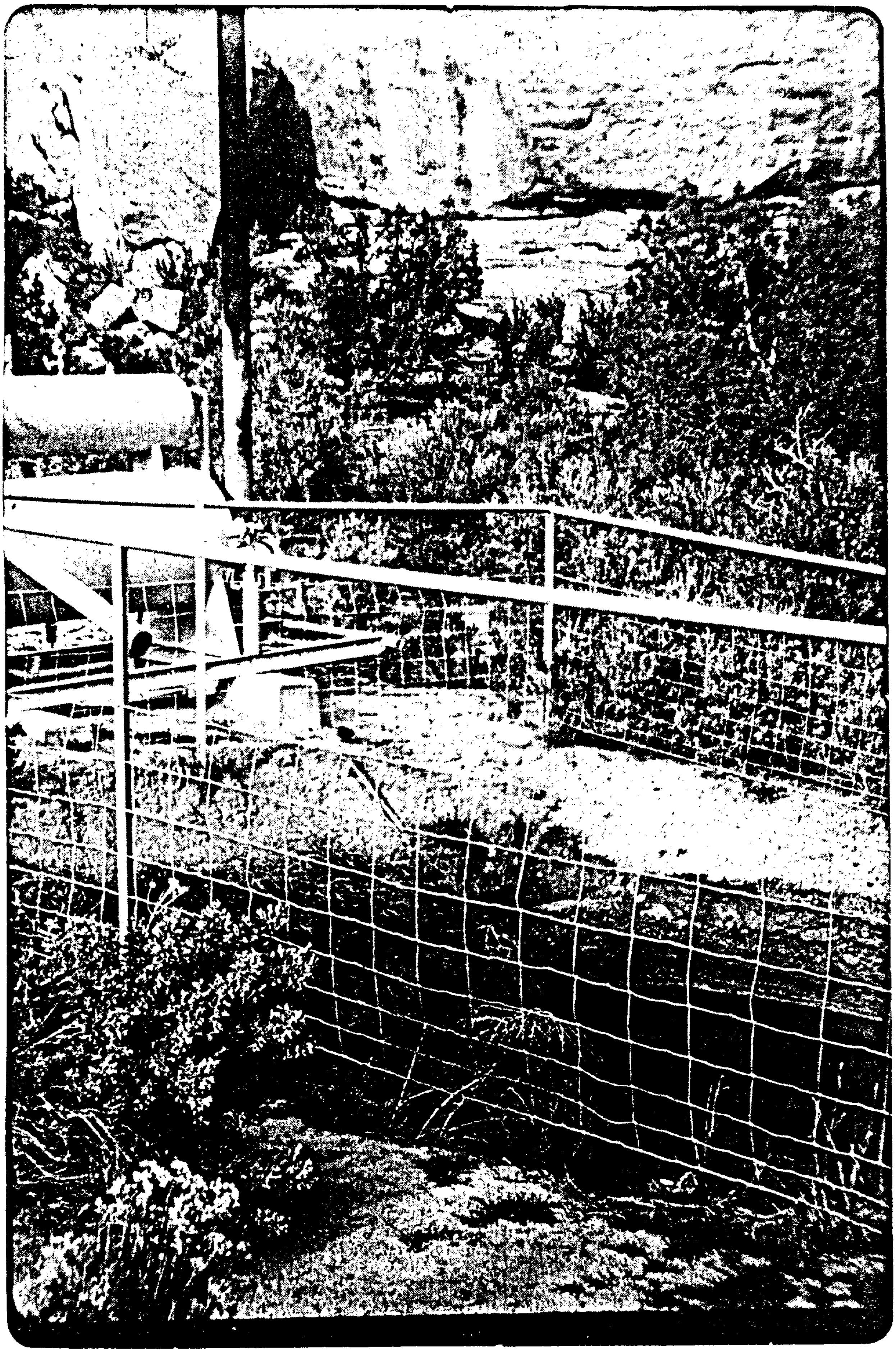
SHUT IN PUMP WASH IS RUNNING TODAY

4/10/85

RTH

FLORENCE 9 Roll #6 Slide 16

ILLEGIBLE



FLORENCE 9 Roll #6 Slide 17

LLEGIBLE

Geoscience Consultants, Ltd.

	Section	TWP	RNG
Location	NESE 35	29N	12W

WELL NAME GCU #169

Drainage Basin:

San Juan   La Plata   Animas   other: ____

Description of Location:

River Bottom * Valley Slope   Dry Tributary   Mesa   Other: ____

Barrels Water/Day Produced: — — 0.02

Estimated Hydraulic Gradient: ~~0.003~~ 0.01

Estimated Hydraulic Conductivity: 10^3

Formation/Grain Size of Unsaturated Zone: SOIL

Very Fine   Fine   Med   Coarse   Very Coarse

Sorting: Poor   Fair   Good

Estimated Depth to Ground Water: ~22'

Pit Description   Dry

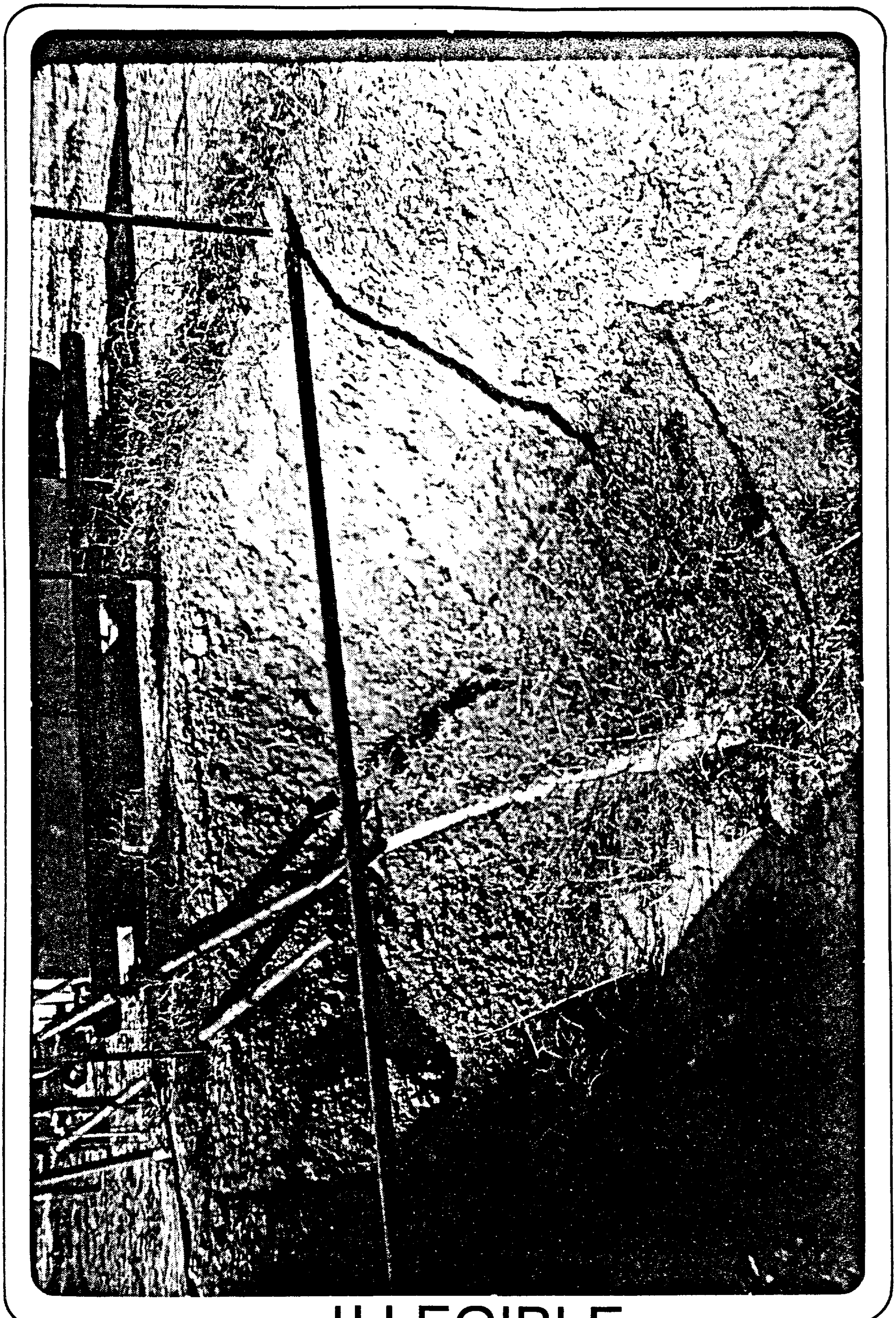
Standing Water   Estimated Depth: ____

Photographs of Site: ~~20~~ 21 — PIT

Producing Formation: BASIN DAKOTA

Comments: * 1ST RIVER TERRACE   CANALS ETC NEAR

RAPID INFILTRATION



GCU 169 Roll #3 Slide 20

ILLEGIBLE

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	SW SW 18	31N	10W

WELL NAME CANEPLE GAS COM #1

Drainage Basin:

San Juan La Plata Animas other: ____________

Description of Location:

River Bottom Valley Slope * Dry Tributary Mesa Other: ________

Barrels Water/Day Produced: 0.16 SMALL DRIP

Estimated Hydraulic Gradient: .004

Estimated Hydraulic Conductivity: 10^2 or 10^1 GPD/FT^2 OVER THE GRAVEL

Formation/Grain Size of Unsaturated Zone: SOIL V. FEW COBBLES

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: ____________

Pit Description Dry

Standing Water Estimated Depth: WET DIRT - 2-6' SMA

Photographs of Site: 9 & 10 TWO SHOTS OF PW PIT IRR DITCH TREES BACK

Producing Formation: BLANCO MESAVERDE

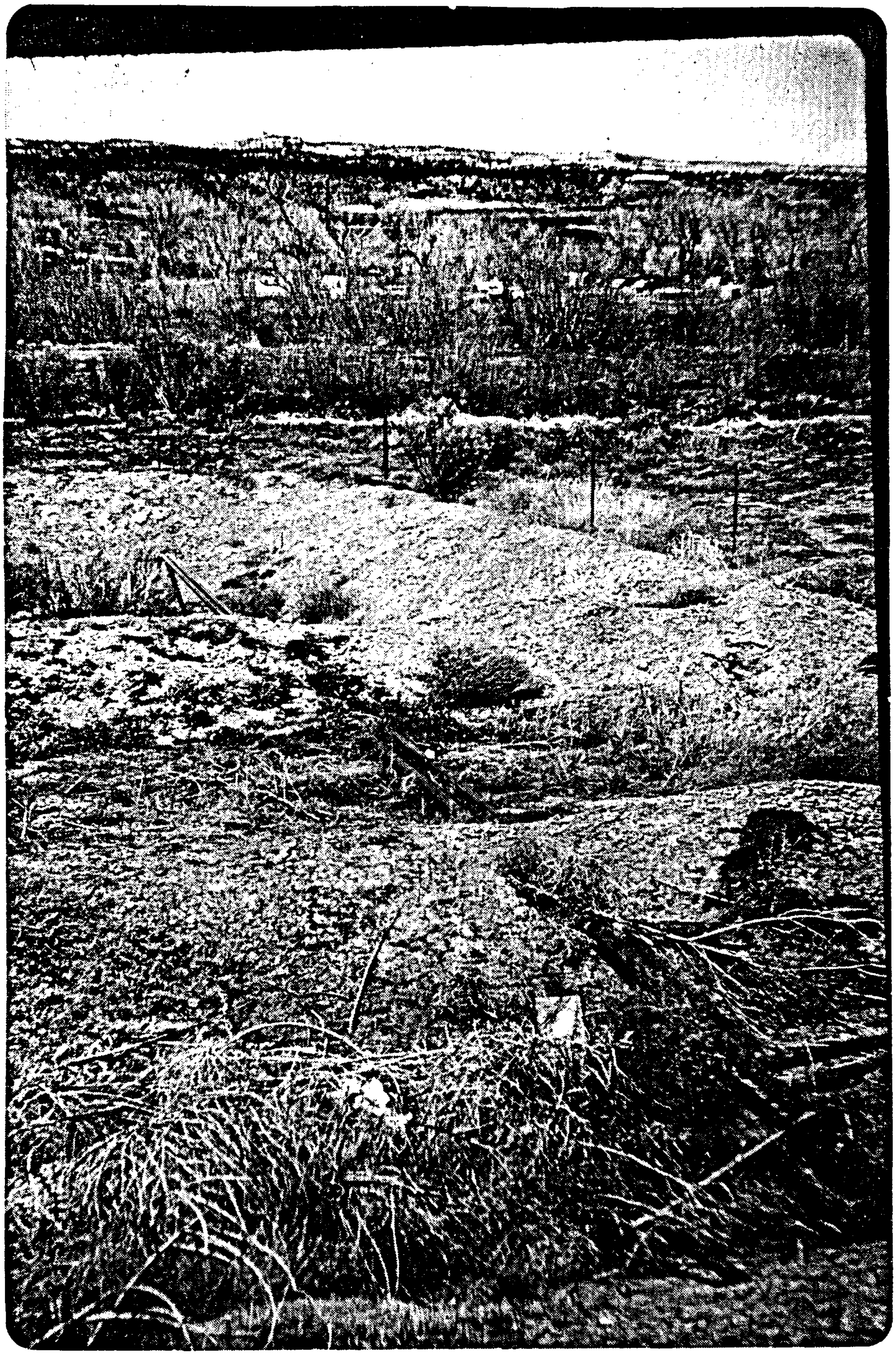
Comments: SHALEY SANDSTONE CROPS OUT ~~[illegible]~~ ON HILL SIDE OF ROAD. *WELL SITS ON OLD RIVER TERRACE

DRIPS INTO PIT

9/10/85 [illegible]

CANEPLE 1 Roll #2 Slide 9

ILLEGIBLE



CANEPLE 1 Roll #2 Slide 10

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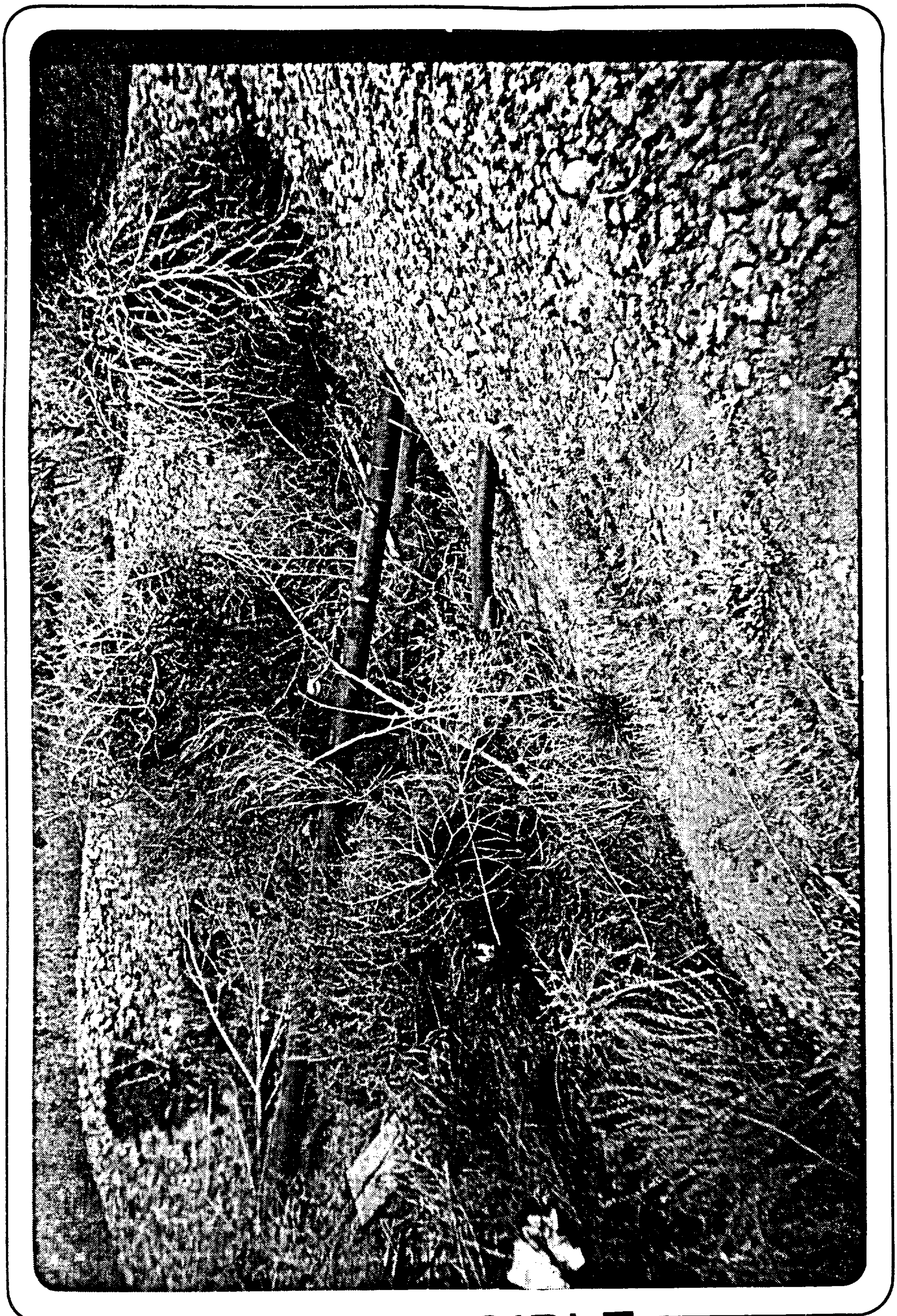


CANEPLE 1 Roll #2 Slide 11

ILLEGIBLE

CANEPLE 1 Roll #2 Slide 12

ILLEGIBLE

VALLEY SIDE SLOPES AND TRIBUTARIES

LOW HYDRAULIC CONDUCTIVITY CASES

Consultants, Ltd.

Section TWP RNG

Location SW SW 22 29N 12W

WELL NAME GCU #150

Drainage Basin:

San Juan La Plata Animas other: ____

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other: ____

Barrels Water/Day Produced: 0.86

Estimated Hydraulic Gradient: 0.01

Estimated Hydraulic Conductivity: 10^2 / 10^3

Formation/Grain Size of Unsaturated Zone: BEDROCK SANDSTONE

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: ____

Pit Description Dry

Standing Water Estimated Depth: 0.2'

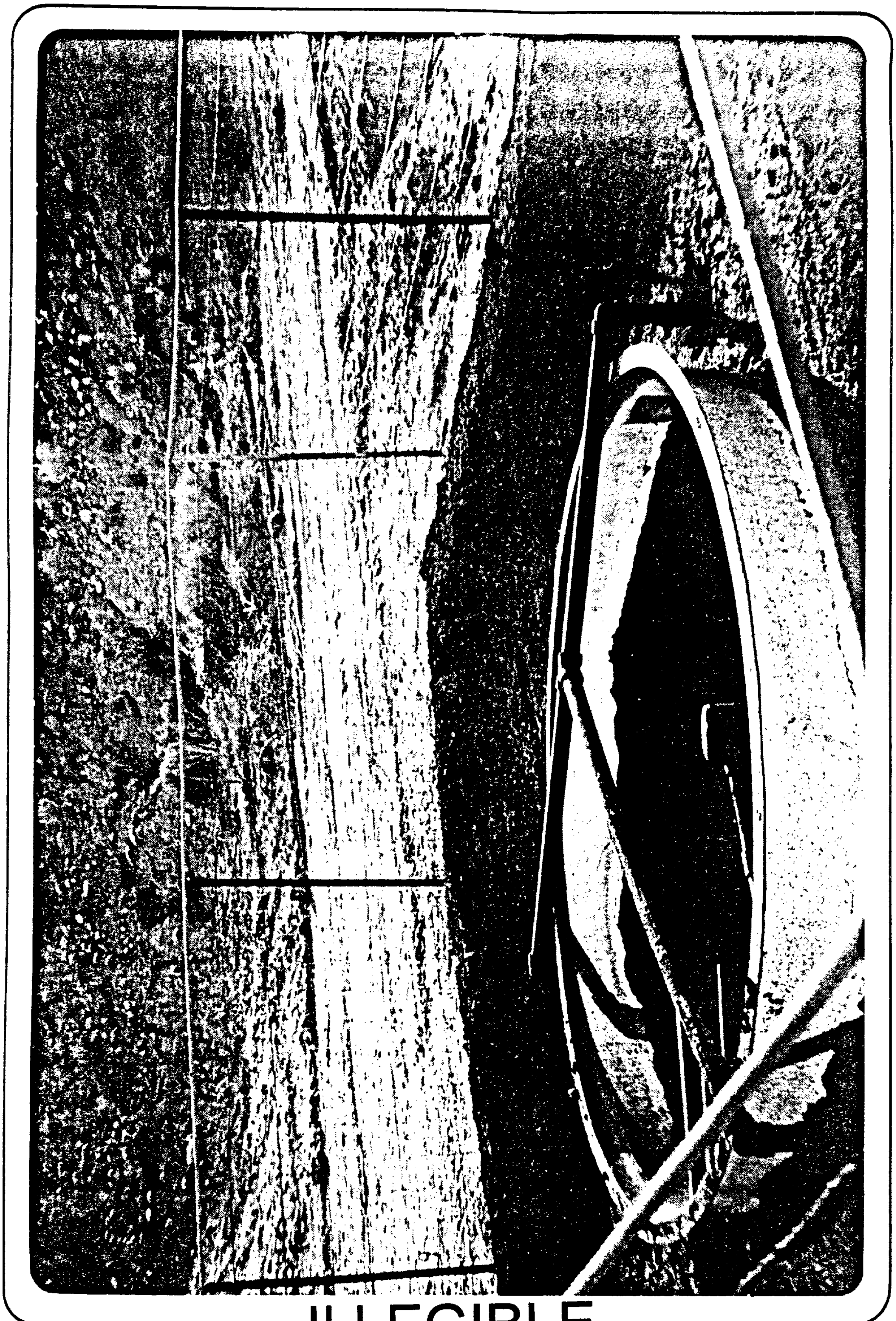
Photographs of Site: #73 14 Pit NOTE SS AND REFINERY

Producing Formation: BASIN DAKOTA

Comments: AT GIANT REFINERY

ALL SEDS DERIVED FROM SANDSTONE AND RIVER GRAVEL

SEE PHOTO



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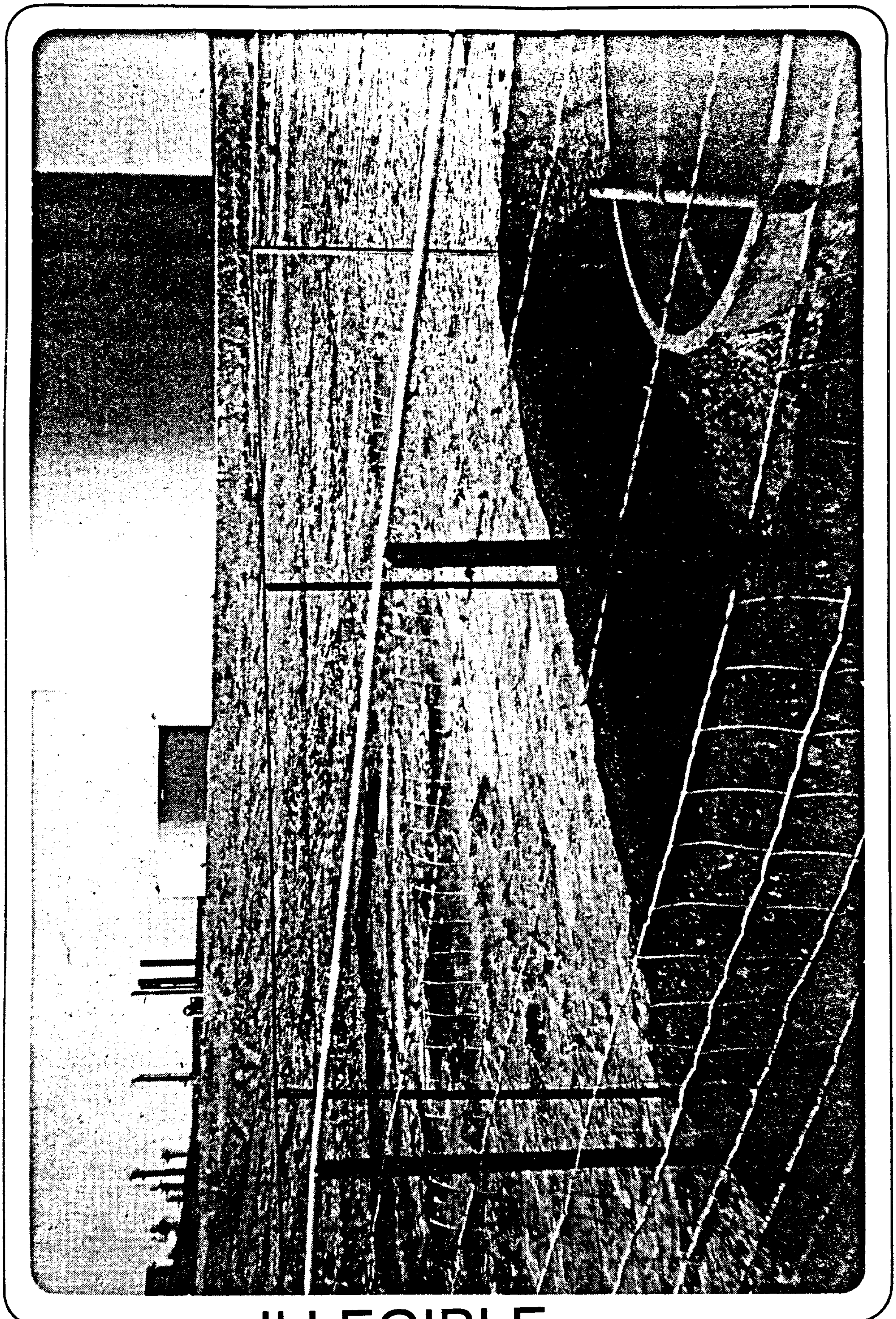
GCU 150 Roll #3 Slide 13



ILLEGIBLE

GCU 150 Roll #3 Slide 14

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	NWSW 24	29N	10W

WELL NAME ~~CANDELARIA A #1~~ MARTINEZ F 1

Drainage Basin:

San Juan   La Plata   Animas   other: ____________

Description of Location:

River Bottom   Valley Slope *   Dry Tributary   Mesa   Other: ________

Barrels Water/Day Produced: 0.2

Estimated Hydraulic Gradient: 10^{2} - 10 GPD/FT^{2}

Estimated Hydraulic Conductivity: 0.01

Formation/Grain Size of Unsaturated Zone: SOIL

Very Fine   Fine   Med   Coarse   Very Coarse

Sorting: Poor   Fair   Good

Estimated Depth to Ground Water: ____________

Pit Description   Dry

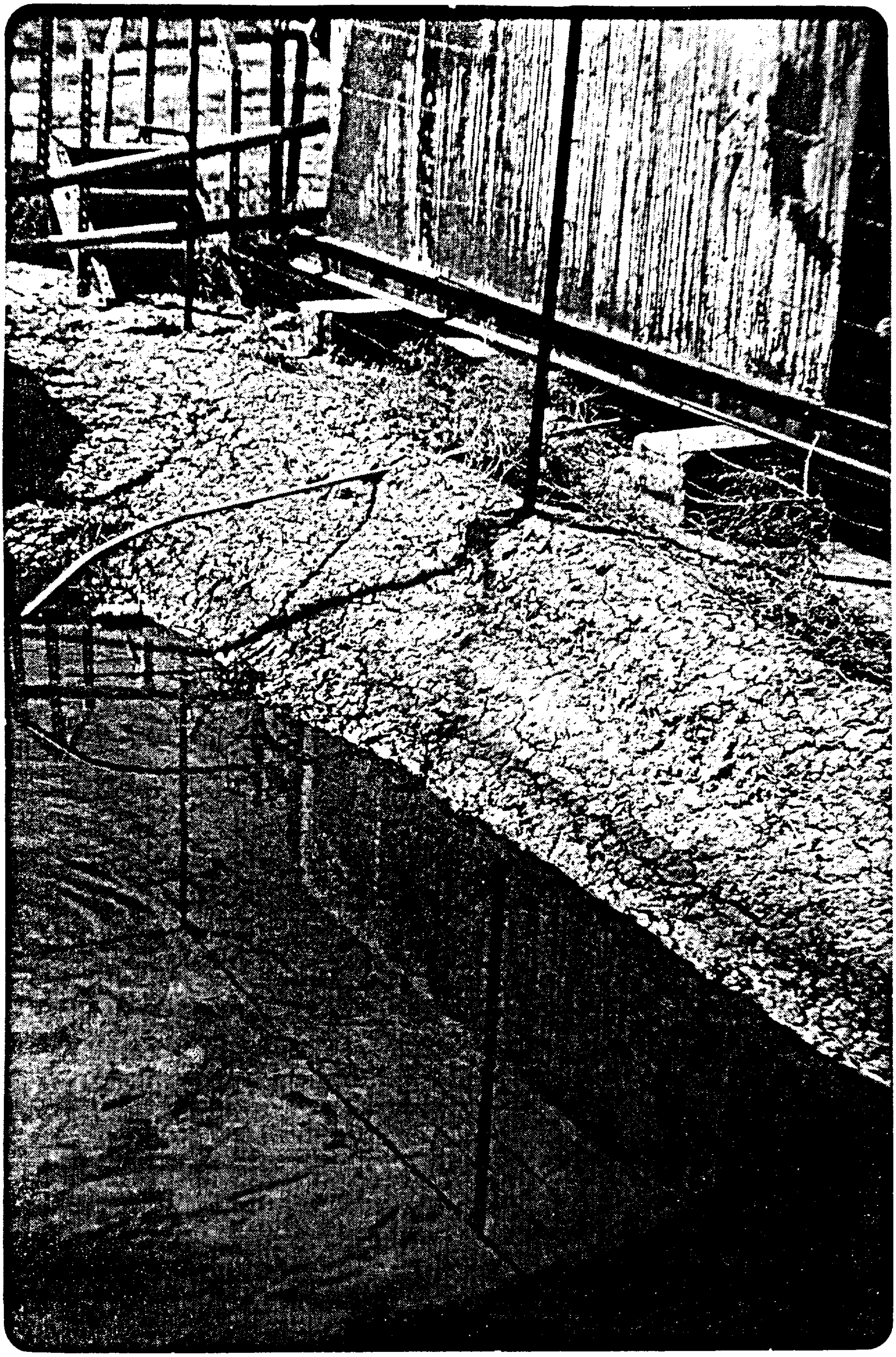
Standing Water   Estimated Depth: 2'

Photographs of Site: 10, 11 PIT - NOTE FINE SOIL

Producing Formation: ARMENTA GALLUP

Comments: * HIGH TERRACE

POOR LOOKING WATER



MARTINEZ F1 Roll #1 Slide 10

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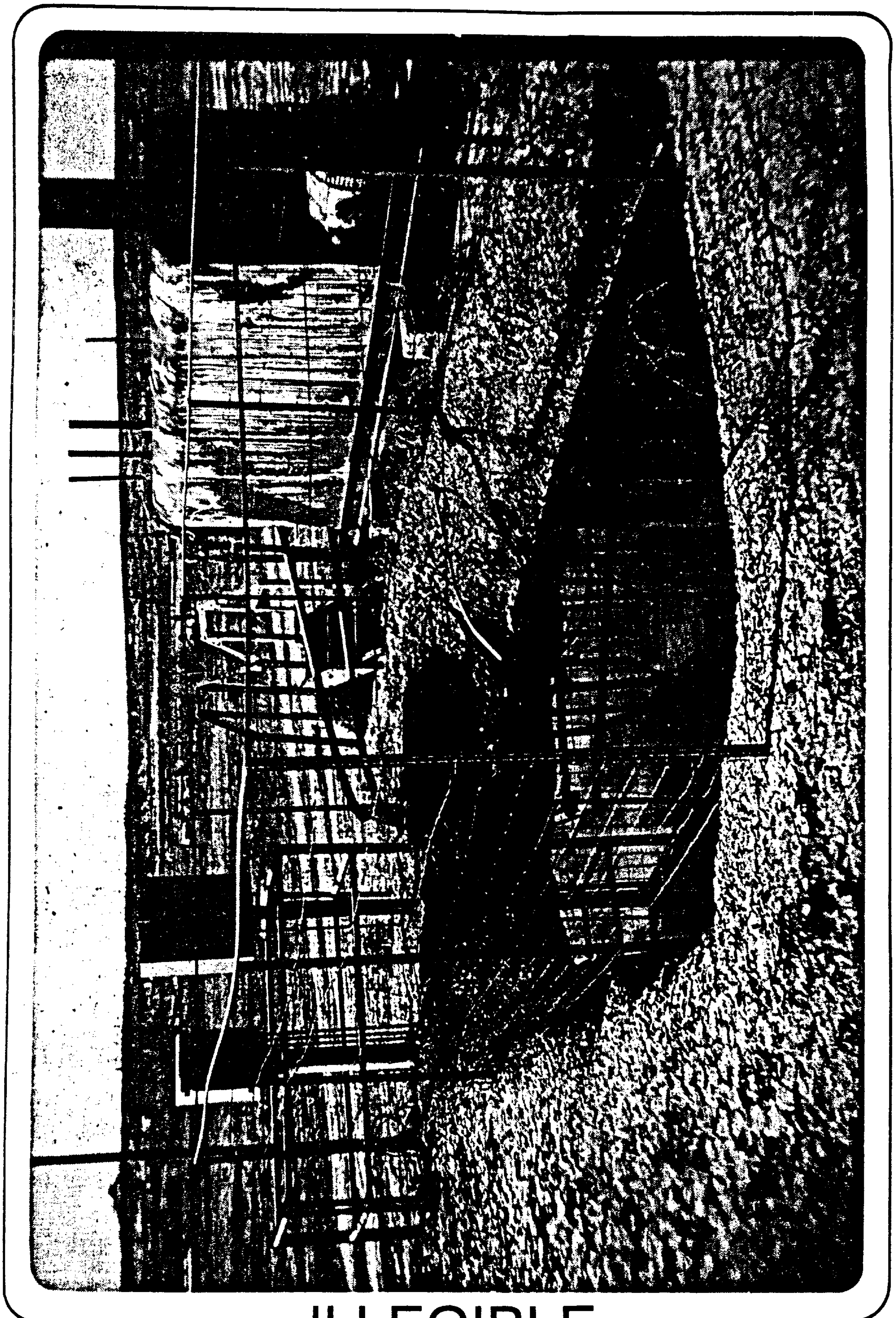


MARTINEZ F1 Roll #1 Slide 11

ILLEGIBLE

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	SW/NE 24	29N	11W

WELL NAME VALDEZ A 1E

Drainage Basin:

San Juan ~~La Plata~~ Animas other: ________

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other: ________

Barrels Water/Day Produced: 1

Estimated Hydraulic Gradient: 0.01

Estimated Hydraulic Conductivity: 10^{-2}

Formation/Grain Size of Unsaturated Zone:

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: 10-12

Pit Description Dry

Standing Water Estimated Depth: ________

Photographs of Site: ________

Producing Formation: DK/CH

Comments: ________

NO PHOTOGRAPHS AVAILABLE

Geoscience
Consultants, Ltd.

	Section	TWP	RNG
Location	28 860 FSL 805 FEL	29	10

WELL NAME POLLOCK COM E #1

Drainage Basin:

San Juan La Plata Animas other: ____________

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other: ________

Barrels Water/Day Produced: -- 0.02

Estimated Hydraulic Gradient: 0.01

Estimated Hydraulic Conductivity: 10^2

Formation/Grain Size of Unsaturated Zone:

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: 14-16'

Pit Description Dry

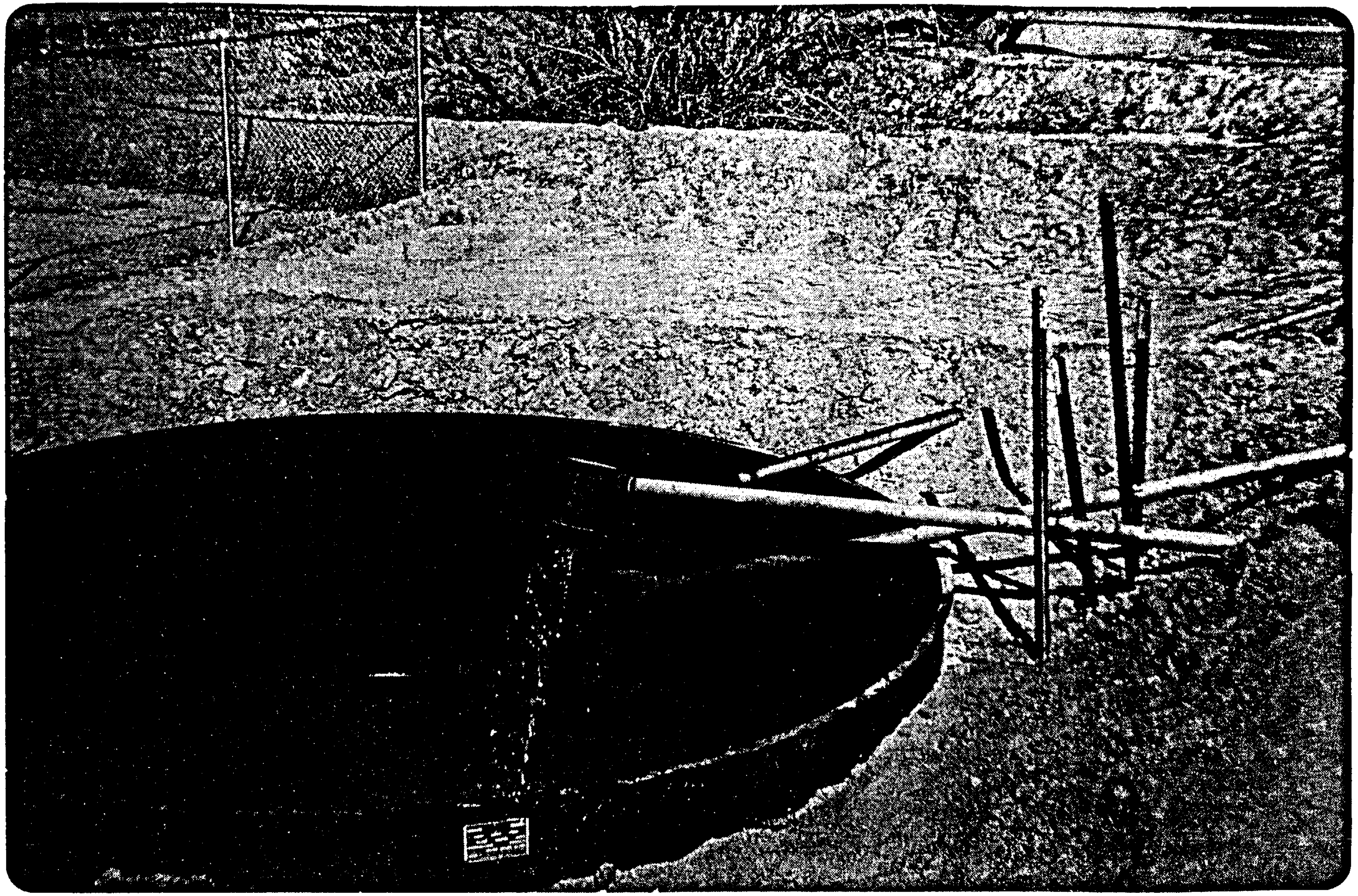
Standing Water Estimated Depth: FENCED - COULD NOT SEE

Photographs of Site: PIT 10, 11

Producing Formation: ARMENTA GALLUP

Comments: CONDENSATE? ENTERING LINED PIT!

[redacted] SEPARATOR UPSET CONDITION



ILLEGIBLE

POLLOCK E1 Roll #4 Slide 10

Consultants, Ltd.

	Section	TWP	RNG
Location	NENW 29	29N	10W

WELL NAME BLACK GAS COM #1

Drainage Basin:

San Juan La Plata Animas other: ______

Description of Location:

☆ River Bottom Valley Slope Dry Tributary Mesa Other: ______

Barrels Water/Day Produced: 0.06

Estimated Hydraulic Gradient: 0.01

Estimated Hydraulic Conductivity: 10^2 GPD/FT^2

Formation/Grain Size of Unsaturated Zone:

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: 10-12'

Pit Description Dry

Standing Water Estimated Depth: ______

Photographs of Site: 12 PIT

Producing Formation: BASIN DAKOTA

Comments: ☆ FIRST TERRACE

BLACK GAS COM #1 Roll #4 Slide 12

ILLEGIBLE

Consultants, Ltd.

	Section	TWP	RNG
Location	11	29N	13W
	1570 FNL		
	1110 FWL		

WELL NAME IRWIN COM 1E

Drainage Basin:

San Juan La Plata Animas other: ______

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other: ______

Barrels Water/Day Produced: ~~0~~ 0.02

Estimated Hydraulic Gradient: 0.01

Estimated Hydraulic Conductivity: 10^2

Formation/Grain Size of Unsaturated Zone:

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: ______

Pit Description Dry

Standing Water Estimated Depth: ______

Photographs of Site: #3 SEPERATOR AND DEHY

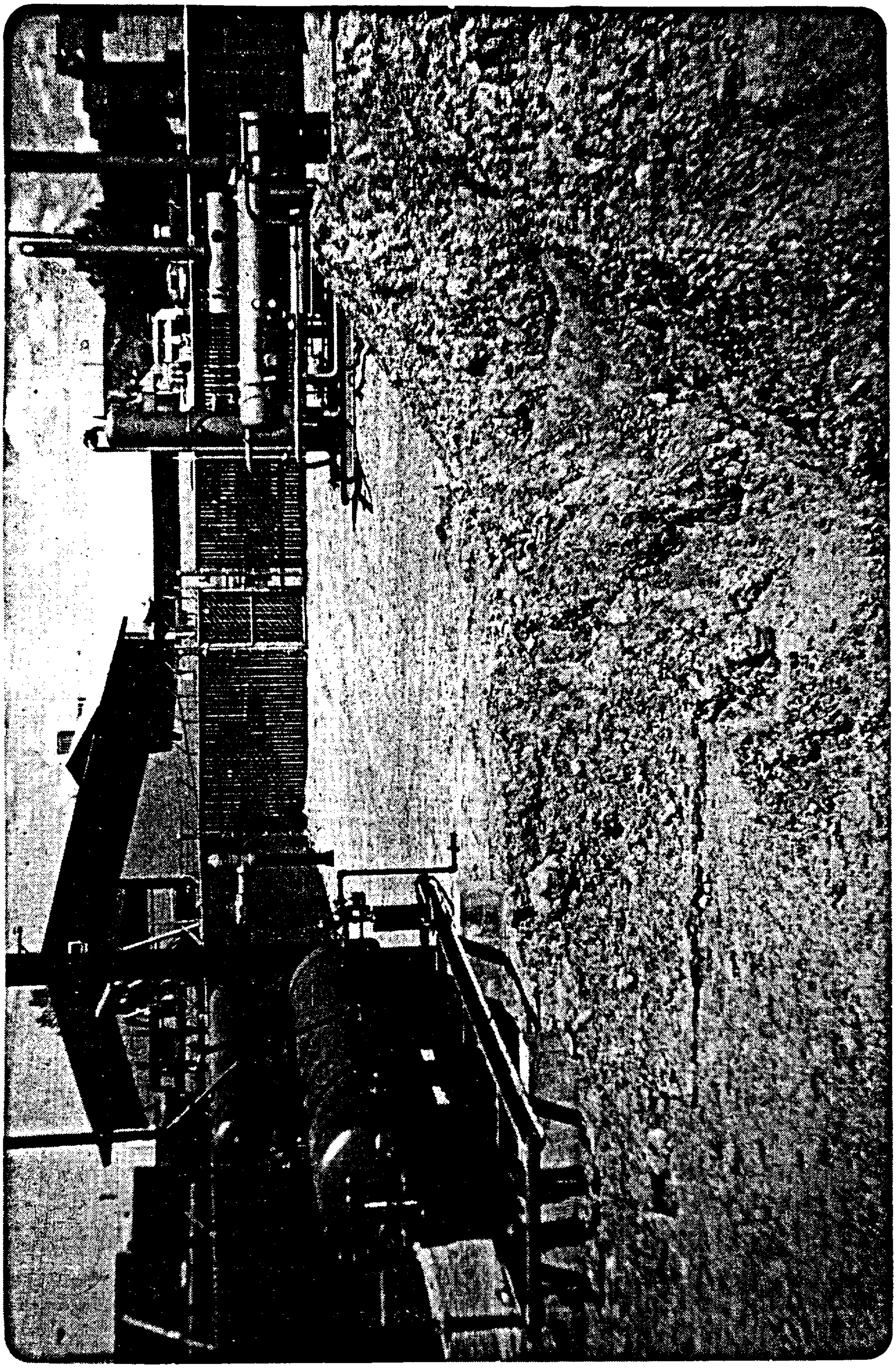
Producing Formation: DK

Comments: VALLEY BANK N of H 1/2 mile left

NEVER BEEN PUT ON LINE! PIT IS FOR HOOK UP - NOT WATER

4/12/85

KTA



IRWIN 1E Roll #2 Slide 3

ILLEGIBLE

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	SESW 8	29N	9W

WELL NAME HEATH GAS COM G #1

Drainage Basin:

San Juan La Plata Animas other: ______

Description of Location:

.027

River Bottom Valley Slope Dry Tributary Mesa Other: ______

Barrels Water/Day Produced: 0.03

Estimated Hydraulic Gradient: 0.01

Estimated Hydraulic Conductivity: 10^2 GPD/FT^2

Formation/Grain Size of Unsaturated Zone: SANDY WASH

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: ______

Pit Description Dry

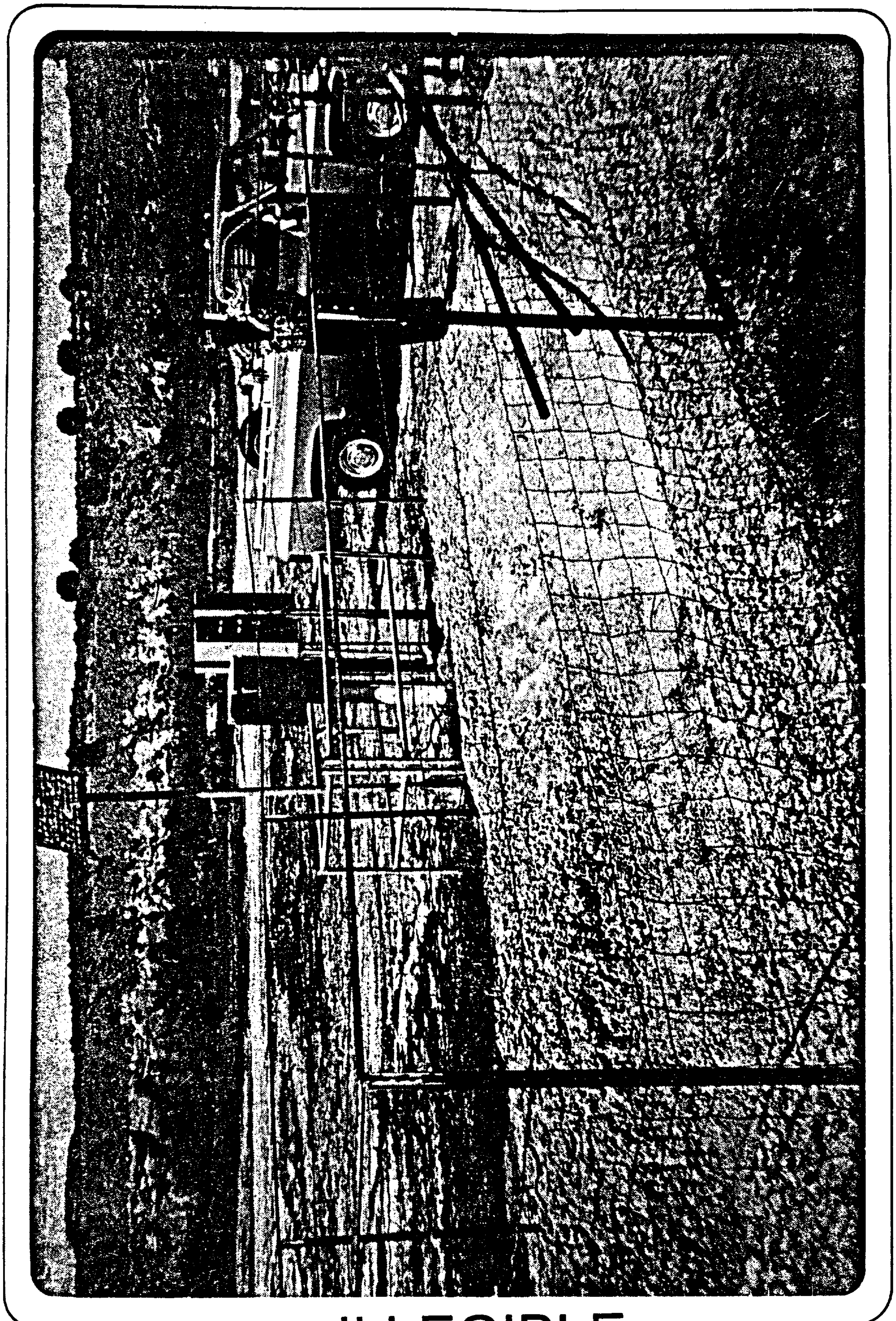
Standing Water Estimated Depth: ______

Photographs of Site: 15,16 PIT DISCHARGE NOTE BEDROCK SIDE OF WASH

Producing Formation: BASIN DAKOTA

Comments: RAPID INFILTRATION

CSH 4/11/85



HEATH GAS COM G #1 Roll #5 Slide 15

ILLEGIBLE

1.4

BEDROCK MESAS CASES

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	SW/SE 10	30N	8W

WELL NAME HOWELL 2A

Drainage Basin:

San Juan La Plata Animas other: ______

Description of Location:

River Bottom Valley Slope * Dry Tributary Mesa Other: ______

Barrels Water/Day Produced: 1

Estimated Hydraulic Gradient: 0.01

Estimated Hydraulic Conductivity: 10^4 GPD/FT

Formation/Grain Size of Unsaturated Zone:

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: ______

Pit Description: Dry ?

Standing Water Estimated Depth: ______

Photographs of Site: #~~4~~, #5, 6 Pit AT SEPERATOR

Producing Formation: MV

Comments: SHUT IN

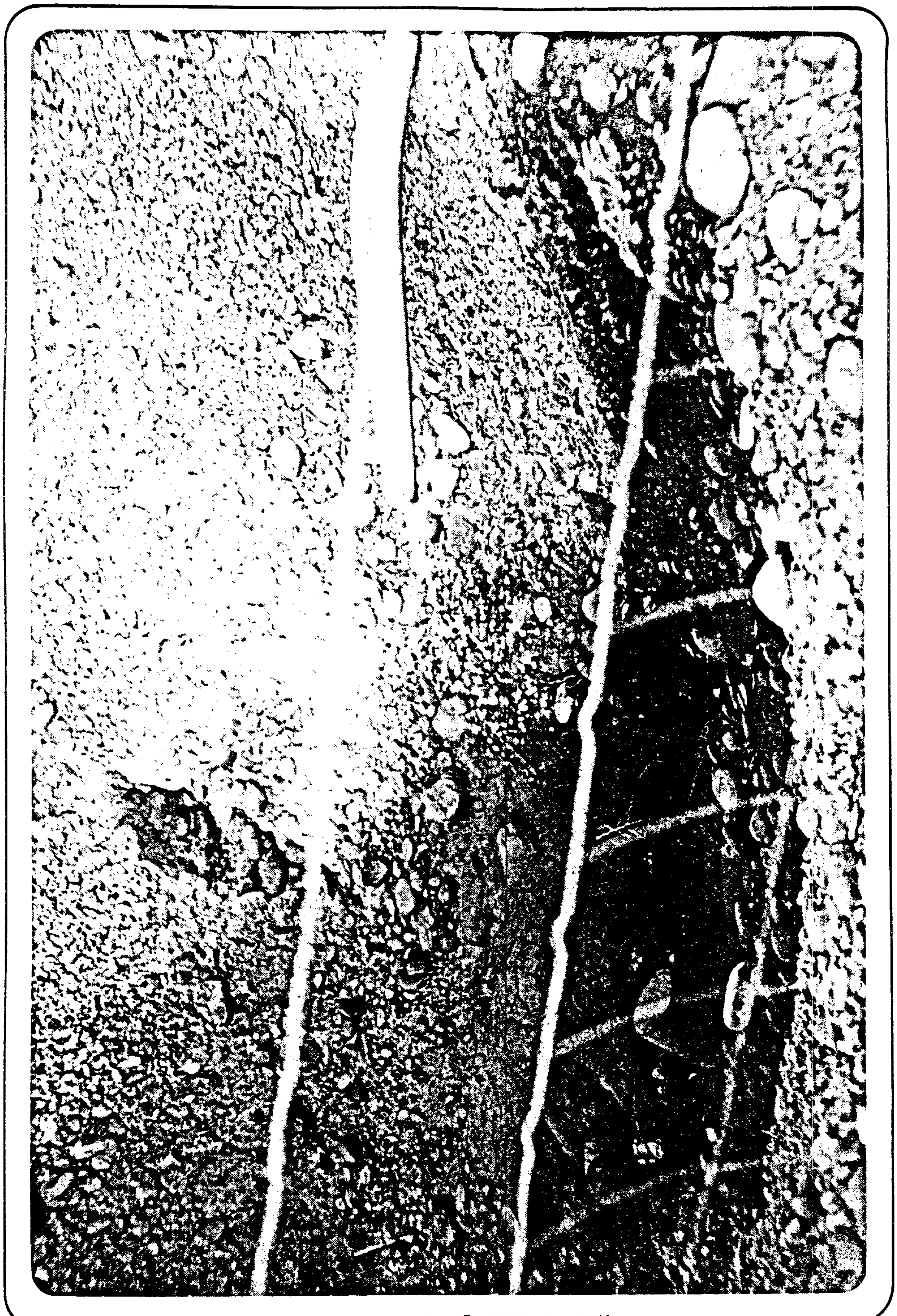
* BEDROCK BENEATH SANDSTONE

EXEMPT

4/10/85 [illegible]

HOWELL 2A Roll #3 Slide 5

ILLEGIBLE



HOWELL 2A Roll #3 Slide 6

ILLEGIBLE

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	NWNW/5	31N	10W

WELL NAME McEWEN GAS COM #1 B1 OUT SIDE VUN AREA

Drainage Basin:

San Juan La Plata Animas other: ______

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other: ______

Barrels Water/Day Produced: --

Estimated Hydraulic Gradient: ______

Estimated Hydraulic Conductivity: 10 PERCHED

Formation/Grain Size of Unsaturated Zone:

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: ~~14~~ 15 - RIVER SHOT TOWARD RIVER 15 - PIT W/FLUID

NOTE AREA OF EVAP PONDS FOR AMOCO

Pit Description Dry

Standing Water Estimated Depth: 0.33

Photographs of Site: ______

Producing Formation: BLANCO - MESA VERDE

Comments: ______

4/10/85 RTH

NO PHOTOGRAPHS AVAILABLE

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	NESW, 7	29N	9W

WELL NAME HEATH, WD, A #3X

Drainage Basin:

San Juan   La Plata   Animas   other: ______

Description of Location:

River Bottom   Valley Slope   Dry Tributary   Mesa   Other: ______

Barrels Water/Day Produced: — —

Estimated Hydraulic Gradient: ______

Estimated Hydraulic Conductivity: 10 GPD/FT²

Formation/Grain Size of Unsaturated Zone:

Very Fine   Fine   Med   Coarse   Very Coarse

Sorting: Poor   Fair   Good

Estimated Depth to Ground Water: ______

Pit Description   Dry

Standing Water   Estimated Depth: 0.5'

Photographs of Site: 17 PIT DISCHARGE

Producing Formation: BLANCO MESAVERDE

Comments: SHOULD INFILTRATE WELL - SOME H-C MAT

EXEMPT

ILLEGIBLE

HEATH, WD, A #3X   Roll #5   Slide 17

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	NWNE 20	30N	8W

WELL NAME LINDA NYE 1

Drainage Basin:

San Juan   La Plata   Animas   other: ______

Description of Location:

River Bottom   Valley Slope   Dry Tributary   Mesa   Other: ______

Barrels Water/Day Produced: 1

Estimated Hydraulic Gradient: ______

Estimated Hydraulic Conductivity: 10^{-1} GPD/FT

Formation/Grain Size of Unsaturated Zone:

Very Fine   Fine   Med   Coarse   Very Coarse

Sorting: Poor   Fair   Good

Estimated Depth to Ground Water: ______

Pit Description   Dry

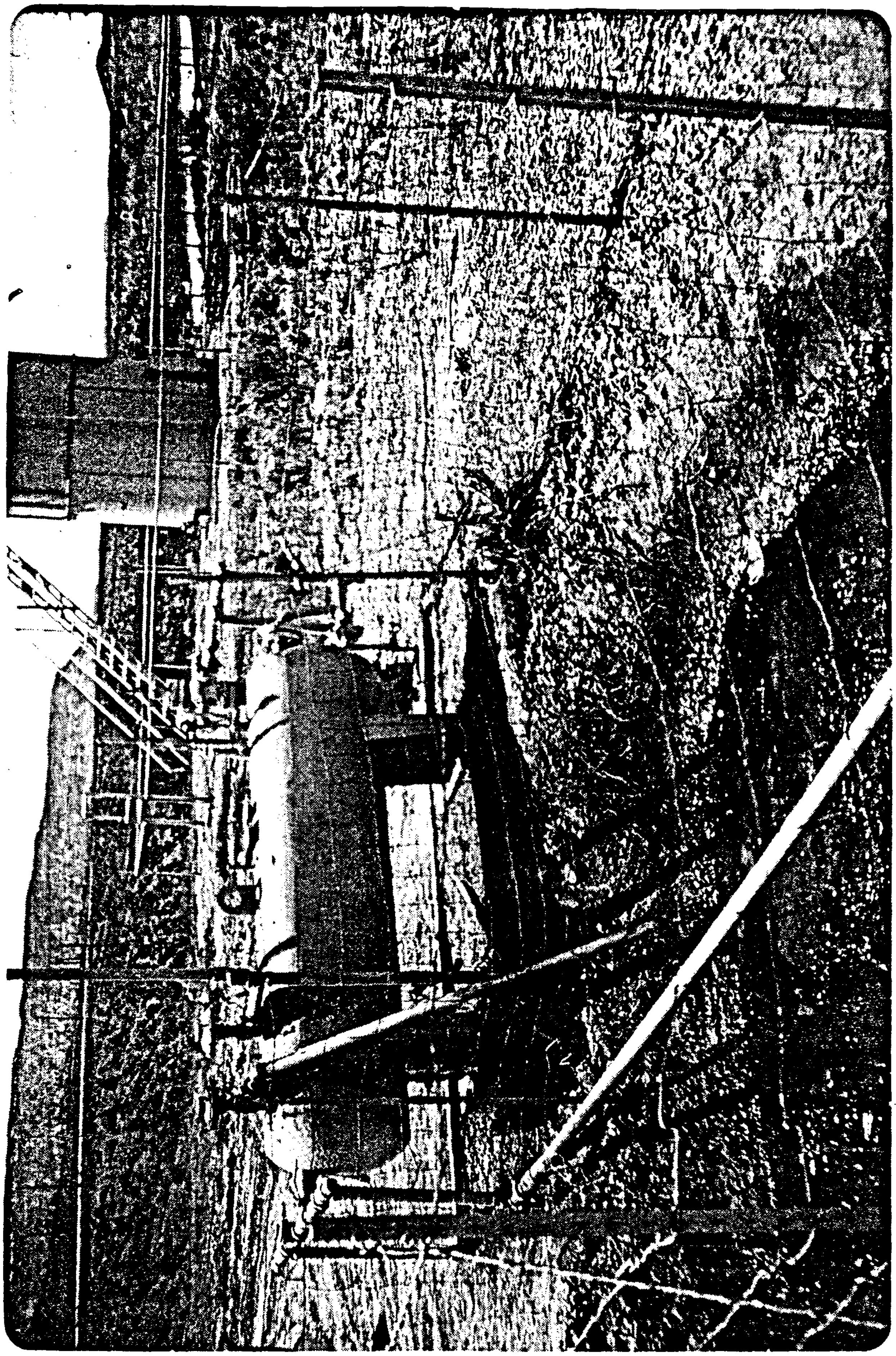
Standing Water   Estimated Depth: 0.25 ft

Photographs of Site: 8 PIT   #9 PIT ; MESA/RIVER

Producing Formation: ______

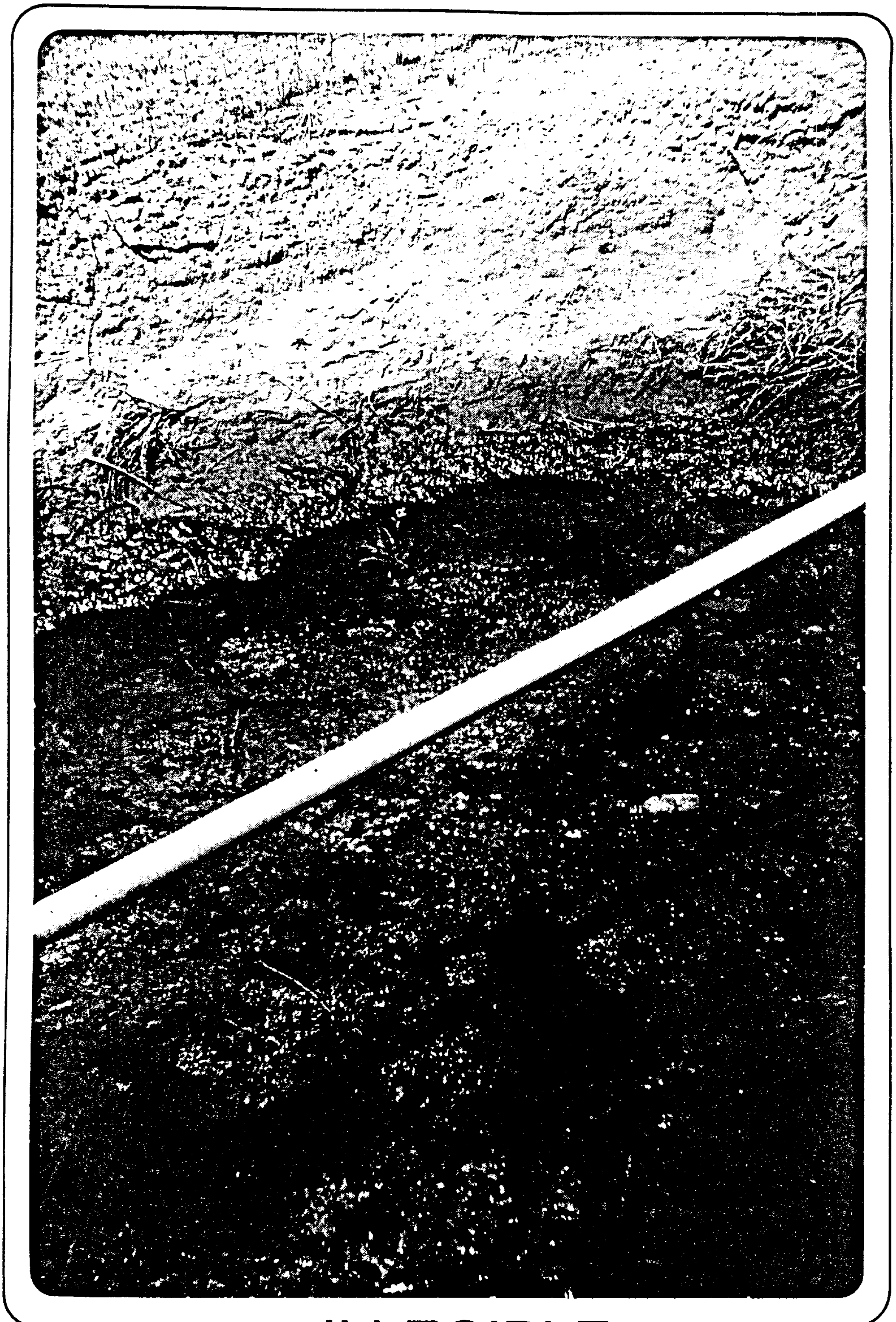
Comments: HC FILM   HC LINER

4/11/85 BTH



LINDA NYE 1 Roll #5 Slide 7

ILLEGIBLE



LINDA NYE 1 Roll #5 Slide 8

ILLEGIBLE

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	SENW 8	29N	9W

WELL NAME HEATH GAS COM H #1

Drainage Basin:

San Juan La Plata Animas other:

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other:

Barrels Water/Day Produced: — —

Estimated Hydraulic Gradient:

Estimated Hydraulic Conductivity: 10 GPD/FT²

Formation/Grain Size of Unsaturated Zone: SS/SH

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water:

Pit Description Dry

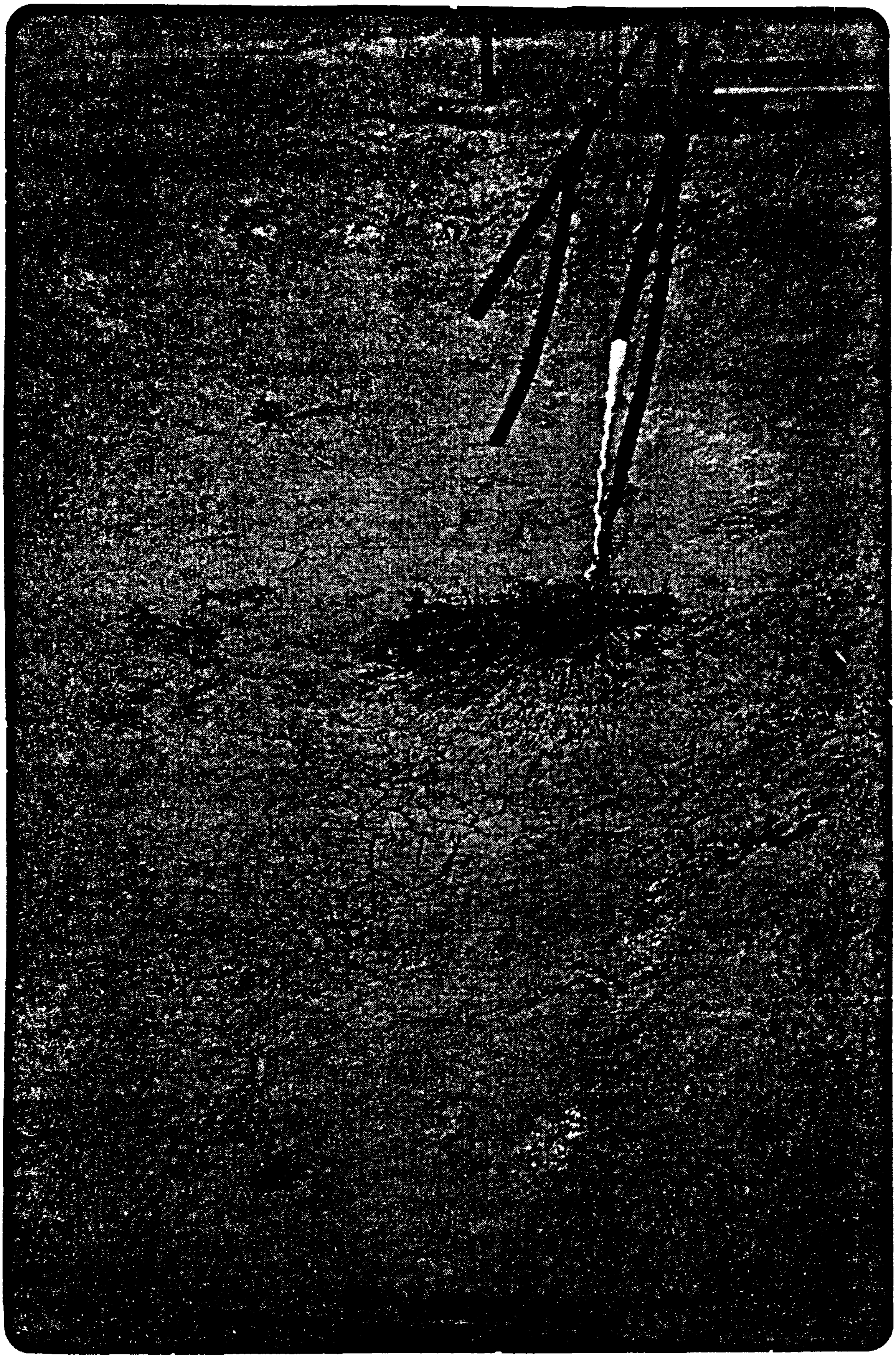
Standing Water Estimated Depth:

Photographs of Site: 13, 14 PIT W/ DISCHARGE

Producing Formation: BASIN DAKOTA

Comments:

4/11/85 RAH



HEATH GAS H 1 Roll #5 Slide 14

ILLEGIBLE

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	SENW 7	29N	9W

WELL NAME NYE GAS COM B #1E

Drainage Basin:

San Juan La Plata Animas other: ______

Description of Location:

River Bottom Valley Slope Dry Tributary * Mesa Other: ______

Barrels Water/Day Produced: 0.07

Estimated Hydraulic Gradient: ______

Estimated Hydraulic Conductivity: 10^{-3} GPD

Formation/Grain Size of Unsaturated Zone: BEDROCK IN WASH ON SHALE

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: —

Pit Description Dry

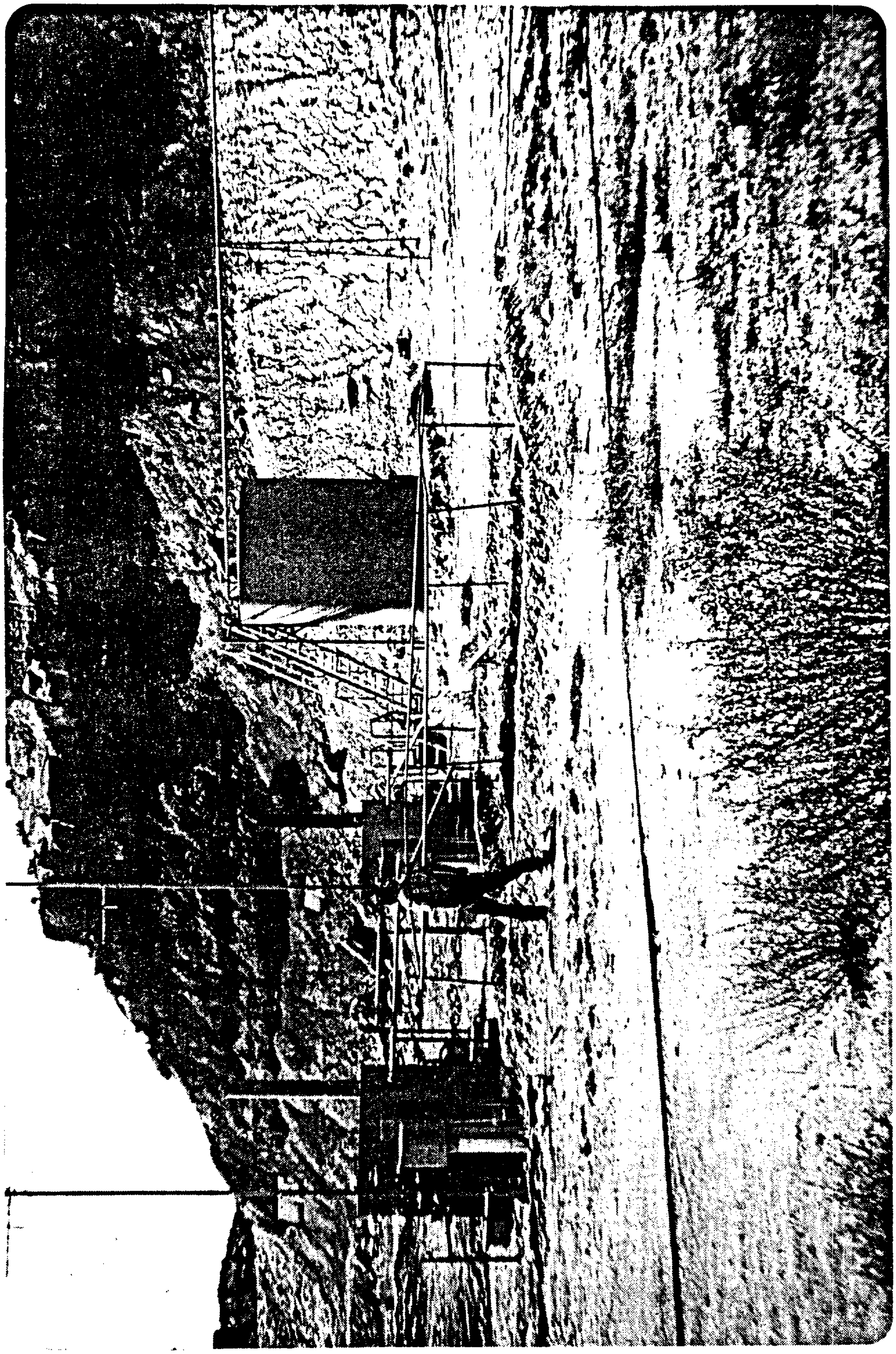
Standing Water Estimated Depth: 1.5'

Photographs of Site: #13 SITE W/ BEDROCK #14 PIT #15 PIT

Producing Formation: BASIN DAKOTA

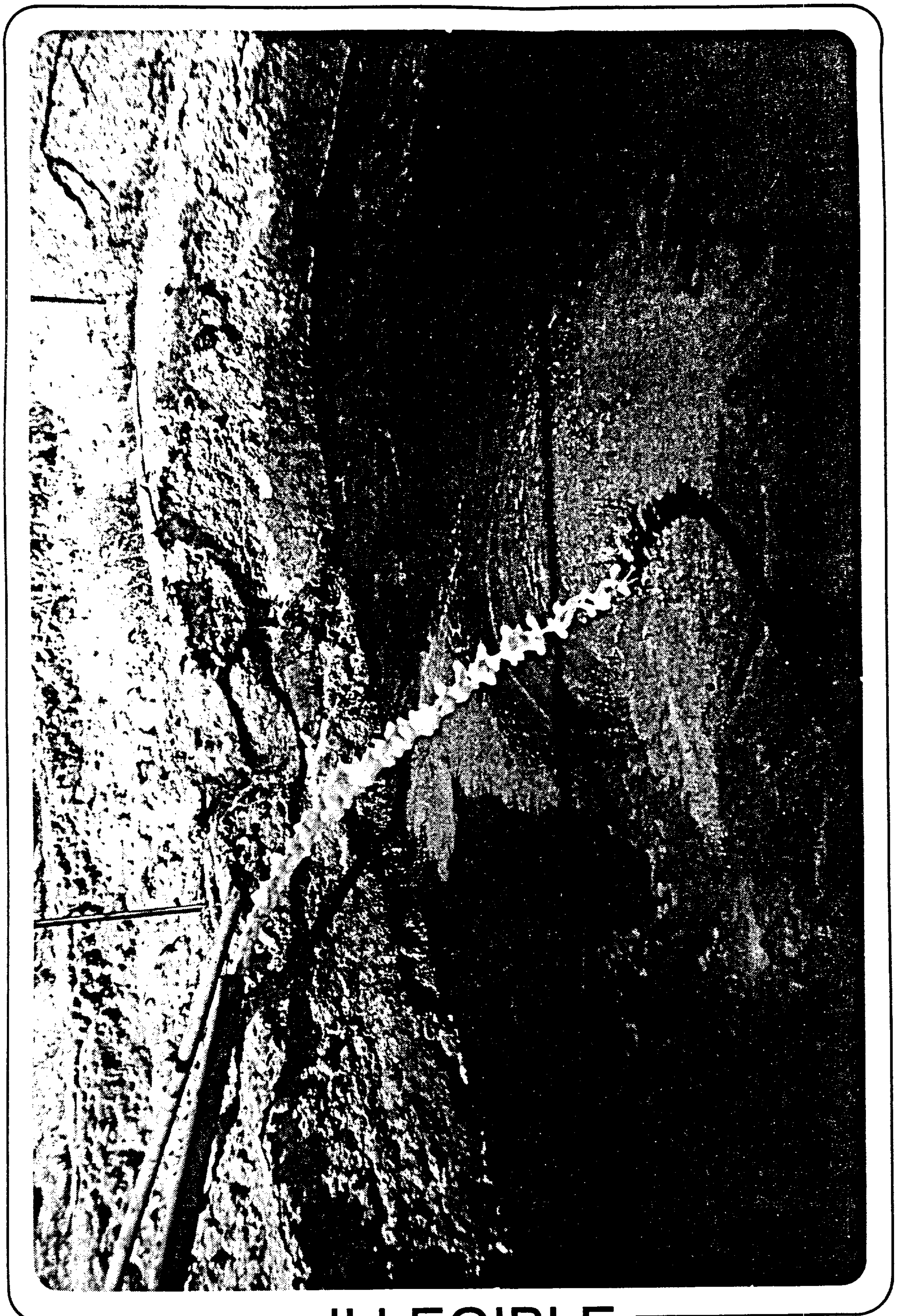
Comments: FILM OF HYDROCARBONS ON FLUID

2 SEPS INTO SAME PIT



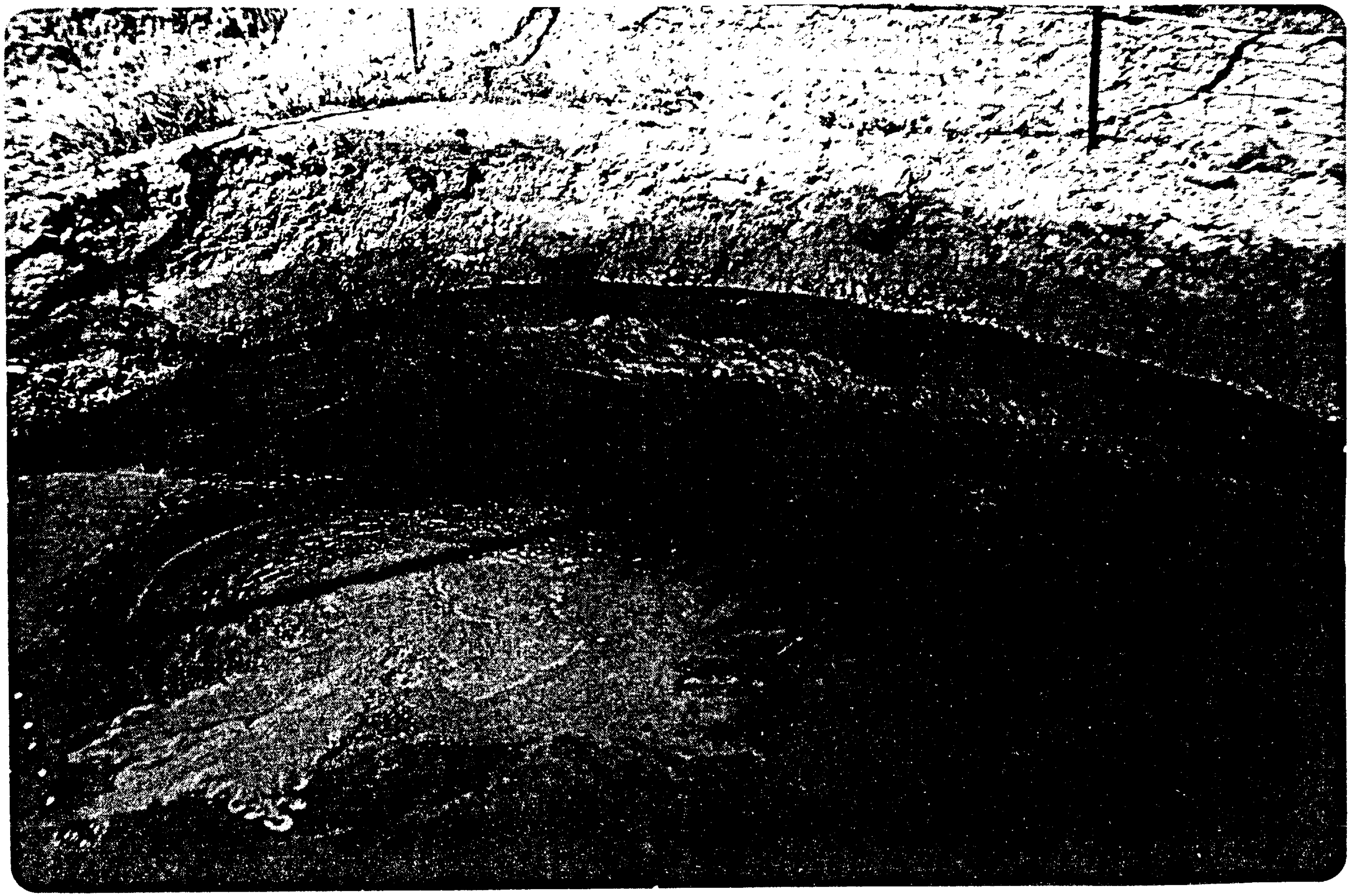
NYE B1E Roll #1 Slide 12

ILLEGIBLE



NYE B1E Roll #1 Slide 13

ILLEGIBLE



ILLEGIBLE

NYE B1E Roll #1 Slide 14

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	NESW17	29N	9W

WELL NAME HEATH, WD A #10

Drainage Basin:

San Juan La Plata Animas other: ____

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other: ____

Barrels Water/Day Produced: — — NO FLUID COULD BE DISCHARGED

Estimated Hydraulic Gradient: ____

Estimated Hydraulic Conductivity: 10 GPD/FT²

Formation/Grain Size of Unsaturated Zone: SHALE/SAND

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: ____

Pit Description Dry

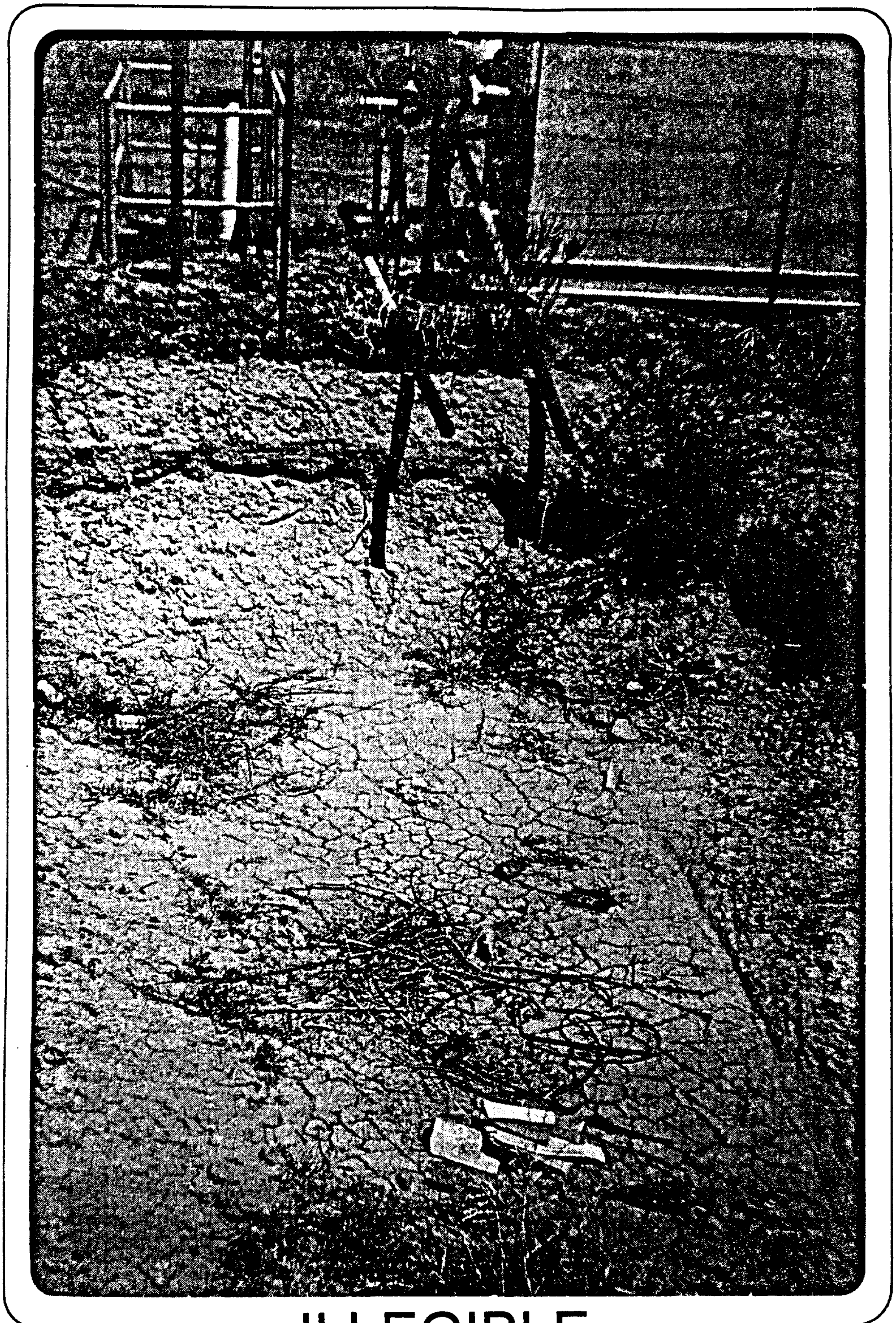
Standing Water Estimated Depth: ____

Photographs of Site: 16 PIT

Producing Formation: BASIN DAKOTA

Comments: Appears to be on shale Mesa between Loops of San Juan — HIGH INFILTRATION POSSIBLE

4/11/85 [illegible]



HEATH, WD, A #10 Roll #5 Slide 16

ILLEGIBLE

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	SESE 17	29N	9W

WELL NAME HEATH, WD, A #5

Drainage Basin:

San Juan La Plata Animas other: ________

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other: ________

Barrels Water/Day Produced: 0.03

Estimated Hydraulic Gradient: ________

Estimated Hydraulic Conductivity: 10^{-2} GPD/FT^2

Formation/Grain Size of Unsaturated Zone:

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: ________

Pit Description Dry SEP PIT

Standing Water Estimated Depth: 0.2' Reserve/Blow

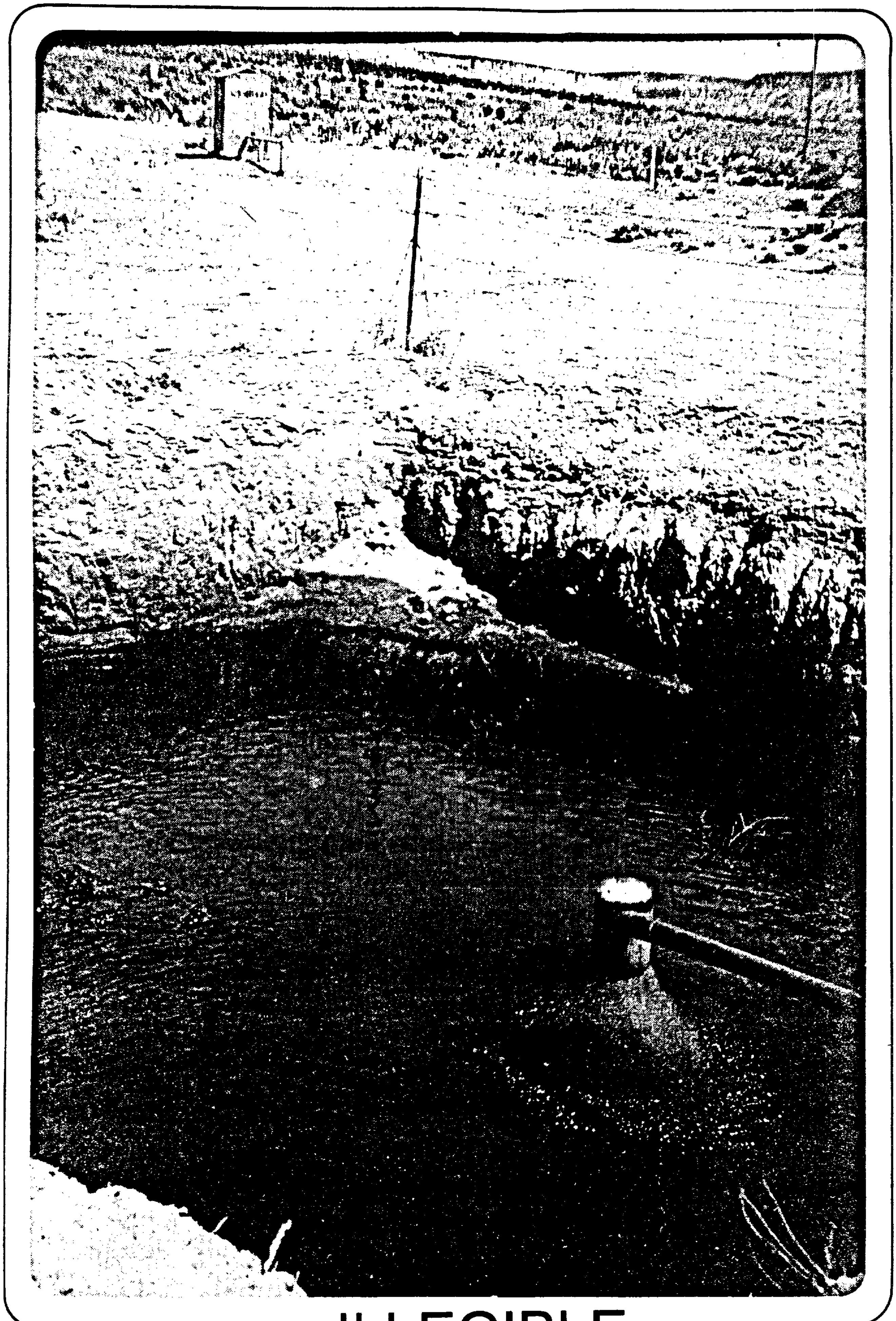
Photographs of Site: 18 Blow Pit 19 Sep Pit

Producing Formation: BLANCO PICTURED CLIFFS

Comments: SHOULD INFILTRATE MAT/LINER PRESENT

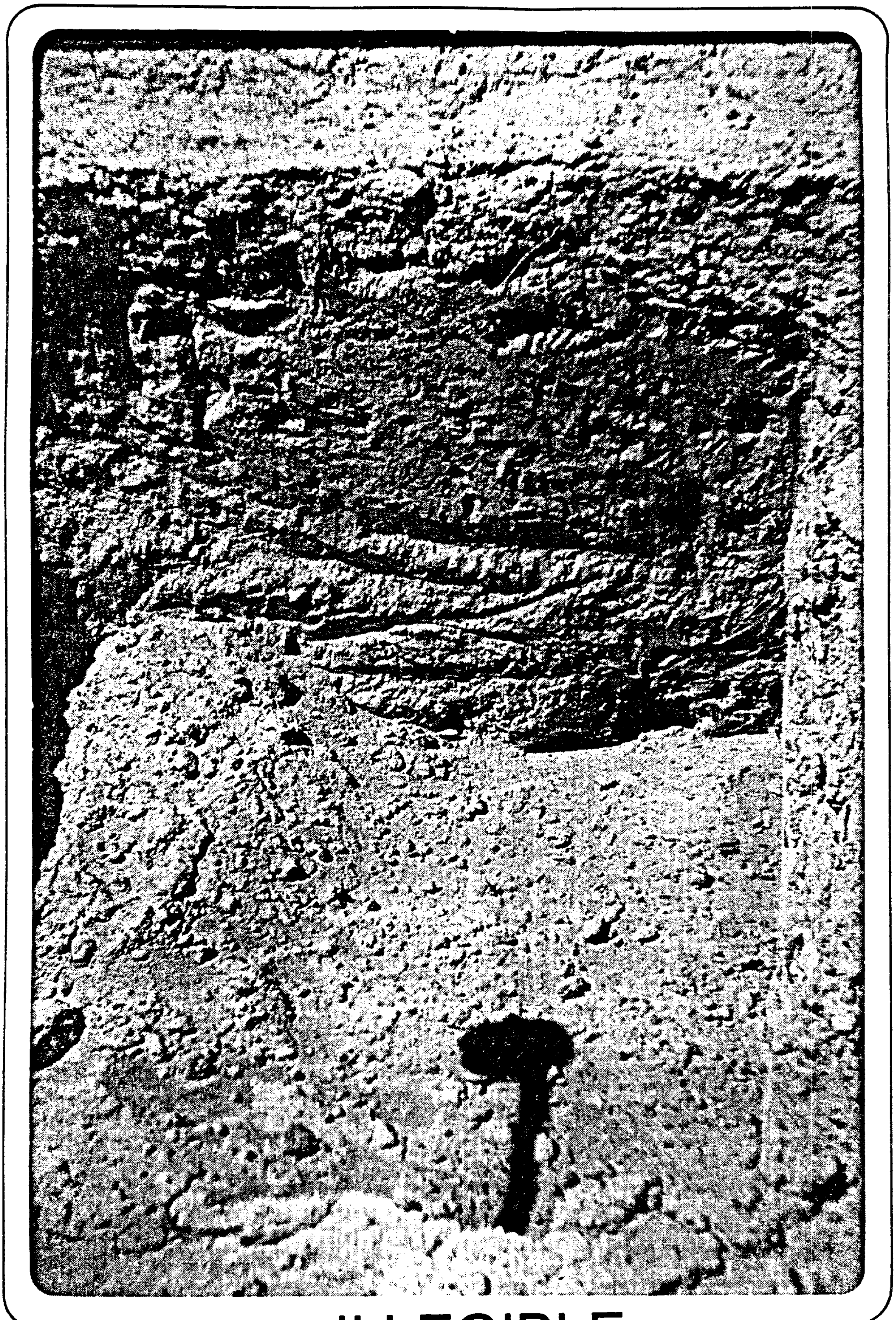
SULLIVAN RD DITCH SHOWS SHALE

1/11/85 RAH



HEATH, WD, A5 Roll #5 Slide 18

ILLEGIBLE



HEATH, WD, A5 Roll #5 Slide 19

ILLEGIBLE

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	15	30N	8W
	990 FSL		
	1650 FWL		

WELL NAME FLORANCE 32

Drainage Basin:

San Juan La Plata Animas other: ______

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other: ______

Barrels Water/Day Produced: 0.25

Estimated Hydraulic Gradient: ______

Estimated Hydraulic Conductivity: ______

Formation/Grain Size of Unsaturated Zone: SOIL

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: ______

Pit Description Dry

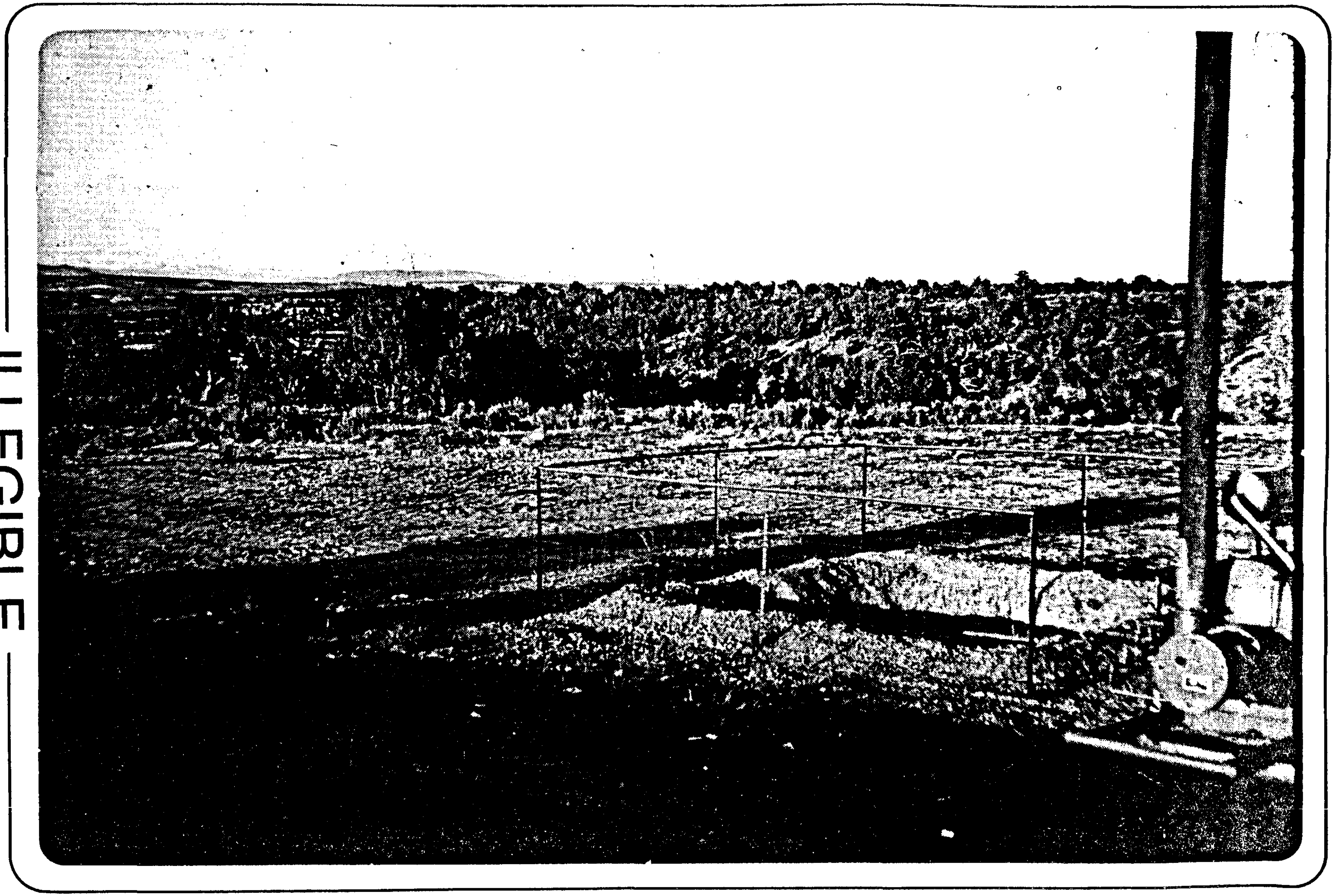
Standing Water Estimated Depth: ______

Photographs of Site: 7, 8, 9 ~~10~~ PIT AND SURROUNDINGS

Producing Formation: MV

Comments: ON THE TOP OF A HIGH MESA
WHAT IS THE GRADED AREA AND WHY IS
THERE GRAVEL HERE
OUT OF VUN AREA

ILLEGIBLE



FLORENCE 32 Roll #3 Slide 7

FLORENCE 32 Roll #3 Slide 8

FLORENCE 32 Roll #3 Slide 9

ILLEGIBLE

Geoscience
Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	SW/NE 19	30N	8W

WELL NAME FLORANCE 111

Drainage Basin:

San Juan La Plata Animas other: ________

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other: ________

Barrels Water/Day Produced: 1

Estimated Hydraulic Gradient: ________

Estimated Hydraulic Conductivity: ________

Formation/Grain Size of Unsaturated Zone: SANDSTONE SHALE SOIL

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: ________

Pit Description Dry

Standing Water Estimated Depth: 0.5

Photographs of Site: #2 #3 #4 Pit NOTE BEDROCK IN BACKGROUND #4 RIVERBANK

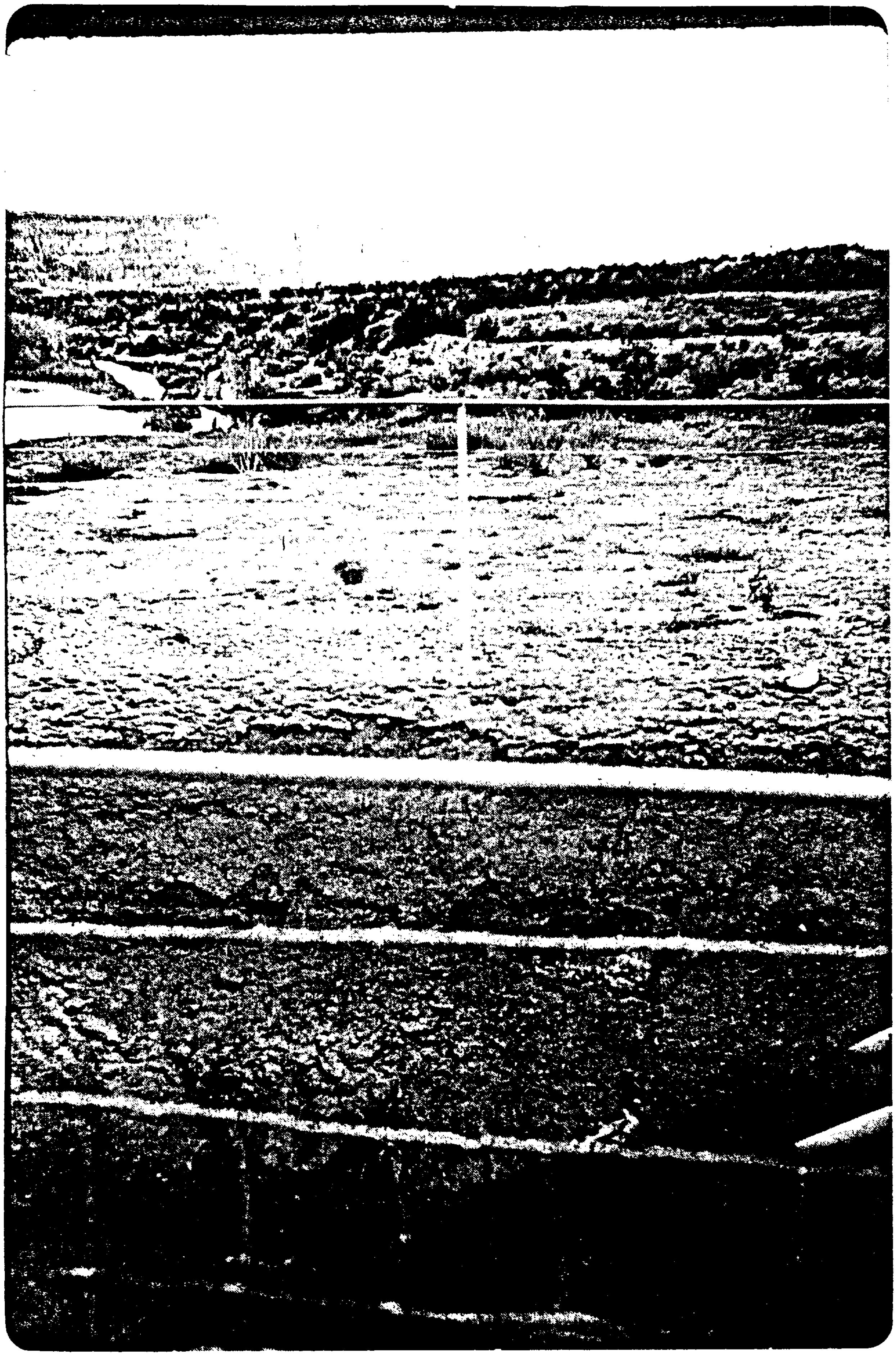
Producing Formation: DK/PC

Comments: UP NEAR THE LAKE EXEMPT!

4/10/85 BAT

ILLEGIBLE

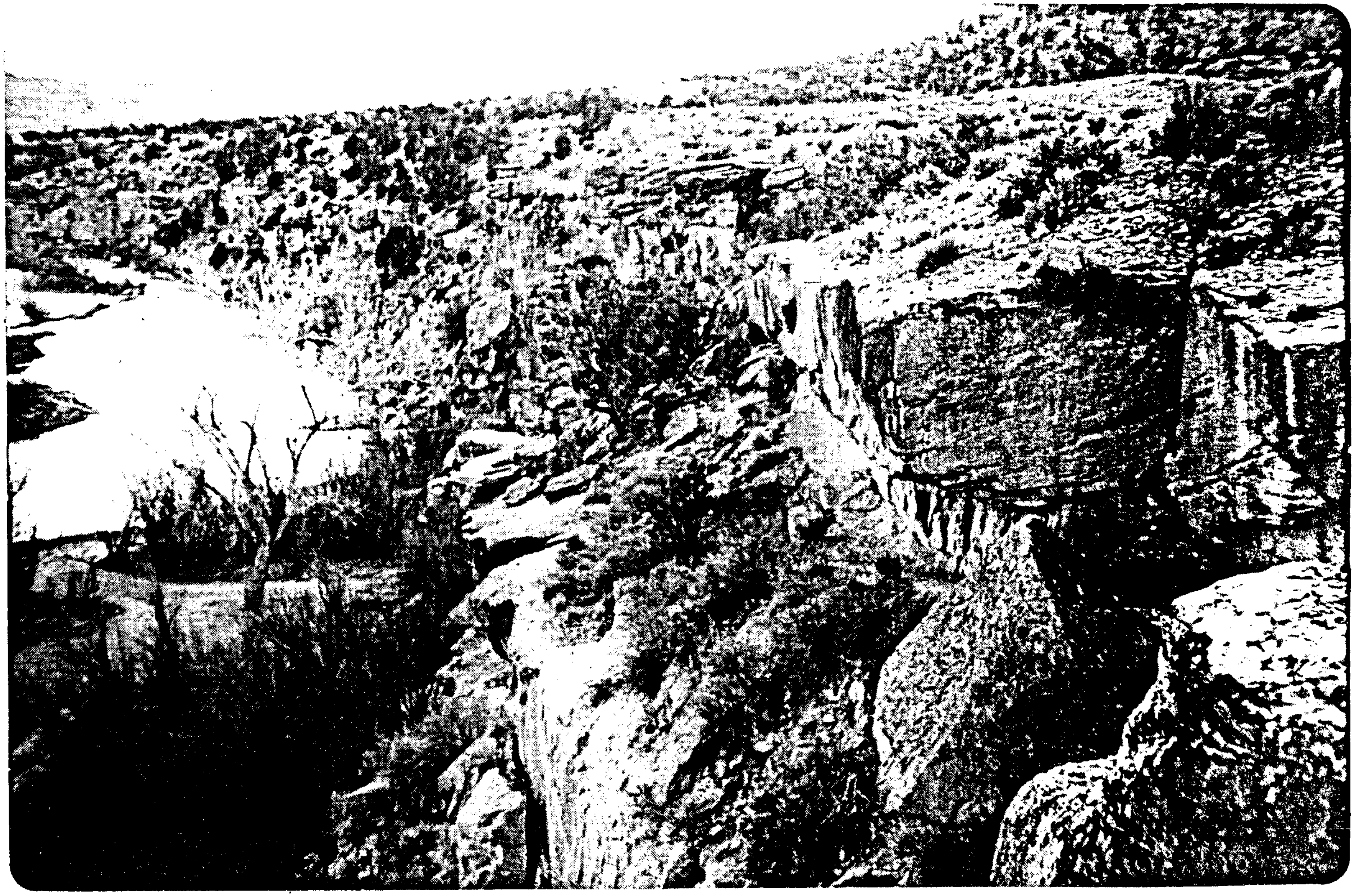
FLORENCE 111 Roll #3 Slide 2



FLORENCE 111 Roll #3 Slide 3

ILLEGIBLE

ILLEGIBLE



NEAR FLORENCE 111 Roll #3 Slide 4

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	SE/SE 25	30N	9W

WELL NAME JACQUES 1A

Drainage Basin:

San Juan   La Plata   Animas   other: ____________

Description of Location:

River Bottom   Valley Slope   Dry Tributary   Mesa   Other: ________

Barrels Water/Day Produced: 1

Estimated Hydraulic Gradient: ____________

Estimated Hydraulic Conductivity: 10^{-2} SURFACE 10

Formation/Grain Size of Unsaturated Zone: SAND

Very Fine   Fine   Med   Coarse   Very Coarse

Sorting: Poor   Fair   Good

Estimated Depth to Ground Water: ____________

Pit Description   Dry   WET DIRT

Standing Water   Estimated Depth: ____________

Photographs of Site: 9, 10 PIT DISCHARGE

Producing Formation: MV

Comments: RAPID INFILTRATION

EXEMPT

JACQUEZ 1 A Roll #5 Slide 9

ILLEGIBLE

JACQUEZ 1 A Roll #5 Slide 10

ILLEGIBLE

Geoscience
Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	NENE35	30N	9W

WELL NAME SANDOVAL GAS COM A #1R

Drainage Basin:

San Juan   La Plata   Animas   other: ______

Description of Location:

River Bottom   Valley Slope   Dry Tributary   Mesa   Other: ______

Barrels Water/Day Produced: 0.03

Estimated Hydraulic Gradient: ______

Estimated Hydraulic Conductivity: 10^{-4} GPD/FT

Formation/Grain Size of Unsaturated Zone: SOIL/UNDERLAIN BY BEDROCK?

Very Fine   Fine   Med   Coarse   Very Coarse

Sorting: Poor   Fair   Good

Estimated Depth to Ground Water: ______

Pit Description   Dry

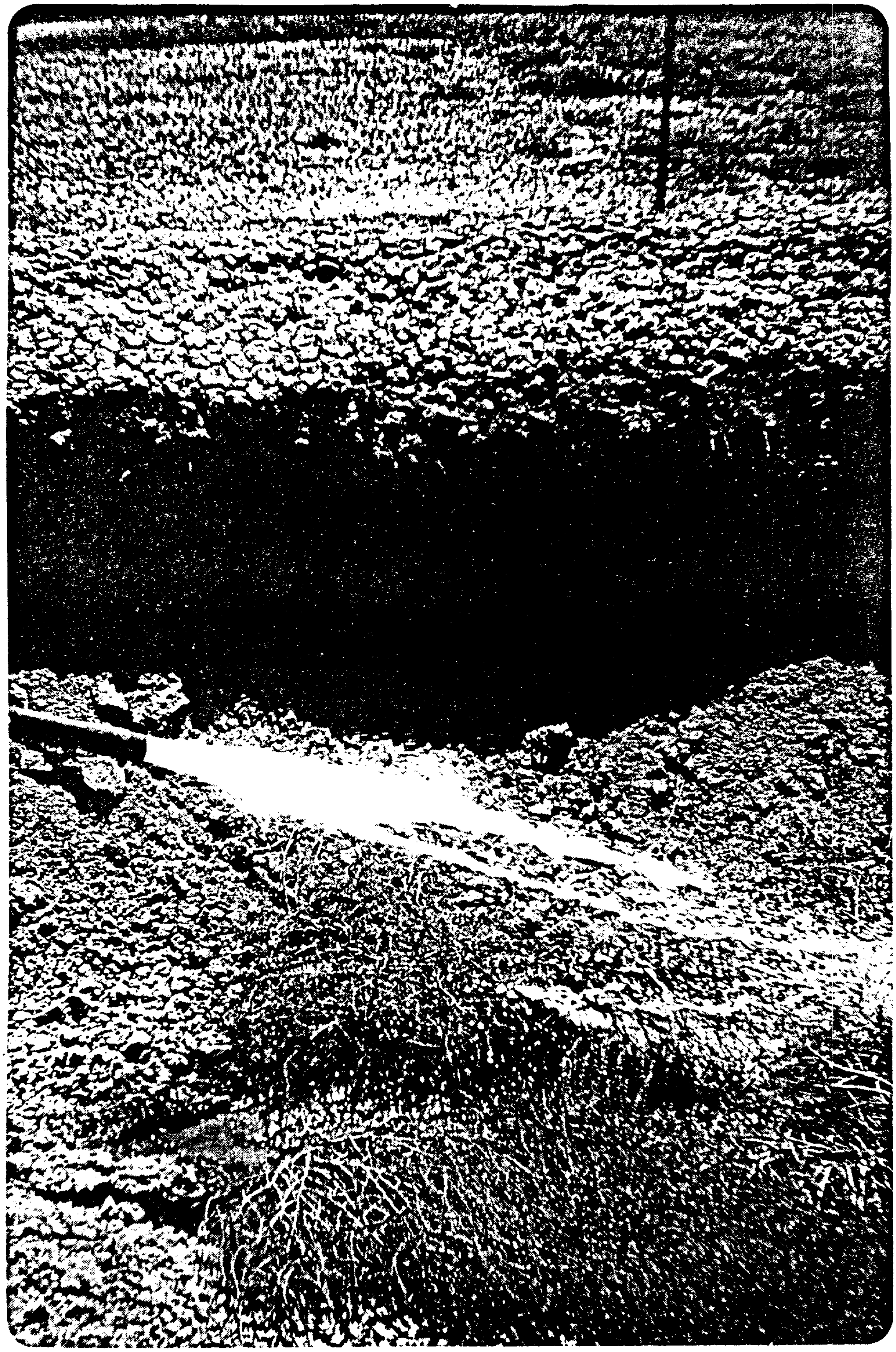
Standing Water   Estimated Depth: 0.25'

Photographs of Site: 5, 6 ~~4~~ PIT w/ DISCHARGE.

Producing Formation: BLANCO MESAVERDE

Comments: ______

4/11/85 BRH



SANDOVAL A 1 R Roll #5 Slide 5

ILLEGIBLE

ILLEGIBLE

SANDOVAL A 1 R Roll #5 Slide 6

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	SE/NW 1	30N	9W

WELL NAME PRITCHARD 1A

Drainage Basin:

San Juan La Plata Animas other: PUMP WASH

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other:

Barrels Water/Day Produced: 1

Estimated Hydraulic Gradient:

Estimated Hydraulic Conductivity:

Formation/Grain Size of Unsaturated Zone: SANDSTONE

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: 250'

Pit Description Dry

Standing Water Estimated Depth: 0.25

Photographs of Site: #20 #1 P.T View to Pump WASH

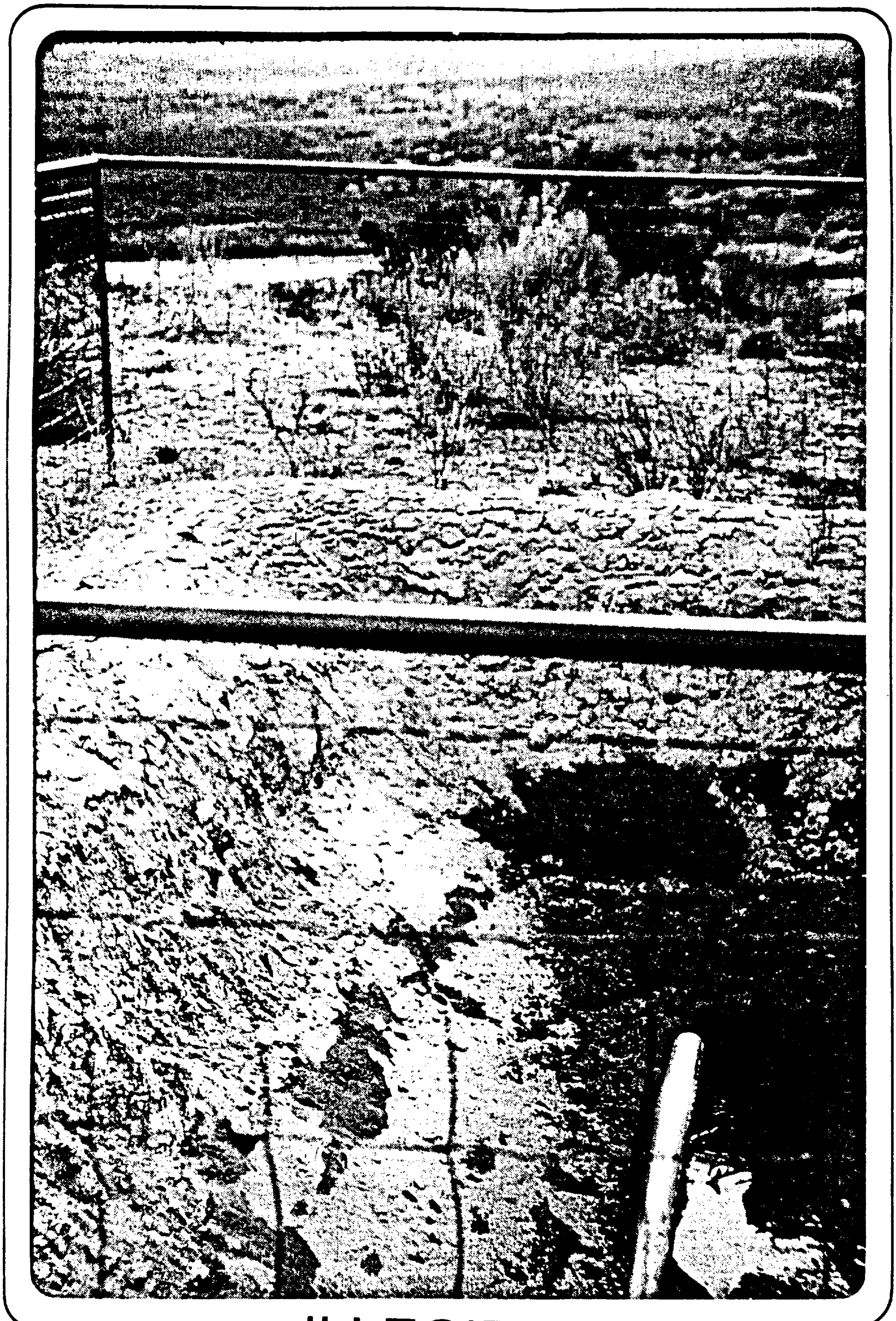
Producing Formation: MV

Comments: UP Pump wash SHUT IN

OUTSIDE OF VUN AREA

EXEMPT

4/10/85 RDT



PRITCHARD 1A Roll #3 Slide 1

ILLEGIBLE

1.5

PICTURED CLIFFS CASES

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	SE SW 5	31N	10W

WELL NAME McEWEN GAS COM C # 1 AND #1

Drainage Basin:

San Juan La Plata Animas other: ______

Description of Location:

River Bottom* Valley Slope Dry Tributary Mesa Other: ______

Barrels Water/Day Produced: — —

Estimated Hydraulic Gradient: 0.004

Estimated Hydraulic Conductivity: 10^4 GPD/FT^2

Formation/Grain Size of Unsaturated Zone:

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: ______

TANK WITH #1 ~~Pit~~ Description Dry

Standing Water Estimated Depth: 6'

Photographs of Site: #13 Road Cut Along Animas #14, #15 PIT (W TANK → ON #1) #16 DEHY PIT

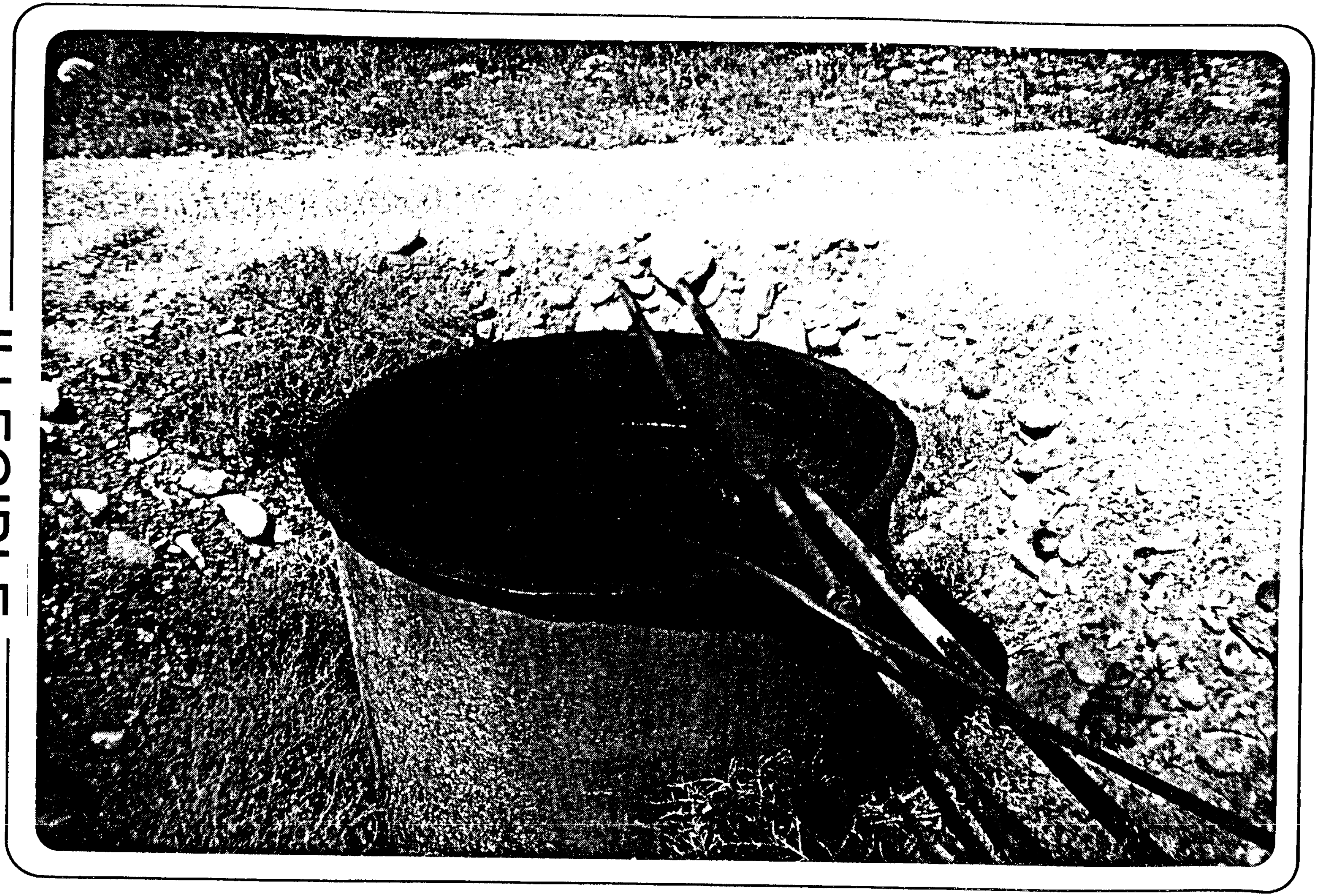
Producing Formation: BLANCO PICTURED CLIFFS #1 ⇒ MV

Comments: NO PIT FOR 'C' 1

* TERRACE 30' ABOVE RIVER

NOT PUMPED OFTEN LOOKS LIKE

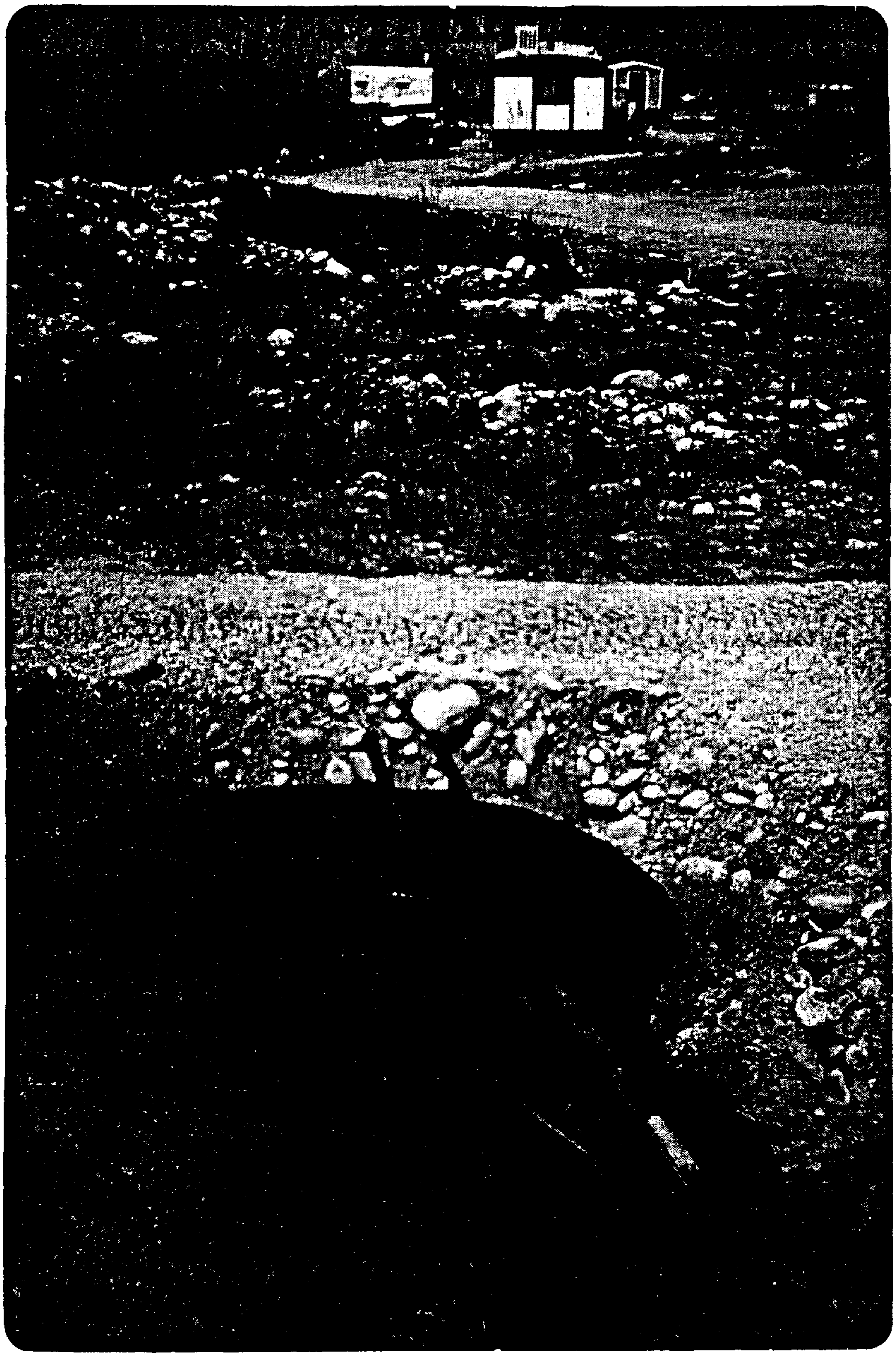
4/10/85 BAH



McEWEN GAS COM #1 Roll #2 Slide 14

ILLEGIBLE

McEWEN GAS COM #1 Roll #2 Slide 15



ILLEGIBLE

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	SE NE 35	31N	11W

WELL NAME WALLACE GAS COM #3 AND #1 also visited (outside of random evaluation)

Drainage Basin:

San Juan La Plata **Animas** other: ______

Description of Location:

River Bottom **Valley Slope** Dry Tributary Mesa Other: ______

Barrels Water/Day Produced: — —

Estimated Hydraulic Gradient: ~~[illegible]~~ 0.01

Estimated Hydraulic Conductivity: 10^4 GPD/FT^2

Formation/Grain Size of Unsaturated Zone:

Very Fine Fine **Med** Coarse **Very Coarse**

Sorting: Poor **Fair** Good

Estimated Depth to Ground Water: ______

Pit Description **Dry**

Standing Water Estimated Depth: ______

Photographs of Site: #8 "MUFFLER" FOR FLARE PIT/PW PIT ANIMAS IN BACK

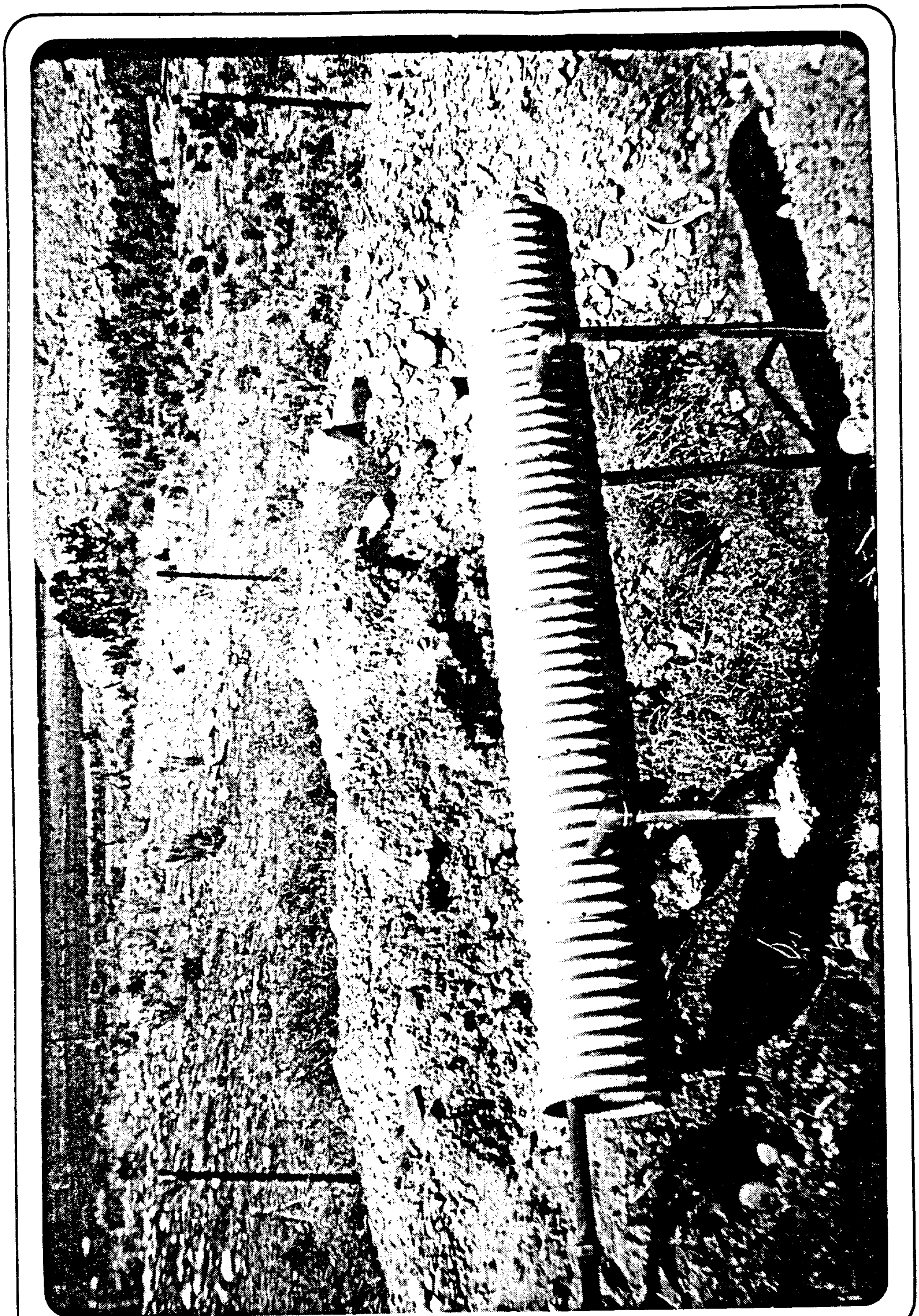
Producing Formation: AZTEC PICTURED CLIFFS – SPECIAL AREA

Comments: NO PITS W/O SEPERATOR!

SEPERATOR ON WALLACE #3 RUNS INTO FLARE PIT

4/10/95

PAH



WALLACE Roll #2 Slide 8

ILLEGIBLE

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	NE/NE 20	29N	9W

WELL NAME HAMNER 9

Drainage Basin:

San Juan La Plata Animas other: ______

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other: ______

Barrels Water/Day Produced: ~~0~~

Estimated Hydraulic Gradient: —

Estimated Hydraulic Conductivity: —

Formation/Grain Size of Unsaturated Zone:

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: ______

Pit Description Dry —

Standing Water Estimated Depth: ______

Photographs of Site: ______

Producing Formation: PC no production equipment

Comments: 5 SIDE LARGO

NO PHOTOGRAPHS AVAILABLE

Geoscience
Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	NE/SE 9	27N	9W
[illegible]	11	27N	10W

WELL NAME SULLIVAN, BRUCE 1

Drainage Basin:

San Juan   La Plata   Animas   other: OUTSIDE OF VUN AREA? SPECIAL AREA?

Description of Location:

River Bottom   Valley Slope   Dry Tributary   Mesa   Other: ______

Barrels Water/Day Produced: -0-

Estimated Hydraulic Gradient: ——

Estimated Hydraulic Conductivity: ______

Formation/Grain Size of Unsaturated Zone:

Very Fine   Fine   Med   Coarse   Very Coarse

Sorting: Poor   Fair   Good

Estimated Depth to Ground Water: ______

Pit Description   Dry

Standing Water   Estimated Depth: ______

Photographs of Site: ______

Producing Formation: PC   no production equipment

Comments: BLANCO

NO PHOTOGRAPHS AVAILABLE

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	26	29N	11W

WELL NAME SULLIVAN, EARL B, #2

Drainage Basin:

San Juan La Plata Animas other: ______

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other: ______

Barrels Water/Day Produced: 0.03 ? NO PIT !

Estimated Hydraulic Gradient: ______

Estimated Hydraulic Conductivity: ______

Formation/Grain Size of Unsaturated Zone:

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: ______

Pit Description Dry

Standing Water Estimated Depth: ______

Photographs of Site: ______

Producing Formation: FULCHER-KUTZ PICTURED CLIFFS

Comments: ______

NO PHOTOGRAPHS AVAILABLE

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	SWSE 35	30N	9W

WELL NAME ULIBARRA GAS COM #2

Drainage Basin:

San Juan La Plata Animas other: ________

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other: ________

Barrels Water/Day Produced: 0.03 -? NO PIT!

Estimated Hydraulic Gradient: ________

Estimated Hydraulic Conductivity: ________

Formation/Grain Size of Unsaturated Zone:

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water: ________

Pit Description Dry NO PIT

Standing Water Estimated Depth: ________

Photographs of Site: ________

Producing Formation: BLANCO PICTURED CLIFFS

Comments: SEE ULIBARRA #1A

NO PHOTOGRAPHS AVAILABLE

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	SE NW 19	29N	9W

WELL NAME LIKINS GAS COM B #1

Drainage Basin:

San Juan   La Plata   Animas   other: ____

Description of Location:

River Bottom   Valley Slope   Dry Tributary   Mesa   Other: ____

Barrels Water/Day Produced: — —

Estimated Hydraulic Gradient: 0.003

Estimated Hydraulic Conductivity: 10^{3}

Formation/Grain Size of Unsaturated Zone:

Very Fine   Fine   Med   Coarse   Very Coarse

Sorting: Poor   Fair   Good

Estimated Depth to Ground Water: ~2'

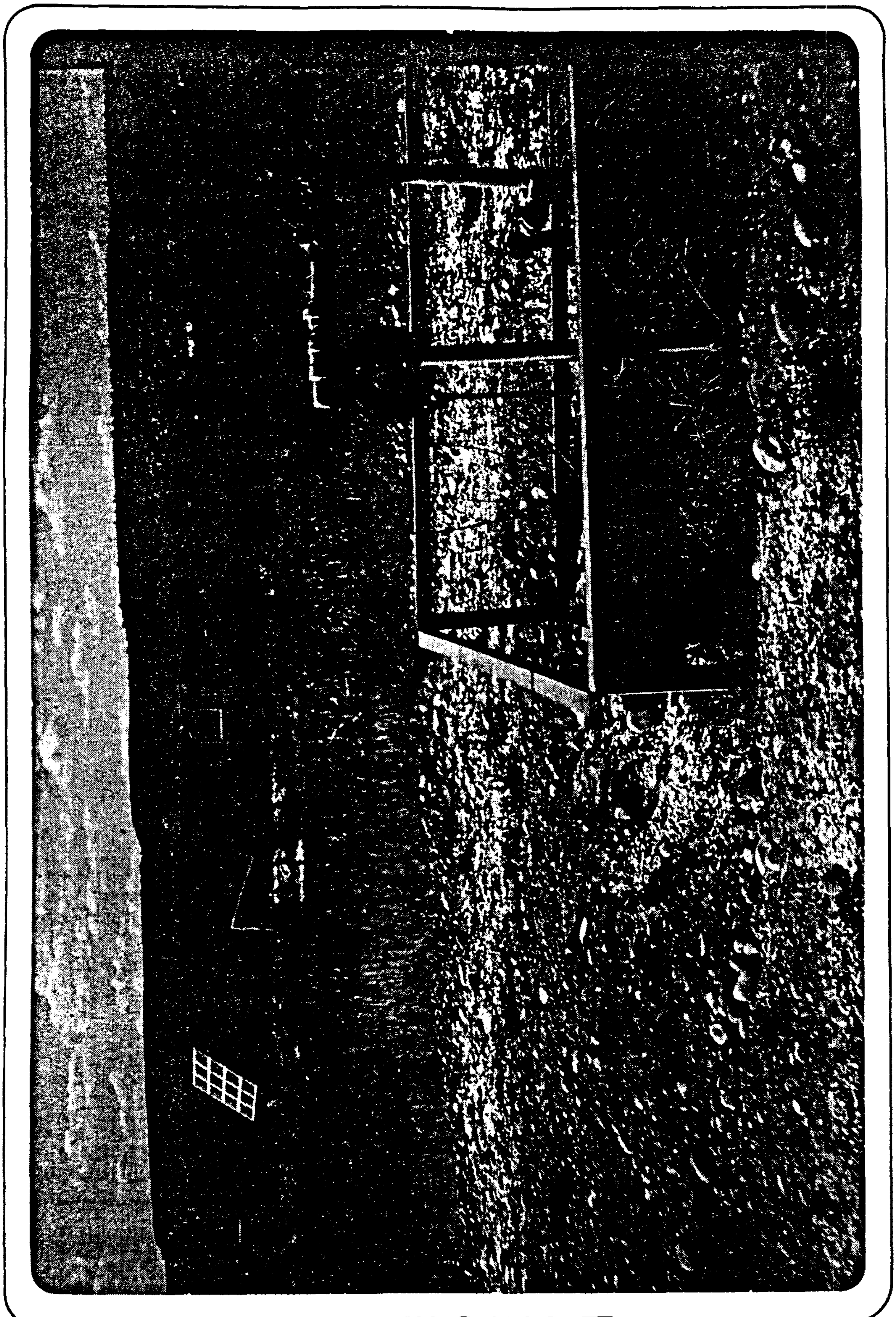
Pit Description   Dry   BLOWDOWN ONLY

Standing Water   Estimated Depth: ____

Photographs of Site: #3 BLOWDOWN PIT   #4 MARKER FIE PIT NOTE SKT

Producing Formation: AZTEC PICTURED CLIFFS

Comments: UNDER WATER



LIKENS GAS COM B 1 Roll #4 Slide 3

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Geoscience Consultants, Ltd.

WELLSITE EVALUATION

Section TWP RNG

Location SW NW 8 29N 9W

WELL NAME HEATH GAS COM F #1

Drainage Basin:

San Juan La Plata Animas other:

Description of Location:

River Bottom Valley Slope Dry Tributary Mesa Other:

Barrels Water/Day Produced: 0.03 -? NO PIT!

Estimated Hydraulic Gradient:

Estimated Hydraulic Conductivity: 10 GPD/FT

Formation/Grain Size of Unsaturated Zone: Soil/SAND

Very Fine Fine Med Coarse Very Coarse

Sorting: Poor Fair Good

Estimated Depth to Ground Water:

Pit Description Dry NO ~~[illegible]~~ SEPARATOR BLOW DOWN PIT

Standing Water Estimated Depth:

Photographs of Site:

Producing Formation: BLANCO PICTURED CLIFFS

Comments: SHOT 13 TO SANDOVAL AIR

NO PHOTOGRAPHS AVAILABLE

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

	Section	TWP	RNG
Location	NESE 33	30N	9W → N1

WELL NAME ELLIOTT GAS COM M #1 NO PIT N1

Drainage Basin:

San Juan   La Plata   Animas   other: ______

Description of Location:

River Bottom   Valley Slope   Dry Tributary   Mesa   Other: ______

Barrels Water/Day Produced: — —

Estimated Hydraulic Gradient: ______

Estimated Hydraulic Conductivity: 10 (10^{2} GPD/FT

Formation/Grain Size of Unsaturated Zone: SAND FROM WASH

Very Fine   Fine   Med   Coarse   Very Coarse

Sorting: Poor   Fair   Good

Estimated Depth to Ground Water: ______

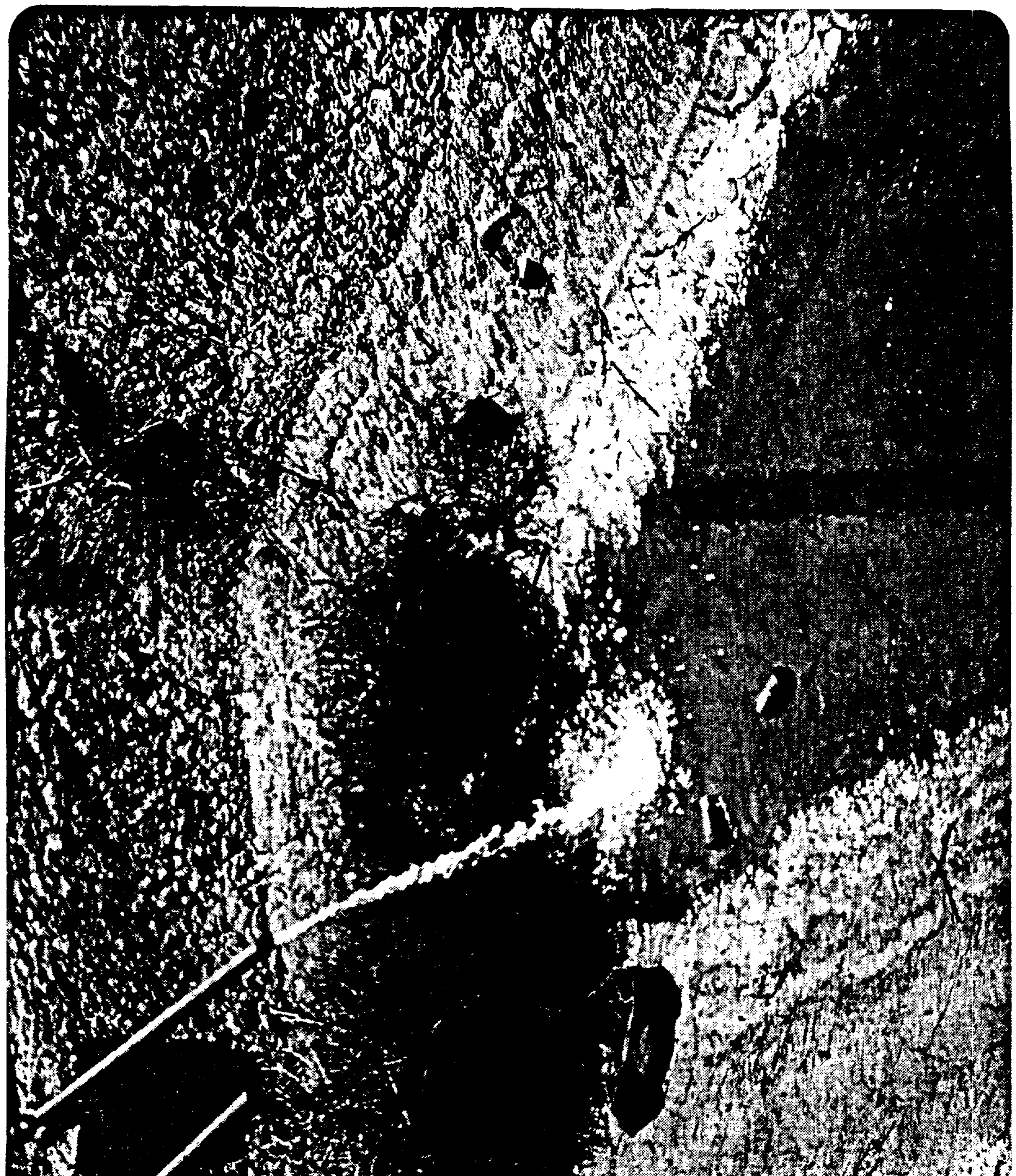
Pit Description   Dry   N1   NO PIT AT PC

Standing Water   Estimated Depth: 0.1 FT

Photographs of Site: 17, 18 N1 PIT

Producing Formation: BLANC PICTURED CLIFFS

Comments: SOME HC FINE SAND LINING
CAPILARITY SUCKS WATER UP SIDES
40' ABOVE WASH



ELLIOTT N 1 Roll #1 Slide 17

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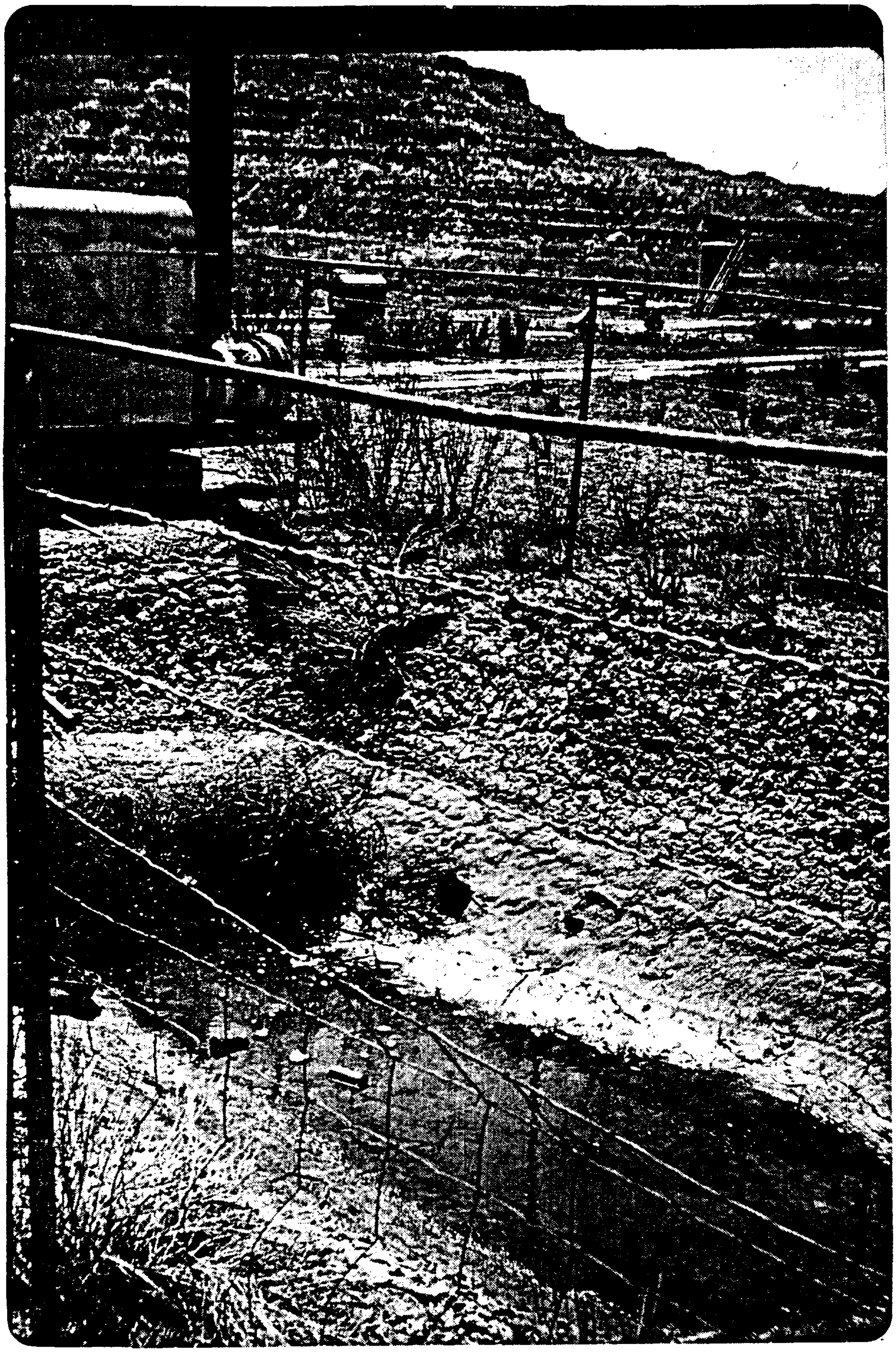


ELLIOTT N 1 Roll #1 Slide 18

ILLEGIBLE

Geoscience Consultants, Ltd.

WELLSITE EVALUATION

Location: Section SW SE 6 | TWP 29N | RNG 9W

WELL NAME JACQUEZ GAS COM E #1 ADJACENT TO "C 1" OUTSIDE OF RANDOM EVALUATION

Drainage Basin:

San Juan   La Plata   Animas   other: ____________

Description of Location:

River Bottom   Valley Slope   Dry Tributary   Mesa   Other: ________

Barrels Water/Day Produced: — —

Estimated Hydraulic Gradient: ____________

Estimated Hydraulic Conductivity: (10 GPD/FT -10^2) 10^4 under

Formation/Grain Size of Unsaturated Zone: Soil and FINE SAND

Very Fine   Fine   Med   Coarse   Very Coarse

Sorting: Poor   Fair   Good

Estimated Depth to Ground Water: ____________

Pit Description   Dry   NO PIT - NO WATER

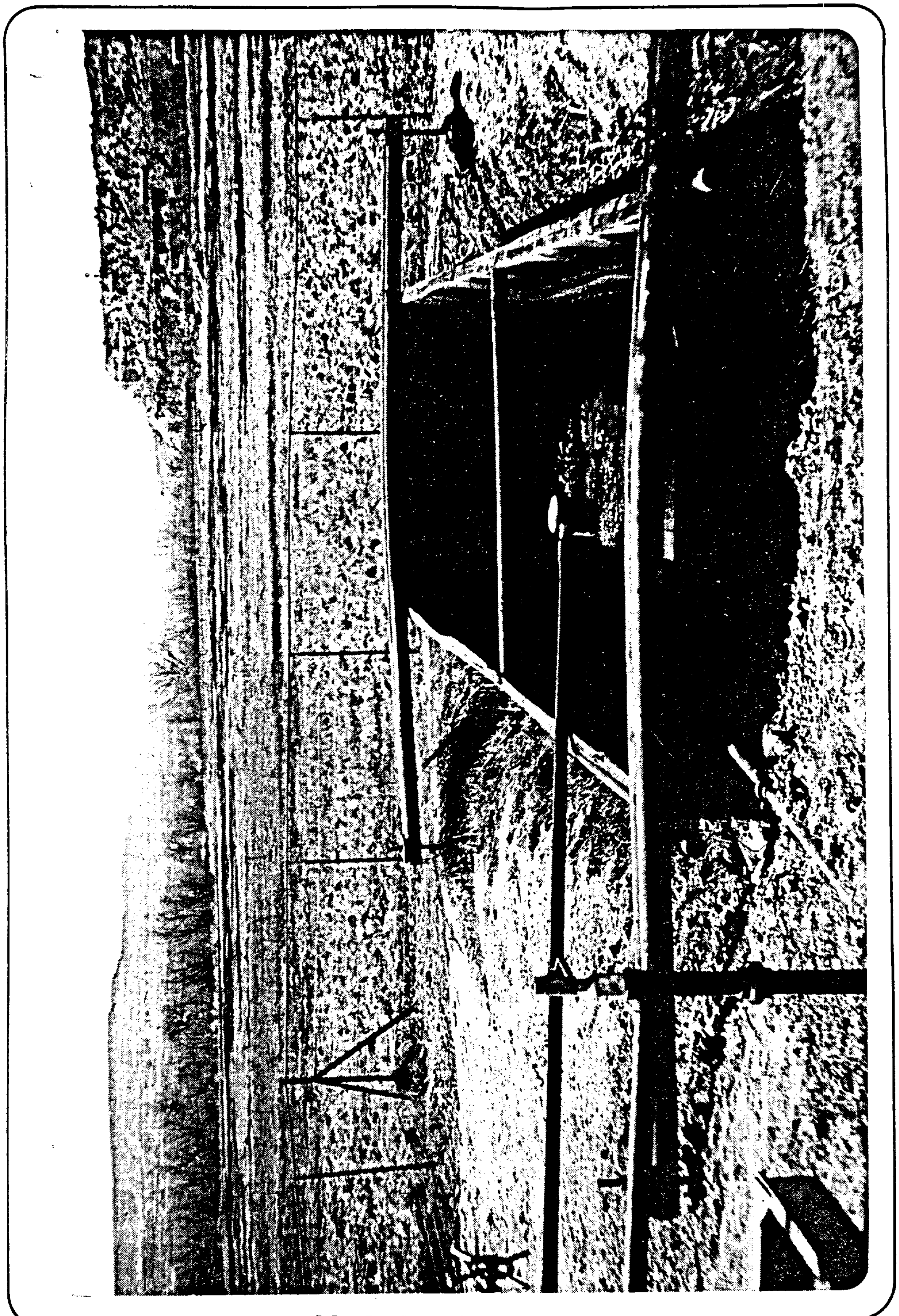
Standing Water   Estimated Depth: 20±

Photographs of Site: ~~NONE~~ "C" / PIT

Producing Formation: BLANCO PICTURED CLIFFS

Comments: NO WATER FROM PC

JACQUEZ C 1 HAS METAL PIT IN FINE SAND



JACQUEZ E1 Roll #1 Slide 15

ILLEGIBLE

Section 2.0

2.0 ANALYTICAL REPORTS

Enclosed are the analytical reports from Assaigai Analytical Laboratories and Rocky Mountain Analytical Laboratories for all samples done on ground water at the three field sites in the vulnerable area. Soil samples were not taken for analysis.

Several of the samples were submitted to the labatory "blind" using only the unique identification number. The identity of these unique numbers are found on the chain-of-custody forms, also enclosed.

It is apparent from the chain-of-custody forms that more samples were taken than were analyzed. Priorities for samples were set based on results and some duplicated samples were not analyzed.

ASCAPO[illegible] ANALYTICAL LABORATORIES, INC.
CHAIN OF CUSTODY RECORD

SAMPLERS (Signature) [illegible signature]

STATION NUMBER	STATION LOCATION	DATE	TIME	SAMPLE TYPE WATER Comp	Grab	AIR	SEQ. NO.	NO OF CONTAINERS	ANALYSIS REQUIRED
	EATON TROUGH	850313	1401		X				Boron/[illegible]
	MCCOY	850313	1230		X				"
	EATON 2	850313	1615		X				"
	EATON 1T	850313	1703		X				"
	EATON 1	850313	1640		X				"
	EATON 1	850313	1711		X				"
	MCCOY	850313	1215		X				"
	MCCOY	850313	1210		X				"

Relinquished by: (Signature)	Received by: (Signature)	Date/Time
[illegible signature]		03/14/85 1240
Relinquished by: (Signature)	Received by: (Signature)	Date/Time
Relinquished by: (Signature)	Received by: (Signature)	Date/Time
Relinquished by: (Signature)	Received by Laboratory for Analysis: (Signature) [illegible signature]	Date/Time 3/14/85 1240

Method of Shipment
HAND DELIVERED

Distribution: Orig. - Accompany Shipment
1 Copy - Files

Sample - all samples rec'd in satisfactory condition
[illegible] - all [illegible] [illegible] [illegible]. RJ

Page 1 of 2

ILLEGIBLE

ASCAIGAI ANALYTICAL LABORATORIES, INC.
CHAIN OF CUSTODY RECORD

SAMPLERS (Signature) [illegible]

STATION NUMBER	STATION LOCATION	DATE	TIME	SAMPLE TYPE WATER Comp	Grab	AIR	SEQ. NO.	NO OF CONTAINERS	ANALYSIS REQUIRED
	PAYNE	850512	1740		\				
	McCOY	850513	1225		X				
	PAYNE	850512	1535		X				
	PAYNE PIT	850512	1545		/				

Relinquished by: (Signature)	Received by: (Signature)	Date/Time
[illegible]		3/14/85 1240
Relinquished by: (Signature)	Received by: (Signature)	Date/Time
Relinquished by: (Signature)	Received by: (Signature)	Date/Time
Relinquished by: (Signature)	Received by Laboratory for Analysis: (Signature) [illegible]	Date/Time 3/14/85 1240

Method of Shipment
HAND DELIVERED

Distribution.Orig. - Accompany Shipment
1 Copy - Files

[illegible] : all sample recd in satisfactory condition
all sample seals intact. [illegible]

ILLEGIBLE

ASSAIGAI ANALYTICAL LABORATORIES

TO: GeoScience
Attn: Randy Hicks
500 Copper N.W.
Albuquerque, NM 87102

DATE: 28 March 1985
0292

ANALYTE	SAMPLE ID/ ANALYTICAL RESULTS		
	Eaton 1 850313 1640	Eaton 2 850313 1615	McCoy 1 850313 1225
Benzene	<0.001 mg/l	0.011 mg/l	0.006 mg/l
	840312 1545	840312 1505	Eaton Trench 850313 1601
Benzene	<0.001 mg/l	0.021 mg/l	<0.001 mg/l
	Eaton Pit 850313 1703	840312 1740	850313 1230
Benzene	3.825 mg/l	<0.001 mg/l	0.011 mg/l 0.012 mg/l Duplicate
	850313 1215	850313 1210	Eaton # 4 850313 1711
Benzene	<0.001 mg/l	<0.001 mg/l	<0.001 mg/l

NOMINAL DETECTION LIMITS: Benzene 0.001 mg/l

REFERENCE: "Measurement of Organic Pollutants in Water and Wastewater", ASTM, STP 686, 1979.

An invoice for services is enclosed. Thank you for contacting Assaigai Laboratories.

Sincerely,

Jennifer V. Smith

Jennifer V. Smith, Ph.D.
Laboratory Director

ASSAIGAI ANALYTICAL LABORATORIES, INC.
CHAIN OF CUSTODY RECORD

SAMPLERS
(Signature)

STATION NUMBER	STATION LOCATION	DATE	TIME	SAMPLE TYPE WATER Comp	SAMPLE TYPE WATER Grab	AIR	SEQ. NO.	NO OF CONTAINERS	ANALYSIS REQUIRED
	Eaton Well #1	3/25/85	1520					2 VOA	Benzene, GC scan
	2	3/25/85	1050					8 "	"
	3	3/25/85	0940 & 1525					3 "	
	4	3/25/85	1055					4 "	"
	5	3/25/85	0945					4 "	
	6	3/25/85	0955					4 "	"
	7	3/25/85	1005					4 "	
	EATON SEPARATOR	3/25/85	0920					8 "	

Relinquished by: (Signature) | Received by: (Signature) | Date/Time

Relinquished by: (Signature) | Received by: (Signature) | Date/Time

Relinquished by: (Signature) | Received by: (Signature) | Date/Time

Relinquished by: (Signature) [signature] | Received by Laboratory for Analysis: (Signature) [signature] | Date/Time 3/26/85

Method of Shipment Hand Carry

Distribution: Orig. - Accompany Shipment
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Page of

ASSAIGAI ANALYTICAL LABORATORIES, INC.
CHAIN OF CUSTODY RECORD

SAMPLERS
(Signature)

STATION NUMBER	STATION LOCATION	DATE	TIME	SAMPLE TYPE WATER Comp	SAMPLE TYPE WATER Grab	AIR	SEQ. NO.	NO OF CONTAINERS	ANALYSIS REQUIRED
	McCoy #1	3/25/85	1330					2 VOA	Benzene, GC Scan
	" #2	3/25/85	1335					"	" "
	# #3	3/25/85	1340					"	" "
	McCoy Pit	3/25/85	1345					"	" "
	Payne Well Separator	3/25/85	1020					4 VOA	" "

Relinquished by: (Signature) Received by: (Signature) Date/Time

Relinquished by: (Signature) Received by: (Signature) Date/Time

Relinquished by: (Signature) Received by: (Signature) Date/Time

Relinquished by: (Signature) J Hunter Received by Laboratory for Analysis: (Signature) Date/Time 3/26/85

Method of Shipment Hand Carry

Distribution:Orig. - Accompany Shipment
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Page of

ASSAIGAI ANALYTICAL LABORATORIES, INC.
CHAIN OF CUSTODY RECORD

SAMPLERS
(Signature)

STATION NUMBER	STATION LOCATION	DATE	TIME	SAMPLE TYPE WATER Comp	Grab	AIR	SEQ. NO.	NO OF CONTAINERS	ANALYSIS REQUIRED
	Mc Coy #1	3/23/85	0851					1 VOA	Benzene, GC Scan
			0854					1 "	" "
		"	0859					1 "	" "
			0900					1	" "
			0909					1 "	" "
		"	"#3"					1 "	" "
EATON UNIT		3/23/85	~~[illegible]~~						

Relinquished by: (Signature) Received by: (Signature) Date/Time

Relinquished by: (Signature) Received by: (Signature) Date/Time

Relinquished by: (Signature) Received by: (Signature) Date/Time

Relinquished by: (Signature) [signature] Received by Laboratory for Analysis: (Signature) [signature] Date/Time 3/26/85

Method of Shipment Hand Carry

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Page of

ASSAIGAI ANALYTICAL LABORATORIES

TO: GeoScience
Attn: Randy Hicks
500 Copper N.W.
Albuquerque, NM 87102

DATE: 3 April 1985
0347

ANALYTE	SAMPLE ID/ ANALYTICAL RESULTS		
	Eaton 1 325851520	Eaton 2 325851050	Eaton 3 325850940
Benzene	<0.001 mg/l	0.014 mg/l	0.007 mg/l
	Eaton 4 325851055	Eaton 5 325850945	Eaton 6 325850955
Benzene	<0.001 mg/l	<0.001 mg/l	0.002 mg/l
	Eaton 7 325851005	Eaton Sep. 325850920	McCoy 1 325851330
Benzene	<0.001 mg/l	10.846 mg/l	0.002 mg/l
	McCoy 2 325851335	McCoy 3 325851340	McCoy Separator 325851345
Benzene	<0.001 mg/l	<0.001 mg/l	0.002 mg/l
	Payne Well 325851020	McCoy Gas Unit 1 325850900	Field Blank
Benzene	53.01 mg/l	0.001 mg/l	<0.001 mg/l

NOMINAL DETECTION LIMIT: 0.001 mg/l

REFERENCE: "Measurement of Organic Pollutants in Water and Wastewater", ASTM, STP 686, 1979.

An invoice for services is enclosed. Thank you for contacting Assaigai Laboratories.

Sincerely,

Jennifer V. Smith

Jennifer V. Smith, Ph.D.
Laboratory Director

7300 Jefferson, N.E. • Albuquerque, New Mexico 87109 • (505) 345-8964

SAMPLE DESCRIPTION INFORMATION

for

Assaigai Analytical Laboratories

RMA Sample No.	Sample Description	Sample Type	Date Sampled	Date Received
4822-01	Eaton#2 325851050	water		3/28/85
4822-02	Eaton Sep. 920	water		3/28/85
4822-03	Eaton#4 325851055	water		3/28/85

April 8, 1985

ANALYTICAL RESULTS

for

Assaigai Analytical Laboratories

PURGEABLE ORGANICS METHOD 602

Parameter	Units	Detection Limit	4822-01	4822-02	4822-03
Benzene	ug/l	3	4	7100	ND

ND = Not detected.

Section 3.0

3.0 SPECIFIC CONDUCTANCE MEASUREMENTS FROM FIELD SITES

Specific conductance measurements were not conducted at any of the field sites nor the random sampling sites in the vulnerable area. Benzene was considered to be the most conservative tracer parameter for the study in. TDS is affected by irrigation for agriculture and is generally high in the uppermost portion of water table aquifers due to evapotranspiration. Due to the lack of background wells and background data, TDS and specific conductants were not analyzed at the field sites.

Section 4.0

4.0 VOLUME RECORDS FOR PRODUCED WATER

Tenneco and Amoco provided estimates of the volume of produced water at each of the individual sites. These estimates were based upon the "pumpers" knowledge of the individual sites and observations during a several month period. To calibrate the pumper's estimates, flow measurement counters were placed on individual sites throughout the vulnerable area. The counters corraborated the accuracy of the pumper's estimates. Produced water volumes for all simulations are found as part of the data on the simulated map of benzene concentration in ground water.

Section 5.0

5.0 DILUTION OF BENZENE IN PRODUCED WATER PITS DUE TO RAINFALL AND SNOWFALL

Enclosed is a calculation which demonstrates insignificant dilution of benzene in produced water pits due to the small amount of rainfall which occurred during the sampling (Table 5-1). The sites that were sampled had at least one or two feet of water in each of the pits and the calculation demonstrates that only slight dilution is observed (Figure 5-1). In no way does this dilution affect the results of the modelling.

TABLE 5-1
RAINFALL DATA FARMINGTON, NEW MEXICO
N.M.S.U. EXPERIMENTAL STATION
MARCH 1985

DATE	PRECIPITATION IN INCHES	
4	TR	
9	0.03	
10	0.04	
11	0.05	
12	0.43	
13	0.01	GEOSCIENCE CONSULTANTS, LTD SAMPLING
16	0.12	
17	TR	
19	0.15	
20	0.27	
25	___	GEOSCIENCE CONSULTANTS, LTD. SAMPLING
29	0.41	
30	0.23	
TOTAL	1.71	

FIGURE 5-1
CALCULATION OF PRECIPITATION EFFECT ON
BENZENE CONCENTRATION

EATON A1E EXAMPLE

Fluid pit dimensions
10ft x 10ft x 2ft (Depth of fluid)

TOTAL VOLUME IN PIT
200 feet^3

TOTAL MAXIMUM PRECIPITATION IN PIT (March 9, - March 13)
$10\text{ft} \times 10\text{ft} \times 0.047\text{ft} = 4.7\text{ft}^3$

EMPLOY DILUTION CALCULATION TO SOLVE FOR BENZENE CONCENTRATION PRIOR TO PRECIPITATION:

$$\frac{C_{RF} * Q_{RF} + Q_P * C_p}{Q_{RF} + Q_p} = C_{FINAL}$$

WHERE:

C_{RF} = 0 mg/l benzene in rainfall
Q_{RF} = 4.7 ft^3 rainfall into pit
Q_p = 200 ft^3 of fluid in the pit
C_p = original benzene concentration in pit prior to rainfall
C_{FINAL} = 3.80 mg/l measured benzene concentration in pit after rainfall

$$\frac{0\ \text{mg/l} * 4.7\text{ft}^3 + 200\text{ft}^3 * C_p\ \text{mg/l}}{200\text{ft}^3 + 4.7\text{ft}^3} = 3.80\ \text{mg/l}$$

$$X\ \text{mg/l} = \frac{3.8 * 204.7}{200}$$

X mg/l = 3.89 mg/l

Rainfall diluted the benzene from 3.89 to 3.80 mg/l

Section 6.0

6.0 STATISTICAL ANALYSIS OF SAMPLING (TO BE SUPPLIED)

Section 7.0

7.0 COMPUTER PROGRAM, INPUT AND OUTPUT

The computer program was obtained through a National Water Well Association short course. Ground Water Modelling Without Mathematics. The Random Walk solute transport model was based upon the article entitled: A "Random Walk" Solute Transport Model for Selected Ground Water Quality Evaluations, by Thomas A. Prickett, Thomas A. Naymik, and Carl L. Lonnquist, Bulletin 65, Illinois State Water Survey, 1981.

The data from the program are out put by the computer in terms of particles per cell. Middligram per liter concentration of each particle is then calculated by determining the volume of water in each cell and, based on the source term, the mass of contaminant which particle represents. The calculation for the enclosed computer run is presented as Figure 7-1.

FIGURE 7-1

WELL: GCU 153 E

T = 125000 GPD/FT (K * 25)

S = 0.1

DH/DL= 0.003

K = 5000 GPD/FT^2

LONG DIS= 10 FOR T GREATER THAN 7500 GPD/FT 5 FOR LESSER T

TRANS DIS = 2

$GPD/FT^2 * 1.55 * 10^{-6} *60*60*24 = FT/DAY$

RET COEF = 1

REG X FLOW = 8.04 $\frac{K * 0.133 * 0.003 \text{ DH/DL}}{0.25}$ = 8.0352 FT/DAY

REG Y FLOW = 0

DMAX = 121 (NO MORE THAN 0.5 * CELL SIZE IN X DIRECTION)

CIRCLE COORDS 500,1500 FOR T GREATER THAN 100,000 50,150 FOR LESSER T

CIRCLE RAD = 5

NO. OF PARTICLES = 20

MAP COORDS = LOWER LEFT 0,0 UPPER RIGHT 3000,3000 FOR T GREATER THAN 100,000
300,300 FOR LESSER T

CELL SIZE = 250,250 FOR T GREATER THAN 100,000 25,25 FOR LESSER T

INCREMENTAL TIME STEP = 15 DAYS

3.5 MG/L IN PIT

0.33 BBLS/DAY * 42 GAL/BBL * 3.785 L/GAL * 3.5 MG/L = 183 MG INPUT PER DAY

$$\frac{183\text{ mg}}{\text{day}} * \frac{15\text{ DAY}}{20\text{ PARTICLES}} * \frac{1\text{ CELL}}{11,062,500\text{ liters}} = 0.000012\text{ PPM}$$

$.012 \text{ PPB} = \frac{1\text{ PART}}{\text{CELL}}$

PROGRAM INPUT AND OUTPUT

9UL F?E

```
------------------------------RANDOM WALK------------------------------

     //////////BASIC TRANSPORT COEFFICIENTS\\\\\\\\\\

          TRANSMISSIVITY (GPD/FT) =   125000  GPD/FT
          STORAGE COEFFICIENT    =  .1
          HYDRAULIC CONDUCTIVITY =  5000  GPD/SQ.FT.
          POROSITY =  .25
          LONGITUDINAL DISPERSIVITY=  10
          TRANSVERSE DISPERSIVITY (FT)= 2
          RETARDATION COEFFICIENT =  1  FT
          REGIONAL X FLOW (FT/DAY) =  8.04
          REGIONAL Y FLOW (FT/DAY)=  0

     /////////////////////////\\\\\\\\\\\\\\\\\\\\\\\\\


   //////////////////////PARTICLES\\\\\\\\\\\\\\\\\

       PARTICLES ON A CIRCLE
        CIRCLE NUMBER  1
        CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
        CIRCLE RADIUS =  5  FT
     NUMBER OF PARTICLES =  20

       TOTAL SYSTEM PARTICLES =  20
    \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\//////////////////////////
/////////////////////////PARTICLE MAPPING\\\\\\\\\\\\\\\\\\\\\\
      MAP WINDOW LOCATION
    LOWER-LEFT COORDINATES =  0 , 0 FT
      UPPER-RIGHT COORDINATES =  3000 , 3000 FT
      CELL SIZE (CDX,CDY) = 250 , 250 FT

      SIMULATION TIME =  0  DAYS
        0        500       1000       1500       2000       2500       3000
    ----|----|----|----|----|----|----|----|----|----|----|----|----|
3000|   0    0    0    0    0    0    0    0    0    0    0    0    0


2750|   0    0    0    0    0    0    0    0    0    0    0    0    0


2500|   0    0    0    0    0    0    0    0    0    0    0    0    0


2250|   0    0    0    0    0    0    0    0    0    0    0    0    0


2000|   0    0    0    0    0    0    0    0    0    0    0    0    0


1750|   0    0    0    0    0    0    0    0    0    0    0    0    0


1500|   0    0   20    0    0    0    0    0    0    0    0    0    0
```

1000	0	0	0	0	0	0	0	0	0	0	0	0	0
750	0	0	0	0	0	0	0	0	0	0	0	0	0
500	0	0	0	0	0	0	0	0	0	0	0	0	0
250	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0

(-1:PUMPING WELL, -2:INJECTION WELL)

PRESENT SIMULATION TIME = 0 DAYS
INCREMENTAL SIMULATION TIME = 15 DAYS
DMAX = 121 FT

NP= 20

//////////////////////PARTICLE MAPPING\\\\\\\\\\\\\\\\\\\\\\

SIMULATION TIME = 15 DAYS

	0		500		1000		1500		2000		2500		3000
3000	0	0	0	0	0	0	0	0	0	0	0	0	0
2750	0	0	0	0	0	0	0	0	0	0	0	0	0
2500	0	0	0	0	0	0	0	0	0	0	0	0	0
2250	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
1750	0	0	0	0	0	0	0	0	0	0	0	0	0
1500	0	0	11	9	0	0	0	0	0	0	0	0	0
1250	0	0	0	0	0	0	0	0	0	0	0	0	0
1000	0	0	0	0	0	0	0	0	0	0	0	0	0
750	0	0	0	0	0	0	0	0	0	0	0	0	0
500	0	0	0	0	0	0	0	0	0	0	0	0	0

```
  250|    0    0    0    0    0    0    0    0    0    0    0    0    0

    0|    0    0    0    0    0    0    0    0    0    0    0    0    0


         (-1:PUMPING WELL, -2:INJECTION WELL)

          PARTICLES ON A CIRCLE
           CIRCLE NUMBER  2
           CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
           CIRCLE RADIUS =  5  FT
        NUMBER OF PARTICLES =  20

          TOTAL SYSTEM PARTICLES =  40
       \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\///////////////////////
       PRESENT SIMULATION TIME =  15   DAYS
        INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 40



          PARTICLES ON A CIRCLE
           CIRCLE NUMBER  3
           CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
           CIRCLE RADIUS =  5  FT
        NUMBER OF PARTICLES =  20

          TOTAL SYSTEM PARTICLES =  60
       \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\///////////////////////
       PRESENT SIMULATION TIME =  30   DAYS
        INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 60



          PARTICLES ON A CIRCLE
           CIRCLE NUMBER  4
           CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
           CIRCLE RADIUS =  5  FT
        NUMBER OF PARTICLES =  20

          TOTAL SYSTEM PARTICLES =  80
       \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\///////////////////////
       PRESENT SIMULATION TIME =  45   DAYS
        INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 80



          PARTICLES ON A CIRCLE
           CIRCLE NUMBER  5
           CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
           CIRCLE RADIUS =  5  FT
```

```
          TOTAL SYSTEM PARTICLES =  100
       \\\\\\\\\\\\\\\\\\\\//////////////////////
       PRESENT SIMULATION TIME =  60   DAYS
        INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 100




          PARTICLES ON A CIRCLE
           CIRCLE NUMBER  6
           CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
           CIRCLE RADIUS =  5  FT
        NUMBER OF PARTICLES =  20

          TOTAL SYSTEM PARTICLES =  120
       \\\\\\\\\\\\\\\\\\\\//////////////////////
       PRESENT SIMULATION TIME =  75   DAYS
        INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 120




//////////////////////PARTICLE MAPPING\\\\\\\\\\\\\\\\\\\\
         MAP WINDOW LOCATION
       LOWER-LEFT COORDINATES =  0 , 0 FT
         UPPER-RIGHT COORDINATES =  3000 , 3000 FT
         CELL SIZE (CDX,CDY) = 250 , 250 FT

         SIMULATION TIME =  90  DAYS
           0        500       1000      1500      2000      2500      3000
       ----!----!----!----!----!----!----!----!----!----!----!----!----!
 3000!     0    0    0    0    0    0    0    0    0    0    0    0    0

 2750!     0    0    0    0    0    0    0    0    0    0    0    0    0

 2500!     0    0    0    0    0    0    0    0    0    0    0    0    0

 2250!     0    0    0    0    0    0    0    0    0    0    0    0    0

 2000!     0    0    0    0    0    0    0    0    0    0    0    0    0

 1750!     0    0    0    0    1    0    0    0    0    0    0    0    0

 1500!     0    0   10   43   42   20    2    0    0    0    0    0    0

 1250!     0    0    0    0    1    1    0    0    0    0    0    0    0

 1000!     0    0    0    0    0    0    0    0    0    0    0    0    0

  750!
```

```
 500|   0   0   0   0   0   0   0   0   0   0   0   0   0

 250|   0   0   0   0   0   0   0   0   0   0   0   0   0

   0|   0   0   0   0   0   0   0   0   0   0   0   0   0


      (-1:PUMPING WELL, -2:INJECTION WELL)

       PARTICLES ON A CIRCLE
        CIRCLE NUMBER  7
        CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
        CIRCLE RADIUS =  5  FT
     NUMBER OF PARTICLES =  20

       TOTAL SYSTEM PARTICLES =  140
    \\\\\\\\\\\\\\\\\\\\////////////////////////
     PRESENT SIMULATION TIME =  90   DAYS
      INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 140



       PARTICLES ON A CIRCLE
        CIRCLE NUMBER  8
        CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
        CIRCLE RADIUS =  5  FT
     NUMBER OF PARTICLES =  20

       TOTAL SYSTEM PARTICLES =  160
    \\\\\\\\\\\\\\\\\\\\////////////////////////
     PRESENT SIMULATION TIME =  105   DAYS
      INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 160



       PARTICLES ON A CIRCLE
        CIRCLE NUMBER  9
        CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
        CIRCLE RADIUS =  5  FT
     NUMBER OF PARTICLES =  20

       TOTAL SYSTEM PARTICLES =  180
    \\\\\\\\\\\\\\\\\\\\////////////////////////
     PRESENT SIMULATION TIME =  120   DAYS
      INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 180
```

```
          CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
          CIRCLE RADIUS =  5  FT
       NUMBER OF PARTICLES =  20

         TOTAL SYSTEM PARTICLES =  200
      \\\\\\\\\\\\\\\\\\\\///////////////////////
      PRESENT SIMULATION TIME =  135   DAYS
       INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 200



         PARTICLES ON A CIRCLE
          CIRCLE NUMBER  11
          CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
          CIRCLE RADIUS =  5  FT
       NUMBER OF PARTICLES =  20

         TOTAL SYSTEM PARTICLES =  220
      \\\\\\\\\\\\\\\\\\\\///////////////////////
      PRESENT SIMULATION TIME =  150   DAYS
       INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 220



///////////////////////PARTICLE MAPPING\\\\\\\\\\\\\\\\\\\\\\
        MAP WINDOW LOCATION
      LOWER-LEFT COORDINATES =  0 , 0 FT
        UPPER-RIGHT COORDINATES =  3000 , 3000 FT
        CELL SIZE (CDX,CDY) = 250 , 250 FT

        SIMULATION TIME =  165  DAYS
          0       500      1000      1500      2000      2500      3000
      ----!----!----!----!----!----!----!----!----!----!----!----!----!
 3000!    0    0    0    0    0    0    0    0    0    0    0    0    0

 2750!    0    0    0    0    0    0    0    0    0    0    0    0    0

 2500!    0    0    0    0    0    0    0    0    0    0    0    0    0

 2250!    0    0    0    0    0    0    0    0    0    0    0    0    0

 2000!    0    0    0    0    0    0    0    0    0    0    0    0    0

 1750!    0    0    0    0    0    0    3    0    1    0    0    0    0

 1500!    0    0   10   43   49   32   36   35    8    0    0    0    0

 1250!    0    0    0    0    0    0    1    2    0    0    0    0    0
```

```
          0     0     0     0     0     0     0     0     0     0     0     0     0

   750!   0     0     0     0     0     0     0     0     0     0     0     0     0

   500!   0     0     0     0     0     0     0     0     0     0     0     0     0

   250!   0     0     0     0     0     0     0     0     0     0     0     0     0

     0!   0     0     0     0     0     0     0     0     0     0     0     0     0


        (-1:PUMPING WELL, -2:INJECTION WELL)

         PARTICLES ON A CIRCLE
          CIRCLE NUMBER  12
          CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
          CIRCLE RADIUS =  5  FT
       NUMBER OF PARTICLES =  20

         TOTAL SYSTEM PARTICLES =  240
      \\\\\\\\\\\\\\\\\\\\//////////////////////
      PRESENT SIMULATION TIME =  165   DAYS
       INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 240



         PARTICLES ON A CIRCLE
          CIRCLE NUMBER  13
          CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
          CIRCLE RADIUS =  5  FT
       NUMBER OF PARTICLES =  20

         TOTAL SYSTEM PARTICLES =  260
      \\\\\\\\\\\\\\\\\\\\//////////////////////
      PRESENT SIMULATION TIME =  180   DAYS
       INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 260



         PARTICLES ON A CIRCLE
          CIRCLE NUMBER  14
          CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
          CIRCLE RADIUS =  5  FT
       NUMBER OF PARTICLES =  20

         TOTAL SYSTEM PARTICLES =  280
      \\\\\\\\\\\\\\\\\\\\//////////////////////
      PRESENT SIMULATION TIME =  195   DAYS
       INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 280
```

```
           PARTICLES ON A CIRCLE
            CIRCLE NUMBER  15
            CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
            CIRCLE RADIUS =  5  FT
         NUMBER OF PARTICLES =  20

           TOTAL SYSTEM PARTICLES =  300
        \\\\\\\\\\\\\\\\\\\\\\////////////////////////
        PRESENT SIMULATION TIME =  210   DAYS
         INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 300




           PARTICLES ON A CIRCLE
            CIRCLE NUMBER  16
            CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
            CIRCLE RADIUS =  5  FT
         NUMBER OF PARTICLES =  20

           TOTAL SYSTEM PARTICLES =  320
        \\\\\\\\\\\\\\\\\\\\\\////////////////////////
        PRESENT SIMULATION TIME =  225   DAYS
         INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 320



//////////////////////PARTICLE MAPPING\\\\\\\\\\\\\\\\\\\\
          MAP WINDOW LOCATION
        LOWER-LEFT COORDINATES =  0 , 0 FT
          UPPER-RIGHT COORDINATES =  3000 , 3000 FT
          CELL SIZE (CDX,CDY) = 250 , 250 FT

          SIMULATION TIME =  240  DAYS
            0        500       1000       1500       2000       2500       3000
        ----!----!----!----!----!----!----!----!----!----!----!----!----!
 3000!      0    0    0    0    0    0    0    0    0    0    0    0    0

 2750!      0    0    0    0    0    0    0    0    0    0    0    0    0

 2500!      0    0    0    0    0    0    0    0    0    0    0    0    0

 2250!      0    0    0    0    0    0    0    0    0    0    0    0    0

 2000!      0    0    0    0    0    0    0    0    0    0    0    0    0

 1750!      0    0    0    0    0    1    0    1    2    3    2    1    0

 1500!      0    0   15   42   43   36   37   39   35   37   17    1    1
```

1250:	0	0	0	0	1	2	0	1	1	1	1	0	0
1000:	0	0	0	0	0	0	0	0	0	0	0	0	0
750:	0	0	0	0	0	0	0	0	0	0	0	0	0
500:	0	0	0	0	0	0	0	0	0	0	0	0	0
250:	0	0	0	0	0	0	0	0	0	0	0	0	0
0:	0	0	0	0	0	0	0	0	0	0	0	0	0

(-1:PUMPING WELL, -2:INJECTION WELL)

PARTICLES ON A CIRCLE
CIRCLE NUMBER 17
CIRCLE CENTER COORDINATES (X,Y) = 500 , 1500 FT
CIRCLE RADIUS = 5 FT
NUMBER OF PARTICLES = 20

TOTAL SYSTEM PARTICLES = 340
\\\\\\\\\\\\\\\\\\\\////////////////////////
PRESENT SIMULATION TIME = 240 DAYS
INCREMENTAL SIMULATION TIME = 15 DAYS
DMAX = 121 FT

NP= 340

PARTICLES ON A CIRCLE
CIRCLE NUMBER 18
CIRCLE CENTER COORDINATES (X,Y) = 500 , 1500 FT
CIRCLE RADIUS = 5 FT
NUMBER OF PARTICLES = 20

TOTAL SYSTEM PARTICLES = 360
\\\\\\\\\\\\\\\\\\\\////////////////////////
PRESENT SIMULATION TIME = 255 DAYS
INCREMENTAL SIMULATION TIME = 15 DAYS
DMAX = 121 FT

NP= 360

PARTICLES ON A CIRCLE
CIRCLE NUMBER 19
CIRCLE CENTER COORDINATES (X,Y) = 500 , 1500 FT
CIRCLE RADIUS = 5 FT
NUMBER OF PARTICLES = 20

TOTAL SYSTEM PARTICLES = 380
\\\\\\\\\\\\\\\\\\\\////////////////////////
PRESENT SIMULATION TIME = 270 DAYS

```
NP= 380



          PARTICLES ON A CIRCLE
           CIRCLE NUMBER  20
           CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
           CIRCLE RADIUS =  5  FT
        NUMBER OF PARTICLES =  20

          TOTAL SYSTEM PARTICLES =  400
       \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\/////////////////////////
       PRESENT SIMULATION TIME =  285   DAYS
        INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 400



          PARTICLES ON A CIRCLE
           CIRCLE NUMBER  21
           CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
           CIRCLE RADIUS =  5  FT
        NUMBER OF PARTICLES =  20

          TOTAL SYSTEM PARTICLES =  420
       \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\/////////////////////////
       PRESENT SIMULATION TIME =  300   DAYS
        INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 420



///////////////////////PARTICLE MAPPING\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
         MAP WINDOW LOCATION
       LOWER-LEFT COORDINATES =  0 , 0 FT
         UPPER-RIGHT COORDINATES =  3000 , 3000 FT
         CELL SIZE (CDX,CDY) = 250 , 250 FT

         SIMULATION TIME =  315  DAYS
           0       500      1000      1500      2000      2500      3000
       ----!----!----!----!----!----!----!----!----!----!----!----!----!
 3000!     0    0    0    0    0    0    0    0    0    0    0    0    0


 2750!     0    0    0    0    0    0    0    0    0    0    0    0    0


 2500!     0    0    0    0    0    0    0    0    0    0    0    0    0


 2250!     0    0    0    0    0    0    0    0    0    0    0    0    0


 2000!     0    0    0    0    0    0    0    0    0    0    0    0    0
```

```
 1500!    0    0   14   38   45   45   41   36   31   41   29   31   26

 1250!    0    0    0    0    0    0    1    2    3    2    2    3    2

 1000!    0    0    0    0    0    0    0    0    0    0    0    0    0

  750!    0    0    0    0    0    0    0    0    0    0    0    0    0

  500!    0    0    0    0    0    0    0    0    0    0    0    0    0

  250!    0    0    0    0    0    0    0    0    0    0    0    0    0

    0!    0    0    0    0    0    0    0    0    0    0    0    0    0


        (-1:PUMPING WELL, -2:INJECTION WELL)

         PARTICLES ON A CIRCLE
          CIRCLE NUMBER  22
          CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
          CIRCLE RADIUS =  5  FT
       NUMBER OF PARTICLES =  20

         TOTAL SYSTEM PARTICLES =  440
      \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
      PRESENT SIMULATION TIME =  315   DAYS
       INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 440



//////////////////////PARTICLE MAPPING\\\\\\\\\\\\\\\\\\\\
        MAP WINDOW LOCATION
      LOWER-LEFT COORDINATES =  0 , 0 FT
        UPPER-RIGHT COORDINATES =  3000 , 3000 FT
        CELL SIZE (CDX,CDY) = 250 , 250 FT

        SIMULATION TIME =  330  DAYS
          0         500       1000       1500       2000       2500       3000
     ----!----!----!----!----!----!----!----!----!----!----!----!----!
 3000!    0    0    0    0    0    0    0    0    0    0    0    0    0

 2750!    0    0    0    0    0    0    0    0    0    0    0    0    0

 2500!    0    0    0    0    0    0    0    0    0    0    0    0    0

 2250!    0    0    0    0    0    0    0    0    0    0    0    0    0

 2000!    0    0    0    0    0    0    0    0    0    0    0    0    0
```

1750:	0	0	0	0	0	0	1	3	2	0	2	3	5
1500:	0	0	13	36	48	40	34	44	34	32	40	29	29
1250:	0	0	0	0	0	2	1	1	3	4	4	1	5
1000:	0	0	0	0	0	0	0	0	0	0	0	0	0
750:	0	0	0	0	0	0	0	0	0	0	0	0	0
500:	0	0	0	0	0	0	0	0	0	0	0	0	0
250:	0	0	0	0	0	0	0	0	0	0	0	0	0
0:	0	0	0	0	0	0	0	0	0	0	0	0	0

(-1:PUMPING WELL, -2:INJECTION WELL)

PARTICLES ON A CIRCLE
CIRCLE NUMBER 23
CIRCLE CENTER COORDINATES (X,Y) = 500 , 1500 FT
CIRCLE RADIUS = 5 FT
NUMBER OF PARTICLES = 20

TOTAL SYSTEM PARTICLES = 460
\\///////////////////////
PRESENT SIMULATION TIME = 330 DAYS
INCREMENTAL SIMULATION TIME = 15 DAYS
DMAX = 121 FT

NP= 460

PARTICLES ON A CIRCLE
CIRCLE NUMBER 24
CIRCLE CENTER COORDINATES (X,Y) = 500 , 1500 FT
CIRCLE RADIUS = 5 FT
NUMBER OF PARTICLES = 20

TOTAL SYSTEM PARTICLES = 480
\\///////////////////////
PRESENT SIMULATION TIME = 345 DAYS
INCREMENTAL SIMULATION TIME = 15 DAYS
DMAX = 121 FT

NP= 480

PARTICLES ON A CIRCLE
CIRCLE NUMBER 25
CIRCLE CENTER COORDINATES (X,Y) = 500 1500 FT

```
         TOTAL SYSTEM PARTICLES =  500
      \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\/////////////////////////
      PRESENT SIMULATION TIME =  360   DAYS
       INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 500




         PARTICLES ON A CIRCLE
          CIRCLE NUMBER  26
          CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
          CIRCLE RADIUS =  5  FT
       NUMBER OF PARTICLES =  20

         TOTAL SYSTEM PARTICLES =  520
      \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\/////////////////////////
      PRESENT SIMULATION TIME =  375   DAYS
       INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 520



///////////////////////PARTICLE MAPPING\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
        MAP WINDOW LOCATION
      LOWER-LEFT COORDINATES =  0 , 0 FT
        UPPER-RIGHT COORDINATES =  3000 , 3000 FT
        CELL SIZE (CDX,CDY) = 250 , 250 FT

        SIMULATION TIME =  390  DAYS
         0        500       1000       1500       2000       2500       3000
      ----!----!----!----!----!----!----!----!----!----!----!----!----!
 3000!    0    0    0    0    0    0    0    0    0    0    0    0    0

 2750!    0    0    0    0    0    0    0    0    0    0    0    0    0

 2500!    0    0    0    0    0    0    0    0    0    0    0    0    0

 2250!    0    0    0    0    0    0    0    0    0    0    0    0    0

 2000!    0    0    0    0    0    0    0    0    0    0    0    0    0

 1750!    0    0    0    0    0    0    0    3    3    5    3    1    2

 1500!    0    0    8   53   32   41   38   44   32   42   30   32   34

 1250!    0    0    0    0    0    0    1    2    1    3    7    2    4

 1000!    0    0    0    0    0    0    0    0    0    0    0    0    0
```

500	0	0	0	0	0	0	0	0	0	0	0	0	0
250	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0

(-1:PUMPING WELL, -2:INJECTION WELL)

PARTICLES ON A CIRCLE
CIRCLE NUMBER 27
CIRCLE CENTER COORDINATES (X,Y) = 500 , 1500 FT
CIRCLE RADIUS = 5 FT
NUMBER OF PARTICLES = 20

TOTAL SYSTEM PARTICLES = 540
\\\\\\\\\\\\\\\\\\\\\\//////////////////////////
PRESENT SIMULATION TIME = 390 DAYS
INCREMENTAL SIMULATION TIME = 15 DAYS
DMAX = 121 FT

NP= 540

///////////////////////PARTICLE MAPPING\\\\\\\\\\\\\\\\\\\\\
MAP WINDOW LOCATION
LOWER-LEFT COORDINATES = 0 , 0 FT
UPPER-RIGHT COORDINATES = 3000 , 3000 FT
CELL SIZE (CDX,CDY) = 250 , 250 FT

SIMULATION TIME = 405 DAYS

	0		500		1000		1500		2000		2500		3000
3000	0	0	0	0	0	0	0	0	0	0	0	0	0
2750	0	0	0	0	0	0	0	0	0	0	0	0	0
2500	0	0	0	0	0	0	0	0	0	0	0	0	0
2250	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
1750	0	0	0	0	0	0	1	3	4	3	2	3	2
1500	0	0	10	44	40	38	44	33	37	45	30	31	32
1250	0	0	0	0	0	0	1	3	2	3	4	5	4

750	0	0	0	0	0	0	0	0	0	0	0	0	0
500	0	0	0	0	0	0	0	0	0	0	0	0	0
250	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0

(-1:PUMPING WELL, -2:INJECTION WELL)

```
   PARTICLES ON A CIRCLE
    CIRCLE NUMBER  28
    CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
    CIRCLE RADIUS =  5  FT
 NUMBER OF PARTICLES =  20

   TOTAL SYSTEM PARTICLES =  560
\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
PRESENT SIMULATION TIME =  405   DAYS
 INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 560

   PARTICLES ON A CIRCLE
    CIRCLE NUMBER  29
    CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
    CIRCLE RADIUS =  5  FT
 NUMBER OF PARTICLES =  20

   TOTAL SYSTEM PARTICLES =  580
\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
PRESENT SIMULATION TIME =  420   DAYS
 INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 580

   PARTICLES ON A CIRCLE
    CIRCLE NUMBER  30
    CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
    CIRCLE RADIUS =  5  FT
 NUMBER OF PARTICLES =  20

   TOTAL SYSTEM PARTICLES =  600
\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
PRESENT SIMULATION TIME =  435   DAYS
 INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 600
```

```
          PARTICLES ON A CIRCLE
           CIRCLE NUMBER  31
           CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
           CIRCLE RADIUS =  5  FT
        NUMBER OF PARTICLES =  20

          TOTAL SYSTEM PARTICLES =  620
       \\\\\\\\\\\\\\\\\\\\//////////////////////////
       PRESENT SIMULATION TIME =  450   DAYS
        INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 620



/////////////////////////PARTICLE MAPPING\\\\\\\\\\\\\\\\\\\\\\
         MAP WINDOW LOCATION
       LOWER-LEFT COORDINATES =  0 , 0 FT
         UPPER-RIGHT COORDINATES =  3000 , 3000 FT
         CELL SIZE (CDX,CDY) = 250 , 250 FT

         SIMULATION TIME =  465  DAYS
```

	0		500		1000		1500		2000		2500		3000
3000	0	0	0	0	0	0	0	0	0	0	0	0	0
2750	0	0	0	0	0	0	0	0	0	0	0	0	0
2500	0	0	0	0	0	0	0	0	0	0	0	0	0
2250	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
1750	0	0	0	0	0	0	3	3	2	6	8	5	3
1500	0	0	13	45	37	42	36	46	30	33	33	37	30
1250	0	0	0	0	0	0	0	1	4	0	2	3	7
1000	0	0	0	0	0	0	0	0	0	0	0	0	0
750	0	0	0	0	0	0	0	0	0	0	0	0	0
500	0	0	0	0	0	0	0	0	0	0	0	0	0
250	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0

```
        (-1:PUMPING WELL, -2:INJECTION WELL)

         PARTICLES ON A CIRCLE
          CIRCLE NUMBER  32
          CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
          CIRCLE RADIUS =  5  FT
        NUMBER OF PARTICLES =  20

         TOTAL SYSTEM PARTICLES =  640
      \\\\\\\\\\\\\\\\\\\\//////////////////////
      PRESENT SIMULATION TIME =  465   DAYS
       INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 640



//////////////////////PARTICLE MAPPING\\\\\\\\\\\\\\\\\\\\\
        MAP WINDOW LOCATION
      LOWER-LEFT COORDINATES =  0 , 0 FT
        UPPER-RIGHT COORDINATES =  3000 , 3000 FT
        CELL SIZE (CDX,CDY) = 250 , 250 FT

        SIMULATION TIME =  480  DAYS
```

	0		500		1000		1500		2000		2500		3000
3000	0	0	0	0	0	0	0	0	0	0	0	0	0
2750	0	0	0	0	0	0	0	0	0	0	0	0	0
2500	0	0	0	0	0	0	0	0	0	0	0	0	0
2250	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
1750	0	0	0	0	0	0	2	2	2	3	5	6	2
1500	0	0	17	39	38	39	47	30	45	32	30	33	39
1250	0	0	0	0	0	0	0	1	3	4	3	2	4
1000	0	0	0	0	0	0	0	0	0	0	0	0	0
750	0	0	0	0	0	0	0	0	0	0	0	0	0
500	0	0	0	0	0	0	0	0	0	0	0	0	0
250	0	0	0	0	0	0	0	0	0	0	0	0	0

```
  (-1:PUMPING WELL, -2:INJECTION WELL)

   PARTICLES ON A CIRCLE
    CIRCLE NUMBER  33
    CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
    CIRCLE RADIUS =  5  FT
 NUMBER OF PARTICLES =  20

   TOTAL SYSTEM PARTICLES =  660
\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\//////////////////////////
PRESENT SIMULATION TIME =  480   DAYS
 INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 660

   PARTICLES ON A CIRCLE
    CIRCLE NUMBER  34
    CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
    CIRCLE RADIUS =  5  FT
 NUMBER OF PARTICLES =  20

   TOTAL SYSTEM PARTICLES =  680
\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\//////////////////////////
PRESENT SIMULATION TIME =  495   DAYS
 INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 680

   PARTICLES ON A CIRCLE
    CIRCLE NUMBER  35
    CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
    CIRCLE RADIUS =  5  FT
 NUMBER OF PARTICLES =  20

   TOTAL SYSTEM PARTICLES =  700
\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\//////////////////////////
PRESENT SIMULATION TIME =  510   DAYS
 INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 700

   PARTICLES ON A CIRCLE
    CIRCLE NUMBER  36
    CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
    CIRCLE RADIUS =  5  FT
 NUMBER OF PARTICLES =  20

   TOTAL SYSTEM PARTICLES =  720
\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\//////////////////////////
```

DMAX = 121 FT

NP= 720

////////////////////////PARTICLE MAPPING\\\

MAP WINDOW LOCATION
LOWER-LEFT COORDINATES = 0 , 0 FT
UPPER-RIGHT COORDINATES = 3000 , 3000 FT
CELL SIZE (CDX,CDY) = 250 , 250 FT

SIMULATION TIME = 540 DAYS

	0		500		1000		1500		2000		2500		3000
3000	0	0	0	0	0	0	0	0	0	0	0	0	0
2750	0	0	0	0	0	0	0	0	0	0	0	0	0
2500	0	0	0	0	0	0	0	0	0	0	0	0	0
2250	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
1750	0	0	0	0	0	0	0	2	2	6	3	3	5
1500	0	0	12	42	43	40	29	50	39	26	43	30	30
1250	0	0	0	0	0	1	0	1	0	2	1	7	4
1000	0	0	0	0	0	0	0	0	0	0	0	0	0
750	0	0	0	0	0	0	0	0	0	0	0	0	0
500	0	0	0	0	0	0	0	0	0	0	0	0	0
250	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0

(-1:PUMPING WELL, -2:INJECTION WELL)

PARTICLES ON A CIRCLE
CIRCLE NUMBER 37
CIRCLE CENTER COORDINATES (X,Y) = 500 , 1500 FT
CIRCLE RADIUS = 5 FT
NUMBER OF PARTICLES = 20

PRESENT SIMULATION TIME = 540 DAYS
INCREMENTAL SIMULATION TIME = 15 DAYS
DMAX = 121 FT

NP= 740

///////////////////////PARTICLE MAPPING\\\\\\\\\\\\\\\\\\\\\\

MAP WINDOW LOCATION
LOWER-LEFT COORDINATES = 0 , 0 FT
UPPER-RIGHT COORDINATES = 3000 , 3000 FT
CELL SIZE (CDX,CDY) = 250 , 250 FT

SIMULATION TIME = 555 DAYS

	0		500		1000		1500		2000		2500		3000
3000	0	0	0	0	0	0	0	0	0	0	0	0	0
2750	0	0	0	0	0	0	0	0	0	0	0	0	0
2500	0	0	0	0	0	0	0	0	0	0	0	0	0
2250	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
1750	0	0	0	0	0	0	3	0	4	6	3	2	4
1500	0	0	12	43	48	34	31	39	36	39	34	32	32
1250	0	0	0	0	0	1	2	2	1	1	2	4	6
1000	0	0	0	0	0	0	0	0	0	0	0	0	0
750	0	0	0	0	0	0	0	0	0	0	0	0	0
500	0	0	0	0	0	0	0	0	0	0	0	0	0
250	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0

(-1:PUMPING WELL, -2:INJECTION WELL)

PARTICLES ON A CIRCLE
CIRCLE NUMBER 38
CIRCLE CENTER COORDINATES (X,Y) = 500 , 1500 FT
CIRCLE RADIUS = 5 FT

```
          TOTAL SYSTEM PARTICLES =   760
       \\\\\\\\\\\\\\\\\\\\////////////////////////
       PRESENT SIMULATION TIME =   555    DAYS
        INCREMENTAL SIMULATION TIME =   15   DAYS
DMAX =   121   FT

NP= 760




          PARTICLES ON A CIRCLE
           CIRCLE NUMBER   39
           CIRCLE CENTER COORDINATES (X,Y) =   500 , 1500   FT
           CIRCLE RADIUS =   5   FT
        NUMBER OF PARTICLES =   20

          TOTAL SYSTEM PARTICLES =   780
       \\\\\\\\\\\\\\\\\\\\////////////////////////
       PRESENT SIMULATION TIME =   570    DAYS
        INCREMENTAL SIMULATION TIME =   15   DAYS
DMAX =   121   FT

NP= 780




          PARTICLES ON A CIRCLE
           CIRCLE NUMBER   40
           CIRCLE CENTER COORDINATES (X,Y) =   500 , 1500   FT
           CIRCLE RADIUS =   5   FT
        NUMBER OF PARTICLES =   20

          TOTAL SYSTEM PARTICLES =   800
       \\\\\\\\\\\\\\\\\\\\////////////////////////
       PRESENT SIMULATION TIME =   585    DAYS
        INCREMENTAL SIMULATION TIME =   15   DAYS
DMAX =   121   FT

NP= 800




          PARTICLES ON A CIRCLE
           CIRCLE NUMBER   41
           CIRCLE CENTER COORDINATES (X,Y) =   500 , 1500   FT
           CIRCLE RADIUS =   5   FT
        NUMBER OF PARTICLES =   20

          TOTAL SYSTEM PARTICLES =   820
       \\\\\\\\\\\\\\\\\\\\////////////////////////
       PRESENT SIMULATION TIME =   600    DAYS
        INCREMENTAL SIMULATION TIME =   15   DAYS
DMAX =   121   FT

NP= 820



//////////////////////PARTICLE MAPPING\\\\\\\\\\\\\\\\\\\\
         MAP WINDOW LOCATION
```

CELL SIZE (CDX,CDY) = 250 , 250 FT

SIMULATION TIME = 615 DAYS

	0		500		1000		1500		2000		2500		3000
3000	0	0	0	0	0	0	0	0	0	0	0	0	0
2750	0	0	0	0	0	0	0	0	0	0	0	0	0
2500	0	0	0	0	0	0	0	0	0	0	0	0	0
2250	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
1750	0	0	0	0	0	3	3	2	2	2	7	6	0
1500	0	0	12	42	40	44	43	33	29	38	36	34	39
1250	0	0	0	0	0	0	1	1	5	1	1	2	2
1000	0	0	0	0	0	0	0	0	0	0	0	0	0
750	0	0	0	0	0	0	0	0	0	0	0	0	0
500	0	0	0	0	0	0	0	0	0	0	0	0	0
250	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0

(-1:PUMPING WELL, -2:INJECTION WELL)

PARTICLES ON A CIRCLE
CIRCLE NUMBER 42
CIRCLE CENTER COORDINATES (X,Y) = 500 , 1500 FT
CIRCLE RADIUS = 5 FT
NUMBER OF PARTICLES = 20

TOTAL SYSTEM PARTICLES = 840
\\\//////////////////////////
PRESENT SIMULATION TIME = 615 DAYS
INCREMENTAL SIMULATION TIME = 15 DAYS
DMAX = 121 FT

NP= 840

LOWER-LEFT COORDINATES = 0 , 0 FT
UPPER-RIGHT COORDINATES = 3000 , 3000 FT
CELL SIZE (CDX,CDY) = 250 , 250 FT

SIMULATION TIME = 630 DAYS

	0		500		1000		1500		2000		2500		3000
3000	0	0	0	0	0	0	0	0	0	0	0	0	0
2750	0	0	0	0	0	0	0	0	0	0	0	0	0
2500	0	0	0	0	0	0	0	0	0	0	0	0	0
2250	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
1750	0	0	0	0	0	2	2	5	2	2	3	4	5
1500	0	0	14	43	38	31	57	32	31	28	39	43	27
1250	0	0	0	0	0	0	1	0	3	4	3	0	2
1000	0	0	0	0	0	0	0	0	0	0	0	0	0
750	0	0	0	0	0	0	0	0	0	0	0	0	0
500	0	0	0	0	0	0	0	0	0	0	0	0	0
250	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0

(-1:PUMPING WELL, -2:INJECTION WELL)

PARTICLES ON A CIRCLE
CIRCLE NUMBER 43
CIRCLE CENTER COORDINATES (X,Y) = 500 , 1500 FT
CIRCLE RADIUS = 5 FT
NUMBER OF PARTICLES = 20

TOTAL SYSTEM PARTICLES = 860
\\\\\\\\\\\\\\\\\\\\//////////////////////////
PRESENT SIMULATION TIME = 630 DAYS
INCREMENTAL SIMULATION TIME = 15 DAYS
DMAX = 121 FT

NP= 860

```
          PARTICLES ON A CIRCLE
           CIRCLE NUMBER  44
           CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
           CIRCLE RADIUS =  5  FT
        NUMBER OF PARTICLES =  20

          TOTAL SYSTEM PARTICLES =  880
       \\\\\\\\\\\\\\\\\\\\//////////////////////////
       PRESENT SIMULATION TIME =  645   DAYS
        INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 880
```

```
          PARTICLES ON A CIRCLE
           CIRCLE NUMBER  45
           CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
           CIRCLE RADIUS =  5  FT
        NUMBER OF PARTICLES =  20

          TOTAL SYSTEM PARTICLES =  900
       \\\\\\\\\\\\\\\\\\\\//////////////////////////
       PRESENT SIMULATION TIME =  660   DAYS
        INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 900
```

```
          PARTICLES ON A CIRCLE
           CIRCLE NUMBER  46
           CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
           CIRCLE RADIUS =  5  FT
        NUMBER OF PARTICLES =  20

          TOTAL SYSTEM PARTICLES =  920
       \\\\\\\\\\\\\\\\\\\\//////////////////////////
       PRESENT SIMULATION TIME =  675   DAYS
        INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 920
```

```
//////////////////////PARTICLE MAPPING\\\\\\\\\\\\\\\\\\\\\
         MAP WINDOW LOCATION
      LOWER-LEFT COORDINATES =  0 , 0 FT
         UPPER-RIGHT COORDINATES =  3000 , 3000 FT
         CELL SIZE (CDX,CDY) = 250 , 250 FT

         SIMULATION TIME =  690  DAYS
           0       500      1000      1500      2000      2500      3000
      ____!____!____!____!____!____!____!____!____!____!____!____!____!
 3000!    0    0    0    0    0    0    0    0    0    0    0    0    0


 2750!    0    0    0    0    0    0    0    0    0    0    0    0    0
```

```
2500|    0    0    0    0    0    0    0    0    0    0    0    0    0

2250|    0    0    0    0    0    0    0    0    0    0    0    0    0

2000|    0    0    0    0    0    0    0    0    0    0    0    0    0

1750|    0    0    0    0    1    1    1    3    3    6    5    3    9

1500|    0    0   13   39   41   45   37   38   47   26   26   28   30

1250|    0    0    0    0    0    0    0    2    2    1    2    7    3

1000|    0    0    0    0    0    0    0    0    0    0    0    0    0

 750|    0    0    0    0    0    0    0    0    0    0    0    0    0

 500|    0    0    0    0    0    0    0    0    0    0    0    0    0

 250|    0    0    0    0    0    0    0    0    0    0    0    0    0

   0|    0    0    0    0    0    0    0    0    0    0    0    0    0


       (-1:PUMPING WELL, -2:INJECTION WELL)

        PARTICLES ON A CIRCLE
         CIRCLE NUMBER  47
         CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
         CIRCLE RADIUS =  5  FT
      NUMBER OF PARTICLES =  20

        TOTAL SYSTEM PARTICLES =  940
     \\\\\\\\\\\\\\\\\\\\\\\\\///////////////////////////
     PRESENT SIMULATION TIME =  690   DAYS
      INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 940



//////////////////////PARTICLE MAPPING\\\\\\\\\\\\\\\\\\\\\
       MAP WINDOW LOCATION
     LOWER-LEFT COORDINATES =  0 , 0 FT
       UPPER-RIGHT COORDINATES =  3000 , 3000 FT
       CELL SIZE (CDX,CDY) = 250 , 250 FT

       SIMULATION TIME =  705  DAYS
         0        500       1000       1500       2000       2500       3000
     ____|____|____|____|____|____|____|____|____|____|____|____|____|
3000|    0    0    0    0    0    0    0    0    0    0    0    0    0
```

2500	0	0	0	0	0	0	0	0	0	0	0	0	0
2250	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
1750	0	0	0	0	1	1	0	3	3	4	5	8	3
1500	0	0	10	44	35	48	37	38	44	34	27	25	28
1250	0	0	0	0	0	0	1	0	3	3	5	5	5
1000	0	0	0	0	0	0	0	0	0	0	0	0	0
750	0	0	0	0	0	0	0	0	0	0	0	0	0
500	0	0	0	0	0	0	0	0	0	0	0	0	0
250	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0

(-1:PUMPING WELL, -2:INJECTION WELL)

PARTICLES ON A CIRCLE
CIRCLE NUMBER 48
CIRCLE CENTER COORDINATES (X,Y) = 500 , 1500 FT
CIRCLE RADIUS = 5 FT
NUMBER OF PARTICLES = 20

TOTAL SYSTEM PARTICLES = 960
\\\\\\\\\\\\\\\\\\\\////////////////////////
PRESENT SIMULATION TIME = 705 DAYS
INCREMENTAL SIMULATION TIME = 15 DAYS
)MAX = 121 FT

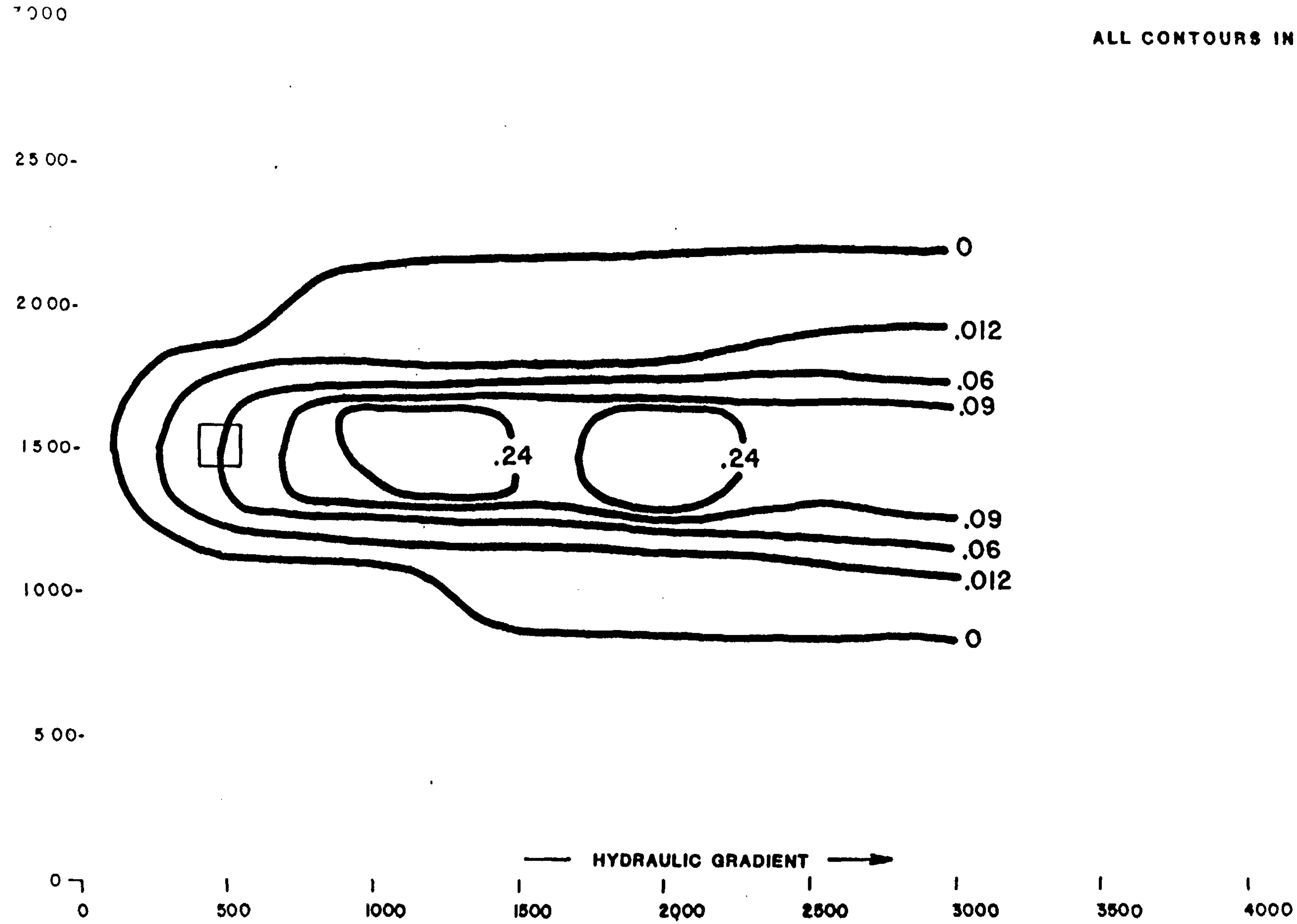
NP= 960

PARTICLES ON A CIRCLE
CIRCLE NUMBER 49
CIRCLE CENTER COORDINATES (X,Y) = 500 , 1500 FT
CIRCLE RADIUS = 5 FT
NUMBER OF PARTICLES = 20

TOTAL SYSTEM PARTICLES = 980
\\\\\\\\\\\\\\\\\\\\////////////////////////
PRESENT SIMULATION TIME = 720 DAYS

```
NP= 980



          PARTICLES ON A CIRCLE
           CIRCLE NUMBER  50
           CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
           CIRCLE RADIUS =  5  FT
        NUMBER OF PARTICLES =  20

          TOTAL SYSTEM PARTICLES =  1000
       \\\\\\\\\\\\\\\\\\\\////////////////////////
       PRESENT SIMULATION TIME =  735   DAYS
        INCREMENTAL SIMULATION TIME =  15  DAYS
DMAX =  121  FT

NP= 1000



          PARTICLES ON A CIRCLE
           CIRCLE NUMBER  51
           CIRCLE CENTER COORDINATES (X,Y) =  500 , 1500  FT
           CIRCLE RADIUS =  5  FT
        NUMBER OF PARTICLES =  20
```

ALL CONTOURS IN PPB



MODEL INPUT PARAMETERS

Transmissivity (GPD/FT)-125000
Storage Coefficient-.1
Hydraulic Conductivity (GPD/FT^2)-5000
Porosity-.25
Longitudinal Dispersivity-10
Transverse Dispersivity-2

Retardation Coefficient (FT)-1
Regional X Flow(FT/DAY)-8.04
Regional Y Flow (FT/DAY)-0

SOURCE TERM

Volume Of Produced Water (BBL/DAY)-.33
Benzene Concentration (PPB)-3500

CASE NUMBER-GCU 153E

Simulation Time (DAYS)-705
NE, NW 28 29 N 12 W
SAN JUAN RIVER
dh/dl = 0.003

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W. Thomas Kellahin
Karen Aubrey

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Area Code 505

May 21, 1985

Mr. Richard L. Stamets
Oil Conservation Commission
P. O. Box 2088
Santa Fe, New Mexico 87504

"Hand Delivered"

Re: OCC Case 8224

Dear Mr. Stamets:

Please find enclosed an original and one copy of Tenneco Oil Company's post hearing documents.

Very truly yours,

Original signed by
W. THOMAS KELLAHIN

W. Thomas Kellahin

WTK:ca
Enc.

cc: Jeff Taylor, Esq. - w/enc.
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cc: Mr. Marty Buys
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P. O. Box 3249
Englewood, Colorado 80155

BEFORE THE OIL CONSERVATION COMMISSION
ENERGY AND MINERALS DEPARTMENT
STATE OF NEW MEXICO

IN THE MATTER OF THE HEARING CALLED BY THE OIL CONSERVATION COMMISSION UPON ITS OWN MOTION TO DEFINE THE VERTICAL AND AREAL EXTENT OF AQUIFERS POTENTIALLY VULNERABLE TO CONTAMINATION BY THE SURFACE DISPOSAL OF PRODUCED WATER IN McKINLEY, RIO ARRIBA, SANDOVAL, AND SAN JUAN COUNTIES, NEW MEXICO	CASE NO. 8224

COMMENTS ON THE HEARING RECORD BY
INTERVENOR CHRIS SHUEY, APPEARING PRO SE

These comments are submitted to the Oil Conservation Commission ("the Commission" or "OCC") by Chris Shuey, an intervenor who appeared for himself during the public hearing held to consider the above-captioned case. The comments are intended only to aid the Commission in reviewing and understanding the testimony pertaining to the Duncan Oil Field Hydrologic Investigation conducted by Mr. Masud Zaman and others, including Intervenor Shuey. A brief section on elements of a proposed order is included at the end of these comments. References to the hearing transcript as presumed to be from the April 3 portion of the hearing, except as otherwise noted.

I. INTERESTS AND STATUS OF THE INTERVENOR

Intervenor Shuey was a member of the Oil Conservation Division's ("the Division" or "OCD") Short Term San Juan Produced Water Study Committee ("the Committee") for the duration of the Committee's activities between July 18, 1984 and January 9, 1985. He attended all meetings of the Committee and its subcommittee on vulnerable aquifer mapping and actively participated in those meetings.

During those meetings, Intervenor Shuey represented Southwest Research and Information Center ("SRIC") by whom he is employed as a research associate for ground water protection. He has represented SRIC in numerous other state and federal regulatory proceedings pertaining to ground water contamination. SRIC, as a not-for-profit educational organization, is dedicated to protecting the quality and quantity of New Mexico's ground water resources.

Intervenor Shuey appeared for himself, and not as a representative of SRIC, during the public hearing on OCC Case No. 8224, because of the Commission's ruling that corporations must be represented by an attorney licensed to practice law in New Mexico. Intervenor Shuey is not an attorney and his employer was not financially able to hire an attorney to represent him at the hearing; therefore, he exercised his constitutional right to represent himself as a taxpayer of the State of New Mexico.

II. FACTUAL BACKGROUND

This proceeding was initiated by the Division after the contamination of a public water supply well in Flora Vista, N.M., was revealed in August 1983. The contamination consisted of oil and grease, phenols and certain metals. A nearby produced water disposal pit was listed as a possible source of the contamination.

In exercising its authority under New Mexico law (Sec. 70-2-12.B.(15), N.M.S.A. 1978) to protect the state's fresh water supplies from contamination resulting from the disposition of water produced or used in connection with the production of oil and natural gas, the Division called a public hearing for June 8, 1984, to determine if the surface disposition of produced water was contaminating fresh water supplies.

Understanding that such a determination would require considerable scientific study, the Division formed a San Juan Produced Water Study Committee consisting of representatives of its environmental staff, other state agencies including the Environmental Improvement Division, representatives of oil and gas producers in northwest New Mexico, and representatives of environmental and citizen groups.

The Committee agreed at its first meeting on July 18, 1984, after lengthy discussion, to limit its investigation to the existing available data on ground water resources and possible contamination from the disposal of produced water in unlined pits in the four counties of northwest New Mexico. A lack of agency financial resources and time limitations were cited as a reason for the Committee not to conduct site-specific ground water studies around unlined produced water disposal pits.

Over the seven-month period, the Committee developed substantial information on ground water resources in the four-county area, including the location of shallow aquifers (that is, those subsurface water bodies 100 feet or less in depth), the locations of existing ground water use, the locations of existing and past oil and gas development, and the chemistry of produced waters being disposal of unlined pits. The hydrologic information permitted the Committee to identify and define areas of shallow ground water that might be vulnerable to contamination from unlined surface disposal pits. The chemical data permitted the Committee to identify and understand the toxic components of produced water, including a class of hydrocarbons called purgeable aromatic hydrocarbons.

The Committee agreed by consensus to a set of recommendations, which were received into evidence in this proceeding as "Committee Exhibit 1." The recommendations reflect the substantial information base upon which the Committee based its definition of "vulnerable areas." The Committee as a whole could not agree, however, on an amount of produced water that could be discharged to an unlined surface pit without causing contamination of fresh water resources. As a result, the Committee elected to present its recommendations to the Division without a recommendation for small volume exemptions.

Knowing that the Committee had not investigated ground water conditions around unlined pits in the vulnerable area due to the financial and time limitations discussed above, two members of the Committee agreed independently to conduct such an investigation and present the results of that investigation to the Commission at the hearing. Those individuals were Mr. Masud Zaman, geohydrologist for the Navajo Tribe, Window Rock, Arizona, and Intervenor Shuey. Their investigation spanned two days, February 25 and March 18, 1985. A third member of the Committee, Gary A. Eiceman, Ph.D., of New Mexico State University, agreed to assist in the March 18 phase of the investigation. Being qualified as an expert in geohydrology, Mr. Zaman presented the results of that investigation to the hearing on April 3, 1985.

III. MASUD ZAMAN'S FINDINGS

Mr. Zaman used a slide presentation and 13 exhibits to present the results of his February 25 and March 18 hydrologic investigations at the Duncan Oil Field in Sec. 6, Township 29 North, Range 16 West, San Juan County, New Mexico.

Mr. Zaman explained that he selected the Duncan Oil Field site for his investigations because (1) the site in on the Navajo Indian Reservation and a local chapter of the Tribe had requested the Tribe's assistance in dealing with oil field spills in the area (Transcript at 15, and Zaman Exhibit 1-A), (2) the site was in the vulnerable area as defined by the Committee (Transcript at 26), and (3) the site contained a number of oil wells and produced water disposal pits

(Transcript at 36).

Mr. Zaman testified that he determined that a produced water disposal pit adjacent to Duncan Oil Well 6-11 was unlined because he probed the bottom of the pit and observed no liner (Transcript at 17 and 18). He also testified that he observed a flow of liquid into the pit from a buried separator at the wellhead via a two-inch diameter pipe, and that based on a 24-hour continuous flow, the pit was receiving approximately two barrels of produced water per day (Transcript at 17).

Mr. Zaman testified he dug test pits to determine the depth to ground water at varying distances from the produced water disposal pit on both dates of the investigation (Transcript at 18-22). He presented maps (Zaman Exhibits 5 and 6) showing the locations of those test pits in relation to the produced water pit. He testified that he inspected the study site and its proximity to the flow of the San Juan River and determined that the hypothetic direction of ground water was north-northwest from the produced water pit (Transcript at 22).

Based on water level measurements in the test pits on both dates of the investigation, Mr. Zaman prepared a water level map (Zaman Exhibit 9). The water level map confirmed that ground water flow was north-northwest from the produced water pit (Transcript at 22). Mr. Zaman testified that he assumed the study site was flat because his survey crews were not available on either date (Transcript at 23). He said that "minor variations" in surface elevation of 3 to 6 inches could slightly alter the shape of the contour lines, but not the overall direction of ground water flow as indicated in Exhibit 9 (Transcript at 23 and 43).

Mr. Zaman presented to the Commission Mason jars containing black oily sands he said he collected from test pits on February 25 and March 18. The jars were marked as Zaman Exhibit 11 and entered into evidence. Mr. Zaman opened the jars during his testimony and inferred that the smell in the material in the jars was the same as the smells he witnessed while digging the test pits in the field (Transcript at 24 and 41). He said those smells resembled the smell of gasoline (Transcript at 19).

Mr. Zaman presented the chemical analyses of samples he took on both dates from the liquid entering the produced water pit, from the liquid in the pit, and from the liquid that entered the test pits (Zaman Exhibit 13). His Exhibit 13 showed analyses for purgeable aromatic hydrocarbons, metals, nitrates and major ions from samples taken February 25 and for purgeable aromatics alone from samples taken March 18.

Mr. Zaman testified that the analyses showed concentrations of benzene above the New Mexico Water Quality Control Commission standard of 10 parts per billion in three of four test pits on February 25, and measured concentrations of ethylbenzene, xylenes, and larger hydrocarbon molecules on the same date. The hearing record shows that such hydrocarbon compounds do not occur naturally (see testimony of David Boyer and Thomas Schultz). While only metaxylene was detected in a test pit sampled by Mr. Zaman on March 18, aliphatic (or "straight-chain") hydrocarbons in concentrations between 100 and 500 ppb were found in samples taken from a test pit on the same date (Zaman Exhibit 13 and Transcript at 31).

Mr. Zaman labeled Total Dissolved Solids (TDS) concentrations from the produced water pit and test pits on Zaman Exhibit 9 and testified that TDS concentrations decreased with distance from the produced water disposal pit. His Exhibits 7 and 8 showed that physical signs of contamination (such as hydrocarbon odors, a black oily staining of sands above the water table, and a black oily film on the water itself) were limited to those test pits down-gradient of the produced water pit. The only exception in the data presented by Mr. Zaman to the conclusion that a plume of contaminants was spreading north-northwest from the produced water disposal pit was a benzene concentration of 100 ppb in an upgradient test pit on February 25.

As to the possible sources of contamination other than the produced water disposal pit, Mr. Zaman said he inspected the casing of the oil well and observed no signs of leaks at the surface (Transcript at 33). His Exhibit 4 showed that the well was cased with cement for its entire depth of approximately 690 feet (Zaman Exhibit 4, p. 2). Mr. Zaman testified that he observed no reserve pits or mud pits at the site in the location shown on page 6 of his Exhibit 4 (Transcript at 40). According to the exhibit (page 7), no drilling muds were used in completion of the oil well, only water. Mr. Zaman also testified that he observed no leaks in oil pipelines at the study site (Transcript at 40).

Mr. Zaman testified that a small amount (1 milliliter) of cyclohexane, an organic solvent, had been used to rinse the insides of the bottles he used to take the organic samples in during the February 25 phase of the investigation. He stated that the only possible effect the presence of the solvent on the results of the analyses of the samples would be to reduce the reported concentrations of benzene and other purgeable aromatic hydrocarbons.

Based on his investigation at the Duncan Oil Field, Mr. Zaman said he would suggest no unlined pits in the vulnerable area.

IV. DR. EICEMAN'S FINDINGS

Dr. Eiceman, an associate professor of chemistry at New Mexico State University (Transcript at 49), testified as an expert in the chemistry of oil field production at the hearing on April 3, 1985 (Transcript at 49).

Dr. Eiceman testified that he assisted Mr. Zaman and Intervenor Shuey in a hydrologic investigation at the Duncan Oil Field on March 18, 1985 (Transcript at 65). He testified that Test Pits 1, 2, 3, 4, 8 and 9 showed physical signs of contamination, such as black stained sands and dirt above the water table and black oily film on the water, and that those pits were in the down-gradient direction (north-northwest) from the produced water disposal pit (Transcript at 66 and 70). He further testified that test pits upgradient from the produced water pit (Test Pits 5, 6 and 7) exhibited no such physical signs of contamination.

Dr. Eiceman presented as exhibits gas chromatograms (Eiceman Exhibits 17 through 21) of water samples he collected from the produced water pit and several of the nine test pits. He testified that the chromatograms from the produced water pit samples were similar in shape and pattern to those from the samples of test pit water (Transcript at 67). He stated that benzene, toluene, xylene and alkylated benzenes were present in both produced water and in water from the test pits located down-gradient from the produced water pit (Transcript at 67 and 68). He testified that Test Pits 5, 6 and 7, those test pits which were upgradient of the produced water disposal pit, showed no detectable organic contamination (Transcript at 70).

Dr. Eiceman further testified that volatile hydrocarbons and extractable hydrocarbons were presented in water samples from Test Pit 1, but only volatile hydrocarbons were present in Test Pit 2 (Transcript at 70). Mr. Zaman's Exhibit 9 showed Test Pit 1 75 feet west of the produced water pit and Test Pit 2 150 feet west of the produced water pit. Both locations are down-gradient of the produced water pit.

Dr. Eiceman explained the he observed the concentration of light hydrocarbons (such as benzene) to diminish with distance west, northwest and north of the produced water disposal pit (Transcript at 96) and that those concentrations documented a contaminant plume moving in a direction consistent with that of the ground water flow (Transcript at 97).

Dr. Eiceman presented preliminary calculations showing concentrations of benzene and other purgeable aromatic hydrocarbons in the produced water and water in the test pits (Eiceman Exhibit 22). The calculations, which were based on the chromatograms (Transcript at 78 and 79), showed benzene concentrations in the test pits ranging from just below the regulatory standard of 10 ppb to well above the standard (that is, in the hundreds of parts per billion).

The Commission allowed Dr. Eiceman's exhibits to be received in evidence, but only upon the understanding that they would not be given much weight (Transcript at 98). The objections to the exhibits that were raised by Tenneco's counsel did not include Eiceman Exhibit 22, the calculations of ranges of concentrations in the produced water and water in the test pits at the Duncan Oil Field.

V. MR. MEYERHEIN'S TESTIMONY

Mr. Rick Meyerhein, director of the organics section of the State Laboratory Division, was called as a witness by the Division to attest to the analytical methods used by the State Lab in analyzing samples of produced water gathered by Division staff (Transcript at 99).

Mr. Zaman's Exhibit 13 showed that the samples he collected and had analyzed for organic constitutents had been analyzed by the State Lab. Mr. Meyerhein was asked by counsel for Tenneco and by Intervenor Shuey during cross-examination to comment on the possible effect the solvent cyclohexane could have on organic concentrations in the produced water and test pit water samples taken by Mr. Zaman (Transcript at 106).

In response to those questions, Mr. Meyerhein stated that the U.S. Environmental Protection Agency does not have a standard for cyclohexane in samples (Transcript at 105), but that rinsing a sample bottle with the solvent was "not unreasonable" to insure that the bottle contained no residual contamination that could affect the reported organic constituents (Transcript at 107).

Asked what effect cyclohexane could have on the organic constitutents reported by the State Lab in Mr. Zaman's samples, Mr. Meyerhein stated that there would be very little effect (Transcript at 106), and if there was, "...the results we reported would be...lower" than reported by the State Lab (Transcript at 110).

VI. TESTIMONY OF DR. THOMAS SCHULTZ

Dr. Thomas Schultz was called as a witness for Meridan Oil Co. to discuss various physical properties that may attenuate or reduce the flow of hazardous substances including hydrocarbons from an unlined produced water into the ground water (Transcript at 144).

Under questioning by Chairman Stamets, Dr. Schultz stated that benzene does not occur naturally in ground water except for perhaps one case near Hobbs. Mr. Stamets then asked, "But in general, if one finds benzene in groundwater as Mr. Zaman has in his pits, then that means that somehow it got there from a disposal pit, a well, something happened to put that benzene in the groundwater" (Transcript at 184). To which Dr. Schultz replied, "Right, if there's no other mechanism, that's correct."

Under later questioning by Intervenor Shuey, Dr. Schultz inferred that the absence of benzene in a test pit water sample does not necessarily mean that benzene is not in the ground water between the test pit and the produced water pit, especially when benzene was detected in the produced water in the unlined disposal pit:

> Mr. SHUEY: Do you have any reason to believe that benzene in measurable concentrations is not in the groundwater between the produced water pit and Test Pit 1 on the second page of Masud Zaman's Exhibit Thirteen?"
>
> DR. SCHULTZ: It's there at some point in some concentration." (Transcript at 216).

VII. IMPLICATIONS OF MR. ZAMAN'S TESTIMONY FOR THE COMMISSION'S DECISION IN THIS CASE

Mr. Zaman's testimony, and that of Dr. Eiceman, Mr. Meyerhein, and Dr. Schultz as related to Mr. Zaman's evidence, is important for the Commission to consider as it reaches a decision in this case. The significant questions raised by Mr. Zaman's testimony are (a) was contamination of ground water demonstrated? (b) if there was contamination, was an unlined pit the reasonable source of that contamination? and (c) if the pit was the source, to what extent can the Commission rely on the testimony to order a prohibition of less than 5 barrels of produced water per day in unlined pits?

In view of the evidence, Intervenor Shuey submits that Mr. Zaman indeed found ground water contamination and that that contamination could reasonably be connected to the unlined produced water disposal pit. If the Commission agrees, it can use that evidence as substantial support for a rule banning the disposal of 2 barrels of produced water per day.

A. MR. ZAMAN AND DR. EICEMAN SHOWED EVIDENCE OF GROUND WATER CONTAMINATION AT THE DUNCAN OIL FIELD

As shown in Section III of these comments, Mr. Zaman presented data showing concentrations of benzene in ground water that exceed the state standard. Mr. Zaman also presented data showing the presence of other aromatic hydrocarbons and unknown aliphatic hydrocarbons in ground water. The presence of benzene and those other organic compounds is evidence by itself of contamination, inasmuch as those compounds do not occur naturally. Mr. Boyer and Dr. Schultz have testified that those compounds do not occur naturally.

Dr. Eiceman presented data (Eiceman Exhibit 22) that showed a range of benzene concentrations in ground water, most of which exceeded the state numeric standard. Those concentration ranges were calculated based on analytic results that were produced by accepted laboratory methods of detecting organic compounds in liquids.

Mr. Meyerhein's testimony demonstrated that the presence of cyclohexane in Mr. Zaman's February 25 samples did not significantly alter the reported organic concentrations, and if it did, the concentrations were likely to be greater than reported because of the penchant for benzene being absorbed by the cyclohexane.

B. MR. ZAMAN'S TESTIMONY DEMONSTRATES THAT AN UNLINED PRODUCED WATER PIT CONTAMINATED THE FRESH WATER SUPPLIES OF AN AREA IN NORTHWEST NEW MEXICO

Taken as a whole, Mr. Zaman's testimony supports a conclusion that the unlined produced water pit at Duncan Oil Well 6-11 contaminated shallow ground water in the area of the study. That conclusion can be reached on the basis of several reasons.

First, Mr. Zaman showed, with one exception, a plume of contaminants emanating from the produced water pit and traveling in the same direction as the flow of ground water. The organic constituents, nitrates, and general chemistry data generally showed decreasing concentrations with distance from the pit, except in only three samples.

Dr. Eiceman's data corroborated Mr. Zaman's data. Dr. Eiceman found organic constituents in test pit water very similar to those in produced water in the adjacent unlined pit. Additionally, the concentrations of those constituents decreased with distance from the produced water pit. Dr. Schultz suggested (Transcript at 216) that benzene had escaped from the produced water pit and was present in the ground water between the produced water pit and the down-gradient test pits.

Second, Mr. Zaman investigated most other possible sources of contamination and concluded that none posed as great a potential for contaminating ground water as did the produced water pit. He testified that the oil well was cased in cement to the producing zone. He testified that he observed no surface spills of petroleum products either from the wellhead, pipelines, or the buried separator. His slides showed no leaks from the backhoe. And his exhibit on the oil well itself (Zaman Exhibit 4) showed that no drilling muds were used to develop the well in September 1975.

Those personal observations and studies of Mr. Zaman have far more weight than Randy Hicks's speculation that some other source than the produced water pit could explain the presence of ground water contamination at the site (see Transcript of April 22 at 122). Mr. Hicks did not visit the Duncan Oil Field nor conduct the visual inspections Mr. Zaman did.

Third, Mr. Zaman brought to the hearing photographic and physical evidence from his investigation. His slides of the study area, the produced water pit, and the physical contamination of sands and water in the test pits on both dates of the investigation were compelling proof of the contamination he found. His Mason jars containing oily black sands extracted from his test pits filled the hearing room with gasoline-like odors -- the same odors Mr. Zaman testified that he smelled in the field.

Mr. Zaman readily admitted that he made some mistakes in his study, but pointed out that those mistakes were not sufficient to alter the analytic results or the hydrologic findings. He had nothing to hide and no reason to hide it because the facts would speak for themselves. He was willing to let the Commission judge the quality of his study as any "reasonable man" would.

C. THE COMMISSION CAN CONSIDER MR. ZAMAN'S TESTIMONY AS SUBSTANTIAL EVIDENCE IN THIS CASE

If the Commission agrees that Mr. Zaman's study discovered ground water contamination that can reasonably be connected with leakage from an unlined produced water disposal pond, it can use that evidence to support an order banning disposal of less than 5 barrels of produced water per day in unlined disposal pits. The Commission is reminded that Mr. Zaman showed an adverse affect to ground water from a pit receiving at the maximum 2 barrels of produced water daily. Mr. Zaman was convinced, based on his investigation and his years of experience as a geohydrologist with the federal government and now the Navajo Tribe, that the contamination at the Duncan Oil Field was significant enough to warrant his recommendation for no disposal in unlined pits.

Intervenor Shuey suggests that Mr. Zaman's evidence, coupled with the calculations performed by David Boyer and Doug Earp, provides a basis for the Commission to take action to prevent contamination of ground water in the four counties of northwest New Mexico. Contrary to Mr. Kellahin's numerous statements at the beginning and end of the hearing that the Commission only had evidence sufficent to support a ban of 5 barrels or more, the evidence placed in the record by supporters of the Division's position demonstrates clearly that contaminants can move from the surface to the water table under a variety of field conditions, and, at least in one case, they already have.

VIII. CONCLUSIONS

Ground water protection policy in New Mexico and throughout the U.S. has evolved considerably in recent years. As more detailed scientific evidence has accumulated, and additional cases of ground water contamination discovered, regulators have increasingly moved toward a posture of attempting to prevent contamination before it happens.

In this case, the Commission heard extensive testimony about physical and chemical factors that retard or prevent the movement of contaminants from unlined disposal pits into the ground water. Mr. Hicks testified that he believed that the absence of large concentrations of benzene in his monitoring wells confirmed the findings of Dr. Schultz and Dr. Gary Miller regarding attenuation factors and biodegradation (see, for instance, Transcript of April 22 at 155).

Mr. Boyer readily admitted in his testimony his understanding that physical factors work to retard contaminant movement into the ground water. But he also noted that there is great uncertainty about the mechanics of attenuation and biodegradation -- a fact admitted by Dr. Miller and even the authors of some of the papers he referenced -- and that prudent ground water protection ppolicy mandates taking affirmative preventive action before contamination occurs.

Intervenor Shuey has appended to these comments a recent technical paper on organic constituent movement in ground water (Joan M. Newsom, "Transport of Organic Compounds Dissolved in Ground Water," Ground Water Monitoring Review, Spring 1985). As noted by Mr. Boyer, Dr. Schultz and Dr. Miller, biodegradation and other attenuation factors have been found to retard the movement of organic compounds in ground water.

But even in the face of positive evidence, the author makes several cautionary statements, including:

> "In some cases, however, the degradation products could be as toxic or worse than the original compound...Limitations include the difficulty of managing environmental parameters that promote biodegradation and the difficulty in maintaining biodegradation as environmental conditions." (page 34)

> "The field conditions under which biodegradation of different compounds is promoted is not well understood." (page 34)

> "The mechanisms of adsorption and biodegradation are not well enough understood to model satisfactorily." (page 35)

The author makes a very compelling conclusion for adopting -- as the Commission as the authority to do under the Water Quality Act (74-6-4.D., N.M.S.A. 1978) -- a conservative approach to ground water protection given the uncertainties involved in assessing organic constituent movement in ground water:

> "Although the technology may exist to clean up polluted ground water and pollution sites, the costs are often high. A water policy is needed to encourage prevention and set priorities for what should be cleaned up. The cost of cleanup can be several orders of magnitude larger than that of preventive measures." (page 35)

IX. THE COMMISSION'S ORDER

In fashioning an order based on the hearing record, the Commission should include all of the recommendations of the Water Study Committee including those pertaining to definitions of the vulnerable area and the various types of pits present at oil and natural gas well sites. The Commission should use its best judgment in reaching a decision on the amount of produced water that can safely be disposed of in unlined pits.

The undersigned wishes to congratulate the Division and the Commission on its response to the potential problem of ground water contamination from unlined disposal pits, and promises to continue to be involved in the matter as the agency pursues additional technical and field studies.

Respectfully submitted,

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ATTACHMENT —

Transport of Organic Compounds Dissolved in Ground Water

by Joan M. Newsom

Abstract

Organic compounds, such as trichloroethylene (TCE) and chlorobenzene, that have been found in drinking water supplies are of public concern because they are possibly carcinogenic. These substances can now be routinely detected in trace amounts with gas chromatograph mass spectrometers. There are some polar organic compounds, which are not detectable individually by common methods and therefore little is known about them.

The transport of organic compounds is more difficult to predict than the flow of ground water because:

- Trace amounts of pollutants are difficult to measure
- Transport is complicated if the compound is partitioned into several phases
- The concentration of organics in ground water may vary due to aquifer heterogeneity and other hydrologic factors
- Reactions with other organic compounds and reactions with the aquifer material (such as adsorption) may affect the mobility of the organics
- Biodegradation may also affect net transport.

Adsorption is a factor in the attenuation of non-polar organics in aquifers with significant organic content (>0.1 percent organic carbon). The organic material adsorbs the non-polar organic chemicals. The mobility of a pollutant in such an aquifer depends on at least two parameters: the levels of dissolved organic matter and the content of organic carbon in the aquifer material. The partition coefficient of the chemical pollutant between the aquifer and water is commonly calculated as a function of the organic content of the aquifer and the partition coefficient between octanol and water.

Field and laboratory results reported in the literature indicate that the following organic compounds may be biodegradable under aerobic conditions: alkyl benzenes and chlorobenzenes. Under anaerobic conditions halogenated aliphatics, alkyl benzenes, several pesticides and phenolic compounds may be biodegradable. Halogenated aliphatics appear not to degrade under aerobic conditions and non-chlorinated aromatics and chlorobenzenes appear not to degrade under anaerobic conditions. Alkyl benzenes biodegrade more rapidly than their halogenated counterparts.

Introduction

Pollution of ground water by organic compounds is an important area of public concern, and hydrogeologists are increasingly required to evaluate hydrocarbon contamination in the subsurface. The methods of analysis have improved in recent years such that concentrations of less than one microgram per liter ($\mu g/L$) can be determined. The ability to measure more organic compounds, especially polar organics, will increase the number of different contaminants detectable in water.

Some of the organic compounds found in water are believed to be harmful in trace amounts. The health risks of the synthetic organics, however, are difficult to determine mainly because of the uncertainty in extrapolating the results of laboratory carcinogen tests on lab animals to humans. The health risks are not likely to become known very rapidly. References on health aspects of synthetic organics are found in Pearson (1982a, 1982b), and Merian and Zander (1982).

Man-made hydrocarbons are used in a wide range of industries and in household products. They are for the most part a product of technology used since the 1940s. Their solubility in non-polar substances and poor solubility in water account for their common and widespread use as degreasers. Trichloroethylene (TCE) is used, for example, to clean oil from industrial machines, to wash oils from airport runways, and to remove grease from clothes in dry cleaning.

Definitions

Hydrocarbon compounds, also called organic compounds, are composed of hydrogen and carbon. Aliphatic hydrocarbons are a group of hydrocarbons in which the carbon atoms are joined to form open chains. Aromatic hydrocarbons usually have structures that contain at least one benzene ring. Monocyclic aromatics, such as alkyl benzenes, have one ring. Polynuclear hydrocarbons possess more than one ring. This class of hydrocarbons can be divided into two groups. In the first, the rings are fused, which means at least two carbon atoms are shared between adjacent rings, e.g., naphthalene. In the second group, the aromatic rings are joined directly or through a chain of at least one carbon atom, e.g., biphenyl.

Many of the organic pollutants are halogenated:

that is, they contain halogen atoms in their molecular structure. Chlorine, bromine and fluorine are the most common halogens. Examples of halogenated aliphatics found in ground water include: trichloroethylene ($ClCH{:}CCl_2$, commonly abbreviated TCE), which contains two carbon atoms joined by a double bond; 1,1,1-trichloroethane (CH_3CCl_3), which contains two carbon atoms joined by a single bond; and tetrachloroethylene ($Cl_2C{:}CCl_2$, commonly abbreviated PCE), which contains two carbon atoms joined by a double bond. Trihalomethanes (THMs) are a subgroup of the halogenated aliphatics that contain three halogens in the methane (CH_4) molecular structure. Examples include chloroform or trichloromethane ($CHCl_3$), bromoform or tribromomethane ($CHBr_3$), and dibromochloromethane ($CHBr_2Cl$). Halogenated aromatics found in ground water include: chlorobenezene (ClC_6H_5), dichlorobenezene ($Cl_2C_6H_4$, abbreviated in this paper, DCB), and trichlorobenzene ($Cl_3C_6H_3$, abbreviated in this paper, TCB).

Hydrocarbon compounds can also be generally divided into polar and non-polar groups. Polar molecules are electrically neutral molecules with concentrations of negative charge in one part of the molecule and of positive charge in another, producing an electric dipole.

Occurrence of Organic Pollutants in Ground Water

The extent of ground water pollution by organic compounds is difficult to estimate both for a given aquifer and in general. Specific studies are difficult to compare because of variations in analytical sensitivity and differences among the compounds studied. Even for a given aquifer, the extent of ground water pollution by organic compounds can only be estimated because such a small fraction of the ground water is usually sampled.

There are many sources of organic pollution. Contaminants may reach the aquifer by way of precipitation, by seepage of pesticides and herbicides from the surface, from pollutants in sanitary landfills, waste storage ponds, polluted streams and lakes, and from accidentally or deliberately spilled material. Organic pollution is found both in industrial areas and in rural areas.

Man-made compounds pose a ground water pollution problem in industrialized countries. One or two percent of ground water supplies in the United States are polluted based on estimates of point sources, but only a fraction of these are contaminated primarily by organic pollutants (Pye and Patrick 1983). The compounds that occur most frequently in ground water in the United States are the trihalomethanes (THMs), which are the halogenated organics produced by chlorination of water containing humic materials (Bouwer et al. 1981). The problem of THMs, such as chloroform, has received considerable attention beginning in 1974 and the maximum contaminant level allowed by the EPA is 100 $\mu g/L$ total THMs (Cotruvo 1981).

The extent of ground water pollution by organics in the Netherlands was measured by sampling all 232 ground water pumping stations in the Netherlands between 1976 and 1978. The samples from 54 of the 232 locations, 25 percent of the locations, contained concentrations >0.1 $\mu g/L$ of chlorinated hydrocarbons with 1 or 2 carbons (e.g., TCE) (Zoeteman et al. 1981). The Netherlands is at the end of the Rhine River and receives pollutants from countries upstream. The compounds detected most frequently at concentrations greater than 0.01 $\mu g/L$ in Dutch ground water include: TCE (67 percent), chloroform (60 percent), tetrachloromethane (43 percent), PER (19 percent), and 1,1,1-trichloroethane (17 percent). These compounds are on the Environmental Protection Agency list of priority pollutants. The concentrations at higher levels ($>10 \mu g/L$) could always be associated with a specific source, i.e., local waste dumping. Concentrations at low levels (0.01 to 0.1 $\mu g/L$) may be due to volatile organics in rain water. Levels of substances such as chloroform and TCE are less than 1 $\mu g/L$ in rain water in the Netherlands.

Measurements of Organic Pollutants

Accurate measurements of the concentrations of organic pollutants in ground water are essential for understanding the behavior of the pollutants in aquifers. The problems of sampling an aquifer are especially severe for volatile organics, which are easily lost to the atmosphere (e.g., Pankow et al. 1984). Problems can arise from the type of well construction and the type of casing used. A study of the leaching of trace organics (0.5 ppb naphthalene and 0.5 ppb p-dichlorobenzene) into water from five common plastics used in well casing showed the following results: Teflon® (no leaching detected), nonglued PVC (0 to 0.1 ppb), Polyethylene (0.1 ppb), Polypropylene (0.5 ppb), glued PVC (0.5 ppb), and Tygon (1.0 ppb) (Curran and Tomson 1983).

Analytical results may be suspect because of the difficulty of analyzing water for trace concentrations of organics. In a comparison of analyses among certified private, state and university labs, large variations were reported even for relatively simple measurements of total dissolved solids (Keith et al. 1983). The following procedures were used to control the analytical precision and accuracy during an extensive investigation of a PCB spill site (Roberts, Cherry and Schwartz 1982). The concentrations of PCBs were determined by several analytical techniques. A standard with PCB concentrations similar to the samples being analyzed was run approximately every ten samples. Blanks were run during a switch from analysis of high PCB concentrations to low concentrations to ensure that the residual response of the system had returned to background levels.

The occurrence of some polar organic compounds in ground water has been much less studied than that of non-polar organic compounds. Very little is known about their health risk or their occurrence because they cannot be easily isolated and measured. The group parameter TOX (total organic halogen) provides a measure of the total amount of halogen in organic compounds and is determined by concentrating the organics by adsorption, and measuring halogen concentrations by titration, specific ion electrodes, or microcoulometer. TOX analyses are both relatively simple and quick compared to gas chromatography. The more polar, non-volatile and high molecular weight halogenated hydrocarbons presently can be detected by TOX and not by GC/MS (Jeckel and Roberts 1980). Field studies have shown that the TOX concentration is several times larger than the sum of halogenated organic compounds by gas chromatographic determination (Roberts, Schreiner and Hopkins 1982).

Advection and Dispersion

The mechanisms of advection and dispersion have an important control on the transport of organic pollutants. Total solute flow in porous media is composed of the portion that travels with the average ground water flow (advection) and the portion that deviates from the average ground water flow (dispersion). Dispersion causes a dilution of the solute concentration and a spreading of the contaminated area. Seen as a plot of concentration vs. the time to reach an observation point, dispersion causes the S-shaped breakthrough curve to broaden. The characteristic length of the porous medium, which is known as the dispersivity length, when multiplied with the ground water velocity, has been shown in the lab to yield the dispersion coefficient. This coefficient is used to determine the flux due to dispersive effects (Anderson 1979).

There are two types of dispersion: dispersion that occurs at the pore scale (microdispersion) and dispersion that occurs at the field scale due to aquifer heterogeneity (macrodispersion). Microdispersion is usually of not much significance for transport in relatively fast-flowing ground water. On the other hand, microdispersion and molecular diffusion are important in underground waste isolation site studies. Macrodispersion is significant due to the heterogeneity of the aquifer (e.g., Sudicky et al. 1983).

Lab dispersivity measurements do not agree with dispersivity measurements determined by field tracer tests because of scale factors. Lab measurements of dispersivity values for calculating microdispersion consist of determining breakthrough times at the outlet of cylindrical columns packed with porous media and then using the solute transport equation to determine dispersivity values. The field measurements of longitudinal dispersivity (in the direction of flow), which are on the order of 10 to 100m, are at least three orders of magnitude larger than lab measurements, 10^{-4} to 10^{-2}m (Anderson 1979). Field tracer tests show that longitudinal dispersivity is not constant for a given aquifer, but increases as the distance between the injection and observation well is increased. At some point, dispersivity stops increasing. This increase in dispersivity with increased travel distance or travel time of the solute is referred to as the scale effect in the literature (e.g., Molz 1983; Sudicky et al. 1983).

The cause of the variable dispersivity is the heterogenity of the aquifer, leading to anisotropic distributions of horizontal hydraulic conductivity. Field data indicate that most compounds prefer to travel through more permeable pathways, such as through gravel lenses. The variation in concentration due to heterogeneity of the aquifer causes the distribution of the compound in a horizontal sense to sometimes deviate from the theoretical plume shape derived for homogeneous aquifer characteristics (e.g., Sudicky et al. 1983).

The problem of aquifer heterogeneity is as important on a vertical scale as on a horizontal scale. Field data have shown that when chemicals enter the aquifers do not mix to the full vertical extent of the ground water and are influenced by aquifer heterogeneities and density effects (Sudicky et al. 1983; Rea and Upchurch 1980; Schwartz et al. 1982). Even though some of the data in these studies are for ions and not organic compounds, one would expect the principles to apply.

from the Glatt River into the upper approximately 9m of a 20m thick Quaternary glaciofluvial valley fill aquifer composed of sand and gravel (Schwarzenbach et al. 1983). The contaminated water was detected several kilometers from the Glatt River in the upper half of the aquifer, while water in the lower half originated from less polluted sources. Monitoring of a PER-spill in glacial deposits in Michigan showed that the PER (density = 1.62 g/cm^3 at 20 C), which was well below saturation, migrated downward as it traveled away from the source (Minsley 1983).

Adsorption

Most aquifers have less than 0.1 percent organic content. Quantitative relationships have not been well established between sorption and the controlling factors, although the specific surface area and the nature of the mineral surface influence the degree of sorption. Some adsorption of non-polar organic compounds was experimentally observed in columns containing materials that contain no organic carbon, such as clean sand, limestone and montmorillonite clay (Schwarzenbach and Westall 1981a). Sand and gravel aquifers are likely to contain insignificant amounts of organic matter, although this parameter is usually not measured. The aquifer near the Glatt River in Switzerland, for example, contains less than 0.1 percent organic content (Schwarzenbach et al. 1983). The retention of hexachlorobenzene, for example, was small between the aquifer next to the Glatt River and observation wells, which are up to 120m away from the river, despite the fact that hexachlorobenzene has a high log Kow of 6.06, and therefore, would be expected to be strongly retained in an aquifer with significant carbon content. The mobility of hexachlorobenzene indicates the low sorption capacity of sandy gravel aquifers with insignificant organic content (Schwarzenbach et al. 1983).

Aquifers comprised of deposits where former living matter is likely to have accumulated, such as from peat deposits, slow-moving streams, lakes or bogs, tend to have significant organic content. Studies have shown that at least 0.1 percent carbon content in the aquifer (0.001 g of organic carbon per gram sorbent) is needed for carbon adsorption to be significant (e.g., Schwarzenbach and Westall 1981a). Instead of solubility, the octanol:water partition coefficient (Kow) is often used as a measure of the partitioning of pollutants between water and organic phases. The Kow is the ratio of the concentration of a compound in octanol, a readily available alcohol that is relatively non-polar, to that in water. An inverse correlation between log Kow values (ranging between 1 and 6) and log solubility values, ranging between -3 to 5 in mg/L, has been found for non-polar organic compounds (Mackay 1980; Zoeteman et al. 1981). Kow values are also used to predict the partitioning behavior of compounds into soil that contains organic matter, as well as into the fat bodies of fish and other biota. Measured values of Kow can be found in: Chiou, Porter and Schmedding (1983); Banerjee, Yalkowsky and Valvani (1980); Kenaga and Goring (1980); and Hutzinger (1982); and estimated Kow values are found in Hansch and Leo (1979); and Leo, Hansch and Elkins (1971). In addition, chemical properties of organic compounds can be found in Verscheuren (1983), Hutzinger (1982, 1980), Weast and Astle (1982).

An example from California illustrates how the order of breakthrough of several organic compounds correlated with solubility and Kow such that the compounds that appear first have the highest solubility and lowest Kow. The order of appearance at an observation well 11m downstream from the injection well from first to last to appear was: chloride, chloroform, bromoform and dibromochloroform, 1,1,1-trichloroethane and chlorobenzene (Roberts, Schreiner and Hopkins 1982).

In another example from western Canada, TCB concentrations increased relative to that of PCB with depth as shown by the increase in the 1,2,4-TCB/PCB ratio from 0.02 in the surface fill to 0.19 in the underlying Regina clay (Roberts, Cherry and Schwartz 1982). The log Kow of 1,2,4-TCB is 4.05 (Leo, Hansch and Elkins 1971) while that of 2,4,5,2',4',5'-PCB is 6.72 (Schwarzenbach and Westall 1981a). The increased mobility of TCB is reflected by the lower Kow. Other indications of greater mobility are higher solubility, lower molecular weight and fewer chlorine atoms in the molecular structure in TCB compared with PCB.

Useful relationships have been found between the adsorption behavior of a pollutant and its Kow value and the organic content of an aquifer. Preliminary work indicates that the partitioning behavior of a pollutant and its residence time can be calculated for aquifers containing sufficient organic material. Karickhoff et al. (1979) demonstrated that the degree to which a compound is adsorbed in a soil, as measured by the partition coefficient (Kp), depends on the Kow and the "fraction organic content" (foc) of the soil by the relation:

$$Kp = 0.63 \text{ foc (Kow)} \quad (1)$$

The equation was developed by examining the adsorption of 10 organic pollutants, whose log Kow ranged from 2 to 6, in river and pond sediments whose foc ranged from 0.1 to 3.3 percent. This equation applies when the pollutant concentration is less than half of the solubility limit in water. Based on surface and aquifer sediments, whose foc is greater than 0.001, Schwarzenbach and Westall (1981a) derived a similar equation:

$$Kp = 3.2 \text{ foc } (Kow^{0.72}) \quad (2)$$

This equation is also valid only for low concentrations of the pollutant. Means et al. (1980) derived a similar equation for PAHs. Figure 1 illustrates the relationship described by Equation 2 for four chlorinated benzenes with different Kow coefficients. The equations establish the similar dependence of the parameters foc and Kow on the partition coefficient between soil containing organic matter and water. These equations apply only for non-polar substances in material with greater than 0.1 percent carbon. Kow provides a better estimate of sediment-water partitioning than does solubility, which gives at best an order of magnitude estimate of the partitioning behavior of a chemical in the organic fraction of the sediment medium (Karickhoff et al. 1979).

Schwarzenbach and Westall (1981a) found that more than 85 percent of the adsorption of the pollutants took place on particles of size less than 0.125mm (fine sand) and Karickhoff et al. (1979) observed that most of the adsorption took place on the particle fraction smaller than 0.05mm (silt or clay). More organic

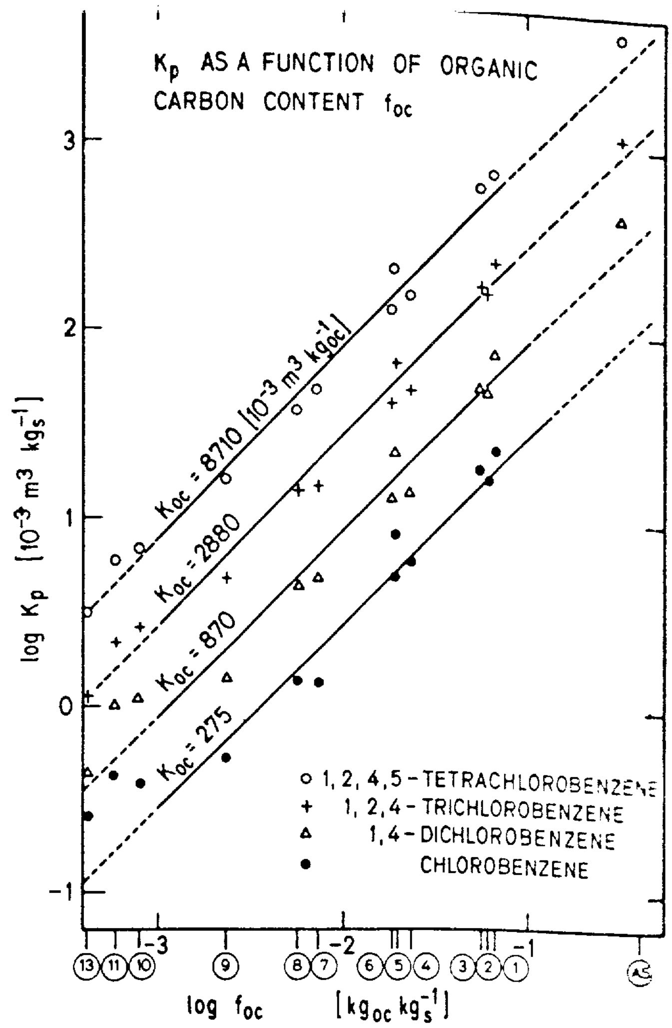

Figure 1. The sorbent to water partition coefficient (Kp) as a function of organic carbon fraction (foc) for four chlorobenzenes (Schwarzenbach and Westall 1981b). Koc is the partition coefficient based on organic content and Koc = Kp/foc. The circled symbols indicate the sorbents on which the data were obtained: AS, activated sludge; 1, 4, sea sediments (coastal zone); 2, detritus; 3, 5 lake sediments; 6, 8, river sediments; 7, 9, 10, 11, 13, aquifer material.

compounds were sorbed on the finer particle size fraction of sediments than on the coarse fraction principally because of the higher organic content as well as the larger surface area. Differences in sorption between silt and clay fractions depend on differences in foc rather than in sediment size (Karickhoff et al. 1979). Organic compounds also partition onto dissolved organic matter, such as fulvic and humic acids, such as in organic-rich water in landfill leachates (Cherry et al. 1984).

A pollutant that is adsorbed travels slower than the water containing the pollutant. The travel time of the solute divided by the travel time of the fluid is known as the retardation factor or the relative residence time (tr), which based on Equation 1 is:

$$tr = 1 + 0.63 \text{ foc (Kow) } \rho/\epsilon$$

where

ρ = average bulk density (g/cm^3)
ϵ = soil void fraction (unitless)
(Roberts, Reinhard and Valocchi 1982)

A comparison among tr values which are dimensionless, calculated from the equation and those derived from the field show that tr values diverge for increasing values of Kow. The tr values are 5 (field) and 6 (equation) for chloroform; 36 (field) and 41 (equation) for chlorobenzene; and greater than 200 (field) and 140 (equation) for 1,4-DCB (McCarty et al. 1981). Kow values for these three compounds are 93, 692, and 2,400 respectively and the calculations are based on an average bulk density of 2 g/cm^3, ϵ = 0.22, and foc = 1 percent carbon (McCarty et al. 1981). Schwarzenbach et al. (1983) derived a similar equation but did not make a comparison with field results.

The common method of modeling the effects of sorption on solute transport is to assume that the solute and sorbent react in instant equilibrium, i.e., no kinetic effects, that the ratio of the sorbed solute to the solute dissolved in water is constant, i.e., linear isotherm, and that adsorption and desorption is a reversible process. The above equations are based on these assumptions.

Formulas for the calculation of limiting kinetic effects, non-linear isotherms and unequal sorption/-desorption behavior are given in Miller and Weber (1984). Kinetic effects are important when the ground water velocity is too fast to allow equilibrium and the above equations are no longer valid. The ground water flow rate (approximately 0.014 cm/s) close to the Glatt River during storm water events was probably fast enough for kinetics to affect the transport of pollutants in the aquifer. Kinetic effects are also important when contaminants are newly introduced to a ground water system and when spike or plug contamination sources are appropriate. Under these conditions less material is sorbed onto the aquifer media and the material that is not sorbed travels farther. Kinetic effects were observed in column experiments when water containing chlorinated benzenes flowed through a column at a rate of 0.01 cm/s (Schwarzenbach and Westall 1981a, 1981b), which is well within the range of typical ground water velocities. The breakthrough times were faster than the breakthrough times of the same column experiment conducted at a velocity of less than 0.001 cm/s. The results of the column experiment at the slower rate (0.001 cm/s) matched those of an 18-hour long equilibrium batch experiment indicating that sorption equilibrium occurred at the slower rate.

Although numerous studies have shown that trace levels of dissolved organic compounds follow linear isotherms, one exception are trace levels of PCBs (Cherry et al. 1984). Non-linear isotherms are most likely to occur when the concentration of the dissolved solute nears the solubility limit. For example, at low concentrations (well below the solubility limit) pesticides showed linear isotherms, but at high concentrations several organic pesticides have very non-linear isotherms (Cherry et al. 1984).

An important source of data on adsorption is the treatment of waste water by artificial recharge of an aquifer. The advantage of studies on waste water recharge is that the rate and length of time that a contaminant was injected or allowed to infiltrate into the aquifer is known, in contrast to most pollution studies.

In one study, approximately 92 percent of the organics were removed from the waste water (Tomson et al. 1979). The highest initial concentration was only 4.05 μg/L and the range in final concentrations was between 0.1 to 1 μg/L. Most removal rates for the 11 classes of compounds studied were between 90 to 100 percent, which included chloroaromatics and alkoxyaromatics, alkyl benzenes, naphthalenes, alcohols, ketones, indoles and indenes. Those groups whose removal rate was below 90 percent include the alkylphenols (85 percent), alkanes (71 percent), and chloroalkanes (70 percent) and phthalates (2 percent). The phthalates was the only group not to exhibit a dramatic decrease in concentration, and it was concluded the observed decline of only 2 percent was in error. A study of dune infiltration in northern Holland actually showed a dramatic increase in phthalate concentration (Piet et al. 1981). Perhaps PVC tubing contamination influenced the phthalate concentrations in both cases.

Adsorption and volatilization were thought to be the significant transport mechanisms for the pollutants studied by Tomson et al. (1981). Biodegradation had a minimal impact for two reasons: (1) The injected fluid was effluent from an activated sludge plant and compounds that easily biodegrade would not have been present. (2) Biodegradation does not occur for low pollutant concentrations. Tomson found that in the lab sewage bacteria reduced 2,3-dimethylnaphthalene from 1.3 mg/L to 40 μg/L in one day and that there was no further degradation for several days.

Under equilibrium conditions the net ratio of the rates of adsorption and desorption do not change and the reaction is said to be reversible. Sorption was reversible in several column studies (Schwarzenbach and Westall 1981a; Karickhoff et al. 1979). The reversibility of the reactions indicated that the initial removal of the compounds from solution was due to sorption and not to other factors such as biodegradation, which would cause the amount removed to be greater than the amount desorbed. A study by Horzempa and Di Toro (1983), however, showed that sorption of PCBs is not readily reversible under field conditions. The amount of sorption correlated with sediment surface area and organic content. The sorption effects were not felt to be attributable to biodegradation because PCBs are not readily biodegraded.

The restoration of aquifers depends upon the ability to remove contaminants adsorbed onto the subsurface material. One method is to flush the aquifer via injection and extraction wells. If the ground water velocity is too fast for equilibrium to be established, the concentration of the pollutant in ground water will decrease below the equilibrium concentration. Once the flushing stops, equilibrium conditions may become established and the concentration of dissolved pollutants may increase as desorption takes place. In such a case, the concentration of the pollutant at the extraction well decreases as the aquifer is flushed and then increases when the flushing is stopped. In addition to desorption during flushing as an important mechanism, the concentrations may also be affected by biodegradation rates of adsorbed, in-phase and dissolved pollutants.

Polar organics appear to be more mobile than non-polar organics, as shown by a study in an aquifer with significant amounts of organic carbon because they are poorly retained in the organic material in the soil (Roberts, Schreiner and Hopkins 1982). Piet et al. (1981) also found that the polar compounds were not as well adsorbed as non-polar compounds in soil column experiments using 50cm-long columns of soil composed of peat and sand layers. Those non-polar chlorine organics that were retained include: nitrobenzene, nitrotoluene and chloronitrobenzene. Similarly, studies with granulated activated carbon (GAC) exhibit less adsorption of the polar organics than the non-polar organics.

Biodegradation

Biodegradation is the breakdown of chemical compounds by microorganisms and is controlled by such environmental parameters as temperature, pH, dissolved oxygen, Eh, salinity, nutrients, competing organisms, toxicity to organisms, and the concentrations of the organisms and compounds. Lab studies have shown that under steady-state conditions a pollutant must be present in concentrations of milligrams per liter to be broken down directly by microorganisms (McCarty et al. 1981). In a similar study it was found that the pollutant concentration must be at least 100 $\mu g/L$ to sustain a microbe population (Wilson and McNabb 1983). If the pollutant concentrations are not sufficiently high to sustain the microorganisms biodegradation will not occur (Kobayashi and Rittman 1982). Sewage bacteria reduced 2,3-dimethylnaphthalene from 1.3 mg/L to 40 $\mu g/L$ and no further reduction was observed for several days (Tomson et al. 1981). A lower limit for biodegradation of 10 $\mu g/L$ has also been found by Wilson and McNabb (1983). Trace levels of a compound can sometimes be broken down as a secondary result of the breakdown of another compound, which is present at much higher concentrations (Rittmann et al. 1980; McCarty et al. 1979).

Biodegradation depends on essential metabolic requirements, such as oxygenated water for aerobic processes. Metabolism can deplete the oxygen or other metabolic requirements in ground water at pollutant concentrations greater than 1,000 to 10,000 $\mu g/L$ (Wilson and McNabb 1983). Thus, pollutants at high concentrations may be only partially degraded when oxygen is depleted.

Results of lab and field biodegradation studies under aerobic and anaerobic conditions for different classes of organic pollutants are presented below. Most of the priority pollutants have been shown to be biodegradable under laboratory conditions (Kobayashi and Rittman 1982). This does not, however, mean that these pollutants are necessarily biodegradable under field conditions. Aerobic conditions generally occur in the unsaturated zone and may be found below the water table at shallow depths as well as at great depths (Winograd and Robertson 1982).

Halogenated Aliphatics. Field and lab results show that several halogenated aliphatics may biodegrade slowly under anaerobic conditions, but not under aerobic conditions. CH_2Cl_2 does, however, degrade under aerobic conditions (R. Schwarzenbach, personal communication 1983). Halogenated aliphatics at low concentrations in treated waste water decreased in concentration when injected into a coastal aquifer in California (Roberts, Schreiner and Hopkins 1982). THMs degraded 10 times faster than the other halogenated aliphatics although the rate of anaerobic degradation was slow for both. The THMs concentration declined from 100$\mu g/L$ to less than 0.1 $\mu g/L$ at a rate of 0.03 per day. The decline was attributed to anaerobic biodegradation and not adsorption because the sorption capacity of the aquifer was saturated before the injection experiment began. Batch culture tests in the lab supported the field results that THMs degrade at low concentrations under anaerobic conditions [illegible] bromodichloromethane degraded slowly under anaerobic conditions of a shallow fluvial aquifer in Oklahoma (Wilson and Enfield 1983). Halogenated aliphatics that have been reported to biodegrade under anaerobic lab conditions include: TCE, trichlorethane, methyl chloride, chloroethane, dichlorobromoethane, vinylidiene chloride, PER, methylene chloride and the THMs chloroform, dibromochloromethane, bromodichloromethane (Kobayashi and Rittman 1982).

No degradation was observed in studies of several compounds under anaerobic conditions, but the rate of degradation may have been too slow to be detected during the period of investigation. Bouwer et al. (1981) observed THMs but not TCE or PER to biodegrade in batch culture tests in the lab under anaerobic conditions. Wilson et al. (1983) did not observe degradation below the water table for several aliphatics: 1,2-dichloroethane, 1,1,2-trichlorethane, TCE or PER, but the period of study may not have been long enough to observe slow rates of degradation. Slow rates of degradation, therefore, cannot be ruled out. Similarly, Schwarzenbach et al. (1983) observed that TCE, PER, 1,1,1-trichloroethane, and hexachlorethane were persistent in the aquifer up to several kilometers away from the river, but the wide error bars on their figures may not rule out slow rates of degradation.

The decomposition of halogenated aliphatics under aerobic lab or field conditions has not been observed. No significant degradation of halogenated aliphatics (THMs, TCE, PER) was found under aerobic lab conditions (Bouwer et al. 1981; Bouwer and McCarty 1984). The persistance of chloroform, under aerobic conditions was reported in a study of ground water recharge, a study of chloroform passage through GAC columns, a study of bank filtration in Germany and a study of waste water percolation in soil columns (Bouwer et al. 1981). Wilson et al. (1983) in a field study in Oklahoma did not observe degradation of several halogenated aliphatics, 1,2-dichloroethane, 1,1,2-trichloroethane, TCE, or PER, above the water table.

Alkyl benzenes. Alkyl benzenes are known to degrade under aerobic conditions and may degrade under anaerobic conditions. Field observations show that toluene degraded rapidly in a shallow aquifer composed of flood-plain sediments in Oklahoma both above and below the water table (Wilson and Enfield 1979; Wilson et al. 1983). Schwarzenbach et al. (1983) observed a sharp decrease in non-halogenated compounds transported from the Glatt River to any of the ground water observation wells, the closest being 2.5m from the river. The alkyl benzenes included: toluene, 1,3-dimethyl benzene, and other 2 and 3 carbon benzene isomers. Aerobic respiration and nitrification occurred predominantly in the first few meters of infiltration, thus supporting the theory that the decrease in concentration was caused by biological processes under aerobic conditions. The biological processes that removed the organic compounds were efficient, considering the short residence time between the river and the closest well and the small retardation factors of the compounds. The decline was observed at different temperature throughout the year, including 5°C in winter. Alkyl benzenes degrade quicker than halogenated aromatics under aerobic conditions, probably because of the breaking of the halogen bond for halogenated aromatics is relatively slow.

Naphthalene and methyl-naphthalene also decreased in concentration but the decrease in on the results of Ehrlich et al. (1982). Ehrlich et al. (1982) observed that naphthalene did not biodegrade under anaerobic conditions, but was slightly sorbed. Bouwer and McCarty (1984) observed that several non-chlorinated aromatics are removed under aerobic but not anaerobic conditions.

Chlorobenzenes. Chlorobenzenes have been observed to degrade under aerobic but not anaerobic conditions (e.g., Bouwer and McCarty 1984). The chlorobenzenes, 1,4-DCB, 1,2,4-TCB and 1,2,3-TCB decomposed under aerobic conditions in the aquifer near the Glatt River, and are suggested to have degraded to chlorinated phenols and catechols (Schwarzenbach and Westall 1981b). The rate of decrease was slower than for the alkyl aromatics, perhaps because the breaking of the halogen bond slows the process (Schwarzenbach et al. 1983). Halogenated aromatics do not degrade under anaerobic conditions. The concentrations of 1,4-DCB did not decrease in July and August of 1979, 1980 and 1981 between the river and 5m from the river, as it did the rest of the year because conditions were anaerobic during these summer months and the compounds did not decompose. During the rest of the year the conditions were aerobic and the chlorobenzenes decomposed. Chlorobenzenes in another Swiss study persisted for at least seven years under anaerobic conditions (Giger and Schaffner 1981). Chlorobenzenes (1,4-DCB, 1,2,4-TCB and 1,2,3-TCB) decomposed above, but not below the water table in a shallow fluvial aquifer in Oklahoma (Wilson et al. 1983). The failure of chlorobenzene to decompose in autoclaved (i.e., sterilized) lab samples established microorganisms as the likely agent of destruction.

Pesticides. Lab studies on sewer sludge indicated that pesticides such as lindane degraded more quickly under active anaerobic lab conditions than under corresponding aerobic conditions, probably due to bacteria (Hill and McCarty 1967). DDT, for example, converted rapidly to DDD under anaerobic conditions, but persisted as DDT under aerobic conditions of several mg/L of dissolved oxygen. Similarly, more than 20 species of bacteria were found to reductively dechlorinate DDT under anaerobic conditions, whereas aerobic conditions apparently did not promote dechlorination (Kobayashi and Rittman 1982). Other pesticides that were dehalogenated under anaerobic conditions in lab culture tests include: toxaphane by bacteria, lindane by soil bacteria and parathion by bacteria (Kobayashi and Rittman 1982). These lab results indicate that pesticides are easier to break down under anaerobic than under aerobic conditions. The breakdown process is relatively easy once the halogen bond is broken.

Phenolic compounds have been shown to biodegrade under anaerobic conditions in an aquifer composed of glacial drift material in Minnesota (Ehrlich et al. 1982). Methane and CO_2 were formed by the anaerobic bacteria breaking down the phenolic compounds. Lab studies supported the field results, and also indicated that principally biodegradation and not sorption account for the decline in concentration (Ehrlich et al. 1982). Glass column experiments showed that chlorophenols can biodegrade under aerobic conditions (Zullei 1981).

Biodegradation is an appealing cleanup method because expensive cleanup methods could be avoided and the pollutant is destroyed rather than transferred the degradation products could be as toxic or worse than the original compound. Management of some of the parameters that affect biodegradation, such as nitrate supply, may allow biodegradation to occur in situ in the vadose zone or aquifer. Limitations include the difficulty of managing environmental parameters that promote biodegradation and the difficulty in maintaining biodegradation as environmental conditions change.

Geological Considerations

The detailed structure and mineralogic composition of aquifers is critical to the transport of pollutants. One example is a PCB spill in a glacial till area in western Canada (Schwartz et al. 1982; Roberts, Cherry and Schwartz 1982). Between 6,800 and 21,000 liters of transformer oil containing PCBs and chlorobenzenes were spilled at a transformer plant. The PCBs traveled mainly in-phase because of the low solubility of PCBs (0.05 mg/L). The laboratory-determined conductivities of the till zone, between 10^{-5} and 10^{-9} cm/s, are too low to explain the observed vertical migration. Vertical movement is primarily through fractures in the clay, silt and till units, as indicated by the high PCB concentrations measured on fracture surfaces. Tritium was also found along fracture surfaces and used to calculate the rate of solute migration. This rate is a minimum because, unlike PCBs, some of the small tritium atoms diffuse into the sedimentary units. The geological units also have a low organic content, 0.2 to 0.9 percent carbon, minimizing the role of organic carbon in absorbing the PCBs.

Conclusions and Recommendations

Although progress is being made in understanding how organic compounds travel in the subsurface, large gaps and unknown important parameters exist. Several recommendations are given below on areas that need research.

- Some polar organic compounds are not commonly detectable by present methods. They appear to be persistent in ground water, able to travel significant distances and be resistant to degradation. Perhaps the increased ability to identify these polar organics will provide a better understanding of this type of contamination. Group parameter methods, such as TOX, may be attractive compliments to the commonly used GC/MS method because of the lower cost and because the measurements include classes of compounds, e.g., polar halogenated organics in the case of TOX, which are not readily identifiable individually.
- In cases where the aquifer might contain sufficient carbon for adsorption to be significant, the empirical relationships that have been developed may be useful for determining the partitioning behavior of organic pollutants. Further study of the effect of grain size, organic content, solute concentrations, dissolved organic matter and other controls on adsorption will help clarify how solutes are transported.
- Some elements, such as N, S, or P-compounds, when injected into pollution plumes may promote microbial degradation. The field conditions under which biodegradation of different compounds is promoted is not well understood. The phase in which the pollutant biodegrades might also be considered, i.e., dissolved in water, in-phase, or adsorbed onto the

matrix.

• More work is needed to determine how flushing of an aquifer via injection and extraction wells affects those pollutants sorbed onto aquifer or soil material. Travel of solutes in-phase during flushing, such as droplets within the water, may be an important mechanism.

Ground water flow models in porous media are useful for understanding a flow regime and for planning the placement of wells. Solute transport models assume constant dispersivity values and the solute is assumed to be dissolved, which in some cases may not be reasonable assumptions. Resolution problems with numerical models may occur in some cases, such as for modeling trace concentrations of a solute, high concentration gradients, or radial flow from a pulse on a rectangular grid. The mechanisms of adsorption and biodegradation are not well enough understood to model satisfactorily. The effects of such mechanisms will probably be lumped together in models because their effects will be difficult to separate in practice.

Although the technology may exist to clean up polluted ground water and pollution sites, the costs are often high. A water policy is needed to encourage prevention and set priorities for what should be cleaned up. The cost of cleanup can be several orders of magnitude larger than that of preventive measures. Monitoring of areas containing organic compounds has begun only recently, and as monitoring continues the understanding of solute transport will improve.

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Biographical Sketch

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STATE OF NEW MEXICO
DEPARTMENT OF ENERGY AND MINERALS
OIL CONSERVATION DIVISION

IN THE MATTER OF THE HEARING
CALLED BY THE OIL CONSERVATION
COMMISSION OF NEW MEXICO FOR
THE PURPOSE OF CONSIDERING:

APPLICATION OF THE OIL CONSERVATION
COMMISSION UPON ITS OWN MOTION
TO DEFINE THE VERTICAL AND AREAL EXTENT
OF AQUIFERS POTENTIALLY VULNERABLE
TO CONTAMINATION BY THE SURFACE
DISPOSAL OF PRODUCER WATER, MCKINLEY,
RIO ARRIBA, SANDOVAL, AND SAN JUAN
COUNTIES, NEW MEXICO. CASE: 8224

TENNECO OIL COMPANY'S MEMORANDUM OF LAW AND ARGUMENTS

On behalf of Tenneco Oil Company, this Memorandum states the legal principles upon which the Oil Conservation Commission ("OCC") must base the promulgation of rules and regulations controlling the disposal of produced water into unlined surface pits within an area defined as containing potentially vulnerable aquifers.

I. INTRODUCTION:

On June 7, 1984, the Oil Conservation Division ("Division") in case 8224 called a public hearing to consider the prohibition of disposal of produced water on the surface of the ground in the San Juan Basin of New Mexico.

On July 18, 1984, the Division again called Case 8224 and at that time established a water study committee.

On February 20, 1985, the Commission held a public hearing to consider the report of the Water Study Committee and to hear a report by the Division hydrologist.

On April 3, 1985, the Commission again heard Case 8224 to hear testimony from various oil & gas industry representatives and experts.

II. FACTUAL BACKGROUND:

The disposal of produced water into unlined surface pits in the San Juan Basin has taken place for a period in excess of 40 years with no known documented case of contamination of ground or surface waters having occurred in Northwest New Mexico.

It is claimed that there are areas in San Juan, Rio Arriba, McKinley and Sandoval Counties, New Mexico where ground or surface water may be vulnerable to possible contamination by oil & gas production. These vulnerable areas were defined by the Water Study Committee from using available water well data, 100 year flood hazard maps, topographic maps and include areas where the depth to ground water is less than fifty feet, the aquifer containing the ground water is presently used for or has a reasonable future use for municipal, domestic, industrial, agricultural, or stock watering purposes as defined by the

State Engineer. These areas were defined as that which lies over or is adjacent to a vulnerable aquifer, including those portions of the San Juan, Animas, and La Plata River valleys which are bounded by the topographic line on either side of the river that is 100 vertical feet above the river channel measured perpendicularly to the river channel.

Special Areas were also identified which fell outside of the "vulnerable area" but which had water well records indicating water production from less than 50' and oil and gas production within the same section.

The Water Study Committee has developed proposed definitions for a vulnerable area and for special areas which are fair and reasonable and should be adopted by the Commission into special rules and regulations.

Within the vulnerable area, there are some 1,200 producing oil and gas wells and some 300 known water wells.

There is no evidence that any fresh water well in the vulnerable area has been contaminated by the disposal of produced water into unlined surface pits.

Currently available data shows that the hydrologic and geologic parameters that are used to define potential ground water contamination within the vulnerable area do not vary greatly and need not be developed on a well by well basis.

Using well accepted methods of hydrologic study, it has been demonstrated that the continued disposal of produced water into unlined pits in the vulnerable area at rates of 5 barrels a day or less for a produced water pit, and of 1 barrel a day or less for an ancillary pit, does not present a potential risk of contamination to ground water.

III. <u>TENNECO'S POSITION</u>:

1. The Division's proposal to ban unlined surface pits in the vulnerable area, except on a pit by pit exemption process, is both unreasonable and unwarranted.

2. That using accepted methods of hydrologic study, the pits in the vulnerable area have been demonstrated not to constitute a risk to ground water if those pits do not receive more than 5 barrels of produced water a day.

3. That there is no currently available method for the economic disposal of the produced water, except with the continued use of the unlined pit method.

4. Small volume disposal rates are so insignificant as to present no hazard to fresh water supplies and should be allowed to continue for an interim period to prevent waste caused by the premature abandonment of wells.

5. That through the New Mexico Oil and Gas Act, the Water Quality Control Commission has delegated the responsibility of administering the Water Control Regulations, with respect to produced water disposal into unlined pits, to the New Mexico Oil Conservation Division which is bound to establish rules and regulations that are not more stringent than those of the Water Quality Control Commission.

6. That the rules and regulations adopted by the New Mexico Oil Conservation Division, concerning the disposal of produced water, must be in compliance with the New Mexico Water Quality Standards.

7. Additional rules and regulations should be established to require the timely metering, and reporting of produced water by the operators of the oil/gas wells in the vulnerable area and the special areas.

ARGUMENT

I. THE OCD MUST BASE RULE-MAKING ON SUBSTANTIAL EVIDENCE CONTAINED IN THE RECORD AS A WHOLE AND MUST COMPLY WITH THE LEGAL RESIDUUM RULE:

A. The Substantial Evidence Rule applies to the OCC.

The standard to apply in determining the legal sufficiency of decisions of the Oil Conservation Commission was most recently stated in Fasken v. Oil Conservation Commission, 87 N.M. 292, 532 P.2d 588 (1975). The court said:

> In cases where the sufficiency of the Commission's findings is an issue or their substantial support is questioned, after the dust of the Commission hearing has settled, the following must appear:
>
> [2] A. Findings of ultimate facts which are material to the issues. Such findings were characterized as "foundationary matters", "basic conclusions of fact" and "basic findings" in _Continental Oil Co. v. Oil Conservation Com'n_, 70 N.M. 310, 373 P.2d 809 (1962). These findings have to do with such ultimate factors as whether a common source of supply exists, the prevention of waste, the protection of correlative rights and matters relative to net drainage.
>
> B. Sufficient findings to disclose the reasoning of the Commission in reaching its ultimate findings. In _Continental_, it was said that although elaborate findings are not necessary, nevertheless:
> " ... Administrative findings by an expert administrative commission should be sufficiently extensive to show ... the basis of the Commission's order." (Citations omitted).
>
> C. The findings must have substantial support in the record.

The pertinent statute delineating the requirements for rule-making by the OCC is silent on the issue of a required statement from the OCC giving the reasons for promulgation of rules. It is necessary, therefore, to look to the New Mexico Administrative Procedure Act for guidance as to whether rule-making and adjudication are subject to the same evidentiary requirements.

Under the N.M.A.P.A., an agency "decision" encompasses decisions made as a result of rule-making, i.e., the promulgation of a rule by an agency is in the form of a decision. See, NMSA S 12-8-5:

> ["Rule-Making Prerequisites: A(3) .... All persons heard or represented at any hearing, or who submit any writing to be considered in connection with the proposed rule, shall promptly be given a copy of the decision, by mail or otherwise (emphasis added)."]

Additionally, the N.M.A.P.A. applies the substantial evidence test to agency decisions. The scope of judicial review of agency decisions is set out in NMSA Section 12-8-22, which reads in pertinent part:

> A. In any proceeding for review of an agency decision or order, the court may set aside the order or decision or reverse or remand it to the agency for further proceedings or may compel agency action unlawfully withheld or unreasonably delayed, if it determines that the substantial rights of a party to review proceedings have been prejudiced because the agency findings, inferences, conclusions or decisions are:
>
> (5) unsupported by substantial evidence; or
>
> (6) arbitrary or capricious or characterized by abuse of discretion or clearly unwarranted exercise of discretion or upon a showing of substantial bias or prejudice.

Thus, the N.M.A.P.A. applies the substantial evidence test to rule-making as well as adjudications, and this practice must serve as a guide to the OCC in properly supporting its rule-making on judicial review.

B. The Substantial Evidence Test Applies to Review Agency Rule-Making.

In Bokum Resources Corporation v. New Mexico Water Quality Control Board, 93 NM 546. 6Ø3 P.2d 285 (1979), the New Mexico Supreme Court applied the substantial evidence test to rule-making: The issue in the case was whether standards set by the Water Quality Control Commission for discharge of certain toxic compounds were appealable as "rules", and, if so, were supported by substantial evidence. The court held that they were rules, and found that they were supported by substantial evidence. In applying the substantial evidence test, the court reviewed "conflicting expert testimony of a highy technical nature" and, while refusing to reweigh conflicting evidence, resolved conflicts in favor of the successful party below (the Commission).

C. The substantial Evidence Test Applies to the Record as a Whole.

The court's application of the substantial evidence rule in Bokum comports with its more recent decision in Duke City Lumber Co. v. New Mexico Environmental Improvement Board and New Mexico Environmental Improvement Division 23 NM St. B. Bull. 447, 681 P.2d 717 (April 4, 1984). In Duke City Lumber, the court held that application of the substantial evidence rule requires that the reviewing court examine the administrative record as a whole, and not ignore segments of the record.

The New Mexico Supreme Court held that the old standard of review, the substantial evidence in support of the agency decision, is.....

> "not only outdated but contrary to the rule followed in other jurisdictions and by the federal courts"...
>
> However, for administrative appeals we now expressly modify the substantial evidence rule as heretofore adopted by this Court and supplement it with the whole record standard for judicial review of findings of fact made by administrative agencies. A review of the whole record is clearly indicated in those cases where the administrative agency serves not only as the factfinder but also as the complainant and prosecutor. See 73A C.J.S., Public Administrative Law and Producure Section 213 (1983).

Administrative agencies can no longer ignore conflicting evidence in either rule-making or adjudicatory proceedings:

> While this rule is applicable to decisions of administrative boards and tribunals, as well as to decisions of courts, it does not permit accepting part of the evidence and totally disregarding other convincing evidence in the record considered as a whole. Duke City Lumber.

The evidence which has been presented to the Commission shows a lack of risk to the vulnerable areas which the Commission may not ignore in propounding its rules.

D. The Legal Residuum Rule Requires that the Agency State Reasons for its Regulation.

In Duke City Lumber, supra, the court was careful to state that adoption of the "record as a whole" standard did not in any way negate the requirement of the application of the "legal residuum" rule to judicial review of agency action. The court said:

> "[t]he standard for admissibility in an administrative hearing under [the New Mexico Administrative Procedure] Act is therefore one of whether the evidence has any probative value. However, New Mexico courts require that an administrative action be supported by some evidence that would be admissible in a jury trial. This has been referred to as the legal residuum rule. Young v. Board of Pharmacy, 81 NM 5, 462 P.2d 139 (1969)."

In Bokum, supra, the court addressed whether the reasons given by the Commission for adoption of its regulations were legally sufficient. The Bokum court found legal sufficiency in that eight reasons were given which were thoroughly analyzed during the hearing and for which additional information was provided after the hearing. The Bokum court contrasted the Commission's actions in that case with its action in a previous case, City of Roswell v. New Mexico Water Quality Control Commission, 84 NM 561, 5Ø5 P.2d 1237 (Ct. App. 1972), cert.denied, 84 NM 56Ø, 5Ø5 P.2d 1236 (1972), in which the Commission gave no reasons at all for its decision. In City of Roswell, the Commission "did not give any general statement of its reasoning, and it gave no indication as to what testimony or exhibits were relied upon in formulating the regulations in question.... We agree with the Court of Appeals that ... reasons should be given upon which the Commission bases its adoption of regulation." Bokum, at 553.

It is clear from this description of what would be adequate reasons that New Mexico courts require that agency rule-making be based on some type of evidence which would be admissible in a jury trial. This standard could not possibly be met by the OCD in promulgating the rule prohibiting disposal of produced water in unlined pits absent some type of scientific evidence which is legally sufficient to support the rule.

II. FAIRNESS AND ACCOUNTABILITY REQUIRE THE AGENCY TO PROVIDE REASONS UNDERLYING RULE-MAKING:

A. Fairness and Accountability of Agency Action can only be Insured by Providing the Public with a Complete and Accurate Statement of the Information Relied on in Rule-making.

The necessity for a complete factual record for judicial review of agency rule-making is examined in Informal Agency Rulemaking and the Courts: A Theory for Procedural Review, Cooley R. Howarth, Jr., Washington, U.L.Q. 61:890-978 (Winter 1984). The author makes a compelling argument for the requirement of such a record in order to be fair to all parties concerned:

> The right to petition for agency reconsideration, or judicial review, of final rules can be exercised most effectively only when the public is fully and accurately apprised of the scope,

> basis, and purpose of the rulemaker's decision. Recordmaking and explanation procedures also provide mechanisms to police the procedural fairness of the rulemaking process. A mandatory requirement that agencies fully explain and document their decisions may well reveal that the agency has failed to consider relevant public comment or has relied upon information or materials which were not subjected to public notice and comment. In addition, a published explanation and documentation of the agency's decision enhances at least the appearance of fairness by opening up the decision making process to public scrutiny. Id. at 966.

Additionally, agency accountability require an organized, detailed record:

> Even if a rulemaking record and a fully explanation are not considered essential for the fairness and effectiveness of rulemaking, it seems clear that agency accountability is unacceptably compromised in the absence of both. While Congress has a number of methods for holding agencies accountable for their actions, and continues to explore new techniques to enhance this accountability, it has placed its primary reliance on judicial review of agency action. Without a complete and organized rulemaking record and a detailed explanation of the basis and purpose of agency rules, courts cannot properly perform the role they have been assigned in the administrative process.
>
> When courts review rules, the agency's factual perceptions, together with its judgment about the legal significance of those perceptions, are to be closely examined. While the court is not to substitute its own judgment for that of the agency, neither is it to assume that the agency's judgment is rational. Instead, agencies are to be held accountable by the review of a court which must satisfy itself that the agency's rule is the rational product of a rational decisionmaking process. Id. at 966-67

The issue of accountability is particularly important in the present case because the OCD has, at present, absolutely no scientific evidence on which to preclude a blanket small volume exemption. Thus, there is no basis on which to decide if the OCD's determination whether the disposition of produced water into unlined pits presents an environmental hazard is rational.

In addition, discusses Howarth whether an agency is acting responsibly when it promulgates a rule without creating a complete record of a factual basis for the rule:

> If reviewing courts are to provide any reasonable barrier to arbitrary decisionmaking, they cannot be expected to guess at or entirely reconstruct the decisionmaking process. They must be provided with a complete and organized rulemaking record and a detailed explanation of the basis and purpose of an agency's rule. Courts simply do not have the expertise, let alone the time and resources, to wander through a huge and unwieldy rulemaking record guided only by vague and simplistic indications of what the agency through it had accomplished.
>
> The Supreme Court also has recognized the need for administrative assistance in responsbile judicial review. In a number of cases, the Court has demanded that agencies supply reviewing courts with records that detail the agency's findings and conclusions and demonstrate a process of reasoned decisionmaking. Even in Vermont Yankee, the Court left undisturbed the judicially imposed requirement that the agency prepare an organized rulemaking record and full explanation of its entire decisionmaking process. Interestingly, it has never seemed to bother the Court that neither the APA nor any organic statute explicitly required these agencies to assemble a record or to prepare findings of fact or conclusions of law supporting their

> decisions. Contemporaneous documentation and a complete explanation of the agency's decisionmaking process was deemed necessary if judicial review of informal decisionmaking was to be at all effective. Id. at 969-70.

Thus, without some documentation of scientific evidence on which the OCD would base the proposed rule, it would be impossible for a reviewing court to be effective in reviewing the decision-making for arbitrariness.

B. Other Jurisdictions Require a Complete Factual Record on Which Rule-Making is Based:

The requirement of a clear factual record is articulated in numerous cases. In St. James Hospital v. Heckler, 579 F. Supp. 757 (N.D. Ill. 1984), the court said:

> It is well-settled that a reviewing court is required to "review the whole record" in determining the validity of a regulation, 5 U.S.C. Section 706, and that the "whole record" consists solely of the administrative rulemaking record.
>
> It is important for "[a]n agency to identify and make available technical studies and data that it has employed in reaching the decision to propose particular rules." Id. at 762, 764.

The court in St. James quotes the U. S. Supreme Court in Baltimore Gas & Electric Co. v. NRDC, U.S. 103 S. Ct. 2246 (1983) for the definition of arbitrary and capricious:

> An agency's rule is arbitrary and capricious if (1) the agency relied on factors which Congress had not intended it to consider; (2) the agency entirely failed to consider an important aspect of the problem; (3) if it offered an explanation for its decision that runs counter to the evidence before the agency or is so

> implausible that it could not be attributed to a difference in view or the product of agency expertise. (Emphasis added).

In the present case, for the OCD to promulgate a rule prohibiting disposition of any produced water into unlined pits in the vulnerable areas would not satisfy either (2) or (3) above. The OCD would fail to consider an important aspect of the case - the fact that no scientific data exists to show contamination by toxic substances - or, alternatively, its decision would run counter to the evidence before it, which is that there is no evidence supporting the rule. Obviously, in this case, the OCD's explanation for promulgating the proposed rule would be "so implausible that it could not be attributed to a difference in view", Baltimore Gas, supra, since there is not yet any scientific information on which to base a view. The OCD's action would be arbitrary and capricious here.

In Wiggins Bros., Inc. v. DOE, 548 F. Supp. 547 (N.D. Texas 1982), the court reviewed the promulgation by the DOE of the marginal property rule, which excluded injection wells from the definition of "wells that produced crude oil." The court reviewed the agency action under the arbitrary and capricious standard, as stated:

> Under the "arbitrary and capricious" standard the scope of review is a narrow one. A reviewing court "must consider whether the decision was based on a consideration of the relevant factors and whether there has been a clear error of judgment....Although this inquiry into the facts is to be searching and careful, the ultimate standard of review is a narrow

> one. The court is not empowered to substitute its judgment for that of the agency." The agency must articulate a "rational connection between the facts found and the choice made." While we may not supply a reasoned basis for the agency's action that the agency itself has not given, we will uphold a decision of less than ideal clarity if the agency's path may reasonably be discerned. Id. at 551.

Without any scientific evidence on which to base the conclusions that produced water in unlined pits in the vulnerable areas causes contamination of the ground water, the OCD cannot articulate a "rational connection between the facts found and the choice made", Wiggins, supra, because there are not yet any facts found.

In United States v. Frontier Airlines, 563 F. 2d 1008 (10th Cir. 1977) the court construed the meaning of the Basis and Purpose Statement of the Administrative Procedure Act, a counterpart of which is found in the NMAPA at Section 12-5-8 (A) 3 and which should be followed by the OCC:

> This provision thus requires the agency to include in the rule a "concise" statement of why the rule was adopted and what it is intended to accomplish. The statement is a summary of what, in the legislative process, would be gleaned from the hearings and the statements of position which make up the legislative history. The Basis and Purpose Statement is a very significant portion of a regulation when an issue arises as to its application and scope. Id. at 1013.

In National Wildlife Federation v. Benn, 491 F. Supp. 1234 (S.D. N.Y. 1980), the Administrator of the EPA defended a claim that its interpretation of a regulation it promulgated was arbitrary and capricious. The court stated that:

> Another important element to consider in evaluating an administrative regulation is "the thoroughness evident in its consideration, the validity of its reasoning, its consistency with earlier and later pronouncements, and all those factors which give it power to persuade, if lacking power to control." Id. at 1245.

Because the EPA could produce scientific evidence substantiating its position in interpreting the regulation, it prevailed. The court said:

> "The plaintiffs' contentions that this procedure is scientifically unsound is refuted by the government's experts . . . While the issue appears unresolved, this Court is constrained to accept the agency's reasonable interpretation of the regulatory requirements." Id. at 1246.

Clearly, if an agency can show a reasonable scientific basis for its rules or its interpretation of its rules, it is afforded great deference. But, when it cannot, as here, establish an adequate factual basis for its regulations, it is impossible for a reviewing court to determine if the agency has acted in an arbitrary and capricious manner, or has based the regulation on evidence which does not meet the substantial evidence test.

III. THE PROMULGATION OF THE PROPOSED RULE WILL HAVE A CONFISCATORY EFFECT, AND AS SUCH WILL ADVERSLY AFFECT TENNECO'S CORRELATIVE RIGHTS AND WILL CONSTITUTE AN UNCONSTITUTIONAL TAKING OF PROPERTY.

The New Mexico Constitution provides that no person shall be deprived of property without due process of Law. N.M. Const. Art II Section 18. All property rights are subject to the reasonable exercise of the police powers of the state. Kaiser v. Thomson, 55 N.M. 270, 232 P2d 142 (1951). Those powers must not be exercised in an arbitrary manner, however. An exercise of police powers which operates to deprive a person of property rights in an arbitrary way amounts to an unconstitutional confiscation of property. Kaiser, supra.

Tenneco has a vested property right in producing its fair share of hydrocarbons from its wells. Until the present rule was proposed, Tenneco and other producers with wells in the vulnerable areas operated their wells in those areas without having to line pits or be concerned that an alleged contamination problem would arise. Tenneco operated its wells under other regulations already promulgated by the OCD pertaining to well permitting, location, etc. None of these other regulations promulgated by the OCD made reference to the possibility that operation of the unlined pits would be subject to any alteration due to the possibility of contamination of ground water by produced water in the pits. Tenneco and others have operated their well in the areas in question for over thirty years without any indication from the OCD that its means of operation would be subject to a requirement which would impose on Tenneco an obligation to safeguard against undocumented hazards. The practical effect of the proposed rule is to reverse over thirty years of an established policy of the OCD's of placement and operation of wells in the areas in question. As such, the proposed regulation operates as a taking of a vested property right.

Tenneco has developed a practice of using unlined pits for thirty years, and the imposition of the requirement to line them, and to stop using them until they are lined, constitutes a tremendous expense to Tenneco not justified by any evidence that such a change in practice is warranted in the interest of protecting the environment.

The question of how to dispose of produced water has been present as long as wells have been operated in the areas under consideration. It is not a new problem, and the OCD has impliedly, if not explicitly, approved of the methods of disposal heretofore employed. A definitive standard of conduct has therefore been established, and conformity to that standard will now be punished, if the proposed rule is promulgated. The extent of reliance by Tenneco and others has been great, since the use of unlined pits is the only means of disposing of the produced water in the area. Thus, the degree of the burden imposed on Tenneco would concomitantly be great, given that it would involve great expense to line the pits or otherwise dispose of the produced wateror be deprived of its property interest.

The statutory interest in applying the rule is questionable, at best, given that there is no evidence to show that a change in practice will improve environmental quality of the area.

IV. <u>THE USE OF A FIVE-BARREL-A-DAY LIMIT WOULD BE THE LEAST BURDENSOME APPROACH, WOULD SERVE THE INTERIM PURPOSES OF THE OCD, AND WOULD COMPORT WITH SOUND POLICY-MAKING</u>.

Tenneco's position is to accept a reduction in the allowable amount of produced water to be deposited in the unlined pits pending the development of a data base from which to determine the proper course of action in the long term. However, in the interim, Tenneco would urge the OCD to adopt an exception for small volume deposits of produced water until reliable data can be developed.

Such an approach to the imposition of an automobile exhaust emission regulation under the Clear Air Act was taken by the Administrators of the EPA, as discussed in <u>Amoco Oil Company v. EPA</u>, 501 F. 2d 722 (D.C. Cir. 1974). The Administrator of EPA, after promulgating a rule establishing emission standards for certain hydrocarbons, suspended the imposition of those standards for a year and in the meantime imposed less stringent "interim" standards. During the time the interim standards were in effect, oil producers challenged the validity of the original emission standard as not being supported by adequate scientific and economic evidence, including a cost benefit analysis, as required by certain provisions of the Clean Air Act. The court in Amoco explained that the oil companies objected to the regulations because of the financial hardships they caused by being unnecessarily and unlawfully far-reaching and abrupt. Thus, the interim standards were effective to "soften the blow" of the great financial impact on oil companies by the new regulations.

In Amoco, the validity of the regulation was determined in light of the requirements of the Clean Air Act, which are more stringent than the Administrative Procedure Act. However, the court in Amoco discussed at length how an agency is required at times to make policy judgments, in the absence of sufficient factual information, concerning the relative risks of underprotection as compared to overprotection. In conjunction with this analysis, the court articulated the factual requirements of the "basis and purpose under the APA", a counterpart of which, as previously mentioned, is found in the New Mexico Statutes. The court said:

> "[i]n particular, the basis and purpose statement must advert to administrative determinations of a factual sort to the extent required for a reviewing court to satisfy itself that none of the regulatory provisions were framed in an 'arbitrary' or `capricious' manner. Id. at 739. Further, the court said:
>
> Where EPA's regulations turn crucially on factual issues, we will demand sufficient attention to these in the statement to allow the fundamental rationality of the regulations to be ascertained. Where, by contrast, the regulations turn on choices

> of policy, on an assessment of risks, or on predictions dealing with matters on the frontiers of scientific knowledge, we will demand adequate reasons and explanations, but not "findings" of the sort familiar from the world of adjudication.
> _Id_. at 740-41.

Tenneco is not unaware or unconcerned about the OCD's interest in regulating on the side of "overprotection". Rather, it urges a course of regulatory action which would serve the interests of the OCD in environmental protection without being arbitrarily or capriciously unfair to the oil producers in the region who have detrimentally relied on a long-standing practice of disposal of produced water. The use of an interim standard for disposal would comport with rational policy-making, when an adequate assessment of the risk cannot yet be made. The interim standard of five barrels a day is low enough to serve the protective interests of the OCD while preventing Tenneco and other producers from suffering an immediate and burdensome expense as a result of having to find an immediate alternative to using the unlined pits.

In light of the fact that the pits have been operated for over thirty years with no restrictions imposed as to quantity of produced water deposited in them, it is unreasonable to conclude that the interim disposal of produced water resulting from no more than five barrels of oil per day would cosntitute a significant addition to whatever environmental hazard exists, if it exists at all.

Thus, the only reasonable approach to managing the problem of identifying the potential environmental hazard to the vulnerable area without being arbitrarily unfair to all of the producers in the area is to adopt an interim standard for disposal of producecd water until reliable data illuminating the risk, if any, can be obtained.

V. IN THE EVENT THE OCC DECLINES TO ADOPT THE INTERIM STANDARD, CERTAIN FINDINGS OF FACT ARE NECESSARY TO SUPPORT THE ORIGINAL PROPOSED RULE.

Should the Commission desire to adopt a rule for the vulnerable area that precludes a blanket small volume exemption, the following are the essential elements necessary to support such a rule:

1. Shallow water monitoring near unlined pits;

2. Location of Alluvial and shallow ground water occurrences;

3. Statistically reliable number of water analyses from pits and evaluation of plume movement;

4. Analyses of tank battery effluents, glycol dehydrator fluids, and transmission line wastewaters;

5. All chemical analyses must include a complete set of analyses, including those for hydrocarbons;

6. Agreed-upon (acceptable) sampling method for all analyses;

7. Agreed-upon method for assessing the volume of produced water in surface pits and the volume of hydrocarbons in produced water;

8. Mass balance analyses to determine water loss from pits;

No scientific evidence now exists upon which the Commission could base findings of fact which would support the interim standard. Even if the interim standard is eventually adopted, substantial testing and analysis is required.

CONCLUSION

Although there has been speculating and postulating about the possibility of contamination of ground water in the vulnerable area, the fact remains that in the vulnerable area where some 1200 gas wells and 300 water wells co-exist and have co-existed over the last four decades, we have yet to experience the first confirmed case of contamination of ground water by the use of unlined surface production pits.

The Oil Conservation Division has been unable to present substantial evidence of the reasonable probability of contamination. It speculates that contamination might occur and wants to place the burden of proof on the industry to show that contamination is <u>not</u> occurring. Tenneco Oil Company has undertaken that responsibility and has established, with its experts, that contamination will not occur by the continued use of unlined surface pits where the volumes are 5 barrels a day or less. To terminate the use of the unlined pits would be unreasonable and arbitrary.

Tenneco Oil Company has attached to this Memorandum its proposed order, Exhibit A, which represents a logical and reasonable decision to be entered in this case.

Kellahin & Kellahin

By ______________________
W. Thomas Kellahin
P. O. Box 2265
Santa Fe, New Mexico 87501

STATE OF NEW MEXICO
DEPARTMENT OF ENERGY AND MINERALS
OIL CONSERVATION COMMISSION

IN THE MATTER OF THE HEARING CALLED BY THE OIL CONSERVATION COMMISSION OF NEW MEXICO FOR THE PURPOSE OF CONSIDERING:

CASE: 8224
ORDER R-

APPLICATION OF THE OIL CONSERVATION COMMISSION UPON ITS OWN MOTION, TO DEFINE THE VERTICAL AND AREAL EXTENT OF AQUIFERS POTENTIALLY VULNERABLE TO CONTAMINATION BY THE SURFACE DISPOSAL OF PRODUCED WATER, MCKINLEY, RIO ARRIBA, SANDOVAL AND SAN JUAN COUNTIES, NEW MEXICO.

TENNECO OIL COMPANY'S REQUESTED ORDER FOR THE COMMISSION

BY THE COMMISSION:

This cause came on for hearing on February 20, 1985, and April 3-4, 1985, at Santa Fe, New Mexico, before the Oil Conservation Commission of New Mexico, hereinafter referred to as the "Commission".

NOW, on this ____ day of __________, 1985, the Commission, a quorum being present, having considered the evidence and being fully advised in the premises;

FINDS:

(1) That due public notice having been given as required by law, the Commission has jurisdiction of this cause and the subject matter thereof.

(2) That on June 7, 1984, the Oil Conservation Division, hereinafter called "the Division", in OCD Case 8224 called a public hearing to consider the prohibition of disposal of produced water on the surface of the ground in the San Juan Basin of New Mexico.

(3) That Division Case 8224 was again called for public hearing on July 18, 1984, at which time the Division established a water study committee composed of various members of the industry, of the Environmental Improvement Division, of the Oil Conservation Division staff and environmental groups and concerned citizens.

(4) That the Division appointed Water Study Committee held meetings on July 18, August 2, October 17, November 29, 1984, and January 9, 1985.

(5) That at the Commission hearing on February 20, 1985, the Water Study Committee submitted to the Commission its Report which was introduced as Commission Exhibit (1).

(6) That the disposal of produced water into unlined surface pits in the San Juan Basin has not contaminated ground or surface waters in Northwest New Mexico.

(7) That there are areas in San Juan, Rio Arriba, McKinley and Sandoval Counties, New Mexico, where ground or surface water may be vulnerable to possible contamination by oil & gas production.

(8) That the vulnerable area was defined by the Water Study Committee from using available water well data, 100 yr. flood hazard maps, topographic maps.

(9) That those vulnerable areas include areas where the depth to ground water is less than fifty feet, the aquifer containing the ground water consists of unconsolidated alluvial fill and the water is presently used for or has a reasonable future use for municipal, domestic, industrial, agricultural, or stock watering purposes as defined by the State Engineer.

(10) That the vulnerable area was defined as that area which lies over or adjacent to a vulnerable aquifer and includes those portions of the San Juan, Animas, and La Plata River valleys which are bounded by the topographic line on either side of the river that is 100 vertical feet above the river channel measured perpendicularly to the river channel.

(11) That Special Areas were also identified which fell outside of the "vulnerable area" but which had water well records indicating water production from less than 50' and oil and gas production within the same section.

(12) That the Water Study Committee has developed proposed definitions for a vulnerable area and for special areas which are fair and reasonable and should be adopted by the Commission into special rules and regulations.

(13) That within the vulnerable area, there are some 1,200 producing oil and gas wells and some 300 known water wells.

(14) That within the vulnerable area there is limited data available concerning the risk, if any, that the disposal of produced water into unlined surface pits has upon ground or surface water.

(15) That any contamination of ground water in the vulnerable area from the disposal of produced water into unlined surface pits, if it occurs, will most likely be from the disposal of large volumes of produced water in excess of 5 barrels a day or from the use of unlined surface pits within 15 feet of the bottom elevation of the major river beds in the vulnerable area.

(16) That until and unless quantification of such risk becomes possible, the disposal in the vulnerable area or in any special area of produced water into unlined surface pits at rates that exceed 5 barrels a day for a produced water pit and exceed 1 barrel a day for an ancillary pit may constitute a hazard to fresh water supplies and such disposal rates should be prohibited.

(17) That currently available data fails to provide substantial evidence that there is contamination or risk of contamination from the continued disposal of produced water into unlined surface pits in the vulnerable area at rates of 5 barrels a day or less for a produced water pit and of 1 barrel a day or less for any ancillary pit, provided said pits are not within 15 vertical feet of the elevation of the major river bottoms in the vulnerable area immediately adjacent to said pit.

(18) That the small volume disposal rates defined in Finding Paragraph (16) above are so insignificant as to present little hazard, if any, to fresh water supplies and should be allowed to continue in order to prevent waste caused by the premature abandonment of wells.

(19) That additional rules and regulations should be established to require the timely metering, and reporting of produced water by the operators of the oil/gas wells in the vulnerable area and the special areas.

(20) That there is no evidence that any fresh water well in the vulnerable area has been contaminated by the disposal of produced water into unlined surface pits.

IT IS THEREFORE ORDERED:

(1) That Special Rules and Regulations are hereby promulgated to deal with produced water into unlined surface pits in certain vulnerable and special areas of the San Juan Basin as follows:

SPECIAL RULES AND REGULATIONS
GOVERNING PRODUCED WATER
FOR UNLINED SURFACE PITS
IN AREAS OF MCKINLEY, RIO ARRIBA,
SANDOVAL AND SAN JUAN COUNTIES
NEW MEXICO

Effective July 1, 1986, no person shall dispose of produced water, or fluids, produced in connection with the production of oil or natural gas, or both, into unlined surface pits within areas of the San Juan Basin designated as either a vulnerable area or a special area, as hereinafter defined, except in conformance with the following rules and regulations:

RULE 1: DEFINITIONS:

As used in these rules and regulations:

(1) Aquifer: means a saturated permeable geologic unit (a geological formation, group of formations, or part of a formation) that can transmit significant quantities of water under ordinary hydraulic gradients.

For purposes of this definition, the word significant means that the water from the aquifer is used for or may reasonably be presumed to be usable for municipal, industrial, domestic, agricultural, or stock watering purposes.

(2) Vulnerable Aquifer: means any of the following:

(a) unconfined aquifers that are less than 50 feet from the surface; or

(b) unconfined aquifers in floodplain areas; or

(c) aquifers in unconsolidated materials.

(3) Vulnerable Area: means an area which lies over or adjacent to a vulnerable aquifer and is defined as an area within the river valleys of the San Juan, Animas, and La Plata Rivers, which is bounded by the topographic line on either side of the river that is 1ØØ vertical feet above the river channel measured perpendicularly to the river channel.

(4) Special Areas: Areas outside of the vulnerable area in which ground water is subsequently found to be within 5Ø feet of the ground surface. Special areas presently identified are listed below:

a) Sections:

T28N-R 8W, Section 17	T3ØN-R12W, Section 13
T28N-411W, Section 18	T3ØN-R12W, Section 15
T28N-R15W, Section 26	T3ØN-R12W, Section 27
T29N-R1ØW, Section 16	T3ØN-R12W, Section 33
T29N-R12W, Section 24	T3ØN-R13W, Section 1
T29N-R18W, Section 17	T3ØN-R15W, Section 6
T29N-R19W, Section 23	T3ØN-R15W, Section 16
T29N-419W, Section 3Ø	T3ØN-R15W, Section 21
T3ØN-R1ØW, Section 5	T3ØN-R16W, Section 29
T3ØN-R11W, Section 3	T3ØN-R19W, Section 34
T3ØN-R11W, Section 7	T31N-R1ØW, Section 13
T3ØN-R11W, Section 8	T31N-R11W, Section 35
T3ØN-R11W, Section 1Ø	T32N-R1ØW, Section 1Ø
T3ØN-R11W, Section 19	T32N-R11W, Section 23
	T32N-R23W, Section 25

b) Areas that lie between the rivers and the ditches mentioned below are also special areas:

Highland Park Ditch
Hillside Thomas Ditch
Cunningham Ditch
Farmers Ditch
Halford Independent Ditch
Citizens Ditch
Hammond Ditch

(5) Produced Water Pit: That pit which receives water produced from primary separation in conjunction with the production of crude oil and/or natural gas whether or not such pit is located at the site of production.

(6) Ancillary Pit: Those pits not receiving fluids from primary separation, including but not limited to, dehydrator pits, tank drain pits, pipeline drip collector pits, blowdown pits, and compressor scrubber pits. Examples are listed below:

(a) Dehydrator Pit: Those pits which normally receive produced water only from the dehydration unit.

(b) Blowdown Pit: Those pits which receive liquid only when a well is blown down.

(c) Tank Drain Pit: Those pits which receive water that is drained from a production storage tank.

(d) Pipeline Drip Collector Pit: Those pits which receive liquids which accumulate in gas pipelines.

(e) Compressor Scrubber Pit: Those pits which receive liquids at the compressor suction in event of primary separator failure.

RULE 2: PRODUCED WATER PITS:

Within a vulnerable or special area, no produced water pit shall receive more than 5 barrels of produced water a day without special permit; and

RULE 3: ANCILLARY PITS:

Within a vulnerable or special area, no ancillary pit shall receive more than 1 barrel of water or fluids a day without a special permit; and

RULE 4: EXEMPTIONS:

The following are exempted from this order:

(1) Pits lying outside vulnerable or special areas are exempt from this order.

(2) Any pits, ponds, lagoons, or impoundments resulting from activities regulated by a discharge plan approved and permit issued by NMOCD or NMEID under Water Quality Control Commission Regulations authorized under the New Mexico Water Quality Act.

(3) Any pits, ponds, lagoons or impoundments resulting from activities regulated by a RCRA or NPDES permit issued by NMEID or EPA under RCRA or NPDES regulations authorized under the Resource Conservation and Recovery Act, New Mexico Hazardous Waste Act, Clean Water Act or Safe Drinking Water Act.

(4) Any pits, ponds, lagoons or impoundments resulting from activities regulated by a mining plan, approved, and permit issued, by the New Mexico Coal Surface Mining Commission under the authority of the Surface Mined Lands Reclamation Act.

RULE 5: SPECIAL PERMITS:

The purpose of this rule is to allow for the disposal of produced water into unlined pits, based on the depth to ground water beneath such pits and provided that such pits meet the quality and soil characteristics criteria as set forth below.

Upon application to and approval by the NMOCD, unlined produced water pits which receive greater than 5 barrels a day and those ancillary pits which receive greater than 1 barrel per day, that are within the vulnerable area, may be permitted under this order based on the following criteria and after satisfying either a. or b. below.

(a) Quality Permit: If the operator can demonstrate that the quality of either existing uncontaminated ground water, or produced water, is such that the introduction of produced water will not cause degradation of the ground water, the unlined pit may be permitted upon application to the NMOCD. The demonstration must include analysis for organic and inorganic parameters as required by the Division.

(b) Soil and Geologic Characteristics Permit: If the operator can demonstrate through the use of standard soil analysis parameters (e.g., percolation tests, infiltration rates, particle size/distribution, etc.) that the existing soil and/or underlying geologic stratum exhibit low permeabilities such that the produced water will not cause degradation of the ground water, the unlined pit may be permitted upon application to the NMOCD. This can be accomplished on an areal or site specific basis.

RULE 6: WELL EQUIPMENT AND REPORTING PROCEDURES:

(a) Upon the effective date of this order and thereafter the operator of any oil or gas well in the vulnerable or special area shall accurately measure the volume of produced water or fluids leaving the separator and being discharged into the produced water pit.

(b) That such measurements shall be taken by the operators not less than semi-annually and shall be reported semi-annually on a daily rate basis to the District Office of the Oil Conservation Division on Division form _______.

RULE 7: EXPANSION OF VULNERABLE OR SPECIAL AREA

(1) That any person seeking to amend or expand the Vulnerable Area or to establish new Special Areas shall file a written application to the Divisiion and shall send a copy of said application to any oil/gas operator within the Vulnerable Area or within 2 miles of any Special Area, by certified mail return receipt, not less than 21 days before any Division Hearing.

(2) That the amendment or expansion of the Vulnerable Area or any Special Area or the creation of a new Special Area shall be done only after notice and hearing.

RULE 8: AMENDMENT OF RULES:

These Special Rules and Regulations shall be amended only after notice and upon hearing by the Division or Commission, as the case may be. Such hearing shall be held only after notice to any and all oil/gas operators, by certified mail-return receipt, who operate any well in the Vulnerable area or within 2 miles of any Special Area.

(2) That jurisdiction of this cause is retained for the entry of such further orders as the Commission may deem necessary.

DONE at Santa Fe, New Mexico, on the day and year hereinabove designated.

STATE OF NEW MEXICO
OIL CONSERVATION COMMISSION

RICHARD L. STAMETS
Director

STATE OF NEW MEXICO
DEPARTMENT OF ENERGY AND MINERALS
OIL CONSERVATION COMMISSION

IN THE MATTER OF THE HEARING
CALLED BY THE OIL CONSERVATION
COMMISSION OF NEW MEXICO FOR
THE PURPOSE OF CONSIDERING:

CASE: 8224
ORDER R-

APPLICATION OF THE OIL CONSERVATION COMMISSION UPON ITS OWN MOTION, TO DEFINE THE VERTICAL AND AREAL EXTENT OF AQUIFERS POTENTIALLY VULNERABLE TO CONTAMINATION BY THE SURFACE DISPOSAL OF PRODUCED WATER, MCKINLEY, RIO ARRIBA, SANDOVAL AND SAN JUAN COUNTIES, NEW MEXICO.

TENNECO OIL COMPANY'S FIRST REVISED REQUESTED ORDER FOR THE COMMISSION

BY THE COMMISSION:

This cause came on for hearing on February 20, 1985, and April 3-4, 1985, at Santa Fe, New Mexico, before the Oil Conservation Commission of New Mexico, hereinafter referred to as the "Commission".

NOW, on this _____ day of ___________, 1985, the Commission, a quorum being present, having considered the evidence and being fully advised in the premises;

FINDS:

(1) That due public notice having been given as required by law, the Commission has jurisdiction of this cause and the subject matter thereof.

(2) That on June 7, 1984, the Oil Conservation Division, hereinafter called "the Division", in OCD Case 8224 called a public hearing to consider the prohibition of disposal of produced water on the surface of the ground in the San Juan Basin of New Mexico.

(3) That Division Case 8224 was again called for public hearing on July 18, 1984, at which time the Division established a water study committee composed of various members of the industry, of the Environmental Improvement Division, of the Oil Conservation Division staff and environmental groups and concerned citizens.

(4) That the Division appointed Water Study Committee held meetings on July 18, August 2, October 17, November 29, 1984, and January 9, 1985.

(5) That at the Commission hearing on February 20, 1985, the Water Study Committee submitted to the Commission its Report which was introduced as Commission Exhibit (1).

(6) That the disposal of produced water into unlined surface pits in the San Juan Basin has not contaminated ground or surface waters in Northwest New Mexico.

(7) That there are areas in San Juan, Rio Arriba, McKinley and Sandoval Counties, New Mexico, where ground or surface water may be vulnerable to possible contamination by oil & gas production.

(8) That the vulnerable area was defined by the Water Study Committee from using available water well data, 100 yr. flood hazard maps, topographic maps.

(9) That those vulnerable areas include areas where the depth to ground water is less than fifty feet, the aquifer containing the ground water consists of unconsolidated alluvial fill and the water is presently used for or has a reasonable future use for municipal, domestic, industrial, agricultural, or stock watering purposes as defined by the State Engineer.

(10) That the vulnerable area was defined as that area which lies over or adjacent to a vulnerable aquifer and includes those portions of the San Juan, Animas, and La Plata River valleys which are bounded by the topographic line on either side of the river that is 100 vertical feet above the river channel measured perpendicularly to the river channel.

(11) That Special Areas were also identified which fell outside of the "vulnerable area" but which had water well records indicating water production from less than 50' and oil and gas production within the same section.

(12) That the Water Study Committee has developed proposed definitions for a vulnerable area and for special areas which are fair and reasonable and should be adopted by the Commission into special rules and regulations.

(13) That within the vulnerable area, there are some 1,200 producing oil and gas wells and some 300 known water wells.

(14) That within the vulnerable area there is limited data available concerning the risk, if any, that the disposal of produced water into unlined surface pits has upon ground or surface water.

(15) That any contamination of ground water in the vulnerable area from the disposal of produced water into unlined surface pits, if it occurs, will most likely be from the disposal of large volumes of produced water in excess of 5 barrels a day.

(16) That until and unless quantification of such risk becomes possible, the disposal in the vulnerable area or in any special area of produced water into unlined surface pits at rates that exceed 5 barrels a day for a produced water pit and exceed 1 barrel a day for an ancillary pit may constitute a hazard to fresh water supplies and such disposal rates should be prohibited.

(17) That currently available data fails to provide substantial evidence that there is contamination or risk of contamination from the continued disposal of produced water into unlined surface pits in the vulnerable area at rates of 5 barrels a day or less for a produced water pit and of 1 barrel a day or less for any ancillary pit.

(18) That the small volume disposal rates defined in Finding Paragraph (16) above are so insignificant as to present little hazard, if any, to fresh water supplies and should be allowed to continue in order to prevent waste caused by the premature abandonment of wells.

(19) That additional rules and regulations should be established to require the timely metering, and reporting of produced water by the operators of the oil/gas wells in the vulnerable area and the special areas.

(20) That there is no evidence that any fresh water well in the vulnerable area has been contaminated by the disposal of produced water into unlined surface pits.

<u>IT IS THEREFORE ORDERED</u>:

(1) That Special Rules and Regulations are hereby promulgated to deal with produced water into unlined surface pits in certain vulnerable and special areas of the San Juan Basin as follows:

SPECIAL RULES AND REGULATIONS
GOVERNING PRODUCED WATER
FOR UNLINED SURFACE PITS
IN AREAS OF MCKINLEY, RIO ARRIBA,
SANDOVAL AND SAN JUAN COUNTIES
NEW MEXICO

Effective July 1, 1986, no person shall dispose of produced water, or fluids, produced in connection with the production of oil or natural gas, or both, into unlined surface pits within areas of the San Juan Basin designated as either a vulnerable area or a special area, as hereinafter defined, except in conformance with the following rules and regulations:

RULE 1: <u>DEFINITIONS:</u>

As used in these rules and regulations:

(1) Aquifer: means a saturated permeable geologic unit (a geological formation, group of formations, or part of a formation) that can transmit significant quantities of water under ordinary hydraulic gradients.

For purposes of this definition, the word significant means that the water from the aquifer is used for or may reasonably be presumed to be usable for municipal, industrial, domestic, agricultural, or stock watering purposes.

(2) Vulnerable Aquifer: means any of the following:

(a) unconfined aquifers that are less than 50 feet from the surface; or

(b) unconfined aquifers in floodplain areas; or

(c) aquifers in unconsolidated materials.

(3) Vulnerable Area: means an area which lies over or adjacent to a vulnerable aquifer and is defined as an area within the river valleys of the San Juan, Animas, and La Plata Rivers, which is bounded by the topographic line on either side of the river that is 100 vertical feet above the river channel measured perpendicularly to the river channel.

(4) Special Areas: Areas outside of the vulnerable area in which ground water is subsequently found to be within 50 feet of the ground surface. Special areas presently identified are listed below:

a) <u>Sections</u>:

T28N-R 8W, Section 17	T30N-R12W, Section 13
T28N-411W, Section 18	T30N-R12W, Section 15
T28N-R15W, Section 26	T30N-R12W, Section 27
T29N-R10W, Section 16	T30N-R12W, Section 33
T29N-R12W, Section 24	T30N-R13W, Section 1
T29N-R18W, Section 17	T30N-R15W, Section 6
T29N-R19W, Section 23	T30N-R15W, Section 16
T29N-419W, Section 30	T30N-R15W, Section 21
T30N-R10W, Section 5	T30N-R16W, Section 29
T30N-R11W, Section 3	T30N-R19W, Section 34
T30N-R11W, Section 7	T31N-R10W, Section 13
T30N-R11W, Section 8	T31N-R11W, Section 35
T30N-R11W, Section 10	T32N-R10W, Section 10
T30N-R11W, Section 19	T32N-R11W, Section 23
	T32N-R23W, Section 25

b) Areas that lie between the rivers and the ditches mentioned below are also special areas:

Highland Park Ditch
Hillside Thomas Ditch
Cunningham Ditch
Farmers Ditch
Halford Independent Ditch
Citizens Ditch
Hammond Ditch

(5) Produced Water Pit: That pit which receives water produced from primary separation in conjunction with the production of crude oil and/or natural gas whether or not such pit is located at the site of production.

(6) Ancillary Pit: Those pits not receiving fluids from primary separation, including but not limited to, dehydrator pits, tank drain pits, pipeline drip collector pits, blowdown pits, and compressor scrubber pits. Examples are listed below:

(a) Dehydrator Pit: Those pits which normally receive produced water only from the dehydration unit.

(b) Blowdown Pit: Those pits which receive liquid only when a well is blown down.

(c) Tank Drain Pit: Those pits which receive water that is drained from a production storage tank.

(d) Pipeline Drip Collector Pit: Those pits which receive liquids which accumulate in gas pipelines.

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Within a vulnerable or special area, no produced water pit shall receive more than 5 barrels of produced water a day without special permit.

RULE 3: ANCILLARY PITS:

Within a vulnerable or special area, no ancillary pit shall receive more than 1 barrel of water or fluids a day without a special permit.

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The following are exempted from this order:

(1) Pits lying outside vulnerable or special areas are exempt from this order.

(2) Any pits, ponds, lagoons, or impoundments resulting from activities regulated by a discharge plan approved and permit issued by NMOCD or NMEID under Water Quality Control Commission Regulations authorized under the New Mexico Water Quality Act.

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(4) Any pits, ponds, lagoons or impoundments resulting from activities regulated by a mining plan, approved, and permit issued, by the New Mexico Coal Surface Mining Commission under the authority of the Surface Mined Lands Reclamation Act.

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The purpose of this rule is to allow for the disposal of produced water into unlined pits, based on the depth to ground water beneath such pits and provided that such pits meet the quality and soil characteristics criteria as set forth below.

Upon application to and approval by the NMOCD, unlined produced water pits which receive greater than 5 barrels a day and those ancillary pits which receive greater than 1 barrel per day, that are within the vulnerable area, may be permitted under this order based on the following criteria and after satisfying either a. or b. below.

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(a) Upon the effective date of this order and thereafter the operator of any oil or gas well in the vulnerable or special area shall accurately measure the volume of produced water or fluids leaving the separator and being discharged into the produced water pit.

(b) That such measurements shall be taken by the operators not less than semi-annually and shall be reported semi-annually on a daily rate basis to the District Office of the Oil Conservation Division on Division form _______.

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(2) That jurisdiction of this cause is retained for the entry of such further orders as the Commission may deem necessary.

DONE at Santa Fe, New Mexico, on the day and year hereinabove designated.

STATE OF NEW MEXICO
OIL CONSERVATION COMMISSION

RICHARD L. STAMETS
Director