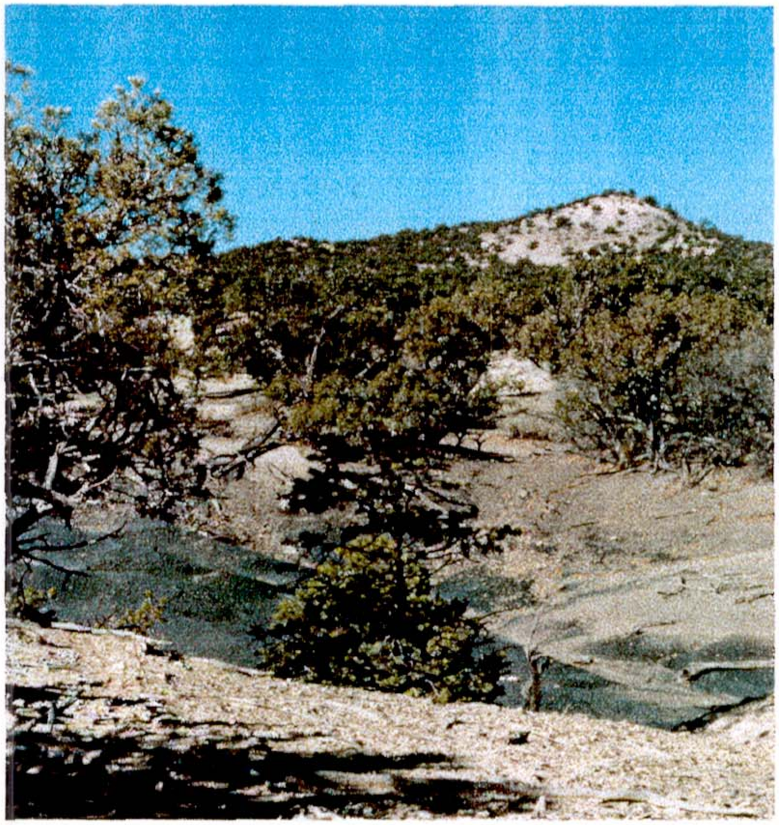
PROJECT # 773

COALBED METHANE DEVELOPMENT
IN THE NORTHERN SAN JUAN BASIN OF COLORADO



A BRIEF HISTORY
And
ENVIRONMENTAL OBSERVATIONS

DEC 20 1999
LO. OIL & GAS CONS. COMM.

A WORKING DOCUMENT

Compiled by

THE BUREAU OF LAND MANAGEMENT

SAN JUAN FIELD OFFICE

December, 1999

Abstract

Since the late 1980's the San Juan Basin (Basin) of southwestern Colorado and northwestern New Mexico has become a progressive center of coalbed methane development from the Fruitland Formation. Earlier development in the Basin concentrated on production from conventional reservoirs, notably the Cretaceous sands of the Mesaverde Group and Dakota Formation. While coalgas was known to be present within the coals of the Fruitland Formation, incentives and technology to extract the methane gas were not previously available.

The coalbed methane (CBM) reservoir is different than conventional natural gas reservoirs in that coalbed methane is stored adhered to the surfaces of the coal itself, rather than merely in pore spaces. Production rates are complexly tied to the existence of water in the reservoir and to water production from the reservoir. The liberation of coal gas is greatly enhanced by the removal of formation water, which reduces hydrostatic pressure within the reservoir. Water production is generally greatest at the onset, and declines over a period of three to six years, although a few wells continue to produce relatively large amounts of water for an extended period. Cumulative water production from all CBM wells in the Colorado portion of the Basin has reached approximately one-quarter billion barrels as of mid-year 1999. Development of CBM wells on 320-acre spacing in the San Juan Basin peaked around 1991 due to specifications of the non-conventional fuel (Section 29) tax credit. Water production from CBM wells in the Colorado portion of the Basin peaked in late 1993, and gas production is probably near its peak today (1999).

During the 1990's several environmental situations of concern potentially related to CBM development were noticed. These include the apparent exacerbation of some pre-existing gas (methane and hydrogen sulfide) seeps and the recognition of newly identified gas seeps along Fruitland Formation coal outcrops and subcrops. In some locations the alignment of recent vegetation mortality is coincident with coal outcrops. At these locations the soil gas was found to be predominantly comprised of methane and largely depleted of the oxygen needed for plant root subsistence. A lowering of groundwater levels has occurred in some coal-sourced domestic water wells and coalbed water monitoring wells. Coal fires have been documented at several locations within specific coal seams of the Fruitland Formation along the

northwestern Basin rim. These environmental situations, recognized since the early 1990's, are concurrent with CBM production from the Fruitland coalbeds in the Northern San Juan Basin. In a recent report on environmental monitoring in the Northern San Juan Basin (Oldaker, 1999), a correlation between down-dip production from Fruitland coalgas wells and bottom hole pressure decreases at Basin rim shut-in gas wells and water monitoring wells was termed probable. What is not clear is the degree to which coalbed methane production may have induced or exacerbated pre-existing situations, and if related, which CBM well(s) contribute to a specific situation.

The Basin is geologically complex with discontinuities in individual coal beds, heterogeneity of coal character, faults and fracture systems in the subsurface, and depositional and structural anomalies. The pattern of precipitation, and hence recharge, is irregular across the Basin. The mechanics of the system present a difficult challenge to interpret and apply to hydrologic and reservoir models of the Basin. Years may pass before a full understanding is achieved. The capability does not currently exist to predict the next area a problem might arise or to mitigate an existing seep.

Public safety and environmental effects are related concerns. Numerous studies continue to evaluate and monitor changes in the land and water that could be associated with coalbed methane production from the Fruitland Formation. These studies include: soil gas monitoring, reservoir pressure monitoring of individual coalbeds, water chemistry, water level monitoring in individual wells, field mapping of coalbeds, reservoir and hydrologic system modeling, near and thermal infrared aerial photographic monitoring of stressed vegetation and coal fires respectively, data logging of soil temperature, and radio-active and stable isotope determinations of domestic/produced water and gas compositional elements.

The Bureau of Land Management, the Colorado Oil and Gas Conservation Commission, the Southern Ute Indian Tribe and members of the oil and gas industry have agreed to fund and support further analysis of impacts potentially associated with natural gas development within the San Juan Basin of Colorado. Entitled the 3M Project, this analysis includes mapping and monitoring the Fruitland coal outcrop, modeling the coalbed methane reservoir and related hydrologic system of the San Juan Basin north and west of the San Juan River, and projecting flows of gas and water movement that could be anticipated given various production scenarios. Potential pilot projects for mitigation are currently under consideration. Some steps toward mitigation of seeps and coalbed fires may be initiated in the near future. Results of these efforts should provide invaluable data that may subsequently be used to mitigate undesirable effects caused or exacerbated by the development of the coalbed methane resource.

Since an understanding of the nature and severity of San Juan Basin rim impacts conceivably related to Fruitland coalgas is incomplete, further infill drilling development proposals in the Ignacio-Blanco Field are being carefully evaluated relative to the known facts and current assumptions. Considering recent indications of deteriorating conditions at specific sites, applications for additional gas wells (especially gas wells to be drilled in proximity of the Basin rim) will be carefully reviewed with due respect to potential impacts manifested at the Basin rim coalbed exposures.

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I. INTRODUCTION

The Bureau of Land Management (BLM) Vision for the Future (as stated in the 1998 annual report) is to "provide for a wide variety of public land uses without compromising the long term health and diversity of the land and without sacrificing significant natural, cultural, and historical resource values". The Director's letter goes on to state, "We seek close partnerships with state and local governments, Indian tribes, other Federal agencies, and all of our publics, as we embrace a process that addresses all of the physical, biological, economic, and social aspects of land and resource management...guided by...a vision that emphasizes public land health and preservation."

The BLM San Juan Field Office is the regulatory agency responsible for preserving the health of Federal public lands in southwestern Colorado, while regulating responsible resource development and serving Southern Ute Indian Tribal mineral interests under the trust responsibility delegated by Congress. This paper focuses on the issues currently facing the San Juan Field Office that relate to Fruitland coalbed methane production and conceivably associated environmental implications. This document will be foundational for documenting historical evidence regarding CBM development in the northern San Juan Basin. It will also serve as a basis for interim decisions concerning gas well drilling on both Federal and Indian mineral leaseholds until basin hydrology and reservoir modeling provide forecasting scenarios that will facilitate development planning. It informs the public of current theories linking Fruitland Basin production to Fruitland outcrop impacts. It provides a basis for discussion and determination of the type and timing of National Environmental Policy Act (NEPA) documentation necessary to address impacts (both at current spacing and potential infill drilling). Finally, this paper documents the need to consider prudent outcrop responses including the issues of private property, off-lease impacts, possible mitigation solutions including cost, responsibility and liability.

While the Fruitland Coalbeds were known to contain significant gas reserves, the understanding and technology of producing that gas was not available to earlier gas well developers. Therefore, the stratigraphically shallower Fruitland coals had been penetrated in the early days of gas exploration in the Basin, but bypassed in preference to deeper geologic horizons offering conventional gas reservoirs that more readily yielded the natural gas resource. The development of unconventional coalbed methane in the Fruitland Formation of the Northern San Juan Basin (Basin) in Colorado began in earnest in the late 1980s. This paper presents highlights of coalbed methane development history and associated issues in the Northern San Juan Basin, Colorado. This development has been administered by the overlapping jurisdictions of the Bureau of Land Management (BLM), Bureau of Indian Affairs (BIA), Southern Ute Indian Tribe (SUIT), Colorado Oil and Gas Conservation Commission (COGCC), and to some extent La Plata County.

This paper also presents and documents recent environmental problems associated with coalbed methane production. Unlike conventional reservoirs, where methane gas is stored in the pore spaces of the formation, considerable coalbed methane is stored on (adsorbed to) the surfaces of the coal matrix and is not free to migrate until pressure is relieved. Even in the coalbeds, though, some free gas is present in pore space and may collect in typical structural traps. In general, hydrostatic head provides the pressure that keeps the majority of the coalgas adsorbed. Once coalbed gas is liberated by the withdrawal of water reducing the hydrostatic head, the methane (estimated at over 50 trillion standard cubic feet (TSCF) in the Fruitland Coalbeds) is free to migrate. Inadequately cemented conventional gas well bores and extraction of produced water from coalbed methane (CBM) wells are suspected of contributing to natural gas resource losses and to methane migration into surface soils and groundwater.

As methane production progressed, some residents noticed an apparent increase in the occurrence of methane in their domestic water wells, while others also noticed the presence of gas seeps in pastures, manifested by dead vegetation. During the next few years, other events were noticed that time-correlated with recent coalbed methane (CBM) production.

Anoxic environments created in near-surface regimes by a predominance of methane support bacterial generation of hydrogen sulfide gas and promote plant suffocation by precluding soil oxygen. Methane from soil gas vapors can accumulate in confined spaces, such as beneath domestic dwellings, and may pose potential explosion hazards. Along the Basin rim where the Fruitland coals crop out, intensified gas seepage and an associated apparent escalation in hydrogen sulfide gas has been reported at historic seep sites. Stands of stressed and dying trees were discovered aligned with coalbeds beneath. North of the Southern Ute Indian Reservation, two homes located directly above the outcrop/subcrop of the Fruitland Formation coalbeds were declared unsafe for habitation due to explosive accumulations of methane; five homes were ultimately removed from the hazardous zone.

Self-heating of near-surface coals can result from fluctuations/lowering of the water table in the coalbeds. On the Southern Ute Indian Reservation several coal fires have been identified during 1998-99. Geologic evidence indicates that pre-historic Fruitland coalbed fires existed in similar locales. The time of ignition or resurgence of current coal fires is virtually impossible to ascertain. The most disconcerting instance (due to speculation of a possible proliferation of coal bed fires) is a coal fire detected in the fall of 1998 at a location approximately eight miles north of active coal fires first noticed during the spring of 1998. These environmentally significant phenomena, which may represent warning signs of impending changes, have engaged the attention of regulatory agencies and the community.

II. BACKGROUND

Geologic Setting

The San Juan Basin (SJB) an asymmetric structural basin formed during Cenozoic and Mesozoic time periods straddles the New Mexico - Colorado border **(Appendix B: Maps and Cross-Sections 1)**. Within the stratigraphic section of the Basin lie three distinct Cretaceous Age fluvial-lacustrine-marine sequences of sediments averaging 5,000 feet in thickness. The northern and western edges of the Basin are formed by a structure known as the Hogback Monocline **(Appendix B: Maps and Cross-Sections 2; Figure 1, below).**

Figure 1: Hogback Monocline near Durango, Colorado

Along the Monocline, Cretaceous and Tertiary age depositional horizons dip steeply into the Basin. Along this structural margin, all of these sedimentary units are either exposed at the surface or subcrop beneath a thin layer of alluvium-colluvium or moraine deposits.

History of Oil and Gas Exploration and Development in the San Juan Basin

Cretaceous Age rocks have been important to the development of oil and gas in *the Four Corners* (common state corner shared by Colorado, New Mexico, Utah, and Arizona) Area. These stratigraphic horizons include: the Morrison, Dakota, Mancos Shale, Lewis, Pictured Cliffs, Fruitland and Kirtland (Sandstone Member) Formations and the Mesaverde Group including the Point Lookout, Menefee, and Cliff House Formations **(Appendix B: Maps and Cross-Sections 3).**

Conventional oil and gas reservoirs include the Dakota, Point Lookout, Cliff House, and Pictured Cliffs Sandstones. Source rocks (providing the organic material) for the hydrocarbons in these reservoirs are probably the Lewis and Mancos marine shales, each several thousand feet thick. Coalbeds, which have generated their own hydrocarbons and which lack the production characteristics of conventional reservoirs, are considered "unconventional" gas reservoirs. Found locally in the Fruitland and Menefee Formations, coalbeds have played a significant role in the history of oil and gas development in the San Juan Basin. In the early stages of natural gas exploration the coalbeds were penetrated in search of conventional gas reservoirs that lay deeper. Problems associated with extraction of coal gas in comparison to conventional natural gas reservoirs, coupled with the fact that methane from coal seams typically has a lower heating value (BTU), made the Fruitland coal seam gas uneconomical to produce. Business risks were considerable due to high startup costs associated with pumping, storage, disposal, and corrosion potential (linked to a significant carbon dioxide content), of the produced water, coupled with a lack of sufficient historical data to establish production trends. With legislation (the production tax credit, a part of the Crude Oil Windfall Profits Tax Act of 1980) that offered lucrative tax incentives to explore unconventional fuel production, the potential for producing coalgas by water removal stimulated the oil and gas industry to invest in more research.

Estimates indicate that gas-in-place in the coalbeds may equal or exceed the gas in the conventional reservoirs of the San Juan Basin. Coalbed methane resources estimated for the San Juan Basin include 50 trillion standard cubic feet (Tscf) in the Fruitland Formation and 34 Tscf gas in place in the Menefee Formation (Mavor, 1997). Similar figures are quoted for the Fruitland (50-56Tscf) and the Menefee (34Tscf) by the Gas Resources Institute (GRI, 1997). Compared with other major coalbed methane reserves of the U.S. in the lower 48 states, the San Juan Basin ranks third in reserves (Greater Green River Basin 134 Tscf; Piceance Basin, 99 Tscf, San Juan Basin 90 Tscf; Northern Appalachian Basin, 61 Tscf; Powder River Basin, 39 Tscf; Black Warrior Basin, 20-23 Tscf; Western Washington Basin, 24 Tscf; Illinois Basin, 21 Tscf; Raton Basin, 10 Tscf; Uintah Basin, 10 Tscf) (Schwochow, 1997; Nelson, 1999). Huge coal reserves in Alaska have been identified with a gas-in-place content estimated at 1000Tscf (Smith, 1995), but no commercial exploitation has occurred to date.

In 1992 the American Gas Association. reportedly predicted recoverable coalbed methane reserves in the Fruitland coalbeds of the Ignacio-Blanco Field (the northern portion of the San Juan Basin located in La Plata County, Colorado) to be 1.5 Tscf. Actual production has already surpassed that estimate with 1.7 Tscf produced by the end of 1998 (Bell, 1999). When the New Mexico portion of the San Juan Basin in included, the production to date exceeds 6 Tscf (Nelson, 1999). In 1998, CBM production from the San Juan Basin was eight times that of the second-ranked Black Warrior Field (Nelson, 1999), which has a cumulative production tally of 1 Tscf. Very little coalgas has been produced from the larger Greater Green River Basin shales and the Piceance Basin due to the extreme depth of burial and low permeability of the coals. CBM production from the San Juan Basin is rivals or exceeds CBM production from any basin worldwide to date. **Appendix C: Chart 1** shows La Plata County gas production through 1998. La Plata County gas production accounted for 57% of the total 1998 gas production in Colorado. Expectations are for CBM production to peak in 1999 and level off in 2000, with declining production anticipated for 2001 and beyond.

History of Conventional Production in the San Juan Basin

Conventional gas exploration began in the early 1900's in the San Juan Basin. Early attempts were confined to completions in relatively shallow sandstones. The first recorded drilled well in the San Juan Basin reached to a depth of 200 feet penetrating the Kirtland Shale near Farmington, New Mexico. This discovery well began as a search for water, but produced only gas (Macdonald and Arrington, 1970). A well was drilled in Durango, Colorado in 1901, which flowed natural gas, and no oil (Arnold and Dugan, 1971). The first commercially successful gas well was drilled near Aztec, New Mexico in 1921, completed in the Farmington Sandstone Member of the Kirtland Shale Formation (Chafin, 1994). Additional development continued through the 1930's until another conventional prospect, the Pictured Cliffs Sandstone, was developed in the 1940's after gas was discovered in this horizon, also in the vicinity of Aztec, New Mexico. By the end of the 1940's deeper drilling proved that there were substantial resources of conventional gas located in the formations of the Mesaverde Group and in the Dakota Sandstone. The 1950's ushered in another wave of boom days in the early gas development in the San Juan Basin. Thousands of wells were drilled in both Colorado and New Mexico (**Appendix C: Chart** 2). The construction of gas pipeline systems that delivered gas to the West Coast and Southwestern United States encouraged this development.

Development and exploration of these conventional reservoirs continued through the 1970's with oversight by the oil and gas commissions of both New Mexico and Colorado. The accompanying strong economic market generated the next drilling boom for conventional gas production in the San Juan Basin. Drilling of conventional reservoirs for gas continued until 1982, when an over-supply of gas nationwide caused a decline in gas prices. Subsequent development of conventional reservoirs has been sporadic with drilling and development dictated by pipeline capacity and prices (**Appendix C: Chart 3**). **Appendix B: Maps and Cross-Sections 4** gives a geographical presentation showing the dispersion of existing conventional gas wells in the Colorado portion of the San Juan Basin.

History of Coalbed Methane Production in the San Juan Basin of Colorado

Methane in the San Juan Basin has been acknowledged as a resource for over 100 years. Professor Arthur Lakes in 1892 reported that "...coal oil and natural gas can be found within four miles...of Durango." (Amoco, 1994). Coal miners encountered methane in several early mines in La Plata County. One encounter in 1924, ten miles northeast of Bayfield, Colorado, was reported this way: "What is believed to be a million foot gas gusher was opened up in the former Tendrick Mine, 10 miles northeast of Bayfield on Wednesday...We predict that the discovery of this gas is going to cause quite a flurry in oil circles, and we may expect to see some real development take place next spring and summer." (Amoco, 1994).

Despite the discovery of methane gas in 1924, and the subsequent rejoicing about its economic impact to the region, over 20 years passed before the first coalbed wells were drilled and completed to produce methane. Beginning in 1948, several wells were drilled into the coal-bearing Menefee and Fruitland Formations. The first recorded methane production from coalbeds was in 1951 at the Pan American Petroleum/Stanolind/Amoco Ute Indian D-1 well located in the Ignacio area of the Southern Ute Indian Reservation (Amoco, 1994). Yet, extensive coalbed methane development did not flourish in the San Juan Basin until the mid-1980's ***(Appendix C: Chart 3)***. This development was encouraged by the passage of the Crude Oil Windfall Profits Tax Act of 1980 (Chafin, 1994). This act was scheduled to expire in 1990, but was extended through 1992. The definition of *deregulated natural gas* addressed in this Act included *occluded gas* - naturally occurring natural gas released from entrapment from the fractures, pores, and bedding planes of coal seams. Also specified were (1) gas produced from deep (greater than 15,000 feet), high cost natural gas reservoirs, (2) natural gas dissolved in an over-pressured brine and (3) natural gas produced from Devonian shale. Fruitland coalbed methane production met the criteria as an occluded gas. Provisions of this bill including subsidies, which will expire in 2002, gave gas operators tax incentives to overcome technical problems associated with coalbed methane production from this unique "unconventional" resource. After a brief lull in the early 1990's, Fruitland coalbed development steadily increased ***(Appendix C: Chart 3, Chart 4). Appendix B: Maps and Cross Sections 5*** gives a geographical representation of cumulative CBM production in the northern San Juan Basin of Colorado. Since the late 1980's coalbed gas development has been the focus of natural gas development in the Basin.

Coalbed Methane Reservoir

Coalbed methane and Devonian shale reservoirs are considered *unconventional* reservoirs in that methane gas is stored in micropores and bedding planes, as well as free gas within natural fractures or cleats (Mavor, 1997). These reservoirs act both as the source rock and storage reservoir for methane gas. Coalbed methane is peculiar in that methane and carbon dioxide are predominantly stored in a molecular adsorbed phase within micropores of the coal. High-cost natural gas produced from deep (greater than 15,000 feet) low permeability sands may also be termed unconventional, as may gas produced from *geopressured* (initial reservoir pressure exceeding 0.465 psi/vertical foot of depth*)* brines (greater than 10,000 ppm total dissolved solids). In comparison, conventional gas reservoirs contain gas molecules within interstitial porespaces, for example between sand grains in a sandstone reservoir, and in fractures. Gas trapped in a conventional reservoir generally is considered to have migrated from its place of genesis to a different geologic zone or horizon into the reservoir rock.

The ability of the coalbed reservoir to store methane is dependant upon numerous factors: reservoir pressure, composition and rank of the coal, micropore structure and its surface properties, the molecular properties of the adsorbed gas constituents, and reservoir temperature (Mavor, 1997). Coalbeds are an attractive prospect for development because of their ability to retain a higher amount of gas at shallow depths in comparison to conventional reservoirs at comparable depths and reservoir pressures. Coalbed methane (CBM) wells are drilled with techniques similar to those utilized for drilling conventional wells, but completion practices and the method of reservoir evaluation are different. The BLM has adopted

COGCC order No. 112-61, which requires that the production casing of all coal-bed methane wells be cemented from producing horizon to surface by grout circulation methods. The intent of requiring this extensive primary cementing is to minimize or preclude inter-zonal flow of fluids between producing horizons and aquifers within the casing annulus. Today, coalbed gas wells are usually completed for production in one of two different manners. By altering the velocity of the gas escaping from the coal reservoir, the so-called "*cavitation method*" creates a cavity in the targeted coal seams, effectively enlarging the original well bore. The increased well-bore volume promotes linking the well bore with the natural fracture system of the coalbeds ***(Appendix C: Chart 5).*** The second method involves *conventional* completion techniques in which individual or multiple coals are hydraulically fractured by pumping water or other fracture-inducing fluids and fracture-sustaining material under high pressure through pipe perforations into the coalbeds ***(Appendix C: Chart 6).*** Since methane gas is stored (adsorbed) on micropores of the coal, and storage is a function of pressure (the higher the pressure the greater the storage potential), production of coalgas is dependent upon reduction of pressure within the coalbeds. Methane can be produced from the coalbeds by reducing overall reservoir pressure or by reducing the partial pressure of the methane alone, while sustaining reservoir pressure. Pressure reduction frees the methane molecules from the coal and allows gas migration. A reduction of reservoir pressure is most often accomplished through formation water removal by walking beam pumps, (**Figure 2 following page**) submersible pumps, piston lift or gas lift)

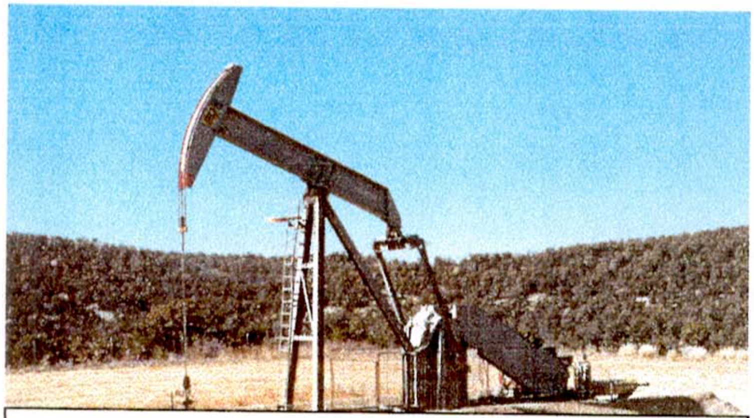


Figure 2: Walking Beam Pump for CBM Water Extraction

Water/gas separators used for conventional gas production were modified to accommodate copious amounts of produced water and associated coal fines. The produced water is often fresher (lower dissolved solids) than is characteristic of the relatively small amounts of produced water derived from conventional gas reservoirs. With hydrostatic pressure reduction at depth, methane gas is desorbed from the coal and is free to migrate through permeable strata, cleats and fractures to an area of lower pressure, ideally into the well bores that created the pressure reduction. In near-surface coal outcrops, hydrostatic pressure reduction may allow locally desorbed coalgas to migrate entrained with groundwater or rise vertically through porous soils to the surface.

As coalbed water is withdrawn and formation pressure declines, the volume of gas produced tends to build from a low initial rate to a maximum rate several years after the onset of production ***(Appendix C: Charts 7a, 7b).*** The progressively increased gas production rate to a maximum flow years later is in direct contrast with conventional *pressure-depletion* reservoirs from which gas production rates tend to be greatest at the onset, then steadily decline over the life of the well ***(Appendix C: Chart 8).*** Decreasing reservoir pressure below 150 psi is not currently considered economic. While a reduction in reservoir pressure frees the methane from the coal, greatly reduced pressure may deprive the fluids of the energy needed to migrate efficiently to the well bore and enable desorption of increasing proportions of carbon dioxide. It is estimated that less than 50 percent of the coalbed methane in place can be economically recovered by reservoir pressure depletion strategy (Puri and Yee, 1990). In areas of the San Juan Basin where reservoir factors do not allow the production of coalgas in economic quantities by pressure depletion methods, enhanced production techniques have been applied. One of these techniques introduces nitrogen under high pressure through *injector* wells into individual coalbeds. Methane desorption is achieved by nitrogen sorption displacement and by reducing the partial pressure of the methane rather than reducing total reservoir pressure (Amoco, 1991). Beginning in the late 1980's, Amoco Production Company experimented with this technology and found that up to

80 percent of adsorbed methane could be recovered by introducing an inert gas, such as nitrogen, into the coal sample (Amoco, 1996). In January 1998, after receiving approval from various state and Federal agencies, Amoco began injecting nitrogen gas into the coal horizons within their Tiffany Nitrogen Injection Recovery Unit in La Plata County, Colorado. Results from this project have been encouraging. Increases in methane production have been reported at *collector* gas wells which have produced more methane gas in the brief time that the project has been operating than they had produced in their recorded past as normal methane gas producers ***(Appendix C: Chart 9).*** It is anticipated that injection pressures may have to be increased as reservoir pressure is raised by the nitrogen input, but the higher reservoir pressure would be expected to increase permeability by opening cleat fractures in the coal. This increase in permeability may actually enable greater production rates and offset the need for increased injection pressure (Amoco, 1991).

The Formation and Composition of Coal Gas and Natural Gas

Coal gas is a by-product of the evolution of plants into coal. Coal begins as an accumulation of *terrestrial* organic debris derived from plant tissues which, subsequent to the influences of heating and pressure (from burial at depths of several thousands of feet) becomes coal. This metamorphic process breaks the chemical bonds of the carbon-based organic matter causing the formation of methane, carbon dioxide, water, and trace amounts of ethane and propane, with very few heavier volatile hydrocarbons. (Some coal beds at depths greater than 4500' can yield commercially significant volumes of light oils when the produced gas is carbon dioxide-rich. This is not typical of SJB coal gas, but is characteristic of coal gas produced from the northern Piceance Basin of Colorado) (Nelson, 1999). The amount of gas stored within the micro-pore structure of the coal is related to the rank of the coal. The more mature (higher-rank) coals, having been subjected to greater periods of burial and higher temperatures, yield proportionately greater volumes of gas. Fruitland coals are generally considered low to medium rank volatile bituminous.

Conventional natural gas is derived through heat and pressure-induced alterations of *marine* organic matter. Like coal gas, natural gas is essentially composed of methane, but generally contains higher percentages of heavier hydrocarbon fractions such as butane, pentane, hexane and condensates, giving natural gas a higher heating value.

History of Coalbed Methane Gas Well Spacing

Initially, the Ignacio Gas Field and the Blanco Gas Field were considered separate pools, under Colorado Oil and Gas Conservation Commission (COGCC) Cause 3 and Cause 45, respectively. Order No. 3-12 (October 11, 1955) pooled the Ignacio Field Fruitland Formation (coalbeds and sandstones) with the Pictured Cliffs sandstone and specified a density of one gas well per 320 acres. Blanco Field rules were established under Spacing Order No. 45-1 (October 11, 1954) and mainly pertained to the Mesaverde Formation. Cause 112 combined the Ignacio and Blanco Fields into one Ignacio-Blanco gas field. Spacing Order No. 112-6 (November 9, 1959) established the Ignacio-Blanco field boundaries and reasserted 320-acre spacing for Mesaverde and Pictured Cliffs/Fruitland pools. Order No. 112-46 (July 16, 1979) allowed a second infill well per 320-acre spacing unit for the respective Fruitland/Pictured Cliffs and Mesa Verde pools. COGCC Spacing Order No. 112-60 (June 15, 1988) separated out the Fruitland coalbeds as a distinct pool and reverted to 320-acre spacing, citing Order No. 112-6. State Spacing Order No. 112-61 (August 15, 1988) amended Order No. 112-60 by establishing additional field rules, but maintained Fruitland coalgas well spacing at 320 acres. Nearly 1000 coalbed methane wells (including new CBM wells and conventional gas wells plugged back and recompleted in the Fruitland coalbeds) were drilled in Colorado by 1999 under Spacing Order No. 112-61.

Beginning in 1992, several operators of coalbed methane wells applied for Spacing Order amendments. The COGCC approved these applications to drill one additional production well per 320-acre spacing unit in explicitly specified areas. This served as a test of reservoir simulation studies that suggested 160-acre spacing was optimal in certain areas for overall reservoir performance, economics and accelerated recovery of additional reserves that might otherwise be left in place. The first proposal was submitted by Emerald Gas Operating Company for four new wells and the recompletion of two conventional gas wells located on the Southern Ute Indian Reservation in the Valencia Canyon Area. Operators, the COGCC and some members of the general public were averse to the proposal on the grounds that correlative rights would be affected, current spacing was adequate, and approval would set a precedent for Basin-wide down-spacing. The Southern Ute Indian Tribe and the BLM supported the proposal as a pilot project. Since Tribal minerals and surface were involved, the BLM had jurisdiction and approved this infill drilling application. Subsequently, four new CBM wells were drilled and two conventional wells were recompleted as coalbed methane wells in late 1992. Several infill-drilling applications (including Red Willow Production Company - 93 additional wells; Vastar Resources, Inc. - 30 wells; Mark West Energy Partners, Ltd. – 11 wells; J.M Huber Corporation - 22 wells; Amoco – 23 wells, and lesser numbers by other operators) were submitted and approved in amending Orders of the Colorado Oil and Gas Conservation Commission. By the end of 1998, approximately 60 infill locations had been drilled and completed. If reservoir models and simulations continue to project that optimum recovery, economics and performance are best accomplished in some areas by 160-acre infill drilling, more wells may be drilled.

History of Natural Gas Seeps in the Northern San Juan Basin

Historically documented naturally occurring gas seeps throughout the San Juan Basin existed prior to oil and gas drilling operations. Coal-miners found pockets of methane in mines in the northern part of the Basin. **Figure 3** shows a coal prospect in the Fruitland coal outcrop.

Figure 3: Prospect in Fruitland coal outcrop

Shallow water wells penetrating Fruitland and Menefee coalbeds around the Basin rim have historically produced methane gas. Especially notable in La Plata County, Colorado, are seeps at the northern and western rim of the San Juan Basin. Known gas seeps include the Carbon Junction area where the Animas River crosses the Fruitland Formation. At this location methane and hydrogen sulfide seeps were commonly recognized as early as the 1930's (Amoco, 1996). Local residents noted as early as 1920 that " a "rotten egg smell" is being emitted from the Carbon Junction Area" (Whitton, personal communication, 1996). Another well-known site of historic gas seepage is a topographic low in the Hogback Monocline between Valencia Canyon and Iron Springs Canyon on the western rim of the San Juan Basin. Historically emitting odors of "rotten egg gas" (hydrogen sulfide), this pass through the hogback was known by old-timers as "stink hill". Other areas of seepage existed at the northeastern edge of the San Juan Basin rim. Ranchers ignited escaping natural gas from water faucets, holes punched in iced-over streams, or known soil seeps in entertaining pyrotechnic displays impressing new-comers or merely celebrating the Christmas Season (Halverson, 1994; Hocker, 1994). Dugan (1990) recalls a mention of a gas seep near Bondad, Colorado and a gas seep in a drill rig cellar in 1955. In approximately 1968, several water wells were drilled in the Cedar Hill, New Mexico area, but the water was unusable due to the strong sulfur odor (Kearl, 1988). Forty years ago a group of local youngsters who inadvertently cast a campfire ember into the Los Pinos River were duly impressed when the surface of the river ignited in a flash (Hocker, 1999).

As early as 1980-1985, new seeps not associated with Basin rim outcrops, but interior to the Basin, appeared to be forming in pastures in the Animas River Valley south of Durango near Bondad, Colorado and Cedar Hill, New Mexico (Shuey, 1990; Beckstrom and Boyer, 1991). Rural property owners in the Cedar Hill and Bondad areas noticed bubbles in the Animas River and in their tap water. Water well pumps cavitated as natural gas exsolved from the groundwater so rapidly that some pumps failed to perform. Several pump houses exploded when methane gas accumulated in the confined spaces and were ignited by a spark, possibly generated by a pressure switch or electric motor brushes. One well owner in the Cedar Hill area reportedly shot a high-powered rifle into his water well casing to develop the well, and inadvertently started the well on fire. Gas seeps in soils that overlie Mesaverde sandstone outcrops were noted in the mid-1990's as manifesting patches of dead grass in pastures northeast of Durango along CR #240.

History of Coal Fires in the Northern San Juan Basin

Scoria, cinders, clinker beds, and ash remnants bear testimony to pre-historic coal fires. North of the Colorado-New Mexico State line lie the Cinder Buttes, distinguished by distinctly reddish oxidized and heat-altered clinker. The name attests to the fact that subterranean fires consumed shallow coalbeds. Recent mapping of the Fruitland outcrop along the Basin rim documents numerous sites where these ash and clinker deposits grade into recognizable coal

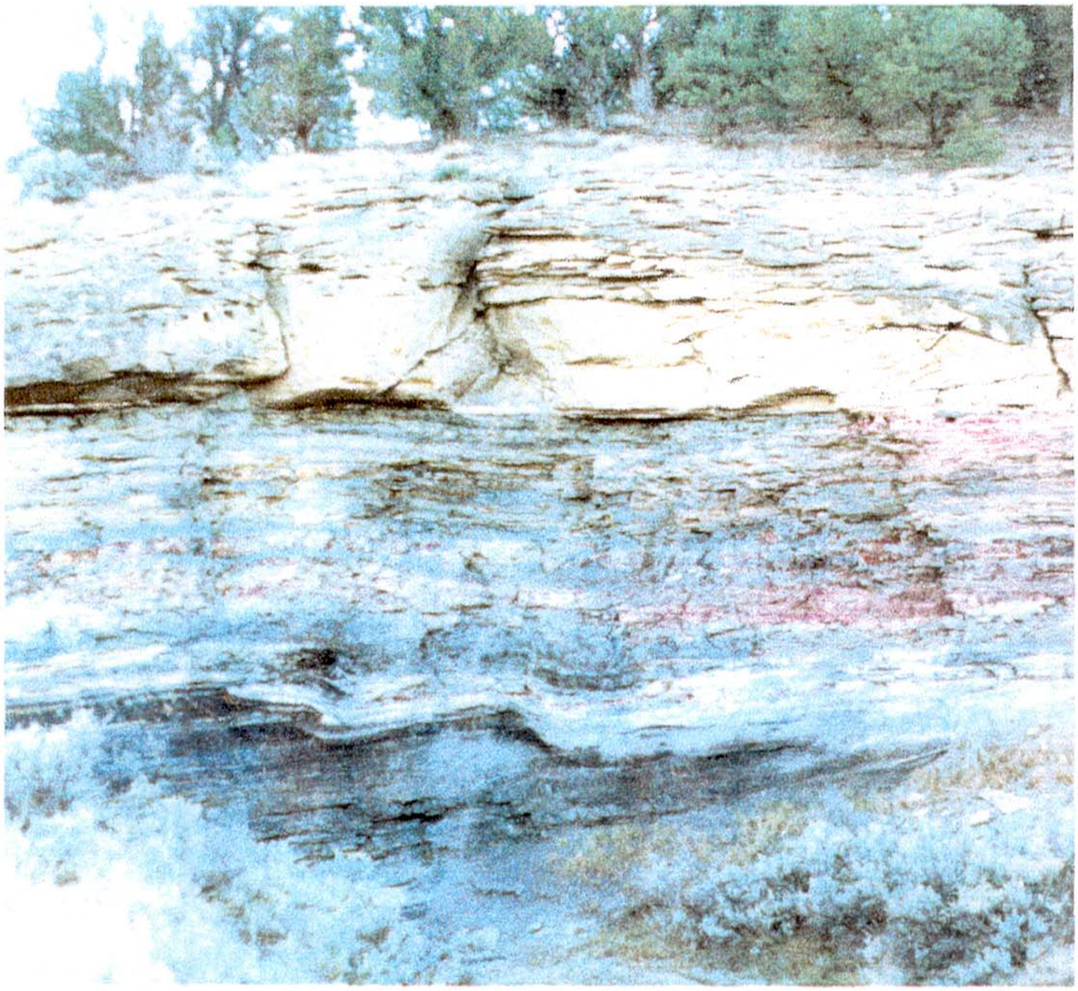


Figure 4: Extent of fire front: coal/ash/scoria; sandstone fractures allowing air intake from surface

Seams (**Figure 4**). It is a matter of clear geologic record that coal fires have been an integral part of the geologic history of near-surface coal exposures in the Fruitland Formation. Spontaneous combustion can be spawned by fluctuation of water levels within coalbeds. This heat-of-wetting can raise the temperature of the coal to the lower self-heating temperature (SHT) of the coal. Once the self-heating potential is invoked by reaching the SHT, an exothermic reaction is triggered that quickly accelerates the heating process until smoldering or combustion of the coal occurs. See ***Appendix B: Maps and Cross-Sections 6*** for a visual representation of the sequence of clinker formation.

Local accounts of Fruitland Formation landslides and explosive events at Carbon Mountain (Parker Mountain, Moving Mountain) begin with a landslide in 1918. One coal prospect was excavated at the southern end of Bodo Park on the western flank of the Animas River near Carbon Junction, but was never produced due to bad (sulfur) gases encountered. The most clearly documented event occurred in December 1932 ("Durango Herald-Democrat", 1932). Explosions may have been the result of spontaneous combustion of coal gas accumulations around the mine prospect. Or alternatively (Vanderwilt, 1933), the explosive sounds may have been generated by rock fracturing during the incremental movement (up to 35 feet per day) of the 1000-foot-displacement landslide, possibly enabled by extensive snowmelt lubrication beneath the sliding rock mass. In a later event during 1939-40, residents observed impressive dust clouds from Durango, several miles to the northwest. Local residents also recall additional explosive events in the 1950's and the 1980's.

III. NATURAL RESOURCE STUDIES/MONITORING/RESPONSE

Early 1990 La Plata County Studies of Groundwater-Entrained Methane

Shortly after the onset of CBM production in La Plata County in the late 1980's, a local citizens group voiced concern about an alleged increase in natural gas contamination of domestic water wells. U.S. Representative Ben Nighthorse Campbell initiated the formation of a committee to address the concerns. As an outgrowth of the Campbell Committee, the U.S. Geological Survey began a study in July 1990. This study focused on documenting the occurrence of natural gas in near-surface ground water and in soils adjacent to gas wells in the Animas River Valley in the San Juan Basin between Durango, Colorado, and Aztec, New Mexico. From analysis of water chemistry in samples collected from near-surface aquifers at domestic water wells, the study sought to identify and map the occurrence, determine potential sources, and suggest possible pathways through which natural gas might migrate to near-surface aquifers. Included was the investigation of the relationship between methane concentrations and mapped geologic fractures.

This study (Chafin, 1994) showed measurable concentrations of methane (greater than the detection level of 0.005 mg/L) in 34 percent of the samples tested, with bedrock wells exhibiting higher concentrations than alluvial wells. Hydrogen sulfide was often found associated with elevated concentrations of entrained methane. On the basis of a thermogenic isotopic signature (***Appendix C: Chart 10)*** and molecular composition of the gas isolated from the water of some domestic wells showing similarity to gas collected from producing horizons, the latter were depicted as probable sources of the methane. (The isotopic character of carbon atom distribution in water-entrained methane can be confounded by the fact that methylotrophic bacteria often oxidize methane. Following methane oxidation, the stable isotopic ratio of the carbon atom population tends to indicate a false maturity and may result in misleading assumptions. The deuterium isotope and chemical composition of the entrained gas can be utilized to minimize confusion over this issue.) Shuey (1990) reviewed gas composition data of samples drawn from domestic water wells and seeps between Bondad, Colorado, and a few miles south of Aztec, New Mexico. He concluded that approximately half of the samples contained gas similar in character to that produced from Fruitland Formation coalbeds. Beckstrom and Boyer (1991) determined that the gas isolated from three conventional gas well surface casings (bradenhead gas) was chemically and isotopically consistent with Fruitland coalgas and hypothesized that gas migration had occurred upward from the Fruitland Formation along uncemented well-bore annuli of conventional gas wells. Proposed methane migration pathways to water wells having a thermogenic gas signature include deficiencies in well casing integrity, a lack of adequate annular isolation through the Fruitland coal horizons, cathodic protection wells, seismic test holes, bedrock water wells, and natural joints and fractures.

Conversely, methane isolated from water wells having carbon isotopic signatures reflecting biogenic sources was attributed to microbial action in near-surface regimes such as sewage lagoons, septic fields, swampy areas, or within the groundwater aquifer itself. While the accumulation of methane in these domestic water wells may represent environmental hazards, the implicated sources are not under the auspices of oil and gas regulatory agencies. Therefore, investigations into biogenic methane sources have been excluded.

With the rapidly increasing CBM development in the years 1989 to 1991, La Plata County residents expressed concern that anticipated increases in drilling activity and production from the Fruitland Formation coals might adversely affect their water wells. In response, the San Juan Basin Oil and Gas Coordinating Committee (with representation from state, local, and Federal agencies, the Southern Ute Indian Tribe, gas industry operators, citizen groups and private citizens) was formed in 1989 to study the effects of oil and gas development, with an emphasis on groundwater quality issues. The need for a baseline of water quality was recognized, and in February 1991, the Colorado Oil and Gas Conservation Commission (COGCC) established a Groundwater Task Force to initiate a study to provide baseline data in La Plata and Archuleta Counties (Velez, 1993). This Groundwater Task Force was comprised of the COGCC, BLM, San Juan Citizens Alliance, Southern Ute Indian Tribe, La Plata County, San Juan Health Department; Colorado Division of Water Resources – Water Quality Control Division and State Engineers Office, Office of Senator Ben Nighthorse Campbell, Colorado Department of Local Affairs, and private citizens. The State of Colorado, Department of Local Affairs Energy Impact Assistance Fund and gas industry contributions to the COGCC Environmental Response Fund provided the needed monies. A total of 324 wells were sampled in 1991, with analyses being completed by several laboratories. Headspace methane concentrations were reported in parts-per-million (ppm) in contrast to the USGS study, which reported in milligrams of methane per liter of water. The latter has become the accepted standard for reporting methane entrainment in groundwater. Unfortunately, quality control split-samples for methane concentration differed substantially between laboratories.

Credibility of the study suffered. Nevertheless, analyses showed 81 wells to have methane above the detection limit of 7 ppm in the headspace. The study also identified specific water wells devoid of measurable methane contamination, establishing a baseline at these locations. Twenty-eight water wells having in excess of 1000-ppm methane in the headspace were isolated and samples from sixteen of these were submitted to the USGS laboratory in Denver for stable carbon isotope determination. Using a breakpoint of -55 per mil ($^{0}/_{00}$), ten samples appeared to be of biogenic origin while six indicated thermogenic origins with potential relationship to gas producing horizons.

A Colorado Western Slope groundwater quality monitoring study (Schenderlein, 1993) evolved out of an agreement between the Colorado Department of Health and the Office of the Colorado State Engineer, Department of Natural Resources, Division of Water Resources. A grant from the Environmental Protection Agency funded this 1992 study to determine the extent of groundwater contamination attributable to non-point source activities on the Western Slope Area of Colorado. During this study twenty water wells and springs were sampled in the San Juan Basin in the summer of 1992; nineteen wells were re-sampled in the fall of 1992. Seventy percent of the first round of samples and eighty-five percent of the second round of samples exhibited quantifiable methane concentrations above the lower detection limit of 0.005 milligrams methane per liter of water. Twenty-five percent of the first round of samples and sixteen percent of the second round of samples divulged concentrations exceeding one milligram methane per liter of water, with two revealing concentrations of methane greater than ten milligrams methane per liter of water. No isotopic determinations were reported.

BLM Response to Environmental and Economic Concerns

Responsible resource management includes minimizing unnecessary producible gas losses and maintaining healthy ecosystems. CBM gas loss through uncemented conventional well bores is of economic importance. Gas lost to aquifers and soils is an environmental concern.

An illustration showing the mechanism for potential CBM gas migration into groundwater aquifers is represented in **Appendix B: Maps and Cross-Sections 7.** Groundwater quality degradation may result from a depletion of dissolved oxygen, giving rise to anoxic environments. In an environment depleted of oxygen, undesirable bacteria can proliferate. These include such organisms as sulfate-reducing bacteria. Residing in sulfate-rich water, these organisms, through normal metabolic functions, tend to release hydrogen sulfide, a toxic gas.

With the recognition of potential problems, measures were taken to mitigate adverse conditions. The Bureau of Land Management, San Juan Resource Area (now the San Juan Field Office) responded with proactive measures to establish a water quality baseline at Basin-interior water wells in areas not included in prior studies. The San Juan Resource Area also drafted a "*Notice to Lessees (NTL), Montrose District Office 91-1*", which was issued by the BLM Montrose District Office and applicable only to gas wells in the Ignacio-Blanco Field. This NTL requires gas field operators to annually monitor all gas well surface casing pressures. These passive mechanical integrity tests are designed to assess the condition of well bores. The character of gas and fluid flowing from gas wells with aberrant bradenhead pressure is documented, the composition analyzed and results reported to the BLM to assist in remedial action plans.

BLM Environmental Monitoring - HD Mountains

The propensity for contamination of groundwater by methane gas was recognized as a valid concern. In 1991 this issue was addressed in the preparation of a joint BLM/USFS (United States Forest Service) Environmental Impact Statement (EIS) for the proposed 64-well coalbed methane (CBM) drilling project in the HD Mountains east of Bayfield, Colorado. In this newly developed area, all wells were to be CBM wells. The potential problem of adversely affecting older conventional well bores, often characterized by incomplete isolation of the Fruitland Formation, was irrelevant due to the lack of conventional wells in this area. All CBM well bores were approved for primary annular cement placement spanning the entire vertical distance from the producing horizon to the land surface. Initial baseline sampling of groundwater to establish a benchmark of water quality was proposed, and a BLM commitment was made to periodically evaluate water quality in subsequent years. Sixty-five to seventy water wells, largely on the periphery of the sparsely inhabited interior of the HD EIS study area, have been monitored in 1993 and 1996 in an effort to provide early warning of any discernable gas production-induced groundwater contamination. So far virtually no adverse water quality impacts have been documented, although concerns have arisen off the northwestern flank of the study area where high levels of thermogenic methane with isotopic signatures similar to Mesaverde gas have been documented in monitoring on private lands.

BLM- Further Environmental Monitoring and Baseline Database

Due to BLM concern for potential environmental impact from gas production in the northern San Juan Basin of Colorado, the concept of establishing a groundwater quality baseline was expanded from the HD EIS periphery to water wells adjacent to other BLM jurisdictional lands. The initial reconnaissance ascertaining groundwater quality implemented by the BLM-SJRA in 1993 was limited to approximately 200 sites, including the HD EIS periphery water wells, within a presumed radius of influence extending one-half mile beyond jurisdictional lands. Seventy-five percent of the wells tested showed measurable methane; twenty-five percent showed significant concentrations. The threshold of immediate concern was established at 1.0 milligram of methane per liter of water. This was in response to the laboratory finding that a 1.0-milligram per liter concentration of water-entrained methane was shown to have the ability under controlled conditions in a confined environment to exsolve sufficient methane to create an explosive atmosphere (Harder and others, 1965). *Critical areas* were defined by including a buffer zone extending up to one mile from any domestic water well(s) with entrained concentration(s) of 1.0 milligram (or greater) methane per liter of water.

The checkerboard of split-estate land surface and mineral lease ownership in southwestern Colorado dictated the importance of Federal, state and tribal agencies and private landowners collaborating in an effort to gather and analyze comprehensive data countywide. In a combined effort by the BLM-SJRA, the COGCC, and local landowners, a comprehensive infill-testing program to augment 1993 test data was implemented in 1994 to characterize water quality throughout the San Juan Basin of Colorado within La Plata County. On the basis of that study, 17 areas of elevated entrained methane in groundwater were defined including buffer zones as before. The identified areas with greater than 1.0-ppm entrained-methane in groundwater are outlined and shaded in the accompanying map ***(Appendix B: Maps and Cross-Sections 8.***)

BLM – Remedial Action Efforts

Currently, the BLM bradenhead program tracks over 1000 jurisdictional gas wells in the Ignacio-Blanco Field. The COGCC also conducts a similar bradenhead-testing program within its areas of jurisdiction. Bradenhead tests represent an invaluable method of isolating gas wells that exhibit excessive surface pressure, and exposing potentially defective gas well bores. The COGCC has ordered many gas well remediation efforts, which combine with BLM efforts to mitigate gas well deficiencies basin-wide within Colorado. This program has proven vital in minimizing producible gas losses, promoting public health and safety, and decreasing environmental impacts to groundwater and soil on public and private lands.

Assuming that gas wells with measurable bradenhead pressure exceeding 2 psig might potentially affect groundwater resources, these gas wells were targeted by the BLM-SJRA for remediation in designated *critical areas.* Secondarily, gas wells located outside of designated critical areas were selected for remedial action when the bradenhead (1) pressure exceeded 25 psig, (2) exhibited sustained measurable flow throughout the 30-minute test period or (3) issued water, mud or oil. As a result of these efforts, hundreds of gas wells have received remedial action including secondary placement of annular cement, wellhead and/or seal repairs/replacement, authorization for bradenhead gas to be designated for beneficial use on lease, or authorization to vent small volumes of trapped gas to the atmosphere. All efforts are intended to de-pressurize the well-bore annuli (and surrounding aquifers) by either re-establishing well-bore integrity or by providing a preferential alternative pathway for gas to escape harmlessly, rather than migrate into shallow groundwater horizons.

The BLM Water Quality Database Today

Earlier water well test data by others was incorporated into the BLM database. Later, combined efforts by BLM and COGCC in subsequent studies (1994, 1996, 1998) included additional areas where jurisdiction is characterized by state, fee and communitized gas wells throughout La Plata County. This database now includes methane data from 669 individual water wells, and isotopic data from 88 producing gas wells.

Gas Seepage at the Northern Basin Fringe

In 1993, the emphasis for monitoring and assessment shifted toward the Basin fringes. While Basin-interior shallow groundwater contamination with thermogenic methane was being addressed by re-establishing gas well integrity, other concerns arose concerning Basin periphery water wells and Fruitland coalbed outcrops/subcrops at the San Juan Basin rim. In August 1993, a resident of Pine River Ranches Subdivision notified the COGCC of gas contamination in his shallow (34 foot-deep) water well and announced his recent observation that streams of gas bubbles were rising through the water of the nearby Los Pinos (Pine) River. As the BLM was engaged elsewhere in groundwater testing for entrained methane determinations in domestic wells proximate to BLM jurisdictional lands, SJRA services were elicited in response to this newly recognized situation. Significant concentrations of entrained methane were detected in samples of water from the well in question and from several other nearby domestic wells. This is in a topographically low area where the Los Pinos River has scoured a valley through the hogback at the northern rim of the San Juan Basin. Nine to thirty-five feet of alluvium overlie the Fruitland Formation subcrop in this valley. Four residences were situated over the Fruitland subcrop in the Pine River Ranches Subdivision. Explosive levels of methane were detected in the crawl spaces of two.

Since 1987 eleven Fruitland coal wells had been drilled within two miles of the Pine River Ranches Subdivision. While the gas well annuli were cemented to the surface and no aberrant bradenhead pressures were observed, millions of barrels of water had already been extracted to facilitate desorption of gas from the Fruitland Formation coal beds. Pressure transient analyses were conducted between the Pole-Barn monitoring well (drilled 0.3 mile west of the Los Pinos River), the Salmon monitoring well (drilled into the subcrop at the southern edge of the Pine River Ranches Subdivision), and the Gurr Federal gas well, approximately 0.5 mile to the west. The response to a shut-in of the Gurr well was evident at the Pole Barn monitoring well (0.14 mile or 760 feet distant) in less than 24 hours with a 0.15-psi/day response. Definite pressure interference (1.3 psi) was also seen at the Salmon monitoring well at the southern border of the Pine River Ranches Subdivision 2880 feet away after 100 days, with a response of 0.07 psi/day. The BLM-SJRA instructed Amoco to shut-in the Gurr Federal CBM gas well in 1995. It has not produced gas or water since. BLM considered a shut-in order on the Litton Federal gas well to the west due to its high water production and suggested that 5-6 fee wells be shut-in additionally. The COGCC and Amoco decided not to shut-in the high water producing coalbed wells located on private mineral estate several miles down-dip, based upon the assertion that a permeability barrier existed between the outcrop and the basin-ward gas wells. A USGS study of the Basin-rim coal beds by James Fassett (Fassett, 1997) supported the hypothesis that subcrops in the Pine River Valley were not contiguous with coal seams being produced basin-ward. In response, the BLM decided not to order the shut-in of the Litton Federal gas well without the support of definitive evidence indicating producing horizons in the Litton Federal were inter-active with the subcrop/outcrop.

Recent published information indicates a loss of bottom hole pressure at the Gurr Federal of 0.02 psi per day and at the nearby Huntington gas well, a loss of 0.02 psi per day. Both indicate pressure transient changes commensurate with that projected by down-dip Fruitland coalgas/water production (Oldaker, 1999). The Huntington is 3640 feet south of the Gurr and in closer proximity to high water-producing Fruitland coalbed gas wells in the Los Pinos River Valley. The Huntington well showed pressure response to down-dip production more rapidly than the Gurr Federal, as would be expected.

Interdependent relationships were shown to exist between a the Dulin D-1 Fruitland coalgas well, located two miles south of the Los Pinos River Fruitland coal subcrop, and three neighboring gas wells: the Bowers #1 at 2340 feet, the State AW-1 at 3700 feet, and the Conrad A-1 at 4640 feet distant. . The Conrad A-1 well lies approximately 1 mile south of the subcrop, and 0.5-mile southeast of the Huntington well. All these wells appear aligned with the highly fractured Los Pinos River valley. A bridge plug was inserted into the Dulin D-1 gas well temporarily suspending production of water from the basal coal seam. This well had been producing 2000 barrels of water per day (BWPD). Within one month of the shut-in time, increased water production was documented at the three neighboring gas wells. Over the two-month shut-in period, gas production decreased. Likewise, water production increased between 200 BWPD and 1000 BWPD at the respective neighboring gas wells. After the Dulin-D-1 well was again allowed to produce water, production of water decreased and gas production increased at all three observation wells. This test indicated reservoir continuity (Pine River Investigative Team Report, 1995). **Appendix B: Map and Cross Sections 9**shows the relative locations of coalgas wells and water monitoring wells in the Pine River Valley north of Bayfield, Colorado.

Water samples drawn from the domestic water wells in the Pine River Ranches Subdivision yielded chemical data indicating Fruitland coal water influence. Gas samples obtained from several nearby Fruitland coalgas wells were comparable in molecular composition and isotopic signatures to those isolated from the domestic water wells. Isotopic signatures of the stable carbon 13/carbon12 isotopic ratio ranged between $-45.56^{0}/_{00}$ and $-49.79^{0}/_{00}$ (per mil) at the gas wells and between $-43.79^{0}/_{00}$ and $-48.95^{0}/_{00}$ at the water wells. The deeper monitoring wells showed signatures of the stable carbon isotope between $-47.12^{0}/_{00}$ and $-56.85^{0}/_{00}$. Water wells drilled into the alluvium overlying Fruitland coal subcrops within the Pine River Ranches subdivision showed higher concentrations of dissolved solids (680 ppm) and bicarbonates than would normally be anticipated in wells completed in alluvium of the Los Pinos River. High bicarbonate levels characterize produced water from coalbed gas wells. Los Pinos River water sampling showed 50-100 ppm total dissolved solids. These anomalous water quality parameters were dominant over the subcrops of the Fruitland, and were conspicuous by their absence upriver from the subcrop. A reduction in these aberrant chemical constituent concentrations was documented downriver of the subcrops (Pine River Investigative Team Report, 1995 Vol. III). These and other water chemistry parameters indicate that coalbed water was flowing into the overlying alluvium. Later evidence suggested water being drawn into the coals (Bennett, 1995), a reversal of prior hydrologic conditions, perhaps altered by produced water withdrawal from the Fruitland coalbeds down-dip. This observation was, however, considered unconfirmed.

Tree roots generally require between three and five percent oxygen in the soil gas mixture to maintain viability. Soil oxygen concentration between ten and fifteen percent is normally required for initiation of new roots and healthy root growth (Puls, undated). Measurements revealed methane concentrations as high as 97% by volume in some soils of the subdivision (Bennett, 1996). Initially, shrubs and bushes located in a well-defined strip parallel to the strike of the subcrop of specific coal seams began showing signs of stress, presumably due to oxygen depletion in the soils. Later, numerous large mature Ponderosa Pine trees also showed signs of stress, and gradually died, many within a three-year period. More are showing signs of imminent death at this writing in 1999.

Gas and Oil Regulatory Team

Organized integrated multi-faceted monitoring of such physical parameters as water quality, soil vapor and gas well surface casing pressures was nurtured by the environmental concerns at Pine River Ranches Subdivision. The Gas and Oil Regulatory Team (GORT) was formed in July and August, 1994 as a data sharing ad hoc committee comprised of regulatory agencies (BLM, COGCC, La Plata County), the Southern Ute Indian Tribe, and gas industry representatives dubbed the Colorado Petroleum Association, each entity designating two representatives. The initial directive was to discuss problems, gather data, and offer potential solutions to the dilemma at the Pine River Ranches Subdivision. The meetings were open to the public with time available for community involvement. This collaboration of efforts was a major success in bringing all involved parties together to discuss problems and offer suggestions for remediation. Important studies were commissioned and relevant data collected and shared. The BLM-SJRA was a major contributor, documenting findings on water quality sampling and observed water-entrained methane relationships over time as related to influence of barometric pressure, ground water table fluctuation, etc. The Gurr Federal gas well was ordered by the BLM to be shut-in indefinitely as a result of pressure transient analysis findings. The Pine River Investigative Team Report (1995) proposed straightforward cause and effect relationships, but industry-funded independent consultants filed a counter-report proposing alternative theories based upon other assumptions which confounded the issues. The essence of discovery may have therein been compromised through academic pursuits, suppositions and the enviable quest for substantiating data, complete with interpretation. As GORT has no legal binding authority, final decisions involving Pine River Ranches Subdivision were relegated to the COGCC (the regulatory agency with local jurisdiction over the fee lands and minerals that were involved) in cooperation with the primary gas operator.

The immediate threat to public health, safety and welfare at the Pine River Ranches Subdivision has been removed by the gas operator's purchase of these and other nearby affected properties. GORT still functions as a forum to discuss local issues potentially connected to oil and gas production in La Plata County. Other concerns are routinely submitted to the GORT forum and discussed in open meetings. The public is invited to comment. Specific concerns are addressed by the respective regulatory entity having jurisdiction.

Environmental Monitoring Including Soils – Incorporated in Mitigation Plans for the Tiffany Enhanced CBM Project

Beyond Pine River Ranches, environmental monitoring was next applied to other areas of concern, such as the enhanced methane recovery project and infill drilling of prior designated spacing units. With the luxury of now having historic water quality and bradenhead pressure data compiled at the BLM-SJRA, this database provided a natural baseline for two specific areas of atypical natural gas development. When the 15-½ square mile Tiffany Unit (centered about six miles southeast of Ignacio, Colorado) was proposed for enhanced coalbed methane recovery through nitrogen injection, approval included a monitoring plan incorporating BLM baseline data. A Contingency Plan, largely developed by the BLM-SJRA in cooperation with the COGCC and the Tiffany Unit operator, stipulated a representative 21-well water-quality monitoring program. This "Plan" utilized baseline parameters obtained prior to the January 1998 commencement of nitrogen injection into the coalbeds. Besides water quality and bradenhead pressure monitoring, this plan incorporated soil vapor monitoring with threshold parameter action levels. Several defective plugged and abandoned well bores were identified by high concentrations of methane in the surrounding soil. These wells were re-entered and remediated prior to nitrogen injection.

In 1998 the COGCC received an application involving infill drilling of Fruitland coalbed wells within five miles of the northern Basin rim (J.M. Huber proposal). With the precedent of the Tiffany Enhanced Methane Recovery Unit Plan, similar environmental monitoring was required. Although no Federal jurisdiction was involved in this application, the San Juan Field Office assisted in a consulting role. The operator prepared a Development Plan, which was approved by the COGCC. The Development Plan included water quality monitoring in seventeen domestic water wells and soil gas monitoring along the outcrop of the Fruitland Formation. (Huber and LT Environmental, 1998).

Remediation Results Across the San Juan Basin of Colorado to Date

Incorporating water quality data with that of the concurrent bradenhead-testing program authorized under NTL-MDO-91-1 continues to provide the necessary information to require remediation of gas well(s) exhibiting excessive surface casing pressure and/or lack of well-bore integrity. **See Appendix B: Maps and Cross-Sections 10** for a 1994 edition of a Bradenhead pressure map and a map showing gas wells with bradenhead pressure greater than 25 psig overlain with groundwater methane concentrations. Periodic monitoring of groundwater quality conducted in 1996 and 1998 served to guide the continuing effort, to evaluate groundwater quality response to remediation efforts, and to locate areas exhibiting resurgent or newly identified methane contamination.

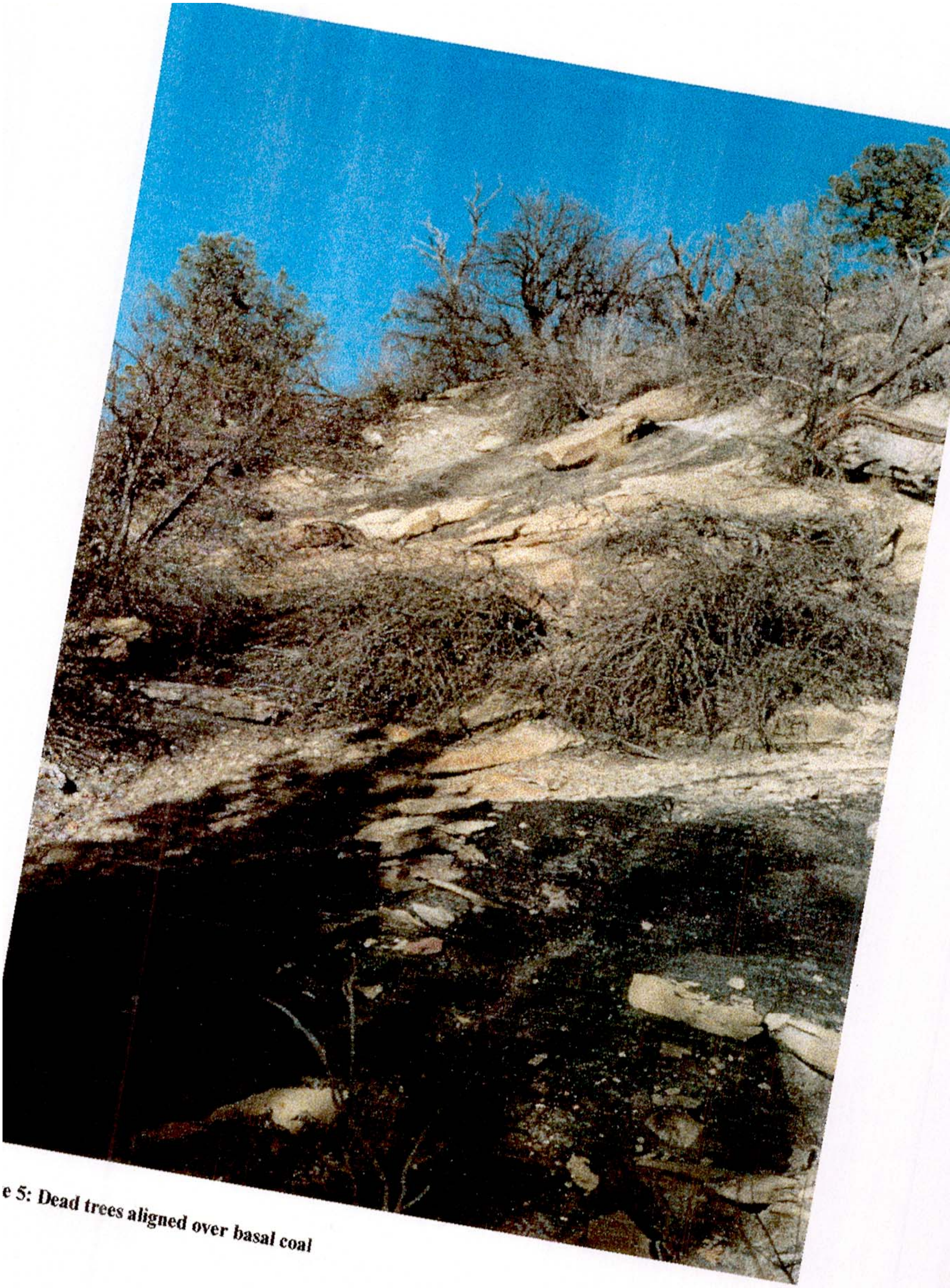
One hundred and twenty water wells were re-tested during the 1998 joint BLM/COGCC effort. Water wells located in the vicinity of remediated gas wells were chosen for this study to evaluate groundwater quality changes in domestic water wells by comparison with prior baseline values. The intent of the study was to evaluate the effectiveness of gas well remediation efforts. Also identified were areas that require continued assessment for potentially defective gas well-bores and/or further remediation. The forthcoming report will also include tests conducted during 1998 monitoring of water quality at 21 water wells in the vicinity of the Tiffany Enhanced Methane Recovery Unit and 24 water wells in the Ticcolote area where the J.M. Huber Corporation has begun drilling infill CBM wells. The final report on the 1998 water quality monitoring is pending, but preliminary results are summarized below.

Preliminary findings of this 1998 study are encouraging. Based upon prior studies of methane concentration in groundwater (Pine River Investigative Team Report, 1995), the criteria denoting significant entrained methane concentration change was established at a 10-fold increase for entrained methane concentrations of less than 0.1 mg/L. An increase/decrease of 5.0 mg/L is considered significant when concentrations vary between 1.0 mg/L and 30 mg/L. (Due to potential losses of methane during collection of methane–saturated water, concentrations in excess of 30 mg/L methane in water are inconclusive for comparison of precise values.) Using the stipulated criteria, a preview of this 1998 study indicates that 32 water wells tested in 1998 in proximity to remediated gas wells exhibited a reduction in entrained methane concentration. (For measurement repeatability and documented methane-in-water concentration variation with respect to time/barometric pressure/water level, reference BLM, 1994.) Eleven wells showed an increase. Six wells tested in 1998 had no prior established baseline for comparison. Sixty-seven wells showed no definitive change. Of these latter 67 wells showing no statistically significant change, latest test values were lower at 44 sites, higher at 14 wells, and essentially identical to earlier tests at 15 locations **(Appendix C: Chart 11)**.

Soil Gas Monitoring at the Fruitland Coal Outcrop along the San Juan Basin Rim

Measurement of soil gas (methane, oxygen, hydrogen sulfide and carbon monoxide) concentrations in coal outcrops of the Fruitland Formation along the Basin rim is intertwined with bradenhead testing and water well monitoring. Local residents perceived an apparent increase in observed hydrogen sulfide odors in the Carbon Junction vicinity where the Animas River is crossed by US Highway #550-160 at Colorado State Highway #3 (known by locals as the High Bridge). These comments augmented the general concern that other exposures of the Fruitland coal might be venting gas, as was observed in the Los Pinos River Valley. Therefore, an early reconnaissance survey was accomplished by the BLM-SJRA in May, 1995 (BLM, 1995) between Moving Mountain (southeast of Durango, Colorado) on the southwest and the Florida River drainage to the east. Evidence of methane seepage from the outcrop was confirmed in several locations, primarily in topographically low-lying areas such as valleys defined by river and stream systems. Conversely, methane seepage was conspicuously absent at topographically higher elevations.

While no pre-CBM-development soil vapor baseline data exist, the recognition of vegetation mortality in recent years indicates degradation from prior soil gas conditions. High methane (and commensurately low oxygen) concentrations similar to those observed in the Pine River Ranches vicinity have been observed within the Southern Ute Indian Reservation along the Fruitland coal outcrop. In the spring of 1995, a Southern Ute Indian Tribal geologist noticed extensive soil gas venting from Fruitland basal coal seams at an historic seep location on the western Basin rim approximately 7 miles north of the New Mexico –Colorado State border. While the Valencia Canyon Gap seep had been known to exist for many years, the venting intensity had notably increased. Gas streams flowing from quarter-inch diameter soil vents were consistently transporting sand grains from land surface to a height of several inches into the air. Pinon and juniper trees and sagebrush vegetation in the local area were showing signs of stress.



e 5: Dead trees aligned over basal coal

The stressed/dying trees were aligned congruent with the strike of Fruitland coal seam outcrops (**Figure 5**). Field analyses of the venting gases in these zones of vegetation mortality showed methane concentrations in excess of the lower explosive limit of methane. Some samples contained in excess of 200-ppm hydrogen sulfide. Soil oxygen levels were depleted to 0.1% oxygen or less. Soon after this discovery of toxic and flammable gasses, the access road was expediently closed by Southern Ute Indian Tribal Council action due to public health and safety concerns.

Less than year later, a half-mile long by fifty to seventy-five foot wide swath of previously healthy pinon and juniper trees, sagebrush and saltbrush stood dead as a stark testimony to recent environmental changes. This scenario is repeated in each of five major coal seams in the Valencia Canyon Gap area. . The closest gas well with high water production is 0.5 miles to the east. This area appeared to respond quickly to the nearby water extraction. Vegetation at other sites more distant from high water producing wells appeared to respond more slowly. Similar illustrations of recently altered soil conditions detrimental to vegetative life were soon noticed along the Fruitland coal seams in other areas **(Appendix B: Map and Cross Sections 11)**. All together, locations along the Fruitland outcrop north of the New Mexico State line account for more than eight miles of stressed/dead vegetation. **(See Figure 6 below.)**

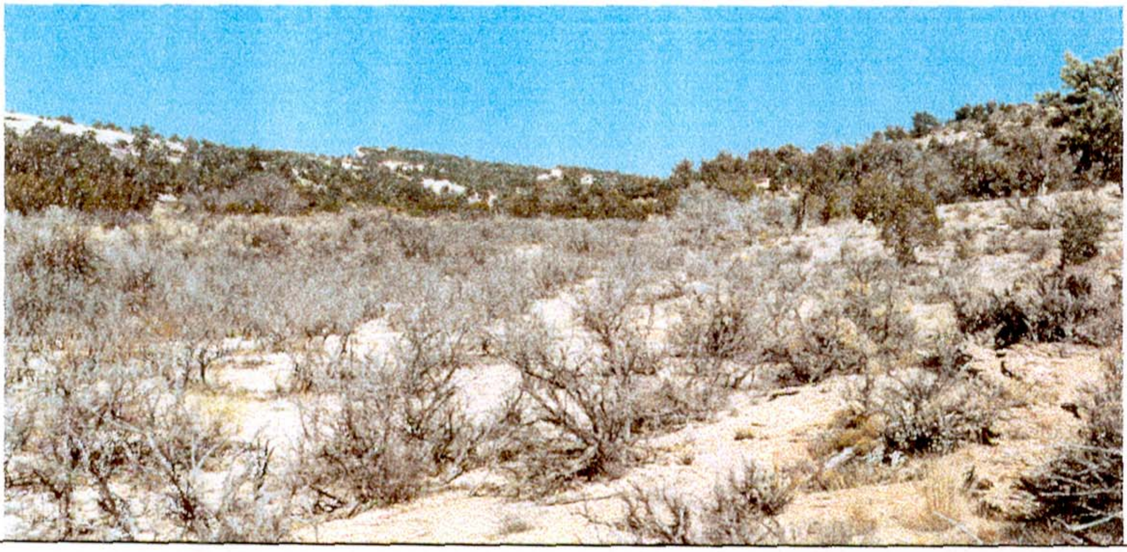


Figure 6: Dead sagebrush over Fruitland basal coal at Soda Springs. (PC sandstone outcrop at left)

Each lineation of dead vegetation corresponds to a coal seam of the Fruitland Formation; however, to date the majority of coal outcrops are not accompanied by stressed vegetation. Soil gas testing within those areas manifesting strips of dead vegetation reveals severe oxygen depletion, accompanied by high methane concentration. (Isolated locations were observed where dead vegetation is not coincident with depleted soil oxygen, but probably relates to disease or other factors). Methane concentrations in the coalbeds along the outcrop have been documented at 1,000,000 parts per million (100 percent methane). Hydrogen sulfide concentrations in the soil exceed 2,000 parts per million at some soil vapor monitoring sites.

With the apparent exacerbation of gas seepage at Valencia Canyon Gap and several other sites within the Southern Ute Indian Reservation, the BLM and the Southern Ute Indian Tribe launched a surficial reconnaissance survey. Geologists walked the Fruitland outcrop along the western flank of the San Juan Basin within the Southern Ute Indian Reservation, making note of abandoned mine sites and strings of dead and stressed vegetation or other evidence possibly linked to increased methane gas seepage such as visible/audible gas vents. Following the initial reconnaissance, the BLM focused efforts on further defining the extent and concentration of soil gas constituents. Approximately eight miles of the Fruitland outcrop was surveyed in specific areas where preceding reconnaissance recorded conditions suggestive of possible methane gas presence. Locations exhibiting stressed/dying vegetation and discernable coal outcrops were targeted for sampling. In the absence of either of these physical indicators, samples were drawn every several hundred yards along the outcrop. With the intent of monitoring the ongoing concentration of methane, hydrogen sulfide, and oxygen in the soils, semi-permanent soil vapor monitoring stations were established at the extremes of stressed zones, within affected areas, and in transects established perpendicular to the strike of the Fruitland outcrop. **See Appendix B: Maps and Cross-Sections 12** for the current design of soil vapor monitoring stations.

Additional monitoring stations supplemented the initial soil tube arrays in areas such as topographic lows (stream/erosion/fault valleys) in which no evidence of seepage was detected, but at sites recognized as having the greatest latent potentials for seepage. Lastly, monitoring stations were established at documented USGS survey locations in horizons stratigraphically above the coalbeds in the upper Fruitland and Kirtland formations, some near exploratory coalbed core holes or gas wells. While most monitoring sites were established by Fall 1995, forty-six were installed as late as Summer and Fall 1998. The latter sites were installed in response to proposed infill drilling activity along the northwestern flank of the San Juan Basin. In all, 184 monitoring locations have been established along the north and western flank of the Basin within the exterior boundaries of the Southern Ute Indian Reservation. More sites are pending installation to specifically monitor the outcrop influence of proposed mitigation wells. Enervest (one of the gas operators in this area) installed a 10-foot by 85-foot soil vapor collector over the basal coal seam at the site of the Valencia Canyon Gap seep to monitor cumulative gas flux and composition emanating from the outcrop. This collector **(Figure 7 below)** has been instrumental in collecting data, especially during the time period subsequent to the slant-well mitigation measure of Winter 1996.

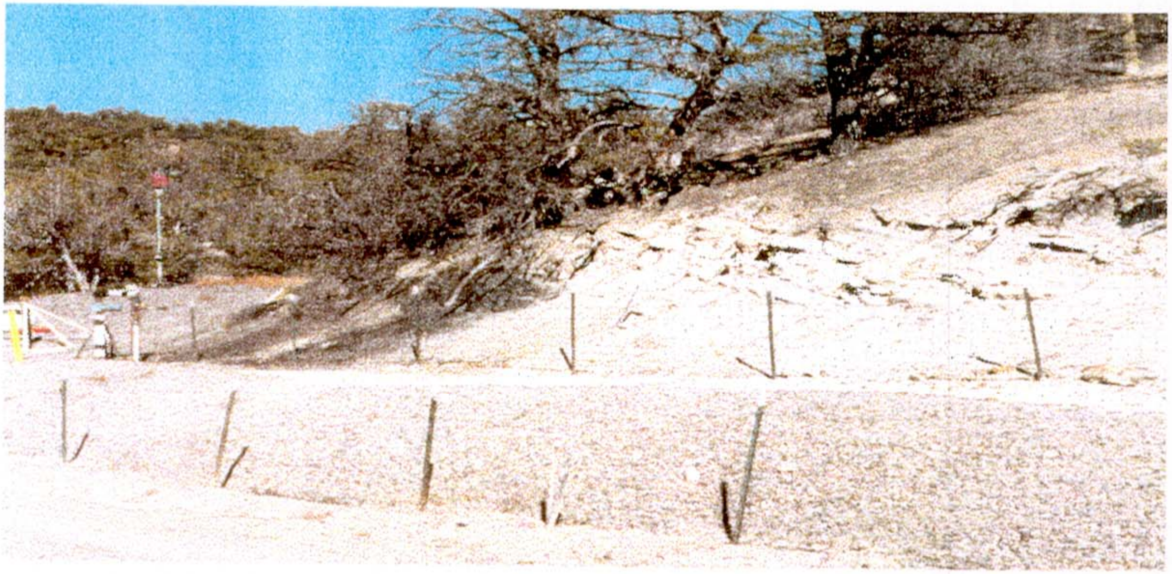


Figure 7: Valencia Gap Soil Gas Collector

(These slant wells, drilled into coal exposures in an effort to capture free gas in the near subsurface before migrating to the outcrop, are further discussed under the "Mitigation to Date" section.)

Concurrent with the activity within the Southern Ute Indian Reservation, the discovery and documentation of methane and hydrogen sulfide seeps along the Fruitland outcrop north of the Southern Ute Indian Reservation and possible implications were discussed in a public forum of GORT. A consortium of efforts largely funded by the COGCC and industry (with BLM participation) enabled an outcrop study extending from the Southern Ute Indian Reservation northern boundary line on the southwest to the Archuleta County boundary to the north and east. A soil vapor reconnaissance was performed by Direct Geochemical (Stonebrooke, 1996) supplementing the initial BLM reconnaissance of Spring 1995. A fracture, cleat and coalbed mapping study was accomplished by the USGS (Condon and others, 1997). L.T. Environmental, Inc (L.T. Environmental, 1998) installed semi-permanent soil gas measuring probes and soil gas flux chambers in 1997. An earlier study (BLM, 1994) detected methane at high concentrations in domestic well water along the South Fork of Texas Creek (northwest of Bayfield, Colorado). The subsequent soil vapor testing in 1996 showed methane-saturated soils. Patches of dead vegetation confirmed the lack of soil oxygen available to plant roots. One hundred and sixty-one stations were ultimately installed north of the Southern Ute Indian Reservation to allow periodic soil gas concentration measurements. Six flux (soil gas flow) measurement chambers and one weather station were positioned over soils exhibiting micro-seepage of methane. These were equipped with solar panels and data loggers to provide continuous data collection.

To date 346 soil vapor monitoring sites have been established in the Fruitland outcrop along 45-50 miles of the northern and western San Juan Basin rim. These sites were installed through cooperation of the BLM, COGCC, Southern Ute Indian Tribe, La Plata County and the gas industry. Monitoring is primarily accomplished by the BLM, San Juan Field Office (SJFO) at intervals ranging from monthly to quarterly. L.T. Environmental is currently commissioned to collect data from the flux chamber sites and the weather station under the auspices of the COGCC and industry.

Soil Vapor Monitoring Reflects Dewatering and the Coalgas Isotherm

Ongoing measurements are critical in assessing the effects of Basin-wide water extraction from the Fruitland coalbeds. As water is produced from coalbeds down-dip from the outcrop, the hydrostatic pressure is reduced most dramatically in the vicinity of each well bore. The influence of coalbed water withdrawal, which is manifested as a decrease in hydrostatic pressure within the various coal seams, would be expected to diminish with increased distance from gas well(s). Hydrostatic pressure reduction on the coalbeds in turn allows sorbed gas to be desorbed when the pressure is lessened sufficiently.

The coal *isotherm* **(Appendix C: Charts 7b)** is a graphical representation of the relationship between the release of adsorbed coalgas (in cubic centimeters per gram of coal) and the effects of pressure at a specified temperature. By consulting this chart, it is possible to predict the equilibrium adsorption/desorption isotherm. This isotherm depicts the amount of gas anticipated to be released/desorbed from the coal at prevailing conditions of temperature and pressure.

Carbon dioxide has a greater affinity for coal than does methane. Therefore, as reservoir pressure is reduced, methane will be desorbed first. Thus, early stages of reservoir pressure reduction yield gas with a methane component often in excess of 99 percent by volume. As reservoir pressure is further reduced, the carbon dioxide component increases. With each incremental pressure reduction, commensurately more gas will be released, but the carbon dioxide component will account for an increasing portion of the gas mixture. Coalgas production may be limited by economic factors when the carbon dioxide component of the natural gas reaches a threshold concentration at which the cost of carbon dioxide removal is prohibitive. At current gas prices, this threshold may be breached when the carbon dioxide component of the produced gas stream exceeds 20% by volume.

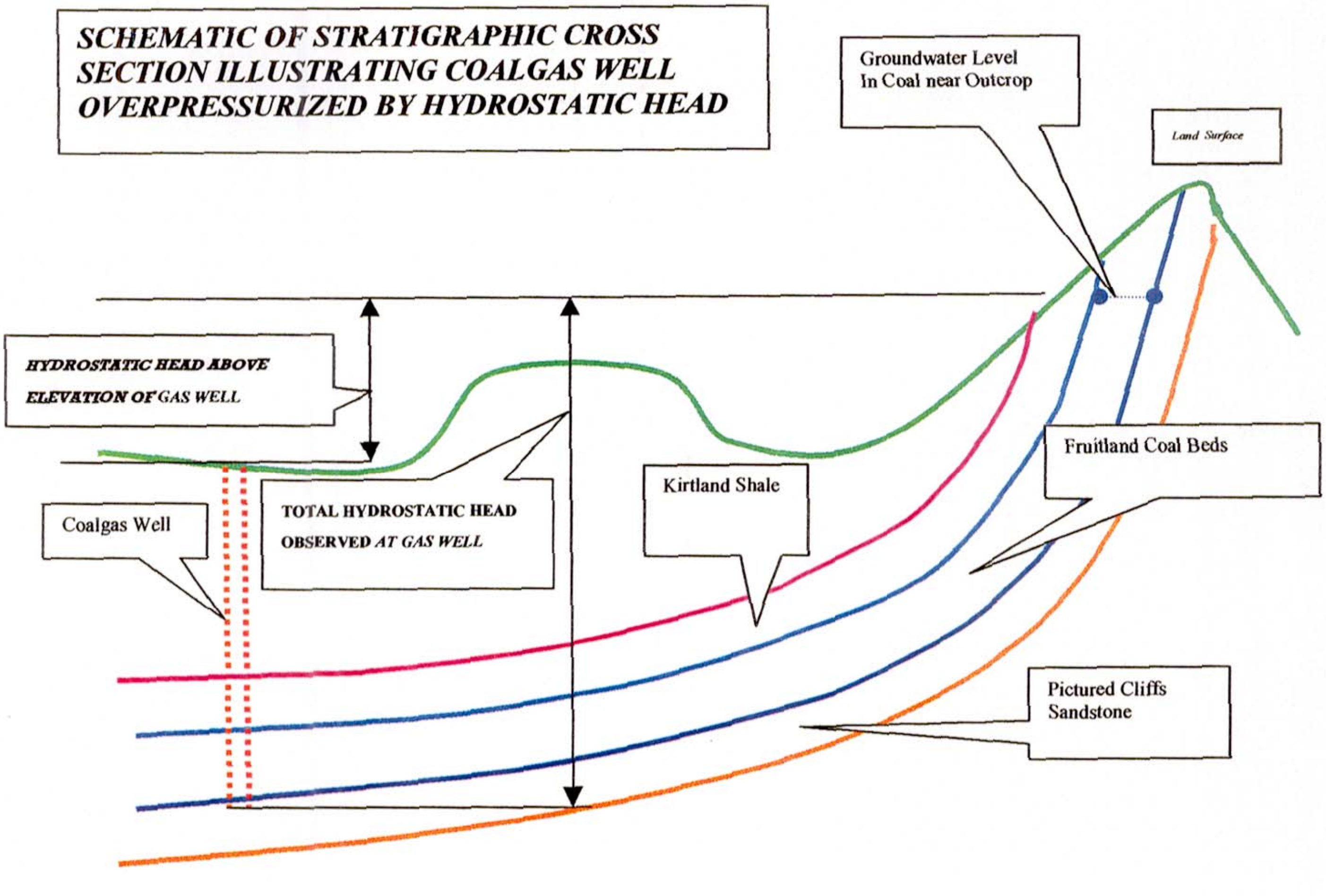
This change in coalgas composition is well illustrated by **Appendix C: Chart 12,** which illustrates the changes observed in soil gas composition at the Valencia Canyon Gap Collector. The methane component has decreased from 91% in 1995 to 84% in July1999. Conversely, the carbon dioxide portion has increased from roughly 9% in 1996 to nearly 16% in July 1999. In October 1999 soil vapor tube determinations at seven sites surrounding the collector yielded carbon dioxide in concentrations from 15% to 18%. This same phenomenon may be perpetuated along the entire Fruitland coal outcrop as water saturation of the near-surface coalbeds decrease. Initial high methane concentrations would be anticipated to decline with a commensurate increase in the carbon dioxide component. Monitoring for the carbon dioxide component of soil gas was initiated in October/November 1999, revealing carbon dioxide concentrations as high as 36% at one site directly up-canyon from a shallow gas well converted to monitoring status. Methane decreases may in part reflect the release of greater percentages of carbon dioxide from the coal. Methylotrophic bacterial oxidation of methane in near-surface environments also produces carbon dioxide (Bennett and Lee, 1996). One third of the soil vapor tubes showing significant change in methane concentration are decreasing. The respective gas-to-coal affinity relationship combined with bacterial oxidation effects may explain why some sites along the outcrop exhibit waning (or fluctuating) soil vapor methane (LEL) concentrations.

While de-watered Fruitland coal exposures may most readily manifest the influence of low pressures predicted by the coalgas isotherm, similar responses would be anticipated in coalgas wells where the reservoir pressure is reduced at depth. Indeed, higher carbon dioxide gas content (to 20%) is currently being observed in portions of the basin where reservoir pressures have been reduced the most dramatically. Northern Basin infill gas wells drilled in 1999 still encounter virgin reservoir pressures and initially produce gas characterized by greater than 99 percent methane and only several tenths of a percent carbon dioxide (Zimmerman, 1999).

Hydrostatically "Over-pressured" Coalgas Wells

The greatest change in reservoir pressure gradient will occur at the well bore from which gas is being produced. The pressure gradient front will gradually extend to the surface outcrop, assuming that the porosity of the entire coal seam is initially water saturated and that the coals at the outcrop are hydraulically connected to the coals produced at the gas well(s).
Virgin (original) reservoir pressure approximates hydrostatic head. "Over-pressured" (similar to artesian) conditions are common at Basin-interior gas wells. The Fruitland coalbeds ascend from a depth of 2500-3500 feet in the interior of the Basin to the surface at Basin rim outcrops. At a "flexure" zone that lies approximately one mile inside of the Basin rim coal exposures, the coalbeds abruptly increase in dip angle from several degrees basinward to 20-50 degrees at the outcrop. Coalbed exposures around the Basin rim lie several thousand feet higher in elevation than the locations of the Basin-interior coalbed gas wells. This geomorphologic condition allows Basin rim coalbeds to be recharged by direct inflow from precipitation events, rivers crossing the coalbeds, percolation, etc. (Preliminary investigation suggests that precipitation events may account for a mere 0.2% of the total coalbed recharge.) Connate water trapped in the coalbeds at the time of deposition could be a factor in the saturation of coal beds elevated above effective recharge areas. Groundwater springs known to exist at numerous locations along the Basin rim coalbeds during the pre-CBM production era indicate that the piezometric surface (elevation of water-saturation) in these Basin-rim coals was well above the elevation of the springs. This implies that the coalbeds were effectively saturated below these elevations. The influence of the weight of a column of water equal in height to the difference in elevation between the level of water-saturation in the Basin rim coalbed and the elevation of the coalbed in the gas well is reflected in the reservoir pressure observed within a Basin-interior CBM well-bore. The additional

(over-pressure) exerted by this hydrostatic head equals approximately 0.433 psi (the pressure exerted by a one foot column of water) multiplied by the elevation difference between the surface elevation of the gas well and the piezometric surface in the respective coalbed expressed at the basin fringe. The schematic stratigraphic cross section following illustrates the foregoing discussion.



As the coals are de-watered through production in the Basin interior, outcrop wells would be susceptible to drawdown effects if the coalbeds are continuous and relatively permeable between the producing area and the outcrop. The coal isotherm predicts that a lessening of hydrostatic pressure would be accompanied by an increase in desorbed gas **(Appendix C: Chart 7b).** The Basin rim springs mentioned previously have diminished. Some no longer flow. Shallow water wells in the coal outcrop (Houston water well, Henderson water well, and some Texas Creek wells) initially showed water within the coal at very shallow depths (a few feet to a few tens of feet). The Henderson water well is now dry. The groundwater level in at least one Texas Creek well has decreased substantially.

Soil Gas Monitoring Results

Monitoring data have been collected from soil vapor tubes strategically located on the Fruitland Coal Outcrop for over 4 years. Many locations showed methane saturation of the soils at the onset of monitoring, while other locations showed no measurable methane. Initial monitoring was analyzed with an explosivity meter equipped with catalytic sensor displaying concentration of methane gas in the soil as a percent of the lower explosive limit of methane (LEL). A one-percent LEL reading is equivalent to 500 parts per million (ppm) methane by volume in air. Likewise a 100% LEL reading would equate to 5 percent methane by volume (50,000 ppm). This is the lowest concentration of methane-in-air which would create an explosive atmosphere. The upper explosive limit for methane (UEL) is 15 percent methane by volume, above which the methane–to-oxygen ratio would be too rich to ignite.

Soil vapor sites generally depicted seasonal patterns that fluctuated in response to soil surface-sealing events such as precipitation and frost, in contrast to dry, warm periods. Precipitation and frost tended to alter the physical structure of the soil porespaces rendering the soil less permeable. During soil surface-sealing events, the preferential escape route for soil gas flow was through the unrestricted soil vapor tubes due to their penetration through the surface seal. (Similar responses were noted in protected crawl spaces beneath homes in the Pine River Ranches Subdivision. Methane concentrations were highest in the crawl spaces following rainstorms.) Annual cycles depict highest methane concentrations around March with secondarily high concentrations around August, with the rest of the year showing considerably lower concentrations **(Appendix C: Chart 13)**. From an environmental perspective, the most disconcerting changes were those noted at soil vapor tube locations which initially harbored low-to-insignificant combustible gas concentrations, but later exhibited escalating LEL values. These identified sites were actively undergoing soil gas composition changes reflective of environmental change, possibly induced by coalbed water extraction. The following **Chart 14a** shows three soil vapor tube responses to changes in soil gas composition. Also see **Appendix C: Chart 14b and 14c** for historic trends of hydrogen sulfide in the Cinder Buttes area and annual trends of methane concentration of soil gas at site #230, a mile south of Valencia Canyon Gap.

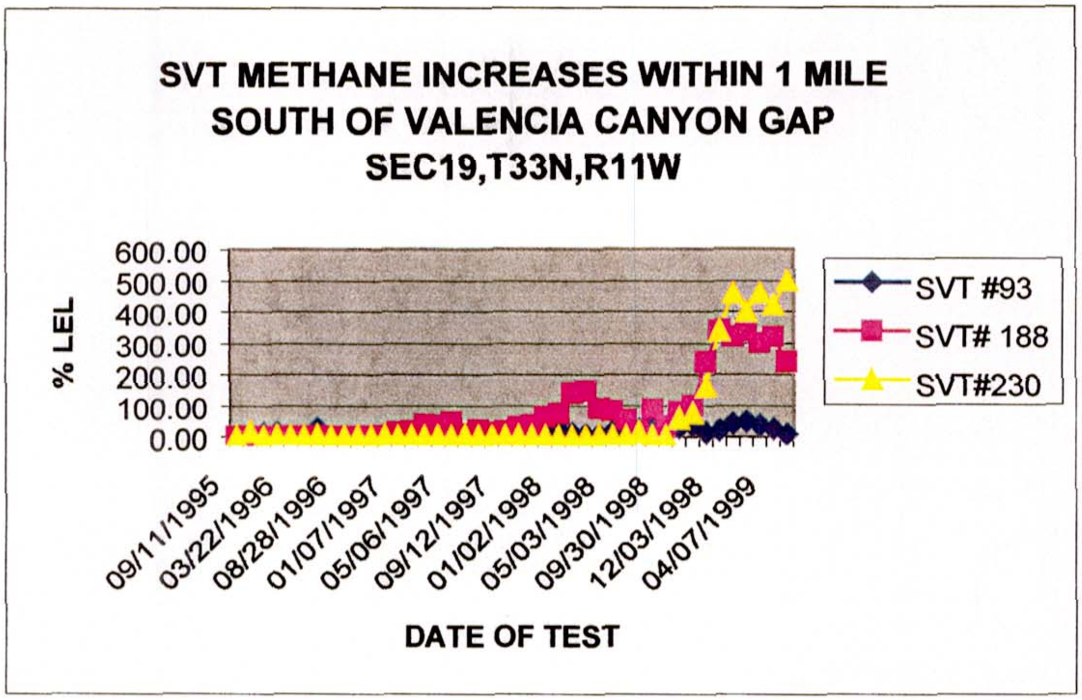


CHART 14a

<u>Statistical Analysis</u>

A statistical analysis of soil vapor methane and hydrogen sulfide data collected over two periods: (1) after July 1, 1998 and (2) before July 1, 1998 has been performed taking into account instrument variability/ accuracy/temperature. See **"Appendix A: Data Statistics"** for an explanation of statistical methods employed and charts generated. In the statistical trends investigated, a " 95% significance level" indicates that the probability of the observed data being due to pure chance is less than 5%; a "99% significance level" means that the probability of the observed data being due to pure chance is less than 1%. There are several kinds of "T" tests. The one used here is a "T" test for the equality of the means of two populations with unknown variances. In this case the two populations are the soil vapor levels before and after the cutoff date. Samples from each population (in this case, the readings before and after the cutoff date) are taken and the sample mean and standard deviation computed. These are entered into an algorithm to produce a significance level. The test takes into account both the difference in means and the amount of internal variation in each sample. Other things being equal, the greater the difference between the means of the samples, the higher the significance level. However, other things being equal, the greater the standard deviation of one or both samples, the lower the significance level of the test.

Of 184 soil vapor tube locations within the exterior boundaries of the Southern Ute Indian Reservation, sufficient data to permit statistical analysis had been collected at 133 sites. Significant increases in methane concentration (99% confidence level) were reflected at 54 sites; 7 additional sites showed less significant methane increases (95% confidence level). Fourteen sites indicated a substantial decrease in methane concentration (99% confidence level) and 17 additional sites showed a less significant decrease (95% confidence level).

T-tests using log (LEL) showed very similar results with several more sites showing upward trends and several fewer showing trends of decline. Sen and Mann-Kendall statistical indicator tests were not dependent upon an arbitrary cut-off date, but captured increases and decreases over the entire period of measurement. These tests are also less sensitive to details such as changes in magnitude introduced by the use of different measuring instruments. The Sen and Mann-Kendall analyses depicted almost identical results when compared to the "T" tests.

There were 97 reservation sites with sufficient measurements of hydrogen sulfide to compute T-tests. The hydrogen sulfide component of the soil vapor increased at 7 sites with a 99% confidence level and 3 more increased when the confidence level was reduced to 95%. There were no hydrogen sulfide decreases at the 99% level and only 2 at the 95% confidence rating (**Chart 14d below**). Soil vapor emission rate comparisons at 133 sites over the same time span showed that flow increased dramatically at 6 sites (99% confidence level), with 4 additional sites exhibiting a less impressive increase in flow (95% confidence level). Substantial flow decreases occurred at 5 sites (99% confidence level), while 16 more sites exhibited a less significant decrease in flow volume (95% confidence level). The remainder of the sites either presented insufficient data to draw a statistical conclusion or the data did not depict a significant trend.

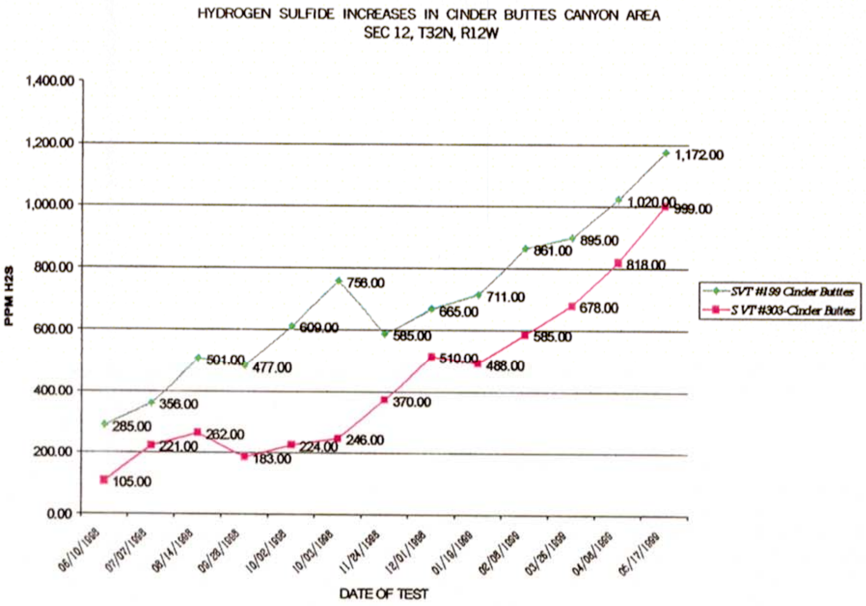


Chart 14d

It is important to note that a decrease in methane concentration does not necessarily suggest a mitigation effect. A decrease in methane concentration would be expected to accompany greatly reduced reservoir pressure. Methane is the first gas to be released from the host coal following reduced reservoir pressure. Carbon dioxide has a greater affinity for the coal and is only released after greater pressure reduction. As reservoir pressure within the coalbed(s) is decreased, more carbon dioxide and proportionately less methane are released according to the coalgas isotherm. The baseline for carbon dioxide monitoring was established by testing within the exterior boundaries of the Southern Ute Indian Reservation during October

1999. The establishment of a baseline on private, State of Colorado, and lands north of the Southern Ute Indian Reservation is scheduled for November 1999.

Of the sites located on public and private lands north of the Southern Ute Indian Reservation exterior boundary, sufficient data to permit statistical analysis had been collected at 147 of 162 total locations. No sites showed a statistical "T-test" increase in soil gas concentrations of methane. At the 99% confidence level 2 sites showed a definite methane component decrease, while no additional decreases were noted when the 95% confidence level criteria was applied. Sen estimators and Mann-Kendall statistics show methane concentration increases at 10-12 sites (at 95% confidence) and decreases at 1-5 sites. A single site showed the hydrogen sulfide concentration to be on the increase at the 95% confidence level, but none under the 99% criteria using the "T test". No decreases in hydrogen sulfide gas components were observed at either 95% or 99% confidence levels. Gas flow at one site statistically decreased, given the 95% boundary, but no other statistically viable flow changes were apparent.

In understanding the foregoing statistical analysis, several cautions must be considered. Due to the shorter duration (one-year) of monitoring at the 50 northern-most stations, statistical tests would be inconclusive; increases/decreases may be seasonal. Therefore statistical tests on these sites have been delayed until additional monitoring is complete. Other interpretative discretion must also be applied. Statistically significant changes may not always reflect actual trends. For instance, a change from 0 ppm to 1 ppm or even 100 ppm could be reported as a significant statistical change, while in reality such data variation might only reflect instrument inaccuracy at or near the detection limits for a particular gas. This is especially true when measuring methane concentration with the Industrial Scientific "ATX-620", which has a lowest detection limit of 50 ppm. Sites that rapidly increased from low values to a crescendo in the first year and maintained at similar concentration might escape detection as statistical increases. Decreases in methane content could be attributable to early mitigation attempts, but more likely are the result of methane replacement by carbon dioxide as predicted by the coalgas isotherm at reduced reservoir pressure. Further monitoring of carbon dioxide concentrations will serve to clarify the issue (**Appendix C: Chart 12**). Marked increases generally correlate to basal and intermediate coalbeds located up-dip of CBM wells producing considerable quantities of water.

Water well methane concentration variations over the past decade were also reviewed for statistical comparisons. Due to the infrequent testing of water wells, meaningful statistical analyses could not be attained. Nevertheless, preliminary indications from 1998 testing of 117 water wells located in proximity to remediated gas wells show an order-of-magnitude *decrease in methane content from prior tests at 32 wells. Order-of-magnitude increases were documented at 11 wells.* Less variation was noted at 67 wells. Of these latter wells, the latest test values were *lower at 44 sites, higher at 14 wells* and essentially identical to baseline values at 15 locations. Six wells had no pre-existing baseline data for comparison. **(See Appendix C: Chart 11.**

Fruitland Coalbed Water Production

Significant changes at some outcrop sites are just beginning to show definitive increases after nearly 10 years of coalbed water production. **Appendix C: Chart 15** shows the rapid recent response of a soil vapor tube 1.5 miles distant from a group of high water producing gas wells in the Cinder Buttes area. Several soil vapor tubes along the outcrop up-dip from these gas wells now show greater than 2,000 ppm hydrogen sulfide (**Appendix C: Chart 14b**) and contain an ethane component, representing recent change. Accompanying charts show daily water production since 1990 from the four closest Fruitland coalbed wells. In the Colorado Portion of the San Juan Basin approximately 250,000,000 barrels of water have been produced to date from the Fruitland coalbeds. Cumulative water production from four wells in the northern portion of the Basin has exceeded 4,000,000 barrels of water per well. Over 30 wells have produced in excess of 950,000 barrels of water (**Appendix C: Chart 16; Appendix B: Maps and Cross Sections 13**).

Soil Temperature Data Loggers

Another aspect of soil monitoring is the placement of data-logging temperature sensors in Fruitland coal exposures. A total of ten sensors were set during Summer 1999, with nine located north of the Southern Ute Indian Reservation. These temperature loggers, set in protective PVC chambers, record soil temperatures at a depth of approximately three feet below the land surface. Annual trends will be assessed. Temperature increases in the shallow coals may give insights as to whether the coalbed temperatures are approaching the self-heating potential range of the respective coal. The loggers were first initialized in April and May 1999, with the first set of readings taken in June and July 1999. Insufficient time has elapsed to differentiate abnormal temperature fluctuations from seasonal variations.

Aerial Photography

Near infrared and thermal infrared aerial photography are useful tools for monitoring stressed vegetation and coal fires respectively. Near infrared photography can be used to detect decreases in water content within leaf cell structure, which indicate vegetative stress or death. In a joint effort, the BLM, the Southern Ute Indian Tribe, and gas operators collected near-infrared data over the Southern Ute Indian Portion of the western Hogback Monocline in September1996. These data showed strips of dead and stressed vegetation overlying the coal outcrop along known methane seeps. The study was so effective in defining the areas of methane seepage that another survey was flown in July 1999. Results are currently being evaluated. Periodically conducting near-infrared surveys in the future will greatly aid in assessing changes to vegetative health in the coal outcrop area. Thermal infrared aerial photography was also flown in July 1999. Thermal infrared is the radiant heat portion of the electromagnetic spectrum that lies between 3 and 14 micro-meters in wavelength. Anomalous heat patterns may indicate coalbed fires. Results of the July 1999 survey are currently being evaluated. Apparent hotspots from the survey must be verified on the ground. If this tool proves reliable, periodic surveys of thermal infrared photography could greatly aid in tracking known coal fire activity and detecting of new or resurgent coal fire occurrences.

Other Environmental Concerns - Coal Fires

In five specific areas within the Southern Ute Indian Reservation along the Basin-rim, coalbeds burning beneath the land surface have recently been discovered. While there is evidence that Fruitland coals have burned pre-historically, moribund trees and recent surface collapse features point to a recent resurgence of fire activity. The heat-of-hydration can facilitate spontaneous combustion of underground coal when the water table fluctuates. Coal most susceptible to self-heating is characterized by high intrinsic moisture and oxygen content, as found in low-rank coal such as sub-bituminous coal and lignite (Sarnecki, 1991). The heat of wetting can be greater than the heat of oxidation (Kuchta et al,. 1980). If the coalbed is an aquifer (as it tends to be in these areas), and the water table normally fluctuates, if only slightly, with seasonal precipitation recharge, the heat of wetting potential is increased dramatically by water removal. When water levels drop in these confined aquifers, ambient air is drawn into the coalbeds, thus supplying the necessary oxygen to support combustion or further oxidation of the coals. Once the lower self-heating temperature (SHT) of the coal (defined by the rank of the specific coal, with lower-ranked coals having the lowest SHT) is breached, the self heating tendency of the coal produces a sustained exothermic reaction (Smith, 1989) increasing oxidation until smoldering and combustion occur. The self-heating temperatures for some coals can be as low as 30 degrees centigrade in lignite and subbituminous coals, and that for bituminous coals can be as low as 60 degrees centigrade (Kuchta et al, 1980). In areas where current coal fires have been recognized in 1998-99, annual precipitation is low. Therefore down-dip extraction of water could have a substantial effect by dewatering the shallow coals if the seams are hydraulically connected to the nearby producing gas wells. Several of the coal fire sites are in areas of recent wildfires. Actual ignition of the coals in these particular areas may have been perpetrated by smoldering tree roots penetrating shallow coalbeds.

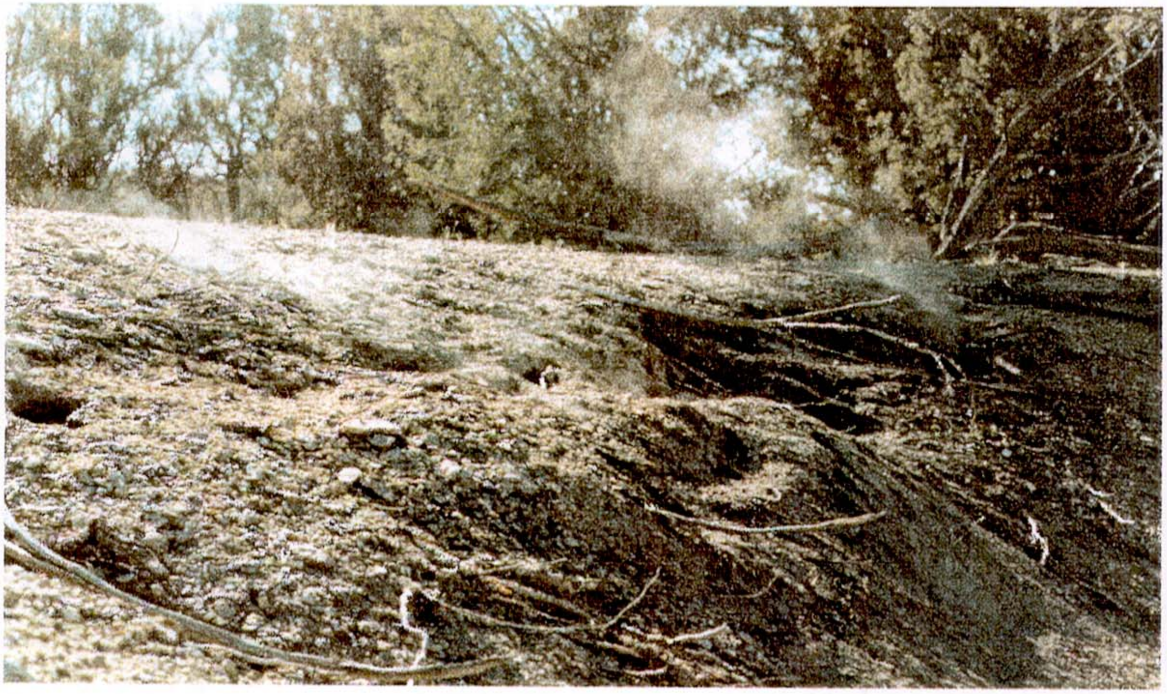


Figure 8: Coal fires near Cinder Buttes

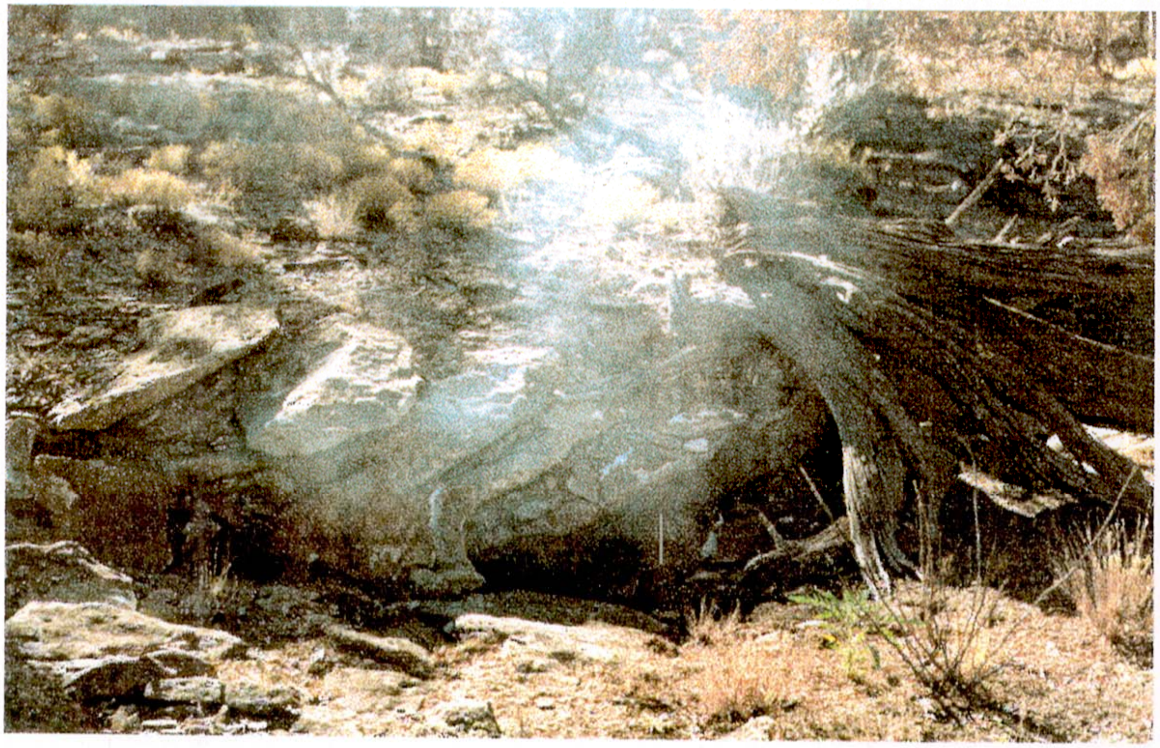


Figure 9: Coal Fires near Cinder Buttes

The newly recognized coal fires **(figures 8 and 9)** were first detected by the presence of steam condensate plumes evident in cold weather, smoky vents, and distinct pungent odors. Vents are high in carbon monoxide with smaller hydrogen sulfide and sulfur dioxide components. Only minor amounts of methane are detected in coal fire vapors due to the methane being consumed by combustion. Many vents are moist, host mossy growths, and show black stains of soot, scorched roots and grass. Infrared thermometer readings indicate vent temperatures at the surface as high as several hundred degrees Fahrenheit.

Other Environmental Concerns – Hot Springs

During 1997 attention was brought to La Plata County officials that a small hot-springs located on private property in the north Animas Valley was exhibiting peculiar behavior. Owners reported that the flow rate and temperature had gradually increased over the past 5 years, and that the water had become too hot for customary household use. Temperatures as high as 133 degrees Fahrenheit and flows to 65 gallons per minute (gpm) were documented at that time. Chemical analyses of the water indicated an increase in sodium content from 400 ppm to 784-800 ppm and an increase in sulfates from 938 ppm to 2150 ppm, when compared to a 1970 test. The Hickerson Hot Springs issues from the Entrada Sandstone, or possibly from the overlying Pony Express Limestone. (Entrada water would normally present a signature with high sodium and chloride content, while Dakota water would show a significant sulfate component.) Trees below the spring were stressed, with some mortality. In recent years snow melted quickly in the yard, on the pavement of County Road #250 in front of the property for a length of several hundred feet, and in the pasture on the west side of CR #250.

Produced water from Fruitland coalbed gas wells in the northernmost portion of the San Juan Basin has been injected into deep water disposal wells (WDW) of non-productive hydrocarbon or non-potable water (greater than 10,000 ppm total dissolved solids) horizons. These horizons include the Mesaverde, Bluff and Entrada sandstones, which have been utilized as disposal zones since ***1988, 1990 and 1989 respectively***. Produced water injection at the Simon Land and Cattle #1 water disposal well (the closest WDW to the Hickerson Hot Springs, nearly 9 miles distant) commenced in 1989. Injection records show that in early 1993 an increase in pressure was required to drive the water injection, lasting until mid 1996. In mid-1996 a dramatic decrease in the injection pressure was observed **(Appendix C: Chart 17).** Evaluations following an April 1998 pressure *Falloff* test conducted by Questa Engineering Corporation (Questa, 1998) concluded that radial flow occurred only for a brief initial period during the test, with subsequent pressure response dominated by boundary effects. The model suggested relatively high permeability close to the well-bore (approximately 100 millidarcys), three no-flow boundaries at approximately 1600 feet channeling water flow toward a fourth constant pressure boundary with significantly higher permeability encountered at greater than 1 mile.

A second fall-off test was performed by Amoco in December 1998 (Yeh, 1999). The shape of the pressure response from this second test was similar to that of the previous falloff test. This test suggested relatively high fracture-stimulation near the well bore and the probable existence of three no-flow boundaries. Induced permeability over the life of the well due to injected fluid along a permeability enhancement in a single direction – *a high unidirectional permeability streak*- to an additional large pore volume at distance, or multiple composite rings with high permeability at an extended distance was considered probable.

As a result of the pressure fall-off tests and other uncertainties regarding this water disposal well, the COGCC, the EPA and Amoco engaged in an informal technical meeting to review the data. Amoco agreed to cease injecting into the Entrada, with actual termination in January 1999. This water disposal well was recompleted into the Bluff Sandstone, above the Entrada. The Hickerson hot spring water temperature declined from 132-133 degrees Fahrenheit (observed between December 1997 and January 1999) to 127 degrees Fahrenheit by August, 1999; the flow rate also decreased to the lowest level (49 gpm) since monitoring began in

November 1997 (***Appendix C Chart 18***). While no definitive correlation has been proven, the changes observed at the Hickerson Hot Springs are concurrent with the termination of injection at the Simon Land and Cattle WDW.

IV. FUTURE PROJECTIONS

Future of Coalbed Methane Development

Current Basin-wide Fruitland coalbed spacing allows one gas well per 320 acres. Recent infill applications **for specific areas** have been approved by the COGCC, allowing an optional second Fruitland coalbed gas well on each 320-acre spacing unit. Infill drilling within 320-acre spacing units is currently occurring and may be a future trend Basin-wide.

The SUIT recognizes the benefits of coalbed methane development, including infill wells, and generally supports CBM development. The BLM under its trust responsibility understands the importance of energy resource development to the Tribe and the nation and has approved infill Fruitland wells while simultaneously preparing a soon to be released Draft Environmental Impact Statement (DEIS) for continued oil and gas development on the SUIT Reservation. The preliminary DEIS states that expanded Fruitland CBM development including infill wells and enhanced recovery methods is the Agency and Tribal preferred alternative. The BLM, BIA and Tribe also recognize that there may be a potential link between down-dip Fruitland production and the gas seeps and coal fires being documented at the Fruitland outcrop. The Southern Ute Indian Tribal Council acknowledges and accepts vegetation kills at the outcrop on Reservation lands as a cost of producing the CBM resource. The calculated losses from dead trees are considered inconsequential in comparison to the economic value of the CBM resource. Recognizing that resource losses are a factor with coal fires and outcrop seepage, the Southern Ute Indian Tribe is seeking professional assistance to extinguish the coal fires. They are also considering a pilot "picket fence" network of shallow gas wells capable of capturing migrating coalgas before venting occurs at the outcrop. The

Tribe and the gas lease operators continue to experiment with mitigation measures to recover the resource and minimize environmental impacts to the Reservation and adjacent areas. Health and safety issues attributable to the seeps are limited since there is no permanent habitation on the outcrop within the Reservation.

To date, the COGCC has approved all spacing applications for Fruitland infill wells on Tribal, and fee mineral acreage. Some limited Fruitland infill drilling and production has taken place north of the Southern Ute Indian Reservation on fee mineral ownership lands. Currently, (October 1999) AMOCO has two "Applications for Permit to Drill" (APD's) pending at the San Juan Field Office to drill Fruitland CBM wells in spacing units for which the COGCC has approved a second well. These are the first Fruitland infill APD's to be received for locations on mineral estate. The San Juan Field Office anticipates more infill Fruitland applications in the near future, on both Tribal and mineral acreage.

If oil and gas operators and regulators continue to see sufficient economic merit and legal justification to perpetuate the current trend of drilling optional infill wells on existing 320 acre spacing units, 1000 additional infill Fruitland coalbed methane wells (350 north of the Ute Indian Reservation) could yet be drilled in the Colorado portion of the San Juan Basin. With more widespread development on the horizon, the development of a monitoring/contingency plan is a necessary and prudent regulatory agency management endeavor.

Future Modeling and Monitoring of Development Impacts

Monitoring wells drilled on the Basin fringe between the outcrop and producing gas wells in the Southern Ute Indian Reservation have documented significant declines in bottom hole pressure (up to 80 psig) equivalent to a loss of hydrostatic head of 185 feet **(Appendix C: Chart 19).** This suggests that the static water level has declined approximately 185 feet in the lower intermediate coal seam during the two years since the monitoring wells were drilled in early 1997. Hydrostatic pressures in other coal seams monitored at these wells have declined at slower rates. No monitoring wells were placed in non-coal horizons to measure whether these adjacent horizons were depleted of groundwater.

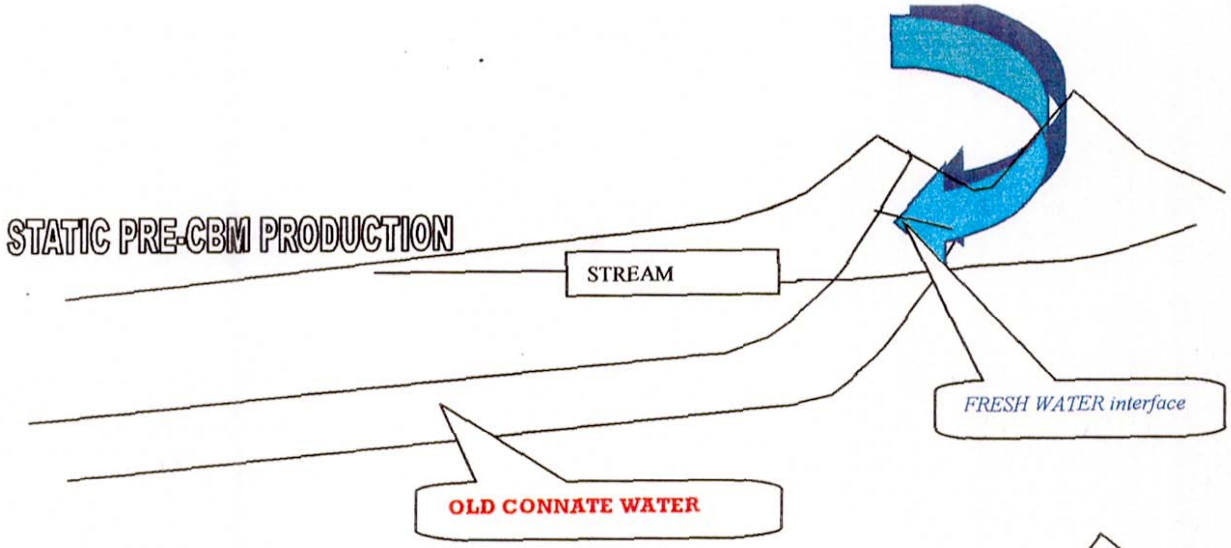
As a decline in the water table would be anticipated to precede increased methane seepage at the Fruitland outcrop, the presence of groundwater monitoring wells completed in each significant coalbed could provide early detection of problematic conditions. Because of different dynamics in the various coal seams, the 2-5 major producing seams (or groups of seams) would necessarily be isolated in respective monitoring wells to yield definitive data without introducing cross-flow ambiguities.

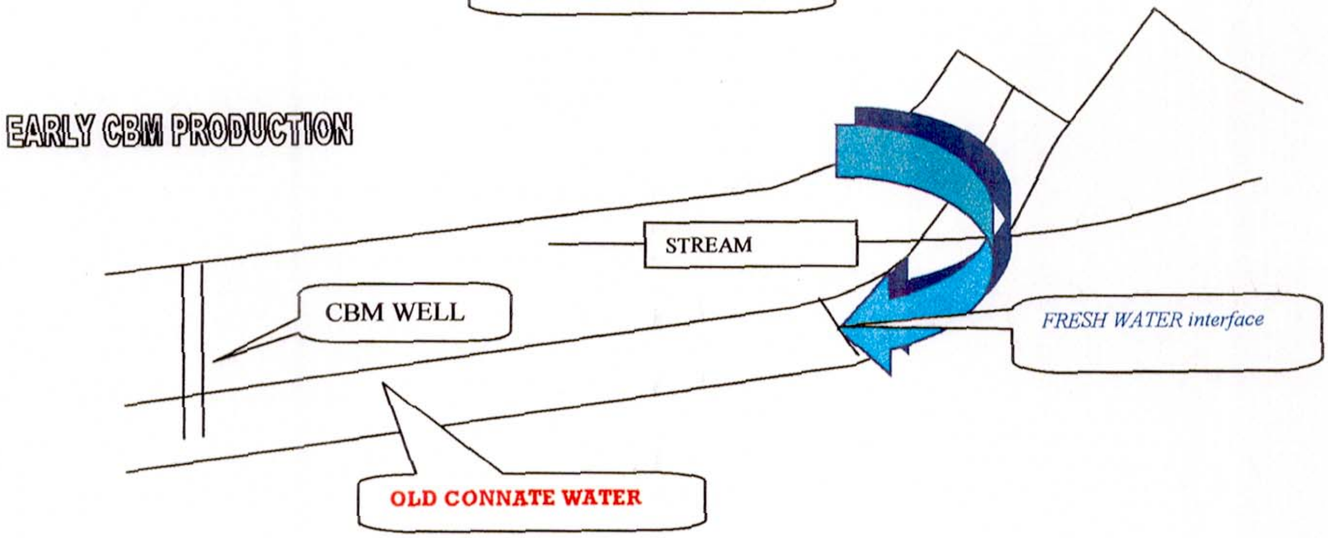
A joint industry/governmental group organized by the COGCC was formed in late 1998. Entitled the 3M Project (named for the monitoring, mapping and modeling components), it is supported by the BLM, COGCC, Southern Ute Indian Tribe, La Plata County, and the oil and gas industry. A technical review team has been formed from the 3M-member constituency. This team offers technical comments and reviews proposals for studies related to the reservoir modeling, hydrology of the San Juan Basin, stratigraphy and structure of the coalbeds, and other technical issues. The Bureau of Land Management-SJFO has committed time and resources to this effort. The first goal of the 3M Project is to map major coal seams at the Fruitland Formation outcrop and correlate these horizons with basin-ward producing coal zones identified in gas well geophysical logs. Monitoring bottom hole pressure and water levels in coal seams at locations intermediate between basin-ward producing gas wells and the Fruitland coal outcrop is the second goal. The third aspect of the 3M Project involves computer modeling. Reservoir and hydrologic models will take into consideration a historical match of past and present conditions and may be able to predict effects of future CBM development on groundwater and the Fruitland coal outcrop.

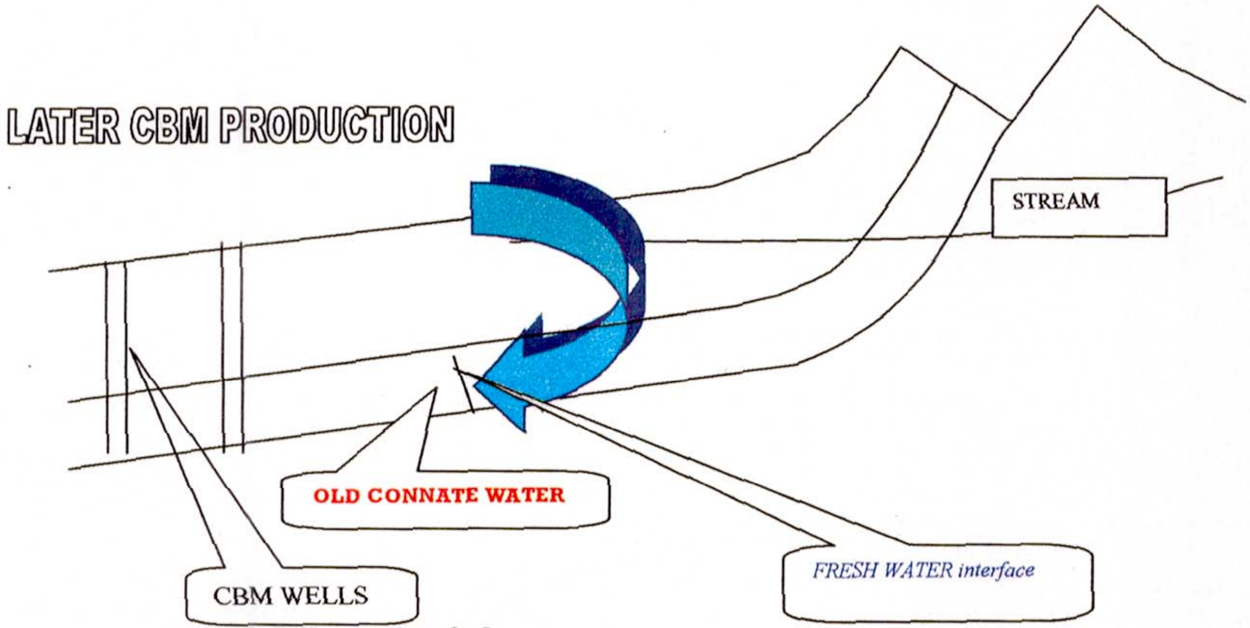
If Basin-ward coal seams are verified as contiguous between producing CBM wells, the Fruitland outcrop and the coal seams may be considered a "U-tube" for ease of discussion.

Consequently, the concept of a dynamic *fresh water front* developing within the Basin can be postulated as follows:

> Assume that the San Juan Basin is non-tributary to boundary rivers. Infer that subterranean coalbeds positioned lower than stream-cuts, spring locations, passes and gullies were saturated with old connate water indigenous to the formation in the pre-CBM production period. The flow of connate coalbed water driven by atmospheric recharge events which provide fresh water at topographically elevated exposures would be anticipated to migrate to surface springs and provide water to streams and rivers intersecting coal outcrops/subcrops. At the onset of CBM water production, connate water was withdrawn from coalbeds within the Basin, drawing on these freshwater recharge sources through permeable zones within the coal beds. Additionally, if recharge were not adequate to replenish the water withdrawn by basin-ward gas wells near the outcrop, it might be postulated that reversals of groundwater flow could occur with subcrops being recharged by surface flow from perennial rivers/streams. At any rate, a *fresh-water front* would gradually progress basin-ward. If sufficient water were withdrawn from the shallower coalbed(s) through gas wells closest to the outcrop, this concentrated high-volume extraction might capture a major portion of the fresh water available, thus pre-empting or slowing the basin-ward migration of the fresh-water front. Basin-ward wells could only draw water available within their respective pressure depletion zones of influence until the connate water surrounding them was depleted, with predominately free gas remaining. In this sense, the basin-fringe wells would shield the down-dip wells from fresh water access. (See next page for illustration.)







No Scale: Illustration Only

Water chemistry data is useful in understand patterns of subterranean water flow. Contrasting Basin interior produced-water characterized by high TDS (total dissolved solids) indicating a longer residence time, is produced-water chemistry data from Fruitland coalbed gas wells on the northwestern edge of the Basin which show lower concentrations of chlorides and bicarbonates indicating fresher water. Produced water data indicates the presence of a relatively fresher water (low TDS) plume along the western end of the Indian Creek area and along the general northern portion of the Basin within 4-5 miles of the outcrop. The occurrence of relatively fresher water in the coalbeds closer to the Basin fringes indicates a connection to a fresh water source, presumably the Fruitland outcrop. The respective fresh water areas, areas with moderate communication with the outcrop, and areas with limited interaction with areas of recharge, if definable, would be invaluable in the current-time match of the computer modeling effort, enabling the model to reliably reflect the nuances of known basin hydrology.

Age-dating, anion/cation and TDS concentrations are all affected by mixing. Old water, once mixed with fresh water, could not be distinguished from medium-aged water. Neither could water with a high TDS be recognized, once mixed with fresh water, etc. Mixing obscures the individual character of all waters mixed because the results of testing can only determine the diluted concentrations of any given parameter. Water assigned a medium age may actually represent a mixture of very old water and very fresh water. Once these limitations are recognized, water analyses can provide useful information.

Preliminary iodine isotope analyses run on the Fruitland produced water from the interior Basin exhibit isotopic signatures indicating 4 to 56 million year old water in some areas (Riese, 1999). Chloride, strontium, or oxygen isotopes may be used to determine ages of younger water predicted in fresher water plumes. Iodine and chloride ion content in produced water yield similar patterns, suggesting areas with high iodine and chloride concentrations probably correlate with older water age dates **(Appendix B: Maps and Cross**

Sections 14). Low chloride values probably correlate with progressively younger water (Riese, 1999). Similar water quality analyses for total dissolved solids and cation-anion concentrations of produced water in the western portion of the Basin also suggest freshwater plumes, and freshening of produced water over time progressing basin-ward. The older dates, in particular, may suggest areas not in effective dynamic communication with the outcrop, or may only be a demonstration of a slower progression of the fresh-water-front basin-ward. Water age maps may not necessarily represent static and impermeable boundaries, or barriers to flow, but merely current conditions. Neither do water age variances necessarily signify that the coalbeds of the Fruitland Formation are not laterally continuous. Dynamic relationships may become evident only after further coalbed methane and formation water production. Gas wells drilled/producing from areas of younger water might be construed as currently more likely to affect the outcrop than gas wells in areas depicted by older water. Yet, if age dating in actuality only produces the position of an ever-advancing front of fresh water basin-ward, this may be an illusion. Water age monitoring over time would provide a useful parameter enabling the computer model to forecast effects of continued or increased CBM production and project correlated effects.

Knowledge gained through analyses of produced water obtained from gas wells is most useful if the water-bearing source strata in the gas well(s)can be definitively associated with specific coal beds expressed at the surface. The Southern Ute Indian Tribe and the Colorado Geological Survey have already mapped the surface expressions of the Fruitland coalbeds within the Southern Ute Indian Reservation and have drawn preliminary correlations between the coals expressed at the outcrop and coalbeds penetrated by nearby CBM wells. The Colorado Geological Survey has recently completed mapping the Fruitland coal outcrops north of the Southern Ute Indian Reservation with the intention of correlating surface and sub-surface coal beds. The Colorado Oil and Gas Conservation Commission in cooperation with the Southern Ute Indian Tribe and the BLM has requested Fruitland CBM operators to voluntarily submit gas well bottom hole pressure data, again to supply much needed information to the modeler.

The monitoring goal of the 3M Project includes the establishment of eight water monitoring well clusters proposed north of the Southern Ute Indian Reservation. Four additional clusters - apart from the 3M Project - are being considered by the Southern Ute Indian Tribe for installation within the exterior boundaries of the Southern Ute Indian Reservation **(See Appendix B: Maps and Cross-Sections 15.)** Each cluster would contain 2-4 water-monitoring wells, each well assessing one exclusive coal zone comprised of one to a few closely related coal seams. These wells would be monitored for temperature and water level/bottom hole pressure. Temperature may be an indirect indicator of fresh water influx (decrease in temperature) or water withdrawal (the heat of wetting). Water level/bottom hole pressures will help evaluate the drawdown effects on the piezometric surface by production of water from basin-ward coal wells.

The modeling goal of the 3M Project will evaluate the hydrologic and gas reservoir potential of the Fruitland coalbeds. Pressure data gathered from producing gas wells and monitoring wells will be used in a modified reservoir to determine past and future effects on the outcrop and feasibility, both economic and environmental, on continued development including infill drilling within the Ignacio-Blanco Field. The hydrologic portion will use the US Geological Survey "MODFLOW" program to calculate recharge along the outcrop, discharge out of the Basin from production activities and other influences that would affect water quality and quantity in the San Juan Basin.

In addition to water monitoring wells, other monitoring tools include thermal infrared and near infrared aerial photography of the entire Colorado portion of the San Juan Basin Fruitland outcrop along the Basin rim. These aerial photos document current conditions, changes from prior photos, and may identify zones of aberrant heat patterns. As a predictive tool, thermal infrared photos may be used to distinguish areas of potential spontaneous combustion in the near-surface coalbeds. Additionally, temperature data loggers installed in the Fruitland coalbeds may provide early warning of coalbed heating. Ongoing monitoring of soil vapor, groundwater and produced water quality will augment the monitoring effort.

Mitigation Questions

The soil gas monitoring records are important in understanding trends and may assist in predicting the likelihood of increased methane contamination or conversely, enable the monitoring of diminishing outcrop gas losses as the result of natural phenomenon or remediation/mitigation efforts, as well as documenting soil gas compositional changes. While continued monitoring is important, it is also important that capture of methane gas seepage and mitigation of existing and future gas seeps be explored. It is estimated (Cox, 1998 from preliminary reservoir modeling that in areas where there are not near-outcrop permeability barriers, a minimum of 1 to 14 billion cubic feet (BCF) of gas per mile (volumes depend on permeability and other factors) will be vented from the outcrop during the next 200 years (**Appendix C: Chart 20**). This is a significant amount of resource potentially lost to the atmosphere. Since methane is considered a greenhouse gas, these emissions could also become an environmental issue. Mitigation measures should be investigated using knowledge gained from future modeling.

At this time, both policy and technical issues remain. Technical questions that need to be answered involve the nature and severity of potential impacts at the Basin rim outcrops of the Fruitland coal and potential ways to mitigate impacts. Why are the existing fires and gas seeps located where they are? How do they change over time and at what rate? What is the likelihood of additional seeps and fires and where are they most likely to occur? What additional or ancillary impacts, such as toxic gas emissions, slumping of overburden, forest fires, and loss of potentially economic resources need to be considered? Policy issues center on the multiple jurisdictions covering coalbed methane production versus land use at the outcrop. Who should study the technical issues listed above and how should the studies be funded? How should the results gained through these studies be incorporated into coalbed methane production management and ultimately incorporated into mitigation plans?

Parameters that may exacerbate impacts include the de-watering process with possible associated heating within the coals due to water table fluctuation. Increased gas seepage might be enabled by a lowering of the hydrostatic pressure on near-surface coals, thus lessening the effectiveness of a groundwater seal. Increased heating of the coals could lead to spontaneous combustion of the coal with associated toxic gas emissions (carbon monoxide, sulfur dioxide), slumping of overlying soils into burned-out voids, and loss of the minable near-surface coal resource. An increase in gas seep activity could be manifested by more vegetation loss, a proliferation of undesirable accumulation of combustible gas beneath dwellings constructed on the outcrop, and near-surface groundwater entrainment of methane. Coalbed de-watering has in specific instances been implicated as affecting the small number of domestic water wells located along the Fruitland outcrop and drilled directly into the coal seams.

To answer the above questions, more knowledge is needed concerning the hypothesized relationship between coalbed methane production and the outcrop. To what extent are seeps and coal fires naturally occurring phenomenon and to what extent and at what locations might these conditions be exacerbated by gas and water production in the basin. As correlations between down-dip production and the outcrop are established, then from what distance does a gas well affect the outcrop? Could that distance be variable, depending upon existing variations in geology or changing hydrologic conditions? Which faults or other geologic features act either as conduits for migration or as barriers to water and gas flow near the outcrop? Will continued coalbed dewatering have an impact on domestic water wells? Or have gas well construction and operation stipulations or remediation programs adequately addressed that issue? What types of mitigation are possible for each potential impact and how can they be tested for safety and effectiveness?

Mitigation To Date

In 1995, action was taken by the Bureau of Land Management with the support of the Southern Ute Indian Tribe to order the shut-in of five shallow (377'-753') producing gas wells in Valencia Canyon on the western flank of the Colorado portion of the Basin. These five Fruitland coal wells were converted to pressure monitoring wells by May 31, 1995, and function in that manner to date. (**See Appendix C: Chart 21.**)

In the Valencia Canyon Area during 1995-1996, previously thriving pinon and juniper trees oriented in a half-mile long by 50-foot wide swath and rooted in the coalbeds had met their demise. Subsequent monitoring results indicated extremely high methane concentration in the soils and a commensurate lack of oxygen required for root health. While no baseline data was available for soil gas in this area, it was deduced that the soil oxygen content necessary to support healthy trees had been recently compromised. An increase in methane micro-seepage had apparently been instrumental in the mortality of the trees over the preceding year as methane gas concentration in the soils overlying coal beds increased, displacing oxygen from the near-surface soils.

In the spring of 1997, a mitigation effort was inaugurated on the Southern Ute Indian Reservation by gas operators having nearby leaseholds and production (Enervest San Juan Operating, LLC, Cedar Ridge, LLC, and Hallwood Petroleum, Inc.). From two well pads located on the coal outcrop and separated by ¼ mile, four boreholes were spudded in the basal coal seams (**Figure 10**). Directional drilling allowed the boreholes to follow the respective coal seams down-dip. Oriented in a "w" pattern, the boreholes were drilled toward one another at depth. Shallow surface casing was set, with the remainder of the 500-1000 foot length being left open-hole. The intent was to capture methane in the subsurface prior to its migration to the surface. The collected gas was to be gathered for production or flared, depending on the economics.

Figure 10: Slant Wells at Valencia Canyon Gap

The southern pair of slant wells was drilled on a well pad adjacent to a soil gas collector approximately 85 feet long by 10 feet wide that had previously been erected over a segment of the basal coalbeds. This collector documented changes in flow at the outcrop showing steady declines from approximately 25 MCFD when the slant wells were drilled, to approximately 12 MCFD two years later **(Appendix C: Chart 22)**. While this mitigation attempt appears productive, the expenses incurred are considered too great to propose this remedial action on a larger scale. Clearly, other options must be investigated.

Pending Mitigation Efforts

During 1999, at least one operator on the Southern Ute Indian Reservation is exploring the feasibility of drilling a close-spaced network of vertical shallow mitigation wells intended to intercept outcrop-bound gas. Five gas recovery wells are being considered in the pilot project. Drilling locations would be approximately 1,000 feet apart at different depths in the basal Fruitland coalbed. A nearby low-pressure production pipeline would collect the gas. Compression would be applied to compensate for the extremely low anticipated production pressures. Reservoir conditions and computer modeling of the coal in the area have shown that developing a series of gas wells between the outcrop and basin-ward production gas wells should significantly reduce both the concentration and flow of methane gas at the outcrop. It is anticipated that these "picket fence" wells may recover more than 1 BCF of methane gas, per mile of outcrop – gas that would otherwise be lost to the atmosphere (Cox, 1999). Based upon the outcome of these test "picket fence" wells, projections indicate that numerous recovery gas wells might be drilled (based on 15 acre spacing) to adequately alleviate gas-seepage at the outcrop. Clearly this recovery approach would be benign to the environment and advantageous to production of the natural resource. Unfortunately, the preliminary studies do not indicate that the process would be driven by economic advantages. Also, closely spaced mitigation wells would only be feasible on the Southern Ute Indian Reservation, since this method would not be desirable in close proximity to residential developments on suburban lands along the northern Basin rim.

Other remedial action proposals may be formulated with the knowledge gained from results of the 3M project. However, no mitigation method currently identified is universally effective. All efforts considered to date are relatively expensive. Each carries implications of unresolved surface issues.

V. SUMMARY AND CONCLUSIONS

The San Juan Basin of southwestern Colorado has a long history of methane gas production. Several formations have been extensively developed for this resource. Since the 1980's, the Fruitland Formation's coalbed methane resource has been the main development target. These coalbeds are continuing to be developed with possible associated side effects manifested. Methane gas seeps, groundwater contamination, and coalbed fires have been discovered. These conditions may be exacerbated by continued production of water from the Fruitland coalbeds. Gas well water production could conceivably influence the potential for spontaneous combustion of near-surface coals due to the quantity of water withdrawn through pumping as compared to water level fluctuations attributable to normal seasonal variations as a product of precipitation and normal recharge alone. Fruitland water extraction could also play a part in drawing ambient air into the coalbeds, providing oxygen necessary for combustion and facilitating a resurgence of dormant (smoldering) coal fires.

Increases in methane content of soils overlying Fruitland coalbeds, lowering of water tables in domestic and water monitoring wells drilled into the basin rim coals, fires in Fruitland coalbeds, alignment of recently killed vegetation with underlying coal outcrops harboring high methane concentrations/depleted oxygen, and an apparent intensification of naturally occurring methane/hydrogen sulfide seeps have all been noticed since the early 1990's. These occurrences have been documented in a series of research reports and studies commissioned and conducted by regulatory agencies, the oil and gas industry and local government agencies. This time-span is concurrent with coalgas production from the Fruitland coalbeds in the San Juan Basin. In a recent report on environmental monitoring at the northern rim of the San Juan Basin (Oldaker, 1999), a correlation between bottom hole pressure decreases at Basin rim shut-in gas wells and water monitoring wells with down-dip water production from Fruitland coalgas wells was termed probable.

The COGCC 3M Project, which includes strategies to map, monitor and model significant environmental and reservoir effects of Fruitland coalbed development was launched in 1999, as a continuation of the efforts already inaugurated by the Southern Ute Indian Tribe and the Bureau of Land Management. The Colorado Oil and Gas Conservation Commission, the Southern Ute Indian Tribe, and the Bureau of Land Management's San Juan Field Office support this 3M Project. This effort to understand Basin dynamics related to CBM development is critical due to anticipated future CBM development. Human health and safety issues, vegetation losses, environmental degradation, and oxidation of coal reserves loom as potential associated consequences of intensified gas development.

New techniques to mitigate coalbed dewatering effects along the Basin rim where the Fruitland coalbeds are exposed may be initiated during 1999. Based upon the results of these and other preliminary pilot projects, the most effective mitigation techniques can be determined for future implementation as necessary.

Recent indications of environmental degradation at an increasing number of sites both on and off the Southern Ute Indian Reservation lead to the concern that these conditions may proliferate. The nature and severity of potential impacts of continued Fruitland coalgas production and additional gas wells drilled close to the San Juan Basin rim need to be more fully understood. Computer model projections and the results of proposed pilot mitigation efforts should enable well-founded regulatory responses to predictable events. Until projected effects are better understood, further approvals of infill drilling development in the Ignacio-Blanco Field, (particularly those in proximity to the outcrop) must be seriously scrutinized.

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APPENDIX A

Data Statistics: Statistical Analysis –Explanation and Charts

Mathematical Analyst

Bureau of Land Management

(Heine, 1999)

Soil Vapor Measurements in the Northern San Juan Basin: A Preliminary Statistical Analysis

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Scope

Beginning in 1995, the San Juan Field Office (SJFO) of the Bureau of Land Management has been collecting soil vapor data, at sites near the outcrop of the Fruitland Formation. At present, monitoring continues at approximately 184 sites on the Southern Ute Reservation and on 161 sites on private and public land outside the reservation.

In this preliminary report, we have applied three statistical tests for trend to the measurements of the following variables at each site:

- Methane as a percentage of Lower Explosive Limit (CH_4_LEL);
- Hydrogen sulfide (H_2S) , in parts per million (ppm);
- Oxygen(O_2) , as percentage by volume;
- Gas flow, in ml/min through 1/4" diameter soil vapor tube and 18gauge needle.

We report on those sites at which there appear to be either significant increases or significant decreases in the periods before and after July 1, 1998.

Summary

In all variables, but especially in CH_4_LEL and O_2, the number of Southern Ute Reservation sites showing significant trends was far more than could be explained by chance variations (assuming the readings at each site were statistically independent). Of the sites showing significant trends in CH_4_LEL, the number of upward trending sites dominated the number of downward trending sites in a much larger proportion than could be explained by chance (assuming independence at all sites with trend). The number of sites showing downward trends in O_2 significantly outnumbered those showing upward trends. (It is expected that O_2 will decrease as other gases increase.) The number of sites showing upward trends in H_2S dominated those showing downward trends, but the proportion was less dramatic. Although significantly many of the reservation sites showed trends in flow, no clear pattern emerged between upward trending and downward trending flows.

At off-reservation sites, only O_2 measurements showed more significant trends than could be explained by chance. At the sites with significant trends in O_2, increases significantly dominated decreases. This is the opposite of the pattern on the reservation sites; however, the off-reservation increases in oxygen seem to be relatively small in magnitude. Monitoring at these sites has been going on for a much shorter period, and it is not unreasonable to expect that the lack of other significant trends is merely an artifact of insufficient data.

Methodology

We started by plotting the measurements over time at several sites. It was visually apparent that some sites showed dramatic increases and others, dramatic decreases. To capture this phenomenon, we used three statistical tests:

1. T-test comparing mean measurement values before and after a fixed cutoff date;
2. Mann-Kendall nonparametric test for trend;
3. Sen's nonparametric estimate of slope.

1) T-test

At each site, for each variable, we computed the mean value before and after a fixed cutoff date and applied a (two-sided) T test for equality of means from populations of different variances. The cutoff date was the same for all sites.

The choice of cutoff date was, of course, important. We tried to choose a date that would minimize the effect of known seasonal variations. Soil vapor measurements are affected by both temperature and soil moisture, and thus fluctuate by seasons. We elected to compare changes before and after July 1, 1998—one year before the latest data available for this preliminary report. The hope is that by including at least one year of data in each population, the effect of seasonal variations would be minimized as much as possible. Some trial calculations convinced us that, in fact, the results described below are relatively insensitive to the choice of cutoff date.

At each site with at least two measurements before and two measurements after the cutoff date, we computed separately the number, the mean, and the variance of measurements before and after the cutoff date. Considering the measurements before and after the cutoff date as separate populations with unequal variance, we computed, using a two-sided T test, the probability of equal means.

Before applying the T test, adjustments were made to the data to compensate for a change in measuring instrument. For reasons explained below, it also seemed advisable to try applying the T test to the logarithm of one variable; however, this adjustment did not significantly affect the results.

2) Sen's nonparametric estimator

At each site, for each variable, we listed all the pairs of dates for which a measurement was available. For every pair of dates, we computed the slope in units per day as

$$\frac{reading2 - reading1}{date2 - date1} .$$

Sen's estimator is the median of all such slopes. We computed approximate two-sided 95% and 99% confidence intervals, using a variant of the procedure given in [Gilbert, 1987]. The procedure assumes approximate normality. We tried to ensure this by only computing the Sen's estimator for sites where ten or more observations were available. Our variant of Gilbert's procedure was to assume that all tied groups had size exactly two. The net effect of this assumption is conservative; some of the confidence intervals may be wider than necessary. On the other hand, the assumption is probably reasonable, since the precision of the instrument is high enough that three or more exactly identical readings at different times are unlikely.

Sen gives a numerical estimate of the amount of increase or decrease in units per day at a site. We recorded, but did not use this feature in the current study. We merely report the number of sites where the 99% and 95% Sen confidence intervals do not contain zero (i.e., the sites where there is a high probability of a trend).

3) Mann-Kendall test for trend

The Mann-Kendall statistic is similar to Sen's estimator. At each site, for each pair of dates, compute the slope as above, but only consider the sign of the slope:

$$\text{Sign of slope} = \begin{array}{rll} +1 & \text{if} & \text{reading2} > \text{reading1}; \\ 0 & \text{if} & \text{reading2} = \text{reading1}; \\ -1 & \text{if} & \text{reading2} < \text{reading1}. \end{array}$$

The Mann-Kendall statistic is the sum of all signs of slopes. Using a procedure in [Gilbert, 1987], we computed standardized scores and two-tailed confidence intervals for the Mann-Kendall number at each site. These standardized scores can be used to compute a chi-square test for homogeneity of trend across multiple sites; the latter test was actually of little use in this case since little spatial homogeneity was apparent. Computation of standardized scores assumes approximate normality, which, as in the Sen estimate, we attempted to ensure by only considering sites with ten or more measurements.

Results—Reservation Sites

Methane

There were 133 sites on the Southern Ute Reservation with enough data to permit analysis by the T-Test. At every significance level, there were many more sites showing change (both upward and downward trends) in measured CH_4 than could be explained by chance. For example, at the 95% level, 92 of the 133 sites showed a significant trend. The probability of this happening by chance, assuming that CH_4 levels at the sites were independent and fluctuating randomly, is microscopically small—less than 10^{-20}.

At every significance level, sites showing an increase outnumbered sites showing a decrease by a wide margin. At the 95% significance level, there were 61 sites with increasing CH_4 and 31 sites with decreasing CH_4. The probability of this happening by chance, if we expected half the sites to be increasing and half to be decreasing, would be about 0.001.

The tests using Sen's estimator and the Mann-Kendall statistic confirmed the results of the T-test, with even greater disparity between the numbers of increasing and decreasing sites.

Despite the predominance of upward-trending sites, the number of downward-trending sites on the reservation is also significant, and far more than can be explained by chance alone. Any explanation of soil vapor trends at these sites must account for the surprisingly large numbers of both upward and downward trending sites. Computing the chi-squared test for homogeneity of the Mann-Kendall statistics shows that the probability of a uniform trend across all sites is very nearly zero.

For reasons discussed in the next section, the T-test was repeated using the logarithm of the observed CH_4 levels in place of the observed CH_4, at both reservation and non-reservation sites. Results were almost identical. Results for CH_4 levels and their logarithms, at reservation sites, are summarized in Tables 1–3. The logarithmic transformation was not necessary for the Mann-Kendall and Sen tests, since these effectively consider only the direction and not the magnitude of changes.

Table 1. Summary of T-Test results, CH4_LEL for 133 sites on the Southern Ute Reservation.

Significance Level	U Number of Sites with Upward Trend	*D* Number of Sites with Downward Trend	*U+D* Number of Sites with Any Trend	Expected Number of Sites with Any Trend	Probability of *U* out of *U+D* Sites Increasing (see Note 1)	Probability of *U+D* Sites with Any Trend (see Note 2)
99.9%	32	5	37	0	3.71E-06	9.92E-79
99.0%	54	14	68	1	5.55E-07	3.82E-98
95.0%	61	31	92	7	1.16E-03	9.02E-87

Table 2. Summary of T-Test results, log(CH4_LEL) for 133 sites on the Southern Ute Reservation.

Significance Level	*U* Number of Sites with Upward Trend	*D* Number of Sites with Downward Trend	*U+D* Number of Sites with Any Trend	Expected Number of Sites with Any Trend	Probability of *U* out of *U+D* Sites Increasing (see Note 1)	Probability of *U+D* Sites with Any Trend (see Note 2)
99.9%	31	6	37	0	2.06E-05	9.92E-79
99.0%	56	7	63	1	6.82E-11	3.13E-88
95.0%	63	10	73	7	7.77E-11	2.04E-58

Table 3. Sen and Mann-Kendall statistics, CH4_LEL for 183 sites on the Southern Ute Reservation.

Significance Level	Sites with Positive Sen estimator	Sites with Negative Sen estimator	**Sites with Positive Mann-Kendall statistic**	Sites with Negative Mann-Kendall statistic
99.0%	55	12	52	7
95.0%	66	17	61	10

Chi-square estimate of homogeneity for the Mann-Kendall scores: less than 0.0001%

Oxygen

Of the 133 sites with sufficient data for the T-tests, there were many more sites showing change (both upward and downward trends) in measured O_2 than could be explained by chance. The number of sites showing significant downward trends outnumbered that showing significant upward trend. This conforms to the results for methane levels, since decreases in oxygen are expected to accompany increases in other gases such as methane. However, the figures in Tables 4–6 do not match exactly those in Tables 1–3. The relationship between decreasing oxygen and increasing methane could be confirmed by correlating the significance level of trend at each site.

Table 4. Summary of T-Test results, O_2 for 133 sites on the Southern Ute Reservation.

Significance Level	U Number of Sites with Upward Trend	***D*** Number of Sites with Downward Trend	***U+D*** Number of Sites with Any Trend	Expected Number of Sites with Any Trend	Probability of *D* out of *U+D* Sites Decreasing (see Note 3)	Probability of *U+D* Sites with Any Trend (see Note 2)
99.9%	6	21	27	0	0.003	1.08E-53
99.0%	16	31	47	1	0.020	1.02E-58
95.0%	34	41	75	7	0.244	3.59E-61

Table 5. Sen and Mann-Kendall statistics, O_2 for 183 sites on the Southern Ute Reservation.

Significance Level	Sites with Positive Sen estimator	Sites with Negative Sen estimator	**Sites with Positive Mann-Kendall statistic**	Sites with Negative Mann-Kendall statistic
99.0%	9	44	10	51
95.0%	11	60	17	65

Chi-square estimate of homogeneity for the Mann-Kendall scores: less than 0.0001%

Hydrogen Sulfide

There were 97 reservation sites with sufficient measurements of H_2S to compute T-Tests. The number showing significant trends was less dramatic, but still more than could be expected by chance. Of the sites showing significant trends, upward trends predominated, and the dominance was more than could be explained by chance. Results for H_2S trends at reservation sites are summarized in Table 4.

Table 6. Summary of T-Test results, H_2S for 97 sites on the Southern Ute Reservation.

Significance Level	U Number of Sites with Upward Trend	***D*** Number of Sites with Downward Trend	***U+D*** Number of Sites with Any Trend	Expected Number of Sites with Any Trend	Probability of *U* out of *U+D* Sites Increasing (see Note 1)	Probability of *U+D* Sites with Any Trend (see Note 2)
99.9%	3	0	3	0	0.125	1.37E-04
99.0%	7	0	7	1	0.008	5.85E-05
95.0%	10	2	12	5	0.019	3.33E-03

Flow

There were 133 reservation sites with sufficient measurements of vapor flow to compute T-Tests. Once again, the number showing significant trends was more than could be explained by chance. Of the sites with significant trends, neither upward-trending nor downward-trending sites show a clear predominance. Results for vapor flow at reservation sites are summarized in Tables 7–8.

Table 7. Summary of T-Test results, Vapor Flow for 133 sites on the Southern Ute Reservation.

Significance Level	U Number of Sites with Upward Trend	*D* Number of Sites with Downward Trend	*U+D* Number of Sites with Any Trend	Expected Number of Sites with Any Trend	Probability of *U* out of *U+D* Sites Increasing (see Note 1)	Probability of *U+D* Sites with Any Trend (see Note 2)
99.9%	2	1	3	0	0.875	3.48E-04
99.0%	6	5	11	1	0.726	1.23E-07
95.0%	10	21	31	7	0.035	5.62E-13

Table 8. Sen and Mann-Kendall statistics, Vapor Flow for 183 sites on the Southern Ute Reservation.

Significance Level	Sites with Positive Sen estimator	Sites with Negative Sen estimator	**Sites with Positive Mann-Kendall statistic**	Sites with Negative Mann-Kendall statistic
99.0%	15	0	22	0
95.0%	23	1	33	1

Chi-square estimate of homogeneity for the Mann-Kendall scores: less than 0.0001%

Results—Off Reservation Sites

Methane

Of the non-reservation sites, 147 had enough data to permit analysis with the T test. The available data does not show that the number of changing, increasing and decreasing sites is more than would be expected by chance. The Sen and Mann-Kendall tests give similar findings. The Mann-Kendall test does gives some evidence of homogeneity of trend across sites in this case; however, there is no evidence that this trend is anything but randomly fluctuating.

An important reason for lack of significance in the off-reservation sites appears to be that the latter have been monitored for a much shorter period of time, so that sample variances are much larger. This makes it more difficult for the set of readings at a site to pass a T-Test. Results for CH_4 levels at non-reservation sites are summarized in Tables 6 and 7.

Table 9. Summary of T-Test results, CH_4_LEL for 147 off-reservation sites.

Significance Level	Number of Sites with Upward Trend	Number of Sites with Downward Trend	Number of Sites with Any Trend	Expected Number of Sites with Any Trend
99.9%	0	0	0	0
99.0%	0	2	2	1
95.0%	0	2	2	7

Table 10. Summary of T-Test results, log(CH_4_LEL) for 147 off-reservation sites.

Significance Level	Number of Sites with Upward Trend	Number of Sites with Downward Trend	Number of Sites with Any Trend	Expected Number of Sites with Any Trend
99.9%	0	0	0	0
99.0%	0	0	0	1
95.0%	1	0	1	7

Table 11. Sen and Mann-Kendall statistics, CH_4_LEL for 147 sites off the Southern Ute Reservation.

Significance Level	Sites with Positive Sen estimator	Sites with Negative Sen estimator	**Sites with Positive Mann-Kendall statistic**	Sites with Negative Mann-Kendall statistic
99.0%	3	0	3	1
95.0%	9	1	7	4

Chi-square estimate of homogeneity for the Mann-Kendall scores: about 59%.

Oxygen

Oxygen was the only variable for which a statistically significant number of off-reservation sites showed either an upward or a downward trend. Of the sites that showed a trend, the sites with increasing oxygen levels showed a marked predominance over those with decreasing oxygen levels. This is unexpected, and contrasts with the results for the sites on the Ute Reservation. Results for O_2 trends at non-reservation sites are summarized in Table 8.

Table 12. Summary of T-Test results, O_2 for 147 off-reservation sites.

Significance Level	*U* Number of Sites with Upward Trend	*D* Number of Sites with Downward Trend	*U+D* Number of Sites with Any Trend	Expected Number of Sites with Any Trend	Probability of *U* out of *U+D* Sites Increasing (see Note 1)	Probability of *U+D* Sites with Any Trend (see Note 2)
99.9%	2	0	2	0	0.250	8.05E-03
99.0%	8	0	8	1	0.004	6.47E-05
95.0%	26	1	27	7	2.0E-07	2.33E-09

Table 13. Sen and Mann-Kendall statistics, O_2 for 147 sites off the Southern Ute Reservation.

Significance Level	Sites with Positive Sen estimator	Sites with Negative Sen estimator	**Sites with Positive Mann-Kendall statistic**	*Sites with Negative Mann-Kendall statistic*
99.0%	4	0	5	0
95.0%	19	5	19	8

Chi-square estimate of homogeneity for the Mann-Kendall scores: less than 0.0001%.

H2S and Vapor Flow

Very few sites in the off-reservation group showed any significant trends in these two variables. The information is summarized in the following tables.

Table 14. Summary of T-Test results, H_2S for 52 off-reservation sites.

Significance Level	Number of Sites with Upward Trend	Number of Sites with Downward Trend	Number of Sites with Any Trend	Expected Number of Sites with Any Trend
99.9%	0	0	0	0
99.0%	0	0	0	1
95.0%	1	0	1	7

Table 15. Summary of T-Test results, flow for 124 off-reservation sites.

Significance Level	Number of Sites with Upward Trend	Number of Sites with Downward Trend	Number of Sites with Any Trend	Expected Number of Sites with Any Trend
99.9%	0	0	0	0
99.0%	0	0	0	1
95.0%	1	0	1	7

Table 16. Sen and Mann-Kendall statistics, flow for 140 sites off the Southern Ute Reservation.

Significance Level	Sites with Positive Sen estimator	Sites with Negative Sen estimator	**Sites with Positive Mann-Kendall statistic**	Sites with Negative Mann-Kendall statistic
99.0%	0	0	0	0
95.0%	0	0	0	0

Chi-square estimate of homogeneity for the Mann-Kendall scores: 100%.

Notes on the Measurements

Methane (CH_4_LEL)

Before October 1, 1998, all reported readings of CH_4_LEL were obtained with a Drager Multi-Pak. This was replaced with an Industrial Scientific ATX-620 for all readings after October 31, 1998.

For readings of combustible gas, the Multi-Pak has a stated accuracy of +/- 4% LEL for readings below 40% LEL, and +/- 10% of reading for readings between 40% and 100% LEL. Readings above 200% LEL are out of range for the instrument and considered highly suspect. On the ATX-620, readings above one million PPM (more than 100% methane by volume) indicate the presence of ethane as well as methane.

The ATX-620 has a stated accuracy of +/- 20%, or one count if this is greater, over the range 0-100% LEL, and +/- 15%, or two counts if this is greater, over the range 500 to one million PPM. These accuracy figures apply to temperature variation between -15° C. and +40° C. At the calibration temperature of 20° C., accuracy for both the catalytic and infrared sensors is plus or minus 5%. Ground observers estimate that most readings were taken between -0° C. and 25° C, so that accuracy is somewhere between five and twenty percent. This information was not used in computing the statistics presented here, but may be useful to readers in evaluating the quality of the data.

During the month of October 1998, readings were taken with both instruments as a calibration check. The readings were identical in 43 of 71 cases. In all but one of the remaining 27 cases, the readings from the ATX-620 were higher. Over all 71 cases, the reading on the ATX-620 averaged about 13% higher than the reading on the Multi-Pak, with a standard error of about 17 percentage points. The discrepancy is not larger than could be expected by chance, but to be conservative, all methane LEL readings before November 1, 1998 were adjusted upward by ten percent.

The maximum published range for the Drager Multi-Pak is 100% of LEL. Reported measurements of greater than 200% were considered by field observers to be likely caused by sensor contamination and not a genuine reflection of soil vapor composition. Statistics were computed based on the measurements as reported, even though the real values might have been much higher. Almost exclusively, this affected measurements in the period before the cutoff date. It is possible, therefore, that at some of the sites with an apparent increase, the phenomenon might be an artifact caused by limitations of the measuring device. A refinement for a future version of this report will be to scan for and identify those sites with LEL readings greater than 100% before the cutoff date. It is our general impression, however, that only a small number of sites will be affected.

Logarithm of CH_4_LEL

The manufacturers' published accuracy standards for both the Multi-Pak and the ATX-620 quote accuracy as percentage of measured CH_4_LEL, rather than as an absolute number. Thus, higher readings are expected to have higher variance. This was confirmed in the process of computing the T statistics, when it was noticed that sample standard deviations had a strong linear relationship to sample means. In such situations it is common practice to even out variance by computing statistics on the logarithms of the original data. We followed this practice. Readings of zero percent of LEL were treated as having a logarithm of −1. The sets of increasing and decreasing sites computed by a T-test applied to the logarithm were substantially the same as those computed by a T-test on the data itself.

Oxygen (O_2)

Measured as percentage of gas by volume. Normal atmospheric gas is 20.9% Oxygen. Stated accuracy of the ATX-620 is +/- 0.5% at 20° C. Ground observers estimate that most readings were taken between 0° C. and 25° C.

Hydrogen Sulfide (H_2S)

Measured in parts per million. Stated accuracy of the ATX-620 is +/- 5% at 20° C. Ground observers estimate that most readings were taken between 0° C. and 25° C. An increase in H2S may be related to an increase in methane, since sulfur-reducing bacteria thrive in an anoxic environment, which could be created by a preponderance of methane stripping the soil of oxygen.

Vapor Flow

Measured in milliliters per minute through 1/4" diameter soil vapor tube and 18-gauge needle. Many sites have no measurable flow.

Conclusions and Further Work

The number of Ute Reservation sites with changes in methane levels is a phenomenon that needs explanation. Any such explanation needs to account for the significantly large number of sites with decreasing methane, as well as those at which methane is increasing. We have provided, in the Appendix to this report, a list of sites with significant changes. It is hoped that observers on the ground might be able to use these lists to help determine why some sites are increasing and others decreasing.

The off-reservation sites should continue to be monitored. Few trends are apparent in this study, but the sites in this area have only a third of the number of measurements of the reservation sites. The only trend that appeared was the surprising number of sites with increasing O_2 levels. The magnitude of the increases was relatively small, and the only site with significant decrease in O_2 had a relatively large decrease. The O_2 data should be analyzed to see whether taking logarithms is appropriate. Also, the site-by-site correlation between trends in O_2 and trends in CH_4 and other variables should be analyzed. We have taken the first step in this effort by making lists of these sites (in the Appendix.)

It would be satisfying to find a model in which some component of soil vapor measurement was a function of local climactic data, especially in this region where temperature and rainfall can vary dramatically between years as well as between seasons. This is complicated by the fact that little climactic data is available in the sparsely populated region of the soil vapor study.

Appendix

Tables 2–7 list the sites with significant increase and decrease in each of the measured variables for the T-test in the on-reservation and off-reservation groups. Explanations of the column headings are as follows:

- *n1* and *n2* are the number of observations before and after the cutoff date of July 1, 1998;
- *m1* and *m2* are the means of observations before and after the cutoff date;
- *Deltam* is the difference *m2-m1;*
- *v1* and *v2* are the sample variances;
- *Tval* is the T-statistic (difference in mean divided by the effective standard deviation);
- *Effective DF* is the effective degrees of freedom
- *Two-sided T* is the probability mass of the T distribution with *DF* degrees of freedom for ordinate values greater than *Tval*; i.e., the two-sided T statistic, or the probability that the observed change in mean might have occurred by chance.

The rows in each table are sorted in order of increasing probability; in other words, in order of decreasing significance.

Table 17. List of Ute Reservation Sites with significant increase in CH_4_LEL, sorted by significance. See the explanation of column headings in the first paragraph of the Appendix.

Site Number	n1	n2	m1	m2	Deltam	Tval	Effective DF	2-Sided T
93	30	13	8.07	28.04	19.97	5.63	18	0.00%
50	26	10	0.76	4.15	3.39	5.36	15	0.01%
284	3	13	223.30	568.28	344.98	5.39	12	0.02%
286	3	13	195.80	374.70	178.90	5.20	12	0.02%
277	15	13	67.39	238.41	171.01	4.27	24	0.03%
138	31	13	184.80	518.29	333.49	4.58	17	0.03%
235	30	13	286.99	1386.15	1099.16	5.00	13	0.03%
303	3	13	268.77	1704.99	1436.23	4.89	12	0.04%
230	27	11	1.83	316.32	314.48	5.23	10	0.04%
206	32	13	287.10	1306.75	1019.65	4.85	13	0.04%
304	3	13	244.93	1446.02	1201.08	4.83	12	0.04%
188	30	13	34.21	197.34	163.13	4.67	14	0.04%
282	5	13	265.32	1511.40	1246.08	4.68	12	0.05%
137	26	13	348.70	1376.89	1028.19	4.67	12	0.05%
274	16	13	347.26	1343.88	996.62	4.54	13	0.06%
306	3	13	182.97	368.05	185.09	4.62	12	0.06%
234	32	13	366.71	1478.37	1111.66	4.61	12	0.06%
283	6	13	192.13	442.26	250.13	4.59	12	0.06%
23	32	13	368.47	1378.68	1010.21	4.51	12	0.07%
5	31	13	382.55	1508.72	1126.17	4.48	12	0.08%
233	32	13	377.47	1289.76	912.29	4.48	12	0.08%
275	16	13	386.38	1541.33	1154.96	4.46	13	0.08%
217	30	13	365.24	1324.26	959.02	4.45	13	0.08%
25	32	13	378.88	1275.92	897.04	4.44	12	0.08%
88	26	13	371.38	1594.32	1222.95	4.43	12	0.08%
100	30	13	377.89	1425.61	1047.72	4.40	12	0.09%
171	31	13	301.40	1125.52	824.12	4.39	13	0.09%
196	30	13	237.27	1335.35	1098.08	4.38	13	0.09%
108	26	13	373.07	1432.05	1058.98	4.36	12	0.09%
166	26	13	387.58	1510.53	1122.95	4.36	12	0.09%
199	32	13	354.37	1206.51	852.14	4.35	13	0.09%
236	30	13	371.10	1547.77	1176.67	4.33	12	0.10%
9	31	13	361.19	1487.58	1126.39	4.31	12	0.10%
232	32	13	371.94	1438.25	1066.32	4.28	12	0.11%
19	32	13	372.25	1573.66	1201.41	4.28	12	0.11%
265	24	13	376.84	1322.01	945.17	4.25	13	0.11%
96	26	13	383.56	1194.87	811.31	4.24	13	0.11%
237	30	13	374.88	1311.75	936.87	4.23	12	0.12%
24	32	13	365.58	1367.96	1002.38	4.21	12	0.12%

Site Number	n1	n2	m1	m2	Deltam	Tval	Effective DF	2-Sided T
271	17	13	374.71	1531.50	1156.79	4.16	13	0.13%
287	3	13	14.30	67.47	53.17	4.08	12	0.15%
240	26	13	366.85	1082.19	715.34	4.03	13	0.17%
225	30	13	389.44	1208.53	819.09	3.89	13	0.21%
211	30	13	400.29	916.60	516.31	3.78	13	0.23%
163	26	13	396.13	1243.02	846.90	3.69	13	0.31%
302	3	13	252.63	813.87	561.24	3.61	12	0.36%
219	30	13	39.16	128.04	88.88	3.45	15	0.36%
270	16	13	212.09	765.10	553.01	3.43	14	0.45%
278	17	12	467.05	1433.83	966.78	3.32	15	0.50%
285	3	13	180.40	316.29	135.89	3.41	13	0.51%
153	31	13	2.16	6.31	4.14	3.10	23	0.52%
195	30	13	39.75	181.78	142.03	3.37	13	0.55%
124	31	13	25.48	63.33	37.85	3.11	16	0.72%
94	32	13	283.25	438.23	154.98	2.85	27	0.83%
208	30	13	108.42	157.47	49.05	2.70	22	1.33%
273	17	13	317.25	700.49	383.24	2.62	15	1.95%
288	4	13	247.78	447.63	199.86	2.44	12	3.13%
205	29	13	4.29	18.19	13.91	2.30	15	3.76%
167	31	13	235.08	325.78	90.70	2.10	43	4.16%
250	26	13	345.95	776.22	430.27	2.25	13	4.27%
223	30	13	30.18	61.17	30.99	2.17	15	4.66%

Table 18. List of Ute Reservation Sites with significant decrease in CH4_LEL, sorted by significance. See the explanation of column headings in the first paragraph of the Appendix.

Site Number	n1	n2	m1	m2	deltam	Tval	Effective DF	2-Sided T
75	32	13	2.75	0.17	-2.58	-4.68	37	0.00%
218	30	13	156.75	1.13	-155.62	-4.16	29	0.03%
229	29	13	169.29	24.31	-144.98	-3.99	30	0.04%
207	30	13	100.36	4.55	-95.81	-3.82	30	0.07%
6	31	13	52.27	1.78	-50.48	-3.77	30	0.07%
215	30	13	10.01	0.25	-9.76	-3.39	29	0.20%
248	20	5	1.32	0.00	-1.32	-3.56	19	0.21%
213	24	5	2.61	0.00	-2.61	-3.36	23	0.27%
239	20	5	1.10	0.00	-1.10	-3.34	19	0.34%
268	19	13	131.77	43.88	-87.88	-3.17	24	0.43%
216	30	13	6.31	0.00	-6.31	-2.96	29	0.61%
74	32	13	20.66	0.32	-20.34	-2.88	31	0.71%
252	20	5	0.94	0.00	-0.94	-2.90	19	0.91%
241	20	5	0.88	0.00	-0.88	-2.89	19	0.95%
68	32	13	23.07	3.78	-19.29	-2.73	32	1.02%
111	20	5	1.60	0.20	-1.40	-2.74	24	1.15%
214	25	5	0.79	0.00	-0.79	-2.69	24	1.31%
259	20	5	0.66	0.00	-0.66	-2.70	19	1.43%
256	20	6	1.05	0.17	-0.88	-2.47	26	2.06%
180	26	13	4.02	0.95	-3.07	-2.38	30	2.43%
238	21	5	0.89	0.00	-0.89	-2.36	20	2.83%
262	20	5	0.61	0.00	-0.61	-2.34	19	3.02%
243	20	5	0.55	0.00	-0.55	-2.24	19	3.75%
249	20	5	1.82	0.00	-1.82	-2.21	19	3.99%
301	4	11	28.88	16.92	-11.96	-2.28	12	4.13%
224	23	5	6.84	0.20	-6.64	-2.14	22	4.39%
76	26	5	2.28	0.64	-1.64	-2.11	28	4.47%
255	20	5	0.61	0.00	-0.61	-2.15	19	4.50%
222	24	5	0.92	0.00	-0.92	-2.12	23	4.51%
246	20	5	0.55	0.00	-0.55	-2.13	19	4.67%
260	20	5	0.39	0.00	-0.39	-2.10	19	4.93%
242	21	5	1.05	0.20	-0.85	-1.96	26	6.11%

Table 19. List of Ute Reservation Sites with significant increase in logarithm of CH4_LEL, sorted by significance. See the explanation of column headings in the first paragraph of the Appendix.

Site Number	n1	n2	m1	m2	deltam	Tval	Effective DF	2-Sided T
230	12	11	1.00	5.34	4.34	10.34	18	0.00%
124	30	12	2.66	4.06	1.40	5.22	40	0.00%
196	30	13	4.83	6.82	1.99	5.51	29	0.00%
93	23	13	1.92	3.19	1.27	5.27	36	0.00%
287	3	13	2.56	3.95	1.39	6.27	15	0.00%
206	32	13	5.31	6.85	1.55	5.13	21	0.01%
235	28	13	5.29	6.91	1.62	4.63	31	0.01%
138	29	13	4.46	6.10	1.64	4.44	38	0.01%
219	25	13	3.19	4.59	1.40	4.47	37	0.01%
171	31	13	5.37	6.73	1.36	4.77	23	0.01%
284	3	13	5.31	6.20	0.89	5.78	12	0.01%
286	3	13	5.18	5.83	0.65	5.74	13	0.01%
304	3	13	5.39	6.92	1.52	5.01	15	0.02%
283	6	13	5.16	5.95	0.79	5.14	12	0.02%
282	5	13	5.49	6.94	1.46	5.08	12	0.03%
188	20	13	3.34	4.94	1.60	4.08	31	0.03%
303	3	13	5.50	7.04	1.54	5.01	12	0.03%
306	3	13	5.11	5.79	0.67	4.92	13	0.04%
208	30	13	4.44	4.97	0.53	3.79	43	0.05%
217	30	13	5.69	6.88	1.19	4.31	16	0.05%
137	26	13	5.68	6.90	1.22	4.41	15	0.06%
274	16	13	5.54	6.87	1.32	3.92	24	0.06%
199	32	13	5.68	6.80	1.11	4.25	15	0.07%
94	32	13	5.27	5.98	0.71	3.64	45	0.07%
195	30	13	3.21	4.68	1.47	3.93	21	0.08%
167	31	13	4.68	5.72	1.04	3.66	35	0.08%
277	13	13	3.28	5.35	2.07	4.30	14	0.09%
88	25	13	5.79	7.01	1.22	4.17	14	0.09%
100	30	13	5.75	6.93	1.18	4.17	15	0.09%
9	31	13	5.71	6.94	1.23	4.24	14	0.10%
302	3	13	5.44	6.41	0.97	4.33	12	0.10%
96	26	13	5.74	6.79	1.06	3.95	17	0.10%
265	24	13	5.76	6.87	1.11	4.12	15	0.10%
24	32	13	5.75	6.89	1.14	4.18	13	0.11%
166	26	13	5.78	6.97	1.18	4.09	14	0.11%
5	31	13	5.78	6.97	1.19	4.14	14	0.12%
108	26	13	5.73	6.91	1.18	4.00	15	0.12%
271	17	13	5.73	6.95	1.22	3.92	16	0.12%
240	26	13	5.67	6.70	1.02	3.75	20	0.14%
234	32	13	5.75	6.94	1.18	4.04	13	0.14%
19	32	13	5.76	6.97	1.21	4.04	13	0.14%
236	30	13	5.70	6.95	1.25	3.90	16	0.14%
275	16	13	5.76	6.97	1.21	3.84	17	0.14%
233	32	13	5.77	6.85	1.08	4.02	14	0.15%
232	32	13	5.76	6.91	1.15	3.96	13	0.16%
25	32	13	5.78	6.84	1.06	3.95	14	0.17%
225	30	13	5.80	6.79	0.99	3.84	14	0.18%
237	30	13	5.77	6.84	1.07	3.85	14	0.20%
23	32	13	5.75	6.87	1.12	3.82	13	0.21%
163	26	13	5.80	6.78	0.99	3.58	15	0.30%
211	30	13	5.81	6.59	0.77	3.39	16	0.40%
221	26	10	1.49	3.22	1.73	3.22	15	0.57%
145	26	12	5.70	6.70	1.00	3.31	12	0.63%
278	17	12	5.81	6.88	1.07	3.09	19	0.63%
288	4	13	5.42	5.91	0.50	3.13	13	0.86%
273	17	13	5.40	6.27	0.86	2.80	30	0.90%
285	3	13	5.10	5.59	0.49	2.88	13	1.38%
223	30	13	2.87	3.72	0.85	2.62	27	1.45%
270	15	13	4.43	6.11	1.67	2.53	25	1.83%
244	26	13	2.90	3.46	0.57	2.41	30	2.27%
115	31	13	4.49	5.34	0.85	2.32	40	2.58%

Site Number	n1	n2	m1	m2	deltam	Tval	Effective DF	2-Sided T
220	30	13	3.09	3.60	0.51	2.17	43	3.59%
172	31	13	2.20	3.17	0.96	2.16	17	4.64%

Table 20. List of Ute Reservation Sites with significant decrease in logarithm of CH4_LEL, sorted by significance. See the explanation of column headings in the first paragraph of the Appendix.

Site Number	n1	n2	m1	m2	deltam	Tval	Effective DF	2-Sided T
218	24	8	3.85	0.52	-3.33	-7.19	26	0.00%
6	21	8	3.40	0.87	-2.53	-5.92	29	0.00%
74	25	3	2.37	0.23	-2.14	-6.18	14	0.00%
103	16	6	1.74	0.23	-1.51	-5.01	22	0.01%
229	29	13	4.49	2.60	-1.89	-4.75	21	0.01%
68	28	12	2.41	1.17	-1.25	-4.26	37	0.01%
215	11	2	3.03	0.35	-2.69	-6.62	3	0.70%
231	23	10	1.56	0.92	-0.63	-2.64	32	1.28%
180	15	6	1.47	0.53	-0.94	-2.77	16	1.44%
268	19	13	4.30	3.40	-0.90	-2.43	32	2.13%

Table 21. List of Ute Reservation sites with significant increases in O2. sorted by significance. See the explanation of column headings in the first paragraph of the Appendix.

FieldNo	n1	n2	m1	m2	deltam	Tval	DF	t2
218	30	13	15.04	18.74	3.70	6.98	33	0.00%
245	22	13	20.27	20.75	0.49	6.02	35	0.00%
216	30	13	19.51	20.30	0.79	4.96	40	0.00%
207	29	13	17.98	20.04	2.06	4.52	41	0.01%
261	20	5	19.94	20.58	0.65	4.25	25	0.03%
74	32	13	19.74	20.49	0.75	3.68	37	0.08%
254	20	5	20.13	20.74	0.61	4.59	8	0.18%
224	23	5	20.03	20.54	0.51	3.44	28	0.19%
103	31	12	20.11	20.57	0.46	3.31	42	0.19%
229	29	13	16.71	19.13	2.42	3.31	36	0.22%
109	26	12	19.74	20.23	0.49	3.26	34	0.25%
262	20	5	18.58	20.12	1.54	3.34	25	0.28%
301	4	12	16.38	19.43	3.06	3.98	9	0.32%
246	20	5	19.99	20.48	0.49	3.11	25	0.48%
228	24	5	20.05	20.68	0.63	3.36	14	0.51%
6	31	13	19.40	20.12	0.72	2.80	34	0.84%
215	30	13	20.06	20.38	0.31	2.70	41	1.01%
255	20	5	20.16	20.64	0.48	3.20	10	1.09%
180	26	13	19.27	19.89	0.62	2.66	36	1.16%
239	20	5	20.18	20.70	0.52	2.99	12	1.23%
256	20	6	20.12	20.57	0.45	2.63	24	1.45%
226	25	5	20.06	20.56	0.50	2.69	17	1.54%
257	20	5	20.15	20.62	0.48	2.94	10	1.65%
220	30	13	19.18	20.15	0.97	2.52	33	1.67%
231	30	13	19.80	20.35	0.55	2.47	42	1.78%
242	21	5	20.33	20.72	0.39	2.68	15	1.80%
127	31	6	19.95	20.38	0.43	2.66	12	2.09%
44	27	5	19.99	20.48	0.49	2.67	12	2.17%
134	31	13	18.28	19.59	1.31	2.38	33	2.37%
241	20	5	20.07	20.48	0.41	2.35	13	3.66%
99	31	13	20.03	20.33	0.30	2.13	43	3.89%
76	26	5	20.29	20.68	0.39	2.14	31	4.03%
266	24	13	12.78	16.78	4.00	2.10	30	4.50%
68	32	13	19.31	20.01	0.70	2.06	37	4.65%

Table 22. List of Ute Reservation sites with significant decreases in O2, sorted by significance level. See the explanation of column headings in the first paragraph of the Appendix.

Site Number	n1	n2	m1	m2	Deltam	Tval	DF	t2
196	30	13	10.87	2.60	-8.27	-6.86	43	0.00%
206	32	13	13.02	4.72	-8.30	-6.75	37	0.00%
171	31	13	15.90	7.98	-7.92	-7.32	19	0.00%
199	32	13	8.14	2.35	-5.80	-5.36	41	0.00%
278	17	12	5.12	1.16	-3.97	-5.81	24	0.00%
145	26	13	5.29	1.75	-3.54	-5.25	34	0.00%
172	31	13	18.64	15.83	-2.81	-5.97	20	0.00%
9	31	13	4.29	1.28	-3.01	-4.82	37	0.00%
274	16	13	10.34	4.08	-6.27	-4.85	28	0.00%
94	32	13	16.76	14.90	-1.86	-4.37	35	0.01%
230	27	11	19.95	15.94	-4.02	-5.99	11	0.01%
138	31	13	17.70	14.69	-3.01	-4.57	21	0.02%
270	16	13	10.43	2.50	-7.93	-4.64	19	0.02%
233	32	13	4.23	1.30	-2.93	-4.01	45	0.02%
96	26	13	10.39	5.52	-4.87	-4.18	23	0.04%
268	19	13	14.72	10.87	-3.85	-3.97	32	0.04%
100	30	13	3.96	1.22	-2.74	-3.82	43	0.04%
235	30	13	11.27	4.05	-7.22	-3.92	33	0.04%
195	30	13	19.50	16.85	-2.65	-4.32	17	0.05%
219	30	13	19.40	18.55	-0.86	-3.87	27	0.06%
303	3	13	2.90	1.18	-1.72	-4.18	14	0.09%
137	26	13	3.69	1.15	-2.54	-3.53	34	0.13%
166	26	13	3.83	1.15	-2.68	-3.37	35	0.19%
194	24	9	19.50	18.17	-1.34	-3.63	12	0.35%
25	32	13	4.86	1.88	-2.99	-3.13	31	0.38%
5	31	13	3.52	1.42	-2.11	-3.11	28	0.42%
188	30	13	18.78	17.48	-1.30	-3.25	17	0.47%
277	15	13	16.64	14.25	-2.39	-3.20	20	0.47%
287	3	13	19.17	16.45	-2.71	-3.20	16	0.59%
236	30	13	3.12	1.24	-1.88	-2.95	31	0.61%
24	32	13	3.41	1.48	-1.93	-2.89	32	0.70%
250	26	13	14.76	10.32	-4.43	-2.96	15	1.03%
211	30	13	12.24	9.70	-2.54	-2.68	23	1.34%
237	30	13	2.80	1.15	-1.65	-2.56	43	1.43%
217	30	13	6.81	3.76	-3.06	-2.60	27	1.49%
265	24	13	3.75	1.45	-2.30	-2.56	35	1.49%
234	32	13	3.37	1.43	-1.93	-2.59	25	1.58%
153	31	13	19.96	18.11	-1.86	-2.49	13	2.82%
275	16	13	3.58	1.74	-1.84	-2.18	29	3.78%
167	31	13	16.49	15.53	-0.96	-2.10	44	4.13%
271	17	13	3.37	1.67	-1.70	-2.08	25	4.76%

Table 23. List of Ute Reservation sites with significant increases in H2S, sorted by significance level. See the explanation of column headings in the first paragraph of the Appendix.

FieldNo	n1	n2	m1	m2	Deltam	Tval	DF	t2
199	32	13	47.41	779.77	732.36	8.10	13	0.00%
265	24	13	0.96	4.08	3.12	5.28	20	0.00%
303	3	13	95.67	475.62	379.95	5.35	12	0.02%
306	3	13	0.67	5.77	5.10	3.99	16	0.12%
24	32	13	10.91	18.62	7.71	3.65	20	0.16%
278	17	12	0.29	3.58	3.29	3.81	13	0.25%
9	31	13	294.06	557.62	263.55	3.06	19	0.68%
235	30	13	3.00	6.00	3.00	2.39	39	2.19%
124	31	13	0.23	1.54	1.31	2.29	14	3.79%
286	3	13	0.00	4.77	4.77	2.24	12	4.47%

Table 24. List of Ute Reservation sites with significant decreases in H2S, sorted by significance level. See the explanation of column headings in the first paragraph of the Appendix.

FieldNo	n1	n2	m1	m2	deltam	Tval	DF	t2
23	32	13	36.88	21.46	-15.41	-2.35	38	2.41%
138	31	13	2.10	0.00	-2.10	-2.08	30	4.63%

Table 25. List of Ute Reservation sites with significant increases in flow, sorted by significance level. See the explanation of column headings in the first paragraph of the Appendix.

FieldNo	n1	n2	M1	M2	deltam	Tval	DF	t2
137	24	13	1.80	4.66	2.85	3.75	36	0.06%
225	28	13	91.61	191.54	99.93	3.71	34	0.07%
265	24	13	0.64	1.35	0.71	3.41	35	0.16%
100	28	13	4.65	8.30	3.65	2.95	40	0.54%
96	25	13	0.32	0.65	0.33	2.91	37	0.61%
88	25	13	5.07	12.10	7.03	2.96	20	0.81%
108	25	13	10.88	44.44	33.56	2.92	17	1.00%
217	28	13	1.55	2.43	0.88	2.56	37	1.49%
275	15	13	1.69	3.25	1.56	2.25	28	3.26%
5	27	13	3.03	4.78	1.75	2.06	39	4.62%

Table 26. List of Ute Reservation sites with significant decreases in flow, sorted by significance level. See the explanation of column headings in the first paragraph of the Appendix.

FieldNo	n1	n2	m1	m2	deltam	Tval	DF	t2
306	3	13	1.38	0.74	-0.64	-7.81	16	0.00%
115	27	13	0.15	0.02	-0.13	-3.45	32	0.16%
124	27	13	0.06	0.00	-0.05	-3.33	27	0.26%
113	27	13	0.12	0.00	-0.12	-3.01	26	0.57%
229	28	13	0.13	0.00	-0.13	-2.93	27	0.67%
214	23	5	0.03	0.00	-0.03	-2.73	22	1.23%
134	27	13	0.07	0.00	-0.07	-2.68	26	1.27%
75	28	13	0.03	0.00	-0.03	-2.61	28	1.47%
220	27	13	0.09	0.00	-0.09	-2.51	26	1.85%
288	4	13	0.13	0.03	-0.11	-3.05	7	1.85%
71	23	5	0.04	0.00	-0.04	-2.50	22	2.03%
224	20	5	0.03	0.00	-0.03	-2.51	19	2.15%
152	24	13	0.07	0.00	-0.07	-2.47	23	2.15%
66	27	12	0.05	0.00	-0.05	-2.31	26	2.95%
255	20	5	0.03	0.00	-0.03	-2.30	19	3.28%
279	16	13	0.09	0.01	-0.08	-2.33	15	3.41%
218	28	13	0.15	0.04	-0.11	-2.20	34	3.46%
268	19	12	0.12	0.00	-0.12	-2.27	18	3.54%
153	27	13	0.04	0.00	-0.04	-2.17	26	3.93%
266	23	13	0.14	0.05	-0.09	-2.12	31	4.26%
210	27	13	0.02	0.00	-0.02	-2.06	26	4.96%

Table 27. List of off-reservation Sites with significant decrease in CH4_LEL, sorted by significance. See the explanation of column headings in the first paragraph of the Appendix.

Site Number	n1	n2	m1	m2	Deltam	Tval	Effective DF	2-Sided T
152	6	5	33.92	0.00	-33.92	-6.15	5	0.17%
151	6	5	12.10	0.00	-12.10	-4.18	5	0.87%

Table 28. List of off-reservation sites with significant increase in O2, sorted by significance. See the explanation of column headings in the first paragraph of the Appendix.

FieldNo	n1	n2	m1	m2	deltam	Tval	DF	t2
152	6	5	18.6667	20.8400	2.1733	8.7018	6	0.01%
121	6	6	19.3667	20.4667	1.1000	5.0442	11	0.04%
149	6	4	19.3333	20.2750	0.9417	4.3714	8	0.24%
143	5	5	19.4800	20.4400	0.9600	5.2063	5	0.34%
151	6	5	19.2167	20.5600	1.3433	3.9349	6	0.77%
144	6	5	19.2500	20.4200	1.1700	3.6773	7	0.79%
140	6	3	19.7333	20.8000	1.0667	3.8084	7	0.89%
103	6	6	19.5500	20.5000	0.9500	3.1814	10	0.98%
135	6	6	19.2500	20.2000	0.9500	3.0582	12	1.09%
157	6	4	19.8500	20.8000	0.9500	3.9278	6	1.11%
105	6	6	19.6500	20.4167	0.7667	2.9521	10	1.62%
139	6	5	19.6833	20.9000	1.2167	3.4512	5	1.82%
141	6	3	19.5167	20.5667	1.0500	2.9574	9	1.82%
142	6	5	19.5500	20.5600	1.0100	2.9557	9	1.83%
115	6	6	18.0667	19.4667	1.4000	2.6932	10	2.26%
134	5	6	19.1000	20.2500	1.1500	3.5184	5	2.45%
118	6	6	18.7667	19.8667	1.1000	2.7367	7	2.91%
122	6	6	19.7333	20.6167	0.8833	2.6790	7	3.16%
119	6	6	18.7333	19.7333	1.0000	2.5355	10	3.19%
132	6	6	19.7333	20.6667	0.9333	2.7456	6	3.35%
153	5	5	19.7800	20.5600	0.7800	2.5174	9	3.60%
137	5	3	19.6200	20.6000	0.9800	2.6899	6	3.61%
147	6	6	19.5000	20.3333	0.8333	2.3560	12	3.81%
148	6	5	19.4167	20.0800	0.6633	2.3549	10	4.30%
104	6	6	19.3333	20.1167	0.7833	2.2734	12	4.40%
159	6	5	19.4833	20.3400	0.8567	2.3355	9	4.78%

Table 29. List of off-reservation sites with significant decrease in O2. See the explanation of column headings in the first paragraph of the Appendix.

FieldNo	n1	n2	m1	m2	deltam	Tval	DF	t2
23	6	6	13.6000	8.4000	-5.2000	-2.3333	10	4.18%

Table 30. List of off-reservation sites with significant increase in H2S. See the explanation of column headings in the first paragraph of the Appendix.

FieldNo	n1	n2	m1	M2	deltam	Tval	DF	t2
34	6	6	1.6667	11.1667	9.5000	2.6900	6	3.61%

Notes

1) Probability that *U* or more upward trending sites occur in a random selection of size *U+D*, assuming that direction of trend at each site is independent, and that upward trending and downward trending sites are equally likely.

2) Probability that *U+D* or more of the sites would show trends at the given significance level, assuming that the measurements at each site are independent and approximately normally distributed.

3) Probability that *D* or more downward trending sites occur in a random selection of size *U+D*, assuming that direction of trend at each site is independent, and that upward trending and downward trending sites are equally likely.

Reference

[Gilbert, 1987]. Richard O. Gilbert, *Statistical Methods for Environmental Pollution Monitoring.* New York: Van Nostrand Reinhold.

APPENDIX B

Maps and Cross-Sections: 1

SAN JUAN BASIN

Showing location in Colorado and New Mexico

(Fassett, 1971)

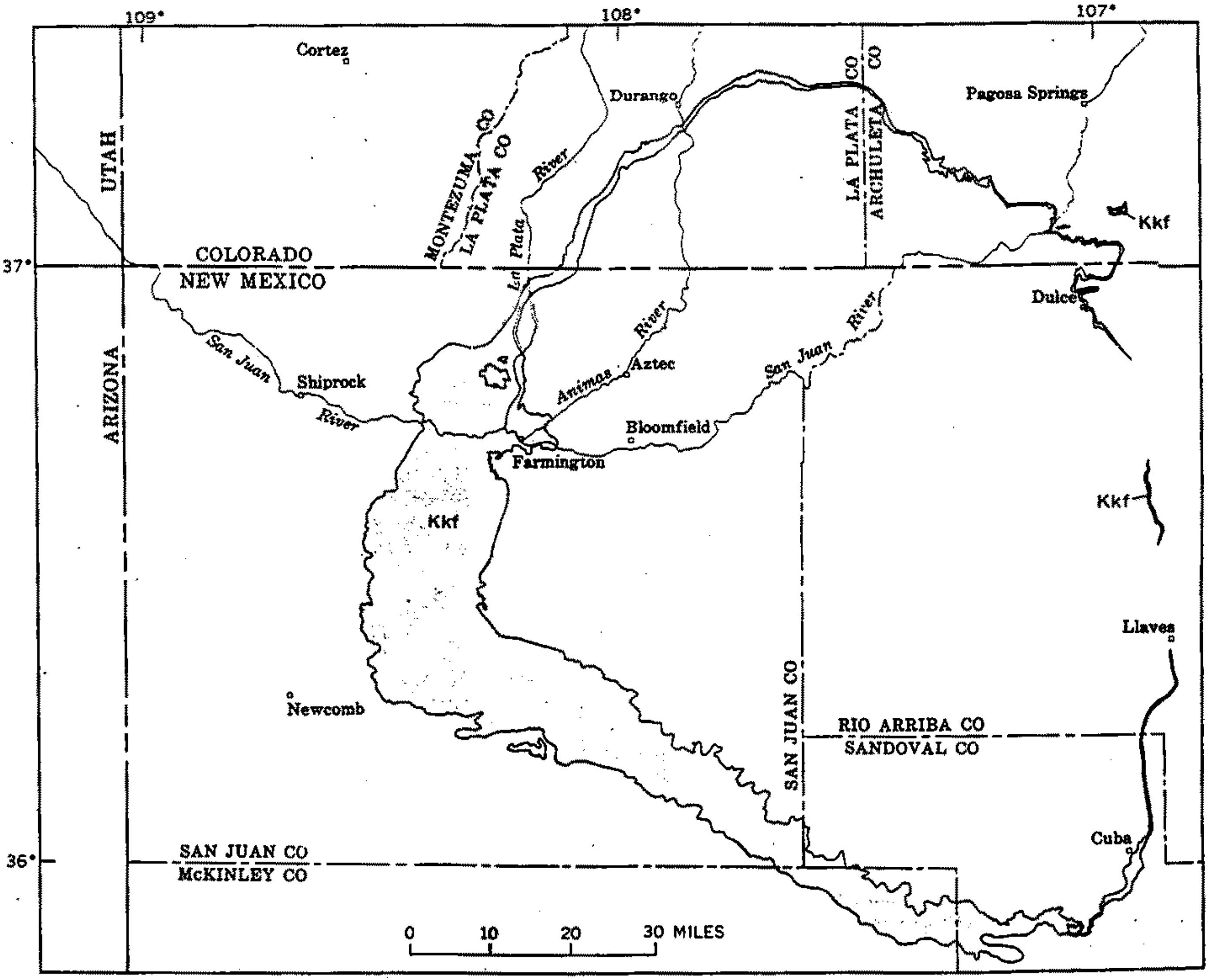


FIGURE 1.—Index map showing the location of the San Juan Basin. Kkf, Fruitland Formation and Kirtland Shale; outcrop is shaded.

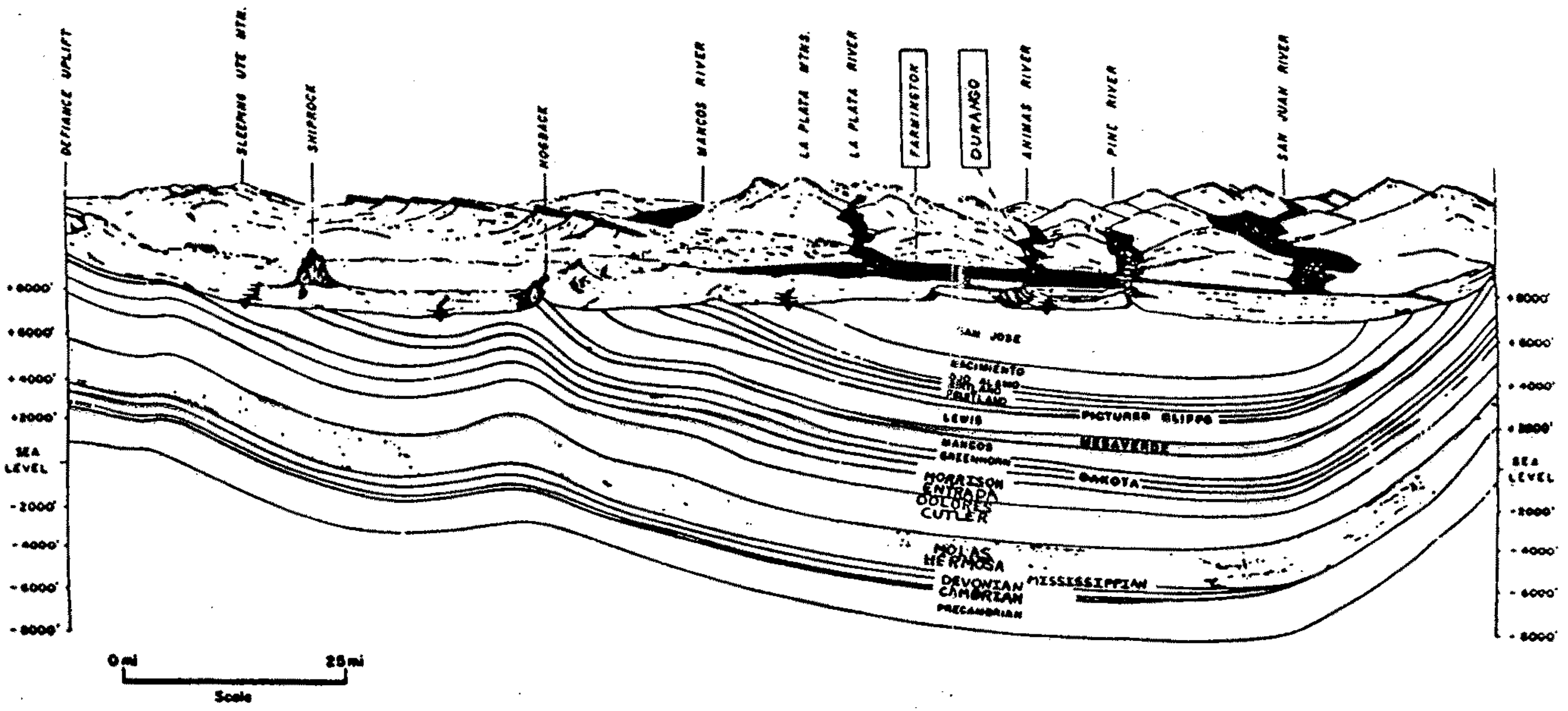
APPENDIX B

Maps and Cross-Sections: 2

SAN JUAN BASIN

Cross-Section showing Hogback Monocline

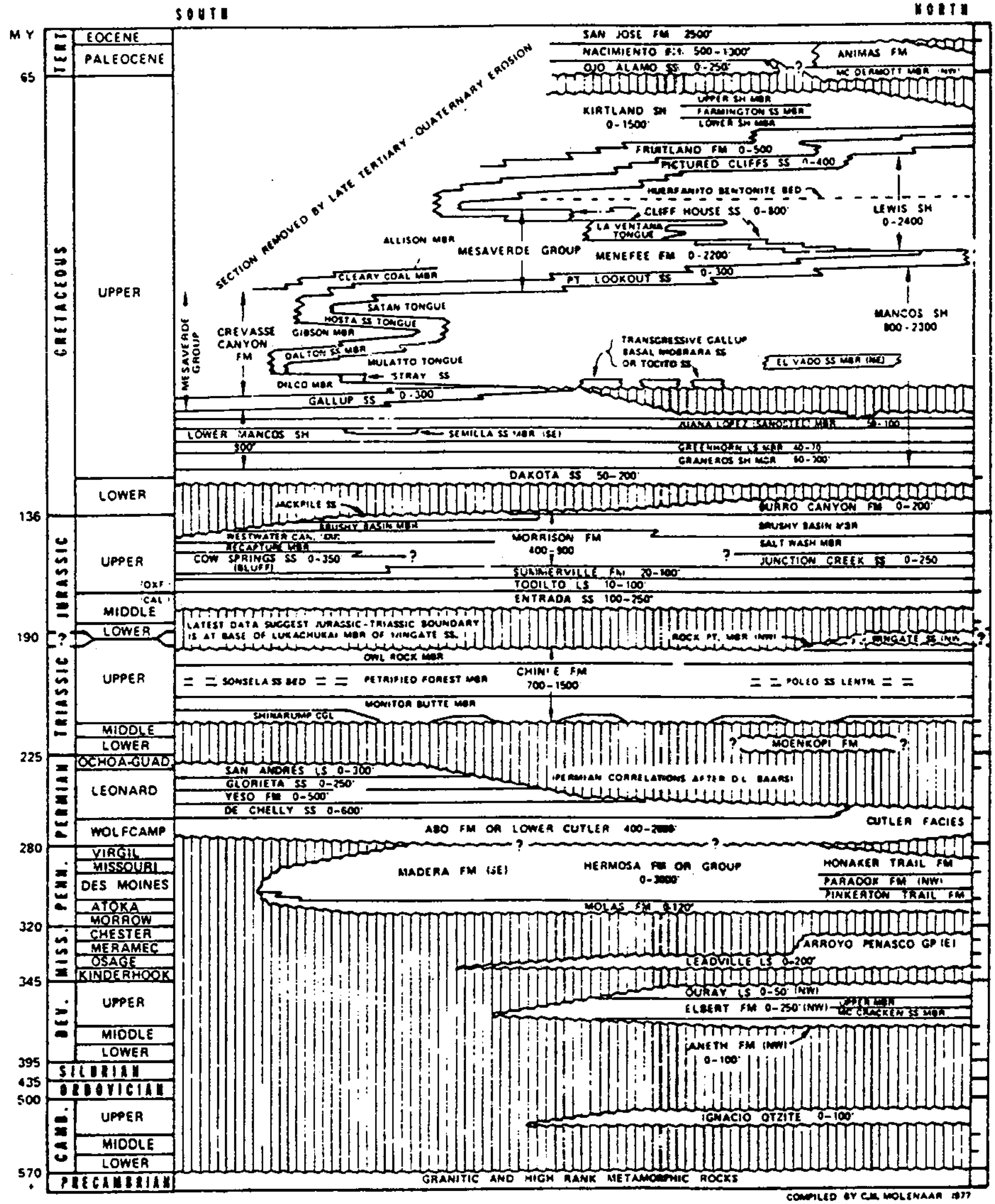
(Chafin, 1994 after Kelly, 1951)



DIAGRAMMATIC CROSS SECTION OF THE SAN JUAN BASIN

EXHIBIT 5

TIME-STRATIGRAPHIC NOMENCLATURE CHART
(SAN JUAN BASIN)



COMPILED BY C.M. MOLENAAR 1977

APPENDIX B

Maps and Cross-Sections: 4

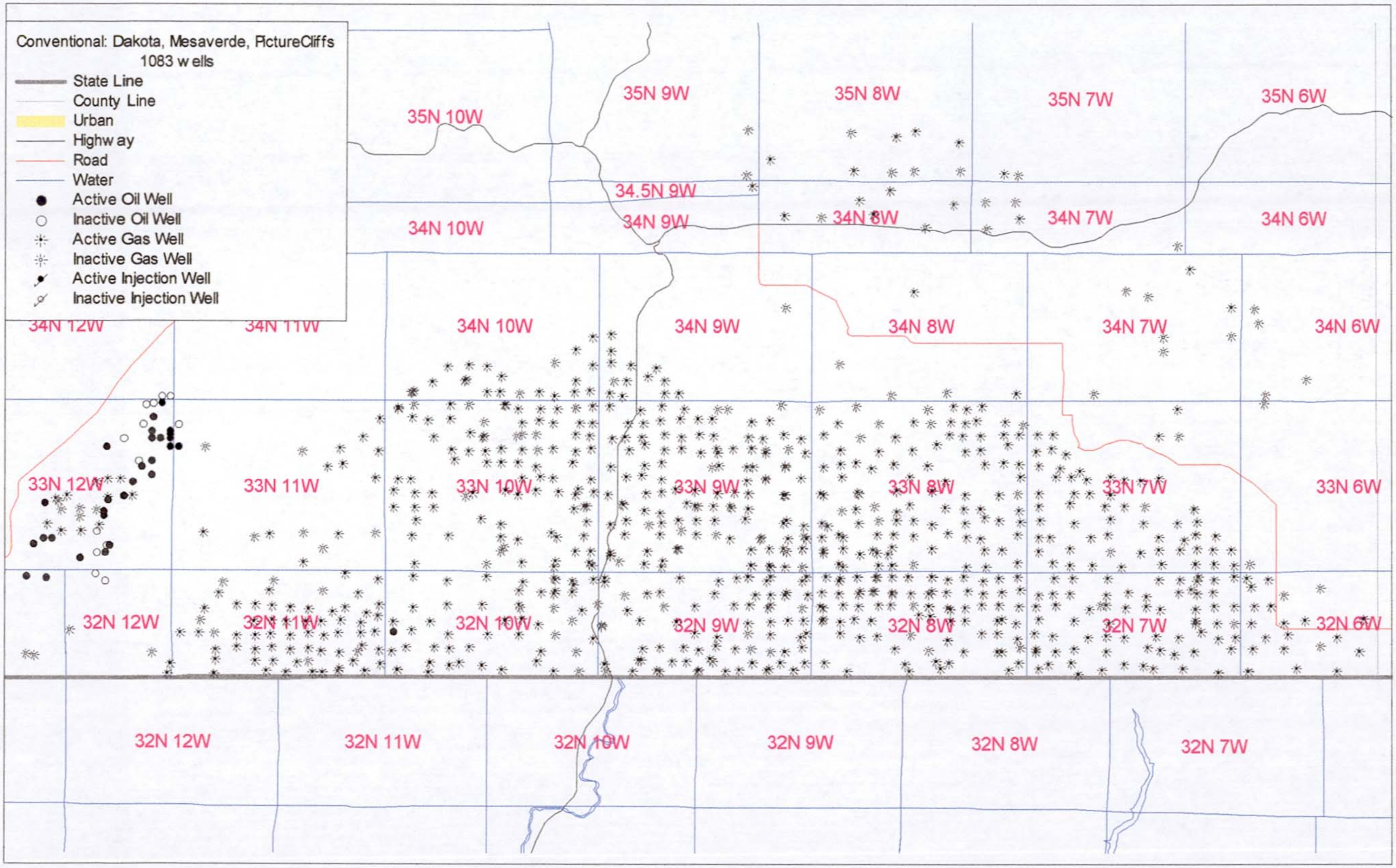
Northern San Juan Basin

CONVENTIONAL GAS WELLS DRILLED

PowerTools Map

Project: C:\Program Files\IHS Energy\PTools35\PROJECTS\LaPlataConvenwells.MDB

Date: 11/10/1999
Time: 2:13 PM



APPENDIX B

Maps and Cross-Sections: 5

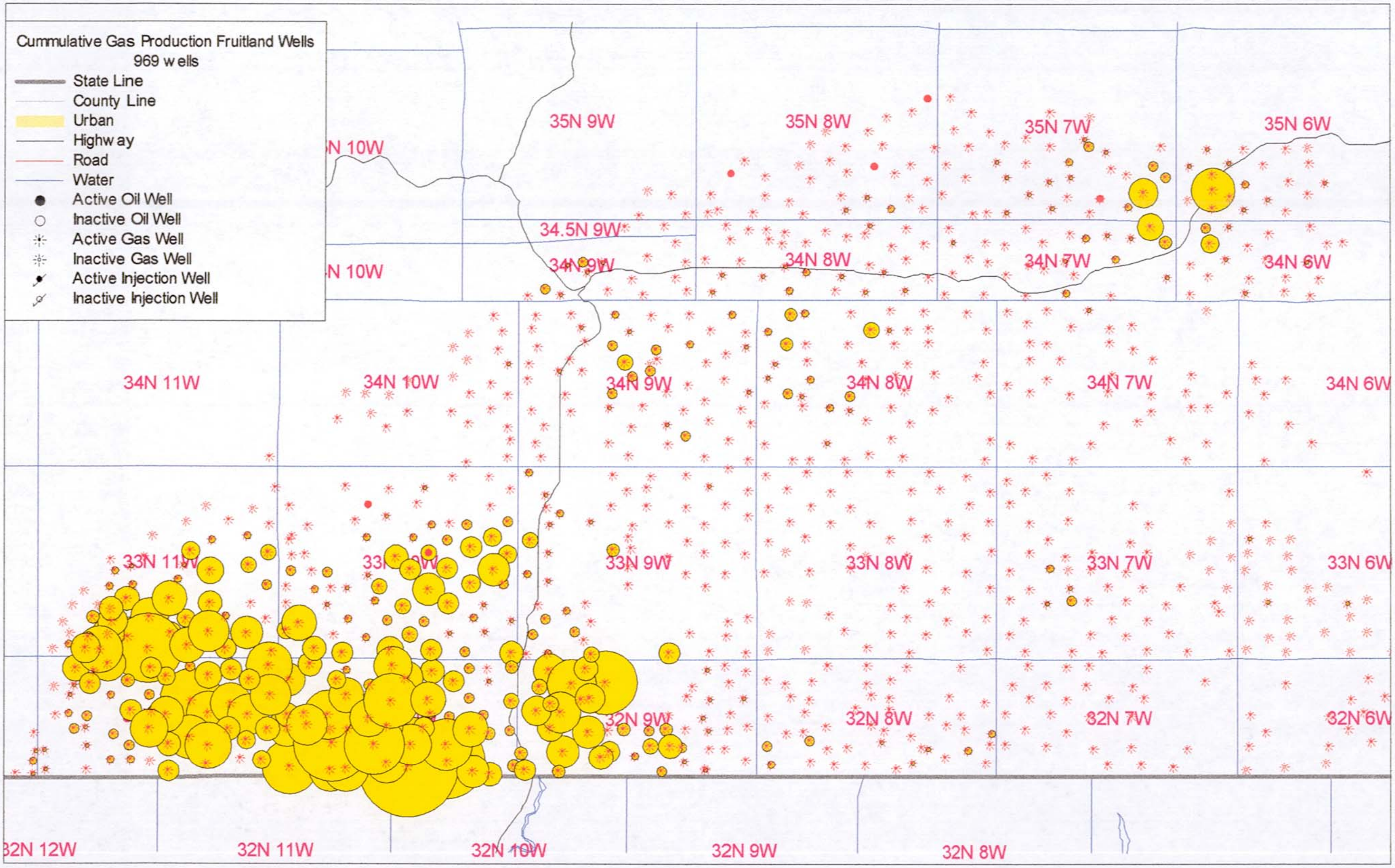
Northern San Juan Basin

CUMULATIVE CBM GAS PRODUCTION BY WELL

PowerTools Map

Project: C:\Program Files\IHS Energy\PTools35\PROJECTS\LaPlataCBM.MDB

Date: 11/10/1999
Time: 3:30 PM



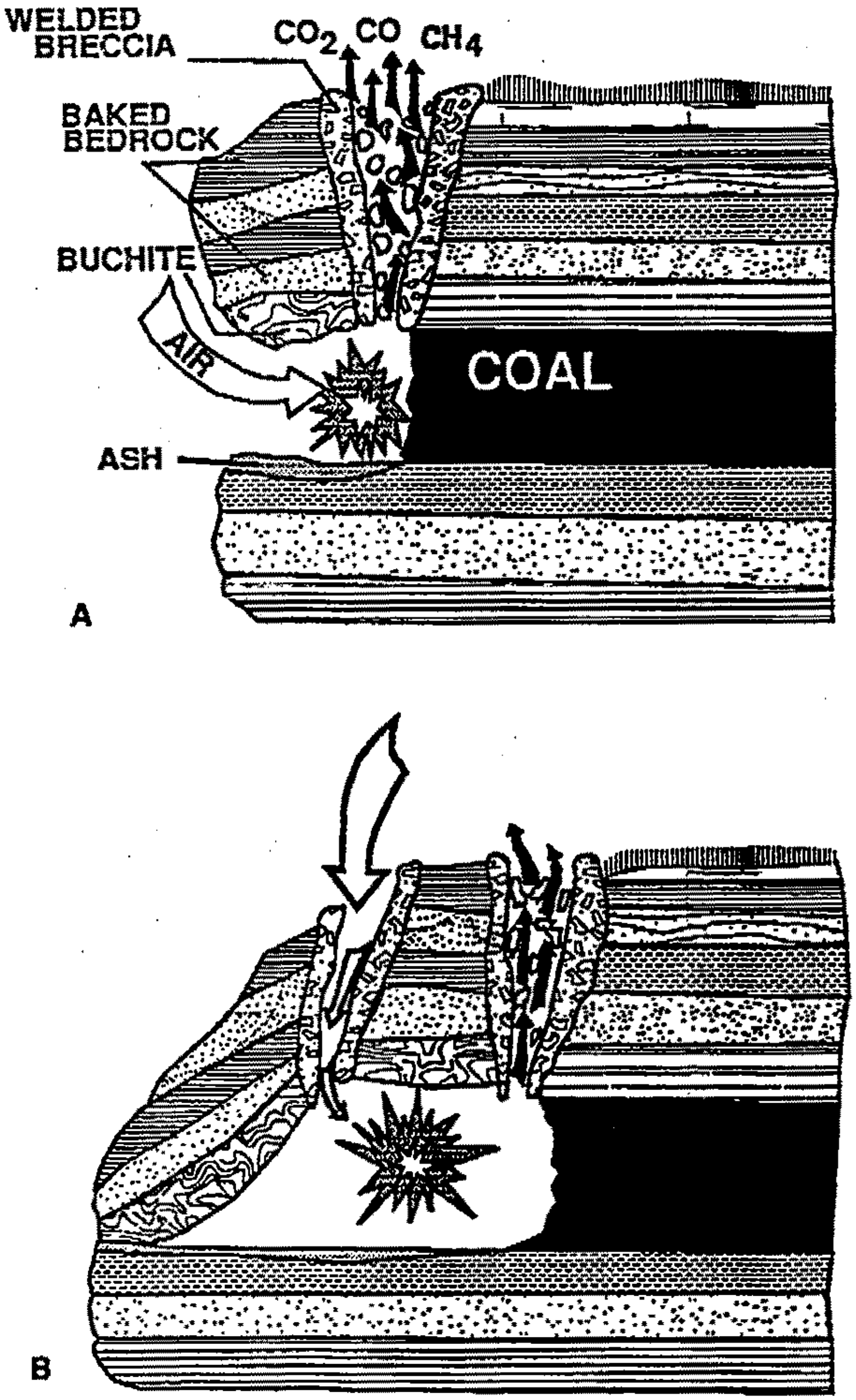
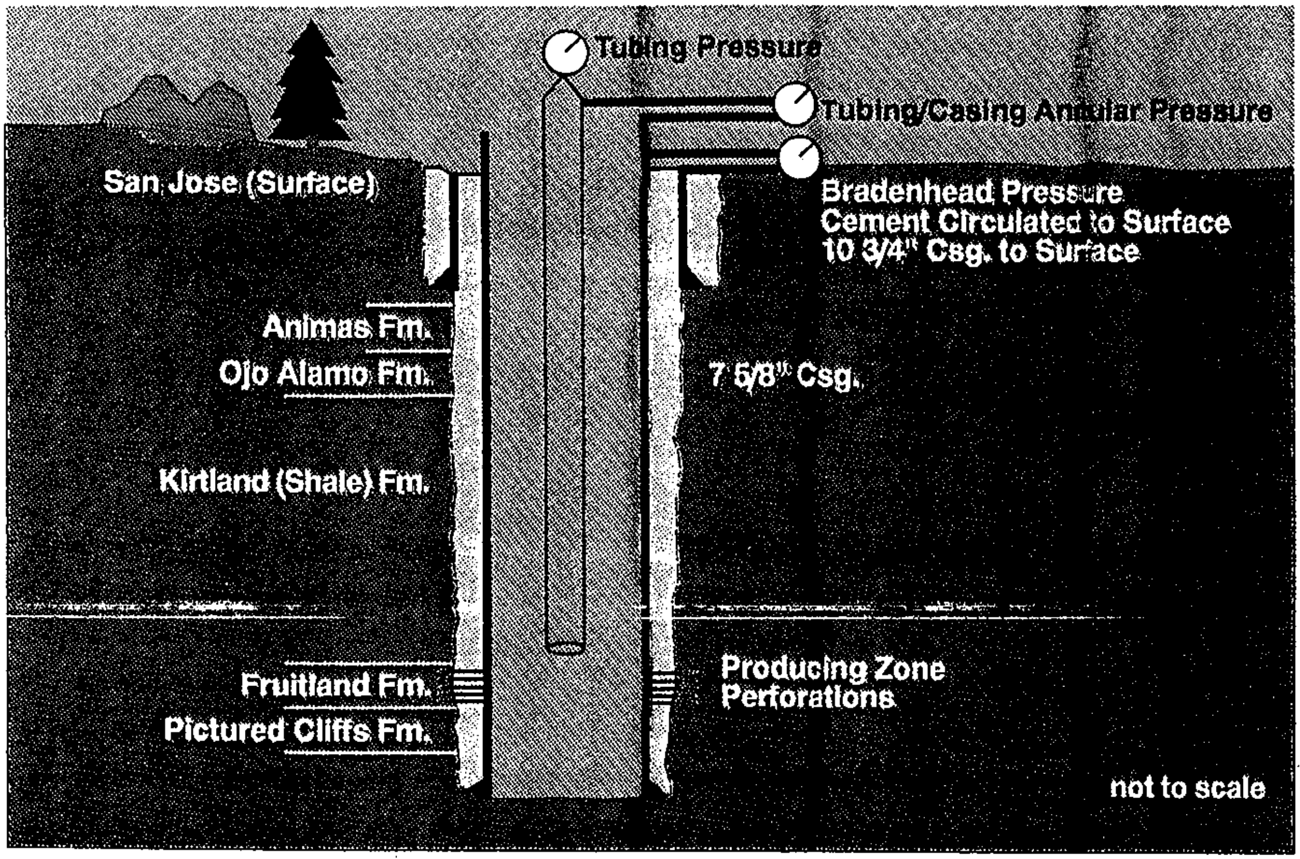


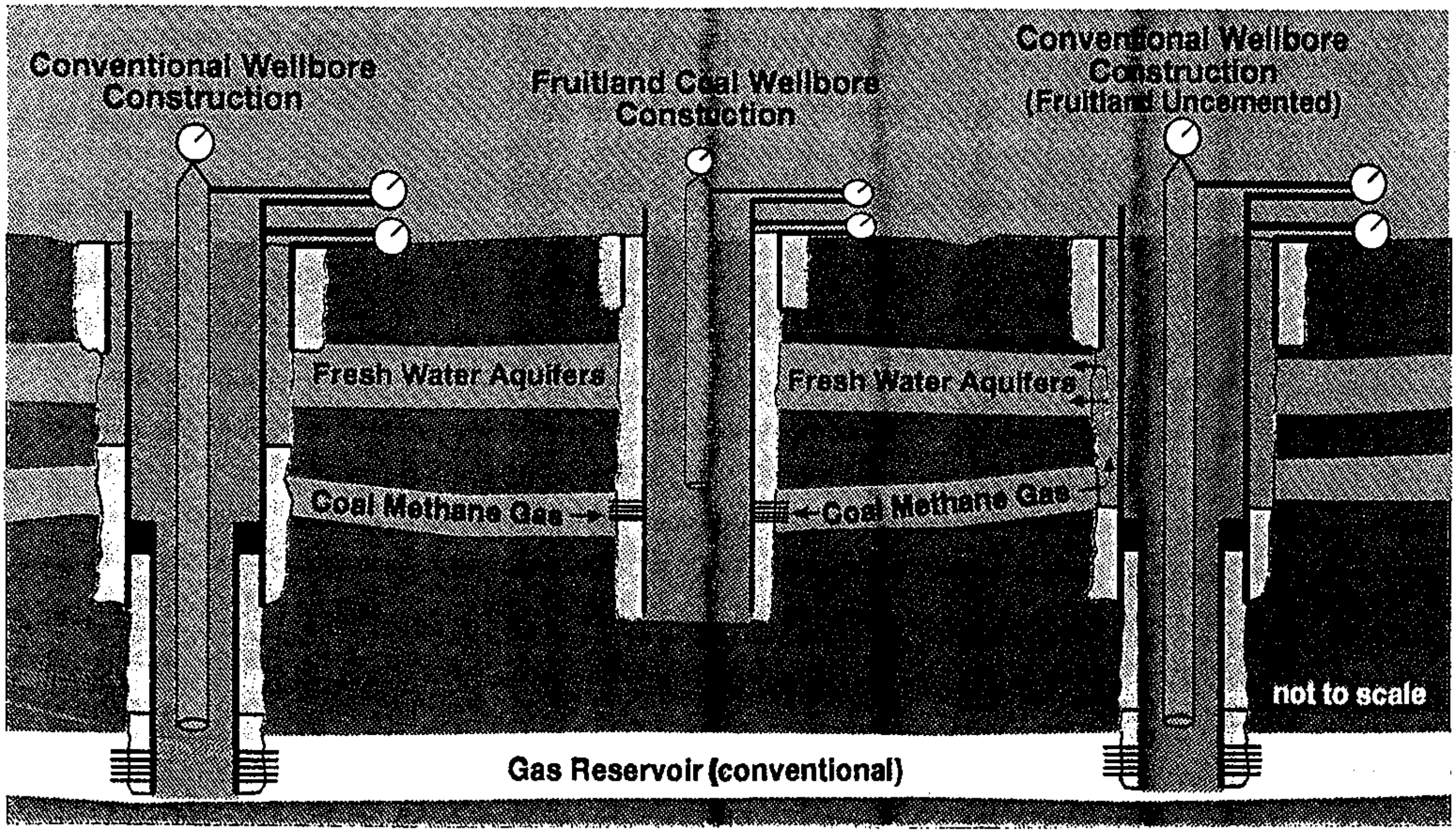
Figure 1. *Clinker formation sequence: A) Initial clinker formation due to natural combustion at the coal outcrop showing resultant rock types, and B) post-collapse burn continuation set up by circulation of air to fire chamber through vents. Fresh-air flow is shown by white arrows, and exhaust-gas flow is shown by black arrows in exhaust vents. Zone of alteration occurs to the left of, and includes, the exhaust vent.*

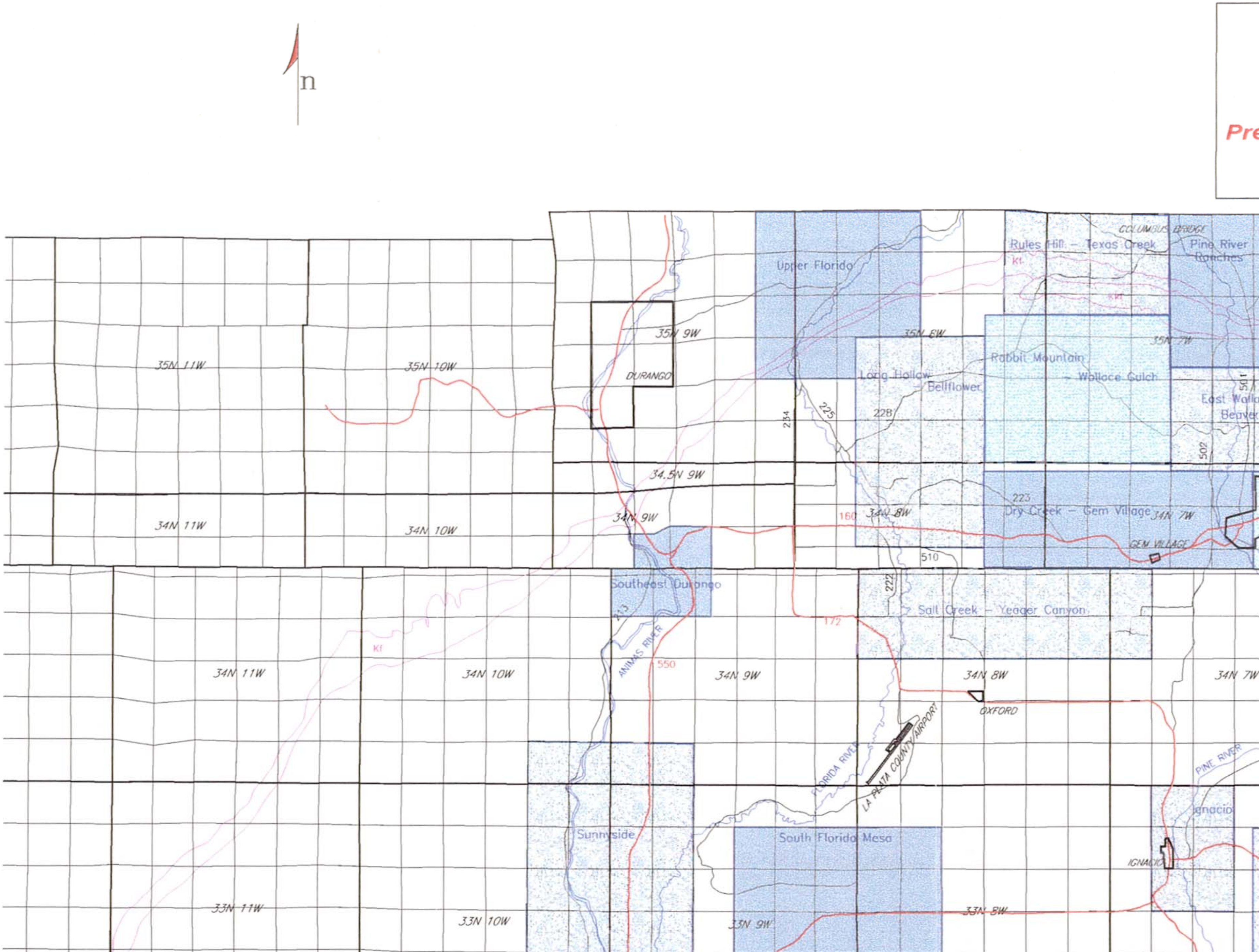
APPENDIX B

Maps and Cross-Sections: 7

Well-Bore Configuration Illustrating Potential CBM Gas Loss


Tubing Pressure
Tubing/Casing Annular Pressure
Bradenhead Pressure
Cement Circulated to Surface
10 3/4" Csg. to Surface
San Jose (Surface)
Animas Fm.
Ojo Alamo Fm.
7 5/8" Csg.
Kirtland (Shale) Fm.
Fruitland Fm.
Pictured Cliffs Fm.
Producing Zone Perforations
not to scale


Conventional Wellbore Construction
Fruitland Coal Wellbore Construction
Conventional Wellbore Construction (Fruitland Uncemented)
Fresh Water Aquifers
Fresh Water Aquifers
Coal Methane Gas
Coal Methane Gas
not to scale
Gas Reservoir (conventional)


n
Pre
COLUMBUS BRIDGE
Rules Hill - Texas Creek
Pine River Ranches
Kf
Upper Florida
35N 9W
35N 8W
35N 7W
DURANGO
35N 11W
35N 10W
Long Hollow - Bellflower
Rabbit Mountain - Wallace Gulch
East Walla
Beaver
501
502
234
225
228
34.5N 9W
223
Dry Creek - Gem Village
34N 7W
GEM VILLAGE
34N 11W
34N 10W
34N 9W
160
34N 8W
510
Southeast Durango
222
Salt Creek - Yeager Canyon
213
172
ANIMAS RIVER
550
Kf
34N 11W
34N 10W
34N 9W
34N 8W
34N 7W
OXFORD
FLORIDA RIVER
LA PLATA COUNTY AIRPORT
PINE RIVER
Ignacio
Sunnyside
South Florida Mesa
IGNACIO
33N 11W
33N 10W
33N 9W
33N 8W

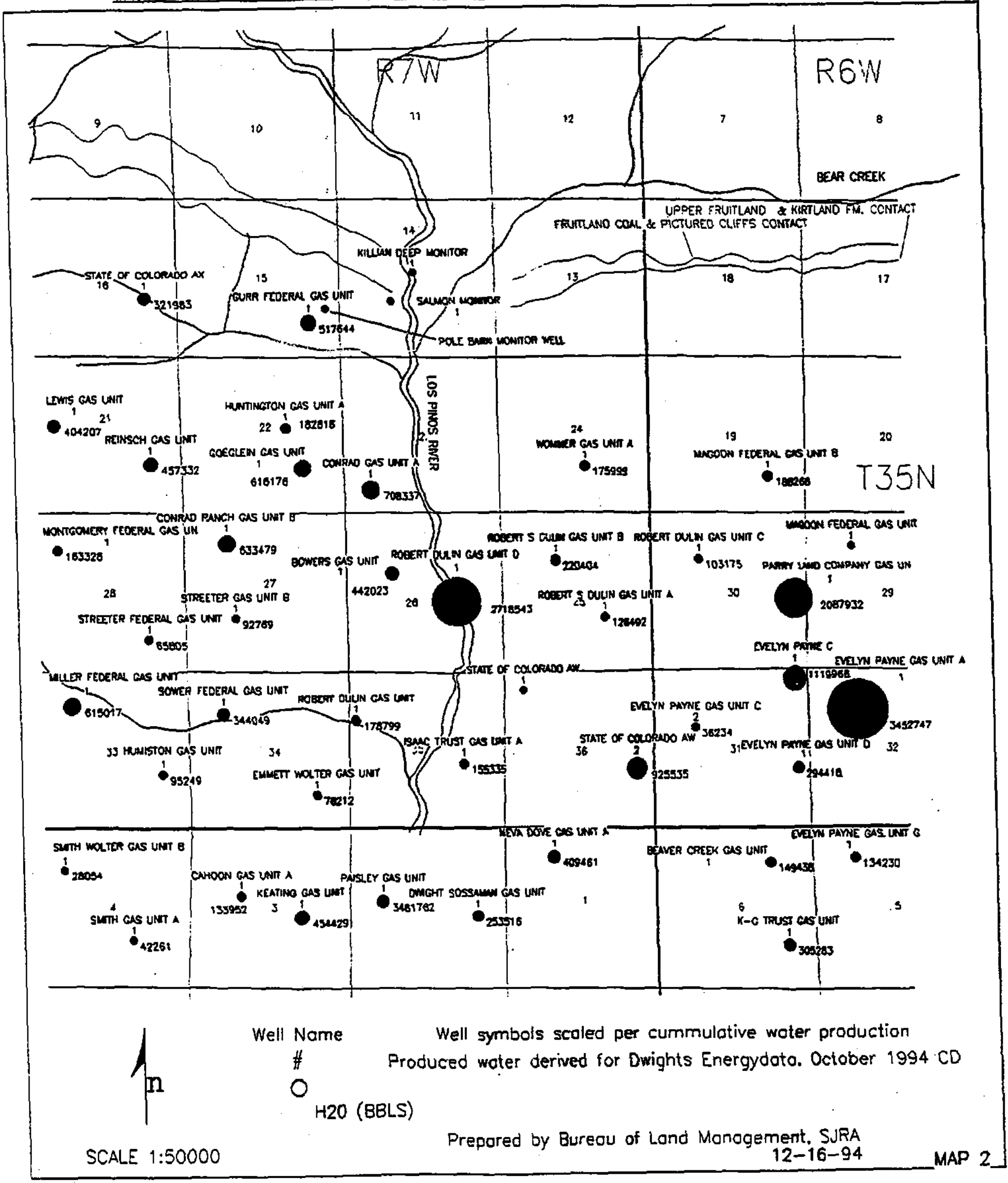
APPENDIX B

Maps and Cross-Sections: 9

Location of Coalgas and Water-Monitoring Wells – Pine River

(Pine River Investigative Team, 1995)

LOCATION OF MONITOR AND FRUITLAND COAL GAS WELLS
CUMMULATIVE PRODUCED FRUITLAND WATER BUBBLE MAP
PINE RIVER RANCHES STUDY AREA, LA PLATA COUNTY, COLORADO



Well symbols scaled per cummulative water production

Produced water derived for Dwights Energydata, October 1994 CD

Prepared by Bureau of Land Management, SJRA

12-16-94

SCALE 1:50000

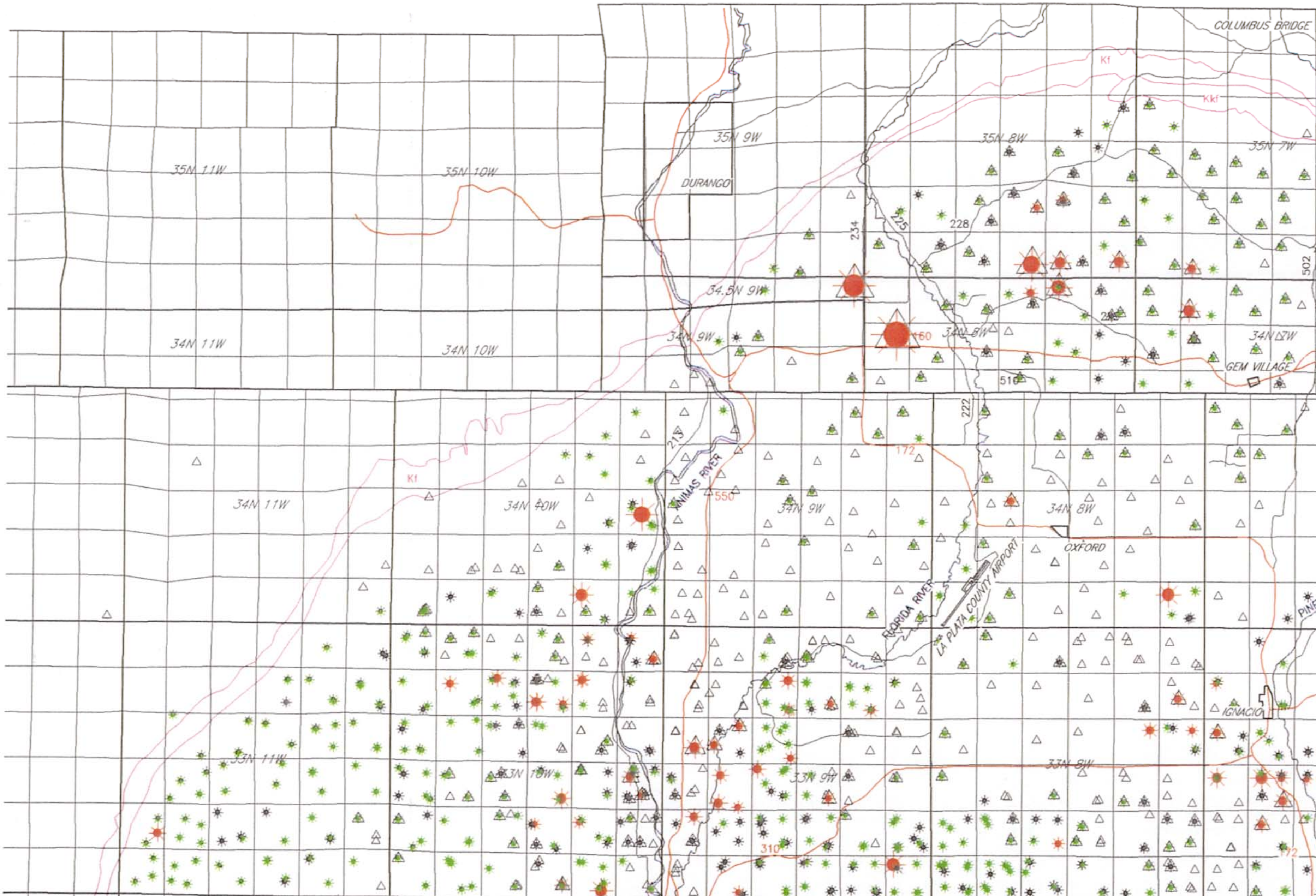
MAP 2

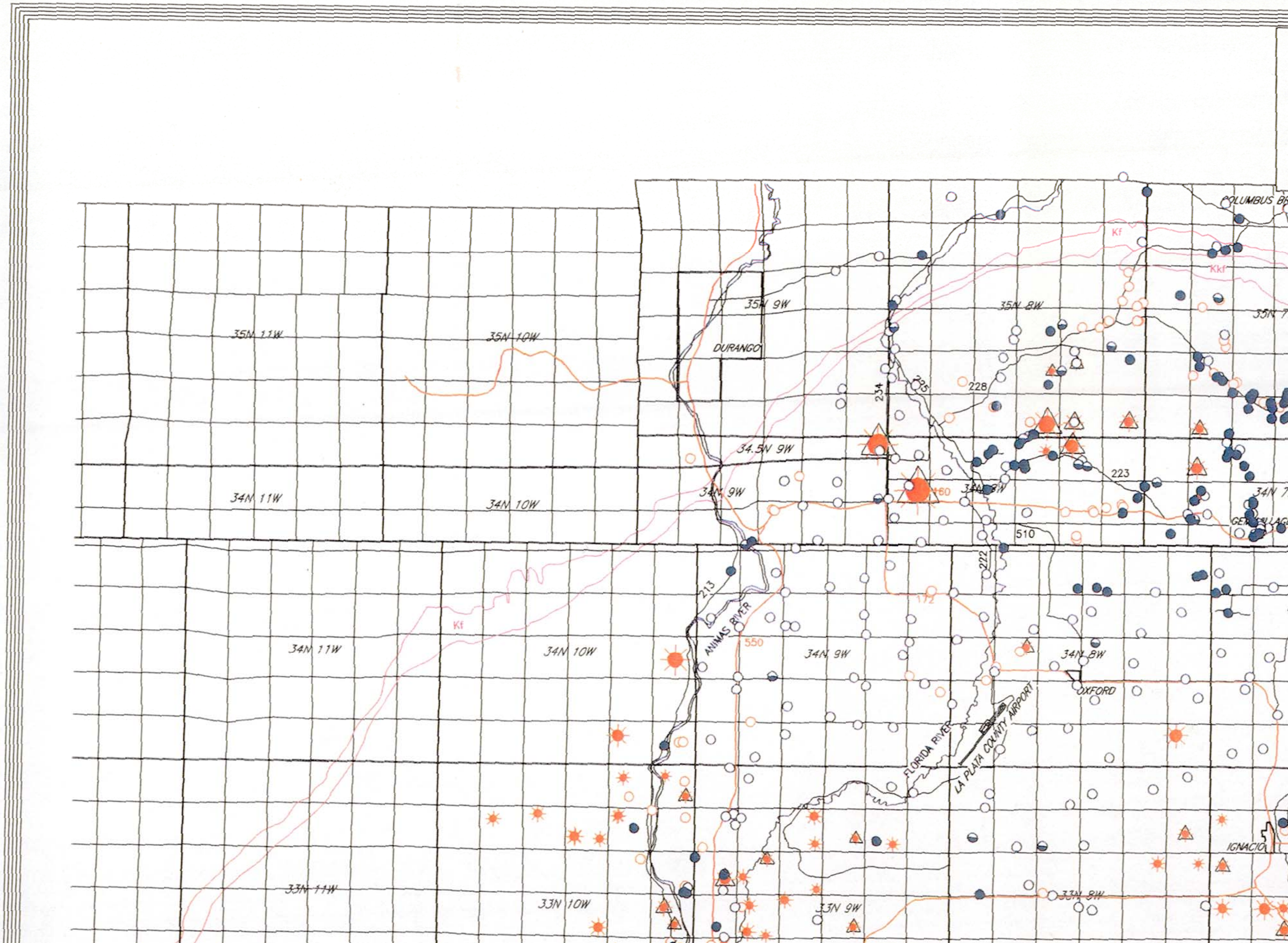
APPENDIX B

Maps and Cross-Sections: 10a,10b

Bradenhead Pressure of Gas Wells, 1994

Bradenhead Pressure >25 psig with Groundwater Methane


COLUMBUS BRIDGE
Kf
Kkf
35N 11W
35N 10W
35N 9W
DURANGO
35N 8W
35N 7W
234
225
228
502
34.5N 9W
34N 11W
34N 10W
34N 9W
160
34N 8W
34N 7W
GEM VILLAGE
516
222
213
172
Kf
ANIMAS RIVER
550
34N 11W
34N 10W
34N 9W
34N 8W
OXFORD
FLORIDA RIVER
LA PLATA COUNTY AIRPORT
PINE
IGNACIO
33N 11W
33N 10W
33N 9W
33N 8W
310
172


COLUMBUS BO
Kf
Kkf
35N 11W
35N 10W
35N 9W
DURANGO
35N 8W
35N 7
234
225
228
34.5N 9W
223
34N 11W
34N 10W
34N 9W
160
34N 8W
34N 7
GEM VILLAG
510
222
213
172
ANIMAS RIVER
550
Kf
34N 11W
34N 10W
34N 9W
34N 8W
OXFORD
FLORIDA RIVER
LA PLATA COUNTY AIRPORT
IGNACIO
33N 11W
33N 10W
33N 9W
33N 8W

APPENDIX B

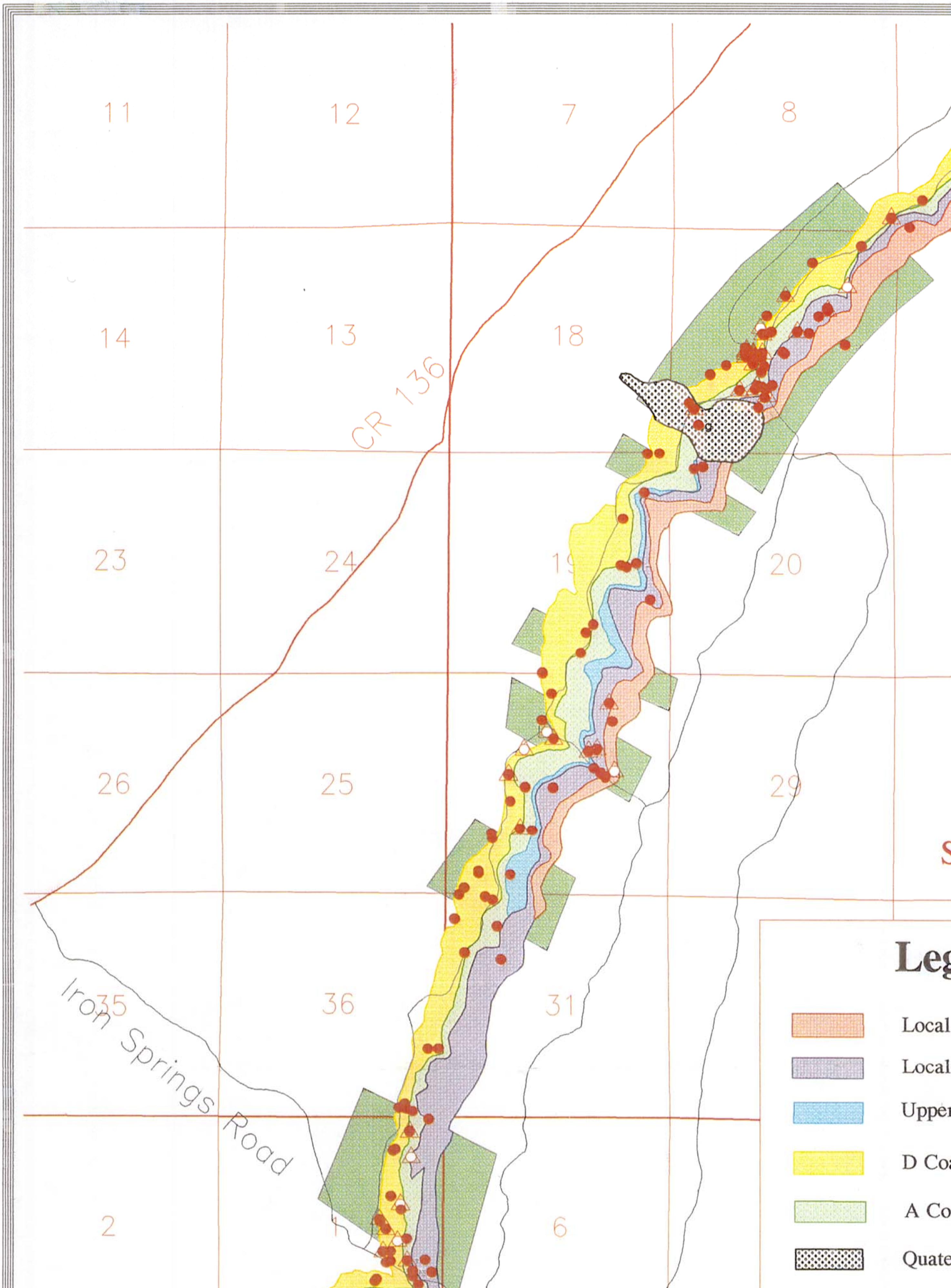
Maps and Cross-Sections: 11

(Northwestern San Juan Basin Rim)

Stressed Vegetation Map

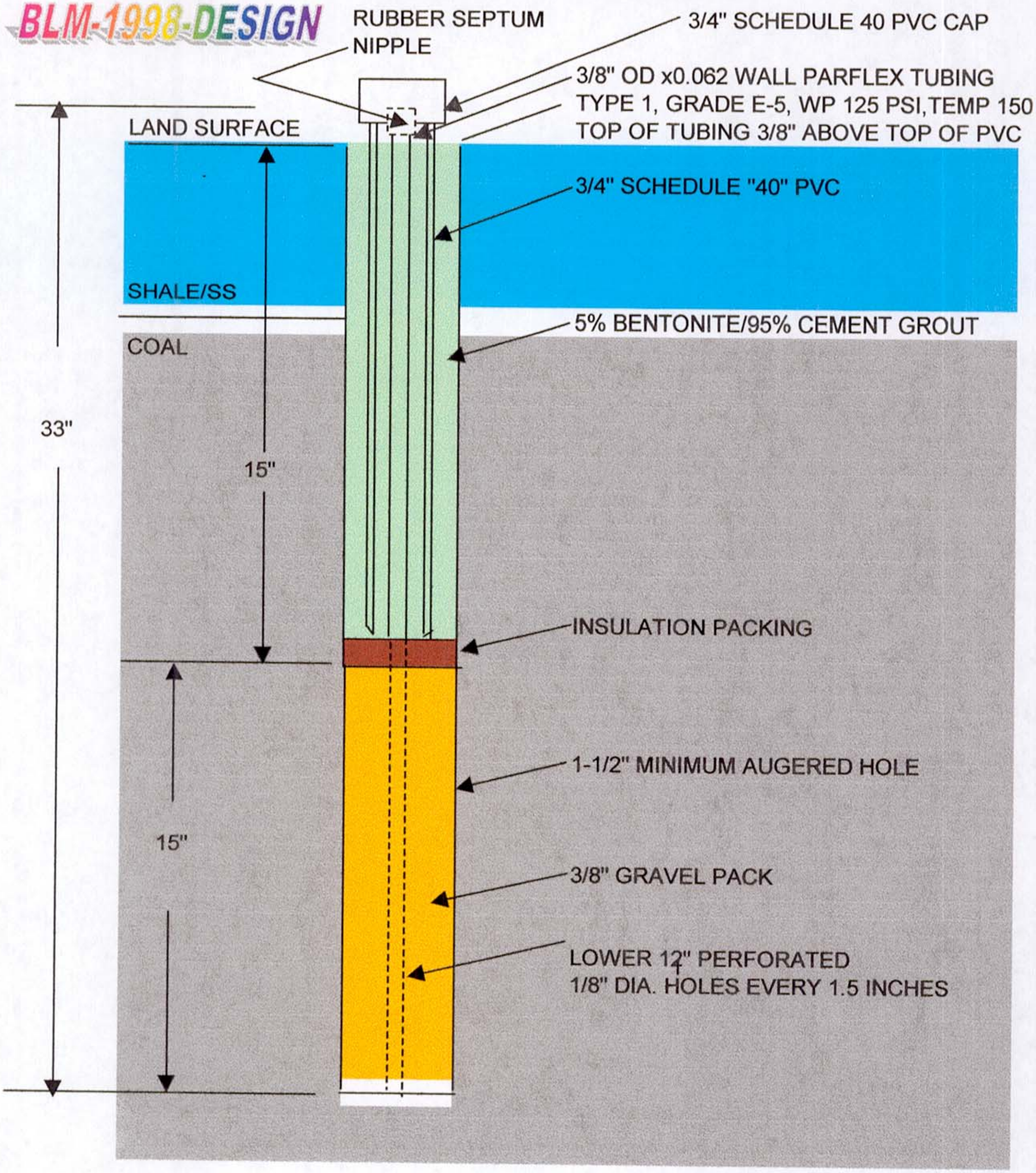
(Southern Ute Indian Land)

(BLM, 1996)


11
12
7
8
14
13
18
CR 136
23
24
19
20
26
25
29
S
35
36
31
Iron Springs Road
2
1
6
Leg
🟥 Local
🟪 Local
🟦 Upper
🟨 D Co
🟩 A Co
▨ Quate

SOIL VAPOR TUBE INSTALLATION

BLM-1998-DESIGN



APPENDIX B

Maps and Cross-Sections: 13

Northern San Juan Basin

CUMULATIVE CBM WATER PRODUCTION BY WELL (MID-1999)

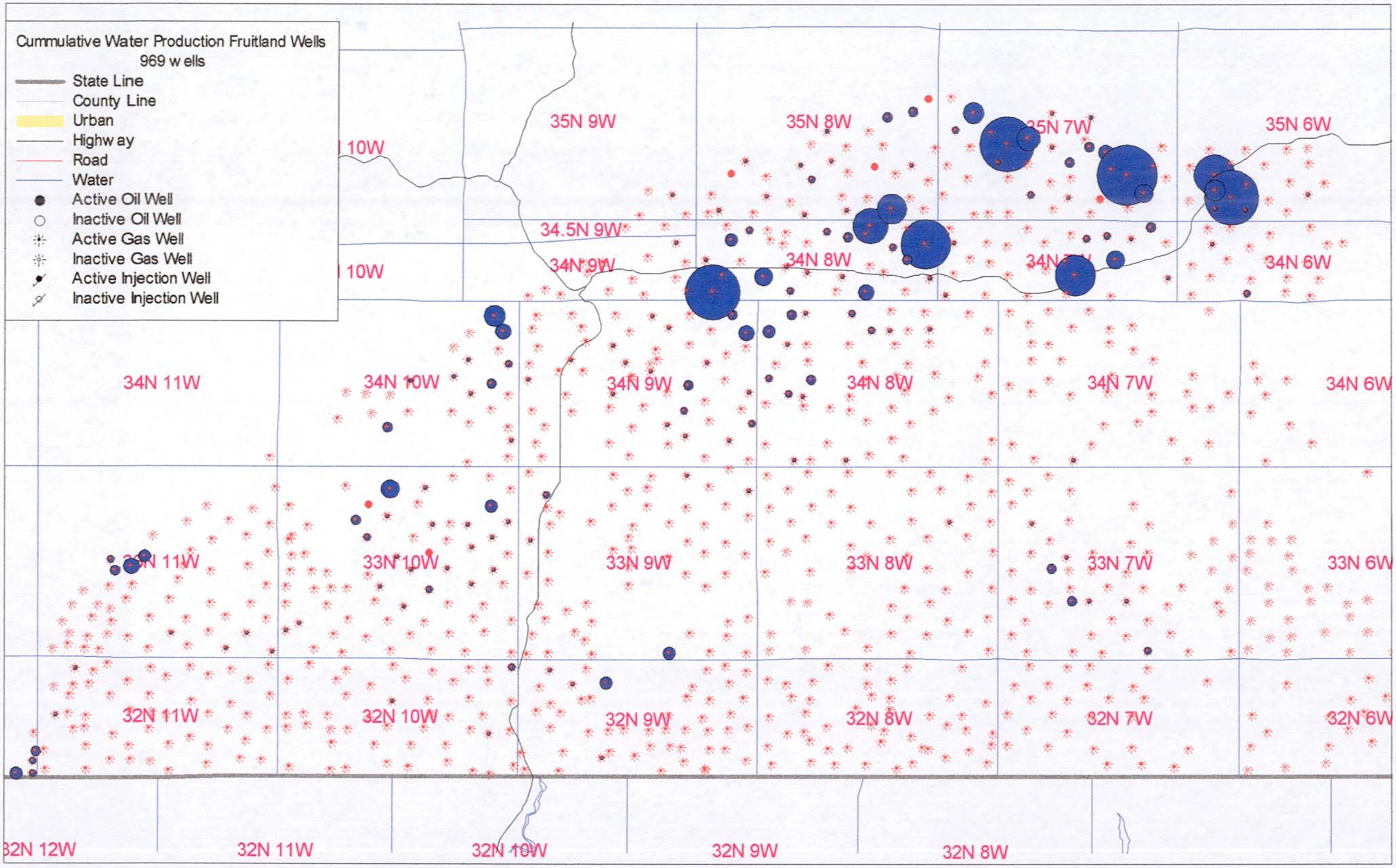
4 WELLS EXCEED 4,000,000 BBLS

30 WELLS EXCEED 950,000 BBLS

PowerTools Map

Project: C:\Program Files\IHS Energy\PTools35\PROJECTS\LaPlataCBM.MDB

Date: 11/10/1999
Time: 3:24 PM



APPENDIX B

Maps and Cross-Sections: 14

IODINE AND CHLORIDE CONCENTRATIONS
IN PRODUCED WATER
AS AN INDICATION OF WATER AGE DATING

Northern San Juan Basin

(Riese, 1999)

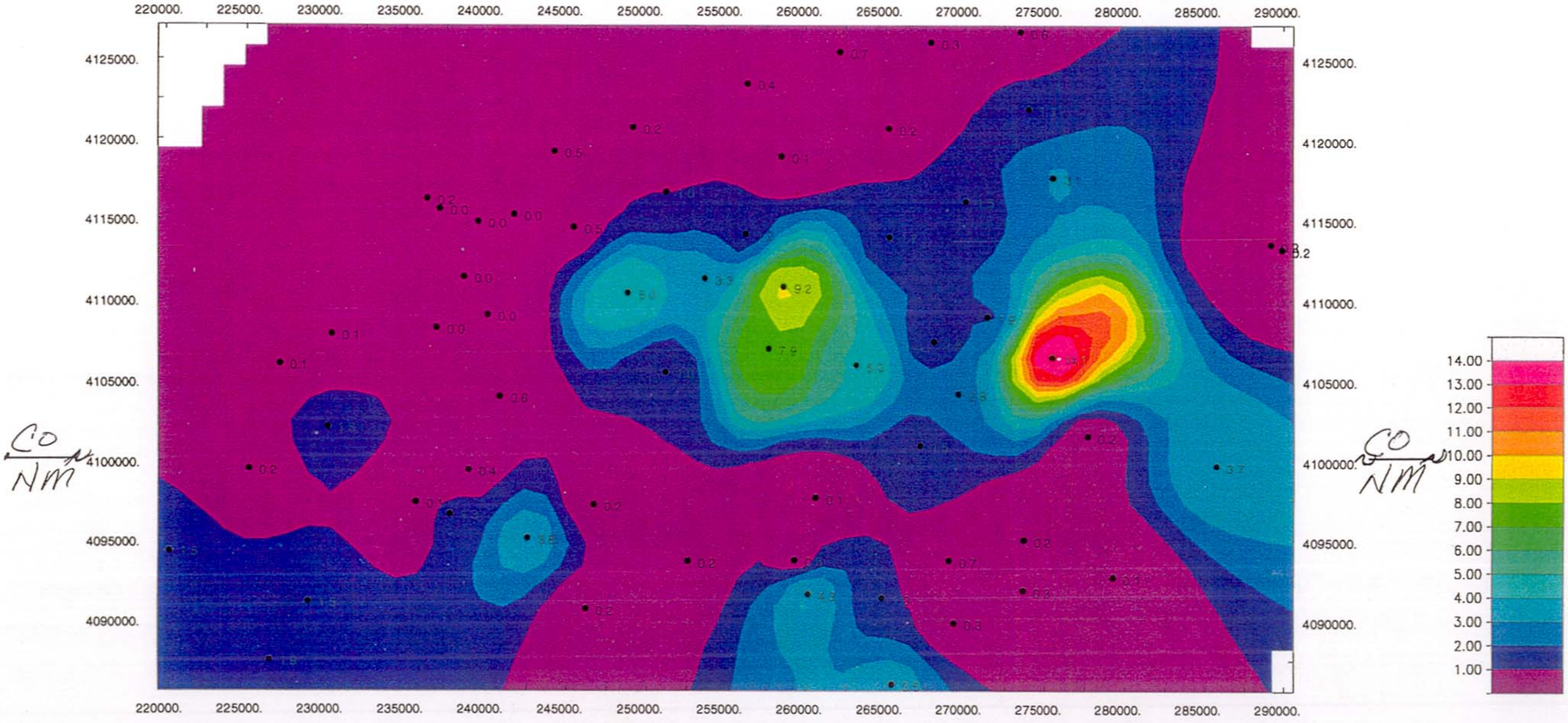
Vastar Resources, Inc.

IODINE (I.S.E.)(ppm)
1999 3-M SAMPLES
ONLY

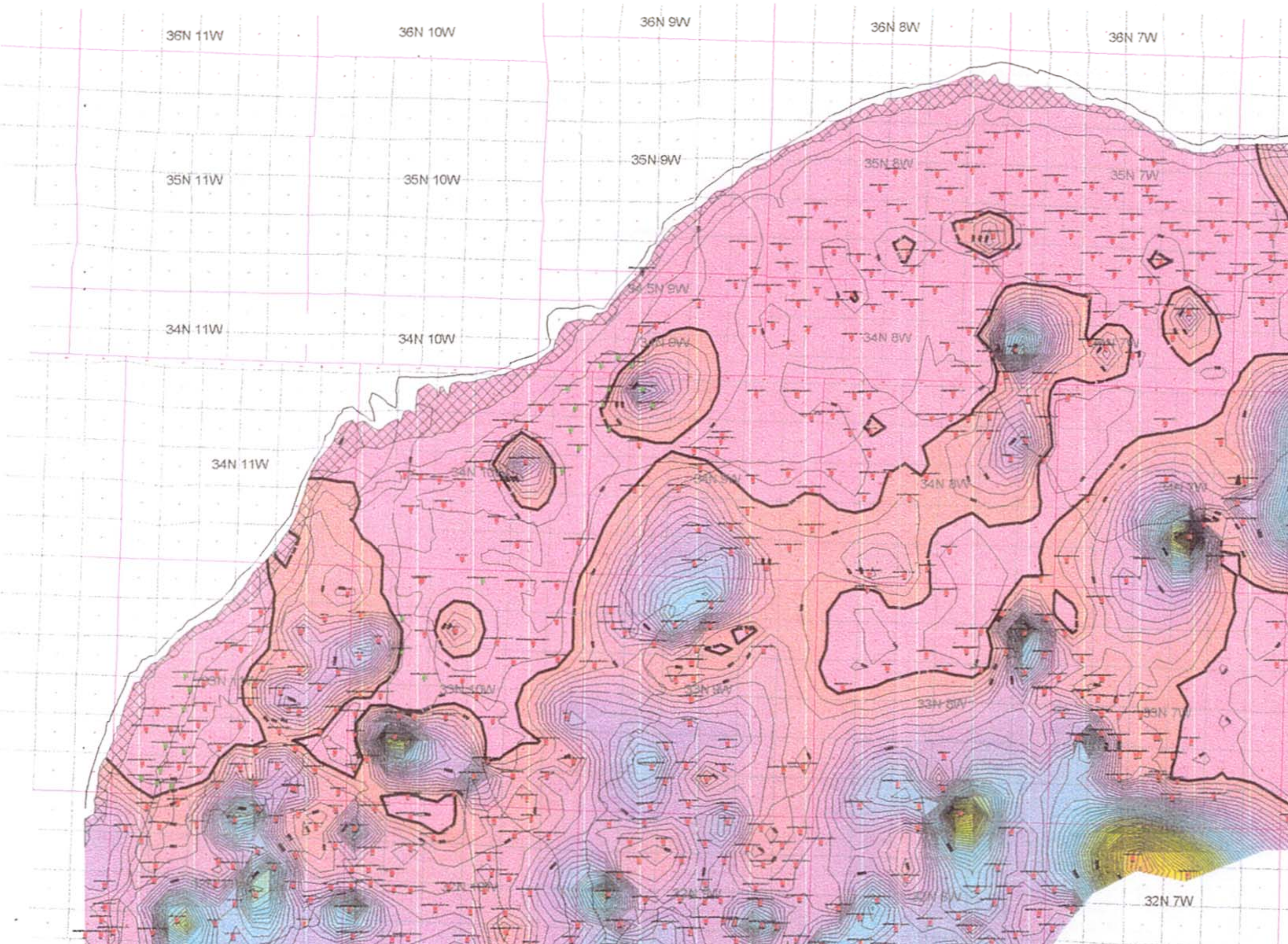
N

GEOPHYSICIST
R RIESE 10/99
GEOLOGIST DATE

SCALE IN FEET



Chloride in Groundwater, Fruitland Formation, Northern San Juan Ba



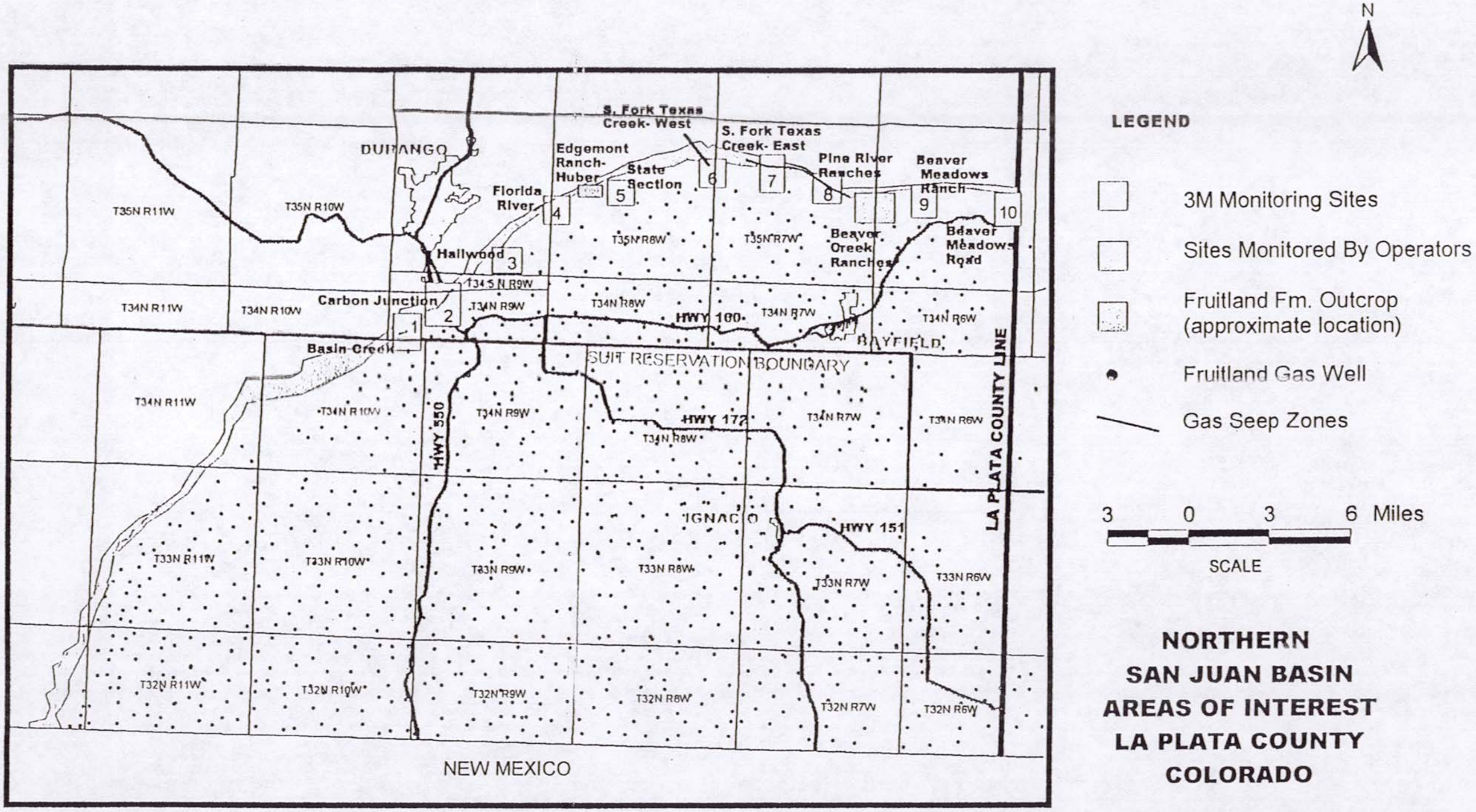
APPENDIX B

Maps and Cross-Sections: 15

FRUITLAND CBM DEVELOPMENT AND COAL OUTCROP

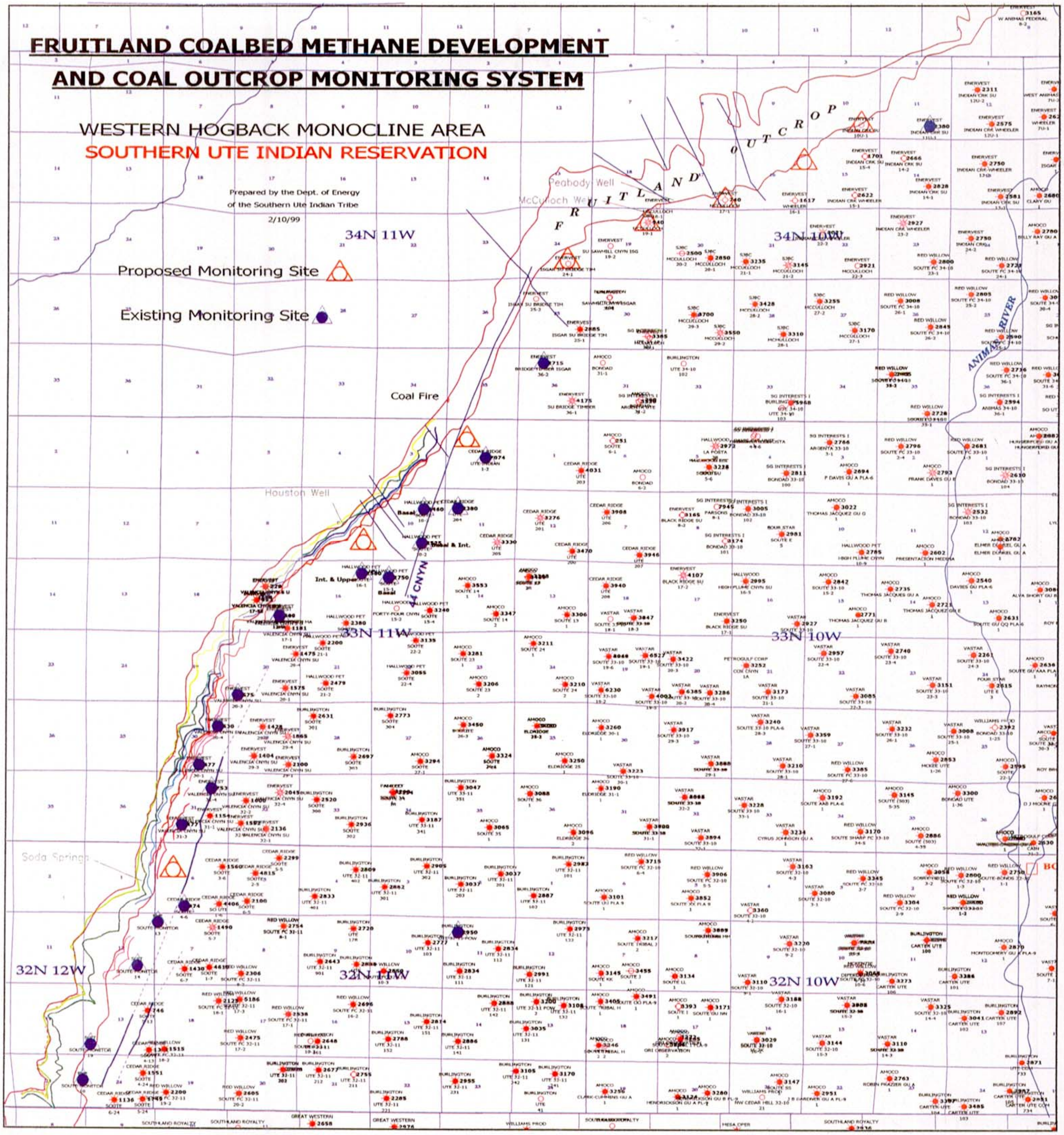
MONITORING WELL SYSTEM

Northern San Juan Basin Monitoring Well Proposed Locations



NORTHERN
SAN JUAN BASIN
AREAS OF INTEREST
LA PLATA COUNTY
COLORADO

COGCC, April 1999



FRUITLAND COALBED METHANE DEVELOPMENT AND COAL OUTCROP MONITORING SYSTEM

WESTERN HOGBACK MONOCLINE AREA

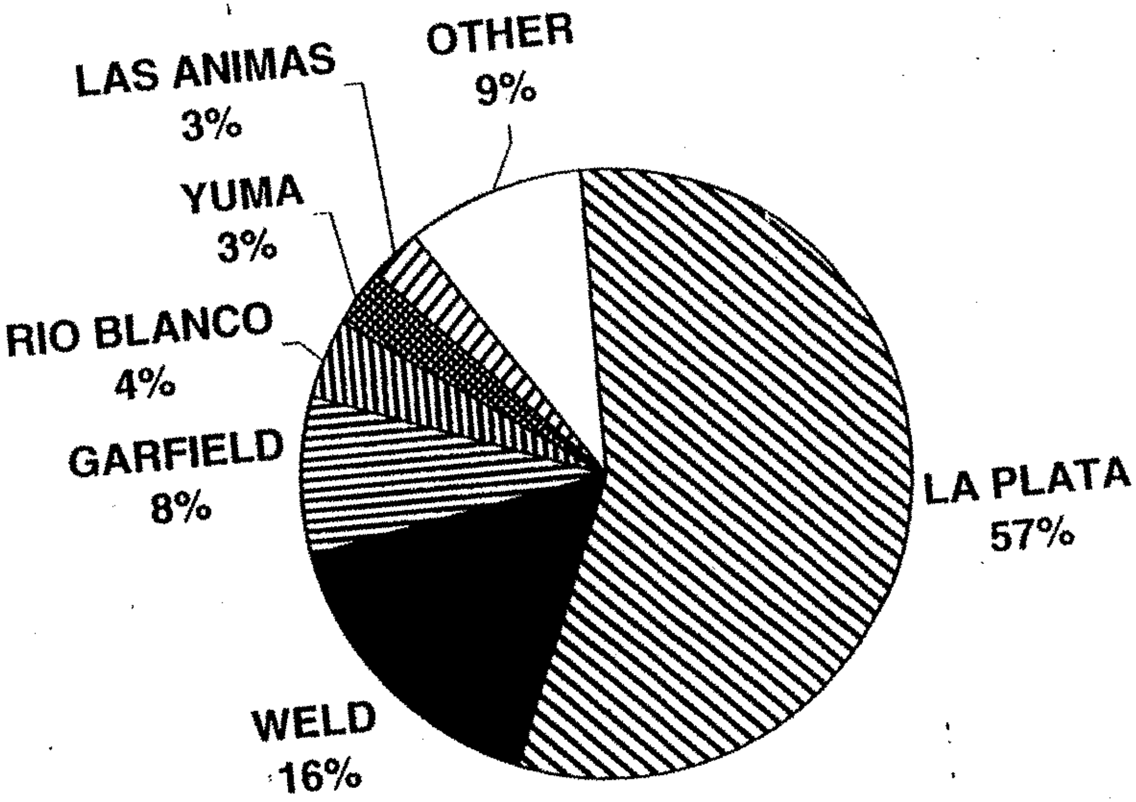
SOUTHERN UTE INDIAN RESERVATION

Prepared by the Dept. of Energy
of the Southern Ute Indian Tribe
2/10/99

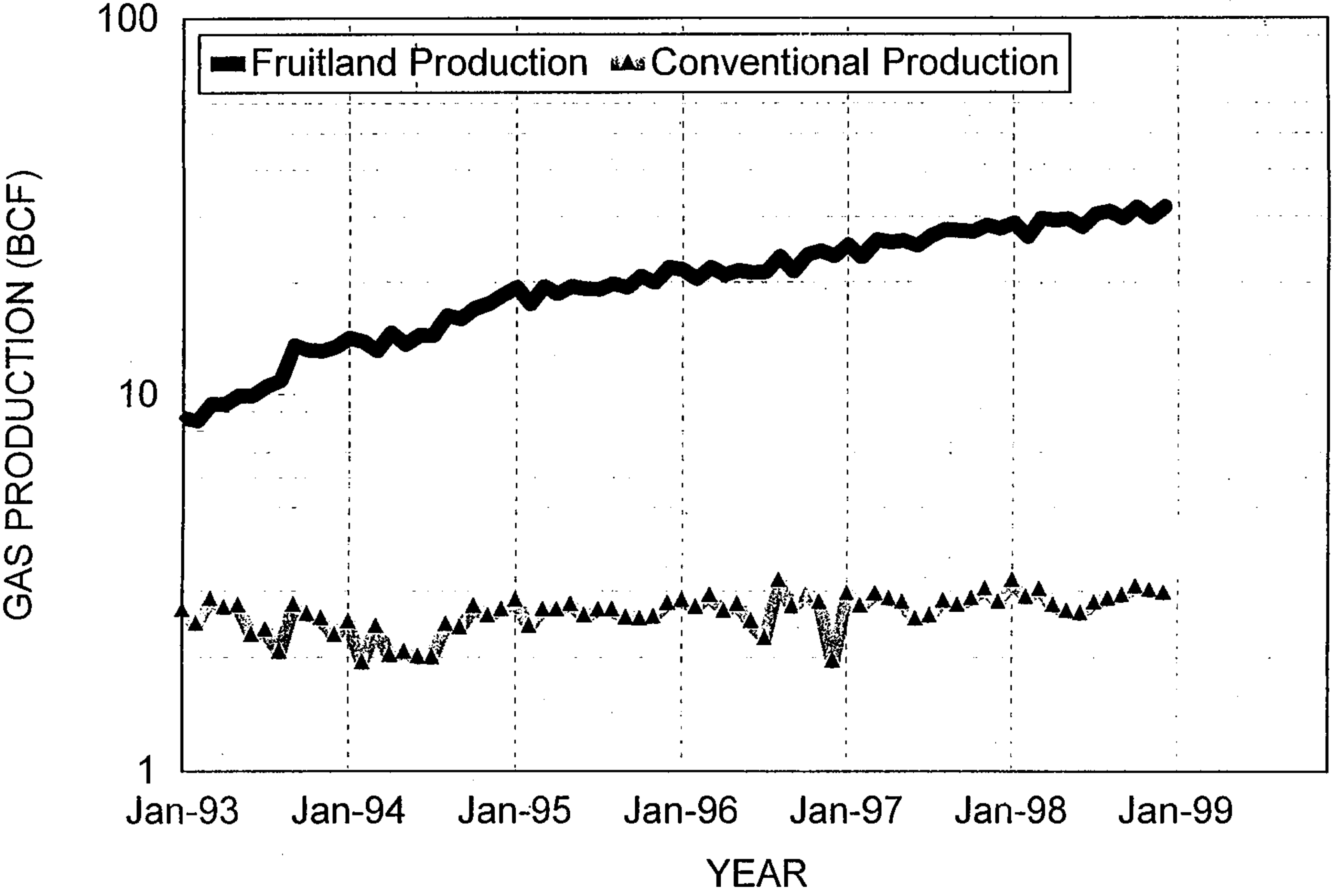
Proposed Monitoring Site △

Existing Monitoring Site ●

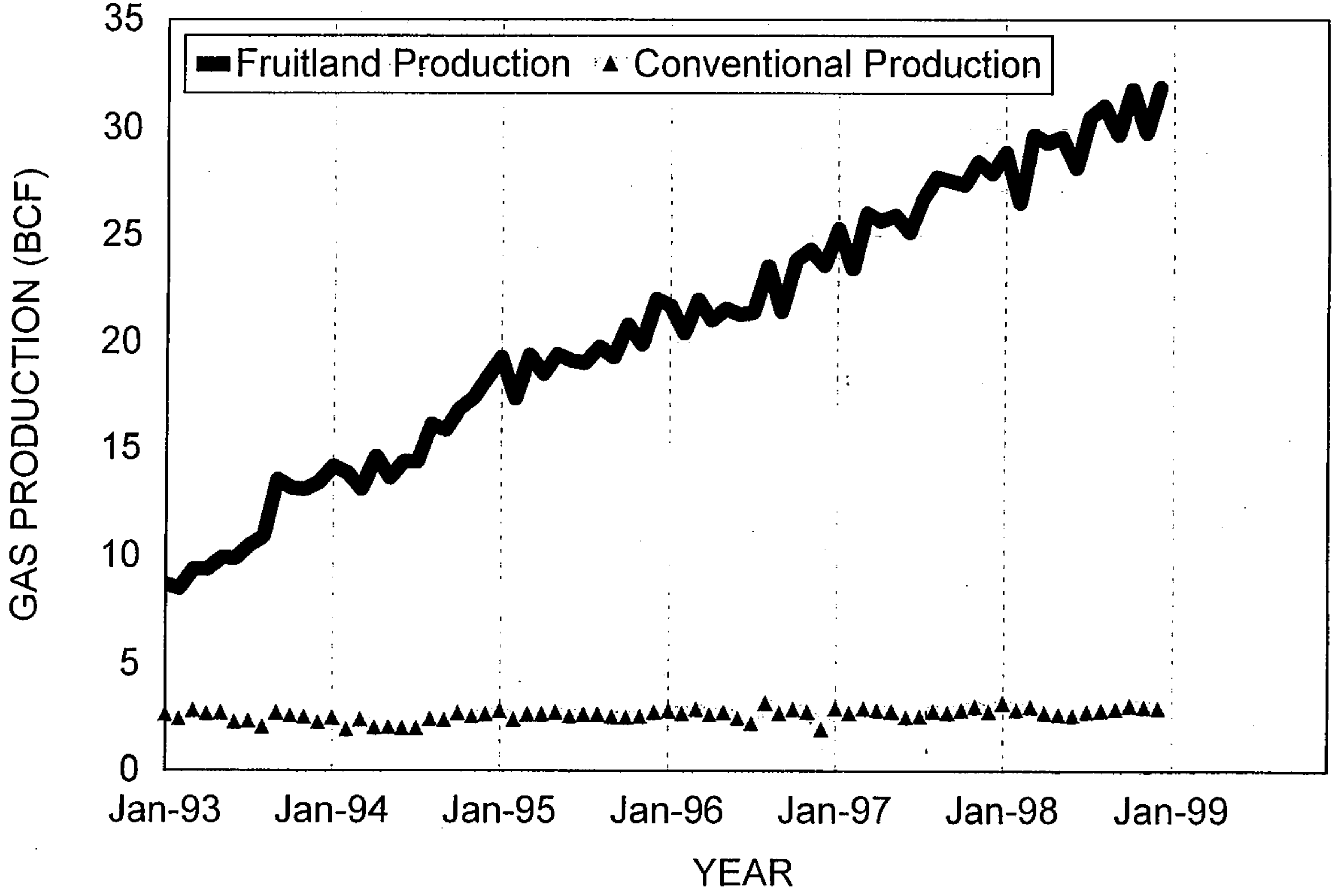
1998 GAS PRODUCTION % BY COUNTY



LA PLATA COUNTY PRODUCTION



LA PLATA COUNTY PRODUCTION



Oil & Gas Wells Drilled, La Plata Cty

Years 1950 - 1992

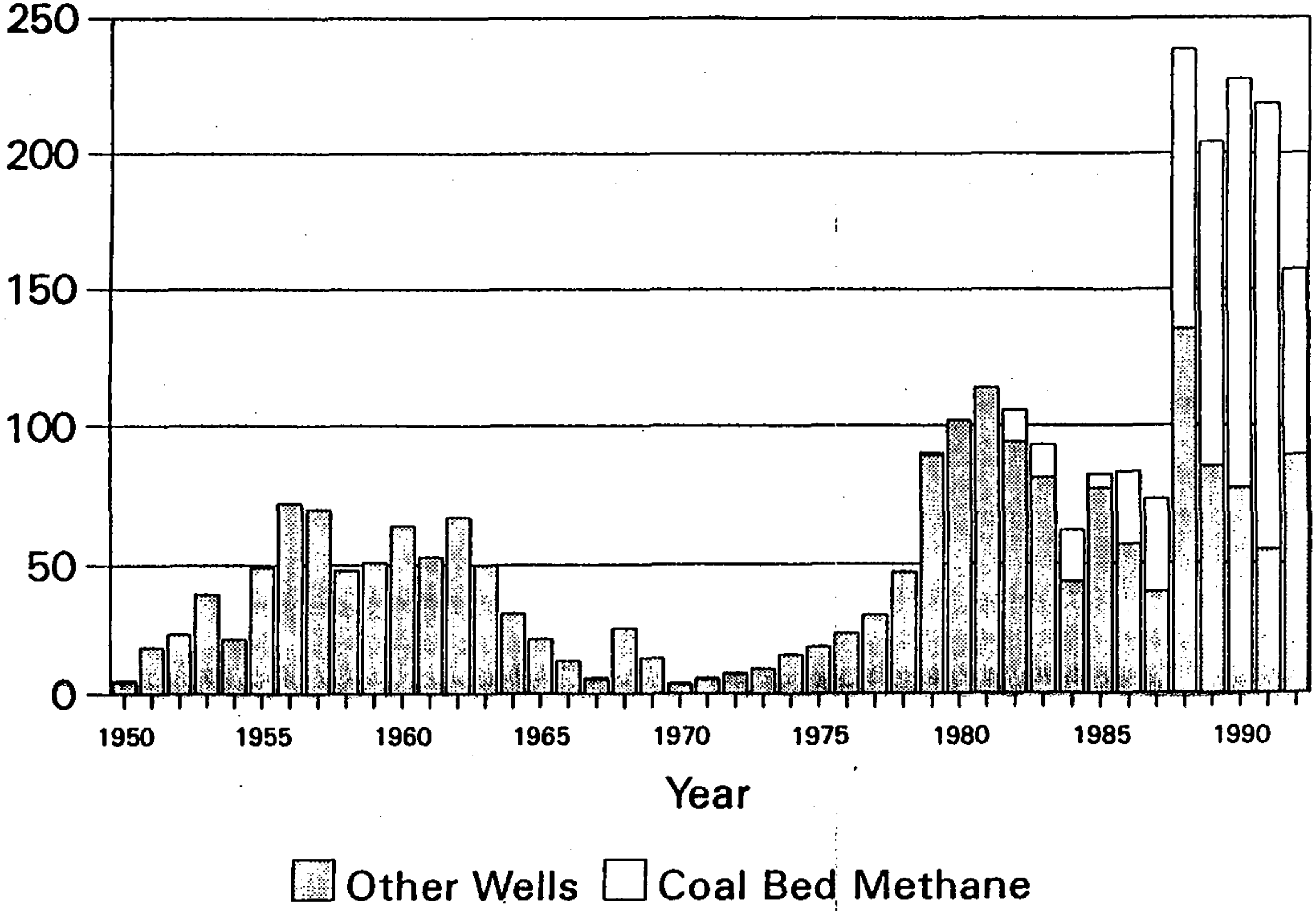


EXHIBIT 3

APPENDIX C

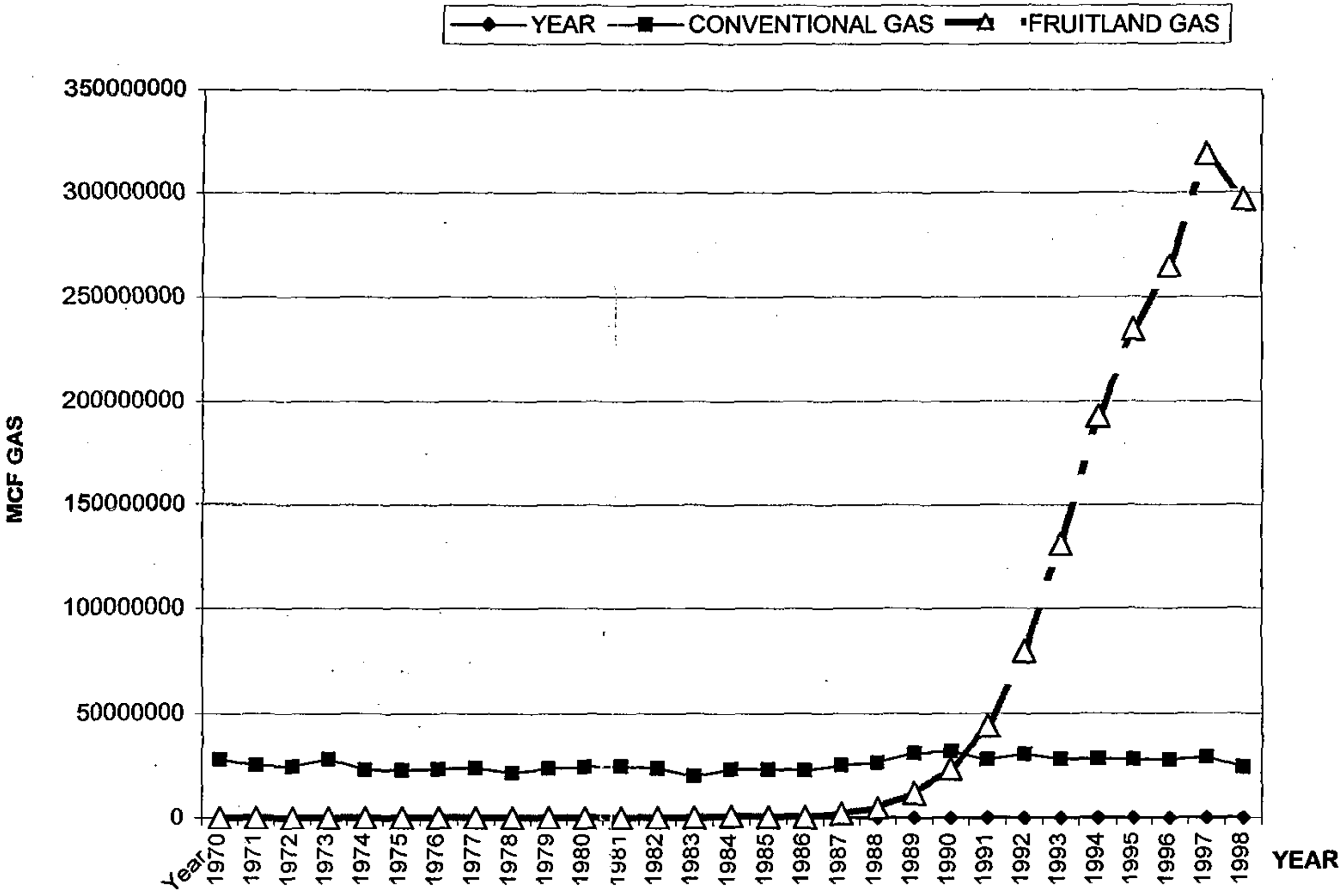
Chart 3

(La Plata County)

Annual Gas Production 1970-1998

(P.I./Dwights Energydata, Inc, 1999)

LA PLATA COUNTY, COLORADO
ANNUAL GAS PRODUCTION 1970 -1998



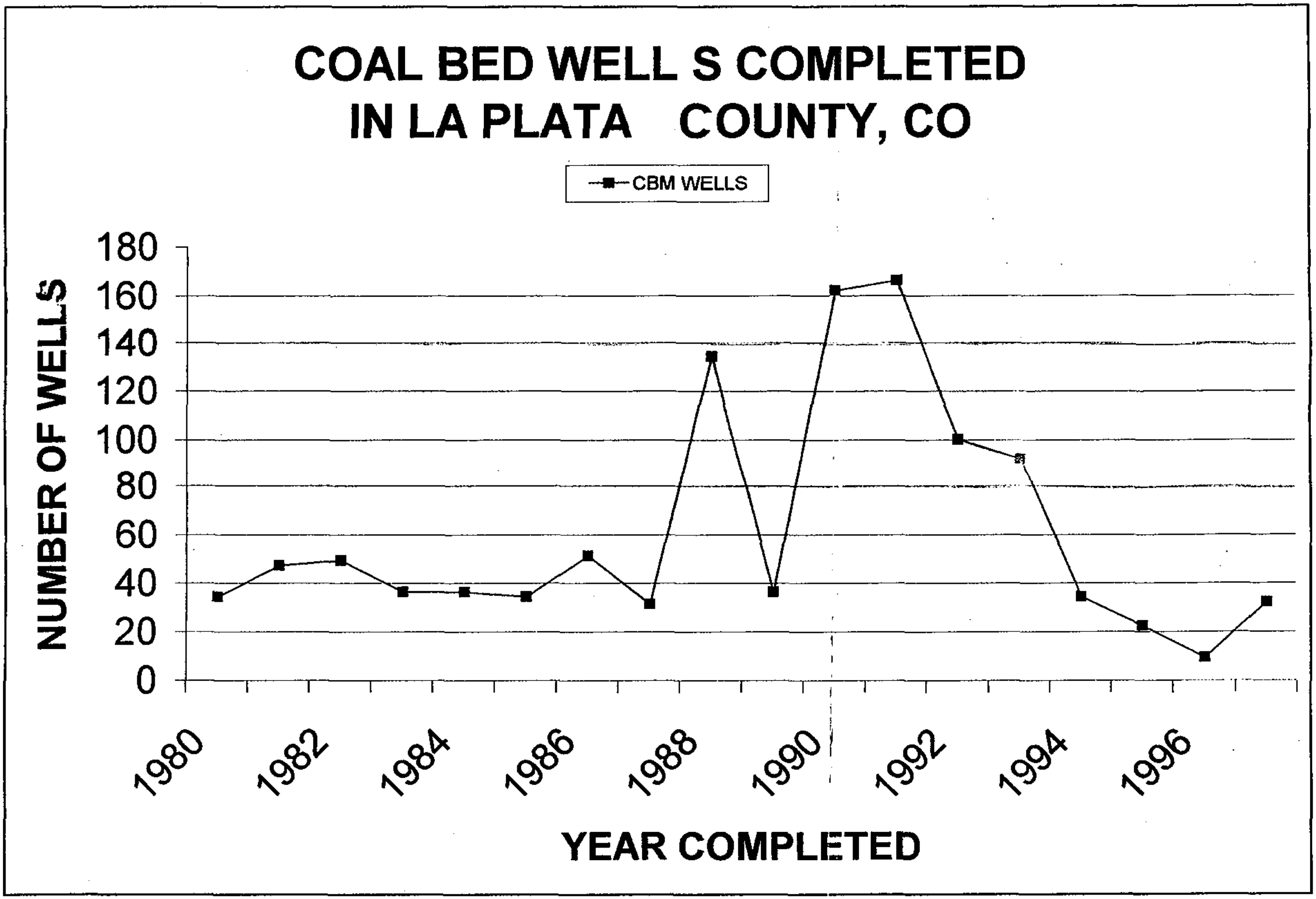
APPENDIX C

Chart 4

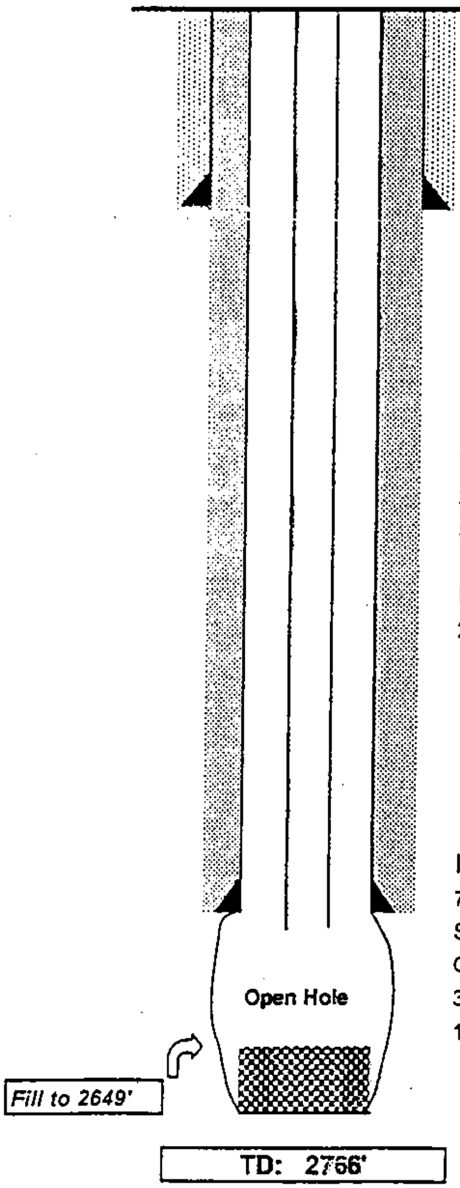
(La Plata County)

Coalbed Gas Wells Completed 1980-1998

(P.I/Dwights Energydata, Inc., 1999)


COAL BED WELL S COMPLETED
IN LA PLATA COUNTY, CO
CBM WELLS
NUMBER OF WELLS
180
160
140
120
100
80
60
40
20
0
1980
1982
1984
1986
1988
1990
1992
1994
1996
YEAR COMPLETED

WELLBORE DIAGRAM



SURFACE CASING
9-5/8" 36 lb/ft, J55, ST&C
Set at 324'
Cmtd. to surface with 200 sx.
Class "B" with 3% CaCl2

GEOLOGIC MARKERS

Nacimiento	Surface	
Animas	330'	KB
Kirtland	1491'	KB
Fruitland	2440'	KB

TUBING
2-7/8" 6.5 lb/ft J55 EUE
Set at 2624'

PUMP
2-1/2 x 1-3/4 x 12 x14.5 RHAC

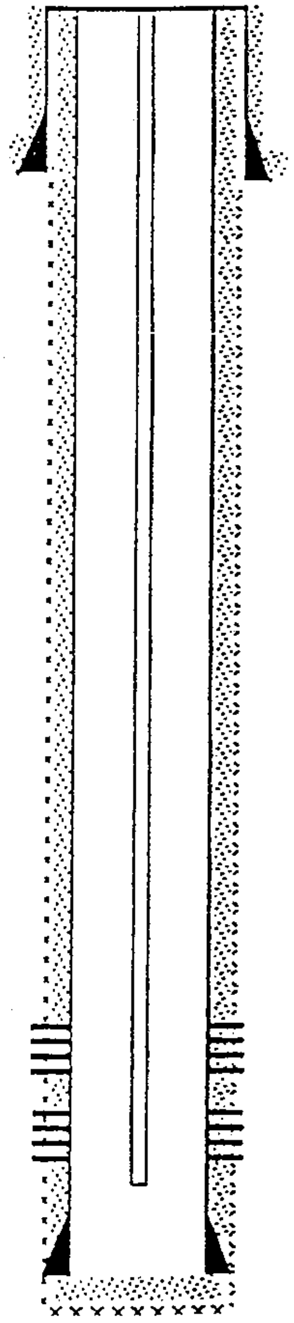
PERFORATIONS
None

INTERMEDIATE CASING
7" 20 lb/ft J55 LT&C
Set at 2610'
Cmtd. to surface with
370 sx. 65/35 Poz and
100 sx Class "B"

OPEN HOLE

	2610-2766'	KB
Coals:	2643-2664'	KB
(Gross)	2686-2700'	KB
	2741-2762'	KB

WELL BORE DIAGRAM



SURFACE CASING (12-1/4" Hole)
8-5/8", 24 #/ft, K-55 CSA 269' KB.
Cemented to surface with 460 sacks cement (CIRC).

PRODUCTION CASING (7-7/8" Hole)
5-1/2", 17 #/ft, K-55 CSA 2568' KB.
Cemented to surface with 620 sacks cement (CIRC).

GEOLOGIC MARKERS

FRUITLAND:	1688'
PICTURED CLIFFS:	2184'

TUBING
2-7/8", 6.4 #/ft, EUE 8RD tubing landed at 2231' KB with 3-1/4" tubing pump and gas anchor below.

PERFORATIONS (FRUITLAND)
1765' - 1943' KB
2098' - 2184' KB

PBTD: 2522' KB
TD: 2604' KB

APPENDIX C

Charts 7a,7b,7C

Gas vs. Water Production from Coalbed Wells

Equilibrium Adsorption Isotherm

(Hobbs, 1993;Price, 1993)

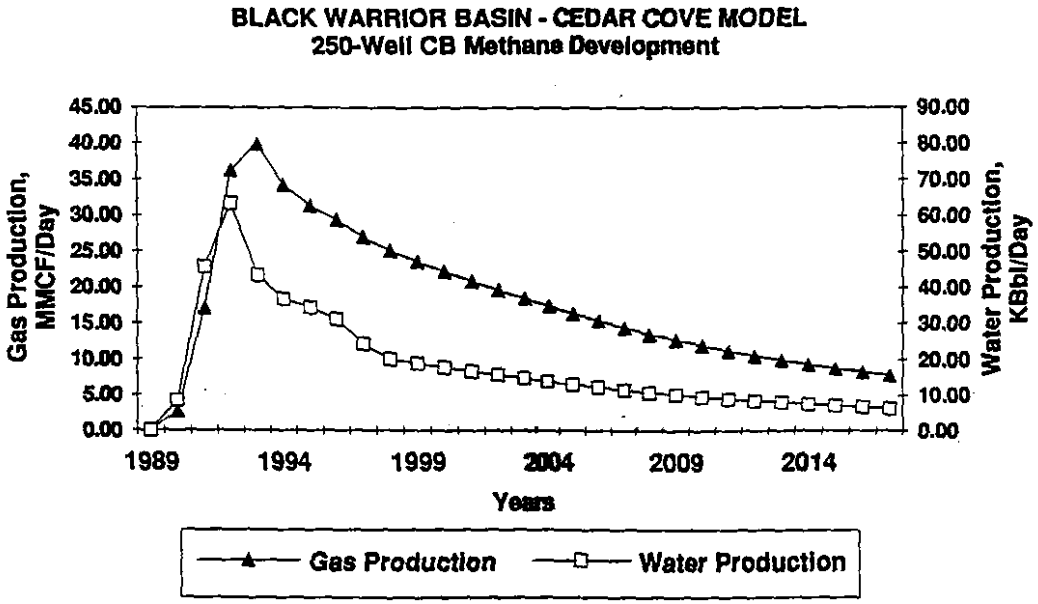


FIGURE 8. MODEL 250 WELL DEVELOPMENT PRODUCTION PROFILE

BLACK WARRIOR BASIN
CEDAR COVE FIELD
HYPOTHETICAL 250 WELL
COALBED METHANE DEVELOPMENT MODEL

ECONOMIC RESULTS

CASE 1:	1990 PRICE SCENARIO		
	Before Tax	After Tax	After Tax With Sec. 29
Future Net Profit* (SMM)	157.7	104.1	211.7
Profit/Investment*	1.8	1.2	2.4
% Internal Rate Return	14.9	12.1	25.3
Present Worth @ 15% ($ MM)	(0.3)	(7.4)	27.0

CASE 2:	ACTUAL GAS PRICES 1990-1992		
	Before Tax	After Tax	After Tax With Sec. 29
Future Net Profit* (SMM)	82.2	54.3	161.8
Profit/Investment*	0.9	0.6	1.8
% Internal Rate Return	7.6	6.2	19.7
Present Worth @ 15% ($ MM)	(22.9)	(22.3)	12.0

(* $ Undiscounted)

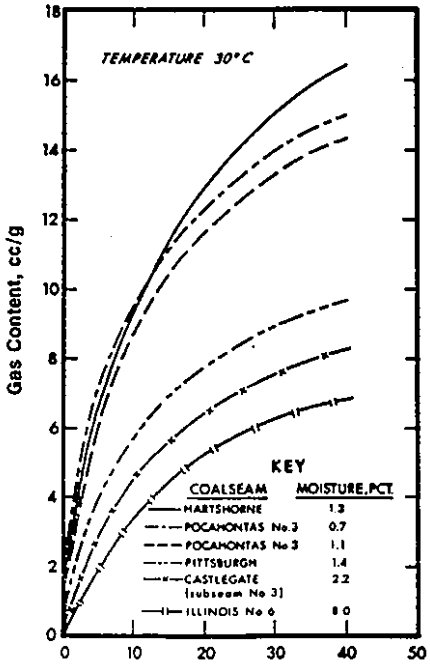
FIGURE 9

Table 3

GAS PVT TABLE

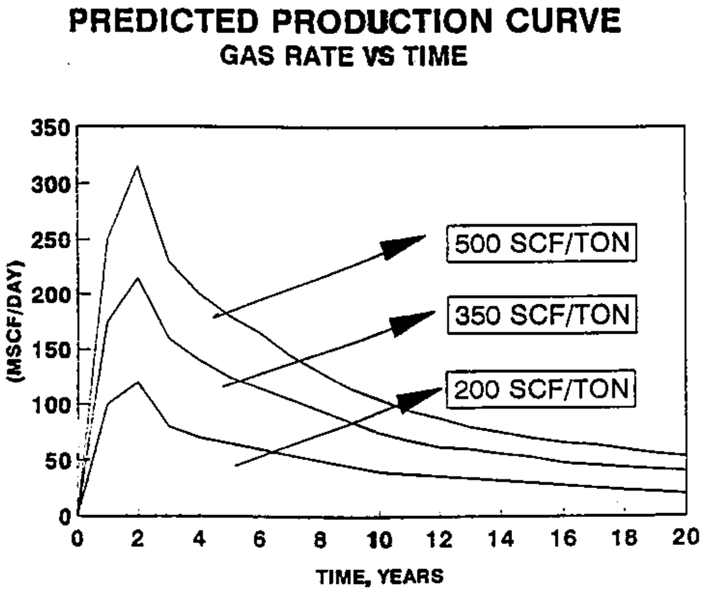
Pressure PSI	BGT RB/MSCF	Viscosity CP	BWT RB/STB	CWT 1/PSI	RST SCF/STB	VWT CP	RKPT K/KI
0015.00	187.5124	.0439	1.0247	.000003	.0000	.4000	1.000
0050.00	056.0259	.0194	1.0246	.000003	.0000	.4000	1.000
0100.00	027.8505	.0111	1.0245	.000003	.0000	.4000	1.000
0200.00	013.7639	.0116	1.0242	.000003	.0000	.4000	1.000
0300.00	009.0702	.0117	1.0239	.000003	.0000	.4000	1.000
0400.00	006.7254	.0117	1.0235	.000003	.0000	.4000	1.000
0500.00	005.3211	.0118	1.0232	.000003	.0000	.4000	1.000
0600.00	004.3871	.0118	1.0229	.000003	.0000	.4000	1.000
0700.00	003.7197	.0119	1.0226	.000003	.0000	.4000	1.000
0800.00	003.2175	.0121	1.0223	.000003	.0000	.4000	1.000
0900.00	002.8266	.0122	1.0220	.000003	.0000	.4000	1.000
1000.00	002.5194	.0124	1.0217	.000003	.0000	.4000	1.000
1100.00	002.2666	.0121	1.0214	.000003	.0000	.4000	1.000
1200.00	002.0583	.0129	1.0211	.000003	.0000	.4000	1.000
1300.00	001.8840	.0132	1.0289	.000003	.0000	.4000	1.000
1400.00	001.7362	.0134	1.0205	.000003	.0000	.4000	1.000
1500.00	001.6086	.0137	1.0202	.000003	.0000	.4000	1.000
1600.00	001.4987	.0140	1.0199	.000003	.0000	.4000	1.000
1700.00	001.4008	.0143	1.0196	.000003	.0000	.4000	1.000
1800.00	001.3154	.0145	1.0193	.000003	.0000	.4000	1.000

Gas Specific Gravity (Air = 1.0) = .570
Reservoir Temperature (Deg. F) = 100.000
Fracture Porosity in Percent (%) = 2.000
Coal Thickness (in Feet) = 100.000



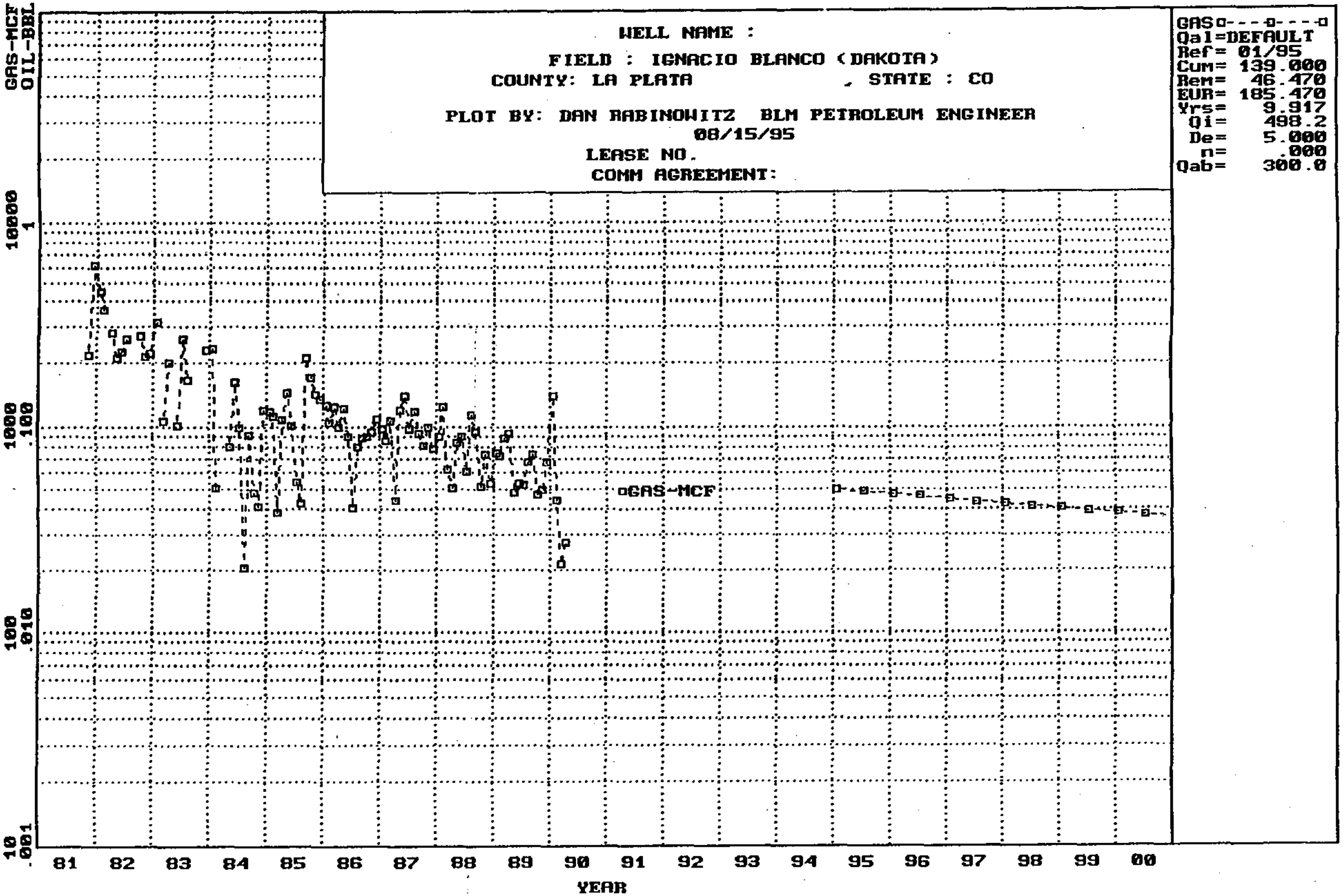
EQUILIBRIUM ADSORBTION ISOTHERMS

Figure 1



PREDICTED PRODUCTION CURVE
GAS RATE VS TIME

Figure 2


WELL NAME :

FIELD : IGNACIO BLANCO (DAKOTA)
COUNTY: LA PLATA , STATE : CO

PLOT BY: DAN RABINOWITZ BLM PETROLEUM ENGINEER
08/15/95
LEASE NO.
COMM AGREEMENT:

GAS□---□---□
Qal=DEFAULT
Ref= 01/95
Cum= 139.000
Rem= 46.470
EUR= 185.470
Yrs= 9.917
Qi= 498.2
De= 5.000
n= .000
Qab= 300.0

GROSS PRODUCTION PLOT

APPENDIX C

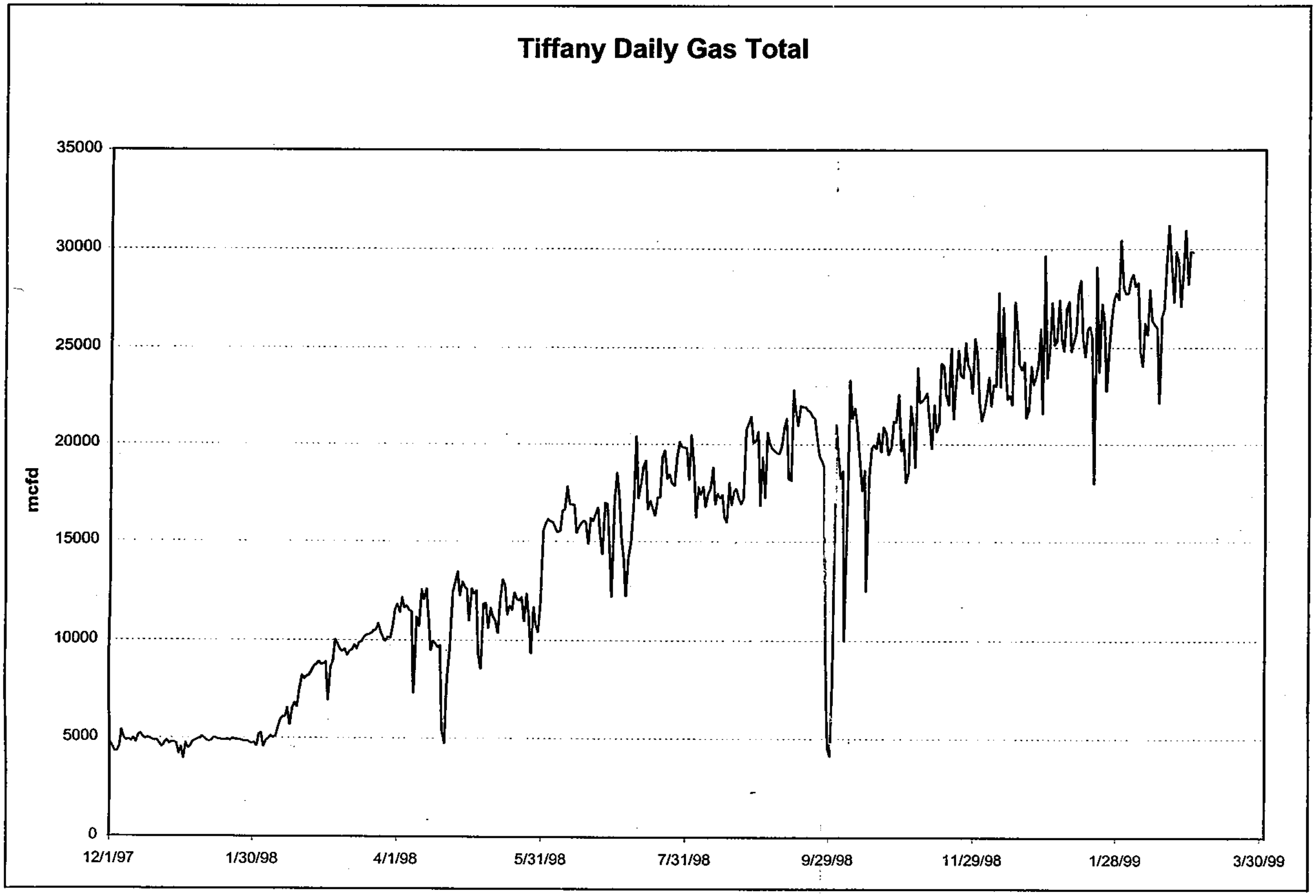
Chart 9

Enhanced Coalbed Methane Recovery

Tiffany Unit, La Plata County

Production Response to Nitrogen Injection Beginning January 1998

(Amoco)


Tiffany Daily Gas Total
35000
30000
25000
20000
15000
10000
5000
0
mcfd
12/1/97
1/30/98
4/1/98
5/31/98
7/31/98
9/29/98
11/29/98
1/28/99
3/30/99

APPENDIX C

Chart 10

(La Plata County)

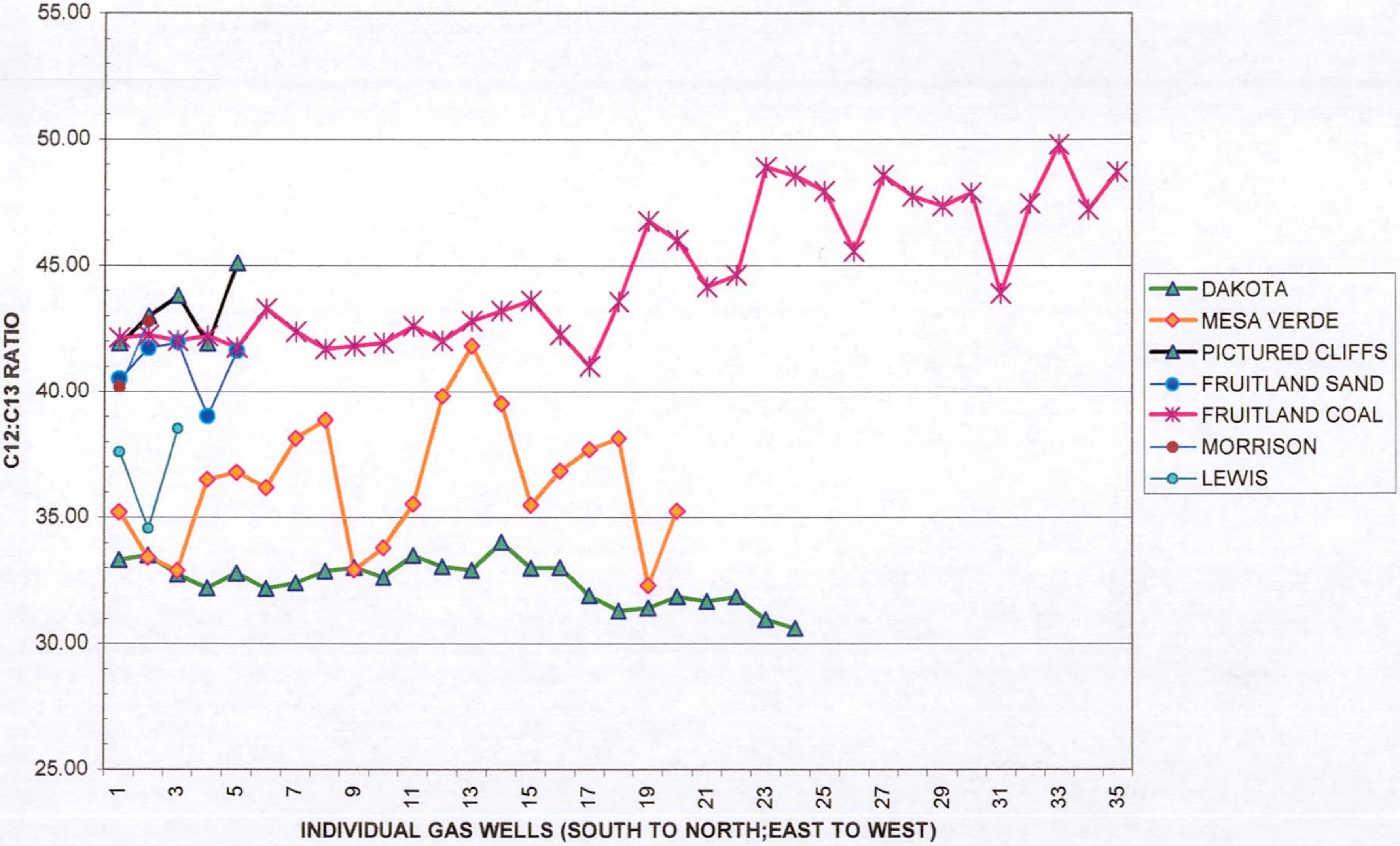
Carbon Isotopic Signatures

of

Produced Gas Horizons

(BLM database)

STABLE CARBON ISOTOPE RATIOS AT IGNACIO-BLANCO GAS WELLS



APPENDIX C

Chart 11

La Plata County

Water Well Methane Concentrations

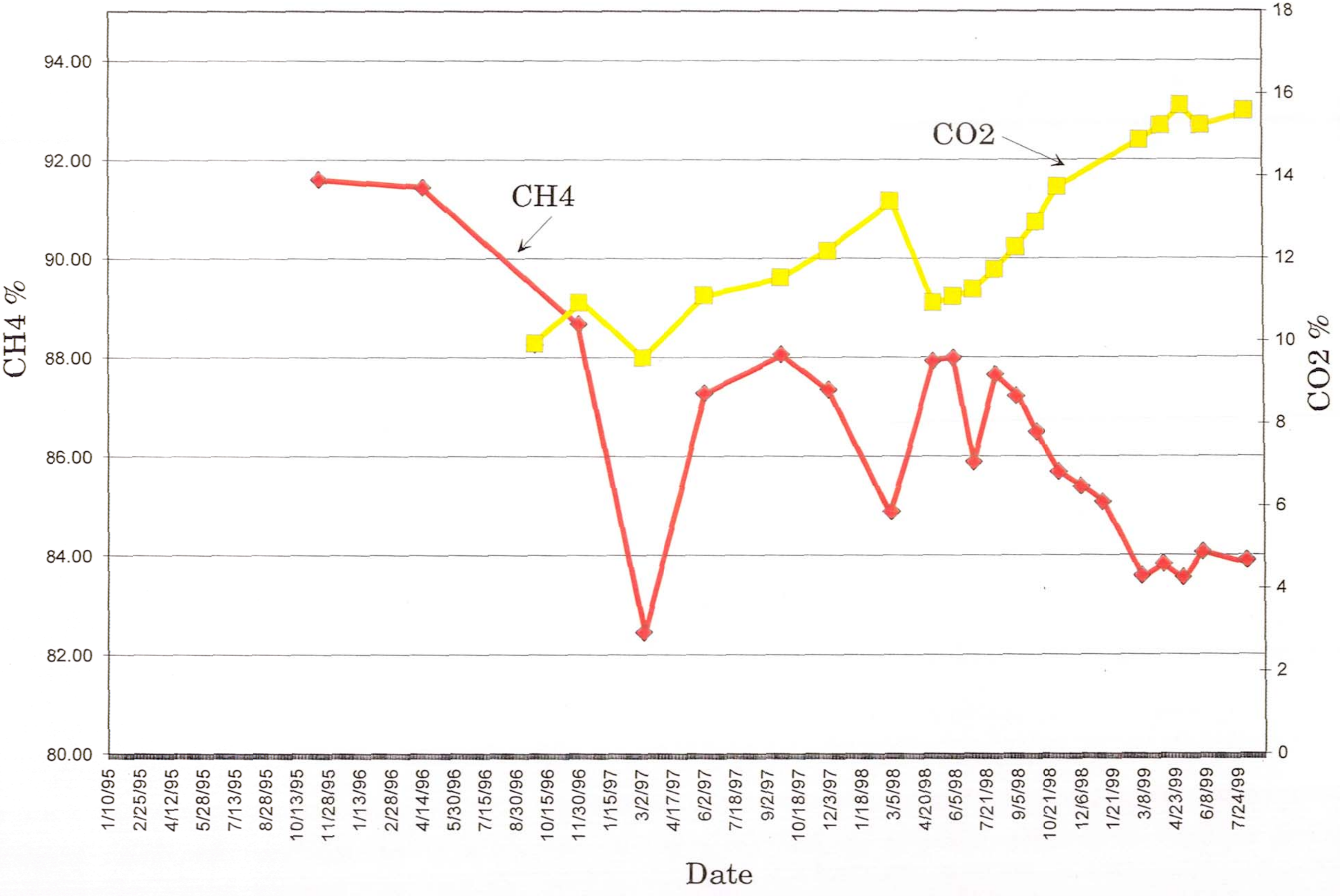
in 1998 in

Proximity to Remediated Gas Wells

(BLM database)

METHANE CONCENTRATION TREND SINCE 1990-94	**ALL WELLS TESTED IN 1998**	**TIFFANY UNIT AND PERIPHERY**	**HUBER INFILL AREA**	**1998 TESTS NOT INCLUDING HUBER & TIFFANY**
INCREASE IN CH4	14	2	1	11
DECREASE IN CH4	43	2	9	32
NO CHANGE*IN CH4	89	17	5	67
	OF THOSE WITH NO CONFIRMED CHANGE, THE LAST TEST WAS:			
< PRIOR TEST	52	5	3	44
> PRIOR TEST	21	6	1	14
= PRIOR TEST	16	6	1	9
NO PRIOR BASELINE ESTABLISHED	15	0	9	6
TOTAL	161	21	24	116

Valencia Canyon Gas Collector - Methane and CO2 %



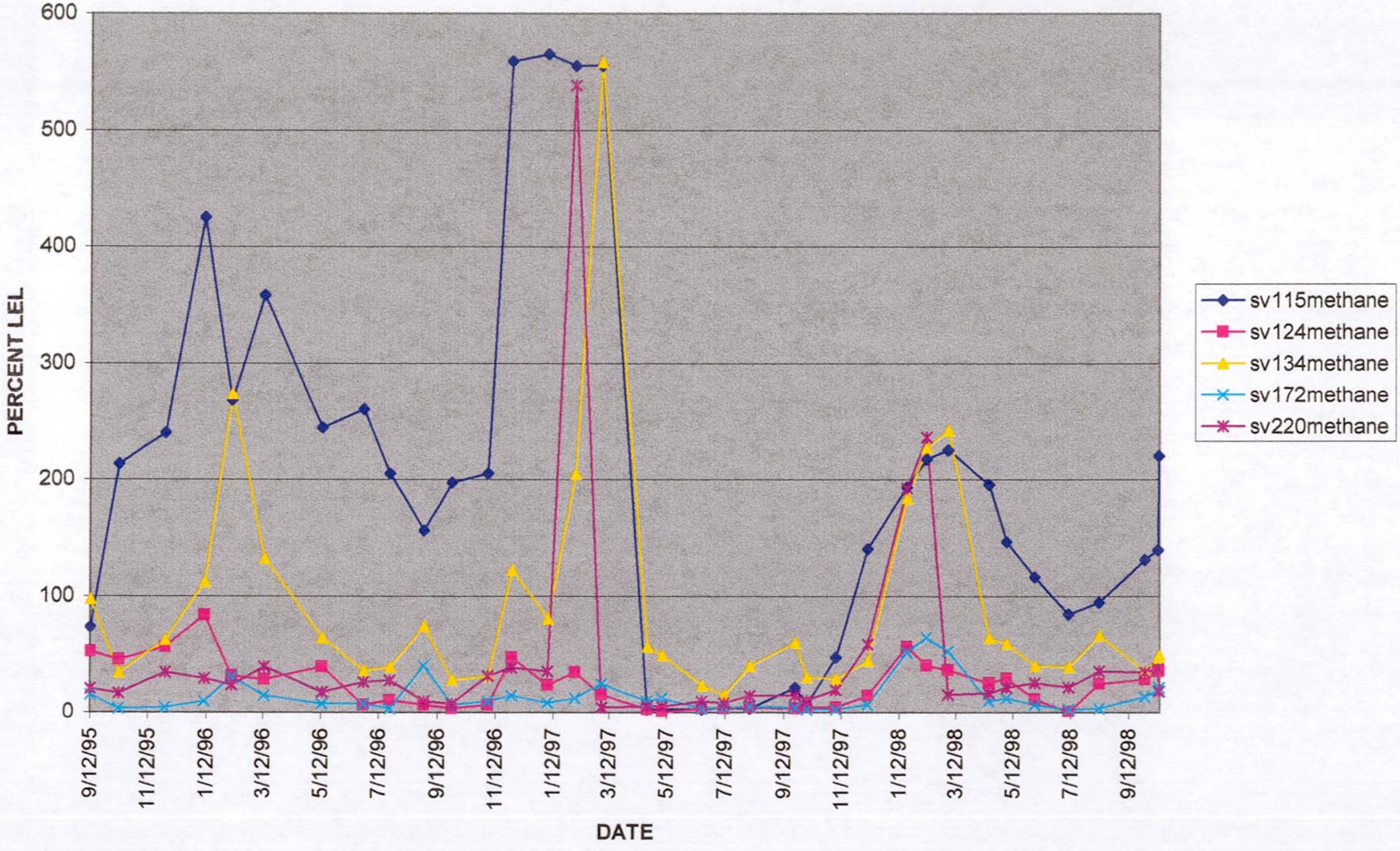
APPENDIX C

Chart 13

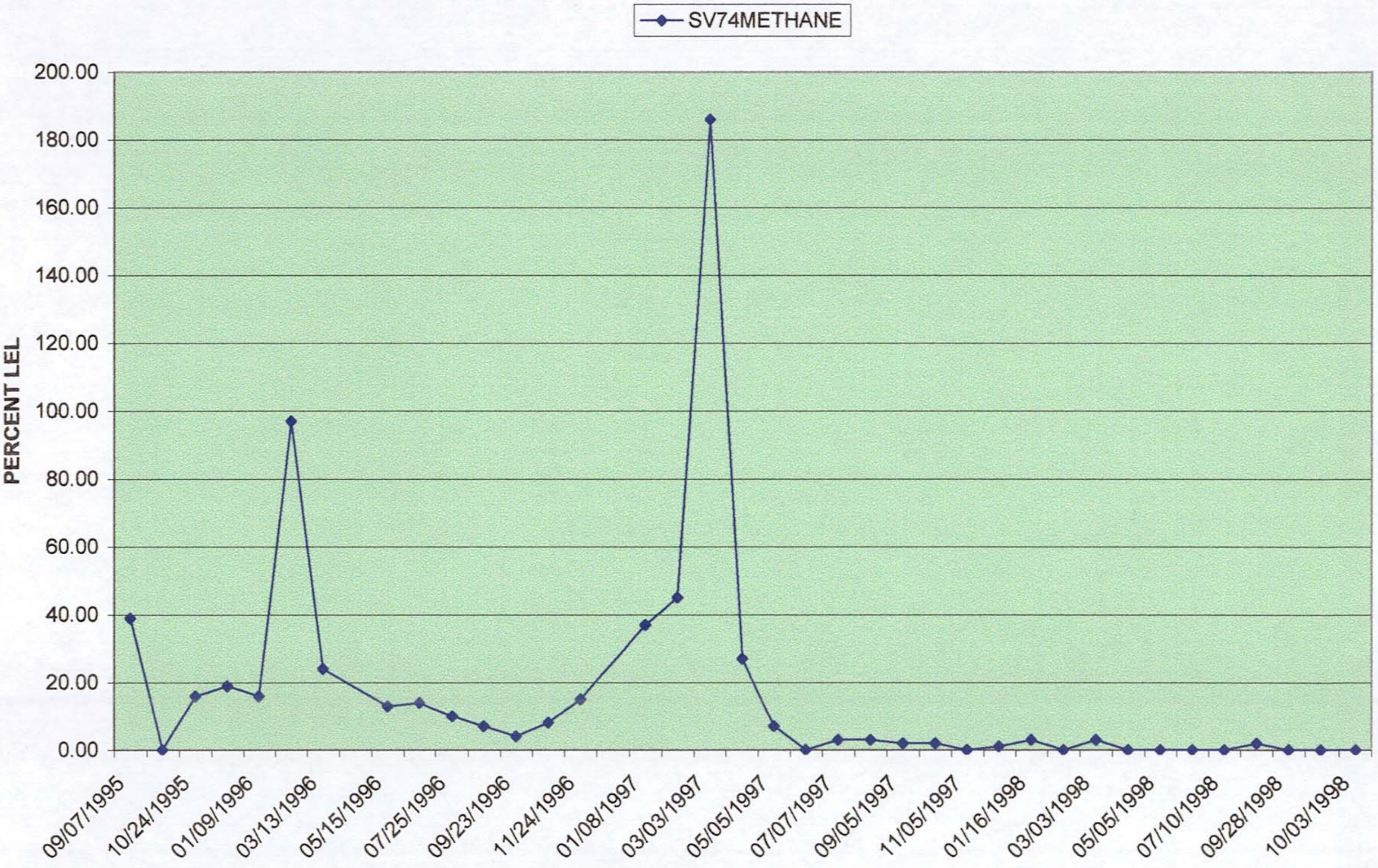
La Plata County

Annual Soil Vapor Methane Concentration Cyclical Trends

CYCLICAL LEL TRENDS IN T33N,R11W,SEC31(#115,#124,#134,#220)&SEC19(#172)



SV74 METHANE IN T32N,R12W,SEC 1



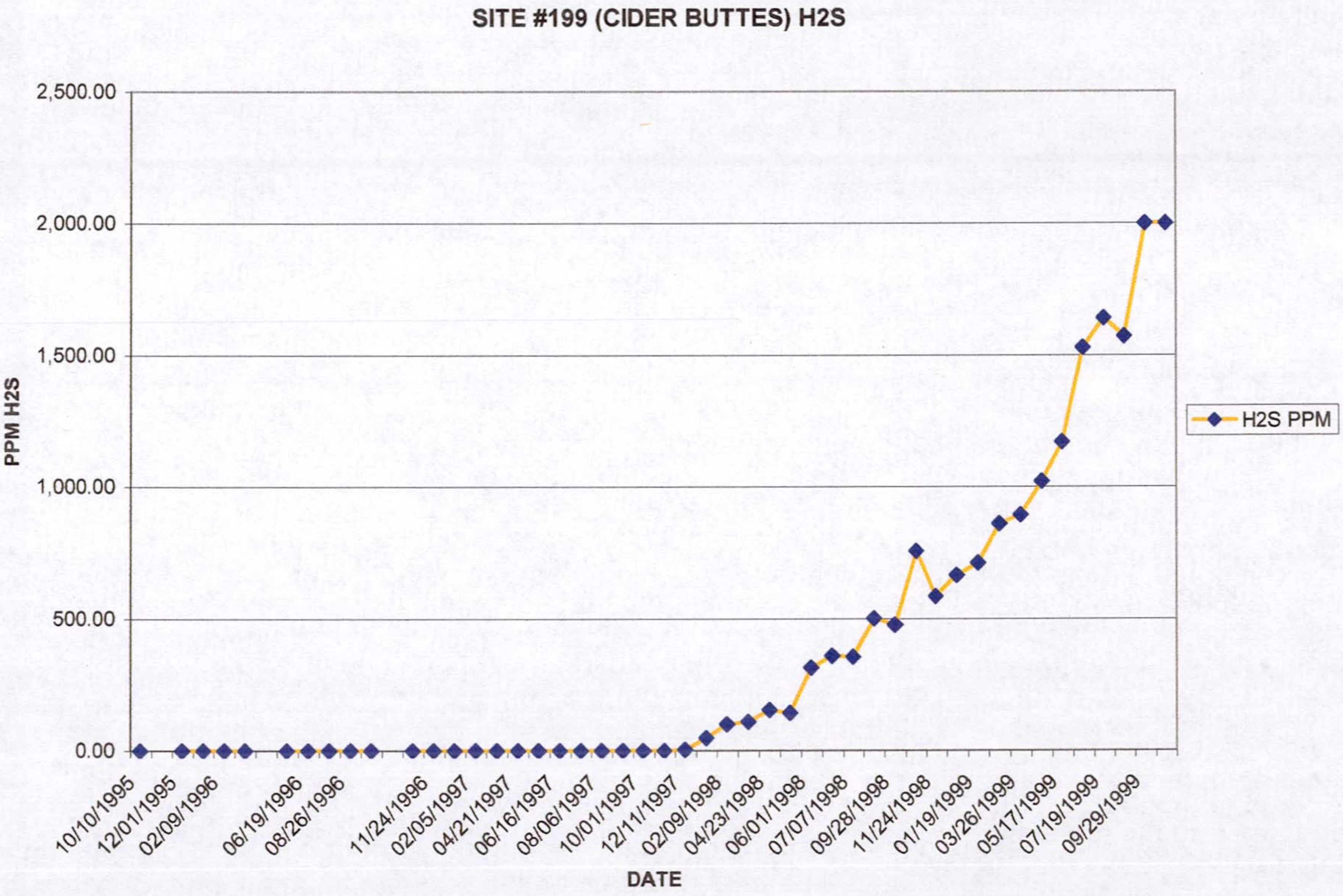
APPENDIX C

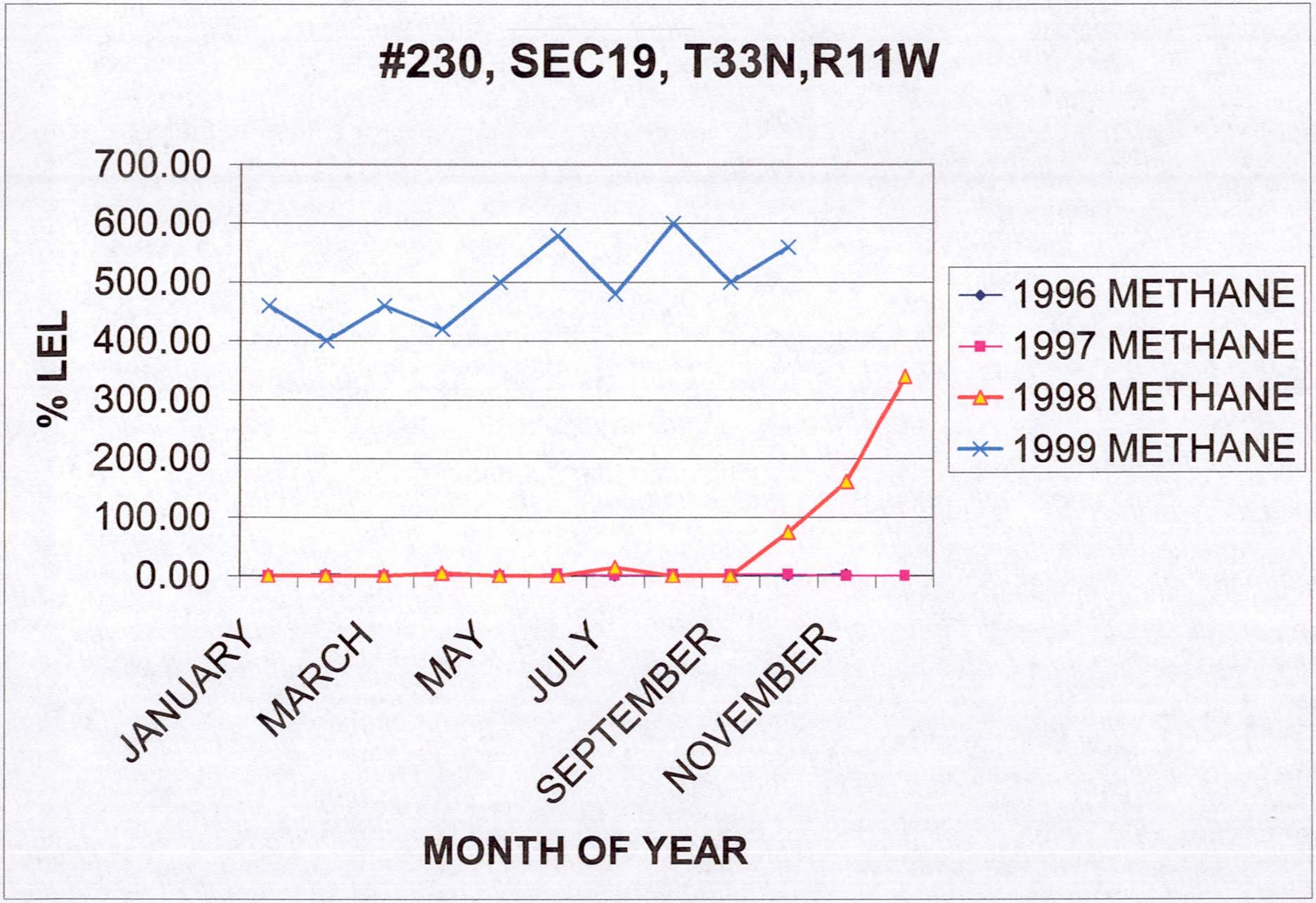
Chart 14b,14c

Soil Vapor Trends

– Hydrogen Sulfide at Cinder Buttes

– Methane One Mile South of Valencia Canyon Gap


SITE #199 (CIDER BUTTES) H2S
PPM H2S
2,500.00
2,000.00
1,500.00
1,000.00
500.00
0.00
10/10/1995
12/01/1995
02/09/1996
06/19/1996
08/26/1996
11/24/1996
02/05/1997
04/21/1997
06/16/1997
08/06/1997
10/01/1997
12/11/1997
02/09/1998
04/23/1998
06/01/1998
07/07/1998
09/28/1998
11/24/1998
01/19/1999
03/26/1999
05/17/1999
07/19/1999
09/29/1999
DATE
H2S PPM



#230, SEC19, T33N,R11W

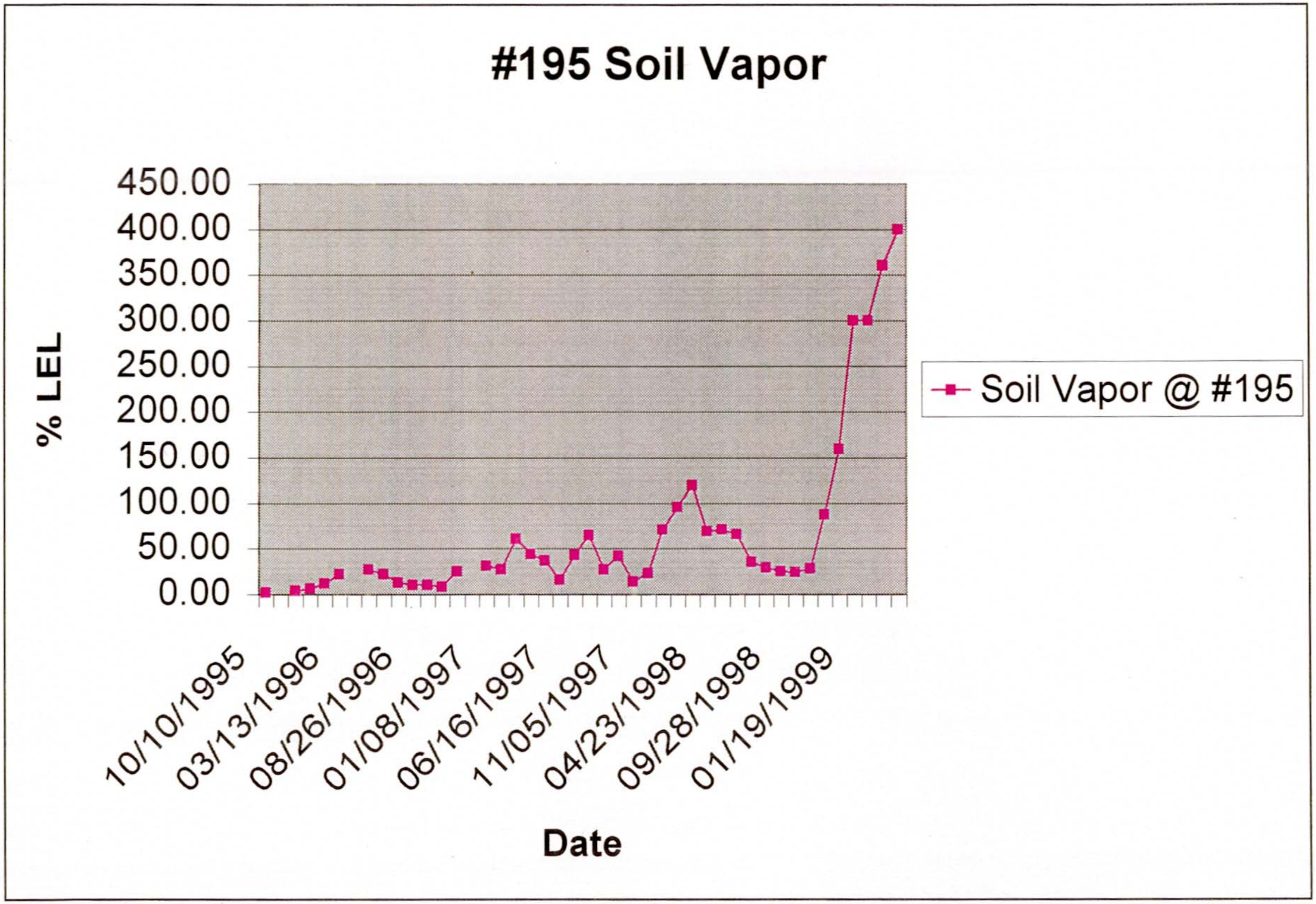
APPENDIX C

Chart 15

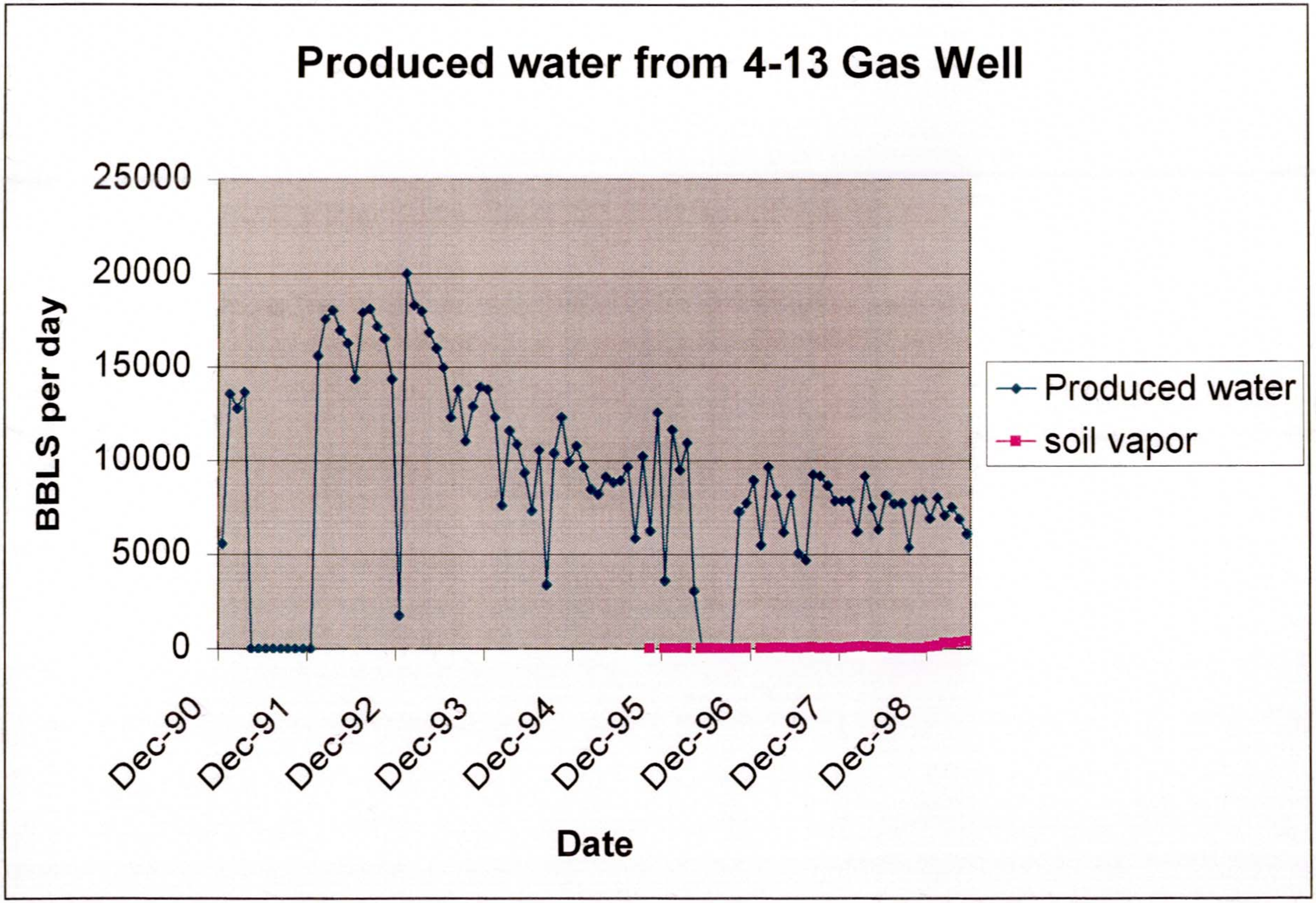
Methane Concentration Increase at Soil Vapor Tube

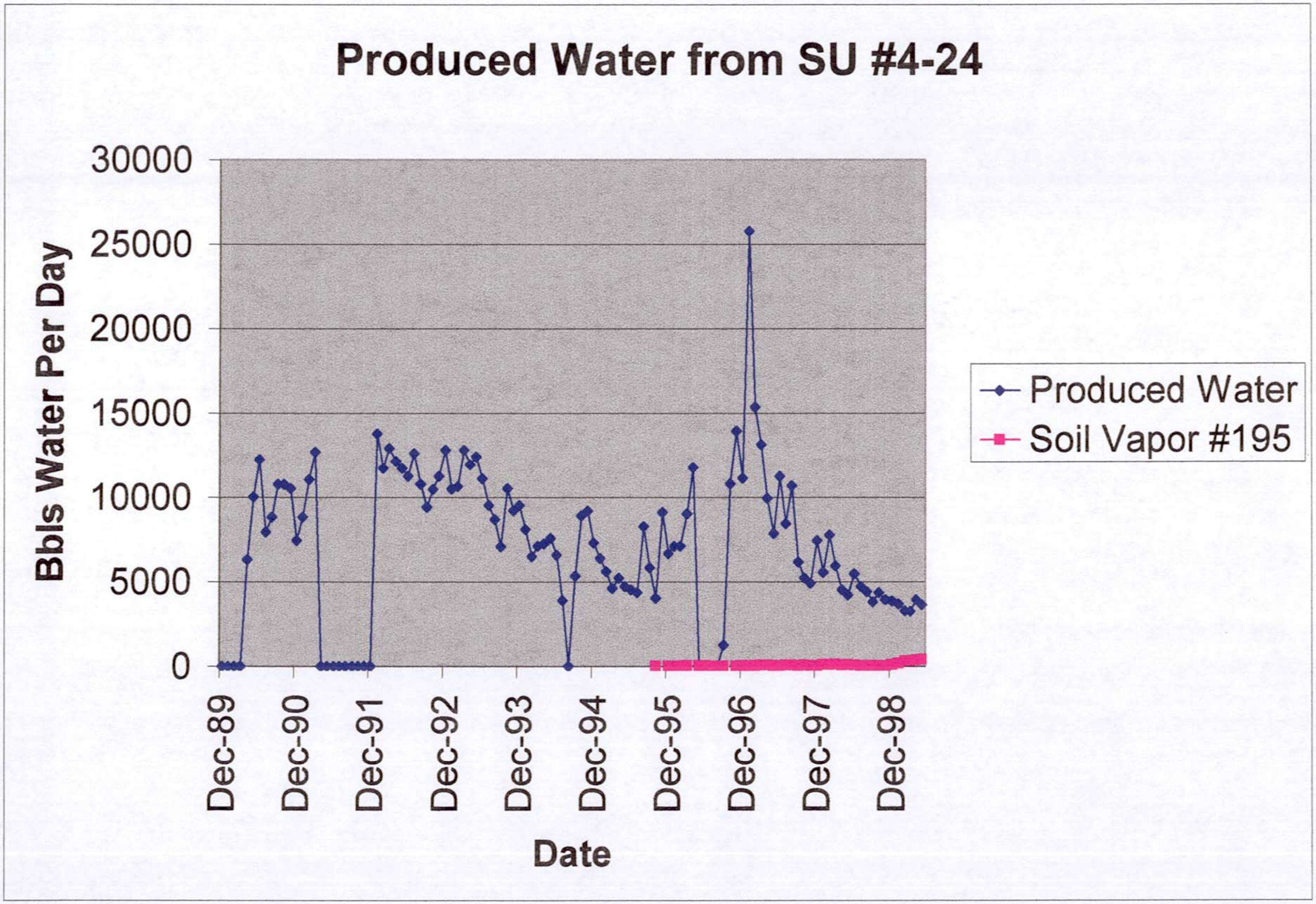
And

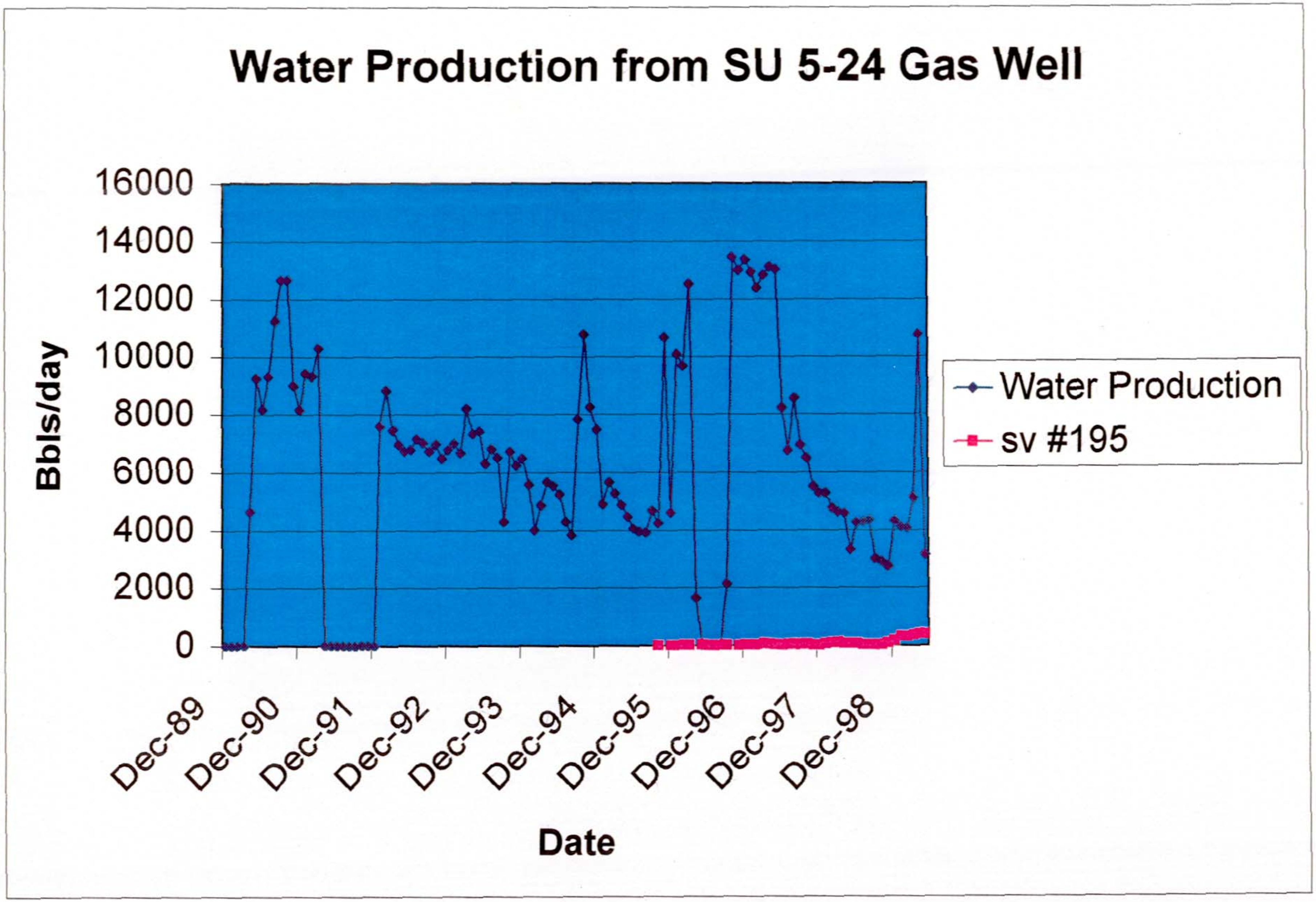
Water Production from Neighboring Coalbed Gas Wells



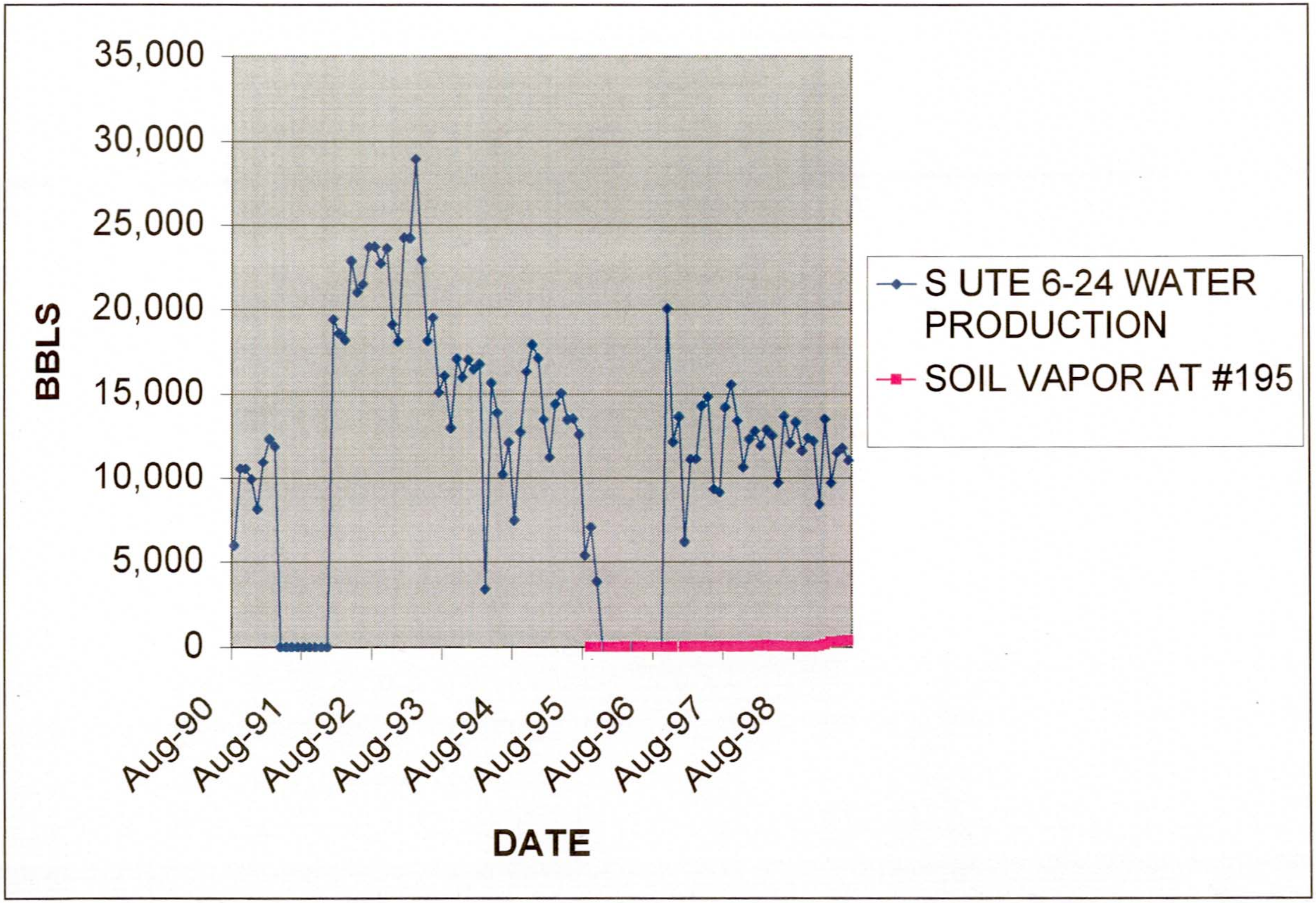
#195 Soil Vapor

Produced water from 4-13 Gas Well
BBLS per day
25000
20000
15000
10000
5000
0
Dec-90
Dec-91
Dec-92
Dec-93
Dec-94
Dec-95
Dec-96
Dec-97
Dec-98
Date
Produced water
soil vapor


Produced Water from SU #4-24
Bbls Water Per Day
30000
25000
20000
15000
10000
5000
0
Dec-89
Dec-90
Dec-91
Dec-92
Dec-93
Dec-94
Dec-95
Dec-96
Dec-97
Dec-98
Date
Produced Water
Soil Vapor #195



Water Production from SU 5-24 Gas Well
16000
14000
12000
10000
8000
6000
4000
2000
0
Bbls/day
Dec-89
Dec-90
Dec-91
Dec-92
Dec-93
Dec-94
Dec-95
Dec-96
Dec-97
Dec-98
Date
Water Production
sv #195


35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
BBLS
Aug-90
Aug-91
Aug-92
Aug-93
Aug-94
Aug-95
Aug-96
Aug-97
Aug-98
DATE
S UTE 6-24 WATER PRODUCTION
SOIL VAPOR AT #195

APPENDIX C

Chart 16

CUMULATIVE WATER PRODUCTION

from

CBM GAS WELLS

In

The Ignacio-Blanco Field

Location	API Number	Cum Water Production (Bbl)
33N-11W-28	050670782700	5,555
3N-0W-32	050670815300	5,517
0-0-0	050670000000	5,450
3N-0W-13	050670623600	5,314
32N-9W-14	050670638500	5,163
32N-11W-21	050670762900	5,090
3N-0W-17	050670815200	4,763
32N-11W-7	050670697900	4,472
3N-0W-16	050670814000	4,310
3N-0W-16	050670815500	4,077
33N-8W-29	050670764200	3,801
32N-9W-13	050670816300	3,739
32N-7W-14	050670797300	3,732
3N-0W-11	050670623800	3,337
32N-8W-15	050670817000	3,243
32N-11W-9	050670799300	3,124
3N-0W-17	050670737200	3,122
33N-8W-31	050670761900	2,742
3N-0W-2	050670630300	2,720
3N-0W-16	050670815600	2,653
3N-0W-13	050670814400	2,556
32N-11W-4	050670760600	2,387
32N-11W-20	050670774000	2,333
33N-8W-30	050670701800	2,230
34N-6W-32	050670648200	2,108
33N-11W-11	050670728000	2,054
3N-0W-2	050670623900	1,890
32N-9W-1	050670624100	1,767
32N-11W-20	050670758600	1,688
3N-0W-1	050670624000	1,565
3N-1W-20	050670660600	1,182
3N-1W-18	050670692400	1,036
3N-1W-19	050670646100	1,016
35N-6W-22	050670667000	990
32N-11W-16	050670762800	946
33N-8W-18	050670746100	831
35N-6W-27	050670712600	530
3N-1W-19	050670639600	432
32N-9W-1	050670624100	401
3N-1W-18	050670647800	194
33N-10W-9	050670641300	143
34N-11W-36	050670772900	1
33N-6W-18	050670667900	0
32N-10W-13	050670745900	0
32N-11W-24	050670793900	0
32N-9W-18	050670767600	0
32N-11W-21	050670800300	0
32N-10W-11	050670754200	0
Grand Total:		246,376,400

Location	API Number	Cum Water Production (Bbl)
32N-11W-6	050670720700	24,881
33N-9W-14	050670787700	23,804
32N-9W-14	050670634600	23,791
33N-8W-7	050670791000	23,247
33N-11W-33	050670739700	22,944
34N-7W-22	050670798200	22,920
33N-6W-7	050670714200	22,878
32N-11W-3	050670768900	21,919
33N-7W-10	050670801300	21,280
32N-6W-15	050670754400	21,099
32N-7W-7	050670710000	21,003
34N-9W-21	050670666900	20,986
32N-11W-17	050670775000	20,729
32N-7W-23	050670800000	20,676
0-0-0	050670808100	20,463
32N-11W-13	050670770300	20,232
32N-6W-9	050670751700	19,535
34N-7W-35	050670801400	19,180
32N-11W-2	050670773500	19,149
3N-1W-22	050670697800	19,000
32N-11W-15	050670769000	18,742
33N-9W-36	050670805800	18,431
32N-11W-4	050670762200	18,229
32N-11W-11	050670762500	18,138
32N-11W-8	050670773700	18,133
32N-11W-22	050670763000	18,083
32N-11W-23	050670771100	17,535
32N-6W-6	050670803600	17,332
34N-6W-15	050670671700	17,268
32N-6W-19	050670723200	17,000
32N-11W-9	050670762300	16,783
33N-8W-24	050670747000	16,137
35N-8W-25	050670755000	15,957
33N-8W-18	050670793100	15,947
34N-8W-24	050670777100	15,641
33N-9W-31	050670811400	15,322
33N-7W-20	050670683600	15,241
35N-6W-27	050670788700	14,615
32N-6W-10	050670762100	14,478
33N-10W-21	050670803100	14,093
3N-0W-29	050670814300	13,551
34N-9W-30	050670811100	13,096
34N-9W-33	050670806300	12,086
34N-6W-19	050670699600	12,021
34N-8W-16	050670769400	11,898
0-0-0	050670000000	11,735
32N-11W-5	050670720600	11,472
34N-6W-7	050670798900	10,756
3N-0W-15	050670815400	10,272
32N-8W-13	050670648700	10,258
33N-11W-12	050670694200	9,928
32N-11W-3	050670770100	9,769
32N-11W-4	050670760600	9,594
33N-6W-34	050670797900	9,369
34N-7W-28	050670796100	9,237
32N-6W-20	050670724300	8,992
3N-0W-12	050670816200	8,578
33N-6W-3	050670668800	8,009
32N-7W-15	050670797200	6,362
32N-6W-5	050670808400	6,230
32N-11W-17	050670647400	5,894
32N-8W-21	050670816500	5,572

Location	API Number	Cum Water Production (Bbl)
34N-6W-30	050670624300	41,273
34N-7W-16	050670798100	41,229
33N-10W-32	050670736900	40,794
34N-8W-24	050670785100	40,759
33N-6W-34	050670662600	40,727
34N-7W-5	050670637300	40,654
32N-8W-5	050670729900	40,525
33N-11W-34	050670778000	40,345
34N-7W-21	050670785800	40,222
33N-11W-12	050670694700	40,073
32N-8W-5	050670727700	40,023
32N-8W-9	050670571300	39,706
33N-6W-32	050670663100	39,623
32N-8W-7	050670721800	39,426
32N-10W-12	050670752100	38,865
34N-7W-24	050670636300	38,399
32N-7W-10	050670752000	37,332
32N-6W-10	050670760100	37,098
33N-11W-16	050670704100	36,290
33N-6W-27	050670661700	36,271
35N-6W-31	050670694900	36,234
33N-8W-29	050670764100	36,162
33N-7W-24	050670704500	36,115
33N-11W-1	050670774800	36,106
34N-7W-20	050670785000	35,481
34N-8W-36	050670679600	34,819
33N-8W-15	050670789400	34,486
33N-11W-11	050670742700	33,815
33N-8W-7	050670791700	33,262
34N-7W-30	050670798300	33,204
32N-8W-3	050670729800	32,731
32N-6W-3	050670762000	32,614
33N-10W-18	050670692300	32,509
34N-6W-18	050670653200	32,418
34N-6W-19	050670635600	32,287
32N-6W-7	050670804000	32,152
34N-7W-5	050670723600	32,149
34N-10W-20	050670724900	32,003
32N-8W-10	050670722000	31,997
34N-7W-11	050670798000	31,826
32N-8W-24	050670711000	31,311
32N-6W-16	050670751600	31,134
3N-0W-6	050670814700	31,118
33N-9W-30	050670811500	30,650
32N-11W-13	050670762400	30,419
32N-11W-8	050670788400	30,044
34N-6W-20	050670628500	30,042
32N-11W-24	050670770400	29,327
34N-7W-12	050670685900	29,016
32N-11W-17	050670775100	28,805
33N-11W-15	050670745600	28,539
34N-7W-19	050670783400	28,244
32N-11W-1	050670770000	28,216
34N-6W-2	050670671500	26,886
34N-10W-25	050670744200	26,324
33N-8W-21	050670789500	26,291
34N-6W-29	050670648300	26,103
32N-11W-14	050670777300	25,954
33N-10W-7	050670692200	25,518
33N-9W-25	050670685800	25,459
34N-7W-36	050670787100	25,076
32N-10W-17	050670691800	25,067

Location	API Number	Cum Water Production (Bbl)
33N-10W-30	050670748600	56,117
34N-7W-18	050670661300	55,914
33N-11W-28	050670754100	55,879
34N-7W-26	050670672300	55,546
32N-6W-18	050670753000	55,513
33N-9W-12	050670765300	55,476
32N-8W-8	050670721900	54,597
34N-7W-22	050670653000	53,810
33N-10W-11	050670703600	53,447
33N-7W-36	050670805600	53,376
33N-9W-24	050670787800	53,334
32N-7W-16	050670800100	52,596
33N-11W-25	050670743200	52,308
35N-8W-31	050670814800	52,275
33N-8W-32	050670702200	52,243
33N-8W-31	050670761800	52,102
32N-10W-17	050670718400	51,708
33N-6W-33	050670670600	50,929
32N-8W-6	050670727000	50,764
32N-7W-21	050670800200	50,744
32N-8W-10	050670727900	50,691
33N-6W-17	050670663500	50,626
34N-9W-15	050670742300	49,703
33N-10W-9	050670726800	49,639
32N-7W-5	050670785700	49,443
32N-8W-14	050670710700	49,324
32N-11W-11	050670770200	49,162
34N-7W-17	050670784500	49,132
33N-11W-23	050670766000	49,095
33N-6W-33	050670707700	48,679
33N-7W-24	050670744800	48,640
33N-8W-27	050670769200	48,527
33N-7W-14	050670714400	48,452
33N-9W-14	050670726400	47,749
33N-9W-36	050670724200	47,748
33N-7W-22	050670743400	47,595
34N-7W-23	050670670300	47,369
33N-8W-26	050670739300	47,178
32N-7W-17	050670784200	47,051
33N-8W-36	050670778200	46,687
33N-8W-9	050670793300	46,417
33N-10W-18	050670736000	46,331
32N-7W-7	050670784300	45,932
33N-7W-35	050670804500	45,699
32N-7W-8	050670786800	45,677
34N-10W-26	050670744400	45,157
34N-7W-25	050670798800	45,014
33N-6W-28	050670663900	44,449
33N-8W-35	050670778100	44,416
32N-10W-5	050670722200	44,375
33N-9W-35	050670724000	44,327
34N-7W-8	050670742500	44,244
32N-10W-6	050670722300	44,115
32N-8W-4	050670743600	43,328
32N-8W-4	050670727200	43,097
3N-0W-4	050670814900	42,910
32N-7W-17	050670786700	42,724
34N-7W-23	050670670200	42,453
32N-8W-9	050670730100	42,311
32N-6W-21	050670723900	41,864
33N-7W-6	050670797700	41,512
35N-7W-30	050670714800	41,369

Location	API Number	Cum Water Production (Bbl)
33N-6W-32	050670664100	69,936
34N-8W-23	050670791600	69,782
32N-11W-18	050670773800	69,585
33N-8W-3	050670790600	69,415
33N-8W-20	050670789300	69,155
33N-11W-14	050670740800	68,876
33N-7W-25	050670744900	68,828
34N-7W-18	050670784600	68,295
34N-10W-25	050670744100	68,006
33N-11W-27	050670782600	67,715
34N-8W-12	050670754800	67,275
32N-11W-2	050670770600	67,204
33N-9W-25	050670727600	67,011
34N-9W-32	050670807500	66,234
33N-8W-19	050670745100	65,902
33N-8W-6	050670791800	65,886
33N-7W-34	050670699900	65,536
33N-8W-5	050670799000	65,301
32N-7W-6	050670758200	64,810
33N-10W-17	050670765600	64,696
33N-8W-36	050670772400	64,620
33N-11W-14	050670740700	64,461
34N-7W-16	050670792700	64,370
34N-7W-9	050670720200	63,480
32N-7W-6	050670793600	63,212
33N-8W-23	050670790800	63,112
32N-7W-22	050670799900	62,512
34N-7W-8	050670785600	62,160
34N-7W-7	050670685600	62,151
34N-6W-4	050670733100	61,915
33N-8W-4	050670786000	61,671
35N-7W-32	050670723800	61,654
32N-8W-11	050670709300	61,465
32N-11W-18	050670788800	61,437
33N-7W-15	050670739100	61,248
34N-7W-7	050670718900	60,950
34N-8W-16	050670790900	60,784
34N-7W-10	050670632200	60,759
32N-7W-18	050670710100	60,747
33N-10W-34	050670721400	60,727
32N-11W-6	050670767900	60,636
34N-6W-31	050670648100	60,596
32N-6W-9	050670763200	60,386
32N-8W-1	050670708900	60,279
33N-7W-32	050670745400	60,278
33N-9W-35	050670724100	60,261
33N-8W-1	050670786100	59,884
34N-7W-4	050670750100	59,792
34N-7W-19	050670684500	59,591
34N-8W-12	050670769700	59,590
34N-6W-10	050670781700	59,343
32N-7W-8	050670783800	58,727
33N-6W-19	050670702500	58,568
33N-6W-19	050670665000	58,403
34N-7W-9	050670722800	58,372
35N-8W-26	050670779900	58,206
33N-7W-23	050670741200	57,868
32N-11W-12	050670762600	57,692
33N-6W-17	050670663400	57,569
34N-10W-26	050670744300	57,471
33N-8W-27	050670769300	56,528
33N-7W-12	050670714300	56,412

Location	API Number	Cum Water Production (Bbl)
32N-10W-20	050670740900	88,241
33N-11W-13	050670780700	88,082
32N-7W-18	050670710200	88,046
34N-7W-9	050670656300	87,795
32N-8W-8	050670727800	87,738
32N-9W-11	050670765200	87,700
33N-6W-21	050670676200	87,401
33N-7W-30	050670741300	87,295
34N-7W-31	050670672800	86,575
34N-7W-28	050670786600	86,463
32N-8W-11	050670709200	85,701
32N-9W-12	050670729100	85,588
33N-8W-12	050670699700	85,376
32N-10W-20	050670739900	84,627
34N-7W-17	050670785200	84,185
34N-9W-35	050670689400	83,746
33N-8W-25	050670790200	83,548
34N-8W-13	050670777800	83,287
32N-8W-18	050670735000	83,155
34N-9W-10	050670742400	83,136
35N-8W-36	050670694500	83,042
34N-7W-7	050670785400	82,684
33N-7W-25	050670745000	82,621
33N-10W-19	050670736200	81,941
32N-9W-7	050670730200	80,157
32N-8W-7	050670730000	79,880
34N-7W-25	050670685100	79,467
33N-6W-18	050670720100	79,458
33N-8W-17	050670793000	79,227
34N-6W-3	050670706700	79,106
34N-7W-15	050670784900	78,468
32N-11W-15	050670758400	77,804
35N-7W-29	050670716800	77,746
33N-6W-20	050670663600	77,541
33N-8W-8	050670746000	77,368
34N-8W-14	050670792800	77,086
33N-8W-15	050670790000	77,015
33N-8W-33	050670770700	76,424
34N-8W-36	050670683200	76,369
34N-10W-14	050670767000	76,080
32N-8W-15	050670717900	75,961
33N-7W-13	050670705000	75,546
34N-10W-24	050670744000	75,283
33N-6W-30	050670661100	75,226
34N-7W-15	050670654400	74,878
34N-7W-17	050670715400	74,778
34N-7W-8	050670711400	74,430
33N-8W-33	050670730400	74,290
34N-7W-4	050670743100	73,486
32N-11W-5	050670767100	73,268
33N-8W-26	050670739200	71,906
32N-7W-3	050670751800	71,880
32N-8W-16	050670728400	71,750
33N-6W-31	050670670500	71,656
33N-7W-13	050670691600	71,546
33N-10W-5	050670749100	71,285
33N-7W-31	050670772500	71,267
34N-10W-35	050670769900	70,880
32N-10W-1	050670699500	70,650
33N-6W-31	050670664000	70,612
33N-10W-7	050670769500	70,596
32N-8W-12	050670710400	70,111

Location	API Number	Cum Water Production (Bbl)
33N-8W-22	050670763300	114,354
34N-6W-16	050670672700	114,316
32N-10W-23	050670758800	112,958
34N-8W-30	050670697400	112,833
33N-9W-23	050670788300	112,667
32N-12W-13	050670768000	112,312
34N-7W-16	050670656700	112,103
34N-6W-8	050670733300	111,719
33N-8W-24	050670790100	111,212
32N-9W-8	050670783200	110,948
32N-6W-16	050670751500	110,913
33N-7W-32	050670753200	110,717
33N-9W-23	050670786900	110,070
34N-9W-36	050670681900	106,923
33N-10W-8	050670773000	106,713
32N-9W-8	050670732200	105,697
32N-11W-19	050670773900	105,610
32N-10W-1	050670697000	105,579
35N-8W-24	050670781600	105,457
32N-9W-14	050670761600	105,175
32N-11W-12	050670776400	104,304
3N-0W-5	050670815000	104,170
32N-8W-13	050670710600	103,871
33N-11W-25	050670717200	103,787
34N-8W-34	050670789600	103,437
33N-7W-10	050670799700	102,363
33N-7W-29	050670799800	102,296
33N-9W-3	050670760900	101,691
34N-6W-9	050670705700	101,676
33N-8W-34	050670770800	101,610
0-0-0	050670000000	100,967
33N-9W-9	050670765400	100,946
32N-9W-23	050670709800	100,525
33N-7W-1	050670663300	99,827
34N-8W-11	050670768600	99,479
32N-7W-5	050670748800	98,702
32N-8W-3	050670721000	98,567
34N-8W-4	050670755400	97,485
33N-7W-15	050670742200	97,195
32N-8W-23	050670710900	97,156
34N-7W-35	050670663700	96,533
34N-7W-20	050670684600	96,509
33N-9W-16	050670700600	96,320
34N-8W-27	050670789000	95,873
33N-7W-21	050670679800	95,755
32N-10W-21	050670759800	95,742
35N-6W-34	050670712700	95,561
33N-11W-32	050670792500	95,282
35N-7W-28	050670707100	94,686
32N-8W-6	050670743700	93,732
35N-6W-28	050670733400	93,704
32N-7W-4	050670726200	93,068
33N-8W-34	050670771400	93,041
33N-9W-13	050670795600	92,914
33N-11W-20	050670793700	92,169
32N-11W-14	050670762700	91,588
33N-7W-22	050670744700	91,576
33N-8W-14	050670776500	91,382
34N-8W-35	050670796300	90,438
32N-10W-5	050670759600	90,238
34N-7W-12	050670796000	88,875
33N-8W-10	050670787500	88,575

Location	API Number	Cum Water Production (Bbl)
33N-11W-32	050670792600	140,903
34N-7W-15	050670719900	140,659
33N-11W-35	050670745300	139,928
34N-9W-11	050670741800	139,591
33N-9W-10	050670761000	139,086
32N-8W-21	050670735300	138,621
35N-6W-30	050670708800	138,233
33N-7W-33	050670752400	137,880
33N-7W-19	050670683900	137,769
32N-10W-4	050670711100	137,688
34N-9W-15	050670669700	137,545
32N-8W-22	050670729000	137,435
33N-7W-19	050670682000	136,708
33N-9W-16	050670694600	136,575
34N-10W-21	050670725800	136,447
33N-8W-3	050670786200	136,323
34N-8W-16	050670769400	136,241
34N-8W-26	050670772300	136,230
32N-9W-11	050670709700	136,209
34N-7W-14	050670783000	134,879
34N-10W-35	050670781300	134,878
32N-10W-10	050670749600	134,701
32N-10W-19	050670742800	134,564
34N-6W-9	050670703800	134,275
35N-8W-27	050670764700	134,123
35N-7W-34	050670714100	133,815
34N-8W-27	050670771300	133,642
32N-9W-14	050670760500	132,642
34N-9W-24	050670660100	132,048
32N-9W-13	050670718000	131,645
33N-11W-33	050670782500	130,827
33N-7W-8	050670708000	130,513
34N-8W-6	050670792900	130,499
34N-8W-17	050670665700	130,443
35N-8W-34	050670781500	128,779
33N-10W-17	050670779300	128,736
32N-9W-1	050670711500	127,452
32N-10W-8	050670723500	127,161
32N-9W-1	050670701700	126,973
33N-11W-29	050670792400	126,383
34N-7W-9	050670719100	125,593
32N-8W-12	050670709400	125,477
33N-11W-32	050670765900	125,110
34N-9W-4	050670751300	124,102
33N-11W-24	050670740600	123,561
32N-9W-24	050670709900	122,728
34N-6W-8	050670705800	122,704
32N-10W-7	050670691500	122,604
33N-6W-20	050670668400	120,647
33N-8W-16	050670747800	120,212
34N-7W-27	050670671300	120,139
32N-7W-4	050670753500	119,775
33N-9W-21	050670538200	119,457
32N-9W-6	050670774900	119,205
34N-8W-11	050670753800	118,864
33N-6W-28	050670653900	118,364
34N-6W-7	050670739500	116,387
33N-8W-9	050670787900	115,873
3N-0W-28	050670724800	115,799
32N-8W-14	050670710800	115,032
32N-9W-2	050670709500	115,023
32N-9W-21	050670718100	114,381

Location	API Number	Cum Water Production (Bbl)
33N-9W-11	050670748100	168,232
32N-11W-10	050670737800	167,484
34N-9W-9	050670665100	166,884
34N-8W-28	050670737700	166,178
34N-8W-15	050670768700	165,737
34N-7W-21	050670670400	165,367
35N-9W-35	050670689400	165,193
33N-9W-21	050670731000	164,170
35N-8W-31	050670778900	163,879
32N-9W-2	050670709600	162,286
3N-0W-6	050670797800	162,210
33N-9W-16	050670541500	161,998
33N-7W-5	050670702300	161,711
35N-7W-31	050670692000	161,427
33N-6W-18	050670667900	161,076
33N-7W-5	050670707900	160,892
34N-8W-22	050670770500	159,125
33N-7W-33	050670752500	159,106
33N-8W-1	050670787300	158,736
33N-9W-11	050670748200	157,491
33N-9W-29	050670735400	157,292
34N-6W-5	050670733200	157,260
33N-11W-22	050670704200	157,146
35N-7W-25	050670707500	156,819
32N-10W-18	050670691900	156,507
34N-9W-25	050670742100	156,050
33N-11W-20	050670780300	155,873
33N-10W-29	050670736600	155,703
34N-7W-27	050670652900	155,700
34N-9W-31	050670744500	154,971
33N-8W-23	050670700000	154,929
34N-6W-3	050670707300	154,852
32N-7W-10	050670750800	154,333
33N-10W-33	050670751100	154,240
33N-6W-29	050670678300	154,065
33N-6W-30	050670708700	153,777
33N-8W-5	050670732900	153,768
33N-7W-27	050670699800	152,811
33N-11W-24	050670740500	151,873
34N-10W-36	050670810600	150,420
33N-10W-1	050670740300	149,637
35N-7W-27	050670719500	148,543
32N-7W-9	050670751900	148,521
32N-11W-16	050670712200	148,144
34N-8W-28	050670737300	147,866
34N-8W-34	050670771000	147,793
34N-7W-8	050670685200	147,676
32N-9W-23	050670729400	146,649
33N-8W-2	050670783600	145,100
32N-7W-3	050670785900	144,646
34N-8W-13	050670769800	143,911
33N-9W-12	050670755300	143,851
33N-9W-10	050670748000	143,695
33N-8W-8	050670791100	143,517
32N-11W-1	050670758300	143,420
33N-7W-31	050670772600	143,416
34N-7W-7	050670635700	142,742
35N-7W-33	050670715300	141,887
32N-11W-7	050670767300	141,846
34N-7W-6	050670713600	141,605
33N-6W-29	050670690500	141,292
32N-10W-22	050670758700	141,290

Location	API Number	Cum Water Production (Bbl)
32N-10W-15	050670734200	210,370
35N-8W-32	050670779000	210,102
33N-9W-19	050670746200	208,585
34N-8W-5	050670753700	208,349
32N-9W-15	050670681300	206,554
32N-8W-22	050670728900	205,958
33N-10W-19	050670736100	205,879
33N-10W-31	050670736700	205,025
32N-8W-15	050670734600	204,739
35N-7W-30	050670720400	204,698
33N-11W-23	050670738600	204,454
35N-6W-33	050670724500	203,497
35N-8W-30	050670753900	203,376
34N-9W-35	050670681700	202,899
35N-8W-36	050670715800	202,342
32N-9W-20	050670732600	201,823
34N-9W-8	050670723700	201,729
34N-10W-27	050670725000	199,991
32N-8W-17	050670734500	199,122
33N-9W-19	050670759900	198,195
32N-9W-13	050670729300	197,313
34N-8W-35	050670794400	196,314
35N-8W-26	050670755100	194,916
35N-6W-21	050670741400	193,630
33N-11W-26	050670728200	193,432
35N-8W-22	050670757800	192,897
34N-8W-15	050670725900	192,434
32N-11W-10	050670712100	192,060
33N-9W-9	050670747900	192,012
34N-6W-7	050670743000	191,801
33N-10W-1	050670722400	191,090
33N-9W-31	050670763400	189,327
33N-10W-28	050670735700	189,000
34N-9W-11	050670697700	187,910
33N-11W-26	050670706100	187,577
33N-10W-35	050670700700	186,839
34N-10W-28	050670764900	186,732
34N-8W-29	050670668100	185,927
34N-9W-20	050670684900	185,296
32N-8W-13	050670710500	183,862
34N-7W-10	050670672600	183,036
34N-8W-8	050670773200	182,332
32N-8W-20	050670735200	182,203
32N-10W-3	050670749200	181,706
33N-9W-4	050670702800	181,013
32N-10W-8	050670718300	180,912
35N-7W-31	050670694400	180,350
32N-10W-16	050670729500	178,817
32N-9W-12	050670729200	177,856
34N-10W-27	050670764800	177,138
32N-10W-16	050670734300	176,994
32N-10W-17	050670756800	176,715
35N-7W-20	050670717500	176,591
34N-7W-31	050670687500	174,172
34N-6W-18	050670745700	173,516
34N-8W-10	050670661400	172,383
33N-9W-31	050670791900	172,199
33N-9W-13	050670788200	170,159
32N-9W-19	050670739800	170,115
32N-9W-7	050670764000	169,735
34N-9W-31	050670714900	169,520
32N-10W-7	050670718200	168,425

Location	API Number	Cum Water Production (Bbl)
33N-10W-32	050670736800	247,539
34N-9W-11	050670703900	247,189
35N-7W-35	050670696200	246,521
33N-10W-28	050670759200	246,361
33N-7W-35	050670698400	245,785
34N-8W-11	050670633700	245,402
33N-10W-25	050670773400	245,232
32N-8W-18	050670734900	243,751
35N-7W-35	050670765500	243,677
34N-6W-6	050670718700	243,665
34N-6W-10	050670706800	243,475
33N-11W-10	050670713000	243,219
34N-9W-8	050670723000	242,874
33N-10W-29	050670752800	242,740
33N-10W-25	050670726600	242,445
35N-7W-28	050670716500	241,964
34N-8W-22	050670777900	241,904
34N-7W-3	050670718800	241,428
33N-10W-34	050670757400	241,357
34N-8W-4	050670767400	241,057
33N-9W-2	050670696600	240,834
34N-9W-19	050670696800	240,529
34N-8W-31	050670704700	240,338
34N-8W-21	050670700900	240,265
34N-9W-12	050670785500	239,762
33N-9W-15	050670730700	238,369
34N-6W-5	050670713500	236,164
33N-9W-29	050670764300	235,669
34N-8W-10	050670754000	234,444
32N-10W-12	050670719600	233,933
32N-9W-5	050670734000	230,588
34N-10W-29	050670725100	227,839
33N-7W-16	050670682700	227,168
32N-10W-10	050670761700	227,059
32N-10W-2	050670700800	225,765
34N-9W-33	050670698200	223,292
34N-9W-3	050670708600	222,707
34N-9W-10	050670778500	222,679
33N-11W-29	050670765700	222,230
33N-10W-27	050670722600	221,645
32N-11W-9	050670705400	221,591
32N-11W-5	050670767200	221,210
34N-9W-7	050670669200	220,989
32N-8W-16	050670734700	220,834
32N-7W-1	050670803700	220,785
34N-9W-3	050670775900	219,930
33N-7W-26	050670701400	219,756
34N-9W-2	050670775700	218,790
35N-9W-36	050670746600	218,674
33N-11W-29	050670792300	218,057
34N-8W-14	050670670100	217,934
34N-8W-33	050670777700	217,877
34N-9W-7	050670791400	217,801
32N-10W-11	050670708300	217,435
33N-7W-30	050670702600	217,213
35N-8W-23	050670759300	216,369
33N-11W-13	050670738500	216,344
35N-7W-19	050670717400	215,850
34N-9W-18	050670727300	214,442
32N-7W-9	050670750700	213,579
34N-8W-1	050670745500	211,642
32N-9W-15	050670681200	210,383

Location	API Number	Cum Water Production (Bbl)
32N-6W-18	050670752900	300,598
33N-9W-32	050670735500	300,179
34N-9W-28	050670695700	299,542
35N-6W-28	050670715200	298,853
34N-8W-29	050670752700	295,513
33N-9W-8	050670712800	293,613
34N-9W-20	050670695000	292,418
34N-10W-13	050670765000	292,316
33N-10W-20	050670759100	292,067
33N-9W-4	050670702700	291,139
32N-8W-17	050670734800	290,593
34N-8W-23	050670772700	289,378
33N-7W-28	050670683000	288,939
32N-9W-22	050670716900	288,895
32N-10W-14	050670711700	288,464
32N-9W-16	050670731400	288,158
34N-9W-15	050670741900	286,946
33N-10W-36	050670776700	286,587
33N-10W-36	050670731200	286,316
34N-10W-21	050670769100	284,791
34N-9W-13	050670678500	284,569
33N-8W-13	050670703500	282,027
35N-7W-22	050670692100	281,741
33N-10W-14	050670746300	281,713
33N-10W-20	050670751000	281,327
34N-9W-2	050670776900	280,966
33N-9W-7	050670691100	279,364
33N-11W-20	050670773300	277,863
32N-10W-14	050670711800	274,962
33N-10W-26	050670792200	274,834
33N-11W-27	050670728300	273,824
33N-9W-3	050670696900	271,361
35N-8W-23	050670716100	271,165
33N-10W-2	050670722500	269,563
34N-9W-9	050670784000	269,466
34N-9W-13	050670757000	268,596
33N-11W-32	050670767800	267,786
33N-9W-32	050670776800	266,881
33N-7W-18	050670682900	266,072
34N-8W-15	050670774100	265,147
34N-9W-23	050670718600	264,900
34N-7W-1	050670755600	264,632
35N-6W-19	050670740000	264,457
33N-10W-13	050670756900	264,265
34N-10W-11	050670766600	264,241
32N-10W-24	050670696300	263,865
32N-10W-3	050670722100	262,492
35N-6W-33	050670739000	260,107
33N-7W-20	050670683600	258,329
33N-7W-17	050670682800	257,961
0-0-0	050670000000	257,793
32N-10W-2	050670730300	257,100
32N-10W-18	050670724400	256,563
35N-7W-24	050670719400	255,717
35N-7W-32	050670654600	254,867
35N-6W-20	050670715100	254,112
35N-9W-35	050670749400	254,090
34N-9W-34	050670684000	251,514
35N-8W-29	050670757900	251,377
34N-9W-17	050670696400	249,440
34N-9W-36	050670747300	248,782
33N-9W-7	050670714600	248,539

Location	API Number	Cum Water Production (Bbl)
34N-9W-9	050670786400	368,280
34N-10W-29	050670743500	367,918
32N-10W-4	050670750900	367,801
34N-9W-28	050670708100	367,566
33N-8W-13	050670702900	367,372
33N-10W-10	050670772200	367,209
33N-9W-8	050670690600	366,136
32N-9W-17	050670732400	364,458
33N-10W-24	050670764400	363,423
34N-9W-12	050670676700	362,824
32N-9W-16	050670731500	361,930
33N-10W-35	050670731100	360,537
34N-8W-32	050670698900	360,181
34N-8W-17	050670656100	358,608
35N-7W-18	050670757600	349,754
33N-11W-31	050670774700	348,811
33N-9W-6	050670759500	348,492
35N-8W-33	050670779800	348,327
34N-9W-30	050670728100	347,963
33N-10W-26	050670736500	347,204
33N-7W-21	050670668300	343,778
33N-10W-2	050670789200	340,688
33N-7W-34	050670703700	339,496
34N-9W-14	050670698100	339,057
32N-10W-24	050670708400	335,871
32N-10W-6	050670759700	333,896
35N-8W-21	050670724600	333,072
34N-7W-33	050670652800	332,789
34N-8W-13	050670712500	330,676
34N-8W-16	050670741700	330,197
33N-9W-1	050670696500	328,797
32N-8W-20	050670728500	328,751
32N-10W-12	050670752100	328,069
33N-11W-31	050670780400	327,132
32N-9W-17	050670732300	326,817
32N-9W-15	050670681000	325,219
34N-9W-8	050670784100	323,368
34N-8W-18	050670668600	323,182
34N-9W-26	050670695400	322,843
34N-9W-22	050670699400	322,335
33N-10W-15	050670749300	321,481
33N-9W-30	050670758900	318,926
33N-10W-33	050670746500	318,692
34N-8W-32	050670699000	318,080
34N-9W-27	050670697200	317,920
33N-11W-31	050670793800	317,042
33N-8W-2	050670787000	315,610
32N-10W-15	050670711900	314,940
32N-9W-15	050670681100	314,896
33N-8W-6	050670733600	314,331
35N-8W-35	050670775300	313,172
35N-7W-25	050670707600	313,044
33N-7W-7	050670705200	312,044
35N-6W-29	050670708200	309,217
33N-11W-21	050670716300	308,287
34N-9W-11	050670787400	308,090
32N-9W-18	050670732500	307,590
32N-10W-9	050670711600	306,400
32N-9W-8	050670732100	306,130
33N-11W-30	050670794000	305,151
33N-9W-18	050670761100	305,020
33N-11W-29	050670765800	304,072

Location	API Number	Cum Water Production (Bbl)
34N-9W-35	050670684100	495,413
34N-9W-27	050670687700	489,182
33N-10W-11	050670747100	488,394
34N-8W-31	050670722900	486,960
35N-8W-28	050670653600	485,671
34N-9W-21	050670704000	484,575
35N-8W-27	050670724700	484,250
33N-10W-10	050670784400	481,551
35N-6W-29	050670701200	477,194
33N-9W-1	050670698000	474,149
34N-8W-7	050670773100	473,581
34N-10W-23	050670743900	473,439
35N-8W-22	050670903100	463,787
34N-7W-12	050670743300	453,233
32N-11W-7	050670747500	451,851
33N-10W-31	050670748700	451,585
35N-7W-34	050670714000	448,625
33N-10W-30	050670769600	448,488
34N-9W-36	050670681800	444,763
33N-8W-11	050670698500	444,400
34N-9W-14	050670715700	441,513
35N-8W-33	050670779400	441,325
34N-8W-10	050670779100	439,224
32N-9W-21	050670729700	436,392
33N-7W-17	050670674100	435,951
35N-8W-25	050670703100	435,293
33N-10W-21	050670735600	435,076
34N-9W-19	050670727400	433,262
34N-10W-36	050670723100	432,375
35N-9W-36	050670746700	430,108
33N-10W-23	050670736400	429,029
33N-10W-3	050670752600	428,952
34N-8W-10	050670655900	427,592
34N-7W-6	050670636200	423,942
35N-6W-31	050670694800	423,584
34N-10W-23	050670763800	422,610
34N-9W-16	050670695200	421,589
33N-9W-2	050670697600	421,117
32N-11W-6	050670747400	418,434
33N-11W-35	050670742900	417,301
34N-9W-1	050670775800	416,609
34N-7W-32	050670652700	414,702
34N-8W-9	050670754500	414,635
33N-11W-36	050670738900	414,589
33N-7W-28	050670679900	409,433
34N-10W-22	050670765100	408,911
33N-10W-27	050670728800	406,677
33N-10W-22	050670749000	406,645
33N-10W-13	050670726500	403,781
33N-7W-27	050670702400	401,962
34N-9W-10	050670737900	399,208
32N-9W-5	050670731300	398,458
33N-10W-12	050670713300	393,355
34N-9W-1	050670774200	386,227
34N-9W-18	050670695900	384,662
32N-10W-23	050670707200	380,968
34N-9W-21	050670742000	375,595
33N-8W-12	050670698600	375,259
33N-10W-15	050670746400	373,945
34N-8W-21	050670701000	372,951
34N-9W-9	050670696000	372,897
32N-8W-19	050670735100	368,746

Location	API Number	Cum Water Production (Bbl)
35N-8W-28	050670724800	772,536
32N-12W-24	050670738000	765,221
34N-8W-16	050670778600	759,898
34N-8W-19	050670665900	758,108
34N-7W-3	050670718500	731,906
34N-8W-9	050670700200	726,662
34N-8W-2	050670785300	705,449
34N-6W-17	050670689900	701,061
34N-8W-9	050670700300	696,595
34N-10W-13	050670766800	689,392
35N-7W-19	050670723300	686,959
34N-8W-3	050670757200	684,331
33N-10W-16	050670776600	680,262
34N-8W-5	050670776200	679,571
34N-8W-17	050670772000	678,834
33N-9W-6	050670690700	661,875
34N-8W-30	050670704600	637,809
32N-12W-24	050670738100	626,466
33N-11W-17	050670777000	622,454
32N-10W-1	050670692600	621,653
35N-8W-13	050670781400	618,415
34N-9W-26	050670685000	613,849
34N-9W-25	050670681600	612,209
35N-6W-34	050670703000	600,854
34N-8W-11	050670655600	592,863
34N-8W-33	050670655100	591,346
35N-8W-24	050670764600	589,951
35N-7W-21	050670707000	582,003
34N-9W-22	050670695300	581,204
34N-9W-16	050670622300	580,496
34N-8W-20	050670665500	576,041
35N-8W-29	050670753400	567,628
35N-8W-34	050670650500	563,582
34N-9W-24	050670719200	561,237
33N-10W-23	050670761200	559,725
34N-8W-9	050670754600	559,488
32N-10W-13	050670701300	558,170
34N-10W-14	050670766900	556,567
32N-9W-6	050670734100	555,692
33N-10W-24	050670728700	555,055
33N-10W-14	050670759000	549,167
34N-7W-2	050670755800	545,283
34N-9W-17	050670701100	544,683
33N-10W-16	050670748900	537,213
35N-7W-29	050670720300	531,281
33N-10W-9	050670641400	530,899
35N-7W-15	050670719300	524,665
33N-7W-7	050670698300	524,421
34N-6W-6	050670744600	523,547
33N-9W-18	050670712900	520,848
34N-7W-18	050670715500	520,563
34N-8W-8	050670699100	515,375
34N-8W-12	050670712400	513,842
35N-7W-16	050670715900	510,202
33N-11W-34	050670780500	509,387
33N-11W-36	050670763100	508,449
35N-8W-31	050670758000	508,359
34N-8W-18	050670661500	508,119
35N-6W-32	050670706900	504,180
32N-10W-9	050670711200	499,679
35N-8W-32	050670658100	497,058
34N-9W-10	050670726100	495,851

Location	API Number	Cum Water Production (Bbl)
35N-7W-26	050670729600	4,478,775
34N-8W-18	050670732800	4,212,221
35N-6W-32	050670677800	4,105,939
35N-7W-20	050670717600	4,064,567
34N-8W-1	050670775200	3,819,394
34N-7W-10	050670672400	3,197,124
35N-6W-30	050670690300	3,087,349
34N-8W-2	050670777400	2,663,762
35N-8W-35	050670775400	2,288,711
35N-7W-21	050670723400	1,913,939
35N-7W-18	050670720500	1,757,533
34N-10W-12	050670766700	1,626,780
35N-6W-31	050670690400	1,620,953
33N-10W-4	050670726700	1,528,822
34N-8W-8	050670782400	1,514,773
35N-7W-36	050670700500	1,504,176
34N-7W-11	050670674300	1,429,748
34N-10W-12	050670763600	1,410,695
34N-9W-12	050670669100	1,367,197
35N-7W-23	050670690900	1,365,204
33N-11W-21	050670713200	1,253,149
34N-8W-14	050670779200	1,232,225
34N-8W-7	050670661200	1,202,747
33N-9W-34	050670756300	1,172,552
33N-11W-16	050670713100	1,167,208
32N-9W-10	050670756200	1,158,968
32N-12W-24	050670747700	1,135,492
33N-10W-12	050670721300	1,119,122
34N-8W-7	050670778800	1,087,928
34N-8W-6	050670778700	1,052,654
34N-9W-12	050670695100	987,448
35N-7W-22	050670706000	986,087
33N-10W-8	050670721200	962,874
33N-7W-20	050670679700	921,611
34N-8W-7	050670699300	912,105
34N-8W-20	050670678000	909,557
35N-8W-14	050670764500	883,743
34N-9W-23	050670670700	872,678
33N-11W-20	050670780200	869,065
34N-7W-1	050670755700	864,039
33N-7W-29	050670683100	857,839
32N-12W-13	050670747600	853,304
34N-10W-24	050670767700	848,686
35N-7W-26	050670717700	831,482
34N-8W-3	050670753300	826,325
35N-7W-27	050670713800	819,512
34N-10W-28	050670704900	814,974
35N-8W-13	050670768300	805,649
34N-8W-12	050670715600	802,606
34N-7W-2	050670781800	778,374
33N-10W-22	050670736300	775,468
35N-7W-33	050670713900	774,302
34N-8W-19	050670731700	772,884

APPENDIX C

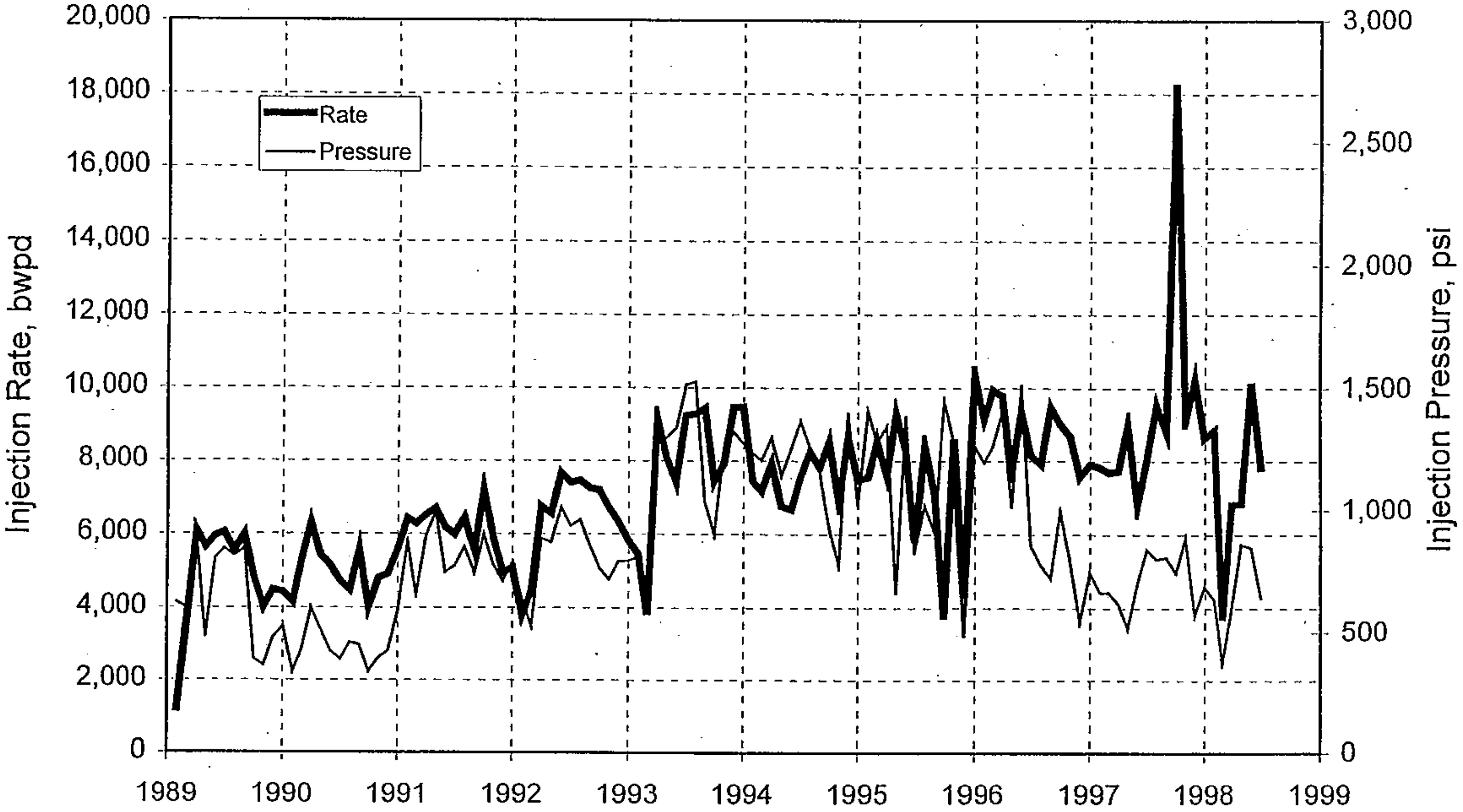
Chart 17

SIMON LAND AND CATTLE #1 WDW

INJECTION PRESSURE AND RATE PLOT

Injection Rate and Pressure,

Simon Land & Cattle Disposal 1



APPENDIX C

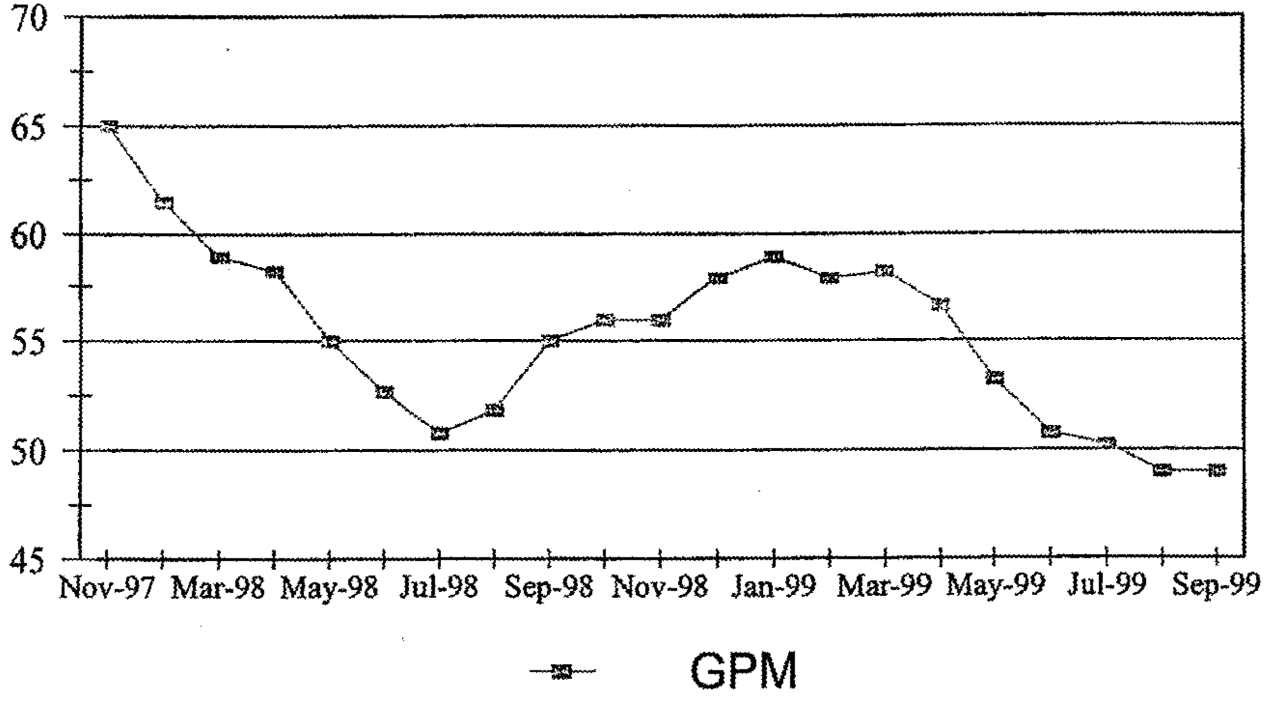
Chart 18

HICKERSON HOT SPRINGS

Flow Rate/Temperature/Stiff Diagram of Water Analysis

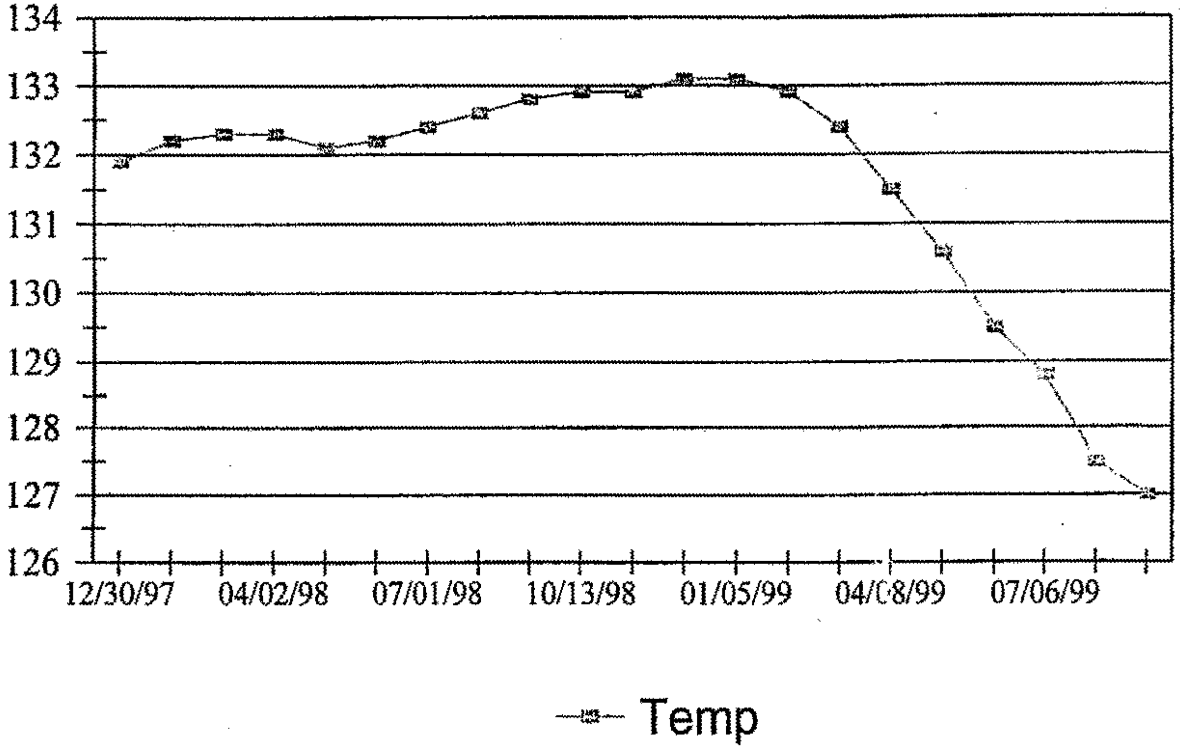
Hickerson Hot Spring

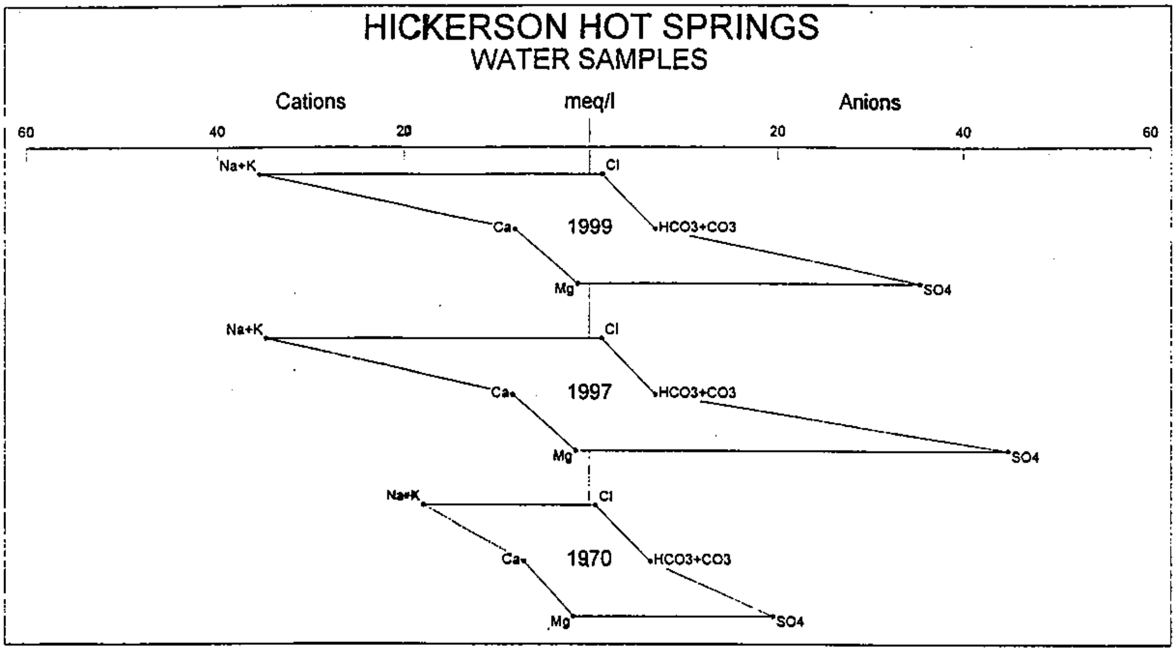
Flow Rate



Hickerson Hot Spring

Temperature




HICKERSON HOT SPRINGS
WATER SAMPLES
Cations
meq/l
Anions
60
40
20
20
40
60
Na+K
Cl
Ca
HCO3+CO3
Mg
SO4
1999
Na+K
Cl
Ca
HCO3+CO3
Mg
SO4
1997
Na+K
Cl
Ca
HCO3+CO3
Mg
SO4
1970

APPENDIX C

Chart 19

La Plata County

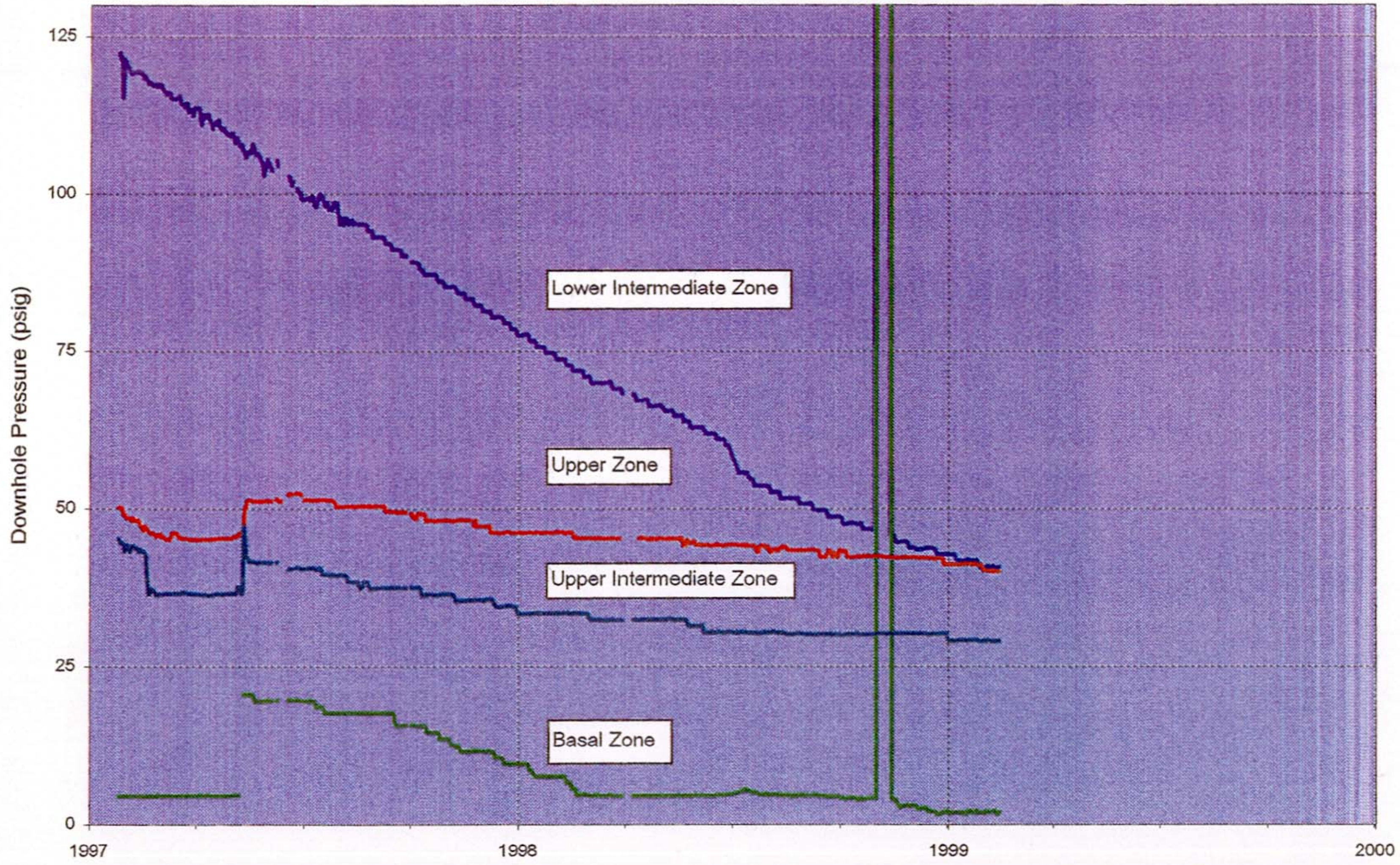
Water Monitoring Wells MA and MB

in

Valencia Canyon Gap

(Enervest)

EnerVest San Juan Operating, LLC
S.U. #17-MA & MB, Monitor Wells
Downhole Pressure 1997-1998-1999



MAMBPRES.xls, 97-99(cont)

2/16/99

COMMENTS REGARDING THE VARIOUS CASES

Model 1: Downdip Fault; Single Well Shut in After 40 Years

The higher permeability cases peak earlier, and fall off faster.

Nearly the same total seepage (7.5 Bcf/mile) occurs in all cases > 25 md, because there is only a finite amount of gas in place.

About 45% of the gas in place is lost to seepage in Model 1.

The remaining gas is either produced, or locked up by water head below the producing well.

Model 2: No Fault; 7 Wells; Shallowest Well SI after 40 Years

The peak rate and timing is about the same for Model 2 as Model 1.

Ultimate seepage is much greater, because there is much more gas to lose.

Also, in Models 2-5, the water can continue to fall into the basin, thereby leaving more of the remaining gas available to move updip after production halts.

Model 3: No Fault; 7 Wells; All Wells SI after 40 Years

Model 3 results are very similar to Model 2.

For low perm cases 1-5 md, slightly less long-term seepage occurs in Model 3.

This is probably because of more water left behind.

In the higher perm cases 10+ md, the long-term seepage is higher than Model 2.

Model 4: No Fault; 7 Wells; All Wells SI after 40 Years; 70 bwpd Recharge

The peak seep rate is reduced even with small amounts of water recharge.

Small amounts of recharge have a major effect only on the 1 md case.

In the low k case, the water helps to form a new "stopper" to restrict seepage.

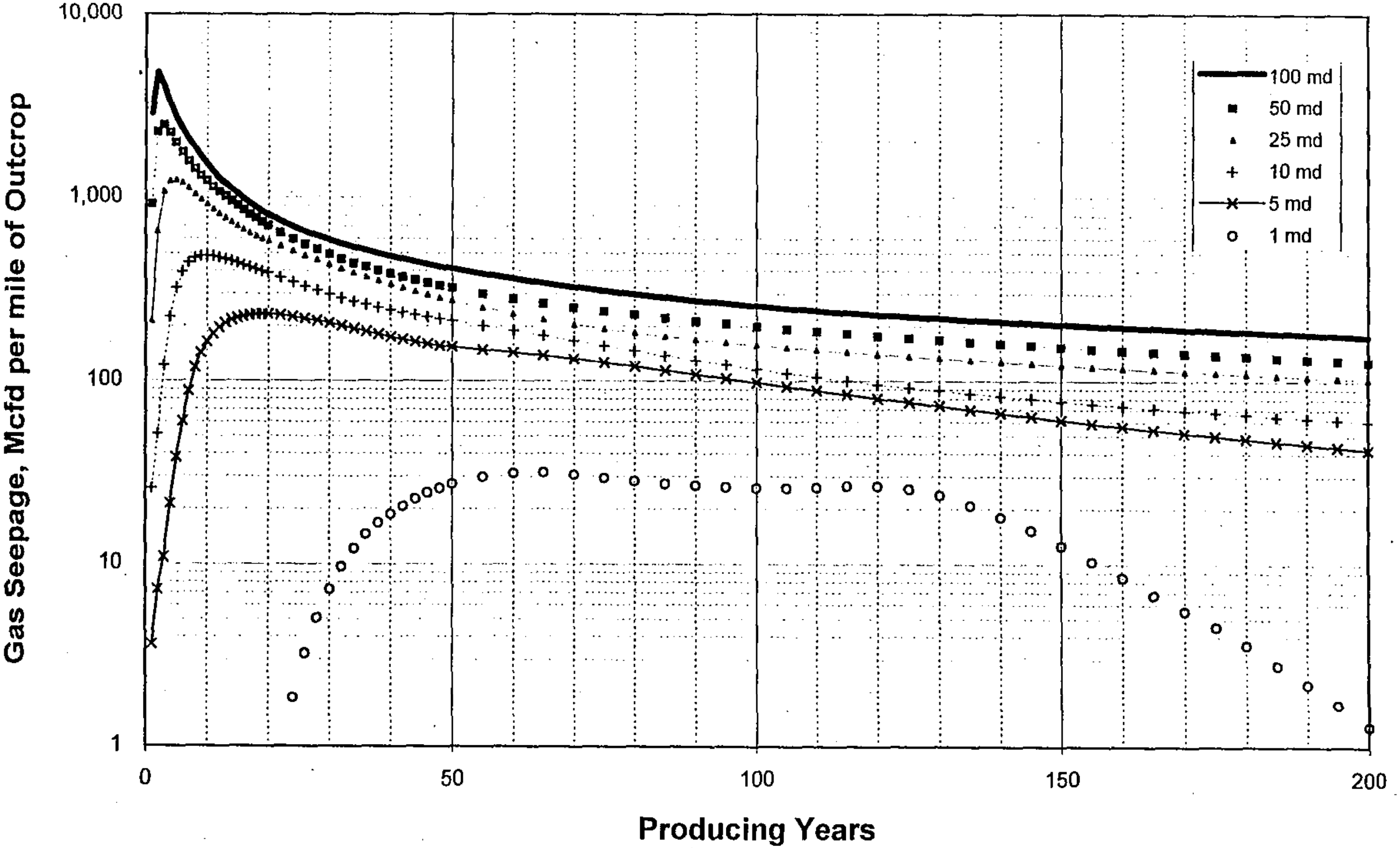
In the other cases, the limited water influx just runs down into the basin.

Model 5: 25 md Case w/ Recharge; 7 Wells; Seepage in 15% of Outcrop

The peak rate is lowered if seepage through the outcrop is restricted, but the ultimate seepage is nearly the same, because there is still about the same amount of gas left to seep out.

Figure 6: Model 4

No Fault; 7 Wells; All Wells SI after 40 Years; 70 bwpd Recharge



SIMULATION RESULTS

Peak Seepage Rates, in Mcfd per mile of Outcrop

Model \ k, md	1	5	10	25	50	100
Model 1	66	310	607	1445	2768	4577
Model 2	66	314	620	1515	2788	5299
Model 3	66	314	620	1515	2788	5299
Model 4	32	233	485	1241	2452	4773
Model 5	—	—	—	468	—	—

Cumulative Seepage over 200 Years, Bcf/mile of Outcrop

Model \ k, md	1	5	10	25	50	100
Model 1	2.9	5.7	6.7	7.6	7.5	7.5
Model 2	3.7	10.5	13.8	20.0	27.9	46.1
Model 3	3.5	10.1	14.0	20.9	28.3	46.7
Model 4	1.2	7.7	11.5	18.5	24.6	33.0
Model 5	—	—	—	15.5	—	—

Cumulative Seepage over 200 Years, as % IGIP

Model \ k, md	1	5	10	25	50	100
Model 1	17%	34%	39%	45%	44%	44%
Model 2	2%	4%	6%	8%	12%	19%
Model 3	1%	4%	6%	9%	12%	20%
Model 4	0%	3%	5%	8%	10%	14%
Model 5	—	—	—	7%	—	—

IGIP = 16.9 Bcf in Model 1, 238.4 Bcf in Models 2-5

CONCLUSIONS

1. Long-term gas seepage should be expected to occur at the outcrop of the Fruitland coals in the San Juan Basin when the following conditions are met:

    a. The coals have been dewatered through CBM production.
    b. A hydraulic connection exists between the down-basin coals and the outcrop.
    c. The outcrop is permeable.
    d. Recharge is insufficient to offset dropping water levels caused by dewatering.

2. The total amount of seepage is a strong function of permeability, recharge, and the total gas remaining in the coals at the end of production.

3. The reason for long-term seepage is simple:

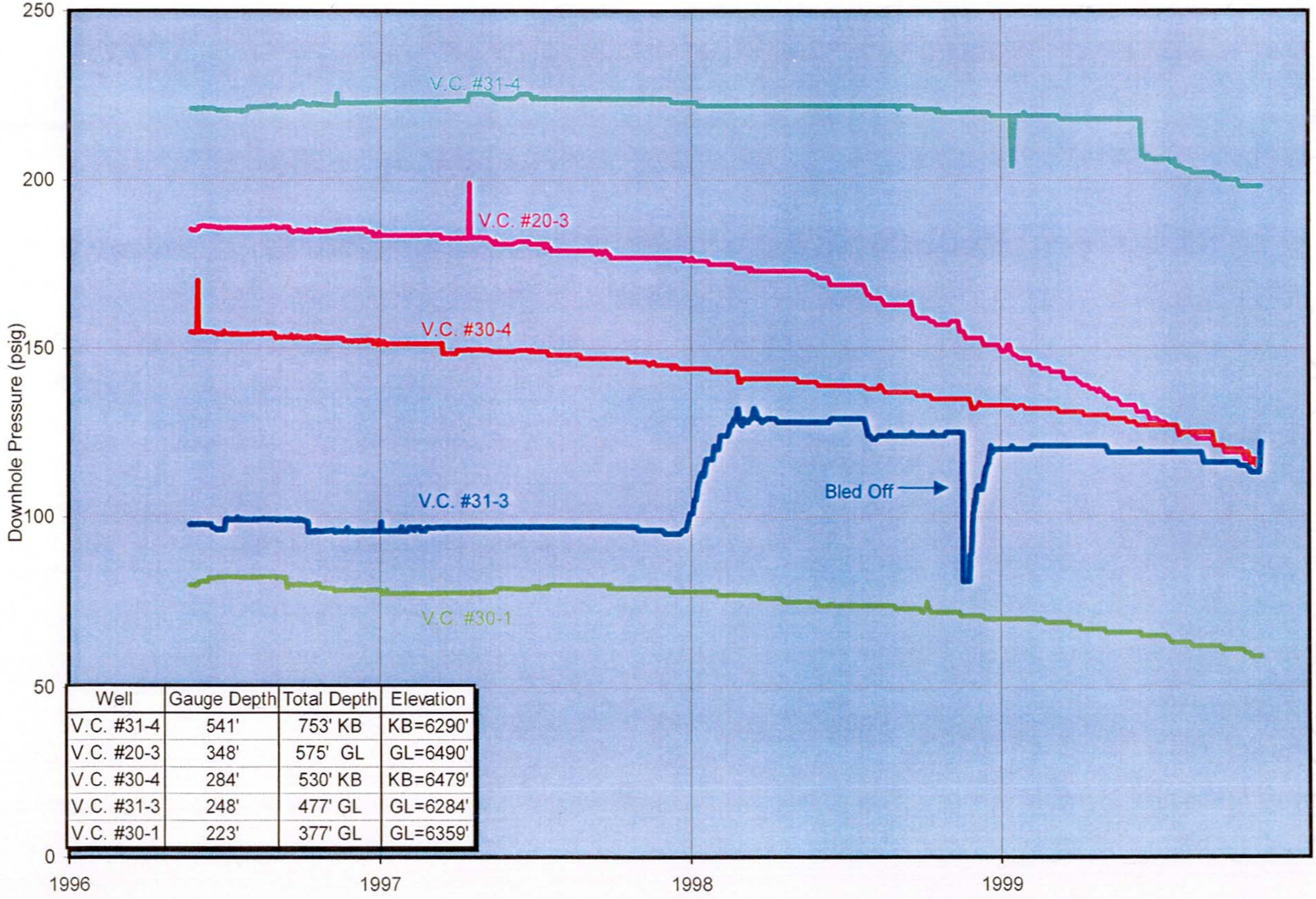
    Once a pathway has been established for gas to move between the basin and the outcrop, the system will seek a new equilibrium where the gas remaining in the coal long-term is held back by whatever static pressure head ultimately occurs.

4. Valencia Canyon is different than the Pine River area, where shallow seepage will be restrained through water influx (pressure support) from the Pine River. The west side of the basin has much less surface water and groundwater.

5. Production down-basin will also contribute to long-term gas seepage at the outcrop along the West Side, in addition to shallower wells near the outcrop.

EnerVest San Juan Operating, L.L.C.
Valencia Canyon Shallow Monitor Wells - Downhole Pressure

(Sentry 0-500# gauges used in all wells)



Well	Gauge Depth	Total Depth	Elevation
V.C. #31-4	541'	753' KB	KB=6290'
V.C. #20-3	348'	575' GL	GL=6490'
V.C. #30-4	284'	530' KB	KB=6479'
V.C. #31-3	248'	477' GL	GL=6284'
V.C. #30-1	223'	377' GL	GL=6359'

Bhp.xls, BHP

11/09/1999

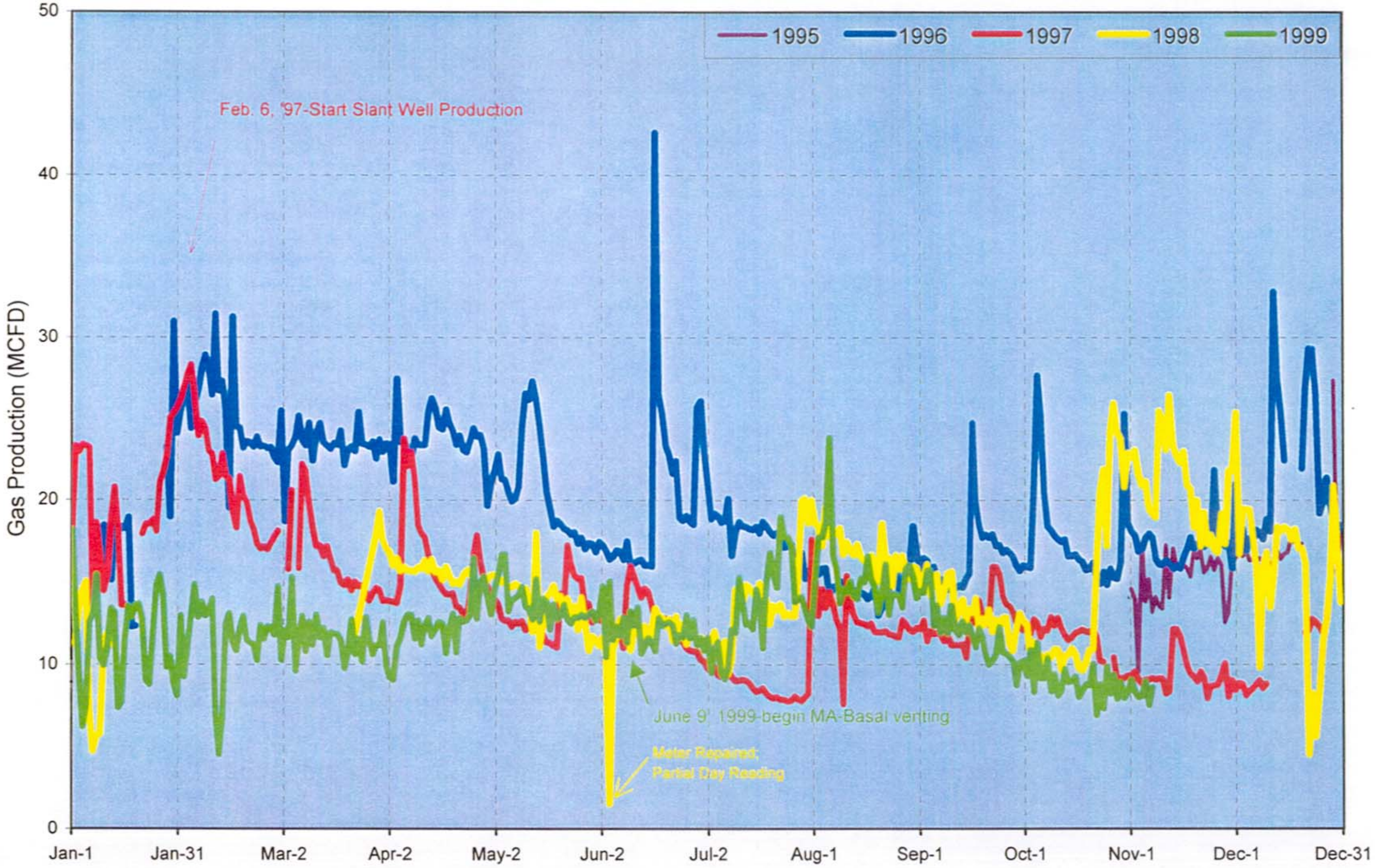
APPENDIX C

Chart 22

Valencia Gap Soil Vapor Collector – Flow Rate 1995-99

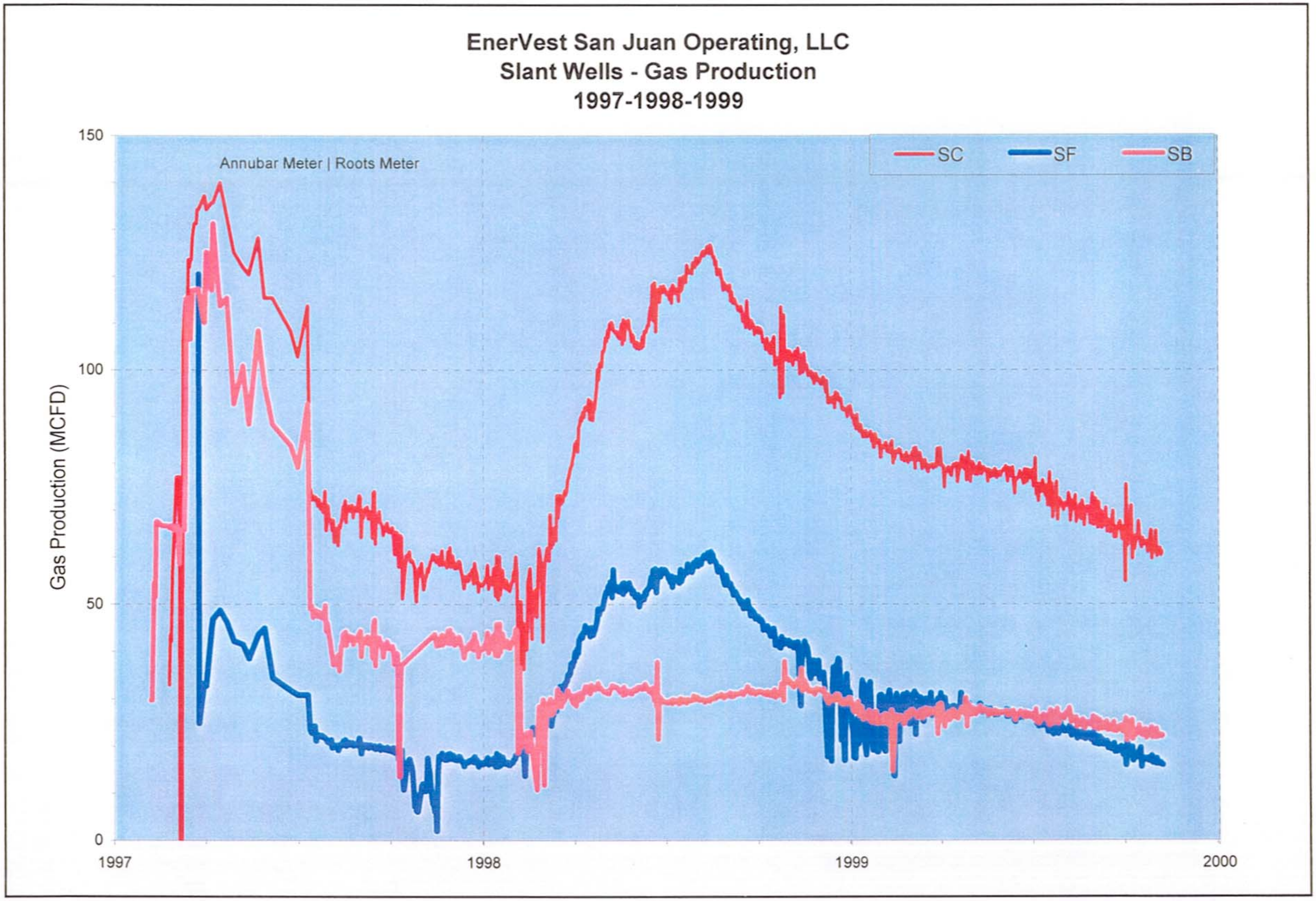
Valencia Canyon Slant Well Production 1997-99

EnerVest San Juan Operating, LLC
Valencia Gap Collector - Gas Production
1995-1999



Seepmtr.xls, 95-99gas(ann)

11/08/1999



EnerVest San Juan Operating, LLC
Slant Wells - Gas Production
1997-1998-1999

slant wells.xls, gas(cont)

11/08/1999