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Contract No. DE-AC21-78MC08089

METHANE from COALBEDS COLLECTION and UTILIZATION SYSTEMS

DRAFT

FINAL REPORT

A Report Prepared for the
UNITED STATES DEPARTMENT OF ENERGY
Methane Recovery from Coalbeds Project
MORGANTOWN ENERGY TECHNOLOGY CENTER
Morgantown, West Virginia

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TRW *ENERGY ENGINEERING DIVISION*
McLEAN, VIRGINIA

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ABSTRACT

During the period 12 December 1977 through 31 December 1980, the TRW Energy Engineering Division was the integrating contractor for the U.S. Department of Energy's Methane Recovery from Coalbeds Project (MRCP) implemented by the Morgantown Energy Technology Center. As the MRCP integrating contractor, TRW directed the implementation of two major technology test projects; conducted coring, logging and other field testing activities; performed and directed resource engineering research; developed specific test procedures and techniques and conducted drilling tests; performed technical and economic analyses; reviewed and reported on MRCP programs; conducted analyses of R&D requirements and projects for inclusion in planning documents and conducted workshops, symposia, and other activities in direct support of the MRCP. This report, briefly summarizes the project activities, conclusions, and recommendations of TRW, based on the effort under Contract No. DE-AC21-78MC08089. Summaries of test projects and field tests are included along with a bibliography of the pertinent documents.

DEDICATION

This report is dedicated to the memory of the late John R. Duda. Mr. Duda managed the Methane Recovery from Coalbeds Project from late 1979 until his untimely death in May 1981. He was an excellent leader, dedicated to government service, and was a force in bringing this resource closer to being a contributor to the U.S. gas supply. His untimely passing will most certainly be felt in the continuing development of the technology base.

ACKNOWLEDGEMENTS

As the Methane Recovery from Coalbeds Project (MRCP) Integration Contractor, TRW's role under Contract Number DE-AC21-78MC08089 required contacts with technical and management personnel in many industries, including oil and gas operators; drilling and well service companies; gas distributors; coal mine owners and operator; equipment suppliers and manufacturers; many government agencies, including the U.S. Department of Energy, the U.S. Geological Survey, the U.S. Bureau of Mines, and various state geological and mineral surveys; and universities and other research organizations involved in various aspects of coalbed methane recovery and utilization. The Technical Project Officer for this contract was Dr. Harold D. Shoemaker. TRW wishes to express its appreciation to these organizations and individuals who provided support in the resource delineation, integration, and technology test project efforts.

METHANE FROM COALBEDS -
COLLECTION AND UTILIZATION SYSTEMS

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EXECUTIVE SUMMARY

Since its inception in 1977, the Methane Recovery from Coalbeds Project (MRCP), an integral part of the Unconventional Gas Recovery (UGR) Program, has endeavored to develop the technologies necessary to foster widespread commercial use of coalbed methane. The project is being conducted by the United States Department of Energy (DOE), with lead responsibility assigned by the DOE Assistant Secretary of Fossil Energy to the Morgantown Energy Technology Center (METC).

MRCP has been implemented as an integrated project, coalescing the research and development efforts of private industry, universities, and Federal and state agencies to enhance the coalbed methane data base. Its goals are to estimate the extent of the resource with increased accuracy and reliability and to provide technically and economically viable means for methane recovery and utilization. The ultimate purpose of MRCP is to promote extensive private use of the resource as a source of national energy.

To date, major MRCP effort has been directed toward locating and estimating the magnitude of the resource, estimating the recoverable reserves, developing economical recovery systems and techniques, and demonstrating utilization in an appropriate manner. To ensure proper integration of ongoing activities, heavy emphasis is placed on project planning and review, tailored within the frameworks of the DOE Gas Resources Research, Development and Demonstration Plan and the Unconventional Gas Recovery Program Charter.

The MRCP has made significant progress in the development of the technology base. The project has more clearly identified technology requirements, potential uses, and the environmental, legislative, and social barriers. Major achievements produced by the project to date include:

- Wellbores at forty-five sites have been logged, and 285 core samples taken from 40 of these sites for desorption and proximate and ultimate tests.
- Twelve basin reports have been issued defining the characteristics of the coal, coalbed methane, and the environment.

- Ten production technology development projects have been initiated; seven of which have been completed.

- Four utilization technology development projects have been initiated; three have been completed, and one is in progress.

- Environmental economic and legal issues of methane technology have been investigated.

- Over 100 technical papers have been prepared and presented at professional meetings and symposiums.

While the project has made significant progress, however, development of coalbed methane as a contributing source of the U.S. gas supply is far from complete. To date, production technology activities have been directed toward commingling of the unconventional gas with conventional natural gas for use by residential, commercial, and industrial customers; and for use as fuel for space heating, coal drying, and onsite power generation. Production and utilization technology will have to be further developed in order to demonstrate the economics of the use of the gas to both coal mine operators and other investors. Without the development of efficient systems, the coalbed methane will continue to be wasted by coal operators and will not be sought as a viable resource for augmenting the U.S. supply of natural gas.

In order to ensure that coalbed methane will contribute to the U.S. supply of natural gas, it is recommended that the MRCP continue to foster extensive commercial use of methane in the following manner:

- Studies of optimum geometric well patterns and optimum spacing of wells be initiated to obtain empirical data which can be used in future commercial coalbed predrainage applications.

- Development of techniques for predrainage of minable coal be accelerated in order to increase the coalbed methane production from active mines.

- Delineation of coalbed methane resources and recoverable reserves be continued as planned in order to provide data for U.S. energy planning.

- Supporting research on coalbed methane processing systems be conducted to increase the number of viable options for utilization of methane vented from coalbeds.

- The technical and economic viability of recovering methane from anthracite coal be demonstrated to motivate utilization of the resource in the northeastern U.S.

The MRCP Management Office is organized to meet the above challenges of technology development. The Office is responsible for the management of the analysis, resource characterization, research and development, and production activities of the project. Due to the recent untimely death of Mr. John R. Duda, the Program Manager position remains vacant; however, under his leadership, a management plan has been implemented which can continue the research and technology development.

Recent budget actions have made future project funding rather uncertain, and may place development of the technology in jeopardy. Without an investment in continued coalbed methane production and utilization research by the Federal government the research conducted thus far, like the resource itself, will be largely a wasted effort.

1. INTRODUCTION

1.1 BACKGROUND

During the natural process of coal formation, methane, the principal constituent of natural gas, is generated and trapped in the coal seam as well as in the adjacent rock area. All coal deposits contain methane; however, its concentration varies from seam to seam, and within the seam. Recent estimates of the methane resource in coalbeds approximate 700 trillion cubic feet (tcf). Given current and conservatively projected economic and technological factors, the recovery of an estimated 300 tcf of the resource appears feasible. Based on present consumption rate, this is equivalent to a 10- to 12-year supply of the commodity. However, the recovery of a significant amount of methane from unmined and minable coalbeds depends on removal of technological as well as institutional barriers such as more effective stimulation designs, quicker ways to predict production from wells, cheaper transportation, etc. Legal issues, such as the rights of oil and gas lessees, and economic issues, such as the effect of predrainage on mining, must also be examined resolved and documented. Given a commitment to a sound R&D effort by industry and the government, the Gas Research Institute (GRI) has estimated that by the year 2000, 5% of the natural gas supply can be attributed to coalbed methane. Without technology development by a sound Federal government R&D program such as the MRCP, the coalbed methane contribution will probably not exceed 1.5% of the supply.

Because of its volatility, methane has been considered hazardous to mining operations. The U.S. Bureau of Mines and many mining companies, in the interest of safety, have developed techniques for draining methane from the coalbeds prior to the start of underground coal mining, and for diluting the methane with fresh air during underground coal mining operations to reduce the concentration of coal dust and methane in the mines, thereby reducing the probability of mine explosions and fires. Presently, virtually all drainage systems vent the gas into the atmosphere. Approximately 250 million cubic feet of methane are vented daily in U.S. mining operations. The methane content of gas occluded in virgin coal is comparable to the quality of natural gas recovered from conventional natural gas reservoirs. The content of methane in gas vented from mined areas (the so-called "gob" gas) varies from 25 to 90 percent, depending on the venting techniques used.

In order to curb the waste of methane contained in coalbeds, and to provide for its recovery and utilization, the DOE initiated the MRCP in 1977 and assigned lead responsibility to METC. Major project objectives include:

- Locate and characterize the methane resources
- Extend and improve coalbed methane recovery technology and improve its reliability and control
- Increase recovery efficiency and reduce costs of technology for resource development
- Reduce uncertainty concerning coalbed methane gas-in-place estimates
- Reduce uncertainty concerning the amount of gas that is technically recoverable
- Investigate legal and institutional constraints
- Transfer applicable technologies to private industry.

1.2 PROJECT OBJECTIVES AND APPROACH

1.2.1 Objectives

On December 12, 1977 TRW was awarded Contract No. DE-AC21-78MC08089 to assist METC in implementation of MRCP. As stated in the contract, the primary objective was "to demonstrate systems for economically collecting and utilizing methane recovered from coalbeds. The results of this effort are intended to provide the economic and technical information necessary for implementation of expanded methane recovery operations by industry."

During Phase I, the Conceptual Design Phase, certain programmatic and technology gaps were identified which required MRCP attention in order to accomplish rapid and orderly technology transfer to industry and other elements of the private sector. Principally, the shortfalls included:

- Identification and quantification of the methane resource in the entire United States, including both minable and unminable coal resources

- o Development of technology in recovery and utilization of the resource to the extent that is economically and technically viable
- o Collection, validation, and dissemination of technological data in an expedient, orderly manner
- o Development of a management methodology to provide constant review and evaluation of plans, accomplishments, and problems for execution of an integrated project to fulfill the MRCP goal and objectives.

Thus, the approach to the contract effort was altered to accomplish the following objectives as an integral part of MRCP:

- o Resource characterization to identify target areas for obtaining updated estimates of the gas in place and the recoverable reserves
- o Definition, selection, and implementation of systems application projects to verify technical and economic viability under a variety of field conditions
- o Support the MRCP information and technology transfer efforts to the extent necessary to foster extensive commercial use of coalbed methane
- o Participate in MRCP planning, review, evaluation, and reporting activities to support implementation and management of an integrated, coordinated project.

1.2.2 General Approach

The general approach used for accomplishing the objectives of this effort was as follows:

- o Conduct a "fast track" field test program in the most promising 80,000 square miles of the 380,000 square miles of U.S. coal basins at a density of one sample per 1000 square miles.
- o Conduct production tests in 16 to 20 of the most promising areas
- o Conduct technology test projects to demonstrate the technical and economic feasibility of specific recovery and utilization system combinations
- o Perform specific research activities to increase the knowledge of the gas production mechanisms and the recovery techniques
- o Conduct technical and economic analyses to determine the viability of coalbed methane production with emerging technology
- o Conduct analyses of resource and production data to improve the overall resource estimate

- Conduct technology interchange activities with industry through cooperative test programs, workshops, symposia and document distribution
- Review emerging technology and MRCP projects to determine overall R&D needs and identify related institutional problems.

Using this building block approach, data obtained from resource delineation, R&D and technology test projects has been rapidly transferred to other project participants as well as to other potential energy development companies from the private sector.

2. RESOURCE ENGINEERING

2.1 BACKGROUND

Early in the life of the contract, DOE recognized the risk of basing estimates of the coalbed methane resource on its limited analysis of coal resources data. The differences in composition of the coal and its environment severely impact the methane content not only in different coal seams, but even at different sites of a coal seam. While coal rank, coalbed thickness, and depth of overburden all affect the methane content of coalbeds, other factors such as the distance to outcropping, proximity to working mines (underground or surface), fracture patterns of the coal, aquifer conditions, etc. also directly affect the quantity of methane trapped in the coal micropores. The number and nature of the variables obviously precludes simple extrapolation of a single value across the total estimated known coal resources. Instead, the initial mathematical extrapolation has to be done on smaller, more homogenous areas to which reasonable statistical parameters could be applied. Thus, the project scope was amended to include identifying the location, environment, and potential production of coalbed methane in known major coal areas of the conterminous United States.

2.2 TECHNICAL APPROACH

2.2.1 Resource Engineering Planning and Analysis

The Methane Recovery from Coalbeds Resource Delineation Plan, published in February 1979, is used as the basis for conducting the MRCP resource delineation activities. It includes the criteria used for selecting the basin areas of immediate interest (primary target areas) and prescribes the types of testing to be done under various circumstances.

The basic approach selected for resource delineation plan reflects the following requisites:

- Operation in a reconnaissance mode using a basic 1,000 square mile sampling pattern within the basins of immediate interest.
- Operate first in those areas which are geologically best known and have the highest probability of early commercialization.

A limited review of the major U.S. coal basins was then conducted to reduce the examination of potential coalbed methane resource areas to manageable proportions and to identify the areas having the highest probability of early commercialization.

The basin selections were based on the following criteria:

- o Physical and chemical characteristics of the coal -- higher rank coals generally contain more methane
- o Seam depth -- deeper coals are more likely to have retained the methane
- o Total effective coal thickness -- higher production per well possible on the basis of multiple seam completion
- o Individual seam thickness -- minimize need for multiple stage fracturing
- o Basin size -- allow extrapolation to a larger area.

Based upon these criteria, portions of 12 major basins were selected as primary targets for the resource delineation activities. The target areas are shown in Figure 2-1.

2.2.2 Field Data and Sample Collection

The data required for resource delineation can be acquired in three different ways:

- o Drilling coring and testing totally funded by MRCP
- o Acceptance of voluntary contributions of freshly-cut core samples and new data from interested industry and government agencies
- o Cooperation with drilling projects of industry and other government agencies.

The first approach is considered both time consuming and expensive, although possibly necessary to complete testing of the target areas. The second approach is considered haphazard, and would probably be of questionable value. The third approach is considered most cost effective, and used for most of the MRCP well testing.

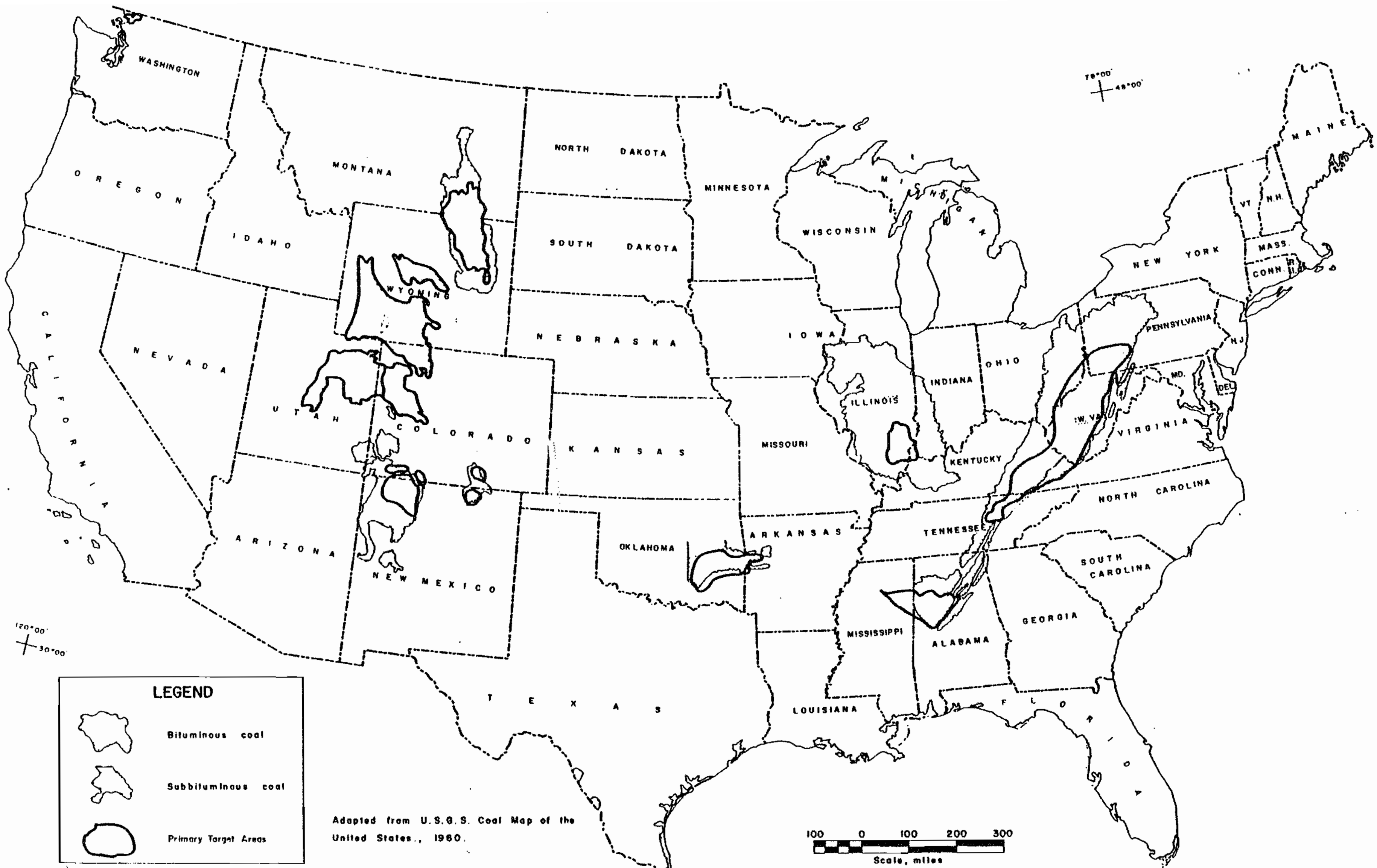

Figure 2-1. Target Areas for Initial Resource Delineation Activities

Implementation of the data and sample acquisition program involved the following:

a. Identification of operators drilling in the primary target areas by a review of records and trade journals including Petroleum Information Services

b. Identification of key individuals within those companies or agencies

c. Establishment of initial telephone contact to discuss MRCP interest and objectives

d. Determination of level of interest in cooperating with MRCP - current active interest, future interest, or no interest

e. Explanation of cooperative agreement mechanism.

One of the side benefits of the person-to-person contact is the development, during the past three years, of a network of professional individuals interested in coalbed methane recovery and utilization. The individuals, from the oil, gas, and coal industries, as well as from R&D firms, government agencies, and universities, have actively participated in development of the MRCP data base by presenting papers and attending workshops and symposiums.

On the other hand, the "piggyback" approach limits the opportunities for executing a program of optimally selected test sites. In addition to the limitation by geographic access (rough terrain, lack of roads, archeological sites, etc.) the testing is limited by lack of operator interest in specific basins during the appropriate time frame. Thus, some of the basins of primary interest probably will not be tested to the desired extent under cooperative agreements.

Certain characteristics were deemed necessary for the determination of the extent of the coalbed methane resource:

- Coal Rank. The general trend seems to indicate that gas content increases with rank, but this relationship is inconclusive, and there are some notable exceptions. Some anthracites, for example, are known to be very low in gas content. Depth of burial and degree of deformation may have a more important influence than rank on gas migration from the seam by reducing porosity and permeability. Rank can be determined from the proximate and ultimate analyses of coal collected by core drilling or sidewall coring.

- Specific Gas Content. Coal samples collected by conventional coring and by sidewall coring will be subjected to gas desorption testing and the desorbed gas will be analyzed for hydrocarbon content. The gas volume per unit weight of coal provides an upper limit for gas production, but is not by itself an indicator of production rate. This rate is controlled by permeability, coal seam gas pressure, and other characteristics of the coal. The methane adsorption capacity of coal can be determined by desorption testing of cored coal samples.

- Gas Pressure. Drill stem tests will be conducted to ascertain the pressure of gas within the coal seam. In situ gas pressure is the major factor other than permeability influencing flow rate. Pressure is related to a number of variables, but is primarily a function of overburden thickness and lateral compression from tectonic stress. Local pressure can result from deformation or folding of strata which tend to compress the formation near the top of the arch and thicken or expand the excess into the limbs. Bed pressure may also be hydraulically controlled.

- Seam Thickness. Coal seam thickness may be determined by examination of core samples or well cuttings, lithologic logs, drillers logs, and borehole geophysical logs. Seam thickness may be an important indicator of production potential. Although total coal thickness may also be a factor due to potential for multi-seam completions, the relationship between individual seam thickness and total coal thickness may not be correlative in an area of interest. Flow rates generally are higher from a single thick seam than from several thinner seams of equal thickness. The reasons are not completely understood, but the volume of connected pore space is probably higher in thicker seams, and friction losses are lower due to a smaller flow surface area.

- Overburden Characteristics. Core material, borehole geophysical logs, and seismic data will be analyzed in order to evaluate overburden characteristics pertinent to the coalbed methane resource. General indicators are that gas content increases with thickness of overburden, which may make many deeper seams now considered uneconomic for mining attractive for methane production despite higher drilling costs. Overburden porosity and permeability determine whether coalbed gases will be contained by the structural and stratigraphic traps in the coalbed. Although classic stratigraphic traps of the size and type forming large oil and gas reservoirs are infrequently found in coal seams, similar features, on a smaller scale, may control the gas content in coal seams and must be considered.

2.2.3 Data Evaluation

The data collected under the MRCP well testing activities are primarily used to determine specific gas content of each of the encountered coalbeds. Whenever possible, coal samples have been collected, desorbed, and subjected to lost gas calculation and determination of the residual gas. The USBM direct method is generally used for measuring gas desorbed from the coal sample, using canisters identical to those designed by USBM. Figure 2-2 shows the process by which desorbed gas is measured. The desorbed gas is measured frequently during the first two hours (15 minute intervals) to facilitate calculation of the "lost gas" volume (the amount of gas lost to the atmosphere prior to the time the sample is sealed in the canister).

The volume of lost gas is determined by extrapolation of the observed gas desorption volume to the time the sample was cored. In actual practice the lost gas is graphically computed using linear graph paper. The computation can be calculated fairly accurately during the first few hours of emission since the amount emitted is proportional to the square root of the desorption time. The drilling medium used, however, does have an influence on the amount of lost gas. If air or mist is used as the cooling medium, it is assumed that the coal begins emitting gas immediately upon

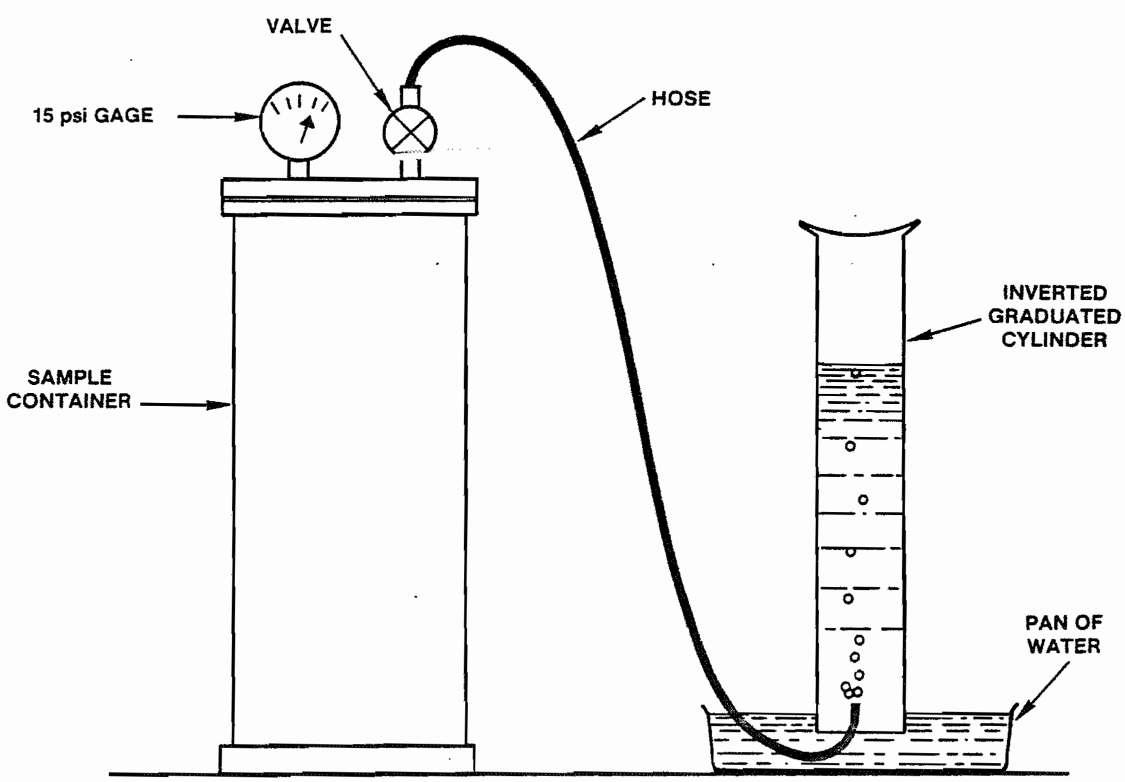

Figure 2-2. USBM Direct Method Desorption Apparatus

penetration by the core barrel. With water or mud, desorption is assumed to begin when the core is half way out of the hole; that is, when the gas pressure is assumed to exceed that of the hydrostatic head (McCulloch et al., 1975).

The volume of residual gas in a coal sample is obtained by sealing the sample in a ball mill with the appropriate grinding media to crush the coal to a fine power in a reasonably short time. The ball mill, constructed of heavy steel pipe, is similar in style to a desorption canister but able to withstand the rattling of steel bars and balls within while tumbling on a roller machine. The equipment for crushing the coal sample is described in the USBM Report of Investigation number 8515 (Diamond and Levine, 1981).

An alternative to the desorption of coal lumps obtained by coring is the desorption of chips and cuttings obtained during drilling. The chips are collected directly from the shale shaker, rinsed off, and placed in standard desorption canisters to within approximately one inch from the top. Each canister is sealed shut and desorption measured in the usual manner. Three advantages of this technique are pointed out: (1) since the technique does not alter any of the conventional drilling operations, there are no extra costs associated with coring; (2) because the collection of chips requires relatively little time at the site, more sites can be sampled because operators and leaseholders are more inclined to allow chip collection from ongoing operations without contractual or financial constraints; and (3) the data is available in a few weeks, rather than months (Williams and Smith, 1981).

To facilitate direct method desorption procedures, the use of other measurement apparatus has been investigated. Figure 2-3 shows an arrangement using a graduated 250 milliliter (ml) buret and a 250 ml leveling bulb which rests in an adjustable support ring. The 250 ml buret was modified by a glass blower, attaching a hose connector to the bottom and forming a neck at the top, fitted by another hose connector. As gas is desorbed, it displaces the fluid which flows through the supply tube into the leveling bulb. The primary advantage of the apparatus is that it is less awkward to use than the open pan of water, and therefore requires less time to measure each sample (TRW, 1981). Williams and Smith (1981) normally use a 500 ml buret and a 500 ml reservoir, but a 100 ml buret is also kept available for

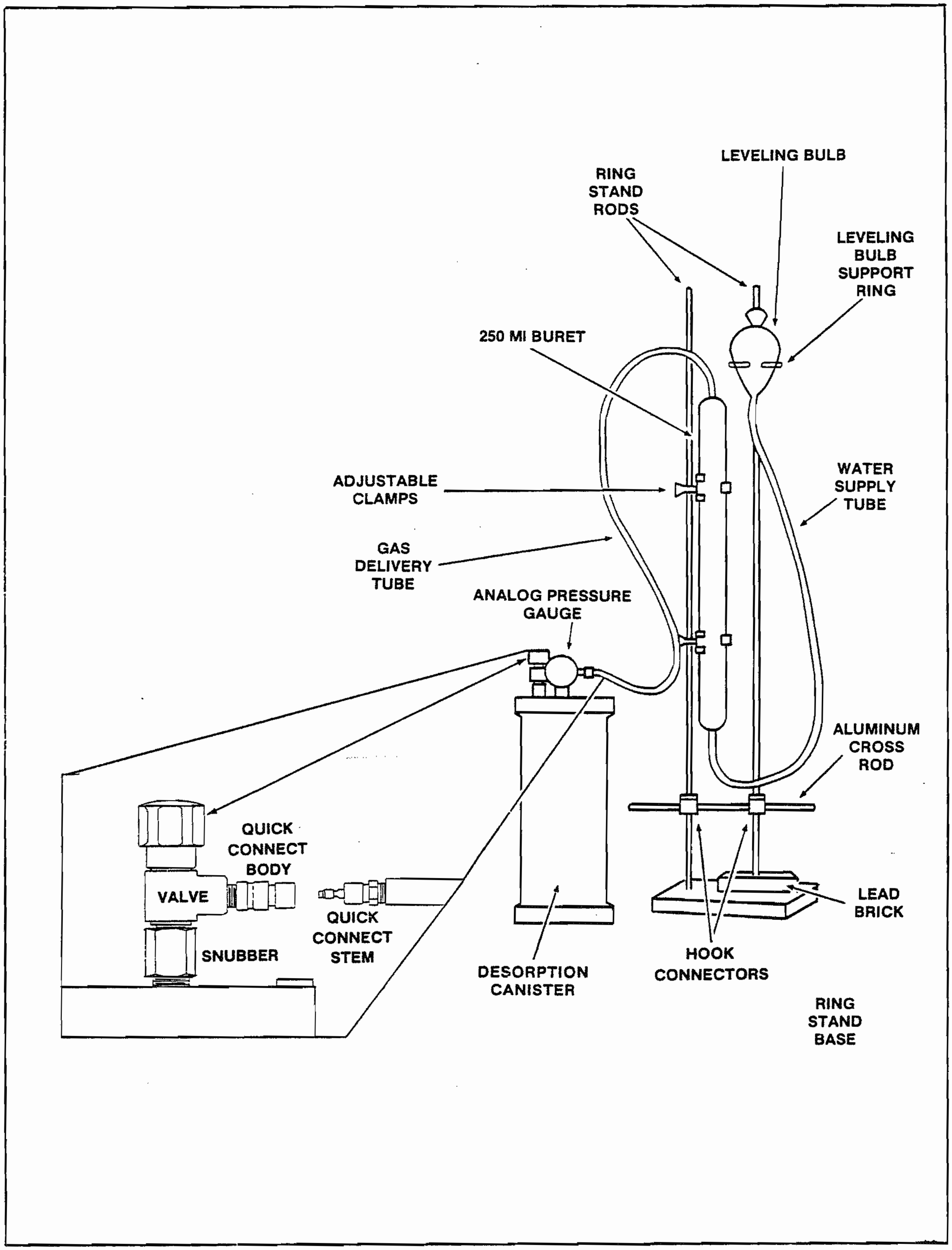

Figure 2-3. Schematic of the Manometric Desorption Measurement Apparatus

more accurate measurement of small volumes. Since much of the field work is done under extreme weather conditions, Williams and Smith use commercial radiator antifreeze as the fluid, while TRW geologists use commercial windshield washer fluid as the medium in extremely cold weather.

2.3 COALBED METHANE RESOURCES AND RECOVERABLE RESERVES

As a result of the 45 well tests performed by the Methane Recovery from Coalbeds Project (MRCP) the available coalbed methane resource have been better defined in the Piceance, Powder River, and Wind River basins. Data discussing the extent of the resource delineation findings is contained in the remainder of this section.

To date no MRCP field testing activities have been performed in the Richmond, Raton Mesa, or Uinta basins. Maps of basins which have been partly tested are included in Appendix A, showing the basin area, MRCP primary target areas, and each well test site. Tables 2-1 through 2-8 indicate the tests performed at each site and summarize resultant gas measurements and estimates.

2.3.1 Arkoma Basin

The Arkoma Basin encompasses approximately 5,300 square miles in Arkansas and Oklahoma. It contains extensive bituminous coal reserves in the Desmoinesian (Pennsylvanian) age rocks. Some minor coals occur in the Atokan Series of rocks, which lie directly below the Desmoinesian age coal-bearing strata.

Coals in the Arkoma Basin were deposited in deltaic environments. The gassiest coals are found in the Upper and Lower Hartshorne beds, which are 3 to 7 feet thick and contain estimated resources of about 5 billion tons. Individual 3- to 4-foot-thick seams are preserved in synclinal basins as narrow belts parallel to steeply dipping beds. Overburden is less than 3,000 feet in approximately 610 square miles.

The U.S. Bureau of Mines has investigated the methane content of the Hartshorne coals. The average methane content ranges from 211 cf/ton with an overburden of 0 to 50 feet to 672 cf/ton with an overburden of 2,000 to 3,000 feet. Four wells have been tested by MRCP in the Arkoma basin (Table 2-1). The Type I field tests have provided additional desorption data for some of the coals in the western part of the Arkoma Basin. Based on these

TABLE 2-1. MRCP WELL TEST SUMMARY ARKOMA BASIN

MRCP SITE CODE	COOPERATOR/ WELL NAME	STATE	YEAR TESTED	TEST ACTIVITIES CONDUCTED: CONVENTIONAL CORING	SIDEWALL CORING	GEOPHYSICAL LOGGING	DESORPTION	GAS ANALYSIS	PROXIMATE	ULTIMATE	DRILL STEM TESTING	MUD LOGGING	PRE-FRAC FLOW	PRE-FRAC PRESSURE	POST-FRAC FLOW	POST-FRAC PRESSURE	OTHERS (Footnoted)	DEPTH OF COAL-BEARING INTERVAL (ft): FROM	TO	NUMBER OF COAL-BEDS ENCOUNTERED	NUMBER OF COAL-BEDS SAMPLED	COMPOSITE COAL THICKNESS (FT)	NUMBER OF SAMPLES TAKEN	GAS CONTENT (ft³/ton): MINIMUM	MAXIMUM	AVERAGE
EAA	Arkla Exploration Co./ Brown No. 1-2	Okla.	1978		•	•	•				•							2700	2740	3	3	6.0	36	73	211	138
EAB	Mustang Production Co./ Barringer No. 1-11	Okla.	1979	•		•	•		•	•								3650	4593	18	1	26	1	243	243	243
EAC	Mustang Production Co./ Day Well No. 1-14	Okla.	1979	•		•			•	•								1615	2613	9	–	20	0[1]	–	–	–
EAD	U.S. Bureau of Reclamation/ DH-A17	Okla.	1979	•		•	•		•	•								192	195	1	1	2.9	1	300	–	300

[1] No coal was obtained from coring operations due to rig problems

limited desorption data, minimum and maximum ranges for expected in-place gas have been estimated for the Hartshorne coals. Assuming an average gas content of 200 to 450 cf/ton, the Hartshorne coals are thought to contain from 1.6 to 3.6 trillion cubic feet of methane.

2.3.2 Greater Green River Coal Region

The Greater Green River Coal Region occupies approximately 21,000 square miles in southwestern Wyoming and northwestern Colorado and includes the Western Wyoming Thrust Belt, the Green River Basin, the Rock Springs Uplift, the Great Divide Basin, and the Washakie Basin. This region contains significant quantities of both bituminous and subbituminous coal; the total original in-place resource is estimated at more than 80 billion short tons. This coal is found in both Upper Cretaceous and Tertiary units that crop out on the flanks of the surrounding uplifts and dip into the basinal areas. Very little is known about the quantity and stratigraphic distribution of coals in the deeper part of the basins. Therefore, the estimate of the total quantity of coal in this region is believed to be conservative.

The area in the western Wyoming Thrust Belt that contains coal outcrops is called the Hams Fork coal region. This is the fifth largest coal-producing area in Wyoming. Because of its location in the western Wyoming Thrust Belt, this region's structure is extremely complex. The major coal-bearing units include the Upper Cretaceous Frontier and Adaville Formations. Other formations containing coal are the Lower Cretaceous Bear River, the Upper Cretaceous Blind Bull, and the Paleocene Evanston. Coals in this area range from about 3 to 118 feet thick and are subbituminous to high-volatile C bituminous in rank. The total estimated original in-place coal resource, both bituminous and subbituminous, in the Hams Fork coal region is approximately 5 billion short tons. The estimated potential coalbed methane resource from this area ranges from approximately 9.3 billion to 1.9 trillion cubic feet.

Under the MRCP resource delineation program, four sites were cooperatively tested in the greater Green River coal region. Methane content from the 44 samples taken for desorption testing ranged from a minimum of 33 cubic feet per ton, to a maximum of 539 cubic feet per ton. Table 2-2 contains a summary of the tests performed at the four MRCP sites and preliminary gas measurements.

TABLE 2-2. MRCP WELL TEST SUMMARY GREATER GREEN RIVER COAL REGION

MRCP SITE CODE	COOPERATOR/ WELL NAME	STATE	YEAR TESTED	TEST ACTIVITIES CONDUCTED: CONVENTIONAL CORING	SIDEWALL CORING	GEOPHYSICAL LOGGING	DESORPTION	GAS ANALYSIS	PROXIMATE	ULTIMATE	DRILL STEM TESTING	MUD LOGGING	PRE-FRAC FLOW	PRE-FRAC PRESSURE	POST-FRAC FLOW	POST-FRAC PRESSURE	OTHERS (Footnoted)	DEPTH OF COAL-BEARING INTERVAL (ft): FROM	TO	NUMBER OF COAL-BEDS ENCOUNTERED	NUMBER OF COAL-BEDS SAMPLED	COMPOSITE COAL THICKNESS (FT)	NUMBER OF SAMPLES TAKEN	GAS CONTENT (ft^3/ton): MINIMUM	MAXIMUM	AVERAGE
GAA	Energy Reserves Group/ Robert Van Dorn No. 1 Type I Testing	Colo.	1979	•	•	•	•	•	•	•	•	•					•[1]	3700	4714	30	12	198	14	87	376	259
GAA	Energy Reserves Group/ Robert Van Dorn No. 1 Type III Testing	Colo.	1980										•	•	•	•										
GAB	Belco Petroleum Corp./ S-29-27	Wyo.	1979	•	•	•	•		•	•							•[1] •[2]	3479	3528	3	3	5.6	16	33	539	412
GAC	Kemmerer Coal Company/ Barrel Springs Unit 29-2	Wyo.	1980			•	•		•	•		•						4406	4986	7	2	38	4	13	26	17
GAD	(Confidential No. 7)	Confidential	1980	•		•	•	•	•	•		•						481	686	2	2	38	10	86	118	84

[1] Peremeability and porosity determinations

[2] Equilibrium moisture tests

The Green River Basin, located in southwestern Wyoming between the western Wyoming Thrust Belt and the Rock Springs Uplift, is a broad synclinal area of about 10,000 square miles. Only minor coals outcrop in the basin, but it is probable that substantial coal resources are present in the subsurface. However, very little is presently known about the quantity and stratigraphic distribution of coals in the subsurface; therefore, any estimate of the potential methane resource would probably be extremely conservative. Upper Cretaceous Mesaverde Group coal from one well in this basin was desorbed and yielded between 420 and 524 cubic feet of methane per ton of coal.

The Rock Springs Uplift is a north-south trending anticlinal feature of Laramide age, located in the center of Sweetwater County, Wyoming. The principal coal-bearing units in the Rock Springs Uplift area include the Upper Cretaceous Rock Springs and Almond Formations of the Mesaverde Group, the Upper Cretaceous Lance Formation, and the Paleocene Fort Union Formation. Coals from these formations are generally subbituminous B to high-volatile C bituminous in rank and average about 5 to 6 feet thick. The estimated total original in-place coal resource of this area, both bituminous and subbituminous, is approximately 13 billion short tons. The estimated potential methane resource is between 29 billion and 5.5 trillion cubic feet.

The Great Divide Basin, located in the northeastern part of Sweetwater County, Wyoming, is a large synclinal basin modified by broad shallow folds and widespread small-scale faults. The major coal-bearing unit in the Great Divide Basin is the Eocene Wasatch Formation. Coals in this formation are best developed in the southeastern and central parts of the basin, where it is estimated that there are approximately 1.6 billion short tons of subbituminous coal within 3,000 feet of the surface. The estimated potential coalbed methane resource of this basin ranges up to 160 billion cubic feet.

The Washakie Basin is a broad syncline that covers approximately 3000 square miles in south central Wyoming and northwestern Colorado. In the primary Washakie Basin, the major coal-bearing units are the Upper Cretaceous Mesaverde Group and the Eocene Wasatch Formation. These coals range in thickness from about 3 to 32 feet and are lignite to high volatile

C bituminous in rank. The estimated total original in-place coal resource in this basin is approximately 23 million short tons of bituminous coal and 119 billion short tons of subbituminous coal. The estimated potential coalbed methane resource ranges from 67 million to 200 billion cubic feet.

The Sand Wash Basin is a southeasterly trending synclinal prong of the Washakie Basin. The major coal-bearing units in this basin are the Upper Cretaceous Williams Fork and Iles Formations of the Mesaverde Group and the Paleocene Fort Union Formation. These coals range in thickness from approximately 2 to 20 feet and are subbituminous B to high-volatile C bituminous in rank. The total estimated original in-place coal resource from this group is approximately 58 billion short tons. The potential total coalbed methane resource is estimated to range from 116 billion to 23 trillion cubic feet.

2.3.3 Illinois Basin

The Illinois Basin encompasses approximately 53,000 square miles in the east-central United States, covering a large portion of Illinois and extending into southwestern Indiana and western Kentucky. This basin contains extensive bituminous coal reserves in Pennsylvanian age rocks.

The U.S. Geological Survey has estimated that the total coal resource of the Illinois Basin might be 365 billion tons. More than 75 individual coal seams have been identified in this area, 20 of which are mined. The majority of the coals are not continuous and do not maintain constant thicknesses. Individual seam thickness ranges from a few inches to 15 feet over large areas. The coals outcrop at the periphery of the basin and dip gently towards the deeper central portion in southeastern Illinois and western Kentucky. Lower and upper Pennsylvanian coals are thin and discontinuous while the middle coals are thick, generally continuous, and provide the major reserves of the basin. The lower and upper coals have not been studied in as much detail and are not as well correlated as the thicker coalbeds of the Middle Pennsylvanian. The greatest cumulative thickness of coal seams presumably occurs in the southeastern portion of the basin (near the tri-state boundary) where the thickest Pennsylvanian section occurs. All Illinois Basin coal seams are covered by less than 3,000 feet of overburden, and the major coals are within 1,500 feet of the surface.

The Springfield-Harrisburg (No. 5) coals in Illinois and their correlatives, Springfield V in Indiana and No. 9 coals in Kentucky, are the most extensive and uniformly thick coals in the Illinois Basin; reserves of these coals are estimated at more than 67 billion short tons. The Herrin (No. 6) coal is also thick and extensive in Illinois and contains estimated coal reserves of over 77 billion short tons. Some deeper coals, the Colchester (No. 2), which is uniformly present over the entire basin, and the Davis (No. 6), and Mannington (No. 4), occurring primarily in Kentucky, contain combined reserves estimated at over 39 billion short tons. The coal is predominantly high-volatile bituminous.

Recently acquired gas desorption data indicates that the gas content of coals in the Illinois Basin is generally low, ranging from 23 to 144 cubic feet per ton (Table 2-3). Based on the limited available desorption data, minimum and maximum ranges for expected in-place gas have been made from the Danville, Herrin, and Springfield-Harrisburg coals and their equivalents. The Danville coals are anticipated to have a minimum of approximately 0.5 trillion cubic feet and a maximum of nearly 1.7 trillion cubic feet of in-place gas. Likewise, the estimated range for Herrin coal is 2.5 to 3.4 trillion cubic feet of gas; and the Springfield-Harrisburg, 2.2 to 9.9 trillion cubic feet of gas. The minimum total in-place gas resource for these three seams totals over 5 trillion cubic feet. It is assumed that the methane contained in major deeper coals (Colchester, Davis, et al.) could add significantly to this figure. Although the specific gas content of coals in the Illinois Basin is quite low, the magnitude of the coal resource produces large in-place gas resource estimates.

The gas content of coals in the Illinois Basin is thought to be higher towards the southeastern portion of the basin, so this was the initial target area defined by MRCP for early coalbed methane delineation. Recently, the coals having the greatest probability for early commercial gas production were redefined, and the primary MRCP target in the Illinois Basin now consists of two areas totalling approximately 4,300 square miles. The initial MRCP target area in the Illinois Basin was approximately 9,111 square miles. Target Area A, located in western Kentucky, contains a thick

TABLE 2-3. MRCP WELL TEST SUMMARY ILLINOIS BASIN

MRCP SITE CODE	COOPERATOR/ WELL NAME	STATE	YEAR TESTED	TEST ACTIVITIES CONDUCTED: CONVENTIONAL CORING	SIDEWALL CORING	GEOPHYSICAL LOGGING	DESORPTION	GAS ANALYSIS	PROXIMATE	ULTIMATE	DRILL STEM TESTING	MUD LOGGING	PRE-FRAC FLOW	PRE-FRAC PRESSURE	POST-FRAC FLOW	POST-FRAC PRESSURE	OTHERS (Footnoted)	DEPTH OF COAL-BEARING INTERVAL (ft): FROM	TO	NUMBER OF COAL-BEDS ENCOUNTERED	NUMBER OF COAL-BEDS SAMPLED	COMPOSITE COAL THICKNESS (FT)	NUMBER OF SAMPLES TAKEN	GAS CONTENT (ft^3/ton): MINIMUM	MAXIMUM	AVERAGE
DAA	Hagen Oil Company/ Henderson No. 2	Ill.	1978	•	•	•	•		•	•	•						•[3]	994	1352	5	5	8	8	32	51	39
DAB	Geowest, Inc./ VIICA Coal 711-1CD	Ill.	1979	•		•	•		•	•							•[2] •[3]	664	732	4	3	12.8	6	23	35	28
DAC	Indiana Geological Survey/ Indiana G.S. SDH 301	Ind.	1979	•		•	•		•	•								468	889	7	7	19.4	7	26	67	49
DAD	Indiana Geological Survey/ Indiana G.S. SDH 302	Ind.	1980	•		•	•		•	•								506	933	7	7	28.9	9	45	144	88
DAE	R. W. Beeson Oil Producer/ Coy Vandeygriff	Ky.	1980	•		•	•	•	•	•	•						•[1]	1200	1305	2	2	10.7	4	45	45	45

[1] Roof and floor rock mechanical property analyses   [2] Equilibrium moisture tests   [3] Permeability, porosity and density tests

section of deep coals in a highly disturbed structural belt. Target Area B, in southeastern Illinois and southwestern Indiana, retains part of the initial target area and contains previously reported gassy coals and thick coal sections at considerable depths.

2.3.4 Northern Appalachian Basin

Coal in the Northern Appalachian Basin is found in Permian Dunkard Group rocks and the Pennsylvanian Conemaugh, Allegheny, and Pottsville Group strata. These rock units contain approximately 198 billion tons of coal reserves in about 90 minable coal seams. The total coal thickness varies from 20 to 60 feet. The individual seams are generally thin, less than 10 feet thick, but continuous over large areas. The coal is low to high volatile bituminous in rank and is known to have methane production potential. Gas emission data exist for mines in at least 15 different seams. Gas content has been measured for three sites in the Northern Appalachian Basin. The gas content ranged from a minimum of 33 to 1 maximum of 313 cubic feet per ton (Table 2-4). The Waynesburg College wellbore was completed and stimulated as a MRCP technology test project, and is currently producing at a measured rate of 40,000 cubic feet per day. The project is further described in Section 3.2.2. The beds in the area range from gently to tightly folded and faulted in the east to nearly horizontal in the west. Most of the coal is covered by less than 3,000 feet of overburden.

2.3.5 Piceance Basin

The Piceance Basin, in northerwestern Colorado, has one of the greatest potential for near-term production of coalbed methane of any basin in the western United States. Coalbeds of the Late Cretaceous Mesaverde Group underlie 6,570 square miles of the total basin area of 6,680 square miles. Preliminary estimates based on interpretation of geophysical logs of oil and gas wells indicate that the average value for total coal thickness throughout the basin is approximately 50 feet and that the total coal resources extending to depths exceeding 10,000 feet, is 380 billion tons. Methane contained within the coalbeds comprising thhis resource is estimated to average 60 trillion cubic feet (tcf). Lower and upper limits for

TABLE 2-4. MRCP WELL TEST SUMMARY NORTHERN APPALACHIAN BASIN

MRCP SITE CODE	COOPERATOR/ WELL NAME	STATE	YEAR TESTED	TEST ACTIVITIES CONDUCTED														DEPTH OF COAL-BEARING INTERVAL (ft)		NUMBER OF COAL—BEDS ENCOUNTERED	NUMBER OF COAL-BEDS SAMPLED	COMPOSITE COAL THICKNESS (FT)	NUMBER OF SAMPLES TAKEN	GAS CONTENT (ft^3/ton)		
				CONVENTIONAL CORING	SIDEWALL CORING	GEOPHYSICAL LOGGING	DESORPTION	GAS ANALYSIS	PROXIMATE	ULTIMATE	DRILL STEM TESTING	MUD LOGGING	PRE-FRAC FLOW	PRE-FRAC PRESSURE	POST-FRAC FLOW	POST-FRAC PRESSURE	OTHERS (Footnoted)	FROM	TO					MINIMUM	MAXIMUM	AVERAGE
AAA	Kinloch Development Corp./ No. 1 Murdock[2]	Penna.	1978		•	•							•	•	•	•	•[1]	329	664	2	2	(All Cased Off)	2	33	64	49
AAB	Waynesburg College/ Waynesburg No. 1[2]	Penna.	1979	•		•	•		•	•						•		888	1292	9	9	38	9	70	198	135
AAC	Rochester and Pittsburgh Coal Co./ R&P DDH 2355	Penna.	1980	•		•	•											570	750	3	3	12	6	141	313	227[3]

[1] Pre-and post-frac injection testing
[2] Stimulated as Technology Test Projects
[3] Desorbed gas only

coalbed methane content in the basin are estimated at 30 and 110 tcf, respectively. The area with the highest potential for coalbed methane production is found in the southeastern Piceance Basin, according to tests of five sites conducted by MRCP (Table 2-5).

Coals of the Mesaverde Group outcrop around the periphery of the basin, and eight coal fields have been established in these units. In the northwest part of the basin, the fields are the lower White River, Danforth Hills, Grand Hogback, Carbondale, Crested Butte, Somerset, Grand Mesa, and Book Cliffs. Coking coals are abundant in the Grand Hogback, Carbondale, Crested Butte, and Somerset coal fields where 450 million short tons have been estimated to be present at depths less than 1,000 feet. Total cumulative production in the basin by 1978 was over 87 million tons, and projected 1980 production has been estimated at 6.75 million short tons, more than double the 1978 figure.

Ranks of Piceance Basin coals range mainly from high-volatile C to medium-volatile bituminous. In the southeastern basin, the high heat associated with Tertiary igneous activity has resulted in coals being metamorphosed to semianthracite rank. Individual coalbeds vary widely in thickness and stratigraphic position and coalbed names generally are not carried throughout the basin. Coal thicknesses decrease to the west and northwestern parts of the basin.

Methane desorption data have been gathered from surface wells on projects other than DOE's Methane Recovery from Coalbeds Project (MRCP). Data from several of these sities were used to construct an east-west cross section which provides insight into the nature of methane generation.

Evaluation of the cross-section indicates that methane content increases with increasing aggregate coal thickness, increasing overburden thickness, and proximity to igneous intrusions. Data collected in northern Piceance Basin by the Geological Survey and the DOE/TRW/MRCP indicate that these lower rank coals are not very gassy. The weight of accumulated data for Piceance Basin supports the theory that increased overburden thickness and geothermal heat flow resulted in coal rank and greater amounts of coalbed methane.

TABLE 2-5. MRCP WELL TEST SUMMARY
PICEANCE BASIN

MRCP SITE CODE	COOPERATOR/ WELL NAME	STATE	YEAR TESTED	TEST ACTIVITIES CONDUCTED														DEPTH OF COAL-BEARING INTERVAL (ft)		NUMBER OF COAL-BEDS ENCOUNTERED	NUMBER OF COAL-BEDS SAMPLED	COMPOSITE COAL THICKNESS (FT)	NUMBER OF SAMPLES TAKEN	GAS CONTENT (ft^3/ton)		
				CONVENTIONAL CORING	SIDEWALL CORING	GEOPHYSICAL LOGGING	DESORPTION	GAS ANALYSIS	PROXIMATE	ULTIMATE	DRILL-STEM TESTING	MUD LOGGING	PRE-FRAC FLOW	PRE-FRAC PRESSURE	POST-FRAC FLOW	POST-FRAC PRESSURE	OTHERS (Footnoted)	FROM	TO					MINIMUM	MAXIMUM	AVERAGE
FAA	Fuel Resources Development Co./ Fuelco 0-28-3-101-S	Colo.	1978	•		•	•		•	•								1584	1603	2	2	3	2	18	81	50
FAB	Twin Arrow Drilling Co./ C&K Well No. 1-13	Colo.	1978			•							•	•	•	•		573	810	5	–	37	–	–	–	–
FAC	Twin Arrow Drilling Co./ C&K Well No. 4-14	Colo.	1978	•		•	•											685	987	4	5	12.6	9	24	243	116
FAD	Western Fuels Co./ Moon Lake 310136-2	Colo.	1979	•		•	•		•	•								1325	1351	3	3	11.4	5	58	70	65
FAE	Western Fuels Co./ Moon Lake 21011-5	Colo.	1979	•		•	•		•	•								742	806	6	6	27.6	8	20	90	63

TABLE 2.5 MRCP WELL TEST SUMMARY PICEANCE BASIN (Continued)

MRCP SITE CODE	COOPERATOR/ WELL NAME	STATE	YEAR TESTED	TEST ACTIVITIES CONDUCTED: CONVENTIONAL CORING	SIDEWALL CORING	GEOPHYSICAL LOGGING	DESORPTION	GAS ANALYSIS	PROXIMATE	ULTIMATE	DRILL STEM TESTING	MUD LOGGING	PRE-FRAC FLOW	PRE-FRAC PRESSURE	POST-FRAC FLOW	POST-FRAC PRESSURE	OTHERS (Footnoted)	DEPTH OF COAL-BEARING INTERVAL (ft): FROM	TO	NUMBER OF COAL-BEDS ENCOUNTERED	NUMBER OF COAL-BEDS SAMPLED	COMPOSITE COAL THICKNESS (FT)	NUMBER OF SAMPLES TAKEN	GAS CONTENT (ft³/ton): MINIMUM	MAXIMUM	AVERAGE
FAF	Western Fuels Co./ Moon Lake 310129-4	Colo.	1979	•		•	•		•	•								879	904	2	2	11	7	1	10	3
FAG	Western Fuels Co./ Moon Lake 310135-4	Colo.	1979	•		•	•		•	•								1188	1207	2	2	11.9	7	32	42	36
FAH	Fuel Resources Development Co./ Fuelco D-26-3-101-S	Colo.	1979	•		•	•		•	•								1149	1223	4	3	22	5	20	36	28
FAI	(Confidential No. 6)	Colo.	1980	•		•	•		•	•								4682	4796	3	3	41.5	16	37	285	157
FAJ	Adolph Coors/ Nichols No. 1-24 (Type III Test)[2]	Colo.	1980										•	•	•	•	•[1]	2625	2633	–	–	–	–	–	–	–
FAK	Adolph Coors/ Nichols No. 1-23	Colo.	1980	•		•	•		•	•	•							2631	2769	10	5	38.9	11	96	240	166

[1] Injectivity test; frac

[2] Test to determine producibility

2.3.6 Powder River Basin

The Powder River Basin contains the nation's largest coal resources. Most of the thick coalbeds occur in the upper member--the Tongue River Member--of the Fort Union Formation, and the overlying Wasatch Formation. Coalbeds do occur in the lower members of the Fort Union Formation, as well as the Lance and Mesaverde Formations, but generally they are thinner and less continuous. Some of these older coalbeds crop out in the southwestern portion of the Powder River Basin, near Glenrock and Douglas, Wyoming.

The coal resource of the Powder River Basin has been calculated from subsurface data to be 1.3 trillion tons. Most of it is in thick beds that are relatively near-surface--with most of the coal at a depth less than 2,500 feet, even in the basin center. Powder River Basin coal ranges in rank from lignite A through subbituminous A. Generally, Powder River Basin coals are low in sulfur with low to moderate ash content, although ash content can vary considerably. Commonly, the coals have an as-received moisture content of 20 to 30 percent, and volatile matter and fixed carbon contents of 30 to 40 percent.

The total number of coalbeds in the Powder River Basin is difficult to determine because the beds split, coalesce, and are sometimes discontinuous, with beds pinching out and new beds appearing. Some correlations between the beds of various fields have been made, but much remains to be done. In the Sheridan County area of Wyoming, as many as 11 persistent coalbeds occur in the Wasatch Formation. In other areas, as many as 12 to 18 coalbeds occur, most of them within the Fort Union Formation. Most of the Wasatch beds occur under less than 200 feet of overburden. However, the Wasatch and Fort Union Formations together attain a maximum thickness of 3,970 feet in the Buffalo area.

Two of the largest coalbeds in the basin are the Wyodak-Anderson and the Lake De Smet beds. The Wyodak-Anderson coalbed crops out over a north-south distance of 120 miles in the Gillette Coal Field. It, and the beds correlative to it, persist downdip to the deepest part of the Powder River Basin. The Wyodak-Anderson bed is locally up to 150 feet thick, but averages 50 to 100 feet in thickness. Based on these figures, the bed contains at least 100 billion tons of coal to a depth of 2,000 feet. This is the largest tonnage in a single continuous coalbed anywhere in the U.S.

The Lake De Smet bed, in the Buffalo Coal Field, is thought to be the thickest coalbed in the U.S. and second thickest in the world. It is 15 miles long, 70 to 220 feet thick, and one-half to two miles wide.

The area considered to be the prime methane exploration target within the Powder River Basin encompasses portions of Campbell, Sheridan, and Johnson Counties in Wyoming, and Big Horn and Powder River Counties in Montana. Field test activities have been conducted at eight sites by MRCP (Table 2-6). Factors used in delineating the target boundaries include:

- o Restricting the area to lands underlain by the Tongue River Member of the Fort Union Formation, and additionally to:
- o Areas in which shallow drill holes are known to flow anomalously large amounts of methane
- o Areas in which flowing artesian wells are concentrated
- o Areas in which three or more individually thick coalbeds are coalesced together into a single superbed.

The in-place methane resource for the Powder River Basin is estimated to range from 9.7 tcf to 39.4 tcf.

2.3.7 Richmond Basin

The Richmond Basin is elongated north to south, and covers approximately 170 square miles in eastern Virginia. Igneous and metamorphic crystalline rocks completely surround and underlie the Triassic sedimentary rocks of the basin. These sedimentary deposits contain the coal resources of the basin. The exact thickness of these Triassic rocks within the basin and overlying the coal is not known.

Exploration in the basin has been minimal, and the extent of the coal resources is not known making resource estimates imprecise. Coal resource estimates for the basin range from two to four billion tons. The coal rank is medium-volatile bituminous and in some areas has been altered to coke by igneous intrusions.

The coal dips steeply toward the center of the basin. The 3 to 5 coalbeds, with some included shale bands, previously mined have recorded a maximum thickness of 70 feet. The deepest part of the basin where coal was recorded was 2,320 feet. It is thought that coal could be found at 3,000 feet or greater in the center of the basin.

TABLE 2-6. MRCP WELL TEST SUMMARY POWDER RIVER BASIN

MRCP SITE CODE	COOPERATOR/ WELL NAME	STATE	YEAR TESTED	TEST ACTIVITIES CONDUCTED														DEPTH OF COAL-BEARING INTERVAL (ft)		NUMBER OF COAL-BEDS ENCOUNTERED	NUMBER OF COAL-BEDS SAMPLED	COMPOSITE COAL THICKNESS (FT)	NUMBER OF SAMPLES TAKEN	GAS CONTENT (ft^3/ton)		
				CONVENTIONAL CORING	SIDEWALL CORING	GEOPHYSICAL LOGGING	DESORPTION	GAS ANALYSIS	PROXIMATE	ULTIMATE	DRILL STEM TESTING	MUD LOGGING	PRE-FRAC FLOW	PRE-FRAC PRESSURE	POST-FRAC FLOW	POST-FRAC PRESSURE	OTHERS (Footnoted)	FROM	TO					MINIMUM	MAXIMUM	AVERAGE
IAA	USGS/ USGS/79-BR-6	Mont.	1979	•		•	•											248	378	2	2	77.1	6	1	3	2
IAB	Montana Bureau of Mines and Geology/ US-7735	Mont.	1979	•		•	•				•						•[1]	121	620	4	4	84.2	10	1	10	4
IAC	Montana Bureau of Mines and Geology/ US-7746	Mont.	1979	•		•	•		•	•							•[1]	155	743	5	5	142.2	10	1	13	4
IAD	USGS/ USGS/80-AU-14	Wyo.	1980	•		•	•		•	•								295	681	2	1	108.9	4	22	32	27
IAE	USGS/ USGS/80-AU-16	Wyo.	1980	•		•	•		•	•								60	585	3	3	86.4	6	1	38	19
IAF	USGS/ USGS/80-AU-7	Wyo.	1980	•		•	•		•	•								200	585	2	2	50.5	4	3	22	12
IAG	Bass Enterprises, Inc./ Bass, Enochs Ranch 7/11	Wyo.	1980			•	•		•	•		•					•[2]	550	2150	15	9	280	9	6	45	22
IAH	Anschutz Corporation/ Anschutz, 10-20 State	Wyo.	1980			•	•		•	•		•					•[2]	810	2665	7	7	96	7	0	0	0

[1] Physical properties analysis   [2] Cuttings

From old records, the coals appear to contain significant quantities of methane. Numerous reports of gas, explosions and disasters are recorded, but measurement of the basin's gas content has not been established. A conservative coal resource estimate of two billion tons was used to determine the methane resource of the Richmond Basin. The potential methane resource may range from 700 billion cubic feet to 1,400 billion cubic feet.

2.3.8 San Juan Basin

The San Juan Basin is an elliptical structural depression encompassing an area of about 7,500 square miles in northwestern New Mexico and southwestern Colorado. A total resource of more than 200 billion tons of bituminous and subbituminous coal is contained in the Cretaceous rocks in this basin.

A few individual coal seams have been named where mined locally, but most San Juan Basin coals are too irregular and discontinuous to be correlated across significant distances. Individual seams range from a few inches to 20 feet thick over broad areas. The shallowest major coal reaches a maximum depth of approximately 4,000 feet in the northeastern part of the basin. Dip is generally shallow, steepening along the bordering structural uplifts and along the eastern margin.

Coal occurs in five formations or units. Not much is known about the thickness and extent of coal in the deepest formations, but these are not considered to contain the large reserves of two major units, the Fruitland and Menefee Formations. The Fruitland contains an estimated 200 billion tons of coal, the Menefee about 1 billion tons, of which more than half are deeper than 2,000 feet. Coal is mainly low sulfur bituminous.

Recent studies of desorbed gas indicate the gas content of San Juan Basin coals is relatively low, ranging from about 3 to 73 cubic feet per ton (Table 2-7). Preliminary limited desorption data were used to calculate estimates of in-place gas. Based on a minimum depth of 1,000 feet, the Fruitland Formation contains a minimum of 1.8 trillion and a maximum of 25 trillion cubic feet of in-place gas. Similarly, the minimum and maximum in-place gas content estimates for the Menefee Formation are 6.7 billion and 88 billion cubic feet. Thus, the total minimum in-place gas resource

TABLE 2-7. MRCP WELL TEST SUMMARY SAN JUAN BASIN

MRCP SITE CODE	COOPERATOR/ WELL NAME	STATE	YEAR TESTED	TEST ACTIVITIES CONDUCTED: CONVENTIONAL CORING	SIDEWALL CORING	GEOPHYSICAL LOGGING	DESORPTION	GAS ANALYSIS	PROXIMATE	ULTIMATE	DRILL STEM TESTING	MUD LOGGING	PRE-FRAC FLOW	PRE-FRAC PRESSURE	POST-FRAC FLOW	POST-FRAC PRESSURE	OTHERS (Footnoted)	DEPTH OF COAL-BEARING INTERVAL (ft): FROM	TO	NUMBER OF COAL-BEDS ENCOUNTERED	NUMBER OF COAL-BEDS SAMPLED	COMPOSITE COAL THICKNESS (FT)	NUMBER OF SAMPLES TAKEN	GAS CONTENT (ft³/ton): MINIMUM	MAXIMUM	AVERAGE
HAA	Western Coal Co./ P-70	N. Mex.	1978	•			•		•	•								387	396	2	1	12.2	2	16	73	45
HAB	Navajo Nations Mineral Dept./ USGS K-3	N. Mex.	1980	•			•											680	815	3	1	–	1	64	64	64
HAC	Navajo Nations Minearl Dept./ Navajo A-5	N. Mex.	1980	•		•	•		•	•								684	748	3	3	44	5	16	29	21
HAD	Dugan Production (McHugh)/ Di's Delight No. 1	N. Mex.	1980	•		•	•		•	•							•[1]	3040	3086	1	1	50.5	8	3	45	11[2]

[1] Roof and floor rock mechanical property analyses and permeability and porosity analyses

[2] Desorbed gas only

for the basin is estimated at 1.8 trillion cubic feet, most of which is in the Fruitland Formation. Gas from deeper coals is not expected to add significantly to this total.

San Juan Basin coal gas content is thought to increase toward the north. Gassy mines and other indicators were used to target three areas totalling about 4,900 square miles, encompassing coals with the highest potential for early commercial gas production. Type I well tests have provided additional data on gas content in the Juan Basin.

2.3.9 Warrior Basin

The Warrior Basin is a triangular area in Mississippi and Alabama bounded by the Appalachian Mountains on the southeast and Ouachita Front on the southwest. It is a structural basin with coal-bearing strata found in the sequences of shale, siltstone, sandstone, and conglomerate in the Pottsville Group of Pennsylvanian age.

The basin is divided into four coal fields. The Coosa field covers approximately 280 square miles, and because it lies in a deep syncline there is limited knowledge of the thickness and extent of its 15 coalbeds. The Cahaba field includes approximately 350 square miles. Although it contains about 60 coalbeds, commercial development has not been as extensive here as in the Warrior field, from which it is separated on the northwest by Birmingham Valley. The Warrior coal field is the most productive of the four and covers 3,500 square miles. The Plateau coal field is composed of several coal bearing areas in the upland regions of northeastern Alabama. While it covers a greater area than all the other coal fields combined (4,500 square miles), its coalbeds are not continuous throughout the field due to erosion, and the same bed may be known by several different names.

Over 25 coalbeds in the Plateau coal field average two to three feet in thickness but local swells have been reported as much as 20 feet thick. The Warrior coal field contains over 20 coalbeds in seven groups, some of which are known to extend into the subsurface of Mississippi.

Coals of highest rank are found in eastern Alabama at Lookout Mountain where at least a portion is close to semianthracite while elsewhere, the coal is high-grade bituminous.

The basin contains a maximum of 10 trillion cubic feet of high-quality methane. This estimate is based on the known and inferred gas contents of coalbeds in this part of the basin and published coal reserve estimates of 35 billion tons. Approximately 86 percent of the coal is contained in the Warrior coal field.

In the Warrior Basin the Mary Lee Group of five coalbeds is known to be a gassy coal. Tests by other investigators show that, at a depth of 1,000 feet, approximately 150 cf/ton of methane has been measured in the coal, with an estimated 500 cf/ton of gas present at 2,100 feet. Two sites have been tested by MRCP under the resource delineation plan. The results of testing at one of the sites is currently confidential, while the other shows a minimum of 16 and a maximum of 102 cubic feet per ton (Table 2-8).

2.3.10 Western Washington Coal Region

The western Washington area encompasses three regions with an area of approximately 6,500 square miles. Though principally Eocene in age, coal deposits in this basin range from Paleocene to early Oligocene. The deposits formed on a broad low-lying coastal plain in a tropical forest and swamp environment that existed along the eastern shoreline of a north-trending, paleo-sedimentary basin. They also interfinger with and grade into, marine coal-bearing rocks to the west. All coal-bearing areas have been structurally deformed since their formation by folding and faulting, and deformation in many of the areas has been intense. Overlying the coal-bearing rocks in most areas of western Washington is a thick mantle of glacial deposits of Pleistocene age. Deposits from at least four separate glacial advances are over 3,000 feet thick in parts of the Puget Lowlands.

Knowledge of coal geology in the basin has been gained almost entirely from mining operations in the Bellingham, Green River, Wilkeson-Carbonado, Centralia-Chehalis and Roslyn fields. In the Bellingham field, coal occurs in more than 10 beds that range in thickness from a few inches to 15 feet. Coal in the Green River district ranges in thickness from 3 to 40 feet in intensely faulted and deformed beds. The Wilkeson-Carbonado field is a source of coking coal and contains from 15 to 20 beds with a thickness of 2 to 8 feet. The Centralia-Chehalis is the largest field containing at least 12 beds averaging in thickness from 6 to 8 feet with individual beds up to 40 feet thick with partings. The Roslyn field contains at least eight beds

TABLE 2-8. MRCP WELL TEST SUMMARY
WARRIOR BASIN, THE WESTERN WASHINGTON COAL REGION, AND THE WIND RIVER BASIN

MRCP SITE CODE	COOPERATOR/ WELL NAME	STATE	YEAR TESTED	TEST ACTIVITIES CONDUCTED: CONVENTIONAL CORING	SIDEWALL CORING	GEOPHYSICAL LOGGING	DESORPTION	GAS ANALYSIS	PROXIMATE	ULTIMATE	DRILL STEM TESTING	MUD LOGGING	PRE-FRAC FLOW	PRE-FRAC PRESSURE	POST-FRAC FLOW	POST-FRAC PRESSURE	OTHERS (Footnoted)	DEPTH OF COAL-BEARING INTERVAL (ft): FROM	TO	NUMBER OF COAL-BEDS ENCOUNTERED	NUMBER OF COAL-BEDS SAMPLED	COMPOSITE COAL THICKNESS (FT)	NUMBER OF SAMPLES TAKEN	GAS CONTENT (ft³/ton): MINIMUM	MAXIMUM	AVERAGE
	WARRIOR BASIN																									
CAA	Grace Petroleum Corporation/ Grimsley No. 1 35-15	Ala.	1979	•		•	•		•									657	1789	4	4	10	4	16	102	70
CAB	USGS/Eastern Region/ USGS/AGS-57	Ala.	1980	•		•												x	x	x	x	x	x	x	x	x
	WESTERN WASHINGTON COAL REGION																									
LAA	DOE/ DOE 7	Wash.	1979	•		•	•		•	•							•[1]	603	624	1	1	21.7	4	32	86	57
	WIND RIVER BASIN																									
NAA	USGS/ USGS/80-WR-27	Wyo.	1980	•		•	•		•	•								573	975	5	4	9.3	4	0	0	0
NAB	USGS/ USGS/80-WR-18	Wyo.	1980	•		•	•		•	•								158	189	2	1	11.8	1	0	0	0
NAC	USGS/ USGS/80-WR-11	Wyo.	1980	•		•	•		•	•								178	193	1	1	5.8	1	0	0	0

ˣInformation confidential

[1] Roof and floor rock mechanical property analyses

with thickness ranging from 2 to 21 feet. The total coal resource in the basin is estimated to be 60 billion tons, principally high to medium volatile bituminous.

Knowledge of methane concentration in this basin is limited and based on methane-related mining accidents, water wells producing methane, oil and gas exploration, and desorption of four core samples from the Centralia-Chehalis district. The samples desorbed yielded a minimum of 32 cubic feet per ton, and a maximum of 86 cubic feet per ton.

Since the four cores were from coal of low subbituminous C rank, a value of 50 cubic feet per ton is thought to be a reasonable minimum value for in-place methane resource. It is assumed that the higher-rank bituminous coals would have a greater methane content, and that prime areas would have even higher concentrations of methane. Therefore, it is thought that 400 cubic feet of methane per ton of coal is a reasonable estimate for the maximum in-place methane resource. Using these figures, the coalbed methane resource contained in known coal reserves in western Washington is estimated to range from 0.3 to 3.0 trillion cubic feet.

2.3.11 Wind River Basin

The Wind River Basin is an asymmetrical intermontane syncline encompassing an area of about 8,100 square miles in west-central Wyoming. It is named after the northward-flowing Wind River, a tributary of the Big Horn River. The coal-bearing area generally coincides with the topographic and structural basin, however, the Wind River coal basin is limited to that portion of the basin underlain by Mesaverde or younger rocks because the Mesaverde Formation is the oldest important coal-bearing unit in the basin.

The coal resources of the Wind River Basin have been estimated between 1.0 and 4.1 billion tons, most of it is in the Mesaverde Formation. Wind River Basin coal is subbituminous in rank. Coals in the Wind River Basin were deposited in deltaic environments. The thickest coalbeds are found in the lower part of the Mesaverde Formation, which are 4 to 28 feet thick and contain estimated resources of about 750 million tons. Individual beds are exposed in narrow belts parallel to steeply dipping beds along the basin's margin. Overburden can be as much as 12,000 feet in the deeper parts of the basin.

The total number of coalbeds in the Wind River Basin is difficult to determine owing to their lenticularity, coalescence and splitting nature. Some correlations between coalbeds and zones across the basin have been made, but much remains to be done.

Three Type I field tests have been conducted in cooperation with the U.S. Geological Survey's Wind River Indian Reservation Coal Study (Table 2-8). All six samples desorbed showed no methane content. Assumed methane values were assigned to the coal resource base for calculating a conservative value of 5.25 billion cubic feet of gas. In addition an optimistic value was assigned to deep lying coals (>3000') giving a maximum coalbed methane resource of 2,225 billion cubic feet.

2.3.12 Raton Mesa Coal Region

The Raton Mesa region occupies approximately 2,200 square miles in southeastern Colorado and northeastern New Mexico where the Upper Cretaceous and Lower Tertiary rocks form a plateau between the Rocky Mountain province to the west and the lowlands of the Great Plains province to the east. The Raton Mesa Region is part of the larger Raton Basin, a northwest-trending asymmetrical trough formed in Early Pennsylvanian and Permian time. The basin is characterized by a steeply dipping western limb, a gently dipping eastern limb, and a broad, nearly horizontal central portion.

Original in-place coal reserves for minable coalbeds at least 14 inches thick with less than 3,000 feet of overburden were estimated by the U.S. Geological Survey to be more than 17 billion tons. More recent geological mapping and new subsurface information show this estimate to be conservative.

Results of methane gas desorption from coal cores indicate gas contents ranging from 25 to 490 cf/ton of coal. These test results, used in conjunction with coal resource estimates, indicate that there are at least 8 and possibly 18.4 trillion cubic feet of coalbed methane gas present in the Raton Mesa Region.

The significant gas-bearing coalbeds in the Raton Basin are:

Coalbed	Estimated Gas in Place (tcf)
Vermejo Formation	11.6
Raton Formation	6.8
Total	18.4

Geologic Features Prevalent in the Raton Mesa Coal Region:

- Deep Coalbeds - The coalbeds dip toward the center of the basin so that a large portion of the coal lies below 1,000 feet. Maximum depths are between 3,000 and 4,000 feet near the Spanish Peaks.

- Thick Coalbeds - In areas where two or more beds are present, the thickest bed is usually the Raton bed. In some areas it may be as much as 14.5 feet thick and is the most extensive and valuable bed in the Raton Field. The beds are not continuous although they lie at the base of the Vermejo Formation, and become progressively older to the west. The coalbeds are found in large, elongated, pod-shaped deposits, some of which have been intruded by igneous sills and partially destroyed.

  The Vermejo contains 3 to 14 coalbeds greater than 14 inches thick everywhere in the Trinidad and Walsenburg coal fields. These coalbeds are lenticular and irregular in thickness.

- Coal in Vicinity of Sandstone - Roof and floor rocks are generally carbonaceous shale and siltstone; at many places however, the roof is a thick sandstone bed in the Raton Formation. Roof and floor rocks of coalbeds in the Vermejo Formation are usually carbonaceous shale and claystone, but locally may be carbonaceous siltstone or sandstone.

- Multiple Coalbeds - Within the Raton coal field, there are three significant coalbeds in the Vermejo Formation and seven in the Raton Formation. In the Trinidad and Walsenburg coal fields there are seven coal zones in the Vermejo Formation and five coal zones in the Raton Formation.

- Highly Fractured Coalbeds - The structural character of coals of the Raton Mesa Regions, such as fracture or cleat density and orientation, has not been systematically investigated. Most coal in the region is fractured either cubically or prismatically, and in some of the mines this cleating is so marked that coal can be readily removed from the working faces by picks. Coal that has been intruded and metamorphosed shows columnar jointing. The jointing is polygonal and is developed at right angles to the intrusive bodies.

- Coal Rank - Coals of the Raton Basin generally range in rank from high-volatile C bituminous to medium-volatile bituminous. Igneous intrusions have locally altered coalbeds to anthracite. In other areas, coalbeds have been amorphosed to prismatic coke, and near Raton, potentially commercial graphite was formed by the metamorphism of the Raton coalbed in the Vermejo Formation. The thin, relatively rare coalbeds of the Poison Canyon Formation are lignitic in rank.

- High Thermal Gradient - The Raton Mesa Region is an area of anomalously high heat flow. This is probably related to the Spanish Peaks intrusive and associated underlying magmatic activity. The occurrence of an area of high heat flow, igneous intrusion, and extensive low volatile-matter coalbeds in the Raton Mesa Region indicates the potential generation of substantial amounts of dry methane gas.

2.3.13 Uinta Basin

The Uinta Basin is an east-west asymmetrical syncline which covers an estimated 11,550 square miles in northeastern Utah and northwestern Colorado. The area includes the Wasatch Plateau, a southwestern appendage of the basin.

The basin contains comparatively minor structural deformation in the form of folding and faulting. Sedimentary deposition in the area occurred from late Precambrian to Quaternary with major coal-bearing strata deposited during late Mesozoic time. The major coal-bearing strata of the basin are contained in the Upper Cretaceous Mancos Shale and Mesaverde Group. The area is divided into seven coal fields and regions with the Wasatch Plateau and Book Cliffs coal fields being the most extensively developed. Their major coal deposits are found in the Mesaverde Group Blackhawk and Price River Formations along the basin's southern perimeter. These coals range in rank from high-volatile B to C bituminous. Little is known about the coal resources at depth in the basin.

The presently available methane resource data from the Utah Geological and Mineral Survey (UGMS) and Mountain Fuel Resources, Inc. were used in evaluating the productivity potential of the basin. A primary target area designated as having the highest potential for coalbed methane production covers most of Carbon County and parts of Emery and Grand Counties, Utah. On the basis of UGMS and Mountain Fuel data, an estimated 368 to 1,212 billion cubic feet of gas is contained in the Book Cliffs coal field.

Based on UGMS data, ranges for expected in-place methane resource have been made for the seven coal fields of the basin. The low value of 231 billion cubic feet and high value of 832 billion cubic feet of gas is estimated to be present.

2.4 UNIVERSITY RESEARCH ACTIVITIES

A significant amount of research in coalbed methane resource engineering has been performed by major universities in order to properly utilize the talent available in that community. In addition to the direct contribution of research efffforts, the universities have also provided an opportunity for interested students to become familiar with the emerging technology, thereby increasing employment opportunities in industry.

The work of the University of New Mexico in the development of the coal chip desorption techniques, which was briefly described in Chapter 2, may significantly facilitate measurement of the content of methane in coal seams. The time and effort involved in collection of core samples, and the time spent in desorbing the coal lumps, would be significantly decreased. A full description of the development of the technique and equations, including the authors' rationales, is contained in a report by Frank L. Williams and Douglas Smith entitled "Methane Recovery from New Mexico Coal."

The work of Virginia Polytechnic Institute and State University (VPI) was directed toward determining the methane production potential of southern coalfields. The investigation was focused on the Richmond Basin, in eastern Virginia, and was based primarily on a review of literature. It provides a framework for determining whether or not the available coalbed methane resources can provide a significant amount of gas to the southern Virginia market area. At the present time, no accurate record exists of the gas content of the coalbeds in the area. The study report provides a conservative estimate of 2.3 billion tons of coal in the basin, and an estimate of 350 billion cubic feet of associated methane. The VPI report "The Methane Potential from Coal Seams in the Richmond Basin of Virginia" has been submitted to the Technical Information Center at the Morgantown Energy Technology Center.

Colorado School of Mines performed research to evaluate the effect of stimulation treatments on coal recovery operations. An extensive literature review and structurual, analytical, and finite element models were used. As a result of the research five reports were compiled:

1. Fay, Collin R., "Hydraulic Fracture Propagation--Direction as Related to Premining Methane Drainage."

2. Clark, G. B., "Basic Theories and Mechanisms of Hydrofracturing State-of-the-Art."

3. Faminengo, F. J., "Design and Construction of the New Triaxial Machine in the Edgar Mine."

4. Bigarella, L., "Potential Methane Drainage Using Hydrofracturing, Carbondale Coal Field, Pitkin County, Colorado."

5. Bigarella, L., "Geomechanical Properties of Coal Measure Rocks--A Review."

Pennsylvania State University also performed research on the effects of hydraulic reservoir fracturing on minable coal seams. The study included development of a stimulation treatment, application of the treatment at a Cumberland Coal Company mine, and mapping of the stimulation results after exposure of the well area by mining.

3. RECOVERY AND UTILIZATION TECHNOLOGY DEVELOPMENT

3.1 TECHNICAL APPROACH

The Methane Recovery from Coalbeds Project has identified a number of areas which need to be developed to foster widespread utilization of coalbed methane. The recovery and utilization technology needs include:

- o Determination of optimum well spacing
- o Determination of optimum geometric well patterns
- o Improved horizontal borehole drainage equipment and methods
- o Extraction of methane from deep coal horizons
- o Extraction of methane from coal underlying heavily developed areas
- o Utilization of coalbed methane for on-site power generation
- o Utilization of coalbed methane for LNG production
- o Utilization of coalbed methane for space heating
- o Utilization of coalbed methane for coal drying.

MRCP solicited candidate projects from the private sector in 1978, to field, as funding permitted, projects to enhance coalbed recovery and utilization technology. Approximately 20 candidate projects, for investigation of one or more candidate areas, were received by METC and evaluated based on the following criteria:

- o Cost
  - Total Cost
  - Cost/Benefit Ratio
  - Cost Risk
  - Cost Flow
  - Capital Investment
- o Applicability
  - Potential Users
  - Availability of Resource
  - Ease of Application (Simplicity)
  - Size

- o Contribution to Technology Advancement
  - Equipment Technology Development
  - Methodology Development
  - System Interfaces
- o Intangibles
  - Environmental Impact
  - Visibility
  - Educational Value.

Four of the 20 projects were recommended for implementation within the constraints of the project budget:

1. Long Horizontal Boreholes, Active Mine Test Project - to be conducted by Occidental Research Corporation at the Island Creek Company Virginia Pocahontas No. 5 Mine near Grundy, Virginia
2. Multiple Completion of a Single Well - to be conducted by Waynesburg College on its campus in Greene County, Pennsylvania
3. Multiple Completion of Multiple Wells in Anthracite Coal - to be conducted by Pennsylvania Energy Resources, Inc. in Wilkes-Barre, Pennsylvania
4. Determination of Optimum Geometric Pattern for Coalbed Predrainage - to be conducted by Bethlehem Mines Corporation at the Marianna No. 58 mine in Washington County, Pennsylvania.

3.2 PRODUCTION TECHNOLOGY PROJECTS

Figure 3-1 shows the locations of the MRCP production technology development projects. The projects are in various stages of progress at the present time. Each project is described in the remainder of this section.

3.2.1 Long Horizontal Boreholes, Active Mine Test Project

The objective of this project is to demonstrate the recovery of methane from multiple horizontal boreholes in an active mine, and the utilization of the gas for the production of liquefied natural gas (LNG) or some other purpose.

The project is aimed at developing coalbed methane recovery and utilization technologies in several areas:

- o Development of a technique to drill long boreholes (greater than 2,000 feet) within an active mine to degasify the seam in advance of longwall mining

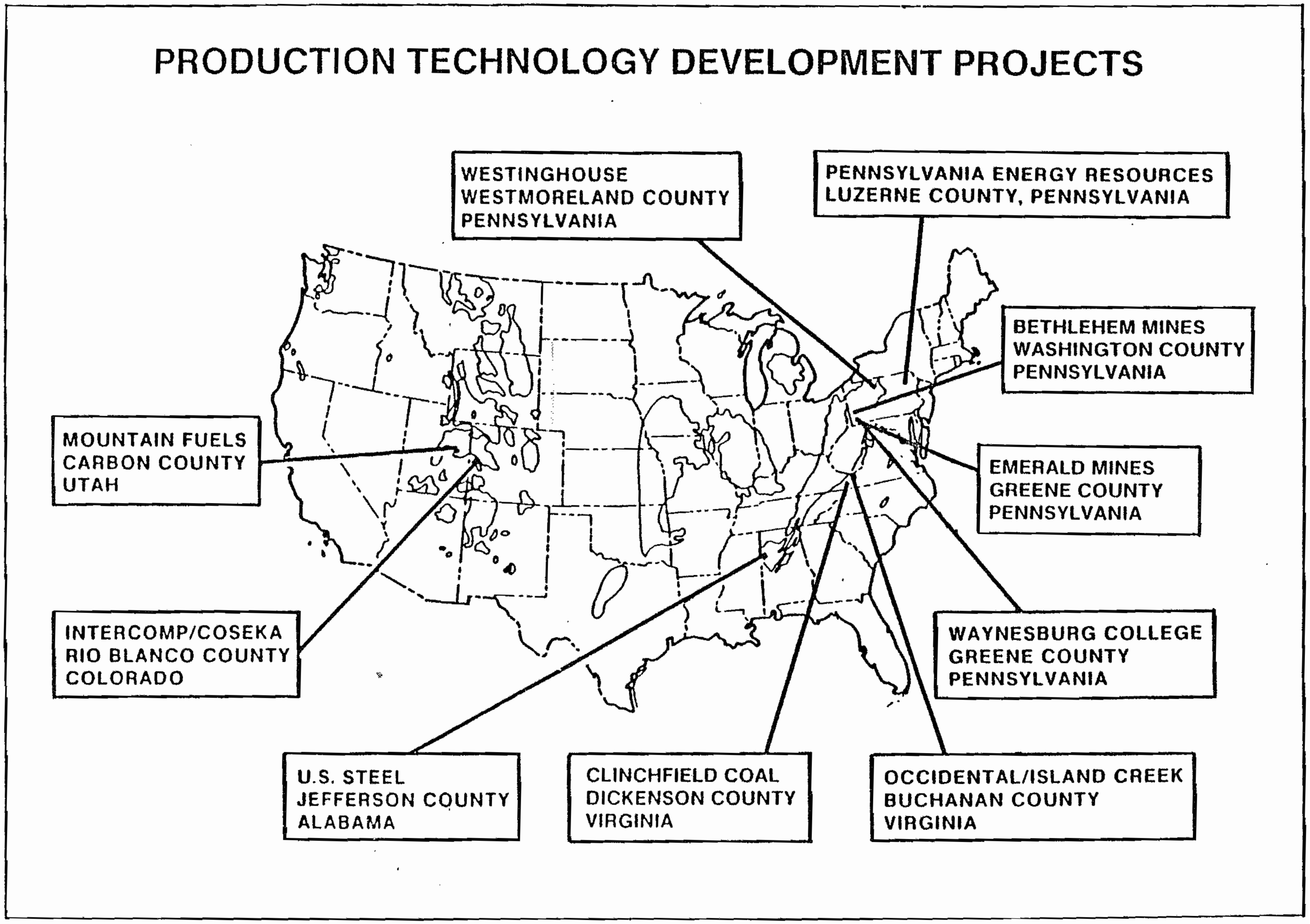

Figure 3-1. Locations of Production Technology Development Projects

- o Development of an in-mine piping system with an integrated safety system using plastic pipe to reduce costs.

Using drilling equipment manufactured by the Acker Manufacturing Company, Occidental Research Corporation (Oxy) personnel have demonstrated the ability to drill horizontal holes in excess of 1,000 feet while remaining in an undulating coal seam. Guidance corrections are made by increasing or decreasing pressure on the drill bit, while the perceived resistance on the bit when entering floor and roof rock is used to provide feedback to the operator for maintaining the bit within the seam.

An in-mine manifold and piping system has been installed to collect the gas at the borehole face and transport it via to the mine surface. The gas transport system is fabricated of polyethylene pipe to withstand flattening without rupture, and is routed through the return airways to keep any escaping gas out of the mine area. Since polyethylene pipe is light, it is easier to handle than steel pipe. A welding technique has been developed so the system can be assembled or modified in the mine. The system is operated at a slight vacuum relative to the mine entry pressure, so any leaks in the line would allow air into the pipeline, rather than permitting gas to escape from the pipeline into the mine.

A leak detection system has been designed, approved by MSHA, and integrated with the in-mine methane transport system. The leak detection system uses a 1/4" PVC pipe loaded with compressed air strapped to the top of the pipeline. If the pipeline sags more than the nominal tolerance of the PVC pipe, which is connected to a failsafe shutdown valve, the leak detection system immediately closes the valves for the transport system.

By December 31, 1980, Oxy had drilled 12 horizontal holes totalling approximately 9,100 feet. Three of the holes exceeded 1,000 feet in length, but the rolling seam as well as extremely high gas pressure has made it difficult to remain within the seam for the targeted 2,000-foot lengths.

Currently, Island Creek Coal Company, the host site and an affiliate of Occidental Research Corporation, has two Acker "Long John" horizontal drilling rigs in its Virginia Pocahontas (VP) #5 mine to drain the VP #3 seam in advance of longwall mining. The effect of the predrainage on mining operations has not yet been evaluated, but actual experience shows that in mine drainage and active mine operations are indeed compatible if properly planned and executed.

Based on an assessment of utilization concepts, plans have been developed to use the gas to fuel the coal drying plant, which now uses fuel oil. The conversion has been designed and will be implemented during 1981 using private funds.

3.2.2 Multiple Completion of a Single Well

The objective of this technology test project was to design, develop and demonstrate coalbed methane recovery by multiple completion of a single well considering a variable need for dewatering each coal zone and utilizing the gas to supplement the College's fuel supply.

Previous discussions addressing the economics of methane drainage from unminable coalbeds have generally involved the use of single completion wells (each well directed to a single coal zone). The Waynesburg College methane well was designed to attain production from three separate zones:

Depth from Surface	Coal Seams
1292-1408	Clarion Mercer #1 Mercer #2
1186-1248	Upper Kittanning Middle Kittanning Lower Kittanning
480-492	Pittsburgh (Pittsburgh Rider)

Wireline core drilling was performed by Tinney Drilling Company in December 1979 to a depth of 1469 feet through all known coal seams in the Pennsylvanian section. Composite thickness of the coalbeds totalled 39.9 feet, of which 30.8 feet was considered suitable for stimulation for methane production.

Following a meeting with the Pennsylvania Department of Environmental Resources and the acquisition of a drilling permit, a contract was let to Chisler Brothers of Pentress, West Virginia for the methane production well. The drilling company moved an air rotary top-head drive drill rig on site and drilled a total of 1450 feet of 7-7/8" hole after setting and cementing 358 feet of 8-5/8" surface casing. After logging, the rotary rig was moved off location to allow setting of a service rig to run 5-1/2" casing to the total depth.

On February 5, 1980 Chisler Brothers moved a Bucyrus Erie 36L cable tool rig on site. On checking the condition of the open hole, a bridge was encountered below 800 feet, in a Pittsburgh red shale interval. An attempt to drill the bridge with a cable tool bit was unsuccessful, since the action of the bit caused the hole to cave further. To save the 7-7/8" hole, the rig was retooled, and the 5-1/2" casing was drilled into place. The casing (J-55, 15.1#, 5-1/2") was cemented to the surface by circulation with 300 sacks of 50/50 Pozmix on February 16.

On February 6 and 7, 1980 a meeting was held to discuss the stimulation design. In attendance were representatives from Waynesburg College, TRW, DOE/METC, and Halliburton Service Company. A review of the well logs and preliminary computer coal logs limited the probable producible seams to three zones: zone 1, Mercer & Clarion coals; zone 2, Middle Kittaning, Upper Kittaning, and Bakerstown coals; and zone 3, the Pittsburgh coal. The principal parameters of the proposed foam stimulation were established as follows:

- Maximum pumping rate: 10 bbl/min
- Maximum sand rate: 1 lb/gal
- Maximum volume: 5,000 gal foam/foot of coal.

On February 22, a cement bond log was run which indicated good cement bond at all target coal seams. The lower zone was then perforated using shape charges, in preparation for the treatment described in Table 3-1.

On February 25, six 210-bbl fracture fluid tanks were moved on site and filled. Halliburton Services moved on site February 26, and treated zone 1 as shown in Table 3-1. After zone 1 screened out and was produced back, zone 2 was perforated and a retrievable plug set at 1270 feet using tubing, preparatory to stimulation the following day.

Table 3-1. Well Stimulation Data

	COMPLETION ZONE	3		2			1		
	COAL SEAM	PITTSBURGH RIDER SEAM	PITTSBURGH MAIN SEAM	BAKERSTOWN	UPPER KITTANNING	MIDDLE KITTANNING	CLARION	MERCER Seam 1	Seam 2
	Number of perforations	2	8	4	2	2	4	2	2
BREAKDOWN INPUT	Volume of water (M³)	1.70		3.75			4.73		
BREAKDOWN INPUT	Casing pressure (mPa)	12.41		13.27			17.75		
BREAKDOWN INPUT	Water pumping rate (M³/sec)	0.03		0.03			0.01		
PAD INPUT	Percent nitrogen	45 to 50		75			75		
PAD INPUT	Casing pressure (mPa)	11.72		17.92			26.47		
PAD INPUT	Water pumping rate (M³/sec)	0.01		0.01			0.01		
PAD INPUT	Total volume of nitrogen and water (M³)	37.85		18.93			16.65		
FRAC INPUT	Percent nitrogen	45 to 50		75			75		
FRAC INPUT	Casing pressure (mPa)	8.96		16.20			26.71 increasing to 27.58		
FRAC INPUT	Proppant sand 20/40 (kg)	15,875		10,200			1,050		
FRAC INPUT	Water pumping rate (M³/sec)	0.01		0.01			0.01		
FRAC INPUT	Total volume of nitrogen, water and sand (M³)	151.40		94.62			17.87		

REMARKS:

ZONE 1 — Frac screened out because of high bottom hole pressure and casing limitation of 27.58 mPa.
— 7M of sand flowed back into the sump.

ZONE 2 — First breakdown attempt failed because of faulty perforation run. Rerun with different shaped charges and perforated Bakerstown only.
— Followed frac with 1.89 M^3 water flush.

ZONE 3 — Followed frac with 2.08 M^3 water flush.

The initial attempt to treat zone 2 on February 27 indicated the perforations had not penetrated the casing. The Bakerstown seam (887.8 to 891.0 ft.) was then reperforated using expendable glass charges, and Zone 2 was then successfully stimulated as described in Table 3-1.

After the retrievable bridge plug was reset at 600 feet, the Pittsburgh and the Rider seams were perforated with 10 expandable glass charges and stimulated on February 28. Before flowback of the third stage had begun, a dark fluid was observed being discharged approximately 350 feet away, on the Waynesburg College practice football field. Apparently, an unknown, improperly abandoned gas well had been blown out during the fracture treatment. The fluid discharge continued for several hours, then changed to a gas discharge. Pennsylvania oil and gas law required Waynesburg College to apply for a plugging permit and plug the well (designated Thayer Hall Tract, Well No. 2), in accordance with state specifications.

Flowback from all stimulated zones continued through February 29. On March 6, 1980, swabbing of the remaining fracture fluid was initiated, and continued through March 10 with estimated water production from 120 to 230 bbl/day. A delay in shipment of the downhole tubing pump caused a delay in the installation of the dewatering equipment until March 24, when a Trico 2-1/4" tubing pump was set with the inlet at 1405 feet. The sucker rod and plunger were set the following day.

On April 8, the site was regraded for installation of a Stallion pump jack which was connected to the polished rod. The final electrical connection was made April 21. After good initial production, water flow ceased due to foreign matter in the ball and seat.

On May 27 a service rig was moved on site by Chisler Brothers. The ball and seat were found to be held open by a substance which appeared to be a mixture of grease and coal dust. The grease may have originated as pipe dope used when the tubing was initially run. After 20 feet of sand was removed from the casing, the mud anchor was shortened to allow the pump inlet to be placed deeper, at 1430 feet.

Elimination of the ball and seat problem allowed detection of a previously undetected gas lock problem. Since no positive life valves were available, the pump was reconfigured, moving the travelling valve from above to below the plunger, positioning the traveling and the standing valves adjacent to each other. The reconfiguration was done on June 12, 1980.

After less than 24 hours of operation subsequent to the reconfiguration, the electric motor failed. The actual cause of failure is not known, although poor quality is suspected. The original motor was replaced with a farm-duty 3 hp motor on June 27. The following day, excessive vibration of the jack caused the motor lead wires to break.

After several attempts at balancing the pump jack without success, Stallion was requested to investigate the problem. The Stallion representative replaced the motor with an industrial grade 3-hp motor. However, after several days of production the pump again became clogged, terminating production.

The service rig was brought back on site on July 19, and the pump and tubing were pulled. The stoppage was again caused by the apparent mixture of grease and coal dust. Chemical analysis of the substance indicated a hydrocarbon origin, but the source is presently unknown. To minimize the stoppage, a weekly treatment using a commercial grade paraffin solvent/ inhibitor is being applied. The treatment has been successful in preventing production stoppage for several months.

After the water level was lowered in the annulus, an imbalance of the beam of the pump jack occurred. The condition, which resulted from a stabilized pumping level at the pump intake, was verified by taking echometer readings of pumping and recovery fluid levels. Additional weights were therefore ordered from Stallion to rectify the problem.

Water and gas production continued until August 30, when the pump jack gearbox failed. On September 5, Stallion Corporation field engineers replaced the entire pump jack unit. On September 6, the electric motor for the unit again failed due to unidentified causes. The motor was replaced by Stallion on September 10.

Since the perforated coalbeds appear to have been effectively dewatered, the pump jack is currently on a cycle of 15 minutes pumping and 60 minutes idle. Production measurement has been initiated and is being done each week. At last reading the methane production was measured at approximately 30 thousand cubic feet per day (Mcfd).

The old abandoned well, Thayer Hall Tract, Well No. 2, has been cleaned out and plugged. The initial plan requested authority to install an offset vent, to prevent interference with the use of the college's practice football field. On June 17, the service rig was moved on site. In cleaning out the borehole, several bridges were noted, at 340 and 420 feet. On June 26, the Pittsburgh coal was encountered at which time the coal underclay began excessive caving, preventing further progress in the cleanout beyond 510 feet. On June 30 a decision was made to set 8" casing to shut off the cave zone and the excess water production.

On July 2, 1980 8-5/8" casing was run into the well to stabilize the wellbore. Rapid progress was then made to a depth of 610 feet, at which point an obstruction was encountered which prevented further cleanout. Waynesburg College then filed for a permit for an alternative method of abandonment, which permitted cementing to the surface. The permit was granted and the cementing accomplished through tubing, in two stages, using 461 sacks of Medusa cement. Restoration of the site and filing of a certificate of plugging fulfilled the state requirements.

In February 1981 the production well was officially connected to the Equitable Gas Company distribution system. On February 25, 1981, Equitable officially opened the valve, to transport the gas from the well to the rest of the system. Figure 3-2 shows the as-built schematic of the system.

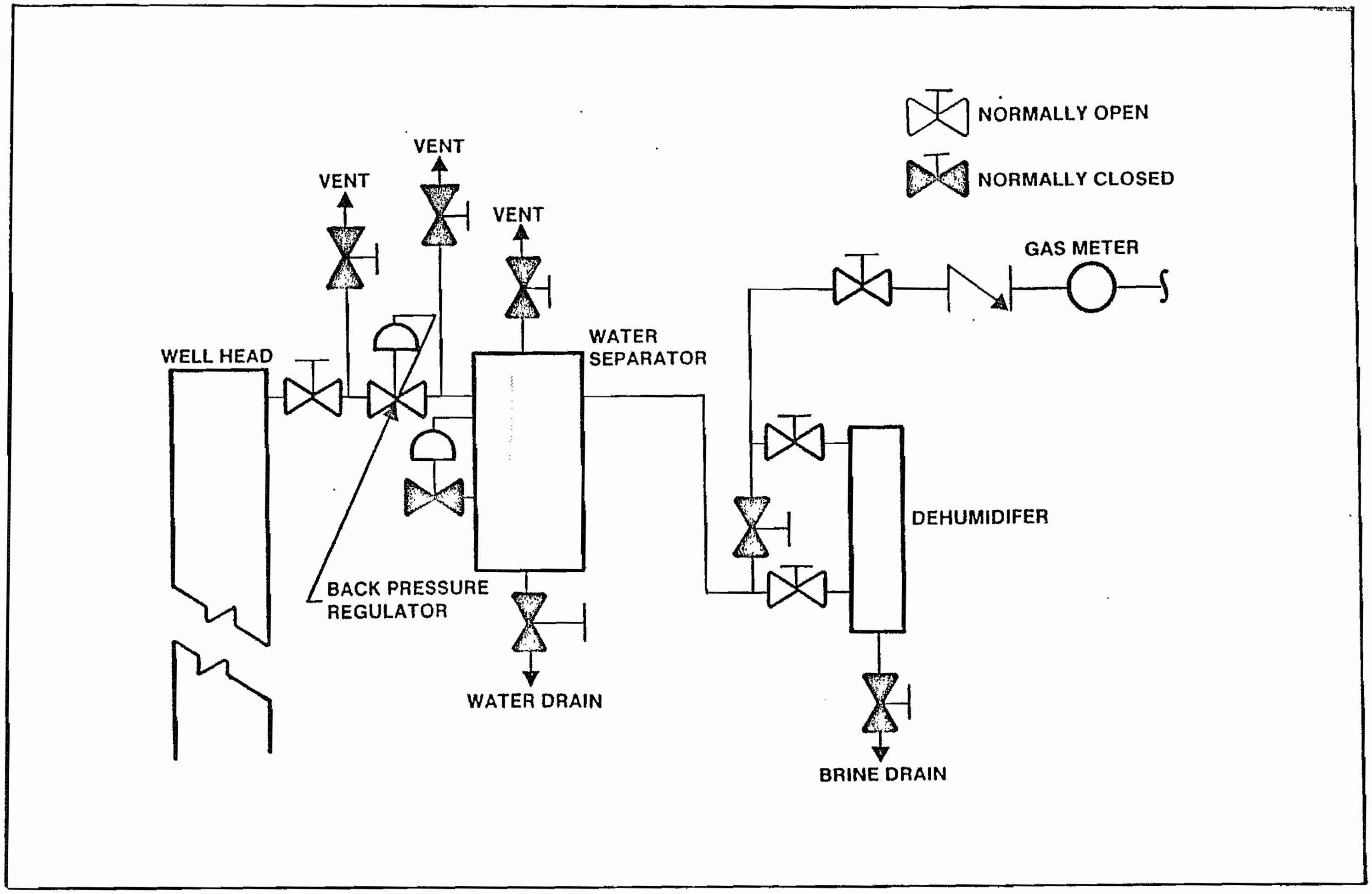

Figure 3-2. Waynesburg College Surface Processing System Schematic

4. PROJECT MANAGEMENT

In its common definition, project management consists of the organization and maintenance of a project from inception to completion. Generically, it consists of the planning and control activities necessary for the execution of a project. For MRCP, project management is composed of the planning, review, and evaluation necessary to develop an integrated technology data base. Activities in project management include planning, evaluation, analysis, information management, and technology transfer sustained in a continuum throughout the life of the contract, highlighted by milestones used to measure accomplishments and establish common baselines.

4.1 BACKGROUND

4.1.1 Strategy

The two previous chapters discussed the approaches and findings of the primary MRCP areas of activity, Resource Engineering and Recovery and Utilization Technology Development. Because of the significance of the elements, and the fact that they could be separately documented, and due to the differences in objectives, required disciplines, and technical approaches the subjects could be separately treated for this report. In fact, however, MRCP has been conducted as an integrated project with totally coordinated efforts in resource delineation, production technology development, and supporting research. The MRCP strategy, which was incorporated in essence at the start of the project and slightly modified each year to reflect its maturation, features the following:

- Establishment and maintenance of a technology data base which includes, to the extent deemed prudent, the efforts of other organizations including other federal government agencies, state and local government offices, industry, educational institutions, and foreign companies.

- Modular expansion of the technology data base by concurrent execution of planned activities in resource engineering, technology testing, research and development, and project integration, thereby facilitating updating of the technology data base and transfer of the technology to industry.

- Heavy emphasis on project integration by the MRCP management staff, with assigned responsibility for the resource engineering, technology testing, research and development, project planning, and documentation assigned to specific individuals.

- A system of constant review and evaluation of activities, using monthly progress reports, semiannual reports, and annual reports for each project.

- A system for technical interchange and transfer of technology, by establishment of information management and technology transfer systems, conducting symposia and workshops, participating in exhibits and expositions, and fostering publication of papers, reports, and fact sheets.

The strategy relies heavily on personal contact, site visits, and other communication with contractors in order to facilitate project management, review and coordination. Personnel and expertise from within the government, including agencies other than DOE, is used in addition to industry and academia to complement the technology base. To enhance technology transfer and foster industry participation, cost sharing is used whenever possible.

4.1.2 Project Management Activities

To provide the proper data for management of an integrated project, a set of tools have been incorporated into the MRCP management system, built around the framework of the UGR project management system. Key elements of the MRCP management system are:

a. The Project Plan Document (PPD)
b. The project reporting system
c. Annual project reviews
d. Symposiums
e. Workshops
f. Contractor and site visits.

4.1.2.1 The Project Plan Document

The Project Plan Document (PPD) is prepared annually by the project manager to discuss in detail the project activities to be initiated or continued during the year. It also addresses the work accomplished to date and identifies technology needs, in order to concisely define the status of the coalbed methane technology.

Preparation of the project plan provides an opportunity to review the status of each element of the project, and to make conscious decisions to start, continue, or end each work effort. It also provides an opportunity to redirect work efforts, as well as to identify and address new issues and problems. Finally, preparation of the PPD provides an opportunity for the project manager to assure himself that the objective of each work element is consistent with the goals of MRCP.

4.1.2.2 The Project Reporting System

The MRCP reporting system utilizes the Uniform Contractor Reporting System (UCRS) and other reporting guidelines for obtaining periodic status reports from each project participant. In some cases weekly reports are required, as well as monthly, semi-annual, and annual reports. The weekly and monthly reports are used to evaluate project progress; the semi-annual and annual reports are used to disclose the progress of R&D, technology testing, and resource delineation tasks to the general public.

The weekly and monthly progress reports provide the project manager with data on achievements and accomplishments of each contractor or agency, as well as identification of problems, problem areas or issues. Integrated reports are submitted to the Manager of the UCR Program and the Manager of Gas Activities.

The semi-annual report is an input to a program level document, the Semi-Annual Report of the Unconventional Gas Recovery Program. In this report the status of each contract or agreement is summarized, with emphasis on the accomplishments during the reporting period.

4.1.2.3 Annual Project Review

Each year, MRCP, in conjunction with the other elements of the Unconventional Gas Recovery Program, conducts an in-depth review to discuss contractors progress and significant findings. Progress reports are presented by each major project participant using visual aids to the extent deemed necessary. The annual reviews provide the program manager and each project manager with an opportunity to identify and discuss mutual issues and problems, as well as to ensure that the objectives of each project participant, when integrated as a whole, will help accomplish the project goals.

4.1.2.4 MRCP Symposiums

In order to foster transfer of new technology to industry, symposiums have been conducted each year since 1978. The first symposium was conducted jointly with Region III of the DOE; the second (1979) conducted solely by MRCP; and the third (1980) in conjunction with the Society of Petroleum Engineering (SPE) of the American Institute of Mining, Metallurgical and Petroleum Engineers (AIME).

In addition to fostering technology transfer, the symposiums have provided an opportunity to develop an industrial communication network for discussing recovery of methane from coalbeds. Partly as a result of such symposiums, interest has been promulgated in private ventures in recovery and utilization of the resource in spite of renewed successful exploration for conventional gas.

4.1.2.5 Workshops

Another facility for evaluation and integration of the project has been the conduct of workshops to address particular MRCP work areas. The workshops have been conducted to discuss exploration activities in the western United States, R&D needs for the exploration technology data base, plans for additional resource delineation, and other related technology matters. The "issues and answers format" of workshops have made it possible for the project manager to discuss research and development needs in the company of coalbed methane specialists, and thus obtain inputs for future MRCP activities.

4.1.2.6 Contractor and Site Visits

Periodic visits to contractors' facilities and research, technology testing, and producibility testing sites have also aided integration of the project. The site visits provide an opportunity to see equipment configurations in their perspective; witness performance of specialized services such as drilling, coring, logging, completing and stimulating wells; and discuss with the well drilling and service companies technology developments in their fields of expertise in the immediate area and in other geographic areas.

4.2 EFFECTIVENESS OF THE PROJECT APPROACH

During the past 3-1/2 years the Methane Recovery from Coalbeds Project has made significant progress in the development of coalbed methane recovery and utilization technology, and transfer of the technology to industry and other interested parties. While the effectiveness of the project approach cannot be quantitatively measured, evidence of the significant developments and the technology transfer exist which attest to the project approach.

1. As a result of the project reporting and review system, and the ability of the project manager to maintain surveillance over all research and technology activities, virtually no duplication of effort has taken place within the MRCP.

2. The project manager has integrated efforts not only of private contractors, but also of other federal agencies and state agencies involved in the parallel effort of resource delineation.

3. The workshops and symposia have provided a vehicle for introducing the project to the private sector, including people in the oil, gas, coal, and well drilling and service industries.

4. The cost sharing approach has served two purposes; it fosters rapid technology interchange, and it increases the purchasing power of MRCP funds.

5. As indicated in Chapters 2 and 3, the coalbed methane exploration, production, and utilization technology bases have been considerably enhanced since the inception of the project in October 1977.

Chapter 5, which concludes this report, will discuss the current state of the art, point out currently existing technology gaps, and cite recommendations for areas which need to be addressed by MRCP in the endeavor to foster commercial recovery and utilization of coalbed methane.

5. CONCLUSIONS

5.1 STATE OF THE ART

In Chapters 2 and 3, certain findings of the MRCP resource delineation, recovery technology development, and utilization technology development were discussed at length. While those efforts represent a significant part of MRCP, the integrated approach required a considerable amount of planning, analysis, documentation, evaluation, and direction. That effort was described in Chapter 4, Project Management. In essence, then, the findings of the project have been discussed in the previous chapters.

A more organized, integrated snapshot of the coalbed methane state-of-the-art uses the work breakdown structure (WBS) as a "checklist", or a basis for discussion. You may recall that the MRCP work breakdown structure has been in effect since the inception of the project in basically the form as shown in Figure 5-1. Each year the WBS has been slightly reoriented to reflect the maturity or cumulative progress of the project and identify new technology gaps.

Table 5-1 shows a summary of the state of the art delineating the progress made under each work element and an estimate of the percentage of completion. The project activities are more thoroughly described in the Semi-Annual Reports of the Unconventional Gas Recovery Program, which was used as a source of the assessment of the project. In addition to those reports, other data points used for the assessment of the technology status include recent technical papers, topical reports published by project participants, the Resource Delineation Workshop, and personal contacts with associates in coalbed methane activities.

5.2 TECHNOLOGY NEEDS

MRCP was conceived in order to mitigate a near term energy shortage problem. The energy shortage of the early seventies, at the same time, encouraged more exploration for conventional oil and gas, which was inspired by the decontrol of prices at the wellhead, thus promising a more reasonable rate of return on oil and gas operators' investments.

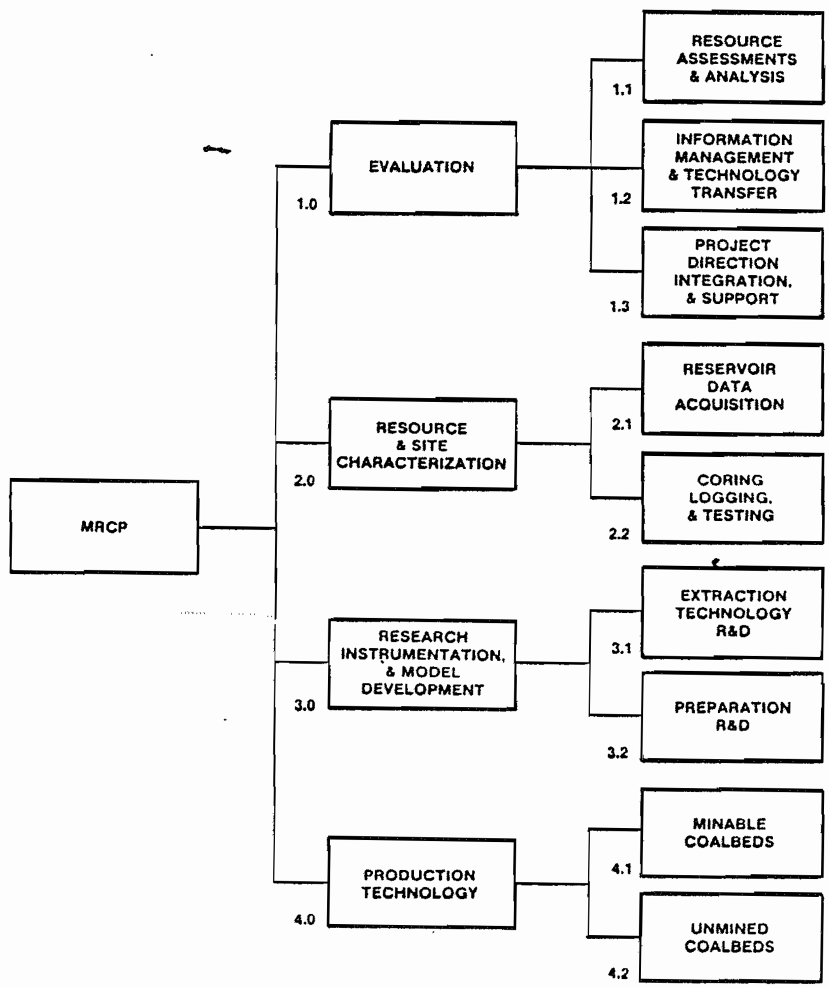

Figure 5-1. MRCP Summary Work Breakdown Structure (WBS)

Table 5-1. Summary of the State of the Art

METHANE RECOVERY FROM COALBEDS PROJECT WBS DICTIONARY		% COMPLETE	REMARKS
1.0 EVALUATION The objectives of the Evaluation activity are: (1) to assess the results of the other activities, (2) to continue the development of the coalbed methane data base, (3) to assess recent technological developments and related industry activities, (4) to update estimates of the potential of the resource, and (5) to develop and monitor project plans that reflect the integration of the technical, geologic, economic, and other types of data that result from the project. The intent of the Evaluation activity is to insure that the DOE efforts complement R&D activities by industry and to assure that the project activities directly support the goals of the overall Fossil Energy Gas Resources RD&D Program. Tasks and elements that support the Evaluation activity are listed below.		65%	Project planning, evaluation, and integration methodology in place and continues for the duration of the project. Resource evaluations in progress; recovery,utilization options evaluation complete.
1.1 ANALYZE AND ASSESS THE RESOURCE This task continues throughout the life of the MRCP. Supporting elements vary in accordance with the types of data being collected, interpreted, and synthesized.	1.1.1 Evaluate Resource Properties Review, analyze, and correlate new data acquired in target area reservoirs (Activity 2.0) and determine more precisely the content and distribution of the methane associated with coalbeds.	60%	Basins of highest potential selected. Twelve basin reports completed; four others to be done; six to be updated.
	1.1.2 Develop Exploration Methods Determine which exploration methods or combinations of methods will provide maximum information on the distribution and producibility of methane from coalbeds.	75%	Methods initially selected; other combinations may be tried as opportunities arise.
	1.1.3 Select Target Areas and Drilling Sites Determine, on the basis of available information, geologic areas of coalbed methane production and select drilling sites that provide the maximum amount of methane resource potential information within the target areas.	60%	Basins of highest potential identified; will be ranked on basis of overall test results after data has been analyzed.
	1.1.4 Update Estimates of the Resource/Reserves Review and analyze new coalbed methane data and periodically provide a more precise estimate of the methane present in coalbeds (the gas-in-place resource) and that portion of the gas which is producible (reserves).	60%	Approach defined and some analyses performed. Additional data required for completing estimates.
	1.1.5 Provide Characterization Test Planning and Analysis Develop a set of tests which will permit acquisition of maximum usable information during each drilling opportunity, whether DOE funded or cost shared.	90%	Suite of conventional tests developed. Novel approaches needed which will facilitate characterization.

Table 5-1. Summary of the State of the Art (Continued)

METHANE RECOVERY FROM COALBEDS PROJECT WBS DICTIONARY (Continued)		% COM-PLETE	REMARKS
1.2 PROVIDE PROJECT INFORMATION MANAGEMENT AND TECHNOLOGY TRANSFER This task continues throughout the life of the MRCP to provide for management of information resulting from the project and to make pertinent portions of this information available to all potential users.	1.2.1 Provide Project Information Management Develop a plan and implement a system for the management of the information from the coalbed methane project activities.	75%	System currently in place — continues over duration of project.
	1.2.2 Transfer Technology to Potential Users Develop a plan and implement a system for transferring MRCP information to potential users on a timely basis. Plan and implement "Methane from Coalbeds" symposiums, normally on an annual basis. Assemble and publish memoranda, reports and other documents to disseminate new technology and other information resulting from the MRCP to potential users.	75%	Symposia and workshops planned and conducted; brochures prepared and distributed; technical papers frequently prepared. Continues over duration of project.
1.3 PROVIDE PROJECT DIRECTION' INTEGRATION AND SUPPORT Provide project direction and the necessary technical and nontechnical coordination and support.	1.3.1 Identify and Initiate Project Support Activities Provide project support in two ways: (1) internally, for the several diverse activities (coalbed methane characterization, resource/reserve estimating, R&D and technology field testing); and (2) externally, by liaison with other UGR programs/projects and private industry activities.	60%	Project management structure and system in place — activities continue over duration of project.
	1.3.2 Identify and Analyze Constraints to Exploitation of the Resource Identify constraints to commercialization. Environmental and legal (ownership) constraints will receive first attention. Determine actions required for mitigation of these constraints.	50%	Addressed with new regulatory developments over duration of project.
	1.3.3 Develop Economic and Cost Factors Determine the economics of methane extraction/preparation/upgrading systems which are proposed or tested. Determine that combination of systems and operating methods which will provide maximum economic production under expected field (commercial) conditions.	60%	Conceptual systems economic and cost study performed; needs to be updated with validated empirical data.

Table 5-1. Summary of the State of the Art (Continued)

METHANE RECOVERY FROM COALBEDS PROJECT WBS DICTIONARY (Continued)		% COMPLETE	REMARKS
2.0 RESOURCE AND SITE CHARACTERIZATION The primary objective of this activity is to acquire the necessary resource data from specific sites in target reservoir areas, so that the information can be used to assess the potential of the resource, to guide modeling efforts, and for technology test planning. Various types of resource data will be collected as provided in the Resource Delineation Plan. Tasks and elements which support the Resource and Site Characterization activity are listed below.		75%	Plans completed, and work in progress.
2.1 ACQUIRE RESERVOIR GEOLOGIC DATA For the target reservoir areas, obtain the geologic data necessary to support evaluation and assessment of the coalbed methane resource. Correlate the data obtained with other available data in order to extrapolate producibility from reservoir to reservoir within a basin.	2.1.1 Determine Coal Strata Properties In the target areas of the basins shown on figure 2-1 determine geologic information, such as seam depth, thickness, porosity, fracture state, etc., which will help determine methane content and production capacity.	75%	Twelve major coal areas analyzed in depth; new data being correlated for inclusion in analyses.
2.2 CORE, LOG AND TEST WELLS OF OPPORTUNITY Arrange and fund or cost share test work in wells being drilled by private industry in the target areas. Perform core tests, logging, sample analysis, and flow tests (where possible) to obtain and correlate coal and methane data.	2.2.1 Core, Log, and Test Wells in Reservoir Target Areas In the target areas of the basins shown on figure 2-1 core, log, and test wells.	75%	Forty five sites logged; ≈ 285 conventional and side-wall core samples taken from 40 sites for desorption, proximate and ultimate tests.
3.0 RESEARCH, INSTRUMENTATION, AND MODEL DEVELOPMENT The objectives of this activity are to improve or develop new diagnostic techniques, to improve or develop new stimulation approaches, and to improve the ability to accurately predict and measure reservoir response to stimulation techniques. Fulfilling these objectives requires basic and applied R&D in the laboratory and the field and the development of models. The models will serve as the repository of knowledge gained from the R&D. They will describe the present understanding of the stimulation processes, gas flow from coalbed reservoirs and economic parameters related to fracturing and production. Models and instrumentation will be evaluated and refined based upon the performance of tests conducted in the field, in Activity 4.0. Tasks and elements which support the Research, Instrumentation and Model Development activity are listed below.		70%	Some applied research development in progress. Some basic research funded, but not required for immediate payoff. Development of water jet drill in progress.

Table 5-1. Summary of the State of the Art (Continued)

METHANE RECOVERY FROM COALBEDS PROJECT WBS DICTIONARY (Continued)		% COMPLETE	REMARKS
3.1 CONDUCT EXTRACTION TECHNOLOGY R&D This task will continue throughout most of the life of the project. The level of effort will increase to a maximum as R&D activities are identified and initiated early in the project and will decrease thereafter as the project progresses.	3.1.1 Develop/Modify Drilling Techniques and Equipment Develop, by modification and new design, drilling techniques and equipment specifically applicable to the extraction of methane from coalbed reservoirs. Drilling techniques include horizontal drilling and directional drilling, while equipment includes downhole motors and waterjet drilling.	60%	Turbodrill evaluation completed; waterjet drilling in development; horizontal and directional drilling demonstrated.
	3.1.2 Perform Stimulation Experiments From single vertical boreholes perform multi-seam stimulations and completions. Design stimulations to maximize production but to minimize roof damage, especially in minable coal seams. Hydraulic, foam, gas, and dendritic stimulation designs will be tested.	60%	Multiseam stimulation design demonstrated; other hydraulic, foam, gas, and dendritic designs tested.
3.2 CONDUCT PREPARATION R&D This task will continue throughout most of the life of the project. The level of effort will increase to a maximum as R&D activities are identified and initiated early in the project and can be expected to decrease thereafter as the project progresses.	3.2.1 Develop LNG Conversion Capability Develop equipment sized for cost-effective liquefaction near the recovery site of gas from coalbeds.	10%	Initial evaluation performed; further analyses needed.
	3.2.2 Develop Membrane Separation Capability Develop equipment and techniques to upgrade low quality gas from coalbeds so that it is suitable for pipeline injection.	10%	Initial evaluation performed; further analyses required.
	3.2.3 Develop Mixed Gas Upgrading Capability Develop equipment and techniques to remove contaminants from gas recovered from coalbeds to the extent that its use will be feasible and cost effective.	0%	Feasibility of technology needed for long term energy potential.
4.0 PRODUCTION TECHNOLOGY DEVELOPMENT The objectives of this activity are to: (1) design, operate, and field test coalbed methane integrated systems; (2) investigate and resolve variables that will be encountered under field (operational) conditions; and (3) evaluate the systems/subsystems and operating methods tested for technical and economic feasibility and readiness for commercial ventures. The activity is in progress, with more than nine technology test projects ongoing and planned, and is expected to continue throughout the life of the MRCP. Tasks and elements which support the Production Technology activity are listed below.		50%	Ten production projects initiated; seven completed; three utilization demonstrations completed; one in progress.

Table 5-1. Summary of the State of the Art (Continued)

METHANE RECOVERY FROM COALBEDS PROJECT WBS DICTIONARY (Continued)		% COM-PLETE	REMARKS
4.1 CONDUCT TECHNOLOGY TESTS ASSOCIATED WITH MINABLE COALBEDS The elements of this task are a series of individual field test projects; each usually involves an integrated system. A test site is selected for each type of production system to be tested (including extraction and product preparation/upgrading equipment, as required, for a complete system).	4.1.1 Conduct Multiple Well Projects In these technology tests methane will be drained in advance of mining operations. New and improved gas extraction methods will be investigated (well spacing, geometric patterns, etc.) using various utilization systems such as pipeline, space heating, etc.	60%	Two long term tests in progress. Spacings and patterns, optimally set by computer simulation, being validated empirically.
	4.1.2 Conduct Horizontal Borehole Drainage Projects In these technology tests methane will be drained prior to or during mining operations. New and improved equipment and methods will be investigated for horizontal borehole drainage using various utilization concepts such as onsite power generation, pipeline, LNG production, etc.	80%	Horizontal drilling tested by MRCP; now being utilized by industry. Evaluation, documentation in progress. Utilization for coal drying being implemented; onsite power generation demonstrated.
	4.1.3 Conduct Advanced Systems Test Projects (Minable Coalbeds) In these technology tests new equipment and methods will be field tested, such as an on-site power generation project, a directional drilling project, single vertical well projects for novel utilization systems, etc.	30%	Directional drilling from surface site demonstrated feasible; dewatering & production problems identified and being resolved.
4.2 CONDUCT TECHNOLOGY TESTS ASSOCIATED WITH UNMINABLE COALBEDS The elements of this task are a series of individual field test projects; each usually involves an integrated system. A test site is selected for each type of production system to be tested (including extraction and product preparation/upgrading equipment, as required, for a complete system).	4.2.1 Conduct Deep Coalbed Drainage Projects In these technology tests methane is extracted from deep coal horizons, many of which will not be mined in the foreseeable future.	25%	Two projects initiated in western coal fields; stimulation designs need to be tested.
	4.2.2 Conduct Drainage Projects in Coalbeds Under Developed Areas In these technology tests methane will be extracted from coal seams that cannot be mined because of their location under developed areas such as an urban community having multiple improvements on the surface.	80%	One project implemented; stimulation and production problems need to be reevaluated.
	4.2.3 Conduct Directional Drilling Coalbed Drainage Projects In these technology tests methane drainage is accomplished using directional drilling techniques.	0%	Deferred due to lack of funding. Required as an alternative to fracturing.

Table 5-1. Summary of the State of the Art (Continued)

METHANE RECOVERY FROM COALBEDS PROJECT WBS DICTIONARY (Continued)		% COM-PLETE	REMARKS
4.2 (Continued)	4.2.4 Conduct Advanced Systems Test Projects (Unmined Coalbeds) In these technology tests new equipment and methods will be field tested for various applications such as on-site power generation, pipeline injection, LNG production, etc. Novel situations such as anthracite coal drainage may be covered under this project category.	25%	Anthracite coal project designed and awaiting authorization to proceed.

Additionally, conservation measures -- especially in terms of decreased consumption of natural gas caused by curtailment of installations for industry and new housing -- decreased the rate of consumption for the near term, thereby deferring the future natural gas shortages.

At the same time conservation is being encouraged by the Federal Government and concerned citizens, however, large quantities of high quality methane are being wasted by ventilation into the atmosphere. Currently, approximately 250 million cubic feet of methane are wasted each day in that manner, purged from working underground mines in their attempt to create a safer mining environment. The more sophisticated mining equipment -- continuous miners and longwall miners -- designed for better coal production have significantly increased the need for more active mine ventilation. Consequently, more and more coal operators are contemplating coalbed predrainage, using established economic and technical feasibility data provided by MRCP. To gain use of the coalbed methane in the near term, work must be completed in the evaluation and further development of the technology, including:

- o Optimum patterns for vertical wells, considering the cleat orientation, natural fractures, permeability, porosity, specific methane content, and underground methane barriers
- o Optimum spacing for vertical wells, considering the mining plan, methane migration characteristics, and methane demand
- o More effective means of predrainage in conjunction with longwall mining, using both vertical and horizontal boreholes, with or without artificial stimulation
- o Better ways of stimulating coalbeds to preclude problems with flowback of sand and other solids while dewatering and producing gas from vertical wells.

As stated earlier, these studies, analyses, and tests have begun but have been constrained by opportunities and funding. For the tests to be worthwhile, they must be repeated under various conditions, carefully documented, and communicated with industry. To expect the continued development of the technology by industry is, to say the least, naive, since the high cost of executing such a program, and the expected low rate of return, make it a poor candidate for private enterprise. The rapid development of coalbed methane technology is attributed to the integration of the efforts of gas, oil, and coal operators, Federal and state government, and private researchers and educational institutions to achieve a common goal.

5.3 RECOMMENDATIONS

The MRCP should continue its efforts to foster extensive commercial use of coalbed methane (a) to conserve the vast amount of energy being wasted by ventilation of coal seams and coal mines, and (b) for the long-term energy posture, to recover and utilize the methane in the deep and otherwise unminable coal of the western and northwestern United States. Specifically:

1. It is recommended that the studies of optimum geometric well patterns and optimum spacing of wells in coal acreage be initiated and executed over a long term (five to ten years) to obtain empirical data which can be used in future commercial coalbed predrainage applications. Enough data must be collected to permit placement of wells from which production, nominally regulated to suit the demand, can be expected over a predetermined well life, and still sufficiently drain the methane from coal to be mined in the future. In addition to conservation of the energy supply by utilization of the methane, the degasification should increase the mine production by decreasing the time and energy for mine ventilation.

2. It is further recommended that the development of techniques for predrainage of minable coal be accelerated in order to increase the coalbed methane production from active mines, to maintain a posture consistent with improved coal production. Although predrainage of methane is becoming increasingly popular with coal mining interests, the production is inadequate for commercial application and the produced gas is generally vented into the atmosphere. Better predrainage methods, which would include stimulation, in-mine horizontal drilling, and drilling horizontal holes from a directional base, must be improved, documented, and related to coal mining operations.

   At the outset of the project, consideration was given to massive hydraulic fracturing as a way to better stimulate coalbeds. However, stimulations most suitable for minable coalbeds are currently thought to require low injection rates in order to propagate horizontal fractures and prevent damage to the roof rock. A minimal amount of proppant should be used in order to reduce pumping problems. Because of the limited life expectancy of demethanation wells, elimination of fracture proppant may be an acceptable solution to sump filling and pump stoppage problems. At the present time MRCP, via the Carbondale Mining Technology

Center, is conducting research on no-proppant, low injection rate stimulation treatments, with promising results. Additional tests should be conducted to influence future fracture treatment designs.

Drilling of horizontal boreholes from within an active mine for degasifying minable seams has been fairly extensively tested and is now being used in a number of underground coal mines. Under MRCP extensive work was done by Occidental Research Corporation at an Island Creek Coal Company mine in Buchanan County, Virginia. The practice will apparently continue in conjunction with their longwall mining operation.

Additional testing is being done by the USBM under the mine safety research program. Consequently, MRCP should concentrate on encouraging development of utilization options for the recovered gas, which currently is vented.

On the other hand, the placement of horizontal holes from the surface by the use of a directionally drilled base has had limited testing, yet seems to be a reasonable alternative to fracturing of a minable seam. Like many other technology development projects, personal experience will be a major factor in reducing the cost of drilling such wells and consequently, further attempts are highly advisable. As stated earlier, however, dewatering of such wells has been a problem which needs to be vigorously addressed. The use of a submersible pump needs to be reconsidered, since such devices are designed for continuous flow of liquids from shallow wells and thus are not effective for gas lifting. Other approaches, such as the use of multistage gas lift pumps, should be investigated.

3. It is also recommended that the delineation of coalbed methane resources and recoverable reserves be continued as planned in order to provide the data for determining the long-term energy posture and strategy of the United States, considering the unconventional sources as well as the conventional sources of energy. Resource delineation includes the analysis and correlation of the coal core samples and other data being gathered under the MRCP "fast track" resource delineation plan in order to better estimate the extent of the coalbed methane resource and the recoverable reserves. Emphasis should be placed on areas for which data is not currently available in a compatible form. Optional approaches for performing well tests, such as contracts for individual drilling, coring, logging, drill stem testing, etc., should be considered in order to obtain data on all basins of interest in a timely manner.

   In addition to the initial characterization for the purpose of estimating the methane contained in the coal basins, the data base should be kept current to abet future exploitation of the resource. Thus the reports covering the remaining basins identified in the Resource Delineation Plan, listed below, should be completed and all basin reports kept current for the duration of the MRCP. Remaining coal basins or regions to be evaluated are:

- o Northern Appalachian Region
- o Middle Appalachian Region
- o Black Mesa Region
- o Henry Mountains/Kaiparowits Basin
- o Jackson Hole Field
- o Denver Region
- o Northern Region
- o Big Horn Basin
- o Hanna Field

4. Supporting research should be conducted on coalbed methane processing systems to increase utilization of methane vented from coalbeds. The identification and field demonstration of cost-effective, portable LNG and CNG plants should receive early attention as an option where utilization as fuel as an onsite fuel source is not considered economically feasible, or is excessive for those needs. Other R&D efforts which would foster utilization are a membrane separation ability to upgrade low-grade methane for pipeline injection and a mixed gas upgrading capability to remove contaminants from vented gas.

   As with much of the MRCP technology development effort, advancement of the technology will not have an immediate impact on utilization of coalbed methane because of the present availability of conventional natural gas on the market. If very economical systems are identified for the public, they may be voluntarily accepted for use. Again, the technology development would only be useful in the mid-term in the face of an energy fuel shortage.

5. Technical and economic viability of the recovery of methane from anthracite coal needs to be demonstrated. As stated earlier, coal characteristics definitely affect the recoverability of methane from coal. The empirical data obtained from technology tests performed in bituminous coal cannot be extrapolated to anthracite coal reservoirs because of that problem and, consequently, some tests must be performed in anthracite coal.

   Anthracite coal exists in substantial quantities in Pennsylvania. Much of the coal has been mined, but approximately 18,812 million short tons remained in the coalbeds as of January 1, 1974. A study of mine maps indicates an environment conducive to methane recovery through abandoned mines to underlying seams which may contain large amounts of methane. Samples desorbed in 1975 by Pennsylvania Energy Resources, Inc., produced approximately 400 cubic feet of methane per ton of coal, and thus is considered extremely gassy. Should the seams eventually be mined as a result of changing technological and economic conditions, predrainage would be an absolute necessity for mine safety.

   The methane recovered from the anthracite coal would be usable for industrial and residential fuel, since the coal fields underlie a heavily populated area. At the present time, the gas supply for that area is pipelined from Texas and Louisiana. In the face of extremely cold winters, the northeastern section of the United States has experienced a fuel shortage, in spite of abundant supplies in storage tanks in Texas.

MRCP activities have been highly influenced by external factors which accounted for rapid interest and development of technology followed by diminishing urgency.

First, anticipation of a shortage of natural gas led to the interest in developing unconventional sources of energy, including coalbed methane, methane from Devonian shale, and gas from tight formations.

Second, anticipation of decontrol of natural gas prices, which would have made the price of conventional gas rise in the marketplace, also encouraged renewed exploration for conventional gas reservoirs.

Third, curtailment of installation of gas-fueled residential and industrial development decreased consumption.

Fourth, renewed interest in coal as a fuel source has increased mine activity and accordingly, an increase in mine ventilation.

Fifth, the newer coal mining methods and USBM encouragement as a result of safety research have resulted in a trend toward predrainage of minable seams in advance of mining.

Sixth, MRCP technology transfer activities marshalled interest in utilizing available techniques and equipment in support of coal mining operations.

Finally, success in the exploration efforts for conventional gas sources, coupled with conservation measures and conversion to oil for industrial and home heating, have kept the price of gas at a level with which coalbed methane cannot compete in the marketplace at the present time. In spite of these barriers, however, coalbed methane continues to be a promising source of energy, and the success of the project to date has created a position where minimal funding and time is required to achieve a major contribution to the future energy posture of the country.

APPENDIX

SITES TESTED BY TRW ENERGY ENGINEERING DIVISION UNDER THE MRCP RESOURCE DELINEATION PLAN

1978 - 1980

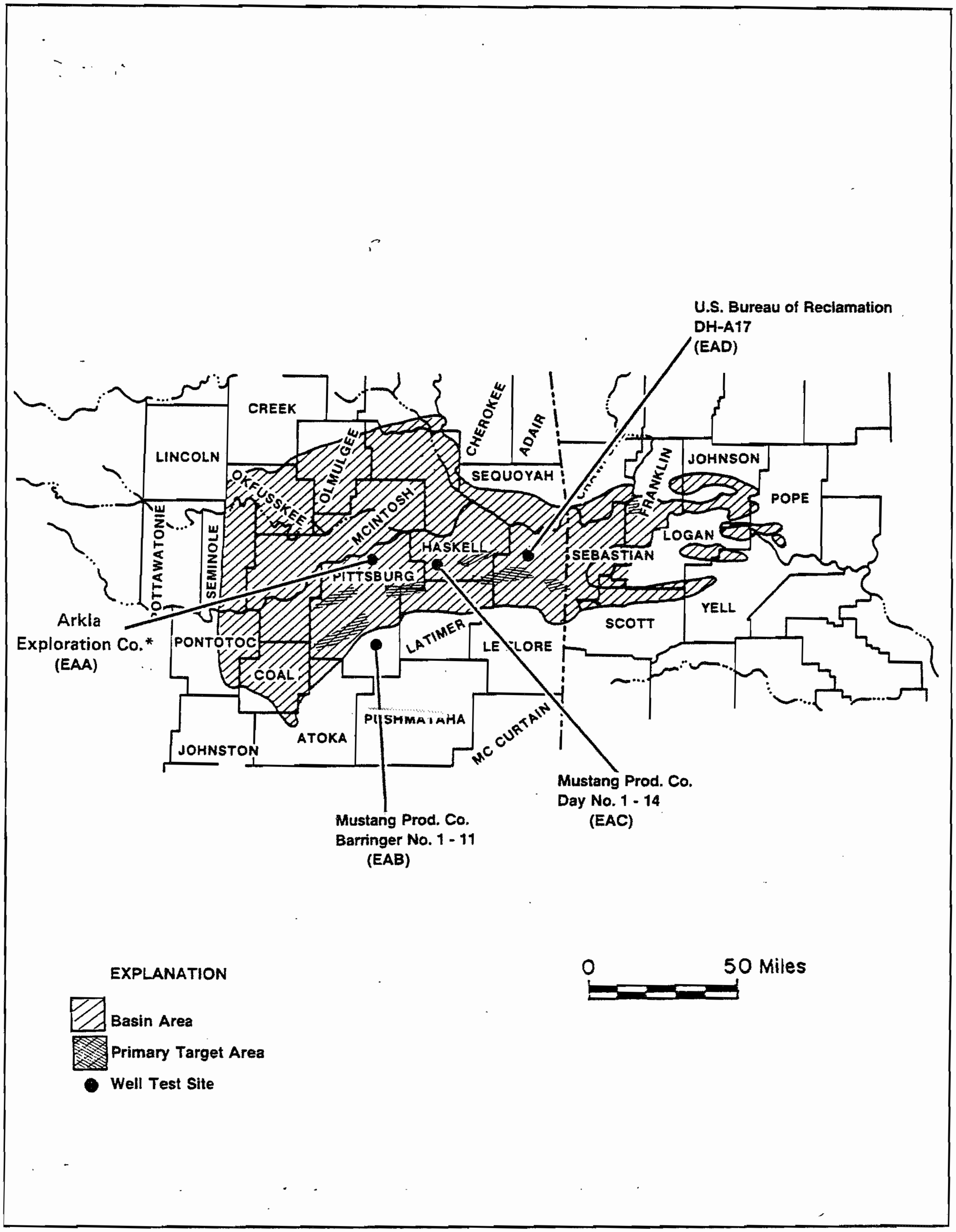

Figure A-1. Map Showing Location of the Arkoma Basin, MRCP Primary Target Areas and Well Test Sites

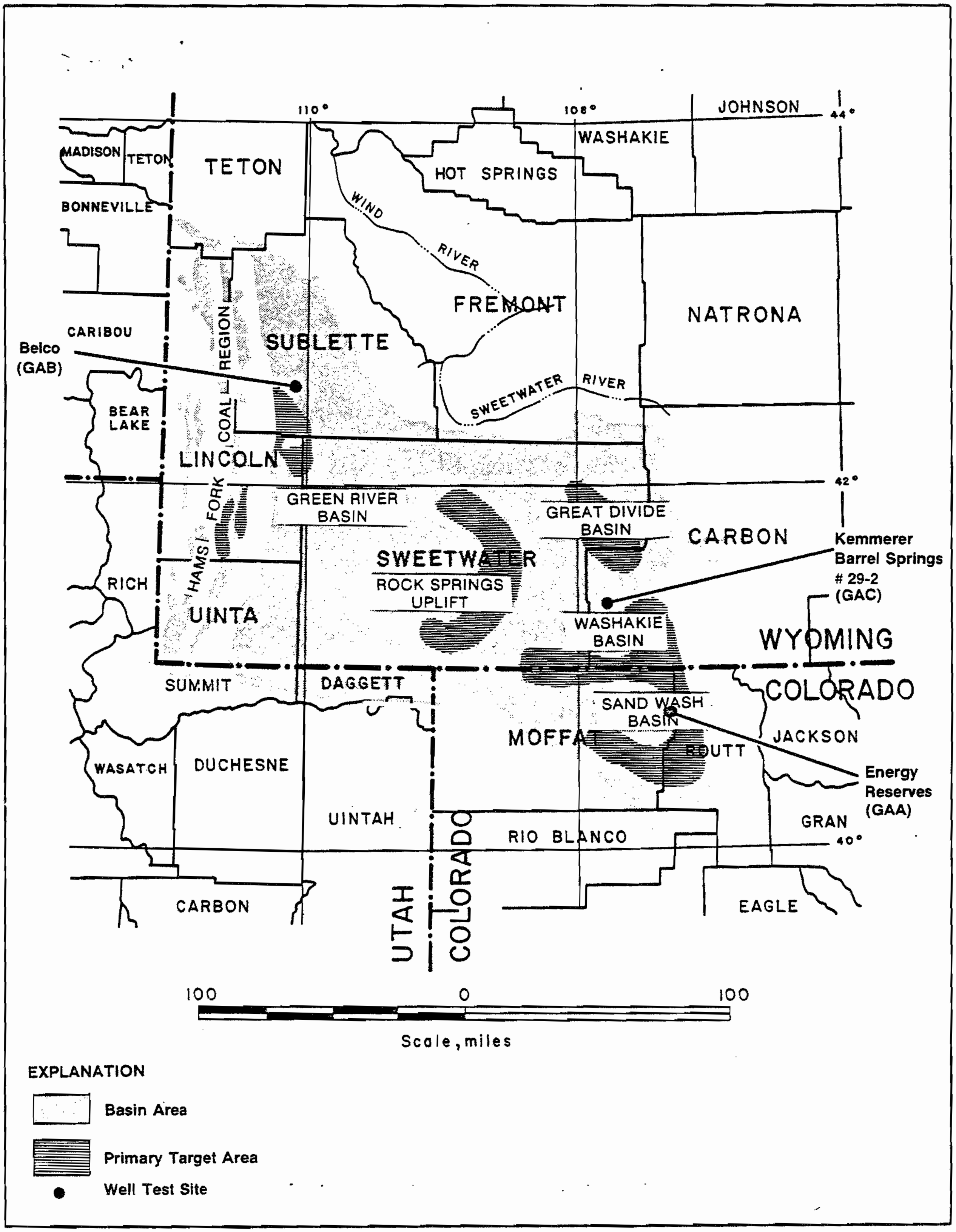

Figure A-2. Map Showing Location of the Greater Green River Coal Region, MRCP Primary Target Areas and Well Test Sites

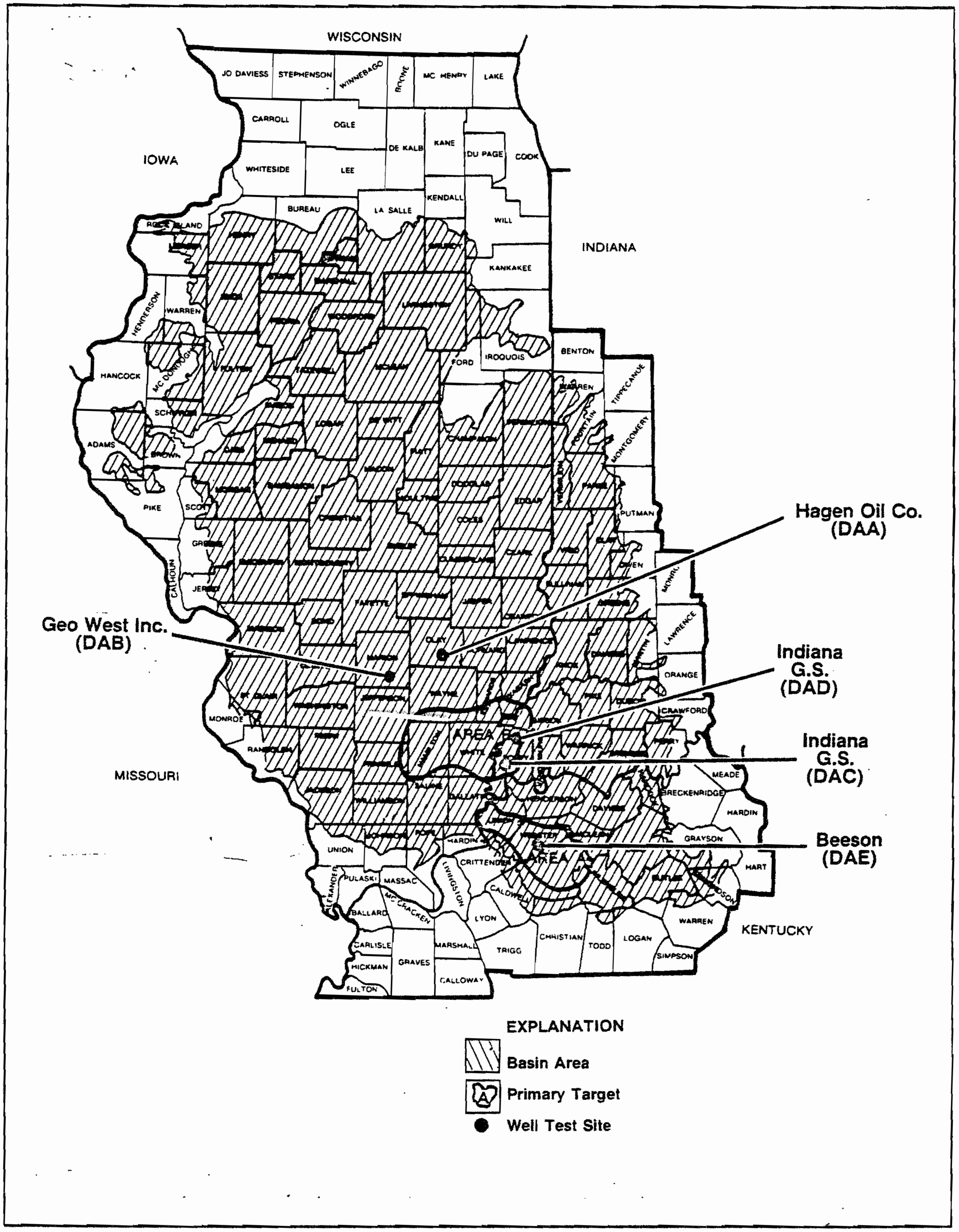

Figure A-3. Map Showing Location of the Illinois Basin, MRCP Primary Target Areas and Well Test Sites

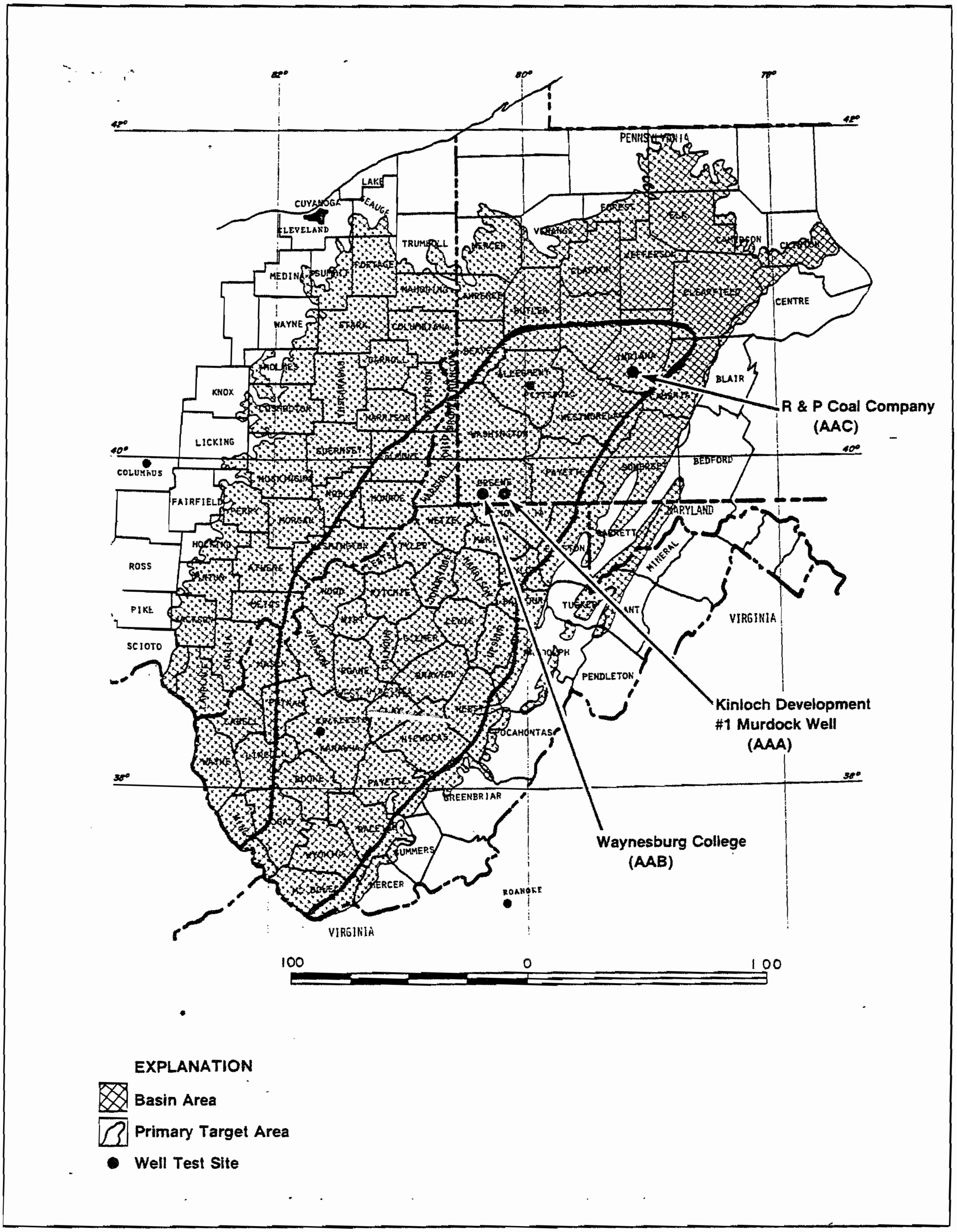

Figure A-4. Map Showing Location of the Northern Appalachian Basin, MRCP Primary Target Areas and Well Test Sites

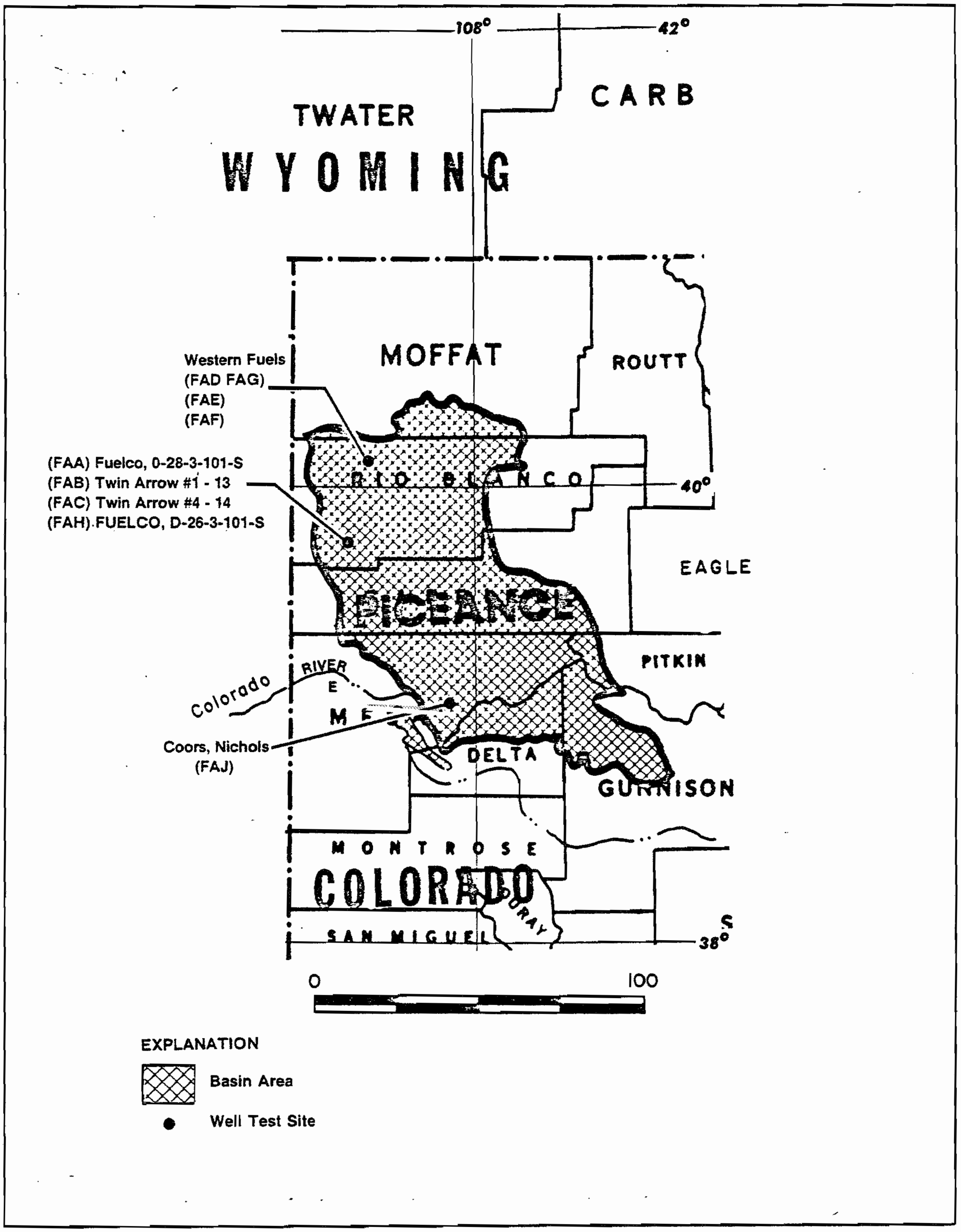

Figure A-5. Map Showing Location of the Piceance Basin and MRCP Well Test Sites

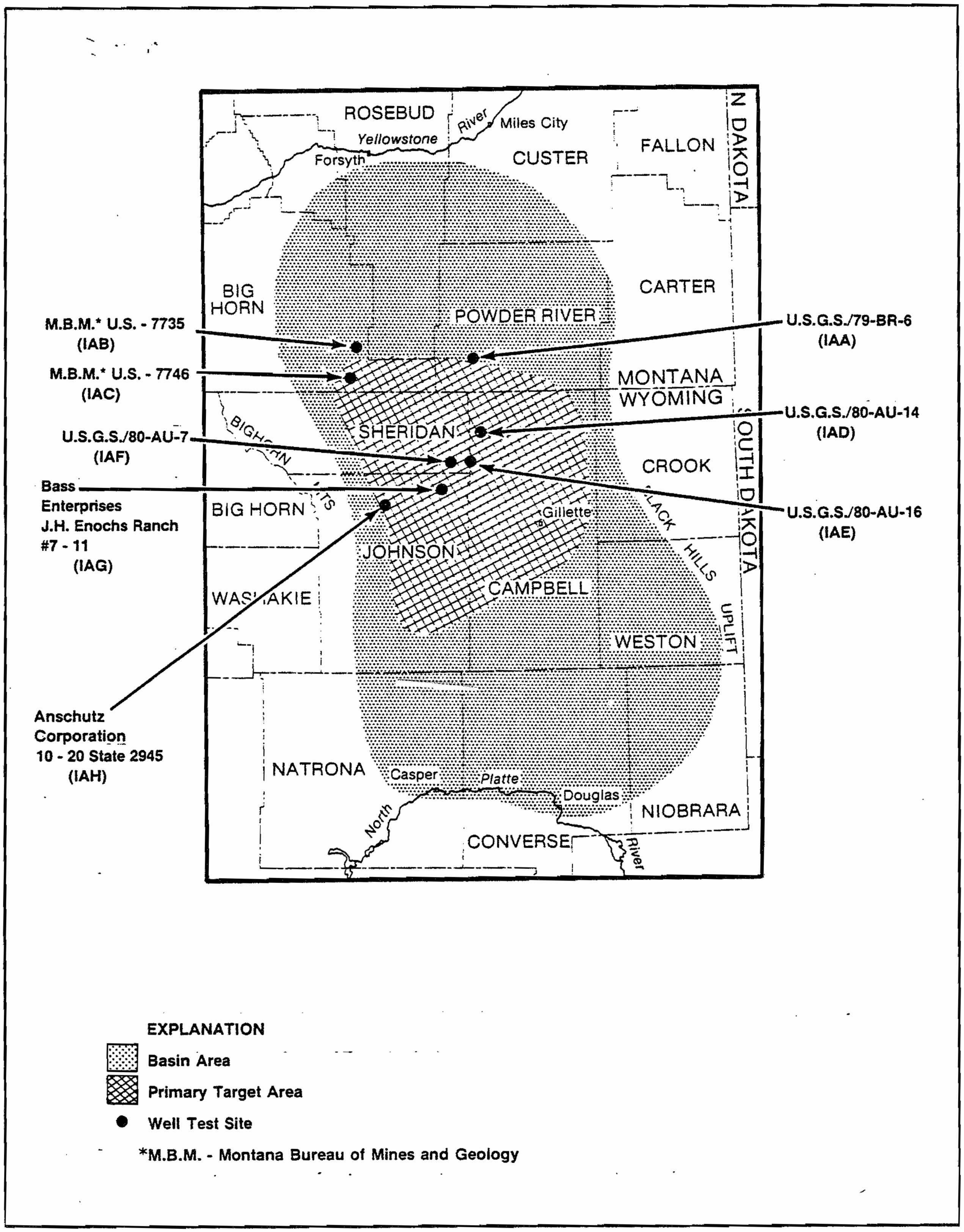

Figure A-6. Map Showing Location of the Powder River Basin, MRCP Primary Target Area and Well Test Sites

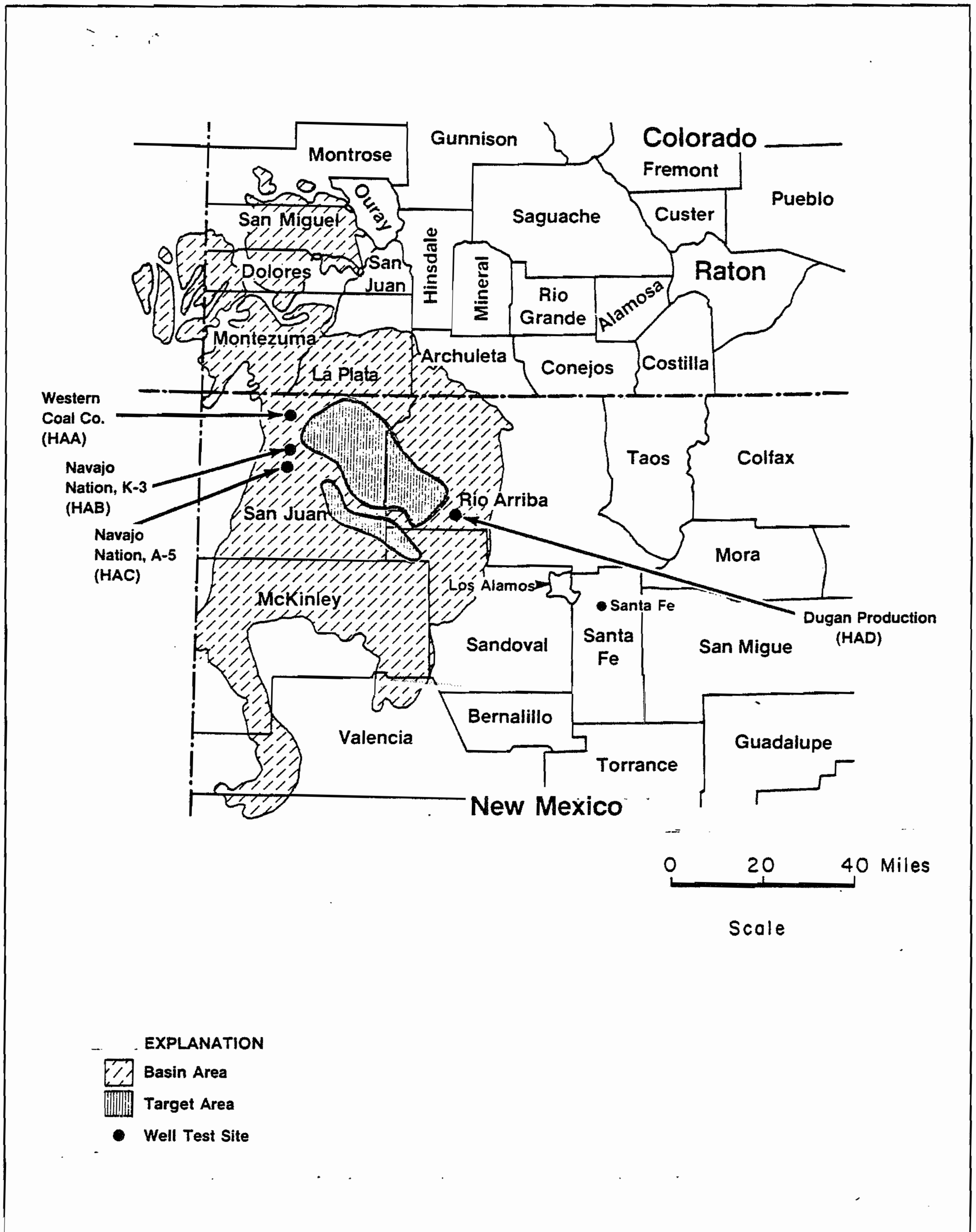

Figure A-7. Map Showing Location of the San Juan Basin, MRCP Primary Target Areas and Well Test Sites

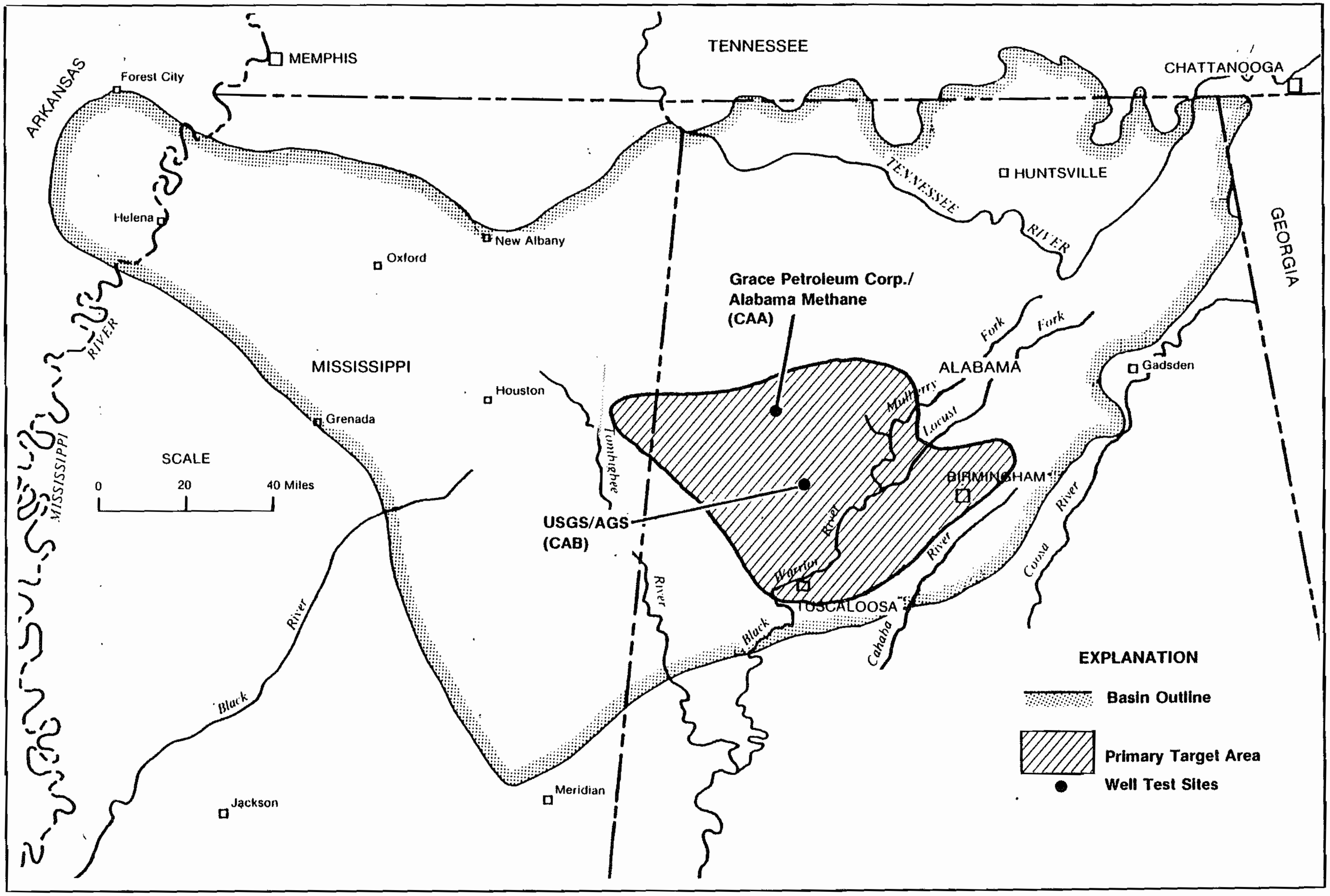

Figure A-8. Map Showing Location of the Warrior Basin, MRCP Primary Target Areas and Well Test Sites

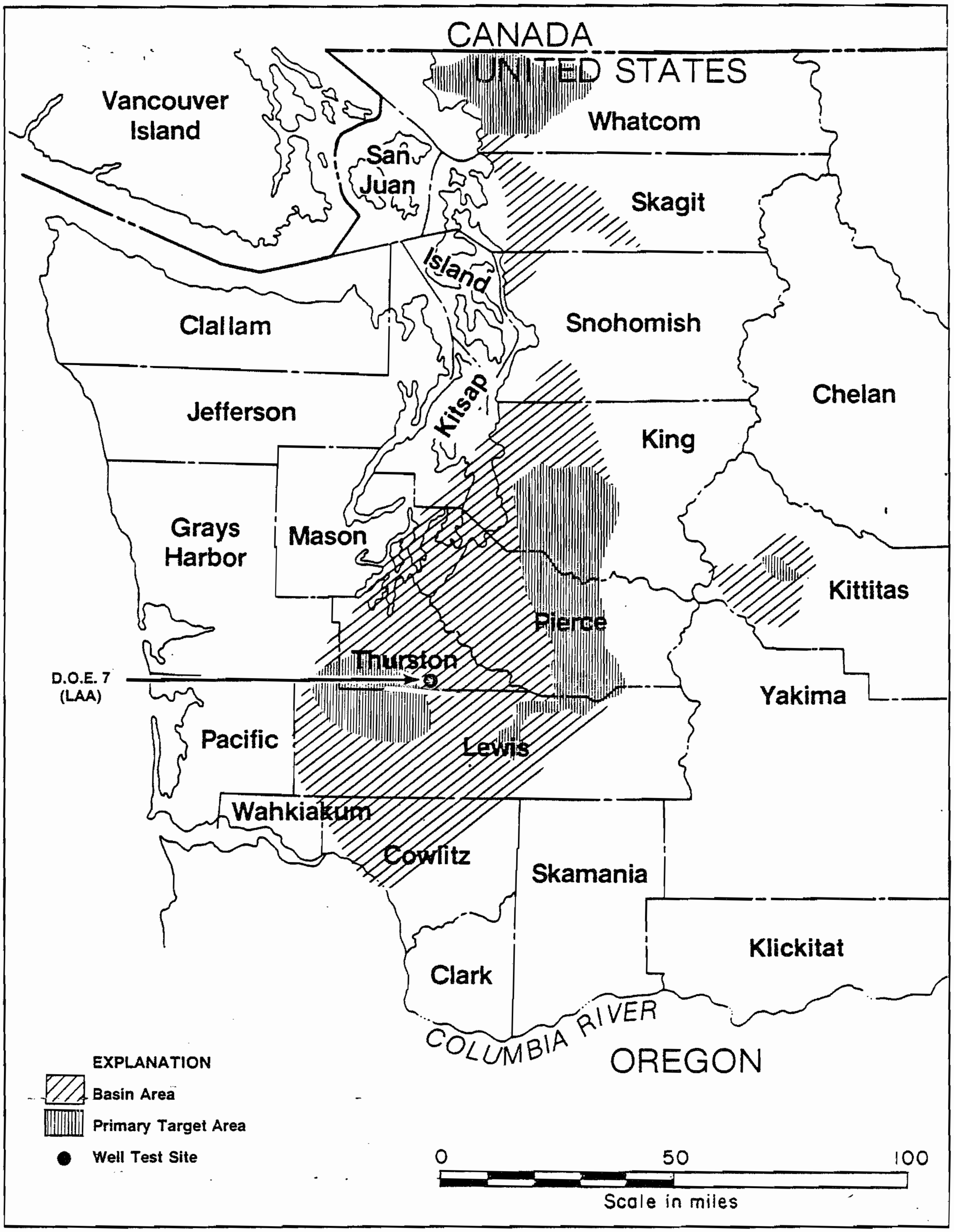

Figure A-9. Map Showing Location of the Western Washington Coal Region, MRCP Primary Target Areas and Well Test Sites

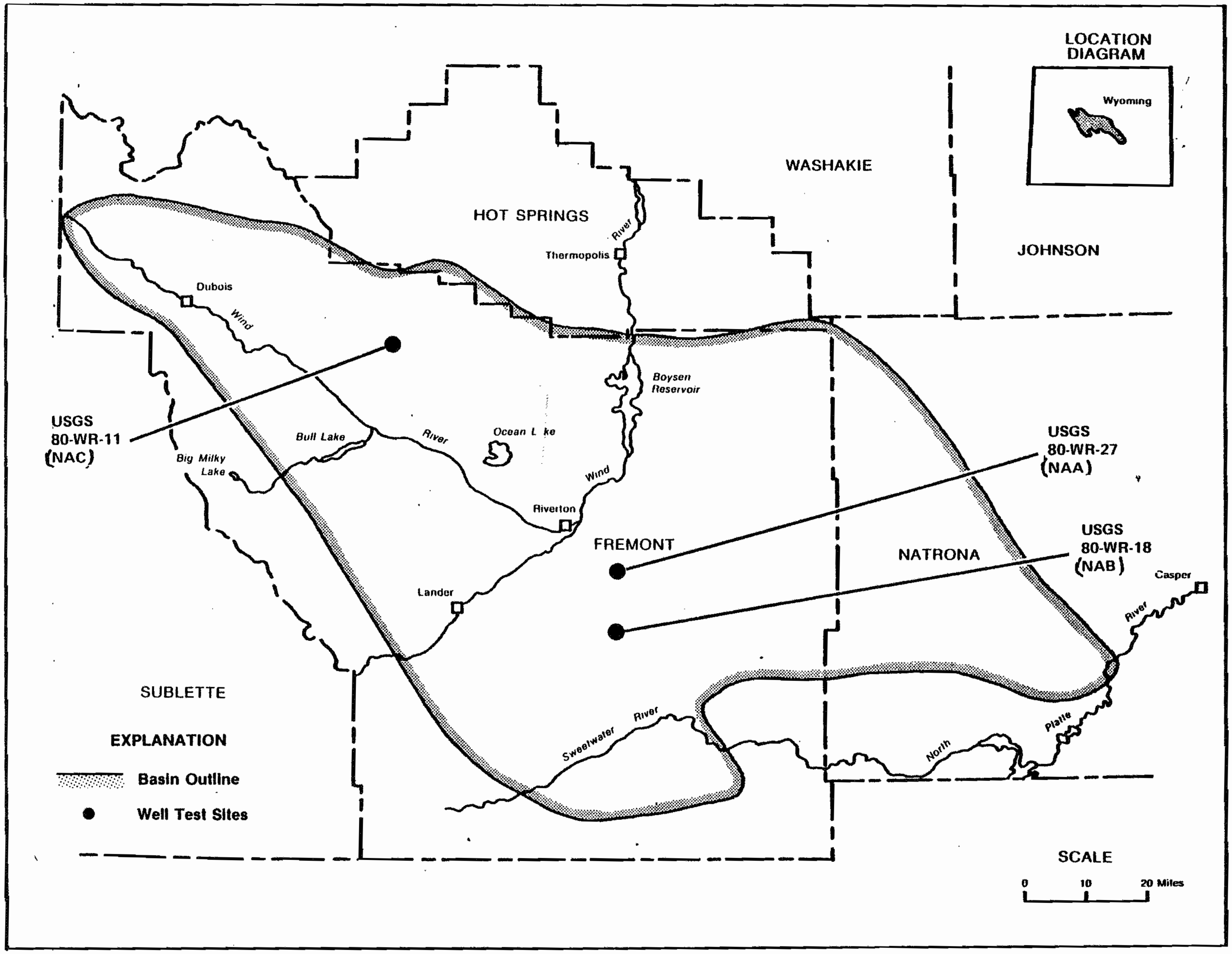

Figure A-10. Map Showing Location of the Wind River Basin and MRCP Well Test Sites

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