SYNTHETIC FUELS DEVELOPMENT

Earth-Science Considerations

U.S. Department of the Interior / Geological Survey

Acknowledgments

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Earth-Science Considerations

Edited by D. A. Rickert, W. J. Ulman, and E. R. Hampton

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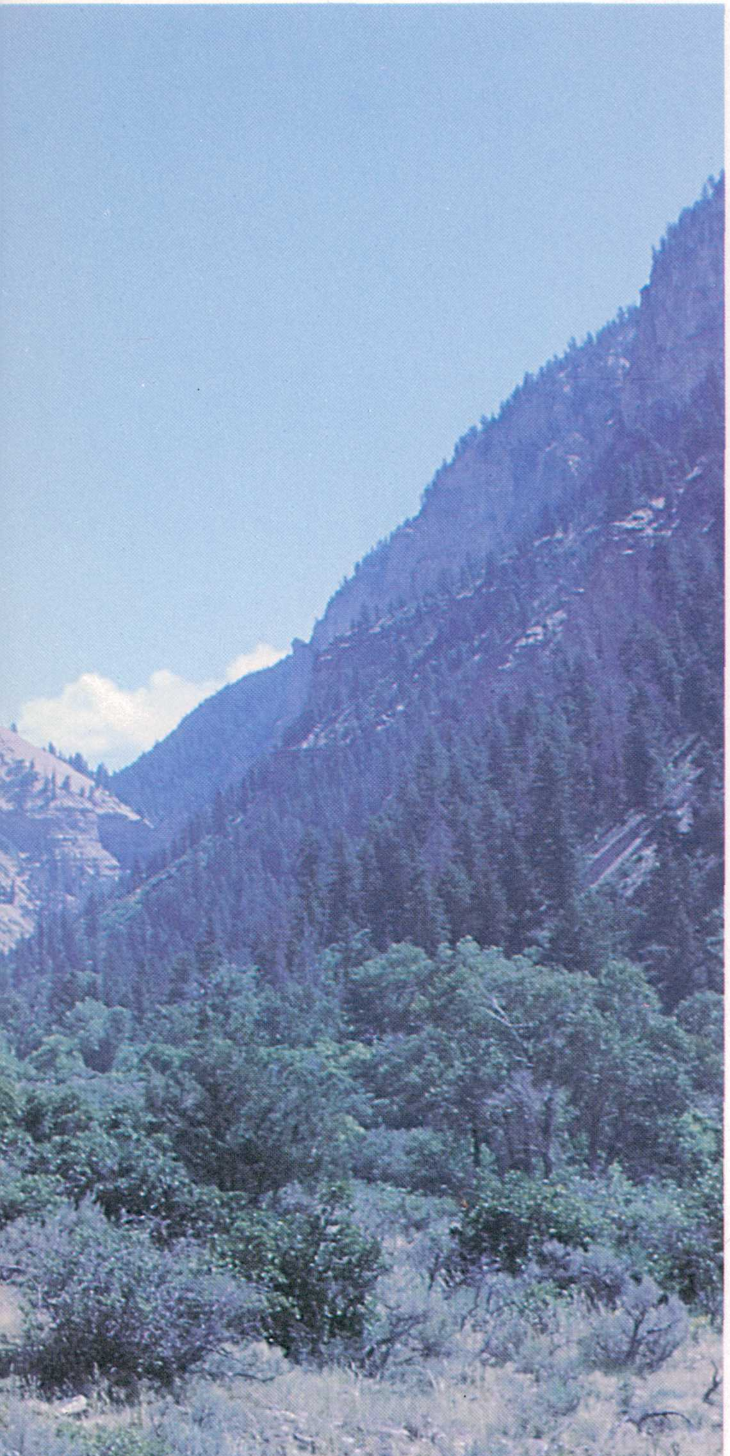
Rugged exposures of oil shale in Parachute Creek Canyon in the Piceance Creek Basin oil shale area, Garfield County, Colorado.



Foreword

THE CURRENT ENERGY CRISIS is affecting the lives of all Americans. Continued increases in energy prices and frequent shortages are stark reminders of our growing dependence on foreign energy resources in today's energy-hungry world.

A comprehensive national energy policy must consider a variety of energy resources, including synfuels, to meet future energy needs.

The development of a major synfuel industry in the United States will require participation and cooperation of all levels of government and private industry. There are many questions to be answered and many problems to be solved. In this report, the U.S. Geological Survey has assembled information to answer some of the broader questions concerning our Nation's synfuel resources and the potential effects of their development. Although the report provides only a brief overview of synfuels and related natural resources, I hope the information will be useful to those making decisions so critical to the future of the Nation.

H. William Menard
Director

Synfuel resources

Water resources and synfuels

Potential geologic and hydrologic problems

Introduction

SYNFUELS—synthetic organic products—are becoming topics of national interest in this time (1979) of rising energy prices and growing awareness of the limited worldwide petroleum supply. Development of a domestic synfuel industry is being proposed by national leaders as one way to decrease our present dependence on imported oil.

This report provides basic information on the natural resources required for synfuel production and briefly describes some of the possible geologic and hydrologic considerations. No attempt is made to address the social, economic, air-quality, and secondary environmental effects that would result from the large-scale production of synfuels.

What are the raw materials for synfuel production?

SYNFUELS can be made from coal, oil shale, tar sands, and various types of biomass such as wood, grains, and garbage. This report focuses on the potential production of synfuels from coal and oil shale.

Mineral chemical composition is an important factor in determining the suitability of different coals for making synfuels. In general, the lower quality lignitic, subbituminous, and bituminous coals are more easily and efficiently converted to synfuels than anthracites. Furthermore, for a given type of coal, the conversion efficiency may vary considerably, depending on the detailed mineralogy.

Oil shale is rich in kerogen, an organic substance similar to the materials which have produced naturally occurring oil and gas. Oil shale must be heated to high temperatures to convert its kerogen to syncrude (synthetic crude) oil.

◀ Decker Coal Mine near Coalstrip, Montana, 1975.

How are synfuels made?

AT THE PRESENT TIME, the two resources most readily available in the United States for conversion to synfuel are coal and oil shale. The methods used to convert these resources to synfuel are here described briefly.

From coal

Coal can be converted to either a synthetic gas (gasification) or a synthetic liquid (liquefaction). It can be converted in place to produce a combustible gas or mined and then processed at the surface into gas or liquid. In both cases, the basic process involves the chemical addition of hydrogen to the carbon in coal. Typically, the weight ratio of carbon to hydrogen, 16:1 in coal, is reduced to less than 10:1 in syncrude oil, and to as low as 3:1 in synthetic gas. Water, in the form of steam, is the common source of hydrogen.

In coal gasification, the heat required to sustain the chemical conversion process is usually produced by combusting part of the original coal. The gas produced is either a low-Btu[1] (100–200 Btu's per standard cubic foot) or medium-Btu (300–650 Btu's) gas, depending on whether air or pure oxygen is used for combustion. A high-Btu (950–1,050 Btu's) gas (comparable to natural gas) can be produced by further processing of medium-Btu gas.

In coal liquefaction, hydrogen, either as a gas or as a hydrogen-rich organic solvent, is reacted with the coal. If a solvent is used, it "donates" hydrogen to the coal and is removed together with syncrude oil and ash. In turn, part of the syncrude might be burned for process heat. The remainder would be available as a replacement for fuel oil or as a feedstock for further refining.

Water is required in coal gasification and liquefaction both as a source of hydrogen and for other process steps. A significant amount of process water is required for removing sulfur compounds from waste gases prior to discharge of the gases to the atmosphere.

A considerable part of the heating value of coal cannot be recovered in synfuel production. Thus, a large amount of waste heat must be transferred to the environment. In present practice, one-third to one-half of the total waste heat is absorbed by cooling water. In conventional cooling, evaporative water losses can account for more than two-thirds of the total water requirements of the coal-to-synfuel conversion.

From oil shale

Mined oil shale will yield shale oil when heated to a temperature of 900°F in a closed vessel ("surface retorting"). High-grade shale can yield 35 or more gallons of oil per ton of shale. However, surface retorting poses a major problem because large volumes of waste shale must be disposed of.

To eliminate the disposal problem associated with surface processing, several underground (in-situ) retorting methods have been proposed. The in-situ method involves fracturing the oil shale underground, introducing heat to liquefy the kerogen, and recovering the oil through wells. A "modified" in-situ method involves the mining of about 20–40 percent of the shale to be processed to form an underground cavity. The shale above the cavity is broken with explosives, and the cavity is filled with shale rubble that is then retorted in place.

As in the synfuel processing of coal, some oil shale conversion processes require large amounts of water for removing waste heat and for cleaning the waste gases. Moreover, in the surface-retorting process, additional water is required for quenching and moisturizing the spent shale prior to its disposal. This last requirement may amount to 50 percent of the total water required for the surface processing of oil shale.

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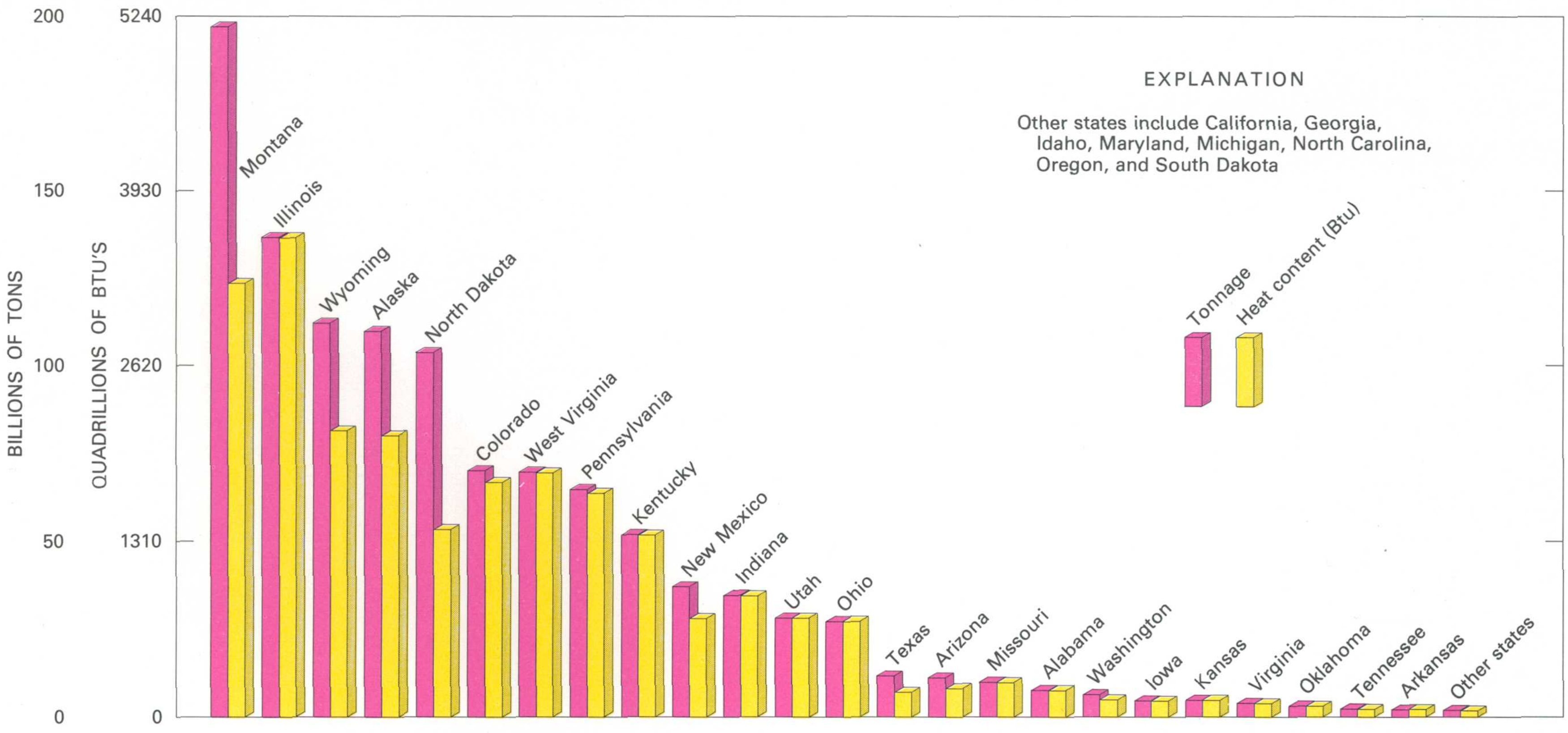
1 Heat measurement is normally expressed in British thermal units (Btu). A Btu is the amount of heat required to raise the temperature of 1 pound of water 1° Fahrenheit.

Where is the Nation's coal and how much is there?

THE ACCOMPANYING MAP shows the location of the Nation's coal resources that might be considered for potential synfuel development. These resources include coal deposits to a depth of 3,000 feet, in beds thicker than 28 inches for anthracite and bituminous coal and thicker than 5 feet for subbituminous coal and lignite. On this basis, the potential coal synfuel resource of the Nation is 1.1 trillion tons. Most (about 90 percent) of these resources are less than 1,000 feet below the surface.

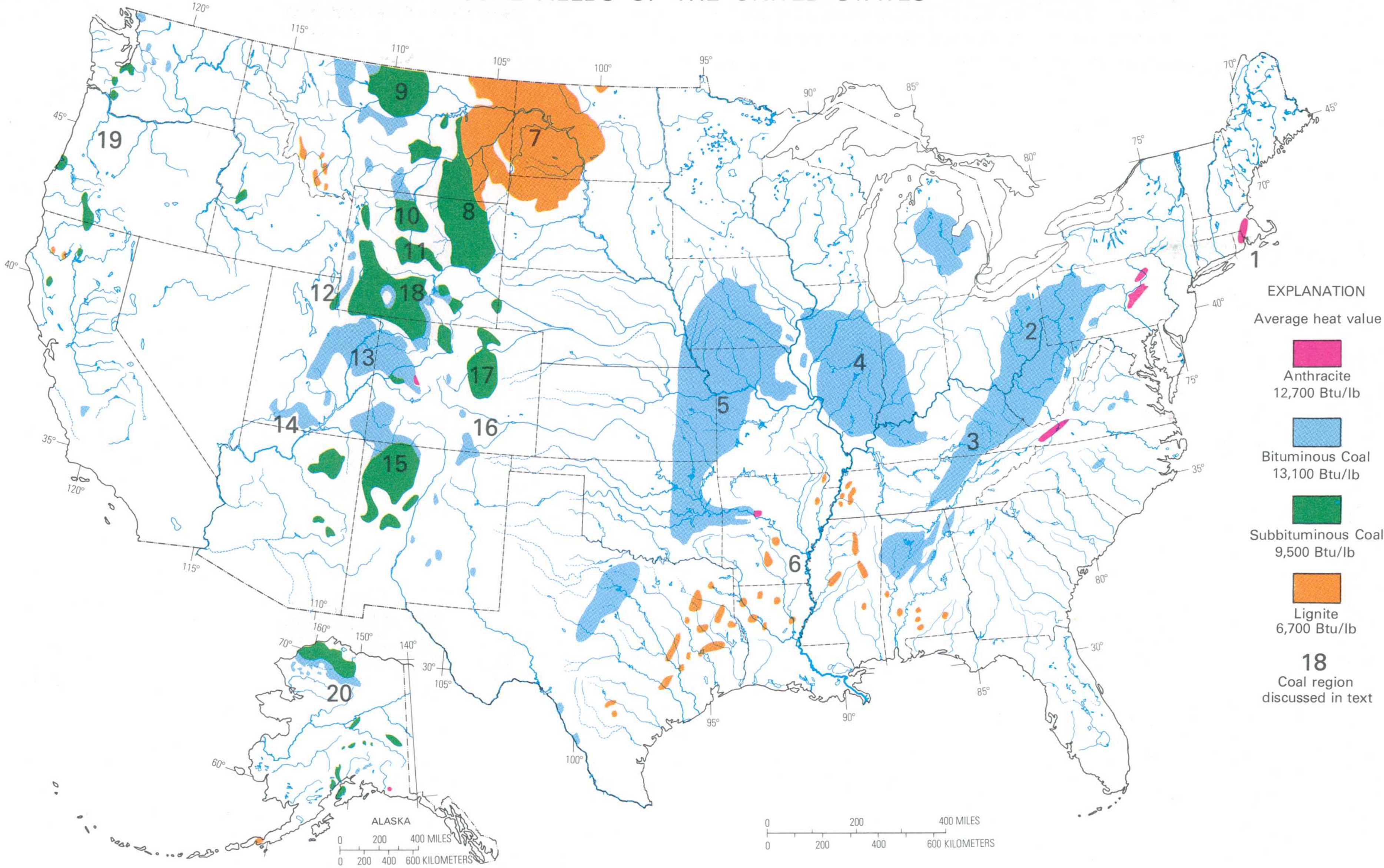
The graph shows the State-by-State distribution of the 1.1 trillion-ton resource. Sixty percent is concentrated in Montana, Illinois, Wyoming, Alaska, and North Dakota. An additional 23 percent is located in Colorado, West Virginia, Pennsylvania, and Kentucky.

Of the total tonnage, 1 percent is anthracite, 48 percent bituminous, 34 percent subbituminous, and 17 percent lignite. Over 80 percent of the anthracite and bituminous coal is in the Eastern United States, whereas 99 percent of the subbituminous coal and lignite occurs in the Western States. The heat content differs significantly for these four kinds of coal. This must be considered when evaluating existing coal tonnages. For example, the total Montana resource of 198 billion tons is 45 percent larger than the 137 billion in Illinois. However, the total Btu content for the subbituminous coal and lignite in Montana is almost 10 percent less than that of the Illinois bituminous coal resource. Similarly, North Dakota lignite ranks fifth in tonnage but ninth in Btu content. Nearly 2 tons of North Dakota lignite are required to produce the Btu's available from 1 ton of Kentucky bituminous coal.



TONNAGE AND HEAT CONTENT OF COAL RESOURCES HAVING POTENTIAL FOR SYNFUEL DEVELOPMENT

COAL FIELDS OF THE UNITED STATES



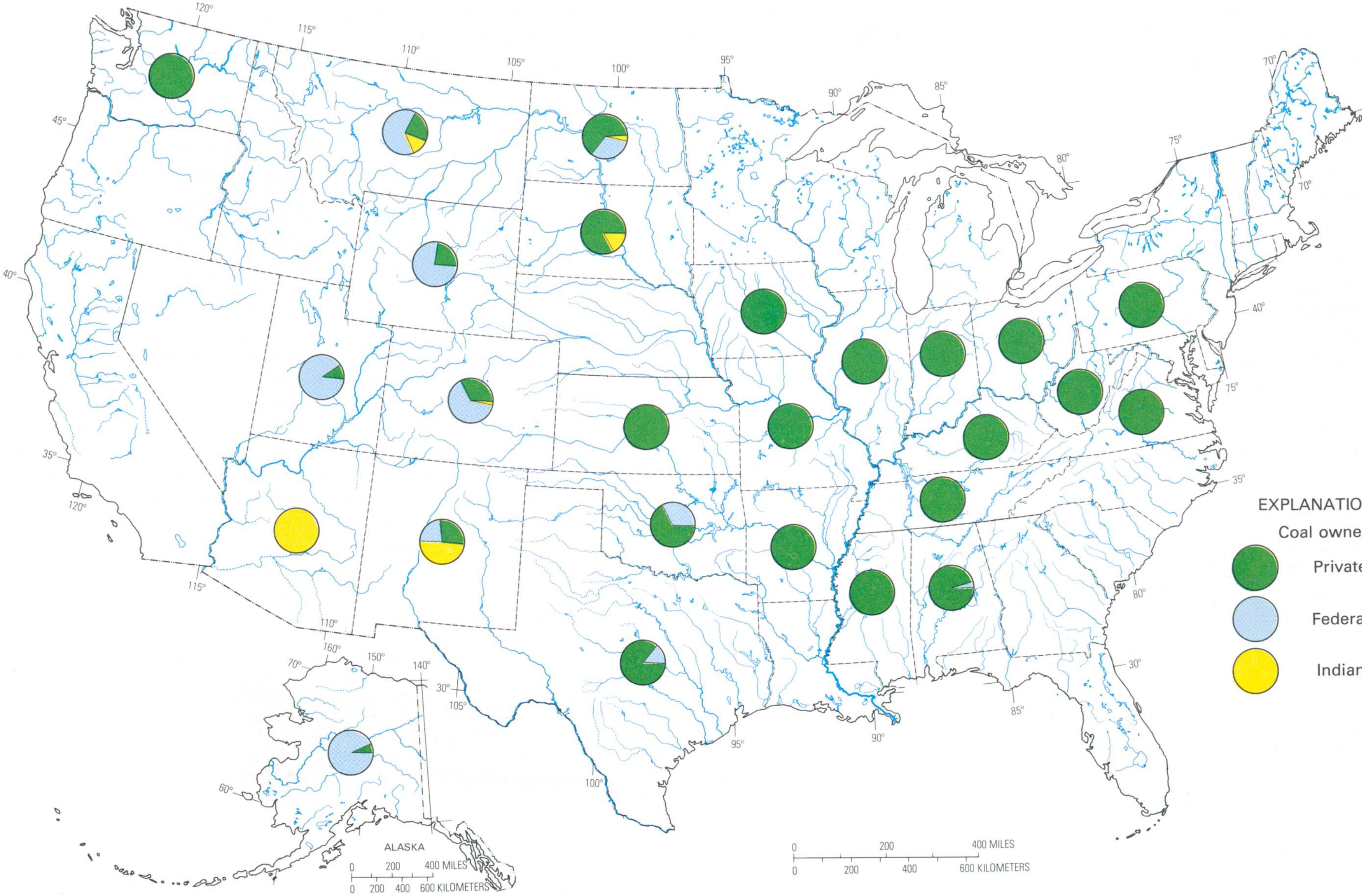
Who owns the coal?

FIFTY-FOUR PERCENT of the U.S. coal reserves lie west of the Mississippi River. In aggregate, ownership of this western coal is 27 percent Federal under Federal lands, 34 percent Federal under privately owned surface, 26 percent private, 8 percent Indian, and 5 percent State. Complex patterns of coal ownership occur in many areas of the West. Such patterns have resulted from State and railway land grant procedures, coupled with laws which provided for severance of the surface ownership rights while reserving to the Federal Government the coal and other mineral rights. State ownership of coal typically consists of two or four sections per township.

In the East, most coal is privately owned. A few States, most notably Alabama, contain a relatively large percentage of Federal coal under privately owned land. In general, Federal coal ownership in the East consists of small tracts, from 40 to 320 acres, interspersed within private holdings.

Bell Ayr South coal mine near Gillette, Wyoming, 1975.

PRINCIPAL OWNERSHIP OF MAJOR COAL RESOURCES



EXPLANATION

Coal ownership

Private

Federal

Indian

What are the major geologic constraints to synfuel production from coal?

LARGE-SCALE USE OF COAL to make synfuels will require expansion of coal production, including development of new deposits. This expansion faces a number of potential geologic constraints that differ from region to region. The constraints for mining coal for synfuel production are very similar to those for ordinary coal mining.

Inadequate coal bodies

A projected standard sized synfuel plant will be designed to produce 50,000 barrels of oil or 250 million standard cubic feet of gas per day. Depending on the type of coal and the type of synfuel conversion process, such a plant will require about 20,000 to 40,000 tons of coal per day. Under average conditions of conventional mining and operation, this means that about 12 million to 24 million tons of coal reserves will be needed to supply each plant for 1 year. Over the estimated 30-year life span of a plant, between 360 million and 720 million tons of coal reserves will be required. Such large tonnages in single blocks are unavailable in certain coal regions.

Thin or discontinuous coal beds

In some coal regions, a substantial part of identified resources is in beds too thin to meet the present requirements of large-scale mechanized mining. This includes layers of bituminous coal and anthracite less than 28 inches thick and subbituminous coal and lignite less than 5 feet thick.

Excessive depth of coal

Resources in many coal regions extend to depths greater than 3,000 feet. These resources are beyond the range of current domestic mining practices.

Complex structure of coal-bearing rocks

In many coal regions, the coal-bearing beds have been subjected locally to severe folding and faulting. The mining of highly deformed coal deposits will require detailed geologic investigations and, perhaps, special mining techniques to avoid high costs and delayed production schedules that would adversely affect large-scale synfuel productions.

Thick glacial deposits or permafrost

In many regions, coal beds are partly covered by thick glacial deposits or glacially derived silts. Such deposits interfere with surface mining, because of increased overburden, and with underground mining, because of their commonly unconsolidated permeable character. Development of coal resources will be locally constrained by such deposits in parts of the Eastern (4), Western (5), Northern Appalachian (2), Fort Union (7), Powder River (8), and North Central (9) regions. Moreover, development of coal deposits throughout the Alaskan (20) region could well be constrained by overlying thick permafrost.

Aquifer disruption

Coal beds are valuable aquifers in several regions. Mining would remove part of the aquifer and could disrupt some supplies and degrade water quality.

Underground mining hazards

Underground mining hazards are common in many regions because of the poor physical characteristics of rocks surrounding the coal and the occurrence of exceptionally thick (20-150 feet) coal beds. Such hazards may present regional problems for underground extraction of coal in poorly consolidated rocks of the Fort Union (7) and Powder River (8) regions. In fact, many mining experts are of the opinion that the thick beds of these regions cannot be deep mined with high recovery rates unless new innovative mining techniques are developed. However, thick coal beds in the Fort Union (7) and Powder River (8) regions may be suitable for in-situ gasification at depths below about 500 feet where fractures and joints are minimal.

Post-mining hazards

The principal post-mining hazard associated with coal mining is the subsidence of beds that overlie mines. Subsidence is common locally in many coal areas, but is currently a major regional problem only in the Pennsylvania anthracite fields of the Northern Appalachian region (2). However, it is likely that widespread subsidence will occur in any coal region if thick beds are extracted at high recovery rates.

Acid mine drainage

Thousands of miles of streams are degraded by acid mine water in the Northern Appalachian (2) and Eastern coal regions (4). This pollution results whenever iron sulfide minerals in coal beds and spoil areas are exposed to oxygen in flowing water. The minerals are oxidized, forming sulfuric acid. Almost all coal beds contain iron sulfide minerals. However, the contents differ from bed to bed, as does the ground-water flow. Therefore, different regions have different potentials for acid mine drainage.

Coal quality

The quality of coal differs from deposit to deposit and from bed to bed. It is known that certain coal-quality parameters greatly affect the utility of coal for various synfuel processes. The important parameters include: content of moisture and ash, coking tendencies, heat content, the amounts and forms of sulfur, and the major and trace element chemistry of the coal and coal ash. Knowledge of such properties in coal deposits is needed both to prevent adverse impacts and to facilitate synfuel production. However, at the present time there is insufficient data on coal-quality parameters for the coal in the regions to warrant their inclusion in the matrix.

The accompanying matrix shows which of the nine major constraints to synfuel production occur in the Nation's 20 principal coal regions. Most constraints are local in extent and will not greatly affect development of the resources. However, coal production could be seriously affected where the constraints are regional in scope or where several local constraints occur in combination. Lack of large regional blocks of coal or the presence of region-wide permafrost will both likely preclude synfuel development.

POTENTIAL GEOLOGIC CONSTRAINTS TO SYNFUEL DEVELOPMENT IN PRINCIPAL COAL REGIONS

Which regions have the fewest geologic constraints on developing synfuels from coal?

BASED ON EVALUATION of geologic constraints, the accompanying map shows 10 coal regions that have the best potential for synfuel development. The following section briefly describes the development potential of each region without attempting to rank their relative importance. It is also important to note that some coal regions excluded from this listing might sometime be deemed useful resources for synfuel production. As prices of petroleum products increase, changes occur in the definition of what constitutes a useable coal resource.

Northern Appalachian region

The coal resources of the Northern Appalachian region (2) are adequate to support several synfuel plants. The major consideration is the difficulty in controlling acid mine drainage in an area already seriously affected. Additional constraints are: (1) Much of the better coal is of a grade suitable for metallurgical use and is already committed to the steel or power industries; and (2) the coal necessary to support a 30-year life for each synfuel facility will require a large number of surface mines or several large underground mines.

Southern Appalachian region

All statements given for region 2 also apply to the Southern Appalachian region (3) except the reference to acid mine drainage.

Eastern region

The Eastern region (4) contains adequate resources for supporting several synfuel facilities. Acid mine drainage, however, is already a serious problem in many places. Another constraint is that the coal areas of the region include some of the best farmland in the Nation. Furthermore, much coal is already committed to the metallurgical and power industries. Most coal extraction for synfuels probably would be from deep mines.

Fort Union and Powder River regions

The Fort Union and Powder River (7 and 8) regions contain large resources of subbituminous coal and lignite in thick beds that are sufficient to support several synfuel facilities. Aquifer disruption could be an important constraint in the Powder River Basin and a local one in the Fort Union region. Thick coal beds in both regions would be difficult to mine underground. Because of large coal resources, both regions are attractive for synfuel development.

Hams Fork region

Although small in area, the Hams Fork region (12) contains sufficient resources for potential synfuel development. The principal drawback is that coal resources are largely committed. Coal can be both surface and underground mined.

Uinta, Southwestern Utah, and Green River regions

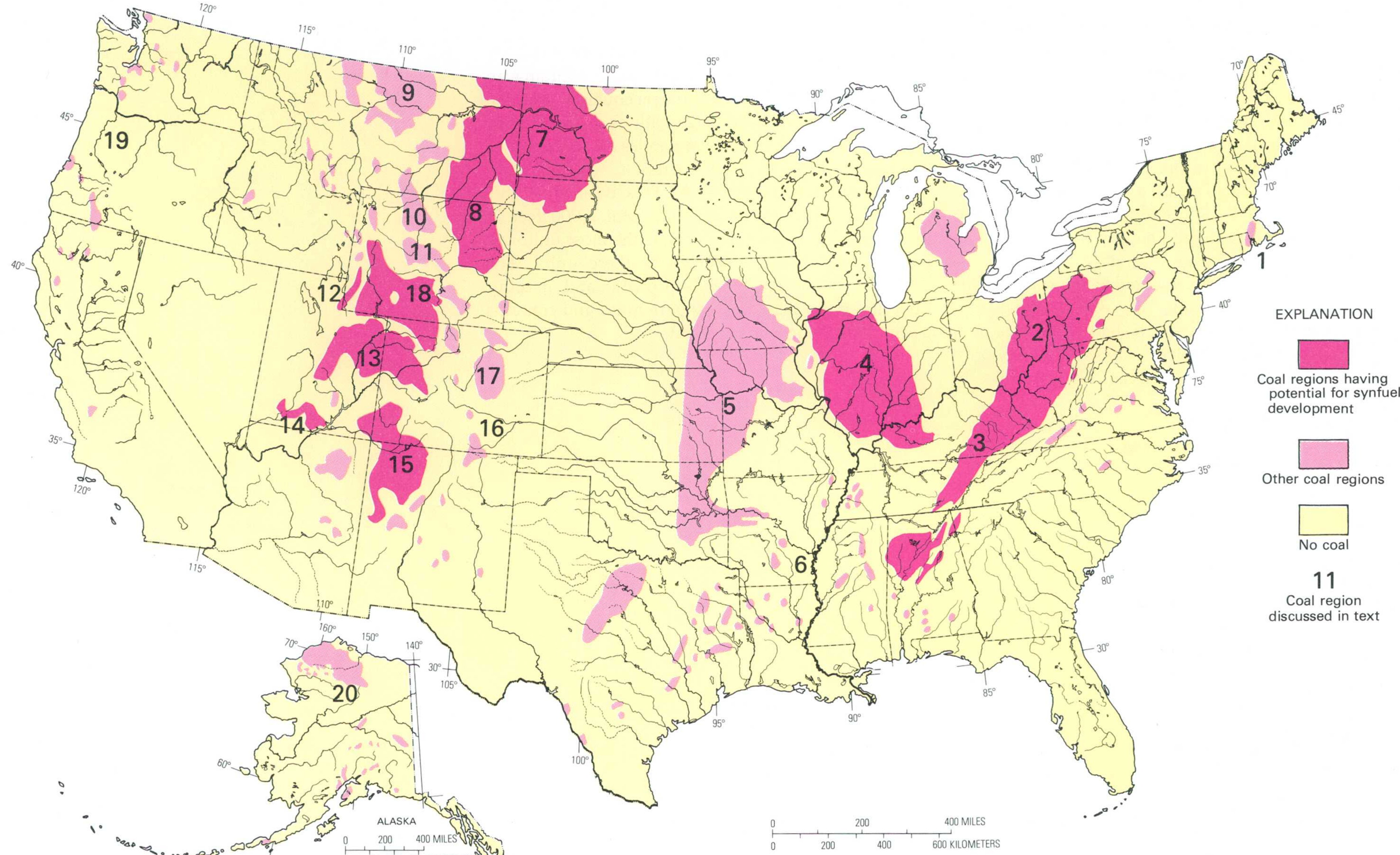
The large Uinta (13), Southwestern Utah (14), and Green River (18) regions contain sufficient coal resources for a number of synfuel facilities, but some of the coal is already committed. A principal constraint to the rapid siting of synfuel facilities is a lack of site-specific geologic knowledge. The coal can be both surface and underground mined.

San Juan River region

The San Juan River region (15) contains sufficient coal resources to supply several synfuel facilities. Part of the coal is already committed to powerplants. The coal can be both mined on the surface or underground.

This assessment highlights the regions where adequate coal resources exist and can be efficiently mined. The first requisite of siting a synfuel plant is that it must be within economic reach of a hydrocarbon resource. However, many additional factors will affect the siting of synfuel plants. For example, adequate water resources must be obtainable (see section on "Water Resources"). In addition, numerous Federal, State, and local guidelines must be met.

COAL RESOURCES MOST LIKELY TO BE USED FOR SYNFUEL PRODUCTION



Where are the oil shale resources and how much is there?

LARGE AREAS of the United States contain oil shale deposits. The richest deposits, however, are found in the Green River Formation in Colorado, Utah, and Wyoming.

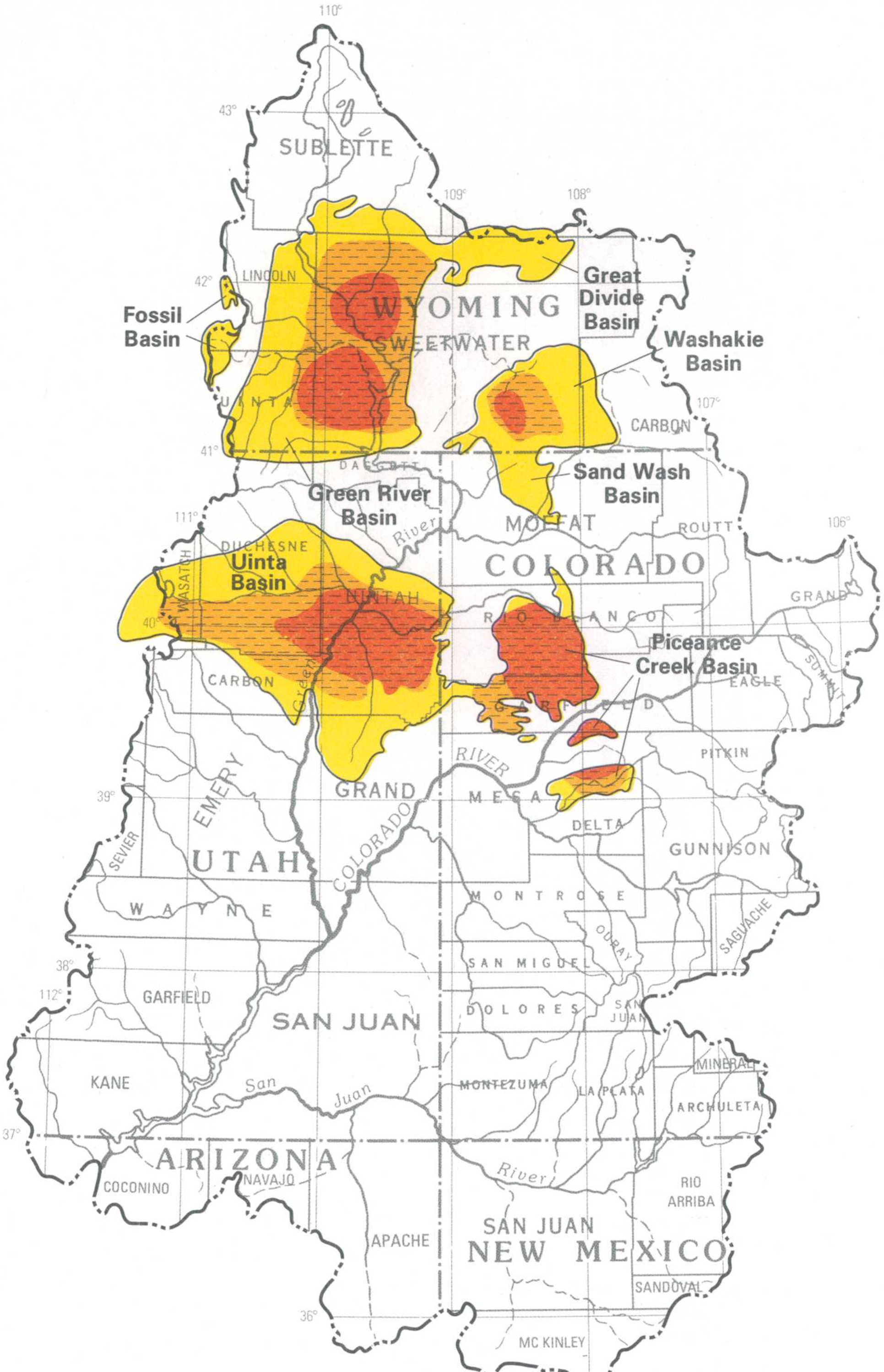
Colorado's Piceance Creek Basin contains 85 percent of this western high-grade deposit that is, in reality, more similar in nature to limestone than to shale. The kerogen-rich shale of this basin contains an equivalent of about 10 times more oil than has been consumed nationally to date. Moreover, in 1974, total oil and gas consumption in the United States was equivalent in Btu content to 12½ billion barrels of oil. At this rate of use, and assuming 100 percent recovery of all the shale oil, the Piceance Creek Basin deposits would supply the needs of the United States for 100 years.

The comparisons are presented for purposes of illustrating the magnitude of energy resources available in the Green River oil shale. However, it is important to note that under today's technology only part of the total oil resource is economically recoverable.

The accompanying map shows (1) that part of the Green River Formation containing oil shale deposits, (2) that part of the deposits, 15 feet or thicker, which will yield 15 gallons of oil or more per ton of rock, and (3) that part 10 feet or thicker, which will yield 25 or more gallons per ton.

Deposits in the 15 gallons or more category underlie 10,000 square miles and contain an estimated 2 trillion barrels (1 barrel equals 42 gallons) of oil. The richest deposits (25 gallons or more) have an extent of about 5,000 square miles and account for 730 billion of the 2 trillion barrels.

In the heart of the Piceance Creek Basin, the shale occurs in seven rich zones that total 2,000 feet in thickness. The Mahogany Zone is the most uniformly rich and areally extensive of these units. The Mahogany Zone also extends into Utah and, in total, underlies more than 6,000 square miles and contains about 250 billion barrels of oil.



PRINCIPAL OIL SHALE DEPOSITS

EXPLANATION

Green River Formation containing oil shale

Shale 15 or more feet thick and averaging 15 or more gallons of oil per ton

Shale 10 or more feet thick averaging 25 or more gallons of oil per ton

Upper Colorado River drainage basin boundary

0 100 200 MILES

0 100 200 300 KILOMETERS

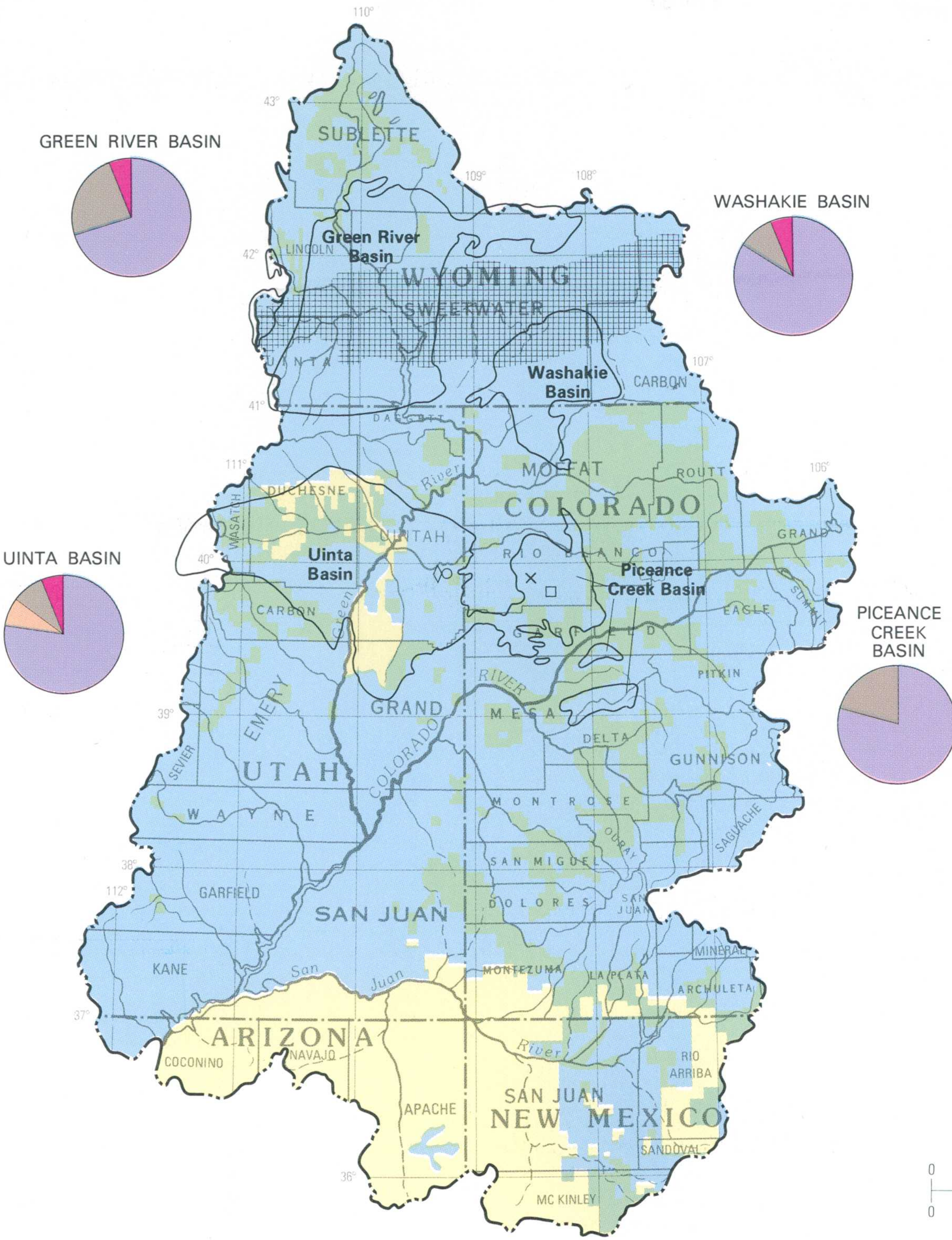
Who owns the oil shale?

THE FEDERAL GOVERNMENT holds the mineral rights to most of the western oil shale and also owns about 70 percent of the associated land surface. The remaining surface ownership is mostly private, accounting for 21 percent of the oil shale land in Colorado, 9 percent in Utah, and 24 percent in Wyoming. In Utah, 8 percent of the oil shale land and mineral rights are Indian owned, whereas in both Wyoming and Utah about 6 percent is State land. It must be noted, however, that Utah has laid claim to 150,000 acres of Federal oil shale land including the area comprising oil shale tracts U-a and U-b.

To date, four Federal tracts have been leased, two each in Utah and Colorado. In addition, several experimental or demonstration projects are in progress on private and State land. Also, about 20 other oil shale development projects are now being contemplated, mostly on private land.

Cliffs of oil shale above meanders along the White River, Rio Blanco County, Colorado.

OWNERSHIP OF OIL SHALE LAND AND MINERAL RIGHTS



EXPLANATION

Land ownership, 1970

Federal

Grid indicates predominately Federal land with numerous interspersed tracts of private, state, municipal, and county

Indian

Private, state, municipal, and county

Oil-shale mineral rights ownership, 1970

State — Federal — Private — Indian

Upper Colorado River drainage basin boundary

Federal lease tracts

× C–a

□ C–b

◊ U–a

○ U–b

0 — 100 — 200 MILES

0 — 100 — 200 — 300 KILOMETERS

What are the major geologic constraints to synfuels production from oil shale?

SEVERAL GEOLOGIC CONDITIONS may constrain development of a shale oil industry. Some of these conditions are local, whereas others occur over entire regions. A general problem with all the deposits is the limestone nature of the rock. This property of the rock increases the amount of energy required for high-temperature retorting to recover the oil.

Initial development of oil shale will probably be limited to areas having large amounts of the high-grade resources. This immediately restricts the prime locations for development to far less than the area of the Green River Formation that contains oil shale.

Another constraint is that the central areas of the oil shale basins have a thick rock mantle overlying the resource deposits. In some areas, this may prevent development. In other areas, it will add considerably to the expense of extracting the oil and will severely decrease the recoverable resource.

Saline minerals occur in the oil shale in the depositional centers of the Green River Basin, Wyoming; the Piceance Creek Basin, Colorado; and to a lesser extent, the Uinta Basin, Utah. In Wyoming and Colorado, thick beds of sodium chloride and highly soluble sodium carbonate minerals such as nahcolite and trona are interspersed in hundreds of feet of oil shale. In addition, analcime, a sodium aluminum silicate, occurs in all three States; and dawsonite, a sodium aluminum carbonate, occurs in the Colorado shale. At a given location, the presence of any of these associated minerals adds to the energy requirements for retorting the oil shale at high temperatures.

In the Piceance Creek Basin, ground water has leached much of the soluble saline minerals from the beds throughout several hundred square miles. Locally, entire beds have been leached and a honeycombed framework of permeable material has formed. The leached beds now constitute an aquifer hundreds of feet thick in the middle of the basin. This aquifer is estimated to contain millions of acre-feet of water, much of which is fresh. In some areas, however, the water is saline, and in certain locations, it contains appreciable concentrations of fluoride, boron, and hydrogen sulfide. If such waters are not disposed of properly, the constituents could be harmful to the environment.

Two prominent fracture systems and several of lesser magnitude occur throughout the oil shale area. Faults locally displace the richer oil shale in both the Uinta and Piceance Creek Basins. The fractures and faults could cause problems in underground mining operations and could also interfere with in-situ recovery of oil.

Stratified layers of oil shale are visible on this cliff face in the Piceance Creek Basin.

Where are the most likely areas for oil shale development?

THE INITIAL DEVELOPMENT of the oil shale resource will probably be limited to areas having amounts of high-grade shale sufficient for sustaining production of 50,000 barrels of oil per day for 30 years. Based on present concepts of technology, the suitable shale deposits will be at least 10-feet thick and will average at least 25 gallons of oil per ton. The location of such deposits is shown on the facing map. It is important to note that Federal leases C-a and C-b in the Piceance Creek Basin, Colorado, as well as leases U-a and U-b in Utah, are within such areas.

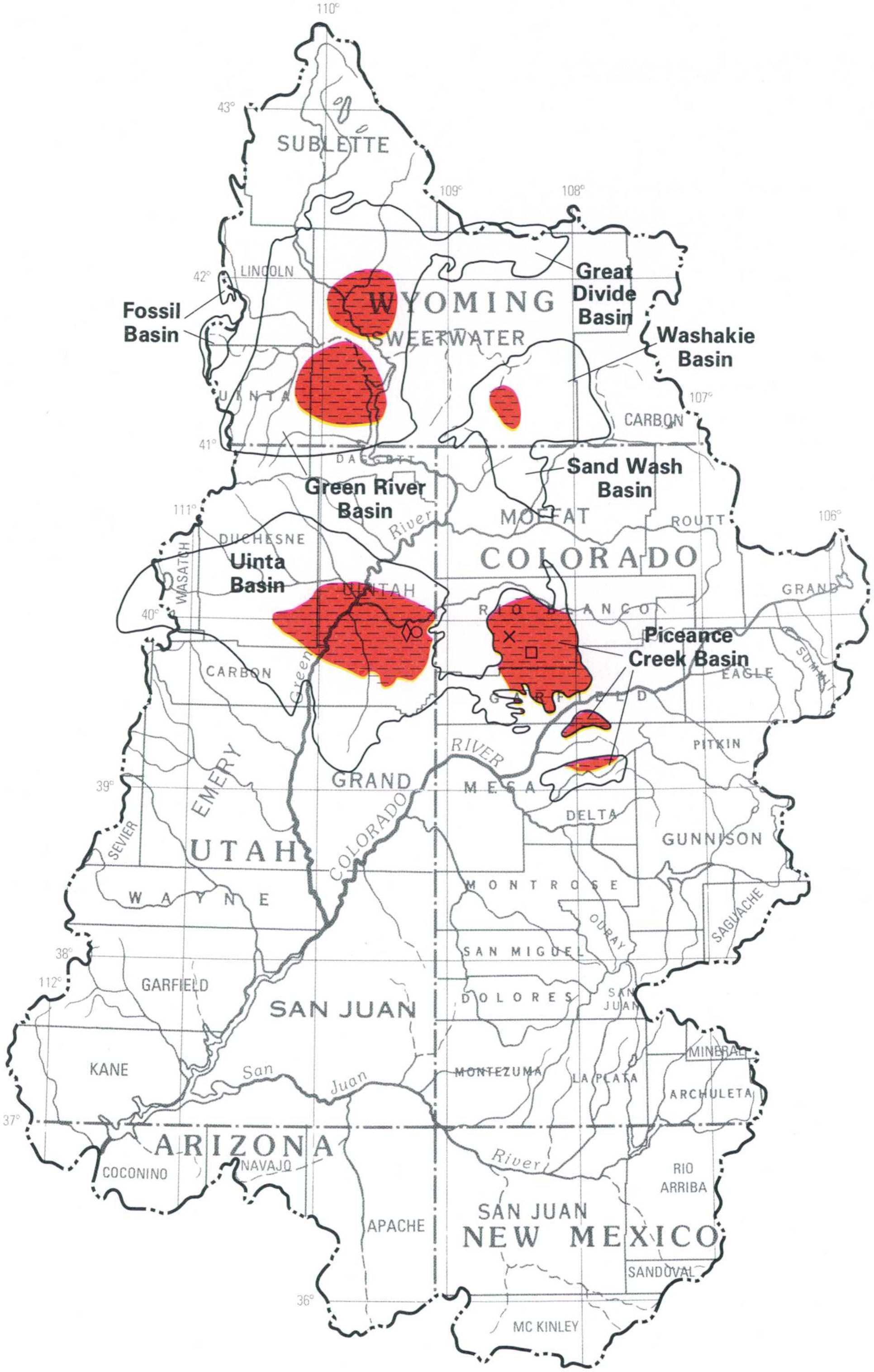
Within the areas identified on the facing map, the ideal deposits for synfuel development would (1) be above the water table, (2) have thin overburden, (3) be unfractured, and (4) be lacking in unwanted accessory minerals and harmful trace elements. No such areas exist; therefore, evaluation and trade-offs will be necessary. The following describes what the trade-offs might be in two areas:

1. In the Piceance Creek Basin, much of the area with the thickest and richest shale also contains a thick aquifer, the thickest zone of saline minerals, and the greatest amount of overburden. The thick overburden is definitely a considerable constraint. However, certain of the saline minerals might be marketable. Nahcolite, the naturally occurring sodium bicarbonate mineral, has potential value in scrubber technology for industrial stack gases. In addition, the dawsonite may have by-product value as a source of soda ash and elemental aluminum.

The associated ground water will have to be pumped during either mining or in in-situ retorting of the shale. The ground-water pumping may be a mixed blessing. Over much of the Piceance Creek Basin the quality of the ground water is quite good, with low quantities of dissolved solids and low levels of potentially harmful substances. Such water represents a resource for processing the shale, especially for cooling water and for moisturizing spent shale. However, in certain areas, the ground water is highly saline, with dissolved solids in excess of 10,000 parts per million (about one-third that of sea water). In these areas and where potentially toxic substances occur, the water will be a major treatment or waste disposal problem rather than a resource. However, such water could possibly be disposed of by injecting it back into the aquifer.

2. Local faulted areas in the Piceance Creek Basin would present problems for utilizing conventional mining and modified in-situ recovery techniques. However, in these areas, the oil shale is moderately thick and rich, and the overburden has maximum depths of a few hundred feet. Such deposits are suitable for surface mining because of the fairly thin overburden coupled with a ratio of overburden depth to ore thickness less than 1:1. A surface-mining approach would essentially eliminate the likely problems associated with underground mining and in-situ conversion. It also would minimize mining problems associated with ground water. An added bonus would be a 90-percent or more recovery of the oil resource in contrast to much lower recoveries attainable with other extraction methods.

OIL SHALE DEPOSITS MOST LIKELY TO BE USED FOR SYNFUEL PRODUCTION



EXPLANATION

Green River Formation containing shale 10 or more feet thick, averaging 25 or more gallons of oil per ton

Upper Colorado River drainage basin boundary

Federal lease tracts

× C-a

□ C-b

◊ U-a

○ U-b

0 100 200 MILES

0 100 200 300 KILOMETERS

What are other potential synfuel resources besides coal and oil shale?

OTHER POTENTIAL SYNFUEL RESOURCES include black Devonian shales, tar sands, and oil shale of the Phosphoria Formation in Montana.

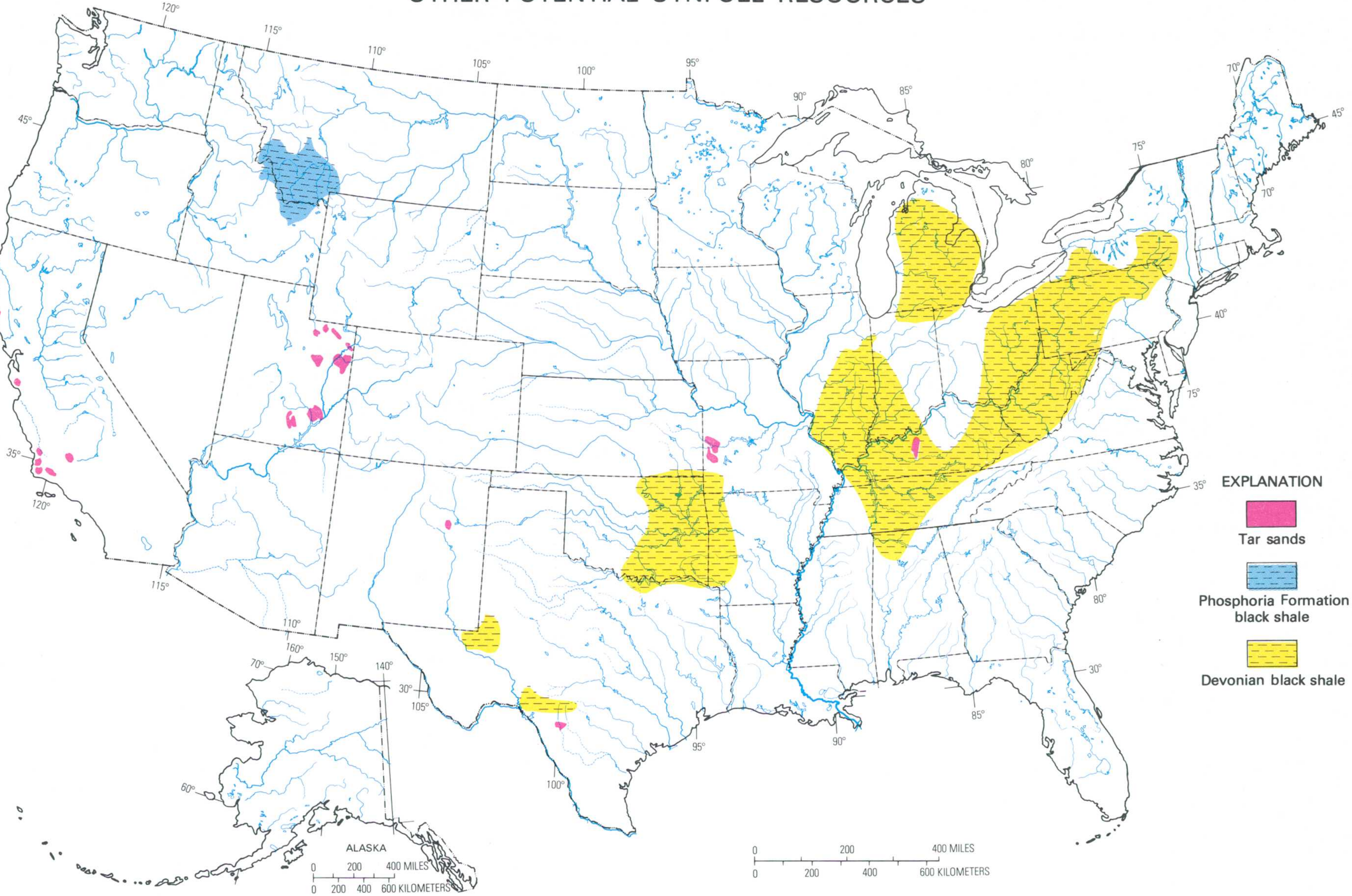
Devonian black and dark brown shales rich in organic detritus are known by many names in the Appalachian, Illinois, and Michigan Basins. In contrast to western oil shales, the eastern Devonian shales contain more natural gas, but will yield less oil per unit volume of rock. It is important to note that the gas in all Devonian shale is locked tightly in the rock, and consequently, only small amounts are economically recoverable by present technologies.

About 160,000 square miles of the Appalachian Plateau are underlain by Devonian black shales ranging in thickness from less than 10 feet in southern Tennessee to an aggregate of more than 1,400 feet in northeastern Pennsylvania. The volume of the shales exceeds 12,600 cubic miles. The oil content of the shales is highest, 15 to 20 gallons per ton, in central Kentucky and Tennessee. It decreases to the northeast and is less than 1 gallon per ton in outcrops along the east side of the Allegheny Plateau of central Pennsylvania. Estimates of the gas in the Appalachian Devonian shale are as great as 3 million billion standard cubic feet. In the Michigan Basin, the Devonian shale ranges in thickness from 250 to 600 feet, and the oil content ranges from 1 to 15 gallons per ton. Scant data suggest that the gas per unit volume of shale may closely approximate the value for the Appalachian Basin. In the Illinois Basin, the Devonian shales range in thickness from 150 to 450 feet, and the oil content is as much as 20 gallons per ton.

Tar sands are sandstones with pore spaces containing viscous to solid petroleum which cannot be recovered by conventional methods. World tar-sand resources are estimated to contain more than 2 trillion barrels of oil, most of it in Canada and Venezuela. The United States has an estimated resource of 29 billion barrels of tar sand oil, most of it in Utah. At present there is no commercial production of tar sand oil in the United States, although oil is produced commercially from similar deposits in the Saskatchewan Province of Canada.

Another significant potential source of oil from shale is the organic-rich Phosphoria Formation in Idaho and western Montana. In southwest Montana, as much as 24 gallons of oil have been extracted from a ton of shale. However, the oil shale occurs in structurally complex folded and faulted mountains, a situation that makes the mining or processing of large quantities very difficult.

OTHER POTENTIAL SYNFUEL RESOURCES



What are the water requirements of synfuel production?

THE WATER REQUIREMENTS of different synfuel production processes are an important consideration in the development of synfuel plants. Even for a particular process, the water requirements will vary depending on the options selected for process application and cooling. Savings in water use usually entail additional costs and sometimes a decrease in the overall efficiency of the conversion process. The accompanying graph shows estimated ranges of water requirements for major synfuel processes and selected other uses of coal. The basis of comparison is the coal input required to produce 50,000 barrels of synthetic oil, or the equivalent input of coal for the other uses.

Coal gasification

Published values for water use in coal gasification vary widely. Key factors affecting water requirements are:

- Coal composition. Consumption of water for waste-gas cleaning increases with sulfur content of coal and generally decreases with increasing carbon content.
- Cooling methods. Nearly two-thirds of the water used is consumed as cooling water. Therefore, alterations in cooling methods can greatly change the net water requirements. For example, the low estimate in the accompanying graph for coal gasification reflects the case where 80 percent of the waste heat is removed by dry cooling. This includes direct dissipation of heat from hot-process streams to the surrounding atmosphere. In contrast, the high estimate for coal gasification corresponds to 50 percent dry cooling. Dry cooling systems in general are more capital intensive and expensive than wet cooling systems. However, as the cost of water increases, dry cooling may become more economical, and water consumption may decrease.
- Product gas heating value. The conversion of energy in coal to energy in gas becomes less efficient as the Btu content of the product gas increases. The less efficient the conversion, the greater the generation of waste heat and, therefore, the greater the volume of cooling water required for a given input of coal.

Coal liquefaction

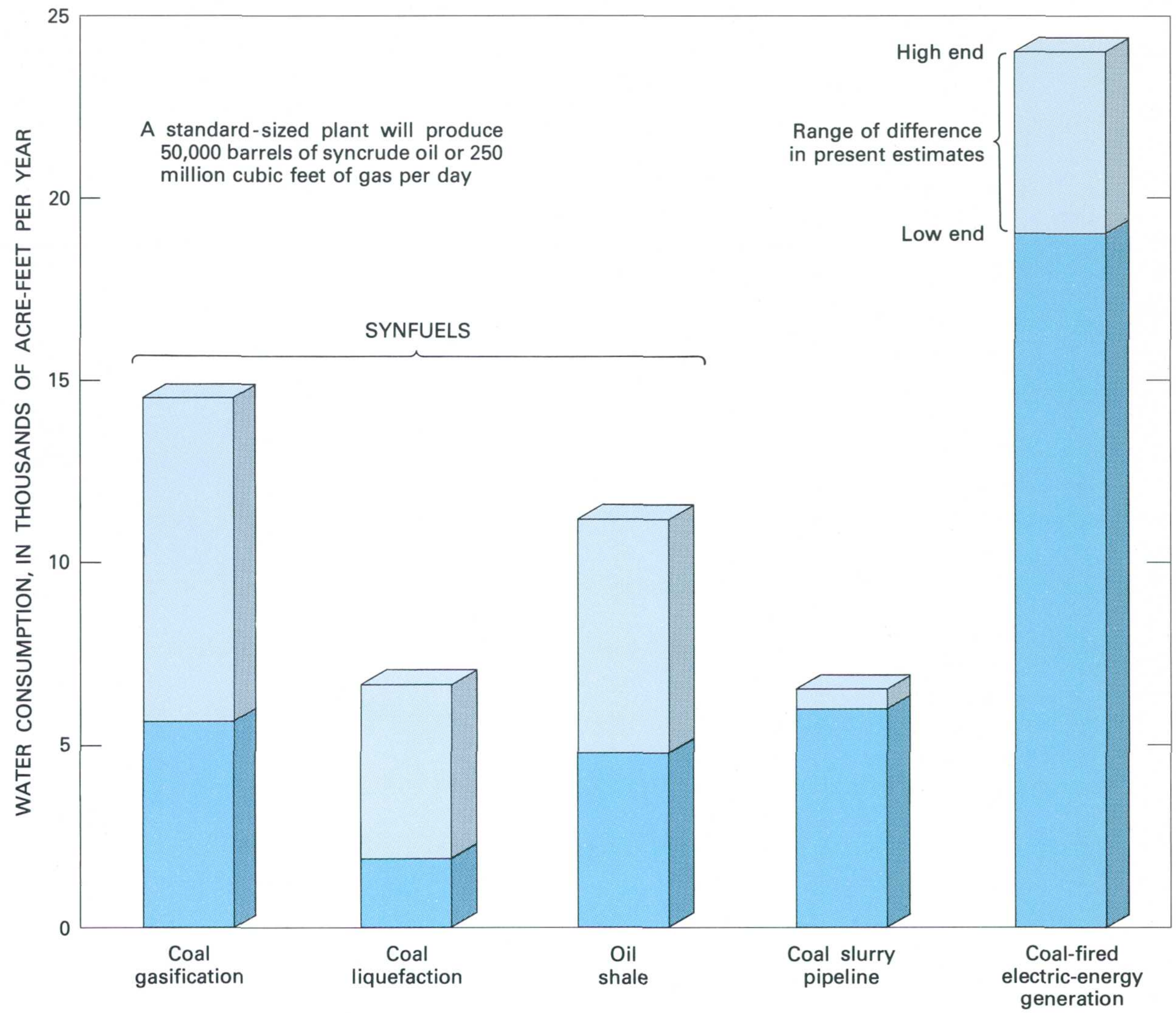
Water use in coal liquefaction is primarily influenced by the same three factors that influence water use in coal gasification. However, as shown on the graph, the water requirements for coal liquefaction are generally smaller.

Oil shale conversion

- Cooling methods. The water required for dry and wet cooling methods is much the same as described for coal gasification.
- Spent-shale disposal. In above-ground processing, water use for spent-shale disposal accounts for nearly 50 percent of the total water used. Underground (in-situ) oil-shale processing eliminates this potential demand and, therefore, requires much less water.

The graph illustrates that estimated water consumption in a coal-gasification plant is about twice that for a coal-liquefaction plant using the same input of coal. Water consumption in the above-ground production of shale oil is generally estimated to be between these values. However, developments of in-situ technology may soon lower the requirements for shale oil production.

From a resource development viewpoint, it is interesting to compare the water requirements for producing synfuels from coal with those for processing equivalent inputs of coal in other ways. For example, in comparison to standard-sized coal conversion plants, there is a low water requirement for transporting coal by slurry pipeline. In contrast, the same coal input would supply a 2,000-MW thermal electric plant and create a water requirement considerably greater than those estimated for producing synfuels.



ESTIMATED WATER CONSUMPTION FOR PRODUCING USEABLE SYNFUEL PRODUCTS IN STANDARD-SIZED PLANTS (DEFINED ABOVE), AND FOR SLURRY PIPELINE AND ELECTRIC-ENERGY GENERATION HAVING COAL IMPUT EQUIVALENT TO THAT FOR A STANDARD COAL-CONVERSION PLANT.

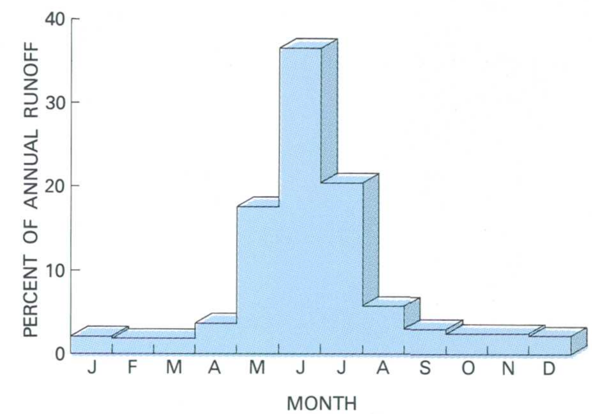
How are the Nation's surface-water resources distributed?

THERE IS ABUNDANT SURFACE WATER in the Nation, but the resources are distributed unevenly over both space and time.

The facing map shows the variations in average annual runoff of surface water for the United States. In the eastern half of the Nation, annual runoff, which is a measure of stream-water outflow, varies but is fairly uniform over large area. In the West, however, particularly in the mountain regions, annual runoff differs greatly from place to place. For example, in Colorado and western Wyoming, average annual runoff can range from less than 1 inch to more than 20 inches within a distance of less than 50 miles. This difference results primarily from topographic influences; the greater depth of runoff per unit area occurs in the mountains.

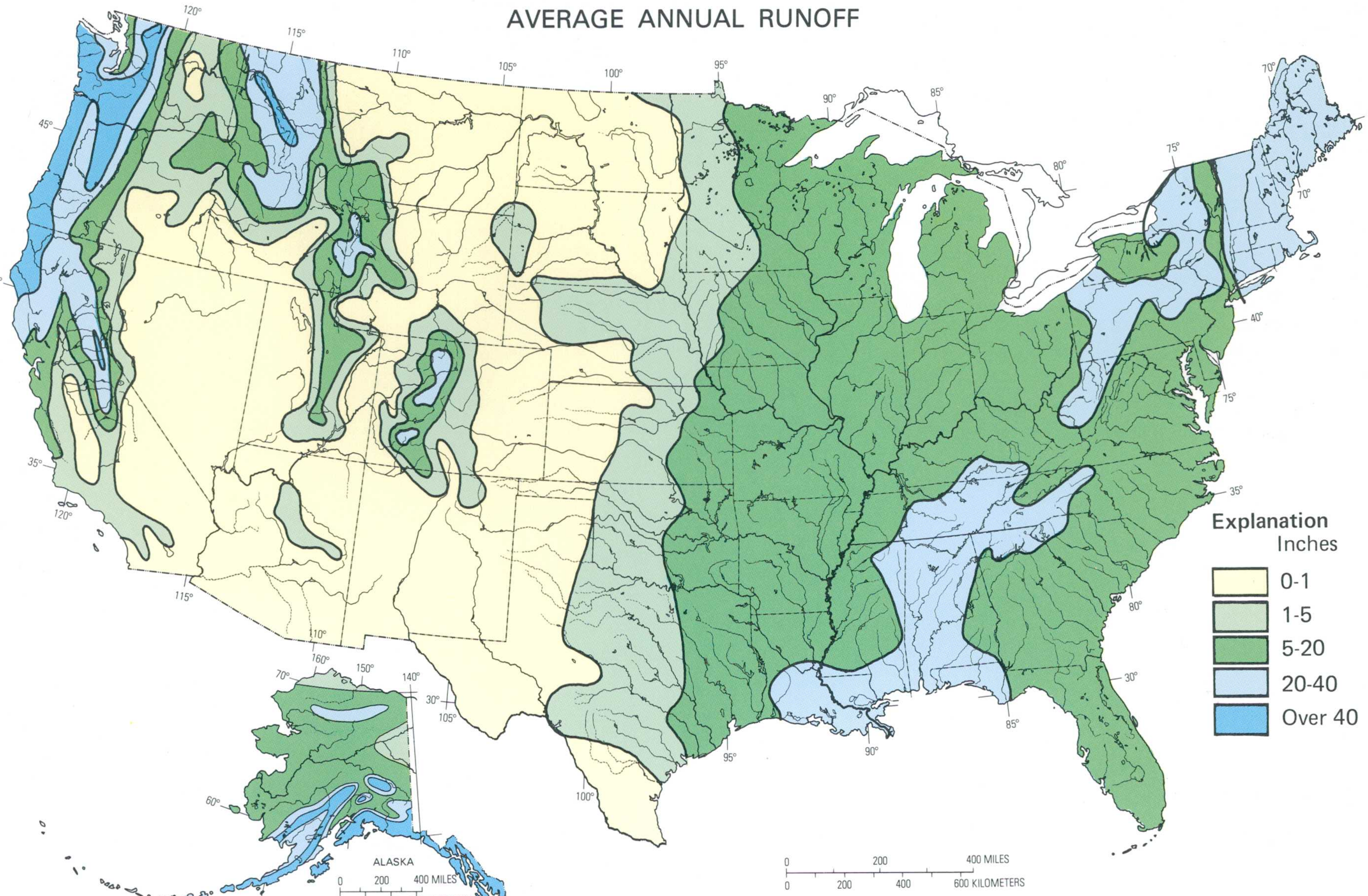
Streamflow variations with time can be short term, seasonal, or long term. Seasonal variations can be marked. For example, June runoff in Clarks Fork of the Yellowstone River is about 18 times the monthly runoff from October to March. This results because precipitation is stored as snow during winter and then melts and runs off rapidly during the subsequent spring thaw. Such a variation illustrates that variability of streamflow is an important consideration in the planning of energy-resource development.

There are means of alleviating problems arising from low average runoff and highly variable streamflow. Where reservoir space can be made available (at the surface or underground), water can be stored during periods of excessive runoff for later release and use. Morever, in some situations, water can be imported into local, water-deficient areas.



Long-term average monthly runoff, Clarks Fork Yellowstone River near Belfrey, Montana

AVERAGE ANNUAL RUNOFF



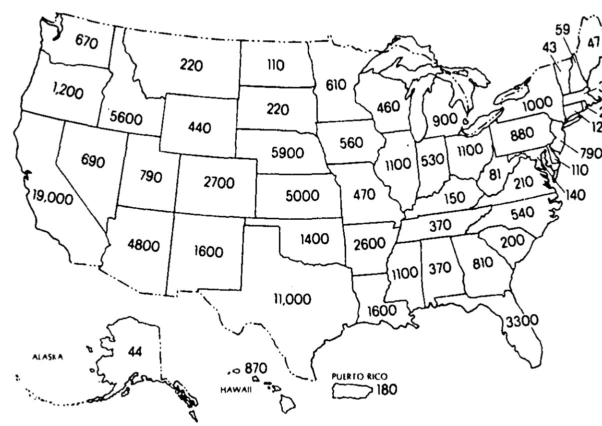
How are the Nation's ground-water resources distributed?

GROUND WATER is stored in aquifers, which are bodies of rock permeable enough to carry or yield water in useful quantities. Aquifers differ in thickness, extent, and depth of occurrence. The Nation's ground-water resource is enormous—it is our largest freshwater resource in terms of volume in storage. Underlying the conterminous United States are about 200 billion acre-feet (65 quadrillion gallons) of ground water within a few thousand feet below the land surface.

About one-third of the Nation's annual streamflow is supplied by ground water that emerges as natural springs and seeps to stream channels. In turn, surface water can be a major source of ground-water recharge. For many streams, much of the flow during the dry months comes from ground water. In years of below-normal precipitation, all of the dry season streamflow may come from ground water. Ground water, therefore, is important to the continuity of streamflow.

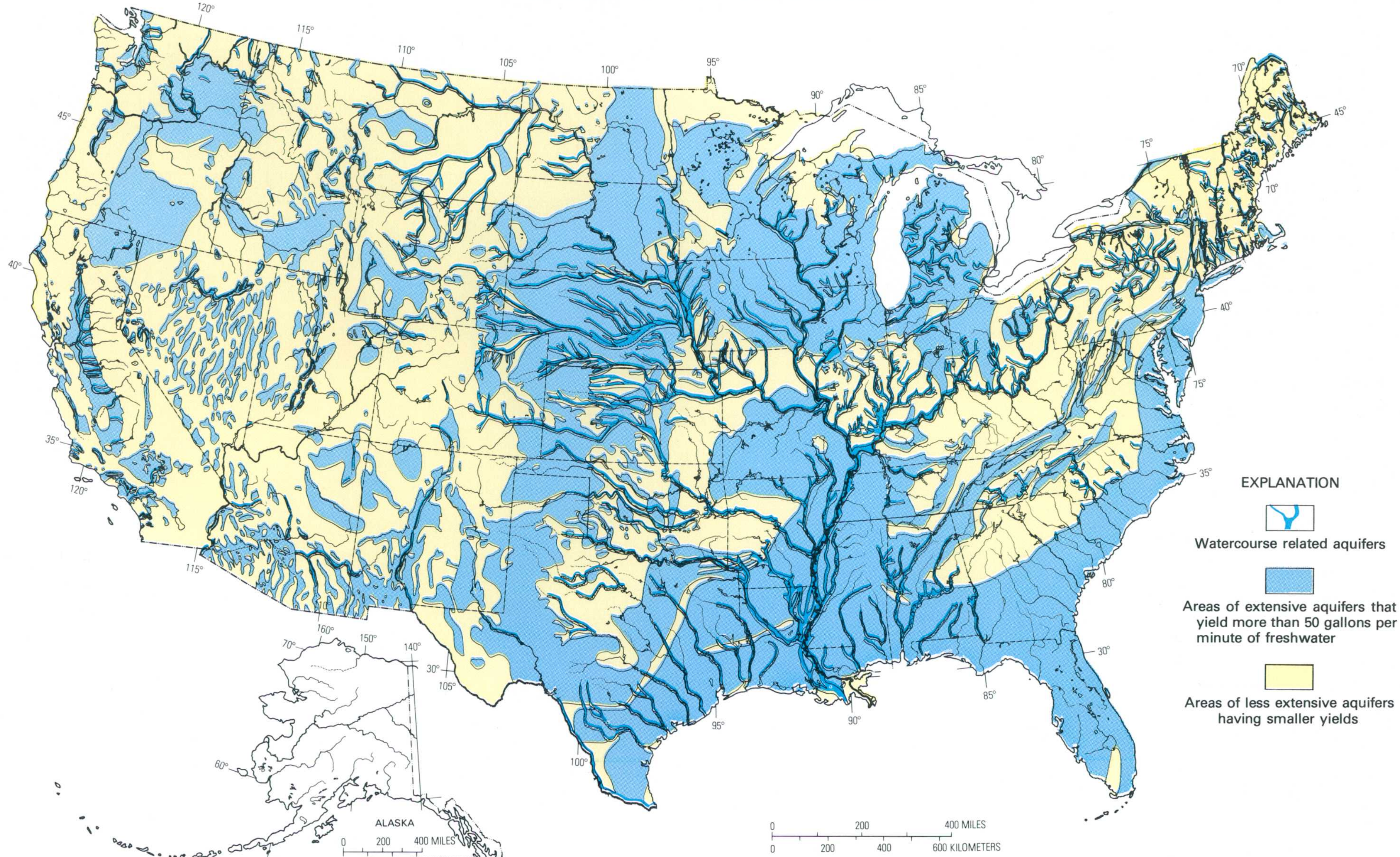
About 48 percent of the total population and 95 percent of the rural population of the United States are dependent upon ground water to supply their domestic, agricultural, or industrial water needs. Currently, about 92 million acre-feet per year (82 billion gallons per day) are withdrawn from U.S. ground-water reservoirs. However, this rate, which represents about 20 percent of the Nation's total water use, constitutes only a fraction of the potential for ground-water development.

The Nation's systems of ground-water reservoirs range from those that are drained and refilled naturally on an annual cycle, to those in which the annual replenishment is small. In the arid West, many ground-water reservoirs receive small replenishment relative to the total volume in storage. In contrast, in the East, substantial yearly replenishment is more common. In general, the more widespread and productive aquifers are found in the humid East, whereas aquifers in the Far West tend to be less continuous and yield smaller quantities of water. However, because of the relative scarcity of surface water in the Far West, ground-water withdrawals are greater there than in the East.



Ground-water withdrawals, in million gallons per day, 1975.

GROUND-WATER RESOURCES



What is the relative depletion of water in different areas of the United States?

IN A GIVEN REGION, the supply of water for use in synfuel production is influenced by the following factors:

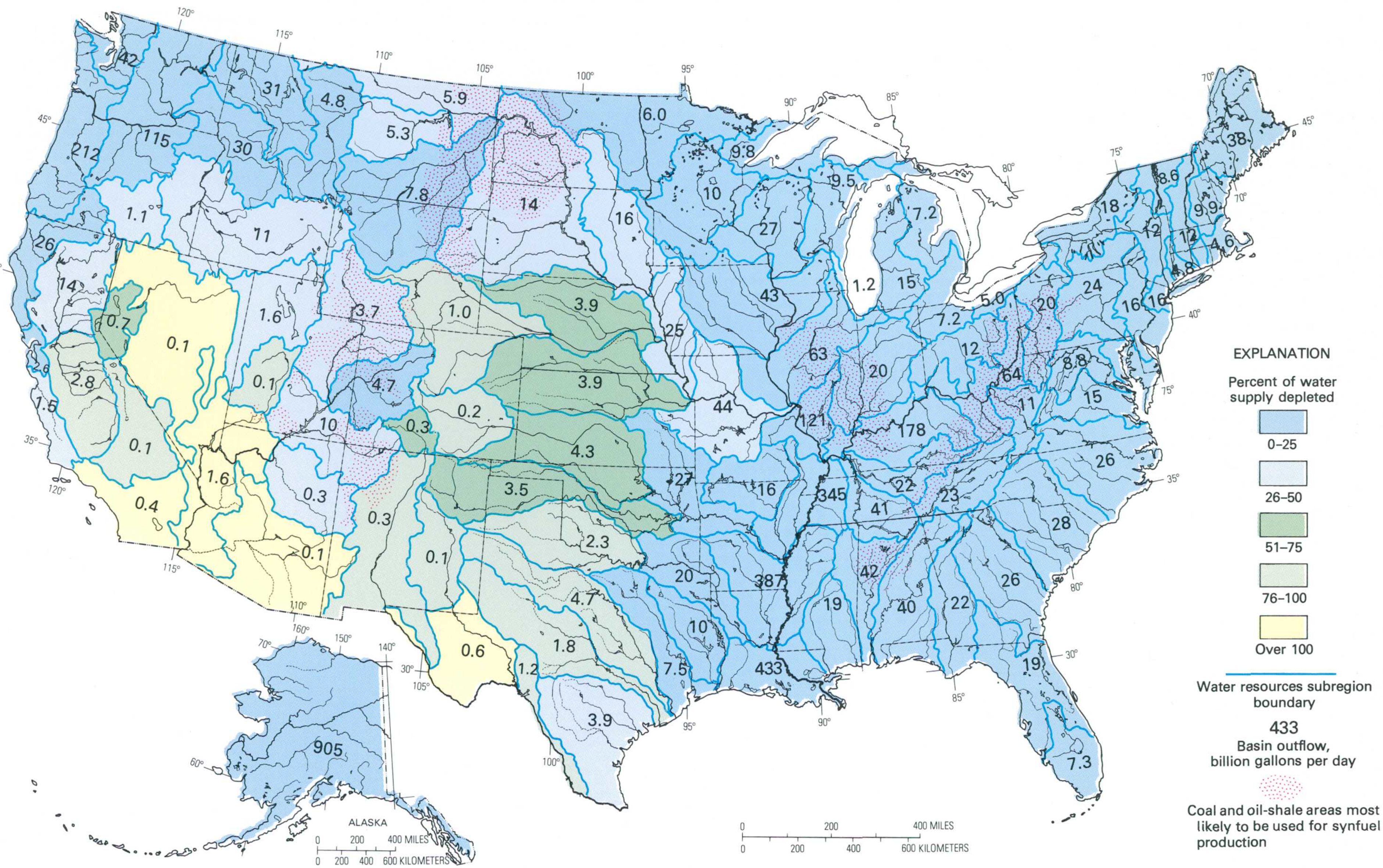
- The natural supply of water, which is influenced by precipitation, natural evapotranspiration, and aquifer recharge.
- Water imported into the region.
- Depletions of supply which include: Water evaporated as a result of industrial, agricultural, domestic, and commercial use; water evaporated from manmade reservoirs; and water exported from the region (alone or with some product).
- Regulation of flows (by reservoirs) which determines the availablity of water in dry seasons and dry years. Without reservoir storage (either surface or subsurface), only a small fraction of the average stream supply can be put to continuous use in an industrial process such as synfuel production.
- The possibility of ground-water mining (pumping from aquifers in excess of recharge rates), which can contribute to short-term water supplies for years, decades, or longer.

On the facing map, the first three factors are evaluated using data from the Water Resource Council's Second National Assessment. The map patterns illustrate the estimated percentage of water depleted in each subregion of the United States (total depletion/total supply) and thus indicate the relative magnitude of human impact on the water cycle. Estimated depletion is generally less than 50 percent of supply east of the 95th meridian and in basins of the Northern Great Plains, the Rocky Mountains, the Pacific Intermountains, and the Pacific Northwest. Depletion exceeds 75 percent of supply primarily in the Southwest, where depletion exceeding the calculated supply occurs in some basins because of ground-water mining.

The number shown for each subregion is the estimated average annual outflow of water in billions of gallons per day. This average outflow is not necessarily a surplus; commonly part is required to satisfy instream-flow needs (as for fisheries, navigation, and hydropower) or downstream compact requirements.

A comparison of synfuel-resource areas with the water-depletion patterns indicates that estimated depletion does not exceed 50 percent of the available water supplies, except for small areas in southwest Utah, northwest New Mexico, and south-central Wyoming.

RELATIVE WATER DEPLETION



Are there undeveloped aquifers that might be used for synfuel production?

YES, IN CERTAIN AREAS there are geologic formations which, for one reason or another, have not been used as aquifers for traditional water uses but are capable of yielding significant quantities of water for energy development.

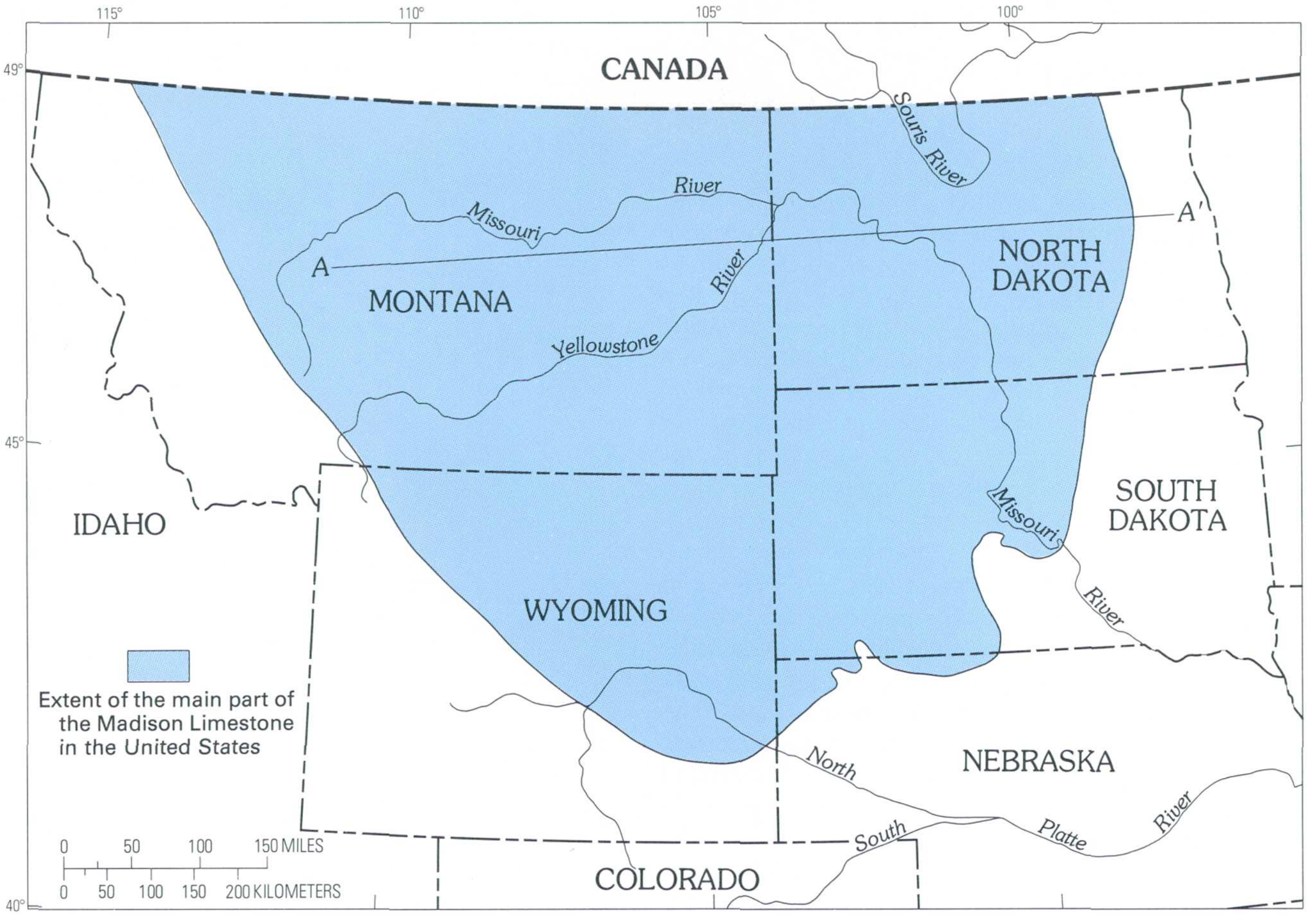
The Madison Limestone in Montana, Wyoming, and the Dakotas is an example. In the past, a number of factors have combined to limit the pumping of ground water from the Madison. Over much of the area, the formation occurs at great depth, so that high drilling costs have discouraged development. In some localities, the water has moderate to high concentrations of dissolved solids, making it unsuitable for irrigation or direct human consumption. Moreover, in some areas, the rock is relatively low in permeability, so that adequate well yields either cannot be obtained or require high pumping costs.

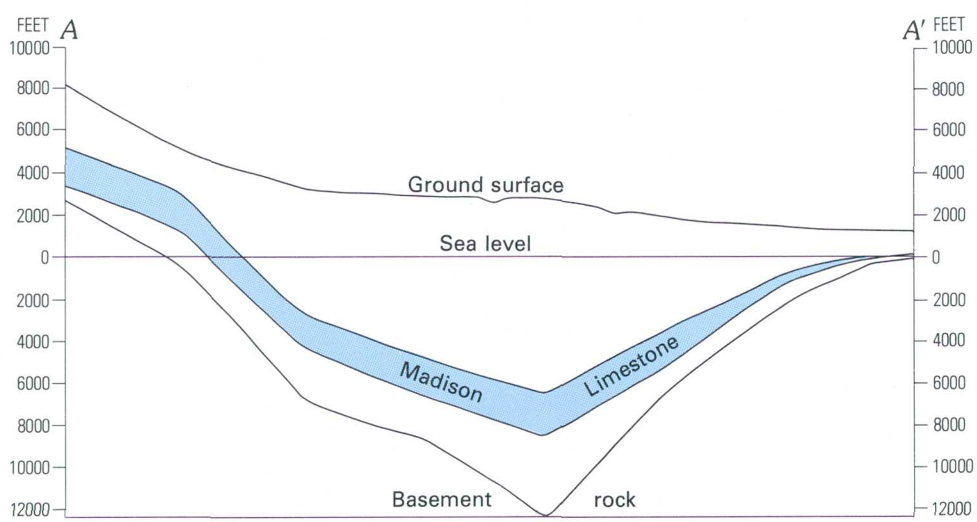
Despite these limitations, it might be desirable to obtain ground water from the Madison for energy-related purposes. This possibility is partly a reflection of economic considerations; water that is too expensive to develop for irrigation is often within economic reach for energy production. In addition, water quality requirements for some energy-related applications are less stringent than those for agricultural use. Thus, some water from the Madison Limestone unfit for irrigation or other uses might still be used for energy production.

There are several other examples of deep-lying and little-used aquifers in areas of potential synfuel resources. For example, the Leadville Limestone underlies much of the oil shale region of Colorado, as do several thick sandstone aquifers. These aquifers contain large quantities of stored ground water, some of which might serve the development of oil shale.

An important consideration in the potential use of deep, little-used aquifers is that the water is largely unappropriated. Thus, depending on State laws, there may be few legal impediments to development of such water resources for energy purposes and, therefore, minimal need for trade-offs on present water use.

MADISON LIMESTONE





Are water resources available for additional use in areas of potential synfuel development?

THE AVAILABILITY of existing water resources for synfuel development is affected by:

- The extent of appropriation of existing water, including ground water.
- The willingness on the part of existing water users to sell their water rights.
- The legislative, judicial, and administrative decisions regarding the transfer of water rights and changes in water uses.
- Uncertainties with respect to the extent of instream-flow requirements for fisheries, navigation, hydropower, and others, and unsettled claims for Indian and Federal water rights.

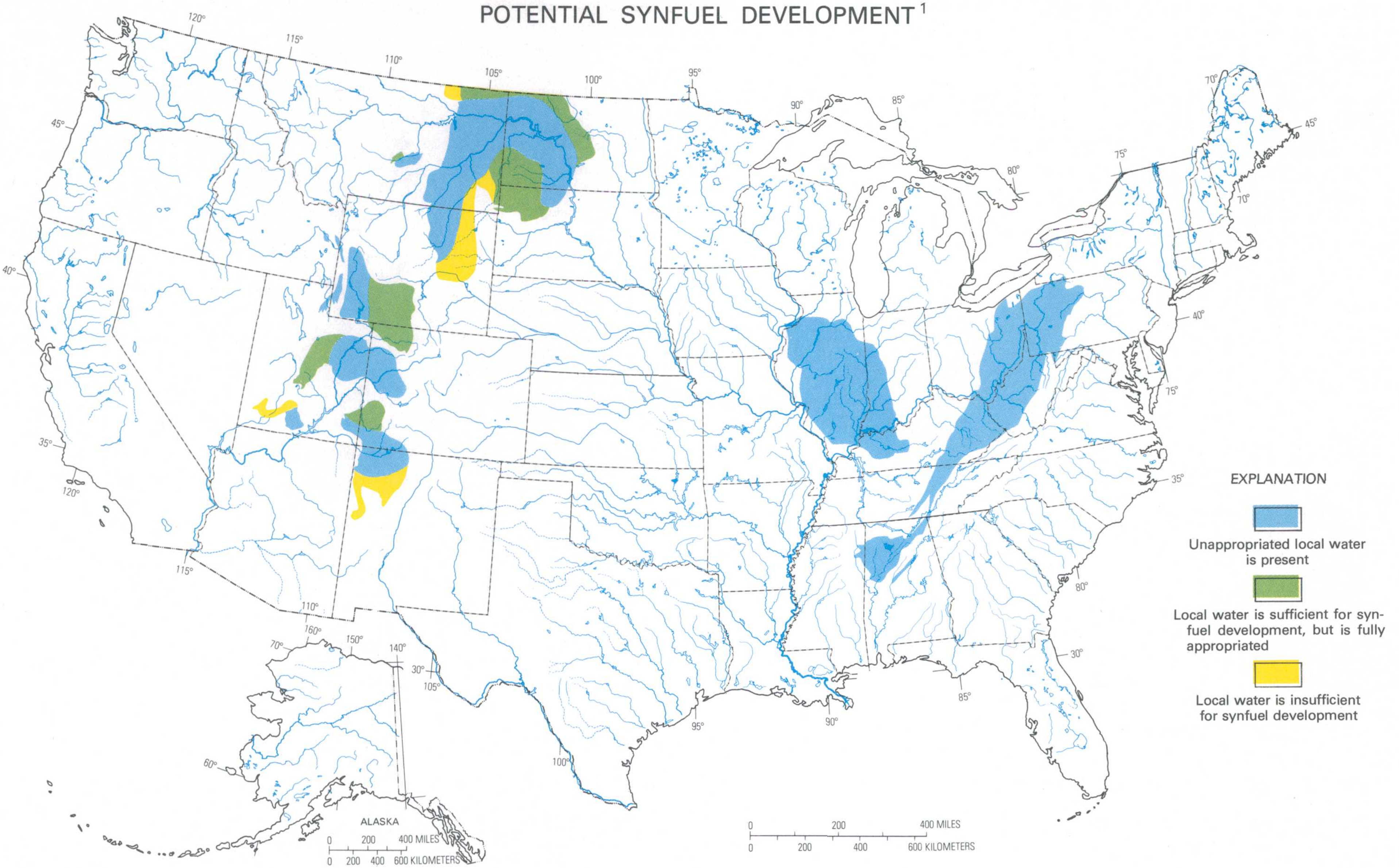
Water allocation is primarily the responsibility of the States, subject to interstate compacts and international treaties. In much of the East and some areas of the West, unallocated water may be available for synfuel development. In the West, however, much of the physically available water may be subject to legal challenge owing to other claims, such as Indian water rights which have not been adjudicated. In some Western States, water rights may be sold. Within those States, where waters are fully committed, some sales have been made by agricultural holders of water rights to energy-development interests. However, in North Dakota, sale of water rights for a change of use is prohibited. Moreover, in Montana, water law forbids the transfer of water rights from agricultural to industrial use if the right allows for diversion at a rate exceeding 15 cubic feet per second.

As previously stated, deep ground water exists and may be available for synfuel development in some areas of the West. In addition, in certain locations, dewatering of the oil shale or a coal seam might provide a significant part of the water required for its development.

Based on the availability of existing local water resources, synfuel-resource areas may be divided into three categories: (1) areas where unappropriated water resources occur in amounts sufficient for significant synfuel development; (2) areas where water resources are sufficient for synfuel development, but are already appropriated or committed to other uses; and (3) areas where water resources are insufficient for synfuel development. Delineation of these categories on the accompanying map is based on: (1) surface reservoir storage that exists or is under contruction; (2) economically useable ground water resources; (3) existing interstate compacts; and (4) an assumed water-transportation radius of 50 miles. Changes in these assumptions or improved knowledge of the ground-water resources could change the distribution.

The map shows that most of the potential synfuel areas of the Nation have unappropriated local water that might be available for synfuel development. In only a few areas do local water supplies appear to be insufficient for synfuel development. However, there are areas of considerable size where local water would be sufficient for synfuel development but is already fully appropriated.

WATER RESOURCES AVAILABLE FOR ADDITIONAL USE IN AREAS OF POTENTIAL SYNFUEL DEVELOPMENT[1]



[1]Based on a canvass of State and Federal officials in the Western States by I. C. James II, September 1979

What are the potential geologic and hydrologic problems associated with synfuel production?

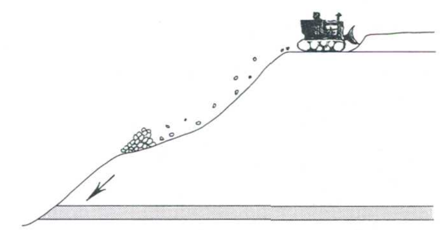
THERE ARE A NUMBER of potential geohydrologic problems that could result from development of a large-scale synfuels industry. However, if the problems are fully recognized, steps can be taken to prevent or minimize the potential impacts. This section describes the types of problems that could arise from the mining of coal and oil shale, the conversion of the resources to synfuel products, and the disposal of resultant waste products.

Landslides

Landslides are a great hazard in coal fields of the United States where only traditional mining methods are in use. Much of the northern and southern Appalachian coal regions are in rugged areas of great relief where the slope materials are inherently unstable. Most of the Rocky Mountain and Northern Great Plains Coal Provinces are underlain by earth materials that can fail under natural conditions or under conditions altered even slightly from the natural state. In addition, several areas in the low-lying Interior Coal Province are subject to slope failure, as shown on the facing map.

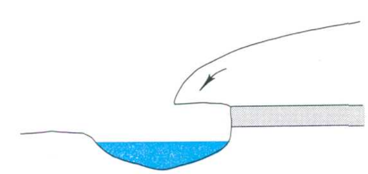
Landslides always involve the failure of earth materials under shear stress. Factors contributing to slope failure are illustrated in the accompanying diagram. These include: (*A*) accumulation of unconsolidated materials on the upper part of the slope; (*B*) addition of water which adds weight to and lubricates the slope materials, and (*C*, *D*), removal of support from the bottom of the slope by mining or erosion. In most cases, several factors occur simultaneously and only await a triggering event such as vibration from heavy equipment or earthquakes.

Landslide damage resulting from development of synfuel resources can be minimized through a program of geologic investigations of slide and slide-prone areas. Such investigations should include the study of factors contributing to sliding, and the examination of physical properties of earth materials in mined and unmined areas. Findings of such investigations can be used to design a program for minimizing slope stability problems in each synfuel development area.

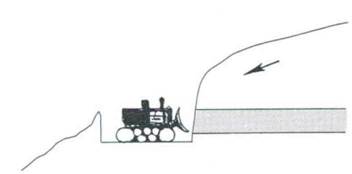


A. Addition of weight from accumulation of earth materials.

B. Addition of weight from infiltrated water.

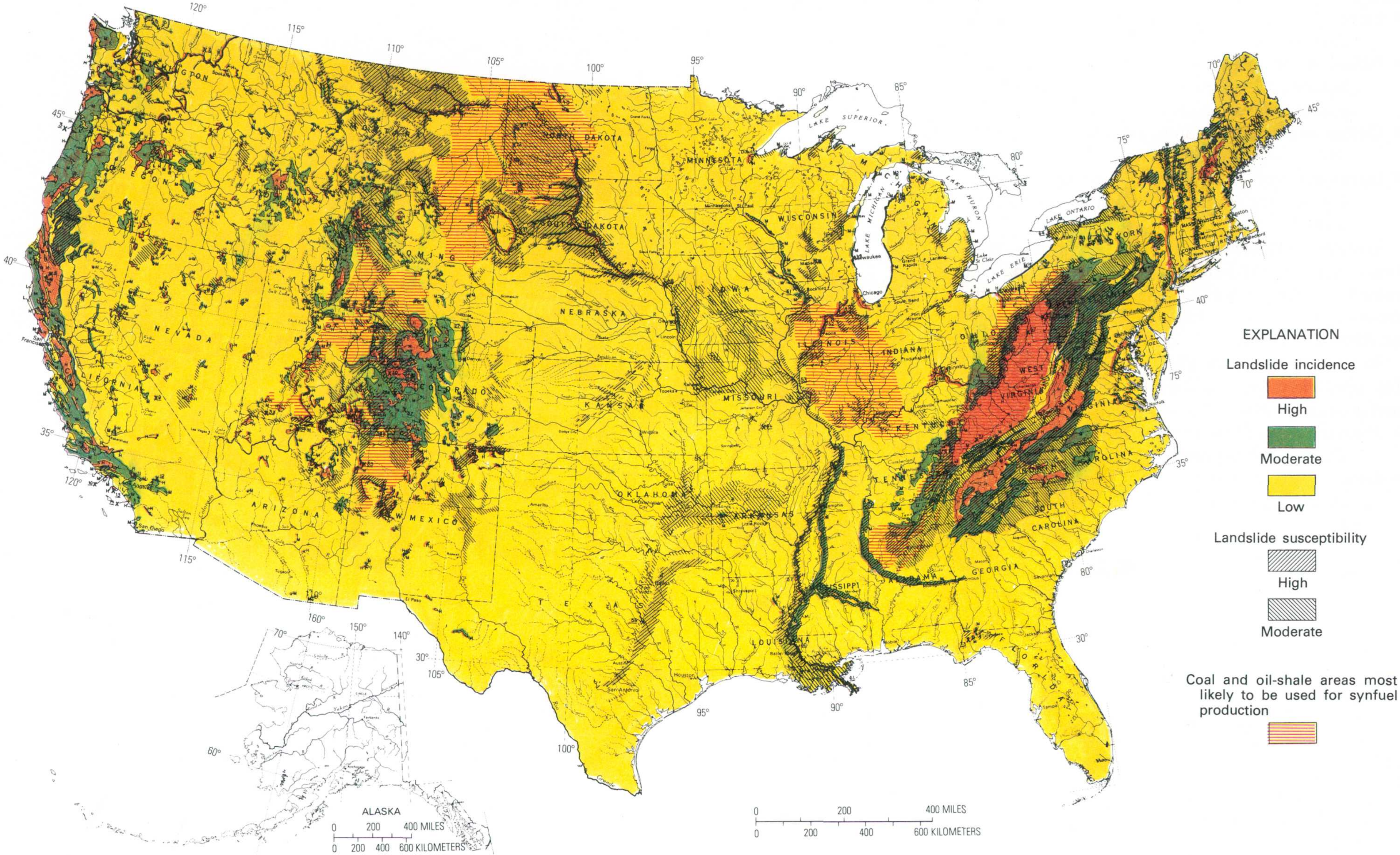


C. Removal of support by erosion.



D. Removal of support by mining or quarrying.

LANDSLIDE MAP OF THE UNITED STATES



Erosion and sedimentation

Erosion and loading of streams with sediment is considered by many to be the most serious water-quality problem resulting from energy resource mining. Erosion rates from the active surface mining of coal have been estimated to be 10 times greater than from the same relative area of cropland. The impacts of erosion and sedimentation associated with mining include:

- Flooding of communities due to filling of stream channels by sediment.
- Filling of reservoirs with sediment, resulting in reduced flood control, irrigation-water storage, power generation, and recreational facilities.
- Destruction or reduction of fish and other aquatic life.
- Increasing costs for maintaining navigation channels and for treating of industrial and domestic water.

Erosion most commonly occurs on poorly vegetated, steep, cut-and-fill slopes in areas having high rates of surface runoff. The problem is considered most acute in the more humid Eastern Coal Province or Appalachian Region.

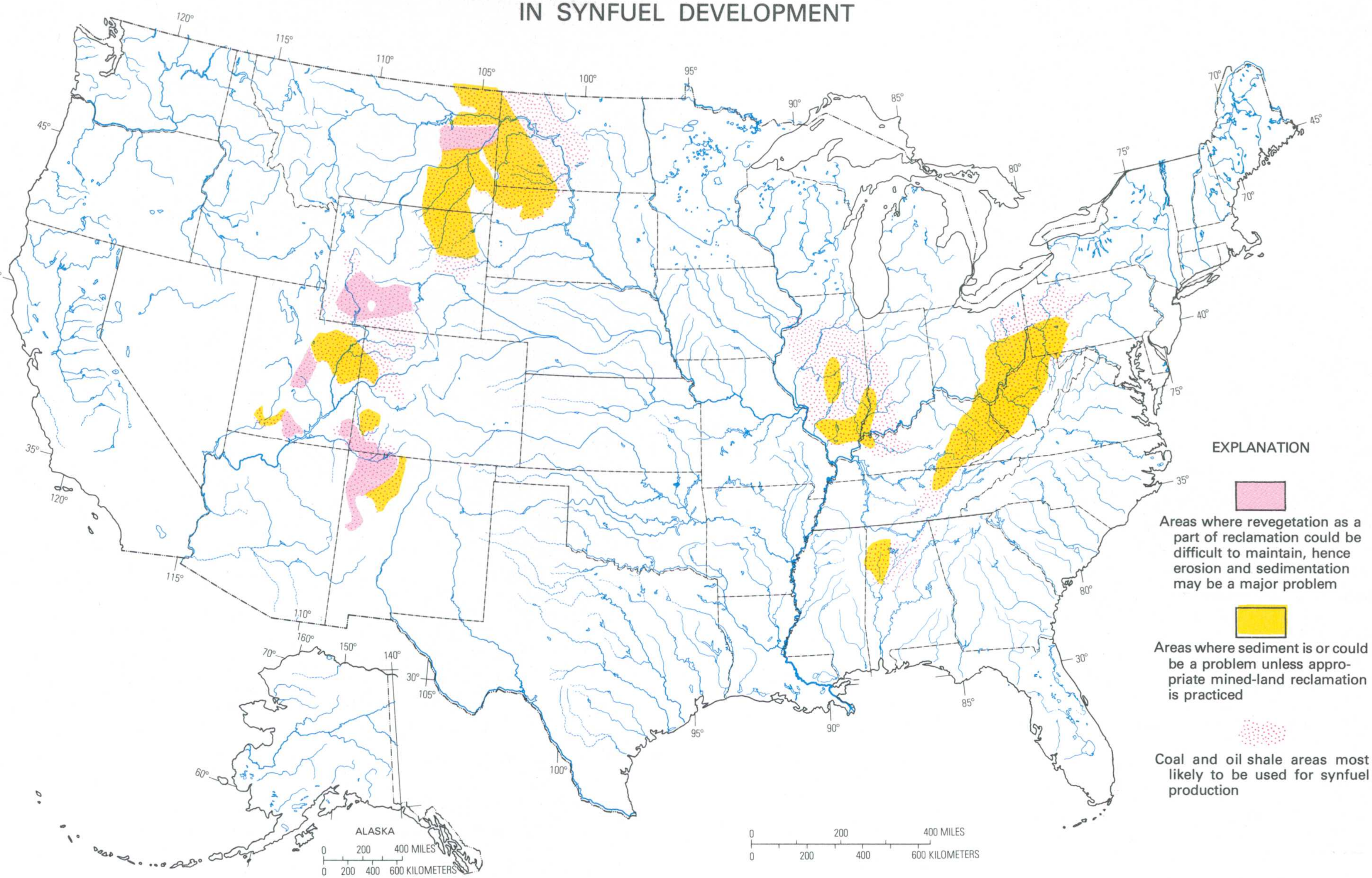
In most cases, a high yield of sediment from mining operations reflects deficiencies in mining and reclamation practices. Sound practices include:

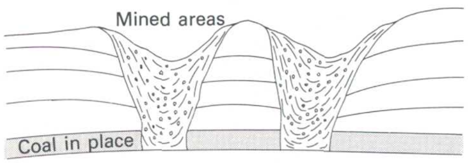
- Preplanning to fit the mining operation to site conditions of topography, soils, and climate.
- Limiting the exposure of denuded land to the smallest possible area for the shortest time.
- Exercising soil-erosion and sediment-control practices concurrent with mining operations.
- Exercising maintenance of reclaimed mining areas.
- Properly disposing of solid wastes.

Shown in the facing map are areas where sediment from mining is a significant problem, but one that can be solved through application of sound practices and available engineering measures. Shown also are problem areas where adequate reclamation may not be entirely feasible. These are arid regions of the West where lack of rainfall may make effective revegetation extremely difficult. Careful assessment of each potential mining site will be called for in these areas. Some of these areas eventually may be considered unsuitable for mining because of the likelihood that erosion and sediment problems will be unmanageable.

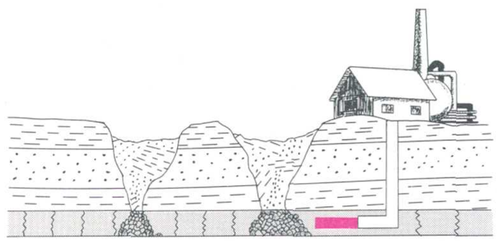
The recently passed Surface Mining Control and Reclamation Act requires the issuing of permits for all coal-mining operations, together with strong measures to control erosion and sedimentation. No such national law exists to cover mining operations of oil shale. However, there are State and local regulations to cover erosion and sediment problems associated with oil shale mining. Through proper planning, engineering, and regulation, the mining of coal and oil shale for synfuel production can be handled with minimum sediment-related impacts in most areas of the country.

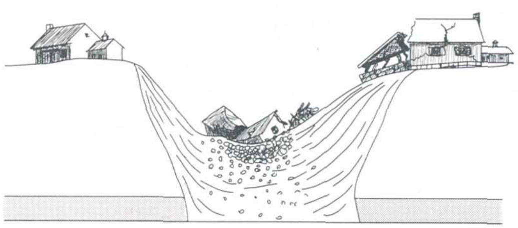
AREAS WHERE WATERBORNE SEDIMENT FROM MINING COULD BE A PROBLEM IN SYNFUEL DEVELOPMENT

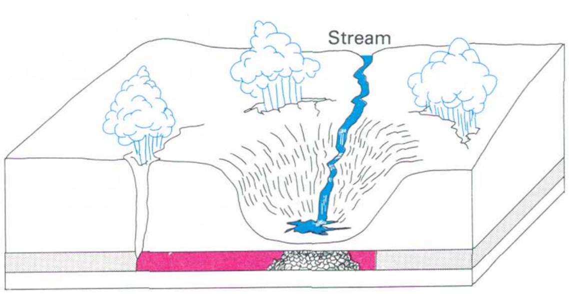




A. Subsidence in area of underground mining.


B. Subsidence caused by in-situ conversion of coal to synfuel.


C. Urban areas over mining districts are subject to severe disturbance.



D. Underground fire in coal bed causes cracks, results in fumes, explosions, diversion of stream.

Subsidence

Subsidence of the Earth's surface follows removal of underground support by either natural or man-influenced causes. As illustrated in the diagrams, subsidence can be caused by (*A*) underground mining and (*B*) in-situ conversion processes involving a loss of volume to subsurface rocks. Subsidence can be sudden or slow; it can occur soon after mining or after many years and can take many forms, ranging from cracks in the ground to gaping holes. In regions where coal is subject to spontaneous combustion, subsidence commonly allows entry of air into coal beds, renewing the fire.

Subsidence in urban areas that overlie underground coal workings has caused severe damage to property (*C*). In Scranton, Pennsylvania, and Sheridan, Wyoming, for example, burning mines abandoned many years ago undergo continuing unpredictable subsidence, spreading of mine fires, and steam explosions that discharge noxious gases (*D*).

Subsidence also can reduce developable coal reserves, decrease mine safety, and disrupt the local hydrologic system. In western coal fields, several mineable coal beds often occur one above the other. Subsidence caused by mining one or two such beds can create stress conditions in surrounding rocks that severely restrict or prohibit mining of the remaining coal. Cracks caused by subsidence can intercept and divert ground water or methane gas associated with the coal and may even divert surface-water drainage to underground workings. In some western coal fields, the entry of oxygen and water through subsidence cracks contributes to underground combustion.

In areas of in-situ conversion, subsidence could cause all or some of the same problems as in mined out areas. This, in turn, would strongly affect recoverability of the total energy resources and future land use.

Subsidence can be avoided by backfilling voids with mining spoil or by leaving large amounts of coal or oil shale in place to support the overburden. Problems caused by subsidence can be decreased by avoiding the use or surface areas over underground mines. These approaches, however, do not provide easy or necessarily desirable results. The first is very expensive and technologically difficult; the second is wasteful of scarce resources; and the third involves a type of land-use planning which is unacceptable to many western landowners. Many of the geological hazards related to subsurface mining can be avoided by surface mining and above ground conversion of coal and oil shale to synfuels coupled with sound reclamation of the disturbed land.

Disruption of aquifers

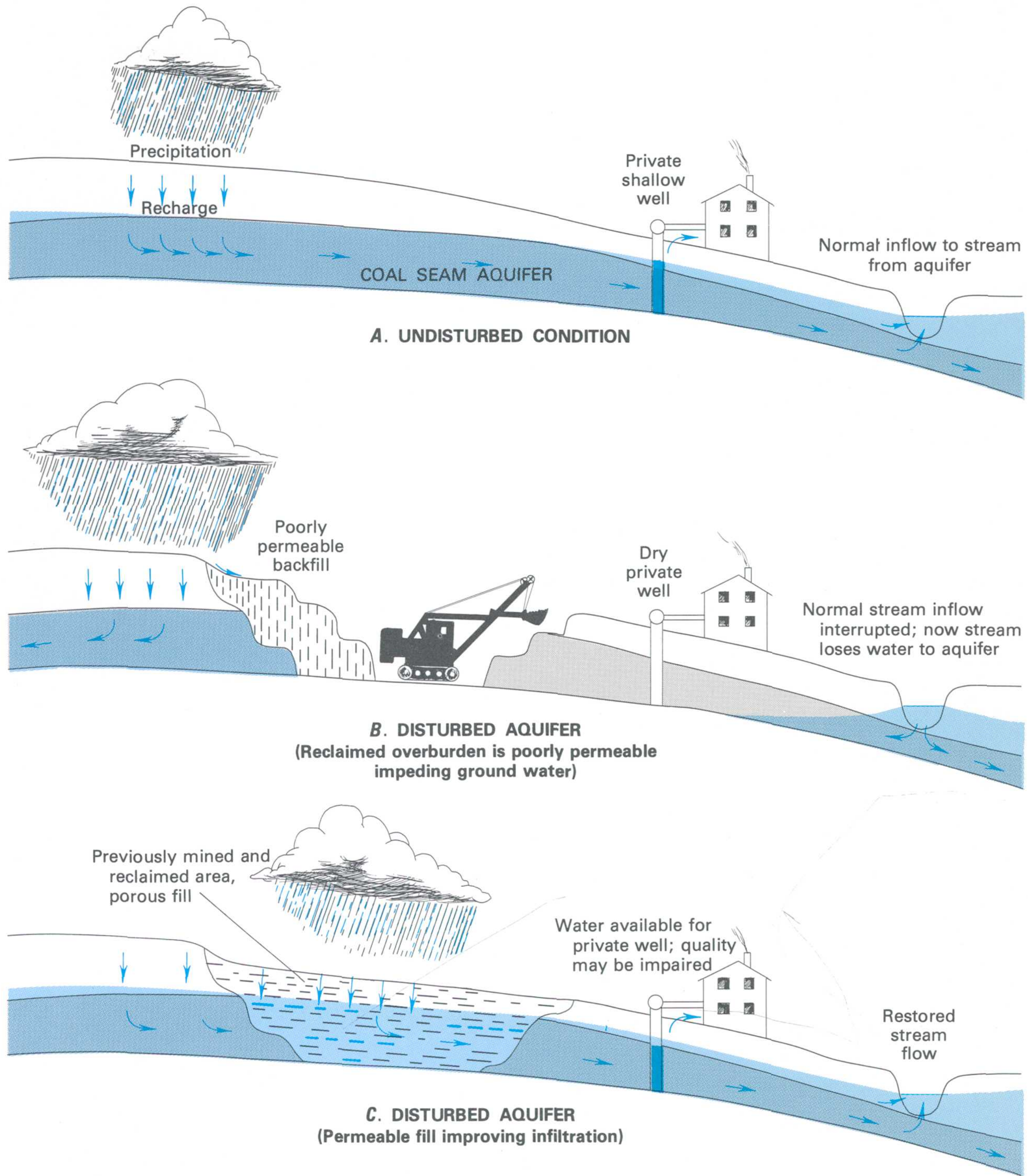
Some coal and oil shale deposits are aquifers. Although such aquifers are found nationwide, they are commonly regarded as undesirable for domestic or industrial water supplies for two reasons: (1) inadequate capacities to supply sufficient quantities of water and, (2) poor chemical quality of the water. In the eastern coal producing areas, the latter problem is frequently one of excess dissolved metals which are toxic to humans and animal life. Where the quality of the water is acceptable, the shallow coal aquifers are commonly tapped for private use of farms and ranches.

Most of the private wells which tap coal or oil shale aquifers are located in the Rocky Mountains and Northern Great Plains, particularly in Colorado, Wyoming, Montana, and North Dakota. In these areas, the water quality is considered acceptable, although the amounts of dissolved solids often exceeded desirable health limits. Although the supply is small, so is the demand in this region of generally low population. A noteworthy exception is the lignite deposits of North Dakota which are a principal source of domestic water. This lignite is now considered to be a prime candidate for coal gasification.

The accompanying illustration shows how the mining of coal may impact the future use of an aquifer. Illustration (*A*) shows a water-saturated coal seam under premining conditions. Water flows from the recharge area through the coal seam to supply water to a shallow well, and a stream. In (*B*), mining has interrupted the normal flow of water through the aquifer, and a poorly permeable backfill has caused flow in the aquifer to change direction. The well has gone dry and water from the stream now flows into the aquifer.

Illustration (*C*) depicts an idealized aquifer restoration in keeping with sound post-mining reclamation practices. The mined area has been filled with porous materials, allowing the surface to act as a recharge zone and permitting water to flow in a pattern similar to premining conditions. Use of the permeable backfill may improve recharge to the aquifer relative to natural premining conditions and, thereby, increase the supply of water to the well and stream. However, the quality of water might be somewhat impaired owing to solution of minerals which might occur in the fill.

The mining of coal and oil shale for synfuel production will seldom impact a principal water supply aquifer. As noted, the most important exception may be the lignite beds of North Dakota. Before these deposits are mined, the area must be carefully evaluated and, if necessary, alternative sources of water identified. Pre-mining planning will also be needed in certain local areas of the country where synfuel production has the potential to disrupt small supply aquifers. Options for minimizing problems include the drilling of deeper wells and obtaining other supplies where impacts cannot be avoided.



POSSIBLE IMPACTS OF MINING AQUIFERS

Acid mine drainage

Acid mine drainage refers to acidic water discharged from active or abandoned mines. The problem occurs whenever pyritic (iron sulfide) minerals associated with coal are exposed to oxygen in flowing water. The minerals are oxidized, releasing sulfuric acid. This may occur in mines, in unreclaimed spoil banks, and on reclaimed land. However, 70 to 80 percent of the acidic water originates from underground coal mines, most of them inactive.

The facing map indicates the extent of significant acid mine drainage in the United States. The problem affects about half of the stream mileage in the coal areas of eight Appalachian States, but is particularly prevalent in Pennsylvania, Maryland, Ohio, Kentucky, and West Virginia. Acid mine drainage is not a significant problem in the Western Interior, Northern Great Plains, and Rocky Mountain Coal Provinces because pyritic materials are less abundant, water is less available, and neutralization readily occurs in the naturally alkaline soils and water.

The factors causing acid mine drainage and measures to control it are known and can be readily applied. The cost of control is considered small relative to the other costs of producing and converting coals to more usable energy forms.

The map shows that the potential coal resources for synfuel production are primarily located in regions having low potentials for acid mine drainage. However, even if synfuel resources are mined in potential problem areas, acid mine drainage can be prevented or minimized through sound application of principles outlined in the Surface Mining and Reclamation Act of 1977.

Leaching of waste materials

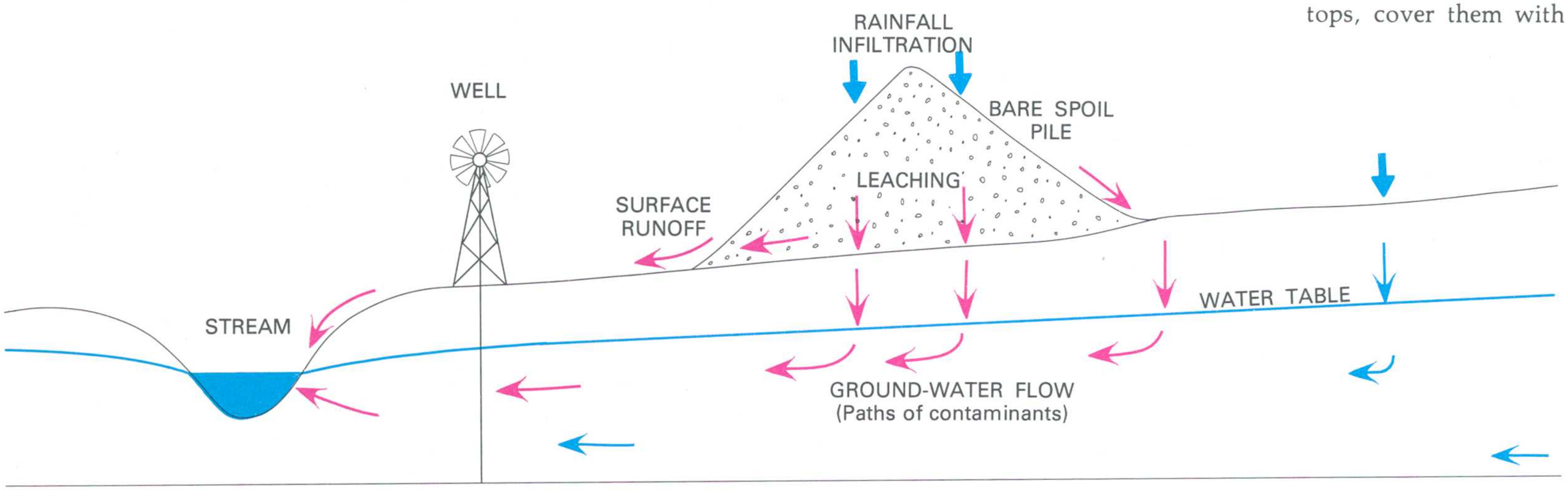
Above ground processes for converting coal to synfuel generally leave a 10- to 30-percent residue of ash, slag, tar, and other products. Moreover, residues from the surface retorting of oil shale consist of rock particles and up to 75 percent of the original organic matter in the form of char, tar, and other materials. These residues from both coal and oil shale conversion contain numerous leachable organic and inorganic substances which have the potential for seriously degrading the quality of the water resources. Some of the leachable substances are toxic to stream organisms and to higher animals where present in sufficiently high concentrations. Certain of the other substances are carcinogenic.

The accompanying schematic illustrates that water infiltrating a spoil pile could leach contaminants into nearby streams or into the ground-water system. The quantity and character of leachate would depend mainly on the type and solubility of the waste materials, the amount and intensity of precipitation, and the infiltration capacity of the spoils (and any material overlying them).

Dissolved contaminants that enter ground water may be reduced in concentration by a number of processes, including attachment to mineral surfaces, biological degradation, and dispersion. Once in the ground water, contaminants move in the general direction of ground-water flow. Movement of ground water is usually very slow compared to stream flow. Years, or even decades, might pass before contaminants in ground water reach a stream, whereas those in surface runoff might enter a stream in a period of hours, days, or weeks. Moreover, contaminants in ground water are correspondingly more persistent than in surface water. Even after contamination from the land surface has stopped, very long periods of time may pass before contaminants in ground water have declined to undetectable levels.

Depending on regional climate, the effects of spoil residues may be mitigated in several ways:

- Dispose of spoils in areas of ground-water discharge rather than areas of recharge; especially avoid recharge areas of extensive fresh-water aquifers.
- Reduce the infiltration into spoils by covering them with a relatively impervious material. One method is to spread the spoils on ridge tops, cover them with gravel to reduce ero-



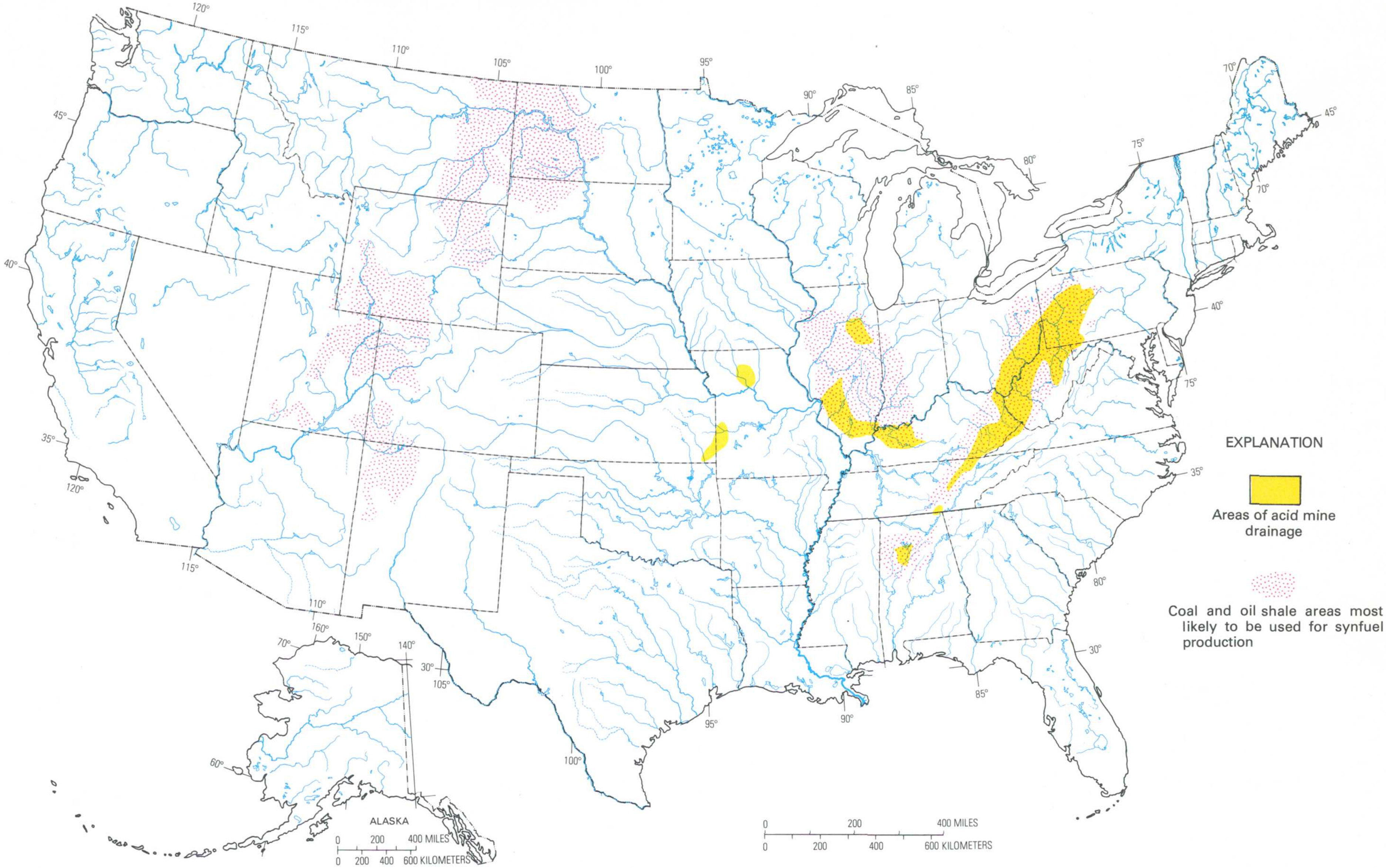
TOXIC SUBSTANCES LEACHING FROM SPOILS

sion, and to top this with a relatively impermeable soil material.

- Contaminated ground water might be prevented from reaching well fields or streams by intercepting the water at pumped wells located upgradient from the area to be protected. Contaminated water pumped from such wells would need to be treated or disposed of in an acceptable manner. One possible method in certain areas would be reinjection through wells into selected subsurface zones that have little or no foreseeable value (such as brine-filled aquifers).

The extent to which such mitigating measures will be successful depends largely upon the climate and local geohydrologic conditions. These must be carefully evaluated before reliable waste-management plans can be made for a specific development.

AREAS WITH SIGNIFICANT ACID MINE DRAINAGE PROBLEMS



Effects of in-situ conversion

MUCH RESEARCH and development work has recently focused on methods to extract synfuels from coal and oil shale in their natural underground (in-situ) environment. Most schemes for the in-situ processing of coal or oil shale involve the underground buring of part of the energy-bearing rock. The heat generated by the burn converts the solid organic material to gaseous and liquid products that can readily flow through pores and fractures in the rock, and hence, be recovered through a production well. Only a relatively small fraction of the organic content (generally 10 to 20 percent) of the rock is consumed to sustain the burn.

In-situ conversion appears to offer several advantages over conventional mining and subsequent processing in surface facilities. For example, disturbance of the land surface, hazards associated with mining, air pollution from retorting plants, and disposal of solid wastes would all be minimized. But there would be a price to pay. Precise engineering control of several factors that affect conversion efficiency, such as particle size, retorting temperature, and moisture content, would not be possible with an in-situ process. In addition, most coal and oil shale beds are saturated with ground water. Dewatering will be required prior to processing oil shale by the modified in-situ method. In contrast, owing to differences in rock characteristics and methodology, dewatering may not be required prior to in-situ conversion of coal. However, the underground conversion of both coal and oil shale will necessarily consume and may contaminate a part of the local ground-water resource.

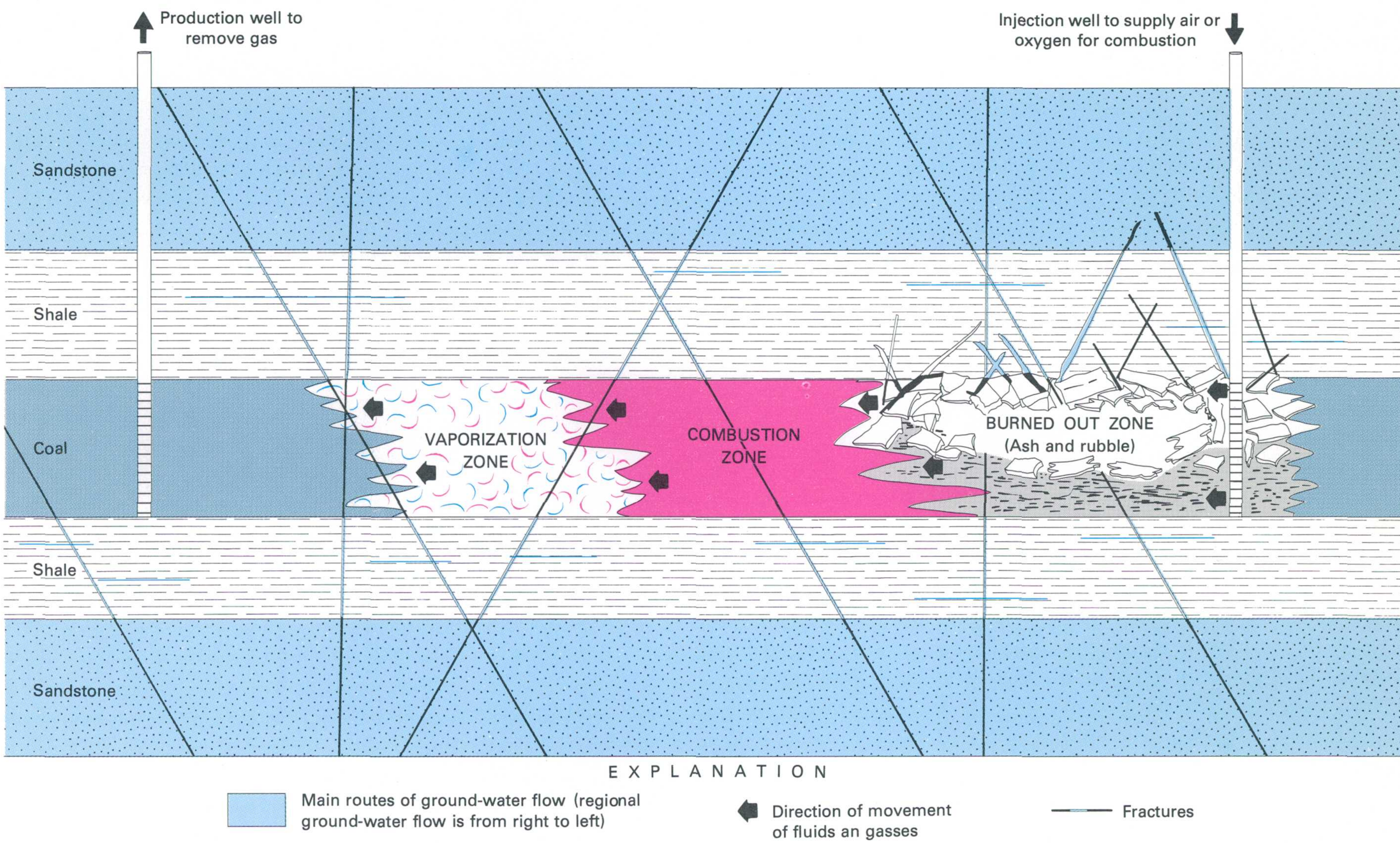
In a given location, numerous factors must be considered to determine whether in-situ or surface processing is the more acceptable. The ultimate acceptability of in-situ processing will depend greatly on aquifer properties and on the existing or potential ground-water uses.

A number of different operational designs have been proposed for underground conversion of both coal and oil shale. The facing schematic is a general representation of an in-situ coal gasification process. The coal is initially ignited at an access point provided by a well. The well also allows the air or oxygen necessary to sustain combustion to be injected into the formation. Heat generated by the burn causes a vaporization zone to form in front of the advancing combustion zone. Within this area, water is vaporized and combustible gases are produced by chemical reactions among carbon, oxygen, and steam. Water is consumed both by steam production and chemical reactions, and ground water adjacent to the vaporization zone (or condensed out of this zone) may become severely contaminated with organic and inorganic compounds.

As the combustion zone advances through the rock, it leaves behind a zone of ash and rubble. Some of the rubble forms by collapse of the overburden into the spaces that result from combustion or from subsequent leaching of soluble residues. If natural fractures or fractures caused by the in-situ process extend into adjacent aquifers, ground water may leak into the ash and rubble zone and become polluted by dissolving combustion by-products or inorganic salts.

Thus, ground water may become contaminated either in front of or behind the advancing zone of combustion. If contaminated ground water is removed by the production wells, it will present a disposal problem, and will probably require treatment prior to being safely discharged above ground. The contaminated ground water not removed by wells will naturally migrate through the rock formations and may eventually reach a well, spring, or stream.

Potential subsurface movement of some contaminants can be predicted after an adequate hydrogeologic and geochemical study of a specific site has been completed. The inclusion of such studies in the planning process provides a means to assure that in-situ conversion will be located only where (1) subsequent downgradient migration of contaminants in the subsurface will have a negligible impact on man and the surface environment or (2) potential contamination can be controlled through engineering practices.



SCHEMATIC CROSS SECTION OF AN IN-SITU COAL GASIFICATION PROCESS

Integrative mapping: a tool for synfuel decisions

THE COURSE OF DEVELOPMENT taken by the synthetic fuel industry will depend on numerous decisions made by the public, private industry, and all levels of government. Maps portraying important characteristics of the energy resources and associated environmental factors are necessary inputs to these decisions. Some key issues can be clarified through use of specially designed maps which portray combinations of pertinent factors and thereby provide the necessary information for answering important questions.

The accompanying map portrays combinations of factors related to the thickness, grade, and depth of the rich oil shale resource, the Mahogany Zone, in the Piceance Creek Basin, Colorado. The specific factors and their numerical values are identified in the explanation. Selection of the values for each factor was based on criteria pertinent to surface mining, underground mining, and in-situ options for production of the resource.

The map was drawn by a mechanical plotter driven by the output of a computer. The computer was fed data on the various factors of interest, and then programmed to synthesize the information required for the map. The mapped information is highly useful by itself, but more significantly, it provides the basis for answering important questions such as the following:

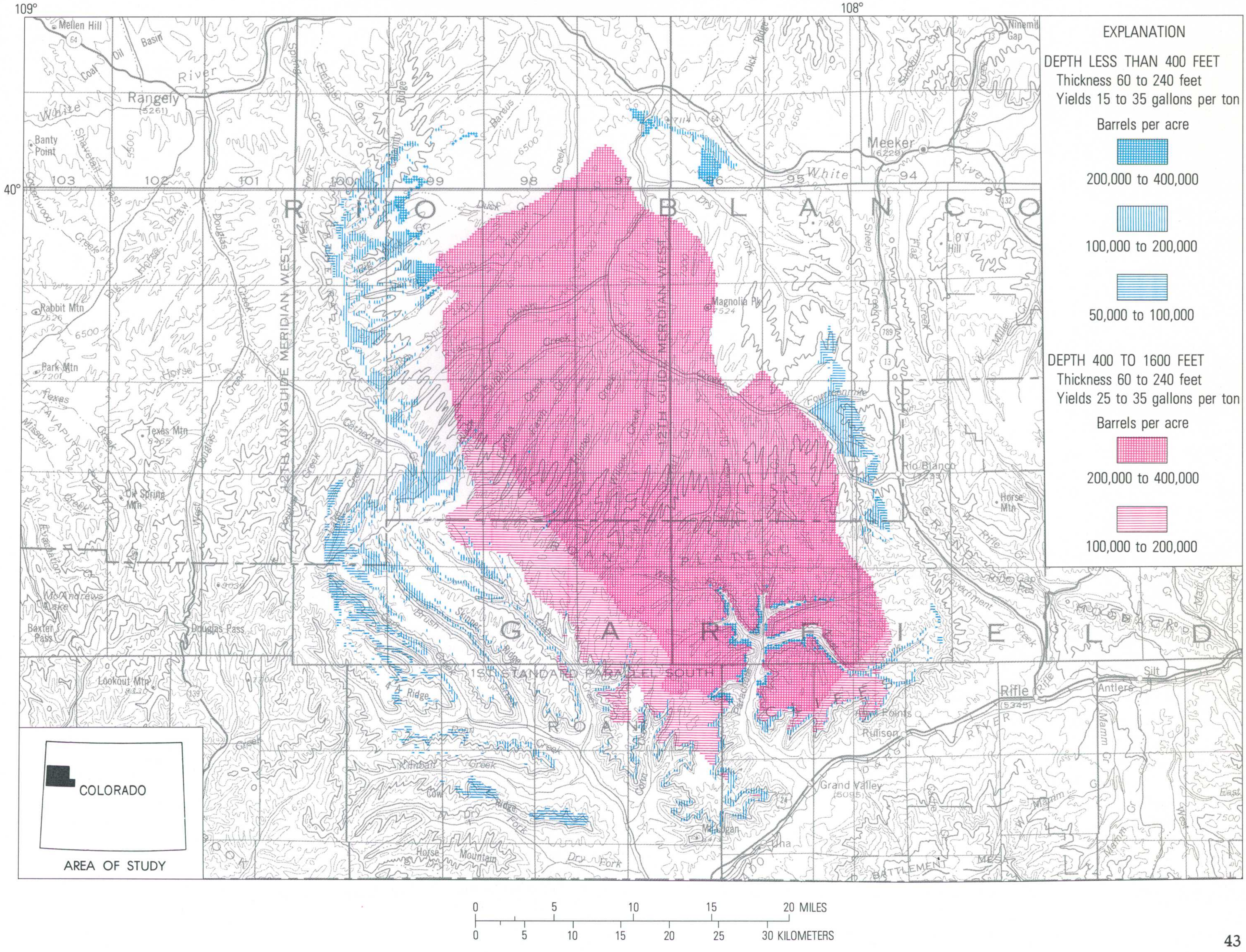
1. Based on the factors considered, which areas would be most favorable for surface mining, underground mining, and in-situ conversion?
2. How much land would be involved in extraction to support a 50,000-barrel-per-day plant for 30 years?
3. How much oil shale must be extracted and processed to support a 50,000-barrel-per-day plant?

Answers to these questions can be obtained from the map based on the explanations given below. The responses do not specify where, or to what extent, extraction would occur because many additional factors will affect such decisions. Moreover, the mapping criteria and assumptions may change, requiring the generation of new derivative maps. The purpose of the mapping and question-response activities is to provide an initial integrated perspective. On this basis, improved planning can be done, criteria can be better defined, and new maps can be prepared to answer new questions or the same questions in greater detail.

FOR THE OPTIONS LISTED BELOW . . .	(Question 1) . . . FAVORABLE AREAS ARE SHOWN ON THE MAP AS:[1]	(Question 2) . . . EXTRACTION AREA FOR 30 YRS, 50,000 bbl/d, IS:[2]	(Question 3) . . . QUANTITY OF OIL SHALE EXTRACTED FOR 50,000 bbl/d, IS:
Surface mining		1,500 to 3,000 acres	60,000 to 140,000 tons/day (19.7 to 45.9 million tons/year)
		3,000 to 6,100 acres	
		6,100 to 12,200 acres	
Underground mining		2,300 to 4,600 acres	60,000 to 84,000 tons/day (19.7 to 27.6 million tons/year)
		4,600 to 9,100 acres	
In-situ retorting		2,700 to 5,500 acres	Not applicable; most of the shale remains underground
		5,500 to 11,000 acres	

Notes: [1]Areas favorable for underground and in-situ options are identical on the map; they are treated here under each option to indicate the differing acreages and tonnages involved.
[2]Recovery is assumed at 90% of total resource for surface mining, 60% for underground mining, 50% for in-situ retorting.

DEPTH, THICKNESS, AND ESTIMATED YIELD OF THE MAHOGANY ZONE, PICEANCE CREEK BASIN, COLORADO



Selected references

THE FOLLOWING REFERENCES are provided so interested readers can obtain additional details on the major aspects of synfuels and water resources described in this report. The list is not intended to be exhaustive. Rather, an attempt was made to list one or two key reports for each topic. Some of the reports contain general information, others are very technical.

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Penstemon sp. near oil shale lease tract C-b, Piceance Creek Basin, Colorado.

On the cover: Part of a Landsat image of the Piceance Creek Basin, a potential source of oil shale from the Green River Formation.

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