SECTION V
YELLOWSTONE RIVER BASIN AND ADJACENT COAL AREA AND UPPER MISSOURI RIVER BASIN

BACKGROUND

The Upper Missouri Basin contains significant deposits of coal and lignite. As a result of the ever increasing demands for energy, this coal has been mined for shipment and used locally in thermal-electric power plants. Now it is targeted for possible development of a synthetic fuels industry.

The most important coal deposits in the area are in the Fort Union formation of Wyoming, Montana, and North Dakota. The structural Powder River Basin of northeastern Wyoming and southeastern Montana contains the world's largest stripable sub-bituminus coal deposits. In southwestern North Dakota, extensive lignite deposits are attractive for coal development. These coal deposits lie within and adjacent to the Yellowstone River Basin and Upper Missouri River and its tributaries. Figure 7 shows the area described.

This analysis of the Upper Missouri River Basin is based primarily on the use of two water-planning documents.

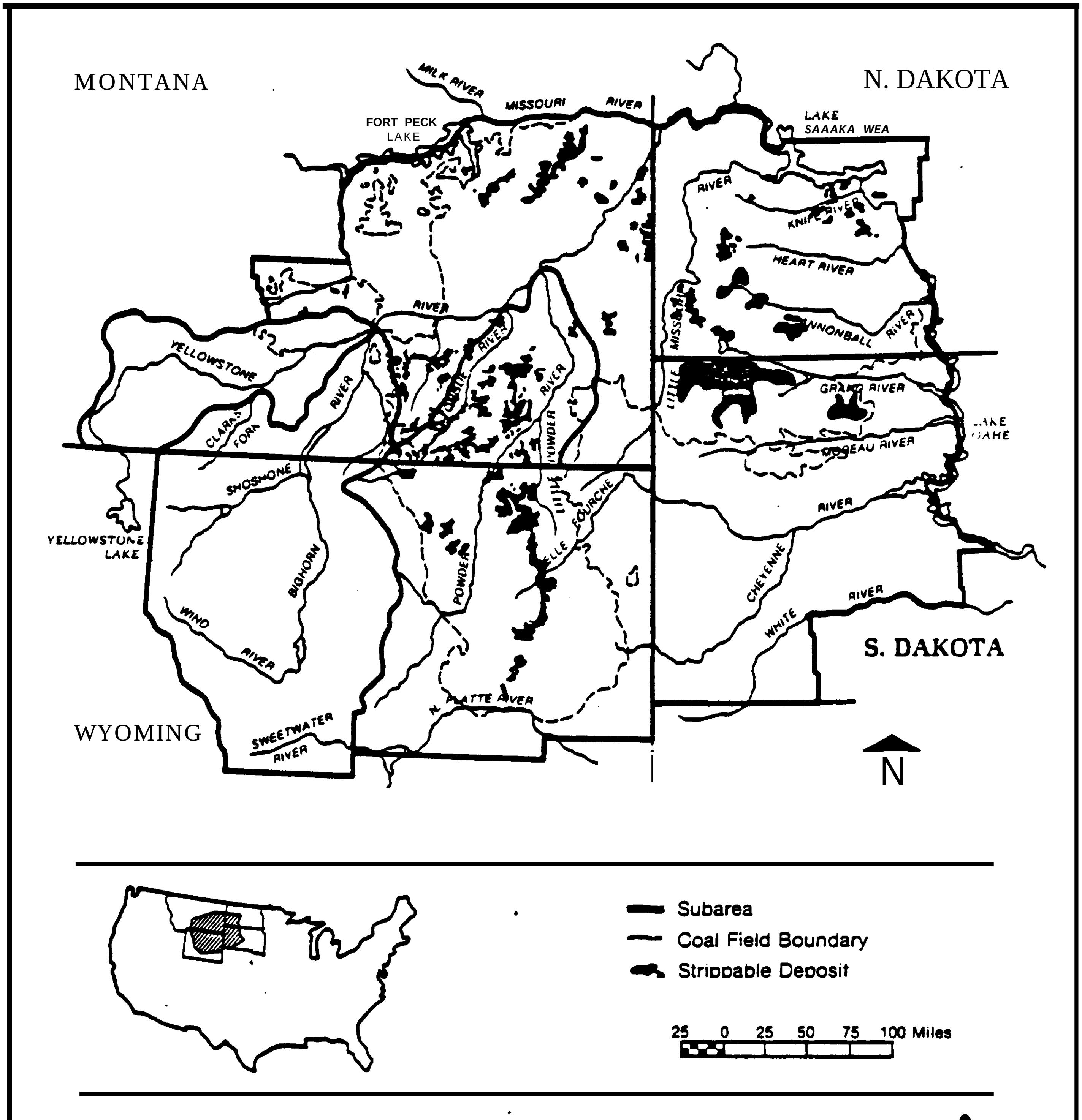
1. U.S. Water Resources Council, "Section 13(a) Water Assessment Report-Synthetic Fuels Development for the Upper Missouri River Basin, 1980."

2. U.S. Water Resources Council, "Great Plains Gasification Project, Mercer County, North Dakota; Water Assessment," 1980.

Additional documents considered in the analysis were a book published by Resources for"the Future Inc. by Constance M. Boris and John V. Krutilla, Water Rights and Energy Development in the Yellowstone River Basin, An Integrated Analysis, 1980, and the Report and Environmental Assessment: Yellowstone River Basin and Adjacent Coal Area Level B Study prepared by the Missouri River Basin Commission. Additionally, there is an expanding body

Distribution of Coal Reserves

UPPER MISSOURI REGION
Figure 7



Source: Upper Missouri River Basin 13(a) Assessment Report of knowledge, which has built up over the years, on water supplies and demands including water for synfuels. Reports have built on other reports; for example, the WRC reportedly relied upon the Yellowstone Level B Study of water supply and demands from the Yellowstone River and its tributaries.

Institutions in Basin

The institutions within the basin are generally the same as those identified in the Upper Colorado River Basin. Identification of specific key institutions is made later in this section.

Organization of Section

This section of the report is divided into two parts. The first part is a case study of the Yellowstone River Basin and the second part is a review of the above-mentioned water planning documents. Conclusions are found at the end of the second part.

This analysis concentrates on the Yellowstone River Basin and adjacent coal area because this is where the significant coal deposits lie within the Upper Missouri River Basin. Additional attention is given to development in North Dakota. Although some deposits are found in western South Dakota, the key issues are in the Wyoming, Montana and North Dakota areas, as noted in the Section 13(a) Report.

This case study focuses on several points which underscore the uncertainties in the various estimates of water availability. These include:

- o. The insufficient attention given by the various analyses to importance of, and necessity for, storage facilities to reduce annual fluctuations in flows and to provide firm supplies from year to year.

- o The limited knowledge about groundwater resources and their unknown contribution to the supply side of the water availability equation.

- o The strong legal and institutional barrier of the Yellowstone River Compact to out-of-basin use. This is an important limitation because significant coal resources are located outside the basin where water resources are limited.
- o The range of estimated capital costs for additional water supply facilities, which is too broad to be used effectively in decision-making even at the policy level.
- o Estimates of successful Indian reserve rights claims, which range from 0.5 maf to 1.9 maf per year.

WATER AVAILABILITY

Surface Water

A discussion of the basin and surface water regime is important to understand the absolute necessity of reservoir storage to meet the water demands for synfuel development in the Upper Missouri River Basin. The critical nature of this factor is not emphasized in the Upper Missouri 13(a) report, and the significance of storage in making a firm supply available each year may not be fully appreciated by the decisionmaker.

The Upper Missouri Basin encompasses four states and includes the Yellowstone, the Little Missouri, the Belle Fourche, and Cheyenne Rivers. These rivers are shown on Figure 8.

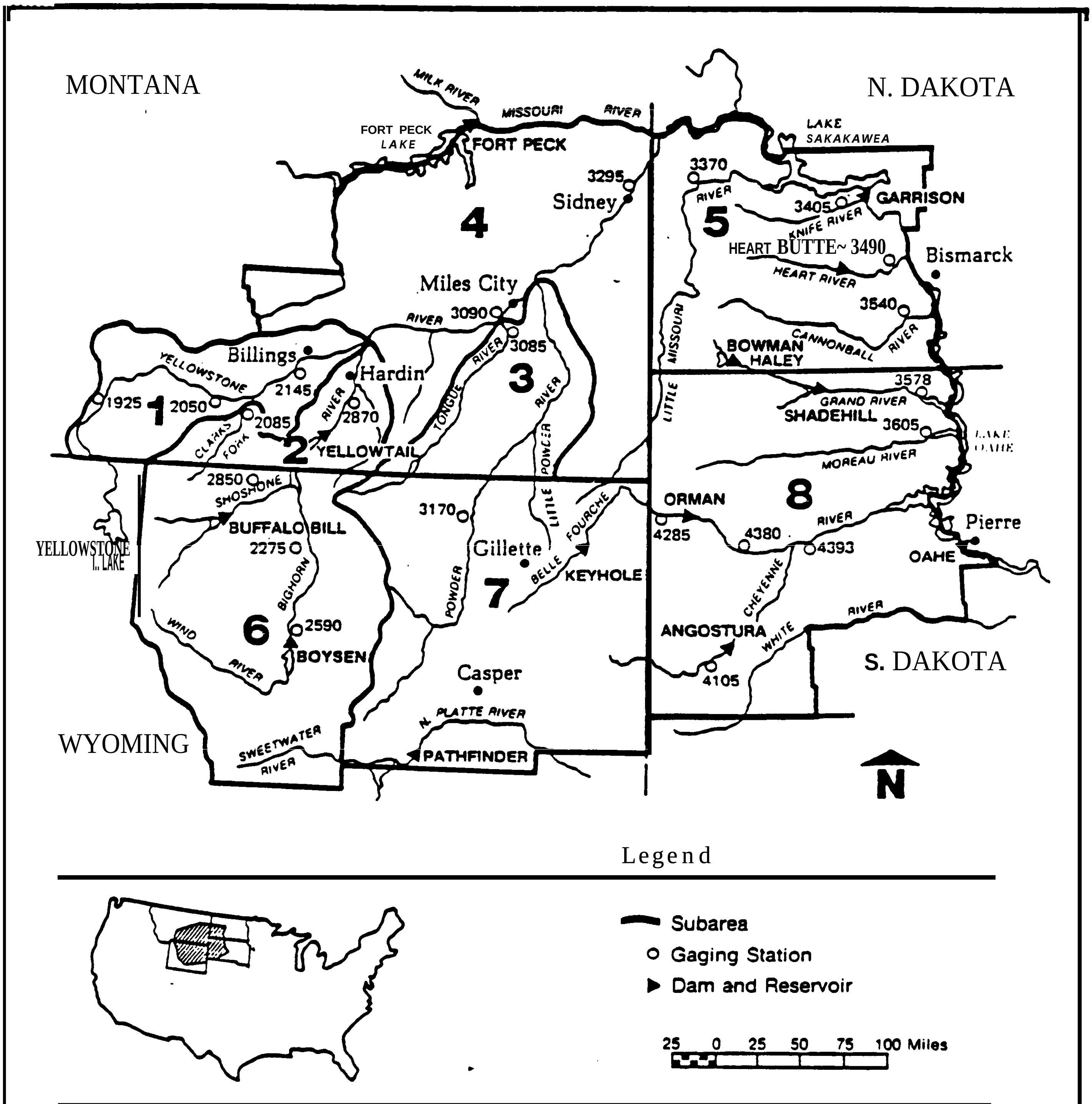
The surface water resources are summarized in Table 1 for several streamgages in the study area. The data in Table 1 are average annual streamflows based on streamgage records adjusted for stream depletions through 1975. The data are based on long term records consisting of 45 or more years of data for most of the streamgages.

Streamflows are quite variable, both seasonally and from year to year. Figure 9 illustrates the annual variability of streamflows and Figure 10 illustrates the seasonal variations. The high streamflows are somewhat coincident with the spring snowmelt runoff. Development of firm water supplies for large scale irrigation on the tributaries, for municipalities

Major Rivers within Assessment Area

UPPER MISSOURI REGION

FIGURE 8



Source: Upper Missouri River Basin 13(a) Assessment Report

Table 1 - Average Annual Streamflow and Water Quality Data

		(1,000 Acre-Feet)	
Sub-area	Stream and Location	Historical Flows	Adjusted to 1975 Depletions
1	Yellowstone R. at Huntley, MT	---	5,605
2	Clarks Fork near Edgar, MT	763.6	752.8
	Bighorn R. near St. Xavier, MT	2,609.8	2,367.6
3	Tongue R. at Miles City, MT	332.2	314.1
	Powder R. at Locate, MT	450.4	423.3
4	Missouri R. near Culbertson, MT	7,774	7,774
	Yellowstone R. near Sidney, MT	8,838.1	8,345.1
5	Heart R, near Mandan, ND	174.4	160.7
	Cannonball R. at Breien, ND	165.8	158.3
	Missouri R. near Schmidt, ND	---	16,352
6	Clarks Fork near Belfry, MT	689	675
	Bighorn R. at Kane, WY	---	2,422
7	Tongue R. at Wyoming-Montana State Line	381.1	370
	Powder R. at Arvada, WY	209.1	189.4
8	Missouri R. at Pierre, SD	---	16,939

Source: Yellowstone River Basin Level B Study; Wyoming Water Planning Program

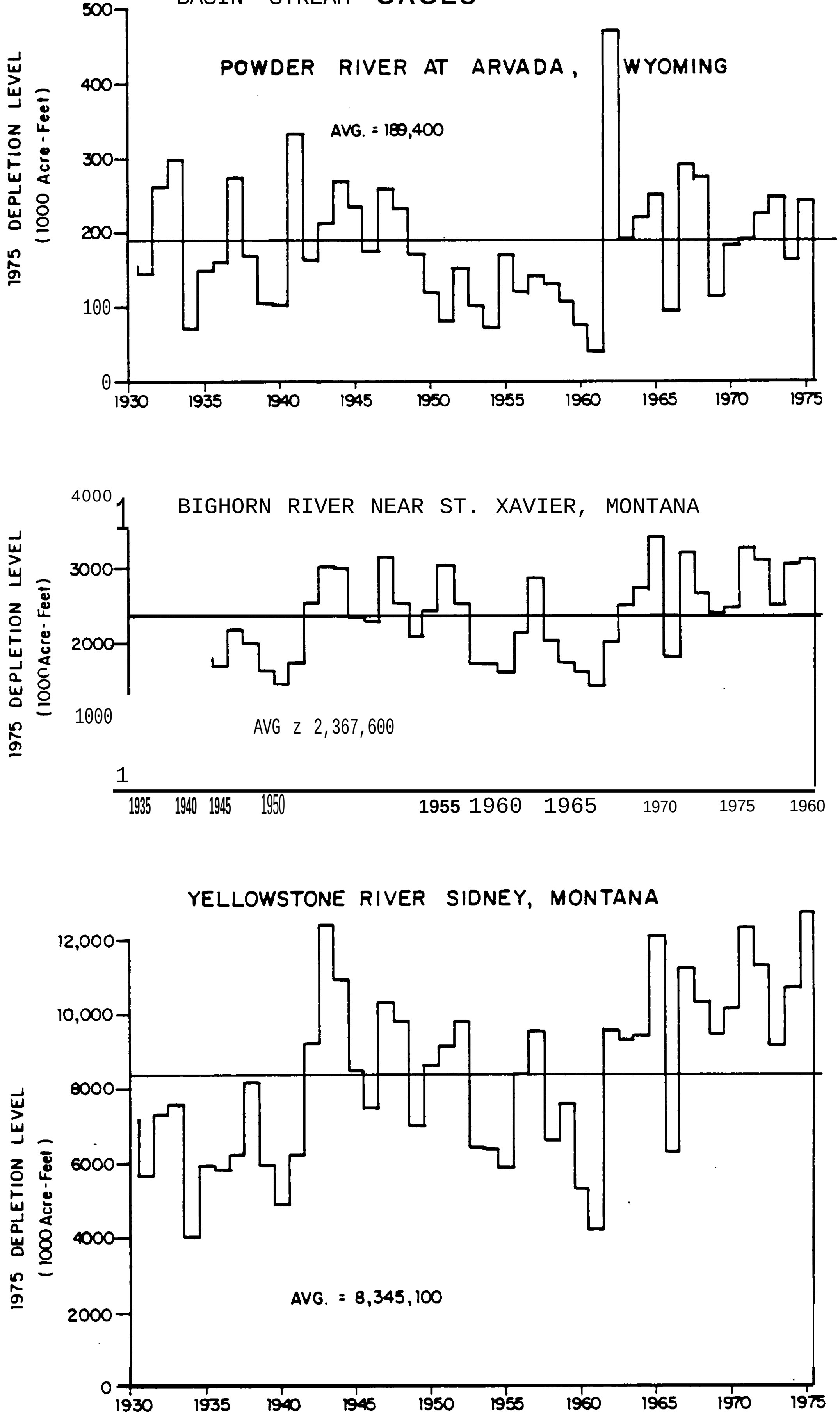
		Surface Water Quality, mg/l[1]			
Sub-area	Stream and Location	Mean Flow cfs	Mean TDS[2]	Mean DO[3]	Mean BOD[4]
2	Bighorn R. near St. Xavier, MT	4,000	622	11.4	1.7
3	Tongue R. at Miles City, MT	594	560	--	--
4	Yellowstone R. near Sidney, MT	14,527	460	9.8	1.8
7	Powdu R. near Moorhead, MT	642	1,522	9.0	3.0
8	Heart R. near Mandan, ND	--	844	9.6	2.9

Source: Yellowstone River Basin Level B Study

[1]**Based on Limited Data.** [2]**Total dissolved solids**

[3]Dissolved Oxygen. [4]Biochemical Oxygen Demand

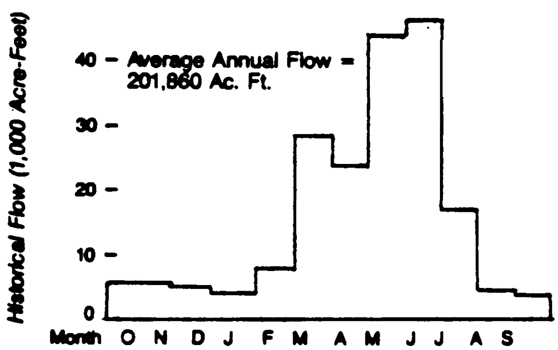
ANNUAL STREAMFLOWS, SELECTED YELLOWSTONE RIVER BASIN STREAM GAGES



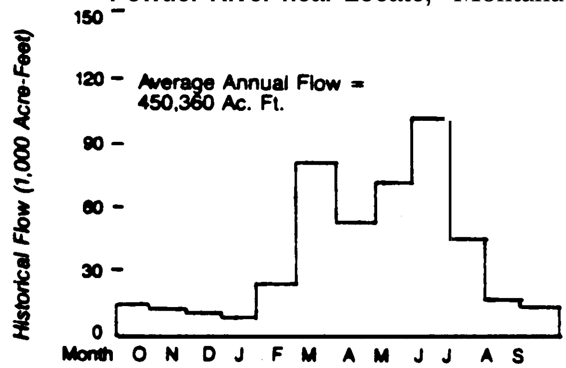
Source' Yellovmtone River Bosin Level B Study

FIGURE 9

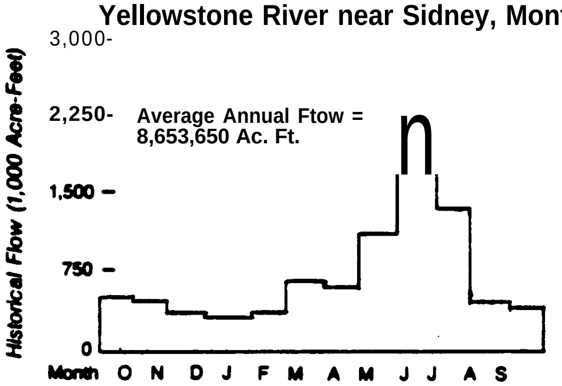
Powder River at Arvada, Wyoming



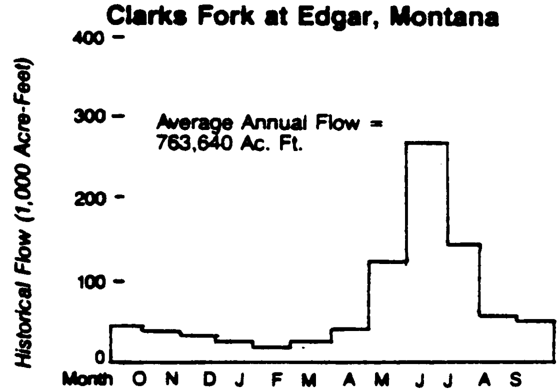
Powder River near Locate, Montana



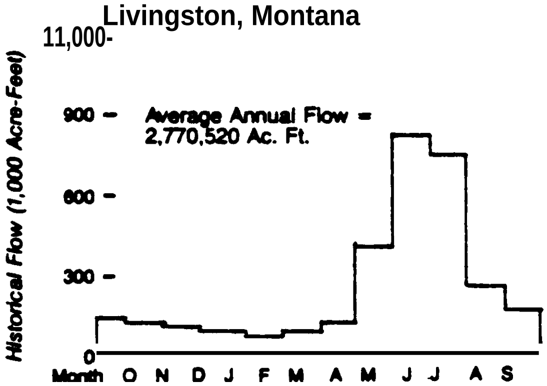
Yellowstone River near Sidney, Montana



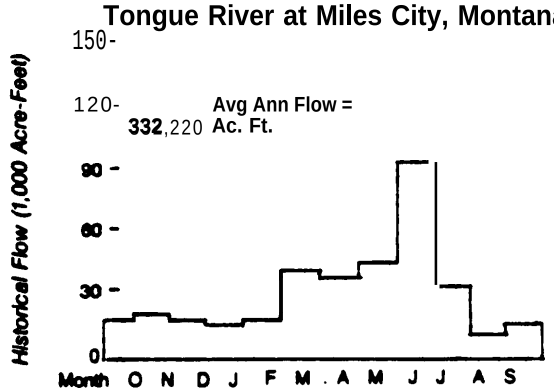
Clarks Fork at Edgar, Montana



Yellowatone Rtver near Livingston, Montana



Tongue River at Miles City, Montana



Blghorn River near St Xavier, Montana

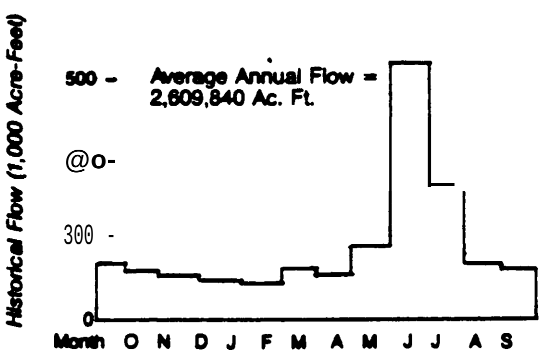


Figure 10
Monthly Flow
of Selected Rivers
in the
Yellowstone River Basin

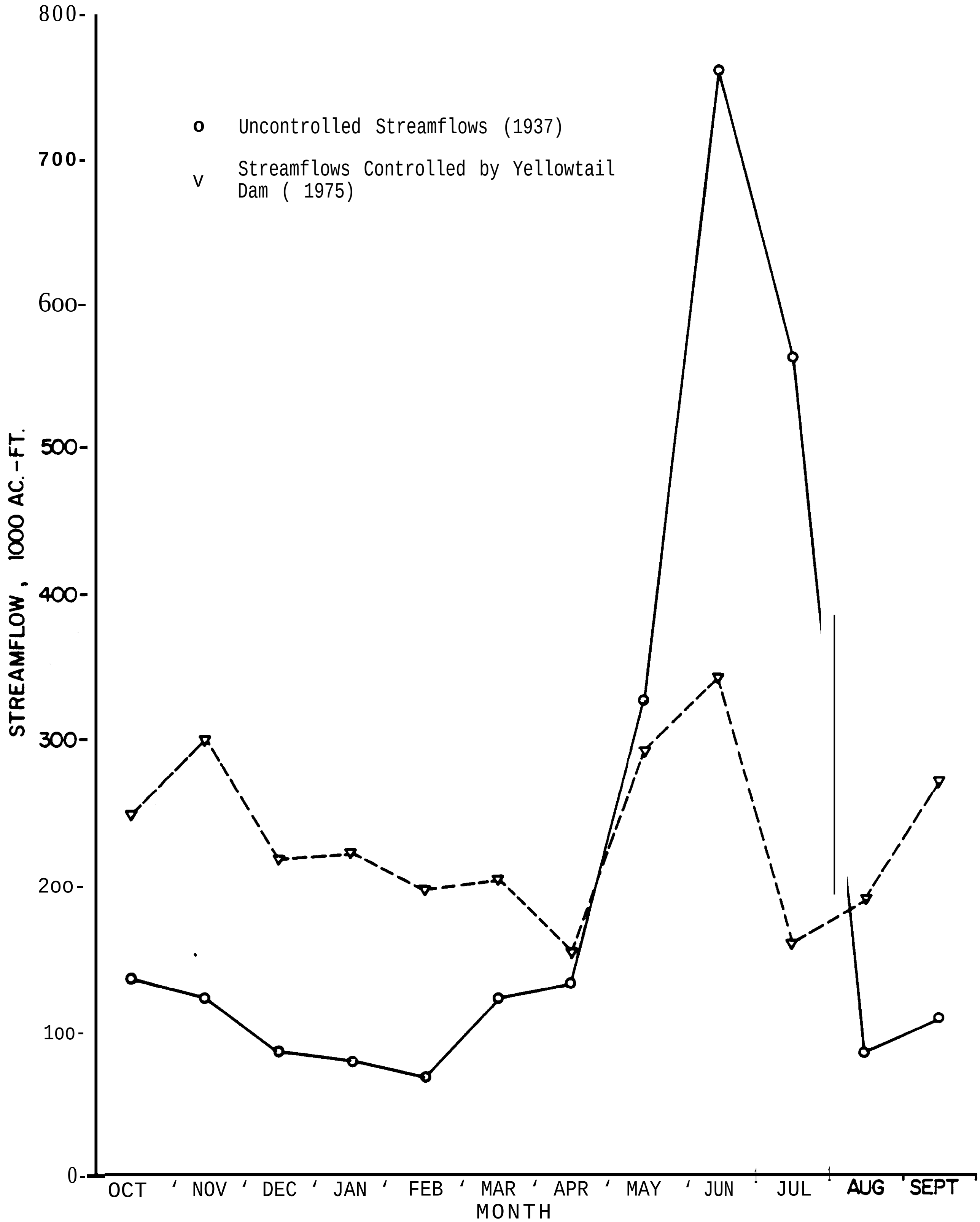
Source : **Yellowstone** River Basin Level B Study and industry, and for use in Wyoming (particularly if instream flows are to be provided) will require storage.

The variation of annual flows on the Powder River, a Yellowstone River tributary in Wyoming and Montana, is shown in Figure 9. This high annual variation illustrates the necessity of storage for developing water supplies for the uses in the area where existing development makes essentially full use of the water supplies in drought years. The data shown for the Powder River on Figure 9 illustrates that little water is available in the stream in dry years. In fact, the Powder River is dry at certain times of each year at some locations.

The only major river control reservoirs in the Yellowstone River Basin are Boysen Dam and Yellowtail Dam (Bighorn Lake) on the Bighorn River. The effect of these dams on the streamflow is illustrated in Figure 11. The monthly streamflows for the water year 1937 illustrate conditions on the Bighorn River before either of the dams was constructed. The monthly streamflows for the year 1973 indicate a comparable year of annual runoff of the Bighorn River and illustrate the effect that the upstream storage has on regulating the river. Note that the summer peak flows are stored in the reservoir and the water is redistributed into the winter release. The 1973 conditions illustrate the use of Yellowtail Dam primarily for hydropower generation and river regulation considerations, not water supply demands.

Besides the two multiple purpose regulating reservoirs on the Bighorn River, including the 922,000 acre-foot Boysen Reservoir and the 1,375,000 acre-foot reservoir behind Yellowtail Dam, there are many smaller reservoirs on tributaries which have been developed primarily for irrigation and hydropower purposes. Buffalo Bill Dam on the Shoshone River, a tributary of the Bighorn River, could be enlarged to provide river regulation and additional water supply. Lake DeSmet, which is fed by tributaries of the Powder River, has been developed by Texaco to provide an industrial water supply. The Tongue River Dam in Montana has been under study for an enlargement to include industrial water supplies. The potential Moorhead Dam site on the

ILLUSTRATION OF THE EFFECTS OF STORAGE ON STREAMFLOWS OF THE BIGHORN RIVER NEAR ST XAVIER, MONTANA



Source: Yellowstone River Basin Level B Study

FIGURE 11

Powder River could also be developed to provide future water supplies. The storage water in Boysen Reservoir and in Bighorn Lake (Yellowtail Dam) can be allocated for future industrial uses including synfuels production.

The Tongue River could be developed to provide new water supplies with an enlargement of the Tongue River Dam to 450,000 acre-feet. There would be enough water available for meeting the most energy intensive scenario postulated, provided the water would be used for energy alone (Boris, 1980). The storage facility would also provide water for the irrigation contemplated for the Montana reserved water rights and Indian reserved water rights; however, the resulting salinity from this irrigation would require instream flows for dilution. The uncertainty of developable supplies on the Tongue River relates to the uncertainties of the Indian claims and the resulting amount of developable water.

The Powder River Basin seems to offer a good potential for developing water supplies for energy. "There is no issue of Indian reserved rights claims in the Powder sub-basin nor substantial full service irrigation. The Powder sub-basin with the proposed storage appears to be the preferable sub-basin in which to locate any energy conversion facilities. ..in Montana" (Boris, 1980). This conclusion is reinforced by the probable occurrence of increasing salinity of water resulting from irrigation.

Although the Bighorn River Basin appears to provide a simple solution to providing water for energy development because of two existing reservoirs with uncommitted water available, it is the most complicated case studied (Boris, 1980). Not only are there Indian water rights claims and Montana instream flow reservations that affect the availability and the allocations of water, but also the Federal reservoirs offer more complexities for water marketing than would private reservoirs.

The mid-Yellowstone River has a 5.5 million acre-feet per year instream flow reservation placed on it by the Montana Board of Natural Resources and Conservation (BNRC) to maintain the qualities of the river as a free flowing stream. That, coupled with the existing uses of water and the reservations of water for future irrigation and municipal uses, creates a situation whereby water shortages would exist for as much as one-third of the time, depending upon the upstream development scenario utilized (Boris, 1980).

Average annual streamflows are a common indicator of surface water availability. However, the ability to average out flows is a function of the amount of storage available to carryover surpluses from wet and average years to dry years. Data on water availability for the Yellowstone River and its tributaries should be expressed in terms of the yield from long-term storage to be truly indicative of conditions on the tributary streams and even certain segments of the mainstem Yellowstone River. Such yield data on existing storage and proposed reservoirs are not presented in the Upper Missouri 13(a) report, and the decision-maker cannot determine the number or size of facilities which will be required to meet the demands. Additionally, the above-mentioned basin storage opportunities, which are identified by Boris, are not presented in adequate detail in the Upper Missouri 13(a) report.

Groundwater Resources

The Yellowstone River Basin and adjacent coal area, unlike other areas of the nation, does not have a significant shallow groundwater resource. There are shallow alluvial aquifers consisting of sand and gravel underlying some of the streams and rivers, but these have not been extensively developed because in many cases the water is of poor quality. There is a vertical series of sandstone and siltstone aquifers within the Wasatch formation and Fort Union group which underlie most of the study area. Some of these aquifers are also hydraulically connected to the surface streams.

A deeper series of sandstone and limestone aquifers extend across much of the Great Plains. Drilling depths range from 4,000 to 20,000 feet. These aquifers are estimated to have large quantities of water and are artesian in some areas. The Madison formation, which underlies part of the area, is of particular interest as a source of water supply for energy development.

Because groundwater development is limited, the hydrologic characteristics' of most aquifers are not understood and safe yields of aquifers have not been determined. However, there have been studies of the area in which estimates have been made and have been published. The Madison formation and associated aquifers are known to contain very large quantities of water; in - Wyoming, the average annual recharge rate (which determines the safe yield of the aquifer) is estimated to be 75,500 acre-feet per year (Wyoming State Engineer's Office, 1976).

The Upper Missouri 13(a) report dismisses groundwater as a primary supply alternative because of the lack of verified quantitative data. While deep groundwater will not be a primary source for the synfuels program, it can be used as a supplemental source. The conjunctive use of groundwater and surface water supplies is good water management for industry and municipalities and can serve to extend surface water supplies.

Water Laws and Management Agencies

All four of the states in the study area have water laws based on the Appropriation Doctrine. Beneficial use of water is the basis, measure, and limit of the water right. The first to beneficially appropriate the water has the senior or superior right to its use. A water right is perfected only by use and is subject to loss if the use is discontinued or abandoned. Appropriations of water are not restricted to the riparian area of a stream but may be used at sites long distances away from the water resource.

Each of the four states' water laws are somewhat different but have basic similarities. All of the states require a permit or other state license to appropriate and use water. The Wyoming water law was established in 1890 with adoption of its constitution, as was the North Dakota water law. In these states, a State Engineer grants permits for the use of water. In South Dakota the Board of Water Management, a division of the Department of Water and Natural Resources, oversees the management and regulation of water resources. Water right applications in excess of 10,000 acre-feet annually must be presented by the Board of Water Management to the South Dakota Legislature for approval.

In Montana, present water law was established by the revised constitution of Montana ratified in 1972. The Montana 1973 Water Use Act established for the first time a centralized system for the acquisition, administration, and determination of water rights. Prior to that time, water rights were determined by usage, and regulation among water right priorities was accomplished annually in the courts. The unique feature of the Montana Water Use Act is that the State of Montana, its agencies, and political subdivisions and United States Government and its agencies may apply to the Board of Natural Resources and Conservation to reserve water for existing or future beneficial uses or to maintain a minimum flow or quality of water. Reservations cannot affect existing rights. The Board is required to review reservations periodically to insure that the objectives are being met.

The significance of this authority is its impact on future water availability. In 1978, the Montana Board of Natural Resources and Conservation granted to the State Health and Environmental Sciences Department and the State Fish and Game Department the right to appropriate 5.5 million acre-feet per year of water in the lower Yellowstone River to ensure water quality and preserve wildlife for future years. The Board also reserved 535,000 acre-feet per year for future municipal and irrigation use. How the instream flow rights are to be recognized under the Yellowstone Compact is yet to be determined.

Of additional significance to synthetic fuel development is Montana's water law pertaining to water rights transfers. Boris notes (p. 22) that:

> Although the state water laws are designed to protect existing water rights, they also inhibit transfers of water rights in a way to reflect the changing relative value among uses as water becomes increasingly scarce in relation to the demands placed on it. The legislature, in changing the allocation of water among users from primarily a judicial process to primarily an administrative process, did not leave much scope for the market in allocating water. Under the Montana Water Use Act, the transfer of water rights is not governed by economic criteria.

The.. law states that an "appropriator may not sever all or any part of an appropriation right from the land to which it is appurtentant, or sell the appropriation right for other purposes or to other lands. ..without obtaining prior approval from the department." [Montana Water Use Act, Section 29(1) and Section 29(3)]. In addition to an appropriation transfer, change of use and change in place of use are also subject to approval by the Department of Natural Resources and Conservation. Boris notes that "at this time, however, holders of existing water rights are protected from the adverse effects of water rights transfers because freely transferable rights in water simply do not exist under present state law." "Transfers in water use are subject to the criterion of non-injury to existing water right holders. It is difficult to meet this criterion when transferring water use from irrigation agriculture to energy development, particularly since agricultural water rights are closely interrelated via irrigation return flow." (Boris, p.22).

A State Engineer, or equivalent, regulates water rights and water uses where necessary in all four of the study area states. The Wyoming State Engineer's staff, aided by county water commissioners, controls water storage, regulates diversions, and performs other water regulatory duties. This water administration function is carried out to a greater or lesser degree in each of the four states.

Each of the four study area states also has an agency with the authority to plan and develop water for irrigation, recreation, or other purposes. The degree of activity or extent and magnitude of projects varies, but none of the states has yet embarked on large projects that would develop extensive water supplies for large scale synfuels development.

The Water and Power Resources Service has been the primary large, multiple-purpose project developer in the Yellowstone River and tributary areas. The Us. Army Corps of Engineers has constructed large dams and reservoirs on the mainstem Missouri River. Both of these agencies have determined that water for synfuels can be marketed from reservoirs including Boysen, Bighorn Lake (Yellowtail Dam), Fort Peck, Sakakawea, and Oahe. Approximately 700,000 acre-feet may be available for industrial use from Boysen and Bighorn Lake alone. The U.S. Department of the Interior is the marketing entity for storage water from these reservoirs.

Interstate Compacts

Interstate stream compacts are agreements among the states to allocate water between states on streams which cross state boundaries. There are two interstate compacts which allocate the water resources within the Yellowstone Basin and adjacent coal area: the Belle Fourche River Compact and the Yellowstone River Compact.

The Belle Fourche River Compact recognizes the existing water rights in Wyoming and South Dakota as of 1943 and divides the remaining water between the states. Wyoming has estimated its compact water to average 7,000 acre-feet per year plus water for livestock reservoirs not exceeding 20 acre-feet capacity each.

The Yellowstone River Compact involves the States of Wyoming, Montana, and North Dakota. It recognizes all water rights existing as of January 1, 1950; provides for a supplemental water supply for these precompact water rights; and allocates the remaining unused and unappropriated flow of the interstate tributaries between Montana and Wyoming as follows:

Tributary	Montana Allocation	Wyoming Allocation
Clarks Fork “	40%	60%
Bighorn River “ (excluding Little Bighorn R.)	20%	80%
Tongue River	60%	40%
Powder River	58%	42%

The compact contains a formula for determining the compact water supplies and has several other significant provisions, including Article VI which states that nothing in the compact shall be construed as to adversely affect any rights owned by or **for Indians and Indian** tribes to the use of Yellowstone River and its tributaries. Thus the quantities available under the Compact are clouded by the uncertainty of the Indian water rights claims which have yet to be quantified and adjudicated.

Article X provides "No water shall be diverted from the Yellowstone River Basin without the unanimous consent of all the signatory States." Because a large quantity of the coal supplies of Wyoming are located outside the basin and because the Montana Legislature has been adverse toward approving out-of-basin diversions, Article X can provide a constraint on the availability of water supplies for development of these coal resources. Legislation in Montana has been proposed but not passed which would establish a review process for future out-of-basin transfer requests. The Upper Missouri 13(a) report does not recognize the fact that unless synfuels plants are located within the Yellowstone River Basin and the coal is transported to the plants, large legal and institutional impediments to' transbasin diversions must be overcome.

The Commission has ruled that consent for out-of-basin transfers must be given by the legislature in each state. Because of this ruling by the Commission, Intake Water Company has taken its petition for an out-of-basin transfer to the Montana court for determination of the constitutionality of the Montana law forbidding out-of-state transfers without approval of the legislature.

The issue of the absolute values of the states' allocations also creates uncertainty regarding the availability of water among the States. The State of Wyoming has made its own interpretation of the Compact and has estimated the unused and unappropriated waters that can be allocated to Wyoming and Montana. The compact water supplies were estimated by Wyoming to be:

Tributary	Montana Allocation Acre-Feet Per Year	Wyoming Allocation Acre-Feet Per Year
Clarks Fork	285,000	429,000
Bighorn River	500,000	1,800,000
Tongue River	144,700	96,400
Powder River	166,600	120,700

Montana has not agreed with the Wyoming estimate, but it has not developed its own estimates probably because instream reservations conflict with the consumptive use provisions of the Compact.

As previously stated, storage will be required to develop the compact allocations. This is because of the extreme variation in the remaining supply as a result of existing uses taking large portions of the firm water supply, particularly in dry years. Reservoir evaporation would decrease the usable quantities of water and would be a part of each state's Compact use. It may be unlikely that the full compact quantities of water would be developed, particularly in the Clarks Fork and Bighorn Rivers because of the limitations discussed earlier.

Federal Reserved Rights

The reserved water rights doctrine implies that water was reserved for use on Federal reservations of land in accordance with the purpose of the land reservations. The effect of Federal reserved rights includes the following: (1) when water is eventually used on the Federal reservation, the water rights of the United States become superior to private water rights that were acquired after the date of the reservation; (2) the Federal use is not subject to s$ate laws regulating the appropriation and use of water. States obviously disagree with these claims. These claims present a major source of uncertainty in water planning.

Indian water rights, which are a part of Federal reserved water rights, are also difficult to quantify in view of the varied interpretation of treaties and agreements between Indian tribes and the United States as approved by acts of Congress or formalized by executive orders. The "Winters Doctrine," which resulted from a 1908 court decision, maintains that the formation of an Indian reservation has necessarily reserved water without which the

Indian reservation lands would have no value. Varying interpretations of the Winters Doctrine would lead to variable quantities of reserved water for the Indian reservation. These interpretations fall into two categories:

(1) Restrictive Criterion. This interpretation states that the quantification of Indian rights should be based upon the amount of acreage which is “practically irritable.” Case law has held that the quantities of the Indian water rights can be measured by the amount of water required for the practically irrigable lands within the reservation.

(2) Expansive Criterion. This interpretation is based on the premise that the Indians are entitled to the water necessary for all present and potential uses of water, and that such uses need not have been contemplated at the time of the reservation. lhese uses would include water for recreation, industry, energy related development, and instream flow. It is still unclear from case law whether the non- irrigation water uses can be considered as a portion of the irrigation water allotment simply changed from its original purpose or whether non-irrigation developments are in addition to the irrigation water quantities.

The two interpretations lead to a wide range in the potential impact of future consumptive use for Indian reserve rights. These estimates range from 0.5 to 1.9 maf. The only official estimates of Indian reserve rights are a 1975 Department of Interior report projecting diversions of 4.8 maf and depletions of 1.9 maf, and a 1960’s Bureau of Reclamation study. The lack of quantitative data is a result of local and state political forces opposing a quantification of the Indian rights, as well as the reluctance of the tribes to provide information while litigation over their rights is proceeding.

Within the Yellowstone River Basin and adjacent coal area there are at least three general water rights adjudications currently in state courts to attempt to quantify the Indian and other Federal water rights. These cases involve the Wind River Reservation, Federal lands in Wyoming, and the **Crow** Indian Reservation - all of which affect the Bighorn River; and the Northern Cheyenne Indian Reservation, which affects the Tongue River. The State of Montana is attempting to negotiate Indian water rights through its Reserved Rights Compact Commission. The Crow and Northern Cheyenne tribes are involved in the Yellowstone water rights issue and negotiations are in progress with the Northern Cheyenne Tribe.

The effect of the Indian claims on projections of water requirements is illustrated in the next section of this report. These claims have helped create uncertainties of water availability in the Yellowstone River and its tributaries. In fact, the Water and Power Resources Service limited its water marketing from Boysen Reservoir for both irrigation and industrial purposes because of the Indian claims.

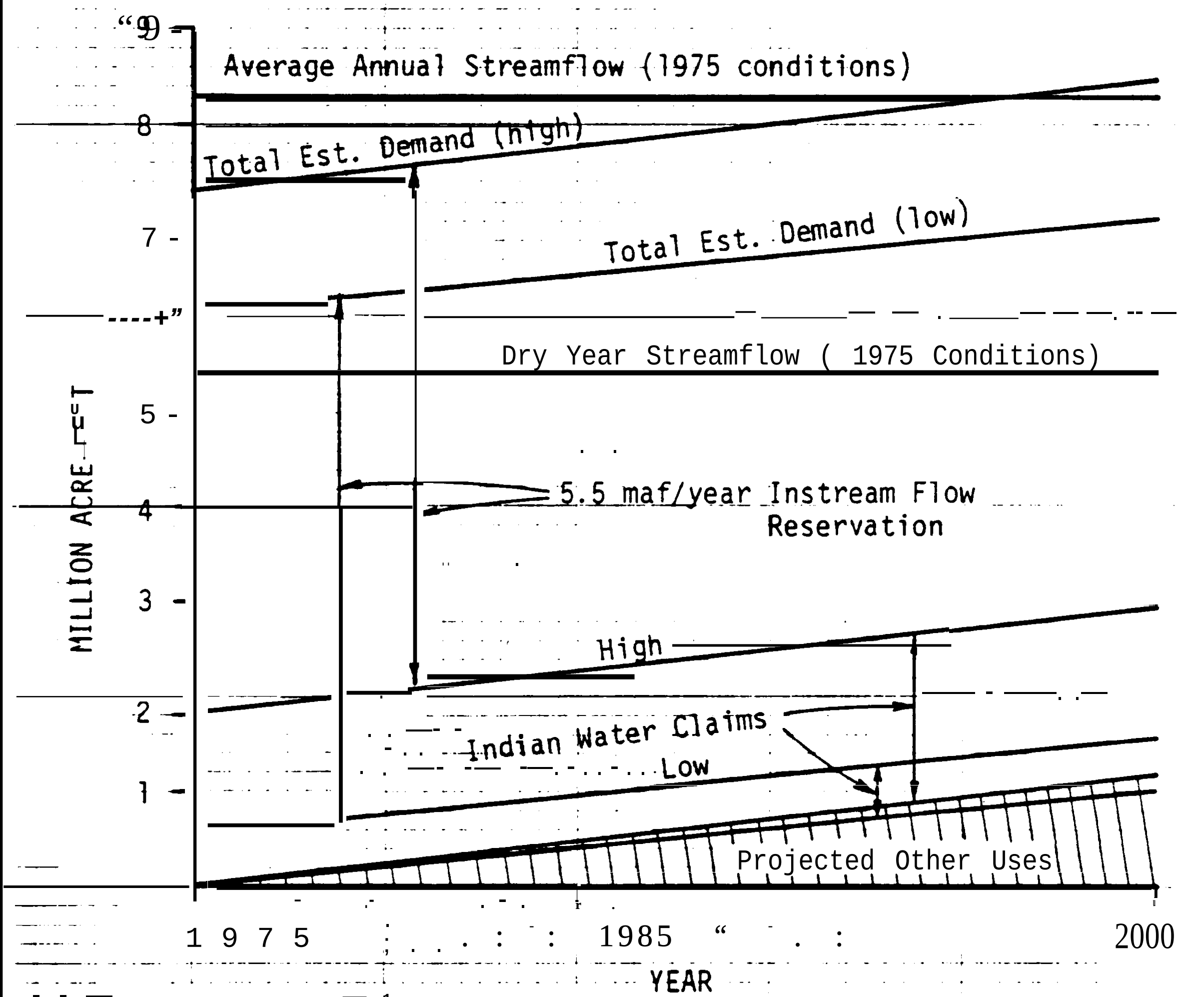
Reservations of water for other Federal purposes appear to be relatively small. They are related primarily to recreation, stock, and domestic water uses on the National Forests and on land administered by the Bureau of Land Management under various acts and reservations.

Proiected Water Uses

Projected new incremental consumptive uses or depletion of the Yellowstone River and tributaries are shown on Figure 12. The range of projected other uses was derived. from state estimates (higher values) and from the Yellow-stone Level B study (lower values). The low estimate for Indian water claims include the depletions from water uses for irrigation, domestic, industrial, minerals, energy, and recreation claimed by the tribes on the Wind River, Crow, and Northern Cheyenne Indian Reservations (Boris, 1980). The low range of Indian claims on Figure 12 was derived by substituting estimates for irrigation made by the U.S. Bureau of Reclamation in the late 1960's. The State of Montana’s 5.5 million acre-feet per year instream flow reservation has been added to the low and high water use projections to illustrate its effect of committing flows of the Yellowstone River at

STREAMFLOWS AND PROJECTED INCREASED INCREMENTAL WATER DEPLETIONS, YELLOWSTONE RIVER AT SIDNEY, MONTANA

FIGURE 12



WRIGHT WATER ENGINEERS, INC.
ENGINEERING CONSULTANTS
2420 alcott str=eet
Denver, CO 80211

Sidney, Montana. The dry year and average year annual streamflows are also plotted on Figure 12 to provide benchmarks of water availability.

Figure 12 shows two scenarios for projected incremental uses for the year 2,000:

(1) Projected other uses plus low estimates of Indian claims plus Montana's instream reservation show a total incremental demand of approximately 7 maf per year. These demands would not be met in a dry year without additional storage, but they could be met if sufficient storage were provided to average out the variation in annual flows.

(2) Projected other uses plus high estimate of Indian claims plus Montana's instream reservation show that not only would these demands not be met in a dry year without storage, but also they would exceed the average annual flow with storage. The estimated high incremental demand is approximately 8.5 maf.

Before concluding that insufficient water exists to meet the high scenario, one should remember the uncertainties inherent in these demands. The non-irrigation portion of the Indian water claims may not be recognized by the courts, and the irrigation claims may be either reduced or not brought into fruition because of economic considerations.

Most importantly, however, it is not clear from the estimates in the literature whether water for industrial, minerals, and energy purposes claimed by the Indians is duplicative of the "other" uses for these purposes. The high estimates for Indian claims include use of Indian water for energy development, industrial and mining. It is assumed that the Indians would lease their water for these purposes. The projected demands for “other uses” also includes water for energy, industry, and mineral development. It is unclear whether these estimates are additive or the estimates in the literature double count this demand. Also, the projected irrigation portion of other future water use may be limited by economics as well.

In other words, it is quite likely that increased water uses by year 2000 will not meet projected demand levels. It appears equally logical to conclude the Montana instream flow reservation also will not be realized for the dry year condition unless additional carryover storage in Montana is provided.

Compounding the uncertainties of demand illustrated above is the opposition in Montana to any new mainstem Yellowstone River storage reservoir. The State of Montana has made a strong commitment to the preservation of the free-flowing character of the Yellowstone River. New storage reservoirs on tributaries would most likely be constructed primarily to provide for new consumptive water uses, and such reservoirs have been encouraged in Montana for the most part.

Projections of water needs for synfuels are given at this point to faci” tate discussion. The WRC Section 13(a) projections give a range. Both scenarios result in higher water requirements than included in Figure 9 projections. The WRC projections are for two cases, or levels, of synfuels production: (1) a base case, which provides for President Carter's 1979 national goal to decrease oil imports; and (2) an accelerated case. Water use projections are based on assumed types of synfuels plants (primary water requirements) and ancillary development requirements (secondary water requirements for the various sub-basins shown in Figure 8. The water requirements are then aggregated for the total area in Table 2 (Section 13(a) study).

TABLE 2 - Primary and Secondary Synfuels
Water Requirements, Acre-feet per year

Water Use	Base[1] Case 2000	Accelerated Case 1985	Accelerated Case 2000
Secondary Uses			
Coal Mining/Land Reclamation	24,200	10,400	31,200
Off site Electric Generation	20,600	5,700	30,200
Municipal Water Supplies[2]	8,200	3,700	12,000
Subtotal	53,000	19,800	73,400
Primary Uses	194,000	78,000	276,000
Total	247,000	97,800	349,400

[1]No synfuels plants under base case in 1985.
[2]Diversion rates shown, depletion 50 to 100%, depending upon wastewater Treatment.

Comparable commercial scale plants which produce different kinds of synfuel products have different water demands. Also different plant processes for producing the same product require higher water demand than other processes. Therefore, it is advisable to utilize a range of water requirements in predicting the future, unless the specific products and processes are known. The Section 13(a) report provided a range as shown in Table 3 (Water Requirements); however, the report does not specify the unit values which were used to determine the ultimate water requirement so that the decision-maker can quantify the range of uncertainty in total projections. The unit values listed below were deduced from Tables 16, 17, 18, and 19 in the Section 13(a) report. These show that the projected water requirements for the high Btu gasification in the accelerated case could range from approximately 61,000 acre-feet below the estimate to 116,000 acre-feet above the estimate. The requirements for liquefaction might be approximately 28,000 acre-feet below the estimate. Thus the range of uncertainty from the estimated projections is -89,000 acre-feet to +116,000 acre-feet, or the total range in water requirements is 173,420 acre-feet per year to 378$060 acre-feet per year.

TABLE 3
WATER REQUIREMENTS FOR SYNFUEL TECHNOLOGY
(Section 13(a))

Unit Size Technology	Water Require-ments (ac-ft/yr)	Assumed Unit Value Used for water Pro-jections in Table 19, Section 13(a) (ac-ft/year)	Total Number of Plants in Acceler-ated Case (Table 16)	Total Estimated Water Require-ments (ac. ft/year)	Range of Uncertainty (ac-ft per year)
High Btu Gasification	5,960 to 14,030	Varies by subarea	22	192,170	131,120 to 308,660
LOW Btu Gasification	6,550	6,550	2	13,100	-o-
Liquefaction	4,700 to 7,800	7,800	9	70,200	42,300 to 70,200
TOTAL			33	275,470	173,420 to 378,860

ANALYSIS OF REPORTS

Background

This assessment evaluates two documents prepared by the U.S. Water Resources Council as required by Section 13(a) of the Federal Non-Nuclear Energy Research and Development Act of 1974:

1. The October, 1980, "Section 13(a) Water Assessment Report, Synthetic Fuel Development for the Upper Missouri River Basin," was prepared by the Water Resources Council essentially to assess the effects of a program of development which would be aided or stimulated by the Department of Energy. This study relied upon the Yellowstone River Level B study for its data on water availability.

2. The WRC 13(a) water assessment for the Great Plains Gasification Project reports its findings concerning a single proposed synfuels plant in North Dakota.

An expanding body of knowledge about the Yellowstone River and adjacent coal area has developed over the past decade. The Level B study used this information and a detailed coal related economic study for formulation of alternative plans for water resources activities and developments. The list of references at the end of the report shows the applicable studies.

The Section 13(a) assessment assumes synfuels development in greater amounts sooner in time than the Upper Yellowstone Basin Level B study, but the water requirements are less than were studied in the Northern Great Plains Resource Program (NGRP). On the other hand, the NGRP study, unlike the Level B and Section 13(a) studies, did not consider increased irrigation.

Upper Missouri 13(a) Report

The report was prepared to comply with the Federal Non-Nuclear Research and Development Act of 1974, which requires an assessment of the impacts of the development of a technology upon water resources if that technology will have a significant consumptive use of water.

The report covers the water resource availability and the probable impacts from developing water for 21 to 33 synfuels plants in the 156,000 square mile Yellowstone River Basin and adjacent coal area in Wyoming, Montana, North Dakota, and South Dakota. It is stated that the report was not prepared for site specific assessments.

Water Availability. Surface water availability is addressed on the basis of average annual flows in a manner similar to Table 1 of the case study. The variability of flows is indicated by graphs and percentages similar to Figure 6 of this case study. The annual variability of flow is indicated only for three rivers in the area by giving the percentage of dry year to average streamflows. The effects that reservoirs can have on stream flows such as Figure 11 of this case study is not given and the critical importance of storage to future availability is not quantified nor stressed in the report.

While the descriptions of impacts of development give percentage changes in low flows, present conditions of low flows are not given in the assessment; thus the absolute change and the severity of the impacts cannot be determined. For example, impacts on fishery habitat conditions with and without synfuels development are given for the year 2000, but without knowing what streamflow levels there would be, the reasonableness of the statements cannot be determined. The Section 13(a) report offers little data upon which to understand the differences between present conditions and year 2000 conditions with and without synfuel development, and this leads to uncertainty regarding the validity of the conclusions.

Table 4 in the Section 13(a) report presents "withdrawals" of surface water. Subareas 6 and 7 were checked with readily available information, and the values are apparently grossly understated. However, the inaccuracies in Table 4 do not affect the future depletion estimates in the report, which when checked against the increased depletions estimated by the states and by the Yellowstone Level B Study, appear to be reasonable.

Further comparison of depletions indicates that the states' and Level B figures include water development for synfuels production, although at rates much lower than the Section 13(a) report. This, however, is understandable, since the Section 13(a) report is based on an increased national program of synthetic fuels production to meet the nation's needs.

Three kinds of coal conversion technology are considered: high BTU gasification, low BTU gasification, and liquefaction; and ranges of water requirements are given for each of the technologies. The estimation of the ranges of unit water requirements for the various types of synfuels production are consistent w{th estimates being used internally by energy companies. The ranges of water use, however, are combined into a single water requirement level for each of the two projection levels of development--base case and accelerated development case. While this is normally done in water resources planning studies in order to reduce the number of cases which must be studied and presented in a report, the basis for selection of the unit value is not provided. The uncertainty which this causes is enumerated in the case study. “

The water requirements projections for synfuels production also include ancillary water needs for coal mining land reclamation, offsite electric generation, and municipal water supplies, These figures appear to be consistent with internal industry estimates and universal municipal standards.

The subject of groundwater is covered rather quickly, and groundwater is not considered as an alternative water source for synfuels development. While it is reasonable to assume that groundwater will not be the primary source for the 33 new unit-sized plants in the accelerated case, it can be used conjunctively with surface water supplies to enlarge the total water supply available. For example, it appears that the first gasification plant for Wyoming, at least, will utilize groundwater for a portion of its supply. Groundwater can also provide a supplemental source for the ancillary uses by mining and municipalities. Groundwater is presently supplying a significant portion of the water requirements for mining as a result of mine dewatering This use is noted in the assessment report, but none of the future water requirements for synfuels mines are assumed to be from groundwater.

The assessment presents three options of surface water development for meeting the synfuels water needs for the base and accelerated cases for the year 2000. The major variable in the three options for the basin is the water supply alternative for the Montana-Wyoming synfuels developments. Three options of water development from the Yellowstone River and its tributaries are diagramed. However, based on the foregoing discussion in the case study, it would appear that a section on river operation and reservoir management is needed in the assessment report, including a discussion of present and future reservoirs and their operations. However, no discussion is presented. The report relies on the stated availabi1ity of 700,000 acre-feet per year of industrial water supply from Boysen and Yellowtail reservoirs, pending completion of EIS and WPRS water availability studies.

Institutional, Legal and Economic Aspects. The institutions of state water laws, interstate compacts, and Federal and Indian reserved rights described in the overview section of this report are placed in an appendix to the Section 13(a) report. The effects of the institutional and legal constraints and the uncertainties described herein, however, are only given brief mention in body of the assessment. For example, in subareas 2 and 6 (which are the Bighorn River and which contain the two regulating reservoirs, Boysen and Yellowtail) the report only makes a few statements. "The legal availability of water may be influenced by quantification of Federal reserved and Indian water-rights in both subareas 2 and 6." "The legal availability of water in this subarea (6) may be influenced by quantification of Federal reserved and Indian water rights." "No synfuel siting was hypothesized for subarea (2 and) 6."

These statements are notable for what is not said more than what is said. For example, if the Indian claims prevail, there may not be 700,000 acre-feet per year available from the Bighorn River unless the Federal government markets the water without regard to the claimed Indian reserved water rights or unless the water is purchased from the Indians.

It is important to note that water from the Bighorn River will not be used within the Bighorn River Basin because of the lack of demand. It can be transported for synfuels production within the Yellowstone River Basin, but it cannot be used outside the basin without approval of the compact states. What seems to be overlooked in the report is the fact that a considerable amount of the coal for synfuels development lies outside of the Yellowstone River Basin. Unless the synfuels plants are located within the Yellowstone River Basin and coal is transported to the plants, the water cannot be taken to the plant sites without the approval of North Dakota, Montana, and Wyoming. While these states and the Yellowstone River Compact Commission have stated that approval of the states means approval of the state legislatures, the approval process is still uncertain as noted earlier.

The climate for approval by the state legislatures is cautious. Montana wishes to preserve the amenities of the Yellowstone River and has gone to great lengths in establishing streamflow reservations and non-energy reservations of water, making it more difficult for coal related water appropriations. Wyoming has placed restrictions on the exportation of water in coal slurry pipelines. In Wyoming there are many applications for reservoir permits for water developments presumably for synthetic fuels production, and the legislature has not yet entered the arena of limiting such appropriations. These illustrate the political constraints which energy development faces in the Yellowstone Basin.

The Section 13(a) report mentions that Indian reserved water rights and instream flows could create a limitation on available water supplies. In describing the water available for the lower Yellowstone in Montana (subarea 4), it is stated: "The aggregated requirements of synfuel development under the accelerated case would be about 2 percent of the average annual flow in 2000, and nearly 3 percent of the dry year flow, and about 15 percent of low flow conditions. These orders of magnitude indicate possible conflicts between instream uses and synthetic fuels development. The legal status of available water supplies may be affected by quantification of Federal reserved and Indian water rights in the subarea and upstream." The report goes on to describe the Montana 5.5 million acre-feet per year of instream flow water, and states, "This reservation will exceed the projected dry year flow of the Yellowstone River and may act as an important constraint on the availability of water supplies in this subarea for synthetic fuels."

This statement seems to miss the point that this instream flow requirement may also restrict the availability of water upstream of the subarea as well, since water from the tributaries makes up the instream flow. Water which could have been stored for upstream uses will need to be passed downstream to meet instream requirements. At least it would seem that this instream flow reservation could restrict appropriations of water in Montana, though not in Wyoming because the compact allocation is based on consumptive uses and Wyoming is not obligated to deliver water for non-consumptive uses.

Option 1 for meeting the projected synfuels water supplies is grossly shown as a diversion from the Powder River toward the Belle Fourche River Basin, and the report narrative states that water would be supplied for the development of streamflows near coal deposits with limited development of aqueducts, reservoirs, and pumping stations. By comparing the future water requirements given in the report tables within each of the subareas with the Option 1 map, it becomes apparent that outside of the rather large projected future water requirements in North Dakota, the largest combined water requirements are within the Tongue and Powder River basins and adjacent coal areas near Gillette, Wyoming. Comparison of the water requirements with the waters available in these two streams would indicate that water could be supplied if the institutional constraints of the Yellowstone River Compact are resolved. Apparently, the assessment report contemplates new storage on both the Tongue and Powder rivers, but this important factor is never spelled out.

Option 2 for meeting the synfuel water needs contemplates use of Yellowtail Reservoir water diverted from the Bighorn River in Montana. Once again, the Yellowstone River Compact and Indian reserved rights constraints could affect the amount of water that could be developed for the Gillette area coal fields.

Option 3 proposes a major aqueduct system diverting from the Yellowstone River downstream of the Bighorn River and pumping water back into the Montana and Wyoming coal fields. This option also has the Yellowstone River Compact out-of-basin diversion constraint. Apparently, the diversion would use identified water releases from Yellowtail Reservoir delivered to the aqueduct to avoid the instream flow problems.

The estimated capital costs for water supply in the Section 13(a) report range from $0.5 to $1 billion. No breakdown is given for these costs or for the cost for each option. Such a wide ranging estimate needs to be substantiated with assumptions, storage requirements, yield, and unit data. Without such documentation or basis, the values are meaningless for the decisionmaker. The annual costs for each surface water supply option ***are*** listed for the base case and accelerated case. For the accelerated case, year 2000 annual costs are as follows:

Water Supply Option	Million Dollars
1	38
2	51
3	63

These costs are for 50 year amortization at 6-5/8 percent interest, the rate specified by law for evaluation of Federal water projects. Again, the bases for these numbers are not given and the costs of storage and delivery are not apparent, even though they are critical components of future water availability.

WRC, Great Plains Gasification Project Section 13(c) Report

General. This is an assessment by the Water Resources Council of impacts on water resources which will result from the commitment of 12,800 acre-feet of water per year for a gasification plant near Beulah, North Dakota, in Mercer County. Water has been made available for the project from Lake Sakakawea under the U.S. Department of Interior water marketing program, and the state of North Dakota has granted a conditional water right permit for the project.

The report describes in some detail the plant processes and uses of water. Water requirements are summarized for the gasification process; associated electric power plant; mining; and increased rural, domestic, and commercial consumption. Groundwater resources are described briefly, and the conclusion is reached that the water requirements for coal mining activities (270 acre-feet per year), adjacent municipal water systems (amount not given), and rural domestic users (410 acre-feet per year) can be met from groundwater supplies.

The impacts of water supplies from the gasification project are listed to be the water use from Lake Sakakawea and the effects of mining on aquifers in terms of quality and quantity of water. It is stated in the impact section that the municipal water and waste water systems already have been upgraded to be able to meet the increased requirements for the project.

Effectiveness for Decision-Making. While The Great Plains Gasification Project Assessment Report appears to contain enough information to adequately assess the impacts of the project on water resources, it did not contribute to the decision-making process. All the major decisions had been made on the project before the report was prepared, and the report only served to meet the requirements of the law.

CONCLUSIONS

The studies indicate that for the year 2000 base level synfuels development of 1.1 million barrels of oil equivalent per day, water consumption would be 250,000 acre-feet of water per year. An accelerated development of 1.7 million equivalent barrels of oil would consume 350,000 acre-feet of water per year. Of the totals, 50,000 and 74,000 acre-feet per year would be consumed by coal mining and land reclamation, thermal electric power generation, and municipal water supply.

Surface water is generally available to support coal conversion development; however, the studies conclude that regional availability of groundwater can only be assessed by further field studies. If water requirements are met by development of water sources nearest the plant sites, up to 20,000 acre-feet per year of water may have to be transferred from current or projected irrigation use. Water requirements met by diversions from the Bighorn or lower Yellowstone Rivers would require no transfer of current or future water uses.

The Section 13(a) report indicates that additional water systems would require careful planning, particularly in the Tongue and Powder River basins, including determination of the magnitude and location of water requirements, full examination of water development alternatives, and minimization of conflicts with instream uses and existing water rights. This is an understatement in view of coal location and Yellowstone River Compact considerations.

These reports cover most of the aspects of water availability for synfuel development in the Yellowstone River basin; however, there are several critical factors which are not treated or treated too briefly for full appreciation by the decisionmaker:

- The necessity of additional storage for meeting water supply requirements of proposed synfuel development.
- The legal impediment of the Yellowstone Compact to out-of-basin transfers and the political reluctance to approve such transfers
- The component costs of storage and conveyance facilities
- The impact of Montana's instream flow reservation of 5.5 million acre-feet on water supply and timing of supplies
- The uncertainty regarding the amount of water which is likely to be successfully claimed by Indian reservations
- The potential impacts of additional regulation and synfuels use on downstream uses in the Missouri and Mississippi River Basin for hydropower navigation, fish and wildlife, and future consumptive uses.

These uncertainties cannot be adequately quantified because of lack of supporting data and assumptions. It can be concluded, however, that the low projections for future depletions can be met with additional storage reservoirs. However, whether or not the high projections shown in Figure 12 can be met is dependent upon the extent to which the constraints identified herein materialize.

SECTION VI
DISCUSSION AND CONCLUSIONS

It is recognized that estimating future water availability for synfuel development is a difficult and complex task often involving inadequate data, imperfect demand forecasting procedures, unforeseen political and legal factors, and time and budget limitations. Furthermore, it is recognized that it is always easy to criticize the work of others. The following conclusions and recommendations are not intended as criticism for the sake of criticism, but rather they are offered to help prepare the way for more effective assessments of water availability in the future--not only for synfuel development, but water resources management in general. They are also offered to highlight for the decisionmaker the difficulties and uncertainties underlying predictions regarding water availability.

The objective of the study has been to: (1) describe and analyze the hydrologic, institutional, economic, and legal issues involved in assessing and interpreting estimates of water availability for synfuels development, and (2) evaluate the adequacy of currently used estimates of water availabi1ity as a basis for energy planning. In accordance with this objective, the conclusions and recommendations are divided into several categories.

GENERAL

The reports and studies reviewed vary significantly in effectiveness for estimating water availability for synfuel development.

The site specific studies reviewed (i.e. "Water Assessment Report for the Great Plains Gasification Project, Mercer County, North Dakota" and the "Water Assessment for Monongahela Synfuel Plant") present adequate water availability assessments in accordance with the relatively limited objectives of the reports. However, the Great Plains 13(c) report was generally precluded from use by decision-makers because the study was done after the decisions had been made.

Reports such as the Section 13(a) assessments of water availability in the Upper Colorado and Upper Missouri Basins (Colorado Department of Natural Resources, 1979 and U.S Water Resources Council, 1980) are generally appropriate, within their limitations, for broad policy decisions by Governors, state agencies, Congress, and energy companies. These reports provide a general indication of water availability and the level of synfuel development that could be supported--if various uncertainties were resolved in specific ways (e.g. the State of Montana continues its reservation of 5.5 million acre-feet on the Yellowstone River). Therefore, the reports are useful to decision-makers concerned with broad policy decisions in the immediate future before the plethora of uncertainties in the long-term (perhaps after 10-12 years in the future) makes meaningful analysis difficult and speculative. Such reports, however, are generally inappropriate for use in specific synfuel facility siting decisions because they: a) present only aggregated flow data for major basins, b) contain only limited, general cost data concerning alternative supplies, and c) lack necessary data concerning reservoir operating policies, minimum flow requirements at specific points, and so forth.

The Upper Colorado River Basin 13(a) Assessment, “The Availability of Water for Oil Shale and Coal Gasification Development in the Upper Colorado River Basin,” represents the most useful and complete report reviewed. It: (1) provides a relatively good discussion of alternative sources of supply; (2) generally gives an adequate discussion of the legal, economic, and institutional constraints, and the uncertainty surrounding these constraints; and (3) provides ranges of future estimated demand and depletions while being candid about the uncertainty in these forecasts.

The various reports reviewed for the Upper Mississippi Basin were concerned with water availability for synthetic fuel development mainly in the State of Illinois because of the concentration of coal resources in that state. These reports (especially “Coal and Water Resources for Coal Conversion in Illinois”) should be useful to a wide range of decision-makers concerned with “real world” programmatic and policy decisions, and, in some cases, siting decisions for specific facilities. These reports avoid many complexities by concentrating on current water availability and not attempting to forecast detailed energy development scenarios for the Upper Mississippi Basin. In addition, they present the most complete set of cost data for water resource development of any report reviewed.

The Section 13(a) water assessment for the Upper Missouri Basin, "Synthetic Fuel Development for the Upper Missouri River Basin," will probably not be as useful a report to decision-makers concerned with water availability in the Upper Missouri Basin as the comparable report will be to decision=makers in the Upper Colorado. The main conclusion of the Upper Missouri report is that major storage and conveyance systems must be constructed before the extensive water demands of the projected synfuel industry can be met. The report, however, only presents general and schematic information on the location, capacity, costs, and other data of these required facilities. Furthermore, the report includes only limited information about the substantial institutional, legal, political and economic constraints which confront acquisition of necessary water rights and implementation of the required storage and conveyance facilities. Failure to communicate the magnitude of these difficulties and constraints to decision-makers is a major shortcoming of the report, which limits its usefulness. In contrast to the Section 13(a) report for the Upper Missouri River Basin, a non-governmental analysis of water availability for energy development in the Yellowstone Basin by Boris and Krutilla (1980) presents a more detailed and complete analysis of the institutional, legal, political and economic obstacles that confront development of required reservoir storage and conveyance and acquisition of necessary water rights.

The analysis of water availability for energy development in the Ohio Basin is probably the least useful of the reports and studies reviewed. It suffers from the usual difficulties (uncertain forecasts of future demand, lack of data, etc.) but has an additional deficiency in that it assesses water availability on only the mainstem of the Ohio River and ignores the tributaries. This limitation to only the mainstem substantially limits its usefulness to decision-makers for programmatic and policy decisions.

It is likely that the present controversy and uncertainty concerning water availability for synfuel development will continue in the future. Doing additional studies in order to get "better" or more refined estimates of water availability for synfuel development will probably not significantly reduce the controversy surrounding water availability. The reason for this is that many assumptions must be made in aggregating data into a form useful to decision-makers and in forecasting future demand and supply. These assumptions cannot all be explicitly detailed, communicated to decision-makers, and properly used by decision-makers in their own analyses. As a result of the general uncertainty surrounding these assumptions, there will always be potential for controversy over water availability. In other words, a finite limit as to quality probably exists for reports dealing with water availability for synfuel development. The Upper Colorado Section 13(a) Assessment probably approaches this limit.

This is not to say that "improved" analyses of water availability cannot be made; they can and should be completed. The point, however, is that seeking perfection in assessing water availability is an asymptotic process.

Because of the many difficulties and uncertainties inherent in predicting the timing and quantity of future demand by industrial, municipal and agricultural users and the related difficulty in forecasting depletions by these same users, considerable uncertainty exists in forecasts of water availability for synfuel development beyond the present. Reliability of forecasts of water availability for the period beyond 2000 is questionable.

In almost all of the analyses of water availability for synfuel development that were reviewed, the emphasis has been on "predicting" what will happen in a situation where unpredictable political, judicial, and administrative decisions are pending. It would appear that the degree of certainty conveyed in many of these reports is misleading--especially to high level decisionmakers who are unfamiliar with the many assumptions upon which the individual reports are predicated. Rather than focus on "predicting," it is recommended that the objective of these reports should be to acknowledge the intractable imponderable and to play out the consequences of some of the ways in which the decisions may go. Such analysis should concentrate on evaluating possible tradeoffs that could result.

Therefore, it is suggested that the primary use of the reports and assessments reviewed should be to assess the availability of water for initial development of synfuel industries in the respective river basins and tributaries. "Initial development" includes that group of synfuel plants presently in some phase of planning and which can reasonably be expected to be in operation in the next 10-12 years.

Furthermore, it is suggested that water availability assessments not be predicated on an energy or synfuel development scenario for the river basin. Except for the case of a report prepared specifically for national level decision-makers concerned with whether the United States can meet a national synfuel production goal by a certain date and whether individual regions can make specific contributions to this goal, the specification of a synfuel development scenario for a river basin does nothing except insert more uncertainty and speculation into the report. Instead, the water analyses assessments should concentrate on future water availability (net of all depletions except for synfuel development) and generally allow decision-makers to supply their own synfuel development scenarios. In addition, the assessments could detail the various tradeoffs that could occur if various levels of synfuel development were to occur.

WATER AVAILABILITY FOR SYNFUEL DEVELOPMENT

The purpose of this section is to bring together information presented elsewhere in this report which will allow a reader to obtain quickly an overview of water availability for synfuel development in a specific basin.

Upper Mississippi River Basin

The Upper Mississippi River Basin is that portion of the Mississippi River upstream from the confluence of the Ohio and Mississippi Rivers at Cairo, Illinois. The Upper Mississippi River Basin includes portions of the states of Illinois, Missouri, Iowa, Wisconsin, and Minnesota. Synfuel development will probably be concentrated in Illinois since this is the only state in the basin with major coal resources.

From a regional perspective water supplies for synfuel development in-the Upper Mississippi River Basin are adequate. Localized problems, however, may result depending on the specific site for a synfuel plant. Water supply shortages and negative impacts on water resources are most likely to occur for synfuel sites on tributaries. These shortages and negative impacts can be eliminated or reduced by construction of reservoir storage on tributaries, conjunctive use of ground and surface water or other measures to reduce diversions from unregulated streams during low flow periods.

Ohio/Tennessee River Basin

These two major river basins include portions of Pennsylvania, West Virginia, North Carolina, Ohio, Kentucky, Tennessee, Indiana, Illinois, Maryland, New York, Alabama, and Georgia. Major coal deposits are scattered throughout many states in these basins and significant potential for synfuel development exists.

The water availability situation in the Ohio and Tennessee Basins is comparable to that in the Upper Mississippi. From a regional perspective sufficient water is available for projected synfuel development but localized problems or deficiencies may occur for synfuel plants sited on tributaries. The extent and nature of these deficiencies can only be predicted with site specific studies.

Upper Colorado River Basin

The focus of synfuel development in the Upper Colorado River Basin is on the impending oil shale development activities. Projections for synfuel development in this area range from approximately 1,000,000 barrels a day to more

more than 8,000,000 barrels per day. Much of this development is expected to take place in a three-county area in northwestern Colorado which experiences an annual average precipitation of less than 12 inches and presently has only one town with a population greater than 5,000.

Water is available, and can be made available, in the Colorado River Basin in Colorado to meet oil shale development in the future. The question is not really whether water is available, but rather what the impacts on agriculture and other sectors will be from allocating this water from its present and potential use to synfuel development. For example, approximately 150,000 acre-feet of water storage presently exists in two federal reservoirs on the Western Slope of Colorado which, in part, could be made available for synfuel production. Assuming the consumptive use requirement of a 50,000 bbl/d shale oil plant is approximately 5,700 acre-feet per year, the available stored water in these two federal reservoirs alone could supply a number of unit-sized synfuel plants, more than the number of synfuel plants presently in some state of planning within Colorado. This available stored water could be more efficiently used and stretched further as a source of synfuel water supply when combined with existing junior rights of energy companies. If, however, the projected plants were to rely on water transferred from agricultural use rather than existing available water in federal reservoirs, the impact on the agricultural sector would be much more severe.

The case study of the Upper Colorado River Basin in Colorado herein goes into detail concerning the economic, political, institutional, and legal uncertainties which make it difficult to predict the level of future synfuel development in the upper Colorado River Basin, and the source arid amount of water supply for this projected level of development.

Upper Missouri River Basin

Within the Upper 'Missouri River Basin, synfuel development can be expected to occur primarily in the Yellowstone River Basin and the adjacent coal area. This area encompasses portions of Montana, Wyoming, North Dakota and South Dakota.

In order to provide necessary water for projected synfuel development in this area, major new water storage projects would be necessary because of the significant inter- and intra-year variation of stream flows for all rivers in the basin. Furthermore, the legal, institutional, political and economic issues are of such magnitude in this river basin that they do not allow an unqualified conclusion as to availability of water for synfuel development. In the Yellowstone River Basin and the adjacent coal areas, it is not a matter, as in the Upper Colorado River Basin, of merely what the effects will be of transferring existing water to synfuel development, but rather whether this water will be available at all. Major state reservations of water on the main stem Yellowstone River, Indian reserved rights, and the Yellowstone River Compact all present major uncertainties as to availability of necessary water for synfuel development in this area. Section V herein details the nature and effect of these legal, economic, institutional, and political uncertainties.

PHYSICAL AVAILABILITY

Of the many data-and information bases required for assessing water availability (e.g., future municipal demand projections, future cooling water requirements for coal-fired electric generating stations, etc.), recorded historic streamflow is probably the most accurate and dependable. In the eastern basins, this recorded data set is used more or less directly to assess water availability based on 7-day, 10-year minimum low flows. The use of 7-day, 10-year low flow data for this purpose in eastern basins is desirable since the 7-day, 10-year flow parameter: (1) coincides with many water quality regulations, (2) provides indication of low flow conditions for navigation, and (3) provides a useful estimate of flow in rivers with limited storage.

In the western basins, water availability assessments are based on virgin flow estimates since western state water laws and interstate compacts are predicated on this concept. Virgin flow estimates are based on recorded streamflow data and estimates of depletions. Significant effort is often made to estimate virgin flows, but the resulting data set may be inaccurate because of poor records of diversions, irrigated area, inaccuracy *in* estimating irrigation consumptive use, etc.

Depletion estimates are uncertain because of inadequate records, unrecorded return flows, illegal diversions, and other limitations. Therefore, the principal parameter in western basins on which water availability for synfuel development is based, mean annual virgin flow, incorporates considerable uncertainty. Furthermore, studies assessing water availability in western basins for synfuel development tend to treat mean annual virgin flow estimates as deterministic rather than stochastic variables. These studies do not clearly express the uncertainty and risk (in the statistical sense) that exist in mean annual virgin flow estimates, thereby giving an unwarranted degree of certainty to this data set. For example, some analyses of water availability in the Upper Colorado River Basin treat the estimated mean annual virgin flow as a deterministic, stationary quantity rather than a stochastic variable.

The use of mean annual flow and mean annual virgin flow estimates for assessing water availability is acceptable for rivers and tributaries where adequate storage exists to control the river. However, where little or no storage exists, or will exist in the near future, some estimate of low flows is needed. This could be weekly, monthly or 7-day, 10-year minimum low flow data depending on local hydrologic conditions and data availability. Without this low flow data, decision-makers will have little idea of how proposed synfuel water demands will affect instream uses: fish and wildlife habitat, run-of-the-river hydropower generation, recreation, and water quality. Low flow data is especially important to assess the cumulative effect of all present and proposed depletions as well as the statistical persistence inherent in the hydrologic record.

Groundwater quantity and quality data are inadequate in all of the basin analyses. Some reports more or less ignore this potential water supply source for energy development because of insufficient quantitative data. Individual energy companies may have adequate groundwater data to assist in specific siting decisions, but this data may be unobtainable or do not exist on a regional scale for governmental decision-makers or entities concerned with state or regional water resources management. Use of groundwater for supplying synfuel development could, in some instances, reduce streamflow depletions, especially during low flow periods. Planned conjunctive use of ground and surface waters could result in more efficient use of the surface water resources; i.e., more synfuel plants could be sited in a basin with less impact on the water resource if conjunctive use is employed. However, because adequate groundwater data are not available to regional or state decision-makers, this opportunity may be lost.

ECONOMIC FACTORS

Data concerning costs of developing necessary water resources for supplying synfuel plants were generally inadequate in all reports reviewed with the exception of "Coal and Water Resources for Coal Conversion in Illinois" (Smith and Stall 1, 1975) and Water Rights and Energy Development in the Yellowstone River Basin - An Integrated Analysis, (Boris and Krutilla, 1980). An effort was made in both these reports to present representative and dependable cost data. There are several reasons for the general inadequacy of available cost data.

First, dependable cost data are difficult to collect. No central collection of, for example, reservoir construction cost data exists; data must be collected from a number of individual sources. Second, cost data are site or project specific, and generalization is often risky and inaccurate. Third, developing or obtaining comparable cost data may be impossible. For example, obtaining data on selling prices of irrigation water rights often results in a set of individual prices for widely different commodities. One selling price; may be for a senior irrigation right while another will be for a junior right requiring construction of storage. Several examples of this variation are presented in the Upper Colorado River Basin section herein.

Within limits, cost data may not be very important to energy companies for selecting a water supply for synfuel development since cost of water is generally minor with respect to total capital and operating costs for a proposed synfuel plant.

Cost of water, however, is one determiner of the nature and extent of tradeoffs that will occur as a result of supplying water for synfuel development. Cost data, therefore, should be important to regional and state decisionmakers for: (1) evaluating alternatives for water users displaced by synfuel development and (2) determining the total estimated costs of water resources infrastructure (reservoirs, pipelines, etc.) necessary to support various levels of synfuel development. For example, in the U.S. Water Resources Council's Section 13(a) Assessment of water availability in the Upper Missouri River Basin, it was indicated that major storage and conveyance systems must be developed if the forecast levels of synfuel development were to take place and that the cost of this water resources infrastructure would be an estimated $0.5 to $1 billion dollars. More detailed cost data were not presented. Such aggregated data are not very useful since they do not indicate proposed sources and amounts of funding, cost of specific major projects, and other matters. Without such information it is difficult to evaluate the likelihood that this water resource infrastructure will or should be built. Without such an evaluation, it is difficult to assess water availability for synfuel development with any certainty.

Economic factors are, without question, important in determining the source of water supply for a particular synfuel development. As discussed throughout Sections II-V herein, there are many factors and constraints besides economics, which ultimately determine the source of supply, depletion, and impact on the water resource of a synfuel development. The succeeding section summarizes some of these factors and constraints which may force energy companies to go to more remote or expensive sources for necessary water supplies.

LEGAL, INSTITUTIONAL, AND POLITICAL FACTORS

Perhaps the most difficult requirement in assessing water availability for synfuel development is estimating the effects of legal, institutional and political factors on water availability.

Future judicial decisions, compact interpretations, implementation of certain compact provisions, administrative decisions on marketing federal reservoir storage, resolution of Federal and Indian reserved rights, reservation of water by states, and uncertainties in riparian law, can all have a profound effect on water availability for synfuel development. Communicating the quantitative effects of these possibilities in a water availability assessment is a large task. This task is complicated by the fact that not only must the possible effects be indicated and analyzed, but also some effort should be made to estimate the likelihood of occurrence.

For example, no interstate compact exists between Colorado and Utah for the White River, a tributary of the Upper Colorado River. Seventy-five percent of synfuel development in the Upper Colorado Basin is forecast to take place in the White River Basin (Colorado Department of Natural Resources, 1979). A White River compact could, therefore, be a major determinant in water availability for synfuel development in the White River Basin. Tracing out the quantitative effects on water availability of such a future compact is a difficult but necessary task in assessing water availability.

In general, the reports and assessments reviewed contain highly variable analyses of the quantitative effects of future legal, institutional and political constraints. Probably the best example is the Boris and Krutilla (1980) study which presents detailed and quantitative analyses of a number of legal, institutional and political factors affecting water availability for the Yellowstone Basin.

Political, legal and institutional factors affecting water availability are generally less numerous, and less complex, in the eastern basins than in the western basins. Complex local situations may exist but, in general, the political, legal, and institutional factors affecting water availability for synfuel development are less involved in eastern basins. The probable reasons for this are: (1) less competition for water in the eastern basins, (2) the relative simplicity of riparian water law for surface water, (3) the general lack of, or relatively simple, groundwater regulatory law in eastern states and (4) the difference in hydrologic regimes. As a result, forecasts of future water availability for synfuel development may be somewhat less involved because of the reduced complexity of political, legal and institutional factors.

The relative simplicity of riparian water law and riparian-based groundwater law can, however, result in significant uncertainty concerning future water availability because of lack of protection given users against upstream diversion or pumping adjacent to their lands. In contrast, water law in western states can be a barrier to implementation of water supply alternatives. For example, western state water law is an obstacle to implementation of measures to increase irrigation efficiency since the Appropriation Doctrine does not generally allow a user to retain a right to salvaged water. These measures could, in turn, provide the water saved to synfuel development.

In all the basins reviewed, existing federal reservoir storage can be a significant source of water supply for synfuel development. However, uncertainty over marketing policies and contract terms and bureaucratic and legal delays reduces the potential of this source of supply for synfuel development. This is unfortunate, since these reservoirs are already in place and additional construction would not be necessary.

Uncertainty resulting from legal, institutional, judicial and political factors causes energy companies to be conservative in their water supply planning and acquire redundant supplies in order to be assured of an adequate future-water supply. The delays and uncertainties inherent in acquiring water rights, obtaining reservoir storage, or otherwise initially securing a water supply also tend to cause energy companies to obtain redundant water supplies. Because of this redundancy, future consumptive use may be less than expected.

PROJECTION AND FORECASTING PROCEDURES

Estimating water availability for synfuel development requires a number of projections and forecasts. These range from estimating future population levels and municipal and industrial water demand for specific areas of river basins to projecting the effects of future legal and institutional mechanisms on water availability. This collection of projections and forecasts must be combined in order to estimate the availability of water for synfuel development. Assessments of water availability for synfuel development are generally developed by aggregating existing forecasts of water demand and use in the various river basins. These existing forecasts are of highly variable quality and sophistication.

Lack of effective mechanisms for water resources planning in many basins which are experiencing, or will experience, synfuel development is a serious limitation in producing dependable forecasts and projections of future water availability for synfuel development. Consider the example in Section III herein of the difference in data availability between West Virginia and Pennsylvania for the Monongahela River. The lack of a consistent data base between these two states makes forecasting various effects of synfuel development difficult or impossible. Furthermore, the compilation of data for various political jurisdictions (e.g., states) which do not correspond to hydrologic boundaries and the use of this data for forecasting purposes also creates bias, error, or uncertainty in the resulting forecasts. States and other political entities generally are optimistic when predicting future water demands and assume significant growth in water use by the industrial, agricultural, and municipal sectors. The total future water use for a basin must be equivalent to the sum of the parts. Reconciling the projections and forecasts of the individual entities so that the total is reasonable is a major job for which there may not be a responsible entity. A major effort was made in the Second National Assessment of the Nation's Water Resources (U.S. W. R. C., 1978) to reconcile the “state futures” with the “national futures,” i.e., to insure that the whole was equivalent to the sum of the parts. In many river basins, no planning entity exists that can produce uniform, consistent and dependable forecasts or predictions of parameters affecting water availability for synfuel development.

Another deficiency in currently available forecasts for water availability for synfuel development is that these forecasts may have good procedures for estimating future water demand, but that procedures for translating these demands into surface or groundwater depletions may be surrounded with uncertainty for a number of legal, political and institutional reasons. Consider, for example, the Colorado River Basin in Colorado. A number of estimates of future synfuel development for various sub-basins of the basin can and are being made. Reasonable forecasts of water demand for synfuel development and associated municipal demand can be made. However, demand estimates are not usually the final desired forecast or estimate. The final desired forecast involves those parameters characterizing expected quality and quantity depletions of the ground and surface waters of the region. Translating demand forecasts into depletion estimates requires numerous assumptions concerning future institutional, political and economic parameters. For example, on the Sangamon River in the Upper Mississippi Basin (see Section II herein) estimating future demand for cooling water for the Clinton Nuclear Power Plant is a reasonably straight-forward exercise. (Estimating future water demand for a synthetic fuel plant at the same location would be a comparable task.) Translating this demand forecast into estimates of future depletions in the Sangamon, Illinois and Mississippi Rivers, however, is far more difficult and requires numerous assumptions about future economic and institutional conditions. For example, economics will largely determine if the source of supply is groundwater, direct diversion from the river, or tributary storage. Each of these sources will have very different effects on depletions during low flow periods on the Sangamon, Illinois and Mississippi Rivers.

Therefore, with respect to the adequacy of forecasting and projection procedures, the following conclusions can be made:

1) Forecasts of water availability for synfuel development in a particular river basin depend on aggregation of a number of individual forecasts in a number of sectors: agriculture, manufacturing, energy, municipal, etc. There may be significant variation in the quality and dependability of the forecasts in these various sectors.

2) Forecasts of water availability for synfuel development require combining data and forecasts for water demand from various political entities (e.g. states) in the river basin. There may be significant variation in the quality and quantity of data and forecasts from these political entities which may seriously limit the ability to predict or forecast impacts of synfuel development on the water resources of a region, river basin, or sub-basin. The lack of an efficient and effective planning entity in most river basins indicates this situation will probably not change in the immediate future.

3) Many forecasting procedures associated with assessing water availability for synfuel development are designed to ultimately produce estimates of water demand. Translating these demand forecasts into estimates of quality and quantity depletions of ground and surface waters involves, perhaps, even more uncertainty than the original demand forecasts. This uncertainty results from potential future legal, political, economic and institutional constraints that may develop.

4) Assessments of water availability for a period of 10 to 12 years into the future should be reasonably good since we generally have some indication for this period concerning what plants may be built, what water supply sources will be used,” specific plant sites, etc. However, after this 10-12 year period, the legal, political, economic and institutional uncertainties become much greater and the dependability of the forecasts diminish.

ALTERNATIVES

For all basins studied, the principal sources of water supply considered in the reports for synfuel development were: (1) direct diversion from rivers, (2) reservoir storage, or (3) acquisition of agricultural water rights. However, numerous other potential sources exist including: (1) development of groundwater, (2) conjunctive use of ground and surface water, (3) weather modification, (4) improvements in efficiency of agricultural and municipal use (and subsequent use of water "saved" by synfuel industry), (4) change to more water efficient processes in synfuel production, and (5) watershed management to increase discharge. Detailed discussion of these alternatives for synfuel development water is presented elsewhere and will not be repeated here (Office of Technology Assessment, 1980; U.S. Environmental Protection Agency, 1979).

Some of these alternatives appear to offer attractive sources of water supply for the synfuel industry but their practical implementation is constrained by political, legal and institutional barriers. For example, the Colorado River Basin assessment report (Colorado Department of Natural Resources, 1979) discusses the possibility of employing municipal water conservation measures to reduce exports from the Colorado Basin for municipal use (primarily to the Denver metropolitan area) and using this saved water for synfuel development water supply. Numerous studies throughout the United States have demonstrated the cost-effectiveness and feasibility of reducing municipal demands by 10 to 30 percent. Therefore, this alternative would appear, at first impression, to offer an economically efficient and environmentally desirable water supply for synfuel development in the Upper Colorado River Basin. However, as discussed in the Upper Colorado River Basin section herein, substantial political, legal and institutional barriers -confront implementation of this alternative. These constraints are not discussed in the Section 13(a) study for the Upper Colorado.

This situation is typical of the treatment of other alternatives in the Upper Colorado River Basin Section 13(a) assessment as well as in other reports reviewed. In general, alternatives for synfuel water supply, other than the usual reservoir storage and direct diversion, are detailed with some limited discussion, but without analysis of the legal, political, economic and institutional constraints that limit their consideration and implementation in the real world.

BASIN COMPARISON

The objectives of the study have been to analyze the various factors involved in assessing water availability for synfuels development in four major river basins and evaluate the adequacy of currently used estimates of water availability as a basis for energy planning in these basins. With respect to the objectives of this study, there are considerable differences among the four basins studied.

In the eastern basins, the Ohio/Tennessee and the Upper Mississippi, significantly less competition exists for water than in the western basins. As indicated in the Ohio/Tennessee and Upper Mississippi discussions herein, the expected future total depletions, both for the mainstems and tributaries, are far less than in the Upper Colorado and Upper Missouri River Basins. In general, for the Ohio/Tennessee and the Upper Mississippi, adequate water supply exists for presently proposed and future synfuel development on the mainstems and larger tributaries without major new reservoir storage. Instream requirements and local shortages may limit availability in some areas and arrangements for alternative water supply during drought periods, (e.g., groundwater, or side channel and tributary reservoirs) may be necessary. This water can be made available with a minimum number of potential legal, institutional, and political obstacles.

The relative’ absence of legal, institutional and political obstacles to water-availability in the eastern basins primarily results from the relative simplicity of eastern riparian water law, lack of interstate compacts, no major Federal or Indian reserved rights questions, and the few institutions concerned with water resources. While this environment of simpler law may make water available more easily, it does not provide the assurance of continued supply that the appropriation doctrine water law of most western states provides. Riparian water law in states such as Illinois, Indiana, Tennessee and other eastern and Midwestern states gives a groundwater or surface water user little protection against depletion by others. This is in contrast to the western basins where appropriation based law and the more complex institutional and political setting will probably provide more obstacles to obtaining a water right; but once the right is obtained, the user has a more certain supply. Therefore, while the legal, institutional, and political environment of water availability is far less complex in the eastern basins than in the western basins, this relative simplicity and ambiguity are responsible for considerable uncertainty concerning future water availability.

For the eastern basins, the absence of interstate compacts, the lack of the general accounting requirements of western appropriation law, and the relatively few institutions concerned with water resources result in no entity having responsibility for regularly assessing the total cumulative depletions or diversions for a particular stream or aquifer. The lack of such an entity creates additional uncertainty concerning future water availability due to disparities among states in water quality and quantity data and estimates of depletion due to future development.

For the western basins, the Upper Missouri and the Upper Colorado, the opposite of much of the above is the case. The complexities of western states' water laws, the numerous interstate compacts, and Federal and Indian reserved rights create obstacles and uncertainty concerning future availability of water for synfuels development. However, these same factors also create a relative certainty of supply once that supply is obtained. In addition, these same factors have resulted in a form of regional and basin accounting of depletions.

Similarities also exist among the basins. In all basins, groundwater data is marginal or inadequate for purposes of assessing its potential as a source of supply for synfuel development. Forecasting demand for all water uses is a very uncertain process everywhere. As a result, assessments of water availability for the future (e.g., beyond 2000) are uncertain at best and must be interpreted very carefully. In general, the reports reviewed are mainly useful for assessing water availability at present for initial development of synfuel industries within the next 1O-I2 years.

REFERENCES

Boris, Constance, and John V. Krutilla, Water Rights and Energy Development in the Yellowstone River, Resources for the Future, Inc., August, 1980.

Brill, E. Downey Jr., Glen E. Stout. Robert W. Fuessle, Randolph M. Lyon, and Keith E. Wojnarowski, Issues Related to Water Allocation in the Lower Ohio River Basin, Volume III-G, Special Study Report, Ohio River Basin Energy Study, Phase I, University of Illinois at Urbana-Champaign, May 15, 1977.

Brill, E. Downey Jr., Shou-Yuh, Chang, Robert W. Fuessle, Robert M. Lyon, Potential Water Quantity and Water Quality Impacts of Power Plant Development Scenarios of Major Rivers in the Ohio Basin, Ohio River Basin Energy Study, University of Illinois at Urbana-Champaign, Urbana, Illinois, November, 1980.

C H M Hill, Inc. et al, West River Aquaduct, for West River Aquaduct Study Management Team, Old West Regional Commission, December, 1978.

Cameron Engineers, Review and Forecast--Wyoming Mineral Industries, prepared for the Wyoming Natural Resource Board and the State Water Planning Program, 1969.

Colorado Department of Natural Resources, The Availability of Water for Oil Shale and Coal Gasification Development in the Upper Colorado River Basin, Upper Colorado River Basin 13 (a) Assessment, A Report to the U.S. Water Resources Council, October, 1979:

Colorado Department of Natural Resources, The Ground Water Resources of the Upper Colorado River Basin, Denver, Colorado, October, 19/9.

Comptroller General of the U.S., Colorado River Basin Water Problems: How to Reduce Their Impact, Report to the Congress of the United States, May 4, 1979.

Comptroller General of the U.S., Water Supply Should Not be an Obstacle to Meeting Energy Development Goals, Report to the Congress of the United States, January 24, 1980.

Danielson, Jeris, Colorado State Engineer, Speech to Colorado Bar Association Hater and Environmental Sections, February 22, 1980.

Denver Water Department, Metropolitan Water Requirements and Resources 1975-2010, prepared for the Colorado State Legislature.

Environmental Protection Agency, Energy from the West, Policy Analysis Report, March, 1979.

Illinois Bureau of the Budget, office of Planning, The Availability and Resource Cost of Water for Coal Conversion, Springfield, Illinois, May, 1979.

Missouri River Basin Commission, Report and Environmental Assessment: Yellowstone River Basin and Adjacent Coal Area Level B Study; November, 1978.

" Montana Board of Natural Resources and Conservation, order establishing water reservations, March, 1979.

Montana Department of Natural Resources and Conservation, Proposed Opinion, Finding of Fact, Conclusions of Law, and Order submitted by DNRC before the Board of Natural Resources and Conservation, 1978.

Montana Department of Natural Resources and Conservation, Water Resources Division, Draft Environmental Impact Statement for Water Reservation Applications, Volumes 1 & 2, December, 1976; Addendum, June, 1977; Final EIS, February, 1977.

Musick, Williamson, Schwartz & Cope, Briefing Paper/Water for Western Energy Development, Boulder, Colorado, October, 1980.

Musick, Williamson, Schwartz, Leavenworth & Cope, Comments on the Draft Upper Colorado Basin 13 (a) Assessment, January 31, 1980.

National Petroleum Council, U.S. Energy Outlook - Water Availability, 1973.

North Central Power Study, Report of Phase I, Volume 1, prepared under the direction of the Coordinating Committee, North Central Power Study, October, 1971.

Office of Technology Assessment, An Assessment of Oil Shale Technologies, Washington, D.C. June, 1980.

Ohio River Basin Commission, Synfuels in the Ohio River Basin, A Water Resources Assessment of Emerging Coal Technologies, prepared for U.S. Water Resources Council, January, 1980.

Ohio River Basin Commission, Water Assessment for Monongahela Synfuel Plant, Cincinnati, Ohio, prepared for U.S. Water Resources Council, June 6, 1980.

Smith, WiTliam H., and John B. Stall, Coal and Water Resources for Coal Conversion in Illinois, Cooperative Resources Report for Illinois State Water Survey and Illinois State Geological Survey, Urbana, Illinois, 1975.

Tennessee Valley Authority, Valley-wide Assessment of Water Needs. December, 1974.

U.S. Department of Energy, Office of Assistant Secretary for Environment, Water Supply and Demand in an Energy Supply Model, December, 1980.

U.S. Department of Interior, Bureau of Land Management, Final Environmental Impact Statement, Proposed Development of Oil Shale Resources by The Colony Development Operation in Colorado, Vol. 1, 1977.

U.S. Department of Interior, Bureau of Reclamation, Upper Missouri River Region, Yellowstone River Basin and Adjacent Coal Fields - Depletion Study - 1975 level of development, November, 1976.

U.S. Department of Interior, Critical Water Problems Facing the Eleven Western States, Westwide Study Report, April 1975.

U.S. Department of Interior, Northern Great Plains Resources Program, Northern Great Plains Resources Program Report, and Appendices, September, 1974.

U.S. Department of Interior, Water for Energy Management Team, Report on Water for Energy in the Northern Big Plains Area with Emphasis on the Yellowstone River Basin.

U.S. Department of Interior, Water for Energy Management Team, Water for Energy in the Upper Colorado River Basin, July, 1974.

U.S. Environmental Protection Agency, Energy from the West: Policy Analysis Report, March, 1979.

U.S. Geological Survey, Water Supply Papers

U.S. Water Resources Council, Coal Liquefaction Demonstration Plant near Morgantown, West Virginia, Water Assessment Report, August, 1980.

U.S. Water Resources Council, Great Plains Gasification Project, Mercer County, N. Dakota; 13 (b) Water Assessment, in Federal Register Vol. 45, No. 151, August 4, 1980.

U.S. Water Resource Council, The Nation's Water Resources 1975 - 2000, December, 1978.

U.S. Water Resources Council, Project Independence Report (Tennessee Region 06), prepared for the Federal Energy Administration, November, 1974.

U.S. Water Resources Council, Section 13 (a) Water Assessment Report, Synthetic Fuel Development for the Upper Missouri River Basin, October, 1980.

University of Oklahoma, Science and Public Policy Program, Energy from the West, Summary Report prepared for Office of Research and Development, U.S. Environmental Protection Agency, August, 1979.

Wigington, Robert F., Letter to Mr. Elmer Staats commenting on GAO report (Water Supplies Should not be an Obstacle to Meeting Energy Development Goals), Boulder, Colorado, May 19, 1980.

Wyoming Department of Economic Planning and Development, Coal Development Alternatives, An Assessment of Water Use and Economic Implications, December, 1974.

Wyoming State Engineer's Office (Wyoming Water Planning program), Investigation of Recharge to Grcundwater Reservoirs of Northeastern Wyoming, (The Powder River Basin), Prepared for the Old West Regional Commission, June, 1976.

Wyoming Water Planning Program, Report No. 10, Water and Related Land Related Land Resources of Northeastern Wyoming, April, 1972.

Wyoming Water Planning Program, Report No. 11, Water and Related Land Resources of the Big Horn River Basin, Wyoming, October, 1972.

Wyoming Water Planning Program, Underground Water Supply in the Madison Limestone, December, 1974.

Wyoming Water Planning Program, A Water Development Program for Wyoming, October, 1974.

Wyoming Water Planning Program, Report No. 3, Water and Related Land Resources of the Green River Basin of Wyoming. September, 1970.