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WATER AVAILABILITY FOR DEVELOPMENT OF MAJOR TAR SANDS AREAS IN UTAH

REPORT SCR 337-79-010

by

Thomas N. Keefer
and
Raul S. McQuivey

May 1979

WORK PERFORMED UNDER CONTRACT EW-78-S-20-0013

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Prepared for:
In Situ Tar Sand Recovery Project
Laramie Energy Technology Center
U.S. Department of Energy
Laramie, Wyoming 82071

Under Contract No. EW-78-S-20-0013

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SUMMARY

INTRODUCTION

The Sutron Corporation, under contract with Colorado State University, has conducted a study for the Laramie Energy Technology Center (LETC) to determine the availabiltity of water for future extraction of viscous petroleum (bitumen) from the six major tar sands deposits in Utah. Specifically, the areas are

- Asphalt Ridge and Whiterocks, which lie immediately west of Vernal, Utah;
- P.R. Spring, a large area extending from the Colorado River to the White River along Utah's eastern border;
- Hill Creek, adjacent to P.R. Spring to the west;
- Sunnyside, immediately across the Green River from Hill Creek between the Price and Green Rivers; and
- Tar Sand Triangle, near the confluence of the Colorado and Dirty Devil Rivers.

The study, conducted between September and December of 1978, was a fact-finding effort involving the compilation of information from publications of the U.S. Geological Survey (USGS), Utah State Engineer, Utah Department of Natural Resources, and other federal and state agencies. The information covers the general physiographic and geologic features of the total area, the estimated water requirements for tar sands development, the availability of water in each of the six areas, and the legal and sociological restraints and impacts. The conclusions regarding water availability for tar sands development in each of the six areas and specific recommendations related to the development of each area are presented also.

TAR SANDS DEPOSITS

Tar sands—sand deposits that are impregnated with dense, viscous petroleum (bitumen)—are found throughout the world, often in the same areas as conventional petroleum. At present, the only deposit of commercial importance is the Athabasca tar sands deposit in Alberta, Canada, which is estimated to contain 700 billion bbl of bitumen.

The Utah tar sands deposits are estimated to contain 20 to 25 billion bbl. They lie within three major physiographic provinces. These are the Uinta Basin, the Colorado Plateau, and the Canyon Lands. Over 60 percent of the land is administered by the federal government, with an additional 15 percent in Indian trust.

Altitudes range from 3000 ft along the Colorado River to 14,000 ft in the mountains. Most of the region has an arid to semiarid climate (less than 5 in. of precipitation per year). The higher plateaus and mountains have subhumid to alpine climates (20 in. or more of precipitation per year). The major geologic features of concern to this study include the Uinta Basin geosyncline near Asphalt Ridge; the Tavaputs Plateau, which contains the P.R. Spring, Hill Creek, and Sunnyside deposits; and the Green River Desert and San Rafael Swell near the Tar Sand Triangle deposit. The area covers four major drainage basins: the Uinta Basin, which also contains the Green, White, Ashley, and Duchesne Rivers; the Price River Basin; the San Rafael Basin, and the Dirty Devil Basin.

WATER REQUIREMENTS FOR TAR SANDS DEVELOPMENT

There are two basic approaches for recovering bitumen from tar sands. The tar sands may be mined and transported to a processing plant where the bitumen is extracted and the sand is discharged, or alternatively, the bitumen may be separated from the sand in situ. This study is concerned only with the water requirements of in situ techniques, whereby the bitumen is separated from the sand without disturbing the deposit to any significant degree.

In most in situ processes, the tar sands are heated to reduce the viscosity of the bitumen. Two methods are usually used to heat the tar sands; in both the formation is initially ignited. In one method, the formation is flooded to force the less viscous bitumen to the surface; in the other, stream is pumped into the formation to force the bitumen to the surface. Both methods produce a water-bitumen emulsion. Water requirements for tar sands development were estimated on the basis of the latter (steam) method since more data were available.

Most in situ processes require that heat be added to the tar sands to reduce the viscosity of the bitumen. This is done by igniting the formation and then flooding with water or pumping stream into the formation, after which a bitumen-water emulsion is withdrawn from the deposit. Data on steam processes were used to estimate water requirements for tar sands development.

Little is known about the exact water requirements for tar sands development. As stated, the only operational tar sands mining and refining facilities are in Canada, and most data on tar sands processing have been collected there. Data from Shell Canada indicate a water requirement of 0.685 ton of steam per barrel of bitumen (3.91 bbl of water per barrel of bitumen). Up to 63 BPD per well of bitumen-water mixture have been produced in experiments. The mixture was 40 percent water by weight.

Based on these data, water requirements were estimated for three sizes of tar sands facility: test, 151 BPD; pilot, 907 BPD; and production, 57,000 BPD.

Ratios of water required per barrel of bitumen produced of 2, 5, and 10 bbl per barrel were assumed. These values are one-third less to a factor of two greater than best guesses on production requirements. The 5 bbl of water per barrel of bitumen was adopted as a standard estimate for comparisons within the study. Thus, the water requirements for the various sizes of tar sands facility are

- five-well test facility:
  35.5 acre-feet/year = 22 GPM = 0.05 cfs;
- 24-well pilot facility:
  213 acre-feet/year = 132 GPM = 0.29 cfs; and
- large-scale (57,000 bbl) production facility:
  13,400 acre-feet/year = 8300 GPM = 18.5 cfs.

WATER AVAILABILITY BY DEPOSIT AREA

The following paragraphs present a summary of the water available at or near each of the tar sands deposits examined and whether the water available could be used to support a tar sands development facility. However, the availability of the water does not imply that a legal right to use the water exists; this is a separate issue and is discussed in the following section.

Asphalt Ridge-Whiterocks

Surface Water

The mean annual discharges (in acre-feet) for the streams near Asphalt Ridge and Whiterocks are as follows:

Dry Fork R. above sinks near Dry Fork	25,296
N. Fork of Dry Fork R. near Dry Fork	4,404
E. Fork of Dry Fork R. above sinks near Dry Fork	7,404
Oaks Park Canal near Vernal	4,800
Ashley Cr. above springs near Vernal	35,700
Ashley Cr. at Sign of the Maine	81,996
Ashley Cr. near Jensen	44,000
Uinta R. near Neola	127,200
Farm Cr. near Whiterocks	4,200
Whiterocks R. near Whiterocks	77,760
Duchesne R. at Duchesne	209,600.

Sufficient water flows out of both the Ashley and Duchesne River Valleys to meet the water requirements for a production-scale tar sands facility. However, not all of the individual streams will support production. For example, while the North Fork of Dry Fork River has sufficient water to support a production-level facility, over 30 percent of the flow of Ashley Creek near Jensen would be needed for such an activity.

Competition with existing uses is another factor. A production-level facility near Vernal would require 43 percent of the water presently used for agriculture, whereas only 5 percent of the water consumed by agriculture in the Duchesne River Basin would be required.

The quality of the water is also important; in fact, the worst problem in this area is the fairly high level of salinity, with some boron also present in the water content.

An important issue is the time required to extract the bitumen from the tar sands deposit. The Asphalt Ridge-Whiterocks deposits are collectively estimated to contain from 1165 million to 1450 million bbl of bitumen. Assuming a 30 percent recovery rate, it would require 17 to 21 years to extract all the bitumen. Larger production facilities could accomplish this in less time; however, the number of production facilities will depend on the amount of water available and the price of water rights. For example, four such facilities would require all the flow of Ashley Creek, and it is highly unlikely that all the water could be used for one purpose even if the cost of the rights were not prohibitive.

The figures presented here do not account for the completion of the Jensen unit of the Central Utah Project, which will bring additional water to the Vernal area. Nor does this study address the question of whether some of this additional water could be used for tar sands development.

Groundwater

The Vernal area is unique among the tar sands areas in that it sits atop a sizable shallow groundwater reservoir. A number of shallow wells (less than 200 ft) in the glacial alluvium produce water at sufficient rates to support pilot-level tar sands facilities. A carefully designed well field could probably support production-scale facilities. A model would be required to determine any adverse impact on other groundwater users in the area. Water rights for a well field may be considerably easier to obtain than surface water rights. The quality of water from the alluvium is good. Fresh to slightly saline water can be expected.

There appears to be no viable source of groundwater from bedrock aquifers to the southwest of Asphalt Ridge. Only the Green River Formation contains water, and it is probably very saline.

To the northeast of Asphalt Ridge, fresh water can be found in several of the underlying sandstone formations, primarily the Weber and Navajo. Wells 4000 to 6000 ft deep would be required. One to two wells in either formation would probably support a pilot-scale facility. A carefully designed well field could probably support a production facility, but again a model would have to be developed to determine its feasibility.

Recommendations

It appears from the data available that the best source for test and pilot facilities may be shallow groundwater from the Ashley Creek Basin. Production facilities would probably require purchase of surface water rights on the Duchesne River and Ashley Creek. The purchase of Duchesne River water might have a less significant effect on other uses, but transportation could be a problem because of the greater distance to the tar sands deposits.

Hill Creek

Surface Water

No gages exist and little is known about streamflows immediately to the west of Hill Creek between Hill Creek and the Green River. Several ephemeral streams join the Green River adjacent to the Hill Creek deposit. These streams appear to drain areas of 20 to 40 mi^2. Yields from individual basins could be estimated from the runoff map, but would be small and uncertain.

The only apparent sources of surface water near the Hill Creek deposit are Hill Creek and Willow Creek. Although Hill Creek is not gaged directly, the flow near the deposit area is estimated to be roughly 4000 acre-feet per year. A proposed dam by the Utah Department of Natural Resources will make water available from the White River for energy development. Approximately two-thirds of the planned 118,000 acre-feet of storage will be set aside for this purpose.

The stream gage on Willow Creek above diversions is immediately adajcent to the tar sands deposit. It has an average annual yield of 14,200 acre-feet per year. Both estimates are based on short periods of record.

Willow Creek and Hill Creek are each capable of supporting large-scale pilot operations, but only Willow Creek is capable of supporting a production-level facility. The combined flow of both creeks near the tar sands area appears to be adequate to support a production-level facility. The intermittent nature of the runoff would certainly necessitate storage facilities, which would involve associated seepage and evaporation losses. Caution should be used here, however, because the P.R. Spring deposit lies immediately east of Willow Creek and the flow is not sufficient to support major production in both areas at once without recycling or other conservation measures.

Very little agricultural demand exists in the Willow Creek Basin. Only 1500 acre-feet per year is attributed to agricultural depletion. However, considerable wetland depletion (10,000 acre-feet per year) exists. If this wetland depletion were prevented, it alone would almost support a production-level tar sands facility.

Since Hill Creek is not gaged directly and the length of record for the area is short, a record for Hill Creek near the tar sands deposit should be synthesized through modeling or correlation techniques. Such a study is essential if storage facilities are to be developed on either Willow or Hill Creek. In the absence of sufficient water from Hill or Willow Creek, the only alternative would be to obtain water from the White River.

Limited samples indicate that the waters of Willow and Hill Creeks are too saline for public supply although no definite conclusions could be drawn from the limited data.

Groundwater

There is no known potential shallow groundwater supply near the Hill Creek deposit. Insufficient information exists to draw any conclusions about the deep groundwater supply. Typical oil and gas wells in the area yield barely enough water to support test tar sands facilities. Several of the underlying formations are good aquifers in other parts of the Uinta Basin. Pump tests on existing oil wells are highly recommended.

Recommendations

At this time it appears that the best source of water to develop the Hill Creek deposits is the proposed White River Dam. The second best alternative is to study the runoff from Hill and Willow Creek in detail and plan to develop storage facilities near the deposit areas.

P.R. Spring

Surface Water

P.R. Spring lies between Evacuation Creek and Willow Creek near the points at which they join the White River. The only major creeks that flow through the P.R. Spring deposit area are Bitter Creek and Main Canyon Creek.

Bitter Creek has an estimated annual runoff of 800 acre-feet and is classified as ephemeral-intermittent. Nothing could be found concerning runoff from Main Canyon Creek. Since it drains considerably less area than Bitter Creek, however, it is not a likely source of water for tar sands development. Stream gage records on both Bitter Creek and Evacuation Creek are short. The estimated runoff for Evacuation Creek ranges from 2600 to 7000 acre-feet per year. The estimate for Willow Creek, immediately west of the P.R. Spring deposit, is 13,000 acre-feet per year. This runoff volume is based on substantial amounts of record. The White River at Watson yields 481,200 acre-feet per year. The records on the White River are also substantial.

Bitter Creek would support test and pilot facilities if storage facilities were available but would fall considerably short of the water supply for a production-level facility.

Willow Creek was identified by Price and Miller (Reference 30)* as a potential location for water development. The stream gage adjacent to the P.R. Spring area indicates a flow of 13,000 acre-feet per year, which is adequate to support a production-level facility. However, unless recycling on the order of 50 percent were achieved, any water withdrawn from Willow Creek would reduce the amount available to the Hill Creek area.

It is difficult to conclude anything about water availability from Evacuation Creek. Based on the low end of the estimated range (2600 acre-feet per year), it appears that Evacuation Creek could support pilot and test facilities. Based on the best-case estimate (7000 acre-feet per year), Evacuation Creek could probably support a half-sized production-level facility. Some type of runoff modeling or record extension should be used before any definite conclusions are reached. Data gathered by USGS for development of Utah's pilot oil shale lease tracts will be helpful in this regard.

Careful hydrologic studies would have to be undertaken to use either Evacuation Creek or Bitter Creek as water supplies. Since the runoff is highly intermittent, storage facilities would be required, and the losses from evaporation and seepage would have to be considered.

There is no question that the flow of the White River at Watson (481,200 acre-feet per year) is adequate to support production at any level. It is certain also that rights to the water would be difficult and/or expensive to obtain. The considerable distance and large increase in elevation (up to 2000 ft) of the area would pose problems in transporting the water to the upper reaches of the deposit area. The Utah Department of Natural Resources is planning a dam on the White River for development of energy and irrigation of Indian lands (Reference 31). Two-thirds of the planned storage capacity of 118,000 acre-feet will be used for energy development.

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*References are listed in Section XI of the report.

Groundwater

There is no known potential source of shallow groundwater in the P.R. Spring area. Almost no data from deep wells exist for comparison to estimated requirements. The Ute Tribe owns several very shallow wells (less than 100 ft) in the Green River Formation near Hill Creek. These wells produce 5-15 GPM. Yields this low are barely capable of supporting test facilities. A Texaco well in T. 15 S., R. 22 E. produced 3 GPM from the Entrada Sandstone-a yield too low to be useful.

One encouraging note can be found, however. Six of seven springs in the P.R. Spring area originate in the Parachute Creek Member of the Green River Formation. Weeks et al. (Reference 32) report that the Parachute Creek Member is the major aquifer in the Piceance Creek Basin of western Colorado. This is less than 30 mi to the northeast of P.R. Spring. In the Piceance Basin, wells in the Parachute Creek Member yield up to 1000 GPM, with 200 to 400 GPM being typical. Only detailed exploration will determine is such yields are possible near P.R. Spring.

Recommendations

Based on the limited data available, the best source for water to develop the P.R. Spring deposit is from the proposed White River Dam. The second choice would be to develop storage facilities on Willow Creek for use at both the P.R. Spring and Hill Creek deposits.

Sunnyside

Surface Water

In the immediate vicinity of the Sunnyside tar sands deposit there are only three small streams, Nine Mile Creek, Range Creek, and Icelander Creek. While there are numerous other small creeks, all of them are ephemeral and not generally worth considering as water supplies for tar sands development. The Price River is the only major stream in the area.

The flow in Minnie Maud Creek averages 7000 acre-feet per year. It varies from a high of 1400 acre-feet per month in May to a low of 30-acre-feet per month in the winter. The gage "Minnie Maud Creek at Nutter Ranch near Myton " on the Nine Mile Creek-Minnie Maud system was operated for a short time above Gate Canyon. The flow in Nine Mile Creek at this location is 12,000 acre-feet per year, ranging from a high of 3530 acre-feet per month to a low of 380 acre-feet per month.

No gaging records are available on Icelander Creek or Range Creek, intermittent streams in the tar sands area. The estimated annual flow is 4000 acre-feet, with a range in monthly flow from 40 to 1630 acre-feet. These figures are for the mouth of the stream at the Green River. Flows near the tar sands area would be only 20 to 30 percent of these values due to the reduction in drainage area. A total yearly runoff from Icelander Creek at Sunnyside probably amounts to 3700 acre-feet.

The only major river near the Sunnyside deposit is the Price. The flow in the Price River is accurately established by gages above Heiner, near Wellington, and at Woodside. The gage at Wellington was established in 1972, and the USGS has not published an average flow there as yet. However, the total flow in 1976 was 30,250 acre-feet. At Heiner, 75,743 acre-feet flowed into the Price subarea; the outflow at Woodside was 75,434 acre-feet.

These values imply that the flow in the Nine Mile Creek-Minnie Maud system might be barely adequate to support production-level activities. Little or nothing would be left, however, for other uses. Storage facilities would be necessary in order to maintain a consistent water supply. In order to capture sufficient volumes of water, the storage facilities would be at an elevation of no more than 6000 ft. Considerable pumping would be required to bring the water up to the deposit area.

Range and Icelander Creeks probably do not yield sufficient water for more than large-scale pilot operations. This is particularly true if storage facilities were developed high in the drainage basin. No definite conclusions should be drawn regarding these two streams without additional gaging or a modeling study to accurately determine the runoff near areas of interest.

The Price River could easily support any level of activity. However, it is at a considerable distance from the deposit and much lower in elevation. The impact of production-level facilities on the Price River would be considerable in dry years. In 1976, the estimated water supply needed for a production-level facility would have used one-third of the total yearly flow at Wellington.

Considerable information is available on the quality of water in the Price River. Data include suspended sediment, dissolved oxygen, specific conductance, pH, and sampling for various chemical constituents. However, water quality information on the other streams of interest is almost totally lacking. Random samples of specific conductance and temperature are available for Minnie Maud Creek. No data are available for Icelander and Range Creeks.

Water in the Price River contains a very high level of dissolved solids and considerable suspended sediment. Both could be a problem when using the water in tar sands processes.

Groundwater

Shallow groundwater in the lower areas along the Price River is unusable because of contact with the Mancos Shale Formation. The total dissolved-solids content is too high for any practical applications. The North Horn, Price River, and Wasatch Formations appear to be potential sources of water for at least test-level facilities. Additional data would be required to form any meaningful conclusions.

Recommendations

Based on the available data, the best sources of water to develop the Sunnyside deposit are the Price River and Minnie Maud Creek. Storage facilities would be required on Minnie Maud Creek. Water quality would be a problem with Price River water. These appear, however, to be the most viable sources.

Tar Sand Triangle

Surface Water

Only two creeks (Happy Canyon and Millard Canyon) originate in the Tar Sand Triangle area. The Dirty Devil, Green, and Colorado Rivers are all within reasonable distances of the tar sands deposit. Little is known about this area.

The mean annual flow of the Dirty Devil River is 73,890 acre-feet per year. It is rare when it does not run dry for one to two months each summer. Reasonable estimates of runoff for the Happy Canyon and Millard Canyon Creeks are only 1920 and 960 acre-feet per year, respectively.

Therefore, the only means of obtaining water for production-level facilities in the Tar Sand Triangle area is to withdraw water from the Dirty Devil, Colorado, or Green River. However, while sufficient water flows in all three for production-level facilities, the water rights to the usage of these rivers would have to be purchased from current holders.

The estimated yield of the ungaged tributaries in the Tar Sand Triangle area is probably adequate to support pilot-level operations but would certainly require storage facilities, involving associated evaporation and seepage losses. Development of such storage facilities on ungaged areas would be risky without some form of gaging or modeling program to determine the exact amount of water available.

Very little is known about the quality of water in the Dirty Devil River. Currently, the USGS collects random observations of temperature and specific conductance at Hanksville. In previous years, suspended sediment records and water quality samples for total dissolved solids have been collected.

The Public Health Service recommends that the level of dissolved solids in drinking water and water supplies used by common carriers be no more than 500 mg per liter. At Hite, the level of dissolved solids exceeds 2400 mg per liter half the time and is always higher than the Pulic Health Service standards. No data have been published on the chemicals that comprise the dissolved solids in the Dirty Devil River.

Groundwater

Little specific information on groundwater near the Tar Sand Triangle is available. The Cedar Mesa and Moenkopi Formations are both exposed to the surface over a considerable area near Tar Sand Triangle. Several streams and creeks flow over the Cedar Mesa. Based on yield values from other locations perhaps 5-10 GPM could be obtained from wells in either of these formations. While low, such yields would at least support test activities. The Moenkopi Formation has yielded quantities of water sufficient to support test facilities. Several springs less than 30 mi from Tar Sand Triangle have yielded quantities from 20 to 400 GPM. Only actual exploration for water in the Tar Sand Triangle area will permit meaningful assessment. Yields of 5 to 10 GPM from several of the formations would be a reasonable expectation. Based on current data, it is not expected that groundwater supplies in this area could support production-level facilities.

Recommendations

It is difficult to make recommendations with the limited data available. It appears that water for production facilities would have to come from storage facilities on the Dirty Devil River or from the Colorado or Green Rivers.

LEGAL AND OTHER FACTORS

Water Rights Governing Supplies

Use of water in Utah is governed by the law of prior appropriation. Its two basic principles are that beneficial use of water, not ownership of the land, is the basis of the right to water and that priority of use, not equality of right, is the basis upon which the water is divided among the appropriators when there is not enough for all. The place of use is not limited to the stream bank, as in riparian law. With few exceptions the water can be used anywhere it is needed. An appropriation is always stated in terms of the right to take a definite quantity of water. Both surface water and groundwater in Utah are governed by these principles. Approved water rights are kept on file with the Utah State Engineer. A complete summary of all water rights over 1.0 cfs, broken down by hydrologic subareas (drainage basins), is available from that office. In general, there are more rights holders than there is water available. The burden of shortage, therefore, falls on those who are lowest on the priority list. There is no prorationing in times of scarcity. Thus, it will be necessary for tar sands developers to purchase rights with sufficiently high priority to guarantee supplies.

Water Development Plans

In addition to the legal framework, tar sands development must take place within the bounds of other water resource developments. The U.S. Bureau of Reclamation (USBR) has a number of planned development projects that will redistribute available water between stream basins and drastically change the time distribution of the flow. Several of the projects currently under consideration are discussed here.

Asphalt Ridge-Whiterocks Area

Several existing and planned projects have potential impact on the use of surface waters for tar sands development in the Asphalt Ridge (Vernal) area.

The Central Utah Project, located in the central and east-central part of Utah, is being developed to utilize the state's allocated share of the Colorado River. The project will develop additional storage for increased water use in the Uinta Basin drainage area and will provide large amounts of additional water to the Wasatch Front, where population and industrial development are rapidly expanding.

The initial phase of this project is composed of the Vernal, Bonneville, Upalco, and and Jensen units. The Vernal unit, located in the Vernal subarea, has been completed except for drainage facilities. This project unit provides supplemental water for about 15,000 acres of land in Ashley Valley. The Jensen unit is located mainly in the Jensen subarea along the Green River from Brush Creek to the mouth of Ashley Creek. This project unit will develop 22,700 acre-feet of water. About 18,000 acre-feet will be used for municipal and industrial purposes in the Vernal area; the remaining 4700 acre-feet will be used for irrigation. The Upalco unit, located northwest of Roosevelt in the Roosevelt-Duchesne subarea, will increase the water supply by approximately 20,500 acre-feet for supplemental irrigation of Indian and non-Indian lands.

P.R. Spring-Hill Creek

The water development project that will have the most impact on tar sands development is the proposed White River Dam. The Utah Department of Natural Resources is planning a dam with 118,000 acre-feet of storage for energy development and irrigation of Indian lands.

Sunnyside

Only vague, general information is available concerning water development near the Sunnyside deposit. The only major storage facility is Scofield Dam on the Price River. This reservoir has a capacity of 74,000 acre-feet.

Tar Sand Triangle

No published information was found concerning water resource development near the Tar Sand Triangle deposit. There is irrigation in areas upstream along the Dirty Devil and Fremont Rivers and Muddy Creek.

CONCLUSIONS AND RECOMMENDATIONS

Based on the study findings, the following conclusions and recommendations are presented for each of the six tar sands deposits.

Asphalt Ridge-Whiterocks

Very little additional hydrologic data will be required for tar sands development in the Asphalt Ridge-Whiterocks area; sufficient data are available to develop alternative plans for using surface water, shallow groundwater, or deep groundwater. The following specific activities are recommended:

- An analysis of current and pending water rights in the Ashley and Duchesne Basins in relation to tar sands development should be undertaken. Water rights holders with sufficiently high priority to guarantee adequate supplies should be identified in anticipation of future purchases of the necessary rights.

- Specific tar sands development sites should be identified.
- Alternative water development plans should be prepared for each site. These plans should include study of
  - likely diversion points for surface water;
  - required storage facilities;
  - potential sources of water rights and their cost;
  - potential well field locations for shallow or deep groundwater wells and modeling studies to assess their impact;
  - costs associated with the development of various water sources, including costs of pipelines, pumping, storage, and other factors; and
  - impact of tar sands development on other planned water resource uses.

Hill Creek

Before plans can be made regarding the Hill Creek area, additional hydrologic data will be required. The surface water supply is poorly defined and hardly anything is known of the groundwater supply. The following activities are specifically recommended:

- The actual flow in Hill Creek near the tar sands deposit should be determined. This could most readily be done by
  - using existing weather records to model rainfall and snowmelt runoff, or
  - establishing a gage site near the deposit area for several years.
- The safe yield of Willow and Hill Creeks should be analyzed, and locations for storage facilities should be determined.
- The losses to be expected in storage facilities should be determined.
- The water rights to the White River and Willow and Hill Creeks should be examined in detail. Water rights holders with sufficiently high priority to guarantee supplies for tar sands development should be identified in anticipation of future purchase of these rights. Particular attention should be given to federal water rights since Hill Creek is part of the Ute Indian Reservation.
- Discussions should be held with the USBR concerning water availability and development on the lower White River Basin.
- Logs of wells in the Hill Creek area should be examined in detail and a good subsurface geology map developed.
- Pump tests should be conducted and quality samples taken on existing abandoned oil and gas wells if possible.

- A limited drilling program to search for water should be considered after the subsurface geology is established. (Core drilling may be required just to establish the geology.)
- A good water quality monitoring program should be undertaken to better determine the nature of the surface runoff.
- Preliminary recommendations for obtaining the necessary water for tar sands development should be developed.
- An interest in obtaining water from the proposed dam on the White River should be expressed in writing to the Utah Department of Natural Resources.

P.R. Spring

Additional hydrologic data and analysis will be required for intelligent planning in the P.R. Spring area. Data on the surface water supply are inadequate and hardly any data on the groundwater supply exist. The following activities are specifically recommended:

- Accepted hydrologic techniques should be used to obtain better estimates of the flow of Evacuation and Bitter Creeks. Data collected by USGS for oil shale development in this area may be helpful. Modeling of rainfall-snowmelt runoff may be required or additional stream gages established.
- The safe yield of Evacuation Creek, Bitter Creek, and other small streams should be analyzed in terms of water storage.
- Potential storage sites should be selected and storage-associated losses estimated.
- The water rights in the area (particularly Willow Creek, Evacuation Creek, Bitter Creek, and the White River) should be examined in detail. Water rights holders with sufficiently high priority to guarantee supplies for tar sands development should be identified in anticipation of future purchase of these rights.
- Water development in the lower White River Basin should be discussed with the USBR.
- Logs from wells in the P.R. Spring area should be examined in detail and a good subsurface geology map developed.
- Pump tests should be conducted and quality samples taken on existing abandoned oil and gas wells if possible.
- A limited drilling program to search for water should be considered once the subsurface geology is established. (Core drilling may be required to establish the geology.)
- A water quality sampling program should be undertaken to more accurately determine the quality of surface runoff.

- Preliminary recommendations for obtaining the necessary water for tar sands development should be developed.
- An interest in obtaining water from the proposed dam on the White River should be expressed in writing to the Utah Department of Natural Resources.

Sunnyside

No further data are required on the flow or quality of the Price River, but supplemental data and analysis will be required to obtain a complete picture of the water resources in the tar sands area. Specifically, the following are recommended:

- The water rights to the Price River and Minnie Maud, Nine Mile, Icelander, and Range Creeks must be clearly determined. Water rights holders with sufficiently high priority to guarantee supplies for tar sands development should be identified in anticipation of future purchase of these rights.
- The flow in the Price River should be analyzed to determine if regulation would be required to ensure stable supplies.
- Data collection and analytical programs should be undertaken to define the flows in Range and Icelander Creeks. These programs might include
  - establishing stream gages,
  - rainfall-snowmelt runoff models, and
  - correlation techniques.
- Limited programs should be undertaken to determine the quality of runoff in Minnie Maud, Nine Mile, Range, and Icelander Creeks.
- Logs of the wells in the area should be examined and an up-to-date subsurface geology map developed.
- Pump tests should be conducted on existing abandoned oil and gas wells.
- The location of potential storage facilities, particularly on Minnie Maud Creek, should be determined and the yield and losses should be more-accurately estimated.
- Preliminary recommendations for obtaining water for tar sands development should be developed.

Tar Sand Triangle

- The water rights in the Dirty Devil Basin should be examined in detail. Water rights holders with sufficiently high priority to guarantee an adequate water supply for tar sands development should be identified in anticipation of future purchase of these rights.

- The locations of any possible springs in this area should be explored and specific rock formations associated with them identified. The yield of each spring should be determined.
- A subsurface geology map should be developed, possibly using a core drilling program as a basis.
- A limited drilling program for groundwater should be conducted if spring yield looks promising.
- Ways to store water from the Dirty Devil River for use in the Tar Sand Triangle should be examined.

CONTENTS

I. INTRODUCTION

PURPOSE

This investigation was conducted by The Sutron Corporation under contract with Colorado State University for the Laramie Energy Technology Center (LETC), U.S. Department of Energy, to determine the availability of water for future extraction of petroleum from the six major tar sands deposits in Utah. It is directed toward researchers and developers of tar sands, who will have to compete with other users for both surface water and groundwater. For each tar sands deposit, this report provides data on the quantity and quality of surface water and groundwater, the availability of such water for tar sands development, and the water rights involved. It also makes recommendations for research in specific areas in which additional information is needed.

REPORT BACKGROUND

The study was conducted between September and December 1978. Data used in the investigation were gathered from files and reports of the U.S. Geological Survey (USGS), Utah State Engineer, Utah Department of Natural Resources, University of Utah, and various petroleum journals. The Office of the Utah State Engineer was particularly helpful in providing data on water rights and on the location and nature of oil and gas wells. Considerable portions of the text, figures, and tables are edited from existing reports. These sources are identified and listed in the Section XI.

In general, the Utah tar sands deposits are located in relatively dry areas. Water is available, but because of competition with other users and the cost of extracting it from the ground, transporting it, and upgrading the quality, its price will be a major consideration.

The tar sands deposit areas treated in this report are

- Asphalt Ridge and Whiterocks, which lie immediately west of Vernal, Utah;
- P.R. Spring, a large area extending from the Colorado River to the White River along the eastern border of Utah;
- Hill Creek, adjacent to P.R. Spring to the west;

- Sunnyside, immediately across the Green River from Hill Creek between the Price and Green Rivers; and
- Tar Sand Triangle, near the confluence of the Colorado and Dirty Devil Rivers.

This report first presents a general physiographic and geologic description of the areas in which tar sands are found. Next, the water requirements for tar sands development are considered. In the following six sections, the water availability for each major tar sands area is discussed. In those sections, surface water and groundwater are considered first. Water quality data are presented when available. Section IX discusses the legal and social factors that govern water use. Section X presents the study conclusions and recommendations for follow-on research.

II. TAR SANDS DEPOSITS

NATURE AND DISTRIBUTION OF TAR SANDS

Tar sands (also known as oil sands and bituminous sands) are sand deposits that are impregnated with dense, viscous petroleum (bitumen). The bitumen can be separated from the sand by a wide variety of methods. However, until recently, the cost of extracting the oil from the sands was higher than the cost of other oil sources and methods. The first commercially successful venture for manufacturing synthetic crude oil from the sands, by Great Canadian Oil Sands, Ltd., has been in operation for several years; a second venture, by Syncrude Canada, has recently been started.

Tar sands are found throughout the world (Figure 1), often in the same geographical area as conventional petroleum. The largest deposit in the world—the only one with current commercial importance—is in the Athabasca area in the northeast section of Alberta, Canada. This deposit contains more than 700 billion bbl of bitumen. [For comparison, this volume is about one-sixth of the U.S. shale oil reserves, and about one-sixteenth of the U.S. coal reserves (Reference 1).]

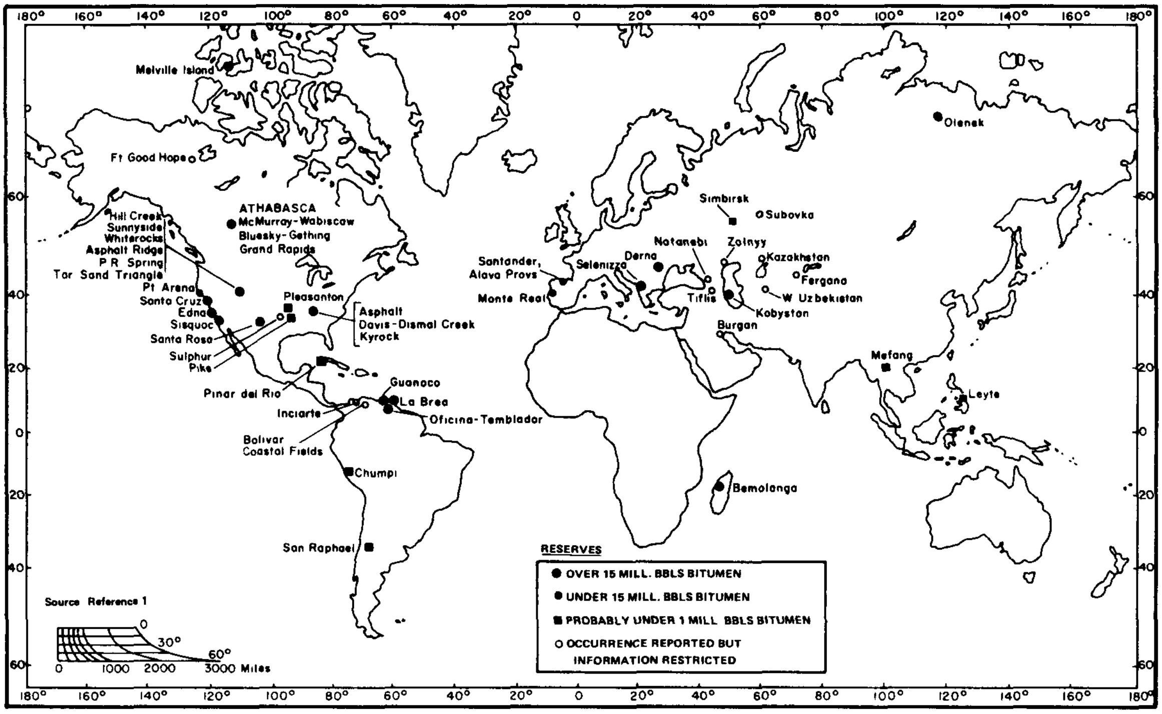


Figure 1. TAR SANDS AREAS OF THE WORLD

While tar sands are not usually considered a major energy reserve, they are significant in light of projected energy consumption over the next several generations. Table 1 compares proven and ultimate reserves for a number of energy sources. Proven reserves have a rather limited and specific meaning. These are reserves recoverable under current conditions of technological and economic feasibility. Proven reserves give an accurate short-term estimate of the working inventory of a particular resource. The proven U.S. reserves of crude oil, for instance, remained relatively constant from 1954 to 1969 despite the fact that 8 to 10 percent of this figure was consumed each year.

Table 1. ENERGY RESERVES
(expressed in Q's[a])

Resource	Proven Reserves		Ultimate Reserves		Predicted U.S. Consumption, 1960-2000
	U.S.	World[b]	U.S.	World[b]	
Crude oil	0.2	2.3	6.0	37.0	1.3
Natural gas & NG liquids	0.3	0.9	3.2	19.6	1.1
Shale oil	0.3	0.9	23.2	79.0	–
Coal	4.6	18.0	55.0	320.0	0.5
Uranium[c]	0.2	0.7	1.2×10^5	–	–
Deuterium[d]	–	–	–	7.5×10^9	–
Tar sands	–	–	0.01	6.5	–

[a] Q = 10^{18} Btu - 167 *billion bbl (crude oil)*.
[b] Including United States.
[c] Proven reserves assume 1 percent recovery of maximum theoretical fission energy content and mining costs of $5 to $10 per pound of U_3O_8. Ultimate reserves assume 100 percent theoretical energy content and no mining cost limit.
[d] By nuclear fusion.

Source: Reference 1.

Ultimate reserves, or in-place reserves, are defined much more broadly. They are the largest reasonable estimate of the total amount of a particular resource, including not only discovered but also "discoverable" (based on reasonable geological extrapolations) resources. The estimate is not limited to today's economic conditions or recovery technology (Reference 1).

Although ten significant tar sands deposits are located within the continental United States, this report deals only with the six tar sands deposits in Utah, which represent a significant portion of the U.S. reserves of tar sands. The key to this development will be the availability of water.

PHYSICAL SETTING OF UTAH TAR SANDS

The Utah tar sands deposits lie within an area called the Upper Colorado Region. The name stems from the location of the area in the upper Colorado River Basin. Figure 2 illustrates the boundaries of the regions and the general area of interest.

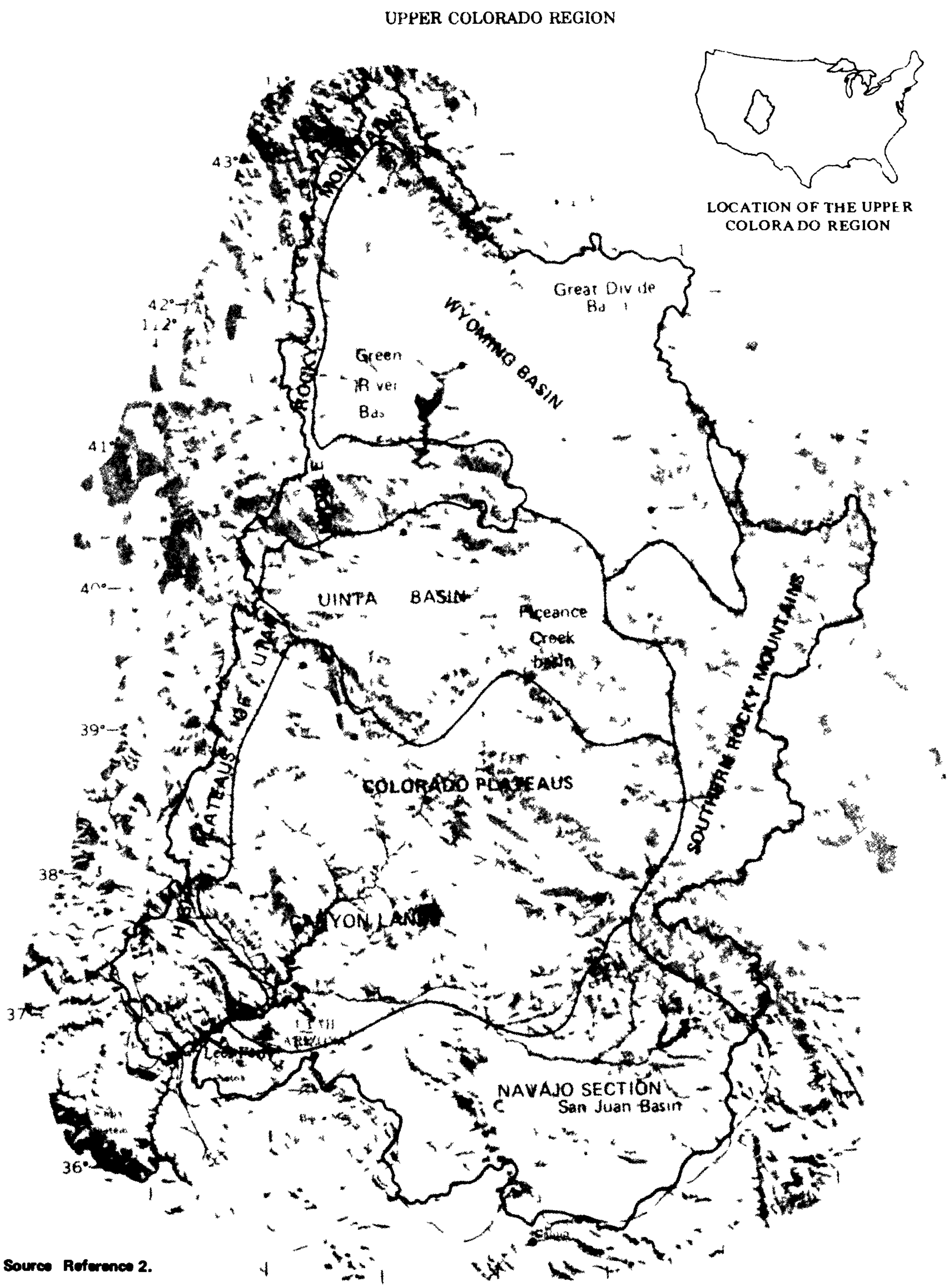
The Upper Colorado Region includes the area drained by the Colorado River and its tributaries upstream from Lees Ferry, Arizona, and the area of the Great Divide Basin, a closed basin in Wyoming. The region covers about 113,500 mi^2 in parts of Arizona, Colorado, New Mexico, Utah, and Wyoming. Physiographic subdivisions that lie wholly or partly within the region are shown in Figure 2.

The Upper Colorado Region is characterized by high, rugged mountains; broad basins; and high plateaus, which have been deeply entrenched and dissected by the Colorado River and manv of its tributaries. Perhaps the most striking, unique physiographic feature of the region is the deep, narrow, intricate canyons that have been carved by streams (many of which are intermittent and ephemeral) in the varicolored rocks that underlie broad basins and plateaus. Altitudes range from 3100 ft above mean sea level near Lees Ferry to more than 14,000 ft in the central and southern Rocky Mountains. Most of the region has an arid to semiarid climate, and some areas receive less than 5 in. of precipitation a year. The higher plateaus and mountains have subhumid to alpine climatic zones, and more than 40 in. of precipitation a year falls on the highest peaks.

Nearly 97 percent of the region drains to the Colorado River; the remainder drains to the Great Divide Basin. Average annual discharge of the Colorado River near Lees Ferry was 17,760 cfs or 12,860,000 acre-feet per year for 49 years of record prior to completion of Glen Canyon Dam in 1963. The river and its three largest tributaries—the Green, San Juan, and Gunnison Rivers—all come to a head in the southern and central Rocky Mountains, and the average annual discharge of each of these tributaries exceeds 2000 cfs.

About 60 percent of the land in the region is owned or administered by the federal government, and another 15 percent is in Indian trust. The region is sparsely populated, averaging about three persons per square mile. As of 1970, Grand Junction, Colorado, and Farmington, New Mexico, were the only communities with populations of more than 20,000. Because of the growing popularity of the region for recreation, however, many of the communities have large seasonal influxes of population. Most of the land is used for grazing, recreation, and mineral development (mostly fossil fuels) (Reference 2).

The physiographic provinces in which the six Utah tar sands deposit areas are located



Source Reference 2.

Figure 2. THE UPPER COLORADO REGION, SHOWING DRAINAGE AND PRINCIPAL PHYSIOGRAPHIC SUBDIVISIONS

are shown in Figure 3 (Reference 3), and the resources of each area are listed in Table 2. The major surface water drainage basins are illustrated in Figure 4. The four major basins are the Uinta Basin area (containing the White, Ashley, Green, and Duchesne Rivers as well as the Uinta River), the Price River Basin, the San Rafael River Basin, and the Dirty Devil Basin. These four basins will be of major concern in evaluating the surface-water availability for tar sands development.

Table 2. BITUMINOUS RESOURCES AND CHARACTERISTICS OF SIX UTAH TAR SANDS DEPOSITS

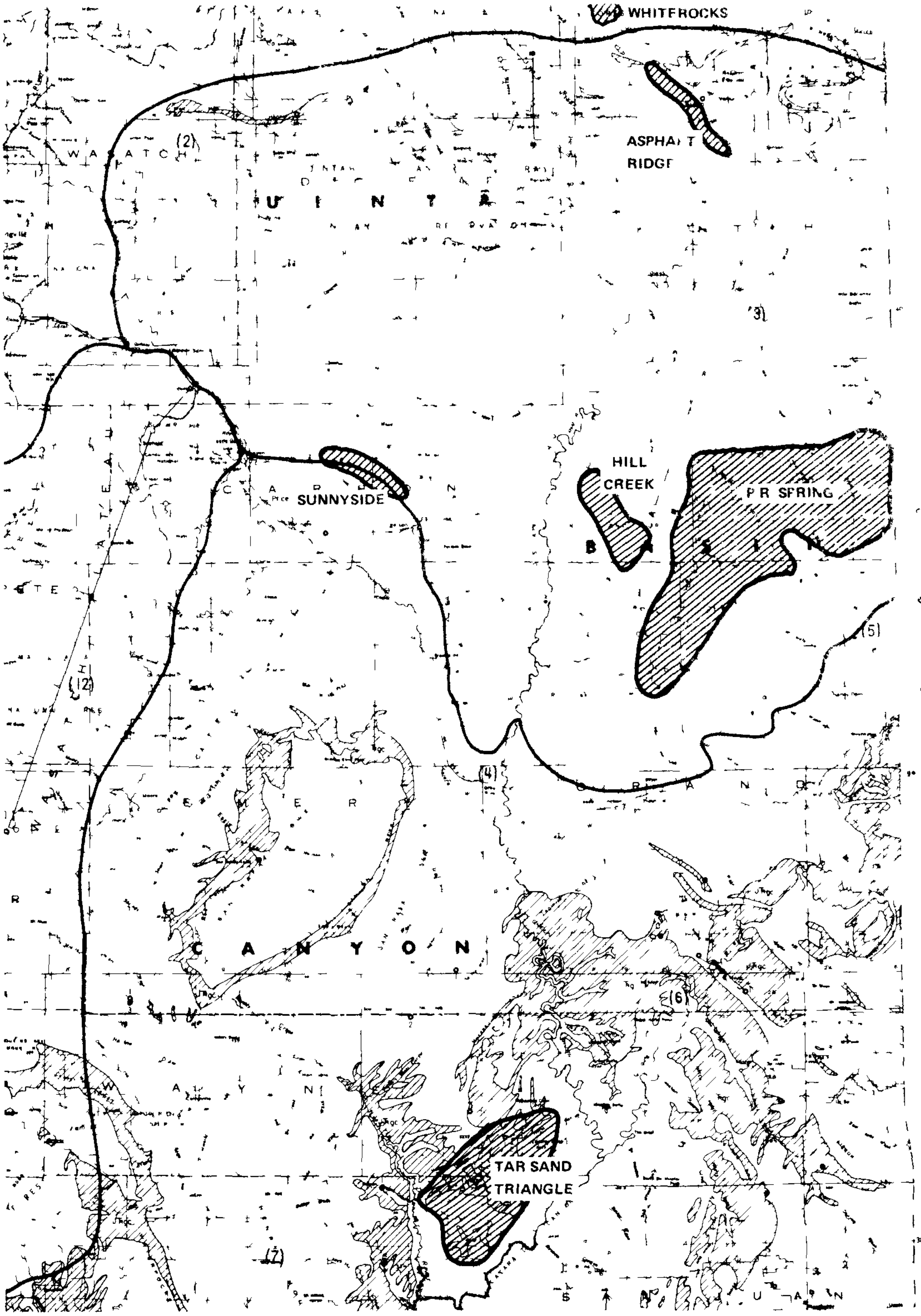
Location	Extent (mi^2)	Thickness (ft)	Overburden Thickness (ft)	Percentage of Saturation by Weight	Resources In-Place (Billions of bbl)
Whiterocks	–	–	–	–	0.065 - 0.125
Asphalt Ridge	20-25	5-135	0-500	11	–
P.R. Spring	215-250	3-7	0-250	9	4 - 4.5
Hill Creek	–	–	0-250	–	0.3 - 1.1
Sunnyside	20-25	10-550	0-600	9	3.3 - 4
Tar Sand Triangle	200-230	Few-300+	0-2000+	–	12.5 - 16

GEOLOGIC SETTING OF UTAH TAR SANDS

In this section, the surface geology of eastern Utah is described. Subsurface geologic conditions are also fundamental to groundwater resources but are not described here; they are described with the groundwater systems of each tar sands area in subsequent sections of this report. In the brief geologic history of the area presented here, emphasis has been placed on the major drainage basins from which the surface water for tar sands development will come.

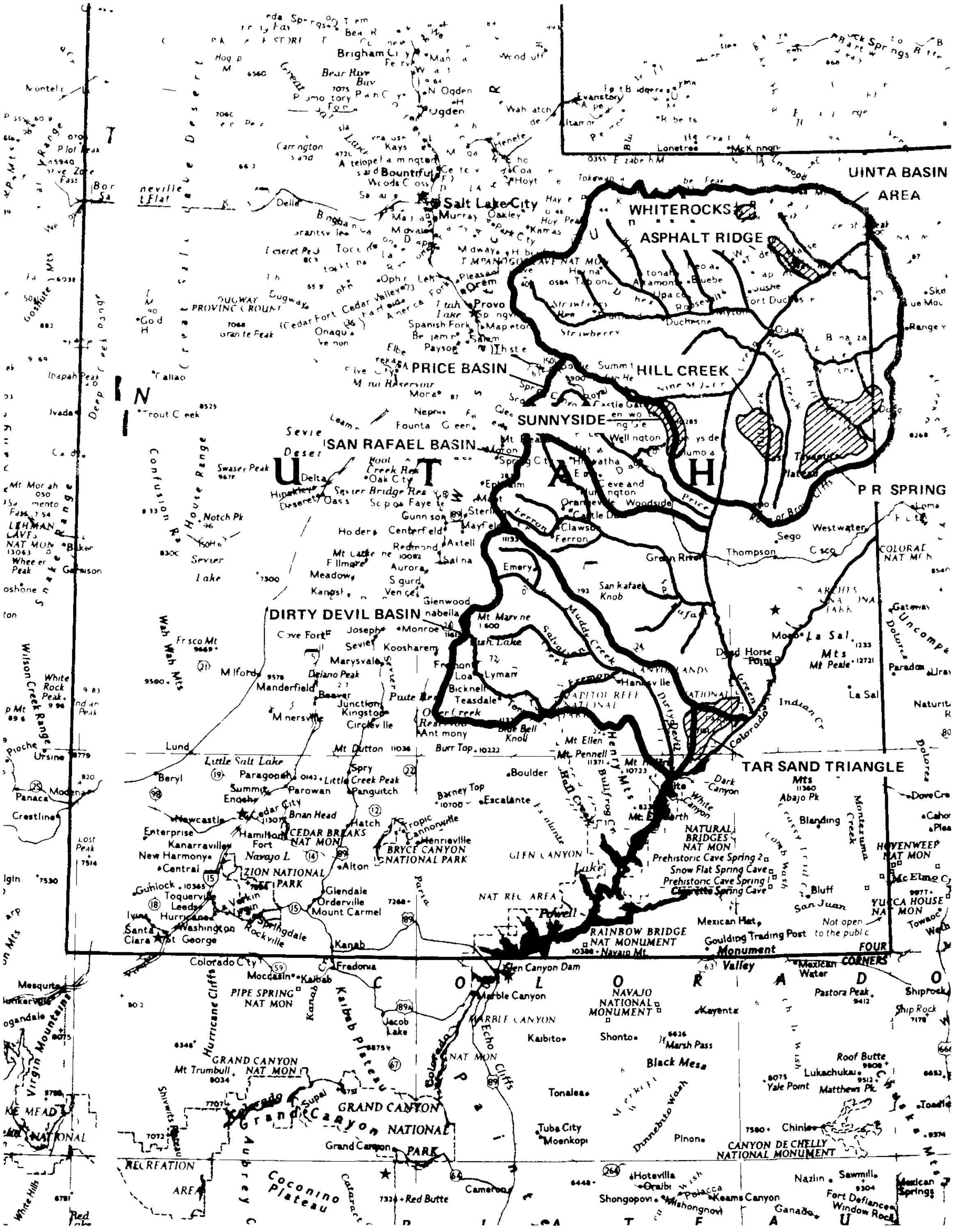
Figure 5 illustrates the general surface geologic characteristics of eastern Utah. (Rock classification units are shown more clearly on a color version of the map provided in the source document.)

The Asphalt Ridge and Whiterocks deposits lie along a contact between the rock units designated 2 (continental rocks) and 3 (continental and marine rocks) in Figure 5. Unit 2 rocks include lake deposits and/or shale, siltstone, and fine-grained sandstones; Unit 3 rocks consist primarily of shales and sandstones. The Hill Creek, P.R. Spring, and Sunnyside tar sands areas lie entirely in Rock Unit 2.



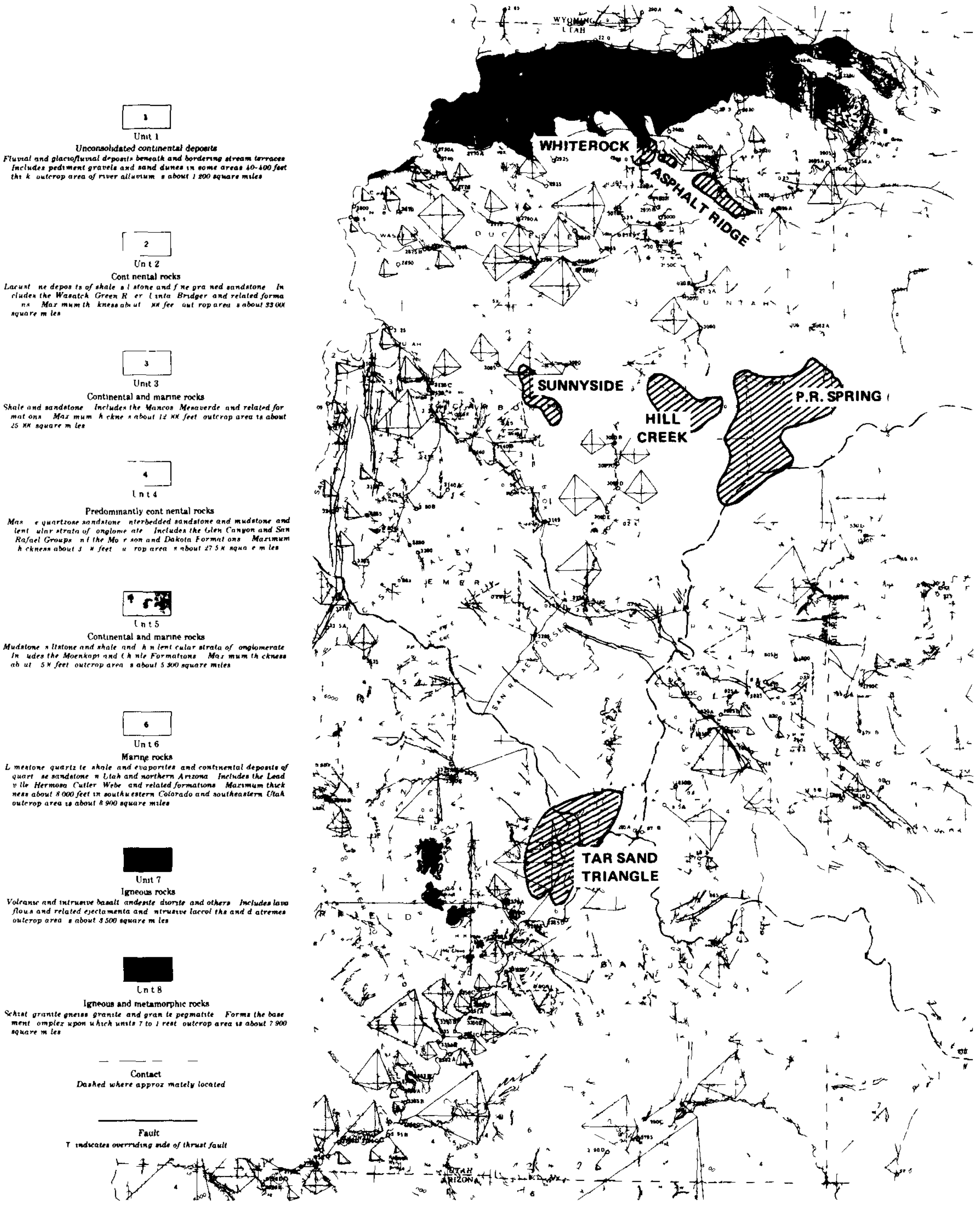
Source: Utah Geological and Mineral Survey Map 47, January 1979.

Figure 3. LOCATION OF UTAH TAR SANDS DEPOSITS WITHIN MAJOR PHYSIOGRAPHIC PROVINCES



Source: Reference 4.

Figure 4. MAJOR SURFACE WATER DRAINAGE SYSTEMS AND TAR SANDS AREAS



Source: USGS Paper 441.

Figure 5. GENERAL SURFACE GEOLOGIC CHARACTERISTICS OF EASTERN UTAH

The Tar Sand Triangle is unique in that it overlaps Rock Units 4, 5, and 6 (continental and marine rocks). Unit 4 is predominantly continental rocks, Unit 5 is a mixture, and Unit 6 is predominantly marine rocks. Unit 4 consists of massive quartz sandstone, interbedded sandstone and mudstone, and lenticular strata of conglomerate; Unit 5 is similar in composition with some shale; and Unit 6 consists of limestone, quartzite, shale, and evaporites.

Austin and Skogerboe (Reference 5) draw on a variety of USGS and state publications (References 6, 7, 8) to present a fairly detailed picture of the geologic history of the Uinta River Basin. The Uinta River Basin is of great interest to the study since it contains all or part of five of the six tar sands areas.

The Uinta River Basin (Figure 4) is an asymmetric, synclinal basin trending east-west, with its axis displaced northward almost to the foot of the Uinta Mountains. It terminates westward at a series of north-south block faults near the head of Strawberry River. Its eastern boundary is sometimes regarded as the series of structures that extend southward from Blue Mountain to the Rangely Dome; however, most geographers consider the Uinta River Basin as including all of the country east to the Grand Hogback. The floor of the basin lies generally at elevations of 4000 to 5000 ft and rises steadily southward to 10,000 and 11,000 ft at the rim of the Tavaputs Plateau. Northward, the flank of the Uinta Mountains sharply delimits the basin.

The Green River, which flows southwestward across the basin, is the master stream. The White River enters the Green River from the east, and the Duchesne River enters from the west, both near Ouray, Utah; with the tributaries these streams drain all of the basin except the northeast corner and a narrow portion adjacent to the Green River itself.

During the Eocene period (References 9 and 10), the Uinta Arch was in existence. A lake once occupied most of the Uinta Basin, receiving sediments from the Uinta Mountains and mountains to the east and to some extent receiving fine-grained volcanic ash. The positions of the southern and western shores of this lake are not known. Generally coarser sediment to the east and southeast and a great thickness of fine-grained material to the southwest suggest that the outlet and deepest portion of the lake lay to the southwest, with a major stream entering from the east.

The next clear geomorphologic record is Pleistocene glaciation within the high peaks of the Uinta Mountains. Glaciation of the Uinta Mountains was chiefly confined to the higher parts of the Uinta Range in Duchesne and Wasatch Counties, where the longest glaciers, some of which attained a length of 27 mi, occurred in valleys that were fed by ice from the Kings Peak area. Outward from this central area, glaciation on both the north and south slopes of the range diminished rapidly. Little if any glaciation occurred east of Ashley Creek in Uinta County. Cirques and neve fields occur at the headwaters of Ashley Creek, in the vicinity of Leidy and Marsh Peaks.

West of Marsh Peak, in the headwaters of Dry Fork, glacial moraines are found 10 mi or more down the canyon at elevations of 8000 ft or more north of Lake Mountain. Whiterocks Canyon contains the longest of the glacial moraines in Uinta County. Its terminal moraine, at an altitude of 7200 ft, like that of the Ashley Creek glaciation, correlates with the maximum glaciation in Uinta Canyon to the west.

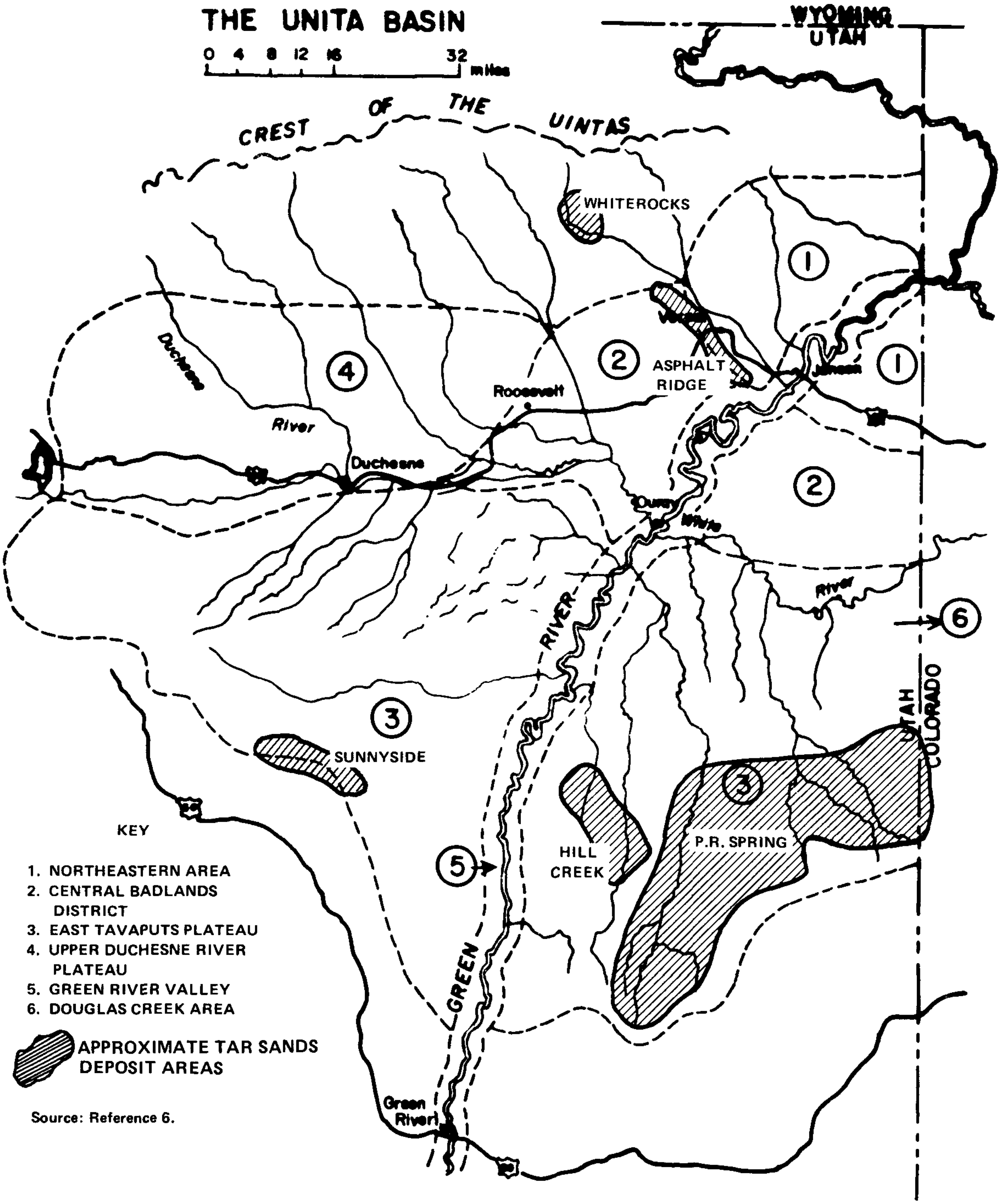
Three stages of glaciation have been recognized in the Uinta Mountains. The earliest stage is represented by moraines that lie west of the Uinta River on a remnant of the Jensen erosion surface. During the stage of maximum advance, the massive moraines extended down to 7000 ft in their descent in Uinta Canyon, where all three stages are recognized. During the latest glaciation, the ice advanced to within a mile of the southern limit of the maximum stage. In Whiterocks Canyon the latest stage extended to an elevation of 7300 ft. Most of the residual moraine is on the east side of the canyon. Ice correlating with this latest stage probably occupied the headwater areas of Ashley and Dry Fork Canyons, but it is not possible to differentiate the late-glacial deposits from those of the maximum state. Glacial lakes, both morainal and tarns, are abundant in the glaciated areas.

The Uinta River Basin proper underwent considerable degradation after the cutting of the Bear Mountain surface and before the Pleistocene epoch. Stream erosion was the dominant process during the Pleistocene epoch and continues to be so. For the convenience of discussion, Clark (Reference 6) has divided the Uinta River Basin into six geomorphical districts as follows:

1. the Northeastern,
2. the Central Badlands,
3. the Tavaputs Plateau,
4. the Upper Duchesne River Plateau,
5. the Green River Valley, and
6. the Douglas Creek Area.

These districts are shown in Figure 6. Only the first three districts are of interest in this report. Asphalt Ridge and Whiterocks lie along the dividing line between the Northeastern district and the Central Badlands to the west of the Green River. P.R. Spring and Hill Creek lie wholly within the Tavaputs Plateau to the east of the Green River. Sunnyside lies along the southern boundary of the Tavaputs Plateau to the west of the Green River.

The Northeastern district lies primarily to the east of Asphalt Ridge and extends to the Colorado border. East of Asphalt Ridge, the northern part of the Uinta Basin is a complex series of minor erosional surfaces cut on tilted Mesozoic strata. The harder strata form hogbacks, and the softer ones, gently sloping valleys. Relief is usually less than 300 ft and always less than 500 ft. The Mancos Shale of Ashley Valley has been cut into a series of minor pediments, but elsewhere pediments are not apparent. The topography is entirely erosional and predominantly subsequent.



Source: Reference 6.

Figure 6. GEOMORPHOLOGICAL DISTRICTS IN THE UINTA BASIN

In the Central Badlands district, a series of pediment surfaces transects the shallow-dipping Duchesne River strata at a very low angle, west from Asphalt Ridge to the vicinity of Roosevelt. The remainder of the area of Tertiary rocks north of the White and Duchesne Rivers consists of broad benches, largely erosional, with extensive badlands rims along the drainages that are now dissecting the benches. Many of these benches have caps of 10 to 100 ft of sand and silt; in places the sand has drifted into low dunes, which are now relatively stationary. Discontinuous patches of heavily desert-burnished cobbles occur occasionally on the benches and the badlands. It is not known whether these benches are pediment surfaces or simply complex erosional surfaces upheld by various parts of their area.

Erosion has clearly etched out the old channel-ways of Eocene and Oligocene streams. A series of east-west-trending sandstone ridges can be followed readily from Coyote Basin, near the Utah-Colorado border, westward past Ouray to a point south of Myton. These ridges mark the course of the Eocene stream that flowed from the Colorado mountains westward to the old lake. Similar smaller channel fill now forms north-south-trending ridges from near the Uinta Mountains toward the northern shore of the lake that existed during the Eocene epoch.

South of the Duchesne River-White River drainages the Tavaputs Plateau rises to the south with the dip of the Green River Formation on which it is cut. The interstream divides are broad, consisting of a series of discontinuous cuestas upheld by local sandstones and indurated limey and siliceous zones. Both streams and dry washes are deeply carved into canyons. The topography is large scale, with distances of half a mile to a mile between tributary drainages. The entire topography is subsequent and in late youth. The area is completely drained, relief is at a maximum, and the largest streams are beginning to develop small flood plane scrolls along their lower courses. Even the largest streams are mere trickles at the bottom of canyons almost 1000 ft deep; flash floods cause most of the erosion.

The rocks of the Tavaputs Plateau are predominantly cream to light gray in color, and those of the Upper Duchesne River Plateau are mostly brick red. This color difference forms a striking boundary that happens to coincide roughly with the physiographic boundary.

The Sunnyside tar sands deposit lies along the divide between the basins of the Uinta and Price Rivers. The geology of the Price Formation is fairly well defined in Reference 12. The western portion of the basin lies in the Wasatch Plateau. The entire northern edge of the basin is bounded by the Roan and Book Cliffs. These cliffs are formed by nearly horizontal sedimentary deposits dipping gently northwestward. The Roan Cliffs are sedimentary red beds and shale, and the narrow plateau area between the Roan and Book Cliffs is composed of conglomerate sandstone, mudstone, and limestone. The face of the Book Cliffs is predominantly shale, coal beds, sandstone, and mudstone.

The major geologic features of the central and lower basin are the Castle Valley and

San Rafael Swell. Both of these features extend southward into the San Rafael River Basin. Castle Valley is a piedmont that has been dissected by the drainage in the area. The San Rafael Swell is an enlongated structure with a north-south trending axis. The Sunnyside tar sands area lies along the northern edge of the basin. Thus, the Roan and Book Cliffs are the primary geologic features of concern in this study.

The San Rafael River Basin is of somewhat indirect concern to the study. It does not lie near enough to the Sunnyside area to be of interest and may be too far north to provide water for Tar Sand Triangle. However, the possibility exists, so a discussion of its geology is included.

Reference 13 provides a fairly clear picture of the San Rafael Basin. The geology of the San Rafael drainage is quite varied. The major features of interest are the Wasatch Plateau, Castle Valley, San Rafael Swell, Green River Desert, and canyons of the Green River. The Wasatch Plateau forms the western part of the drainage basin and is composed of horizontal beds of shale and sandstone. The face of the plateau has been formed by erosion, and it towers as much as 3000 ft above Castle Valley.

Castle Valley forms the transition between the Wasatch Plateau and the San Rafael Swell. Mancos Shale underlies the valley. Overlying the shale are accumulations of clay, sand, and gravel. The San Rafael Swell is an elongated anticline, which forms the most prominent physical feature in the basin. The San Rafael River cuts the swell at its widest part, exposing both Navajo and Coconino Sandstones. Canyons and a large sawtooth ridge of upturned sandstone characterize the eastern edge. The wester edge is not as prominent.

The Green River Desert extends from the San Rafael Swell to the Green River. Much of this area is characterized by mesas, with small patches of soil along the bottoms of washes and streams. Elsewhere, bedrock is present (Reference 14). This Green River Desert area is of most concern to this study.

The final basin to be considered is the Dirty Devil Basin. (Its geology is described in Reference 15.) The Tar Sand Triangle lies immediately north of the junction of the Dirty Devil and Colorado Rivers. The Dirty Devil Basin lies entirely within the Colorado Plateau physiographic region. The western part of the basin is commonly included in the High Plateau district of Utah. The geologic boundary to the north is the San Rafael Swell, which trends northeast for about 70 mi. The Henry Mountains, a classic laccolithic structure, form a part of the southern boundary. The eastern part of the basin is eroded sediments; significant structures include the Teasdale Fault and Teasdale Anticline.

The High Plateaus forming the main watershed are the southern end of the Wasatch Plateau (Muddy Creek drainage), the Fish Lake Plateau (Fremont River drainage), the Awapa Plateau, and the Aquarius Plateau (Pine Creek, Oak Creek, Pleasant Creek drainage). All these plateaus are remnants of larger ones that have been extensively eroded to the east, mostly during the Tertiary period. The western slope of the Wasatch Plateau is a monoclinal structure, while the western slopes of the Fish Lake and Awapa Plateaus were formed by uplifting along the Grass Valley Fault. The western slope of Boulder Mountain (on the Aquarius Plateau) was also caused by faulting. The southern slope of this plateau is monoclinal and is associated with the Waterpocket Fold. The Upper Fremont River Valley, or Rabbit Valley, is a depression caused by faulting and erosion and has been partially filled with alluvium (Reference 16). The eastern side of the valley is walled by Thousand Lake Mountain, which is structurally a part of the Aquarius Plateau.

Considerable evidence of volcanic activity, predominantly during the Tertiary period, exists in the western part of the basin. Most of the Awapa Plateau, Aquarius Plateau, and Thousand Lake Mountain are covered with volcanic rock derived from lava flows.

Sedimentary rocks exposed in the Capital Reef area range from the Coconino Sandstone of the Permian period to the Flagstaff Limestone of early Tertiary period. Quaternary and Recent formations are found covering the older bed along the flanks of the Aquarius Plateau and Thousand Lake Mountain. The Tar Sand Triangle lies within the deeply incised gorges of the canyon lands near the mouth of the river.

With the general geology and physiography of the tar sands area established, the specific water requirements for tar sands development can be discussed. The remainder of the report then presents area-by-area descriptions of water availability.

III. WATER REQUIREMENTS FOR TAR SANDS DEVELOPMENT

Two basic approaches are available for recovering bitumen from tar sands. The tar sands may be mined and transported to a processing plant where the bitumen is extracted and the sand is discharged, or alternatively, the bitumen may be separated from the sand in situ. In this investigation only in situ processes were considered in evaluating the water requirements. This section briefly describes the in situ processes that most probably will be used in Utah and establishes some approximations of water requirements for these processes.

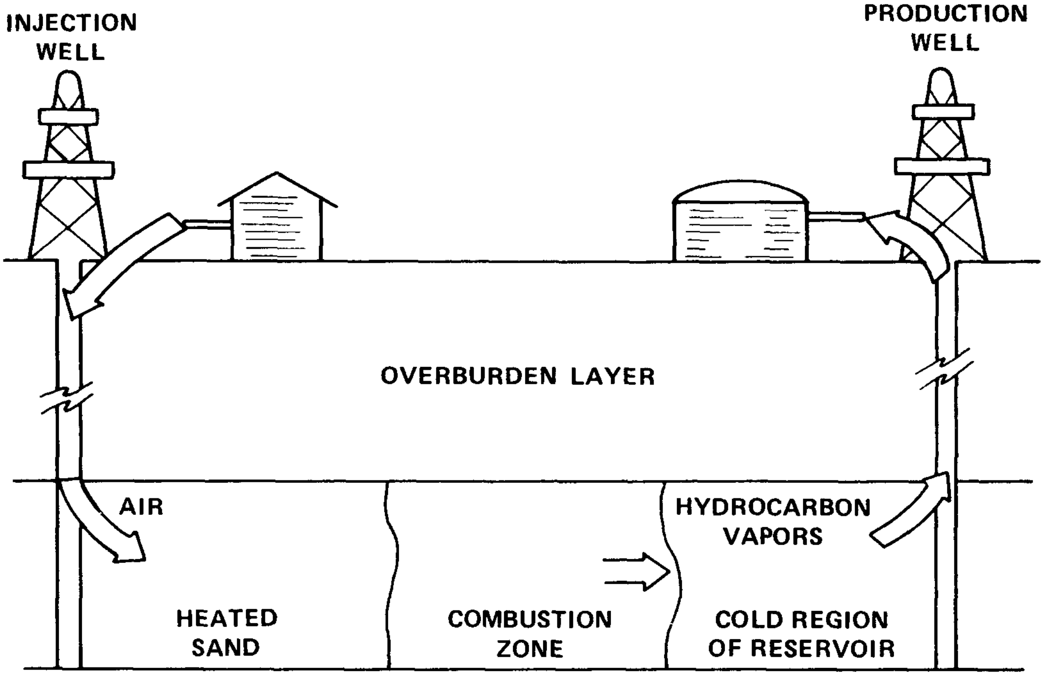
IN SITU PROCESSES

In situ processes have a great deal in common with secondary recovery of conventional crude oil (Reference 1). Conventional crude oil is collected (produced) from the oil-bearing formations by drilling wells down into the formation. Initially, the oil is driven up through production wells by natural energy within the formation, such as the pressure of natural gas. For a period of time, the oil may be pumped from the surface; after that, this operation becomes inefficient. When the natural energy is expended or if there is none, it must be artificially introduced into the formation (via injection wells) to stimulate production. In the case of tar sands, such natural energy is never present.

Most of the viable methods for recovering petroleum from tar sands are described by Cameron Engineers (References 1 and 17). The following discussion is based on Reference 1.

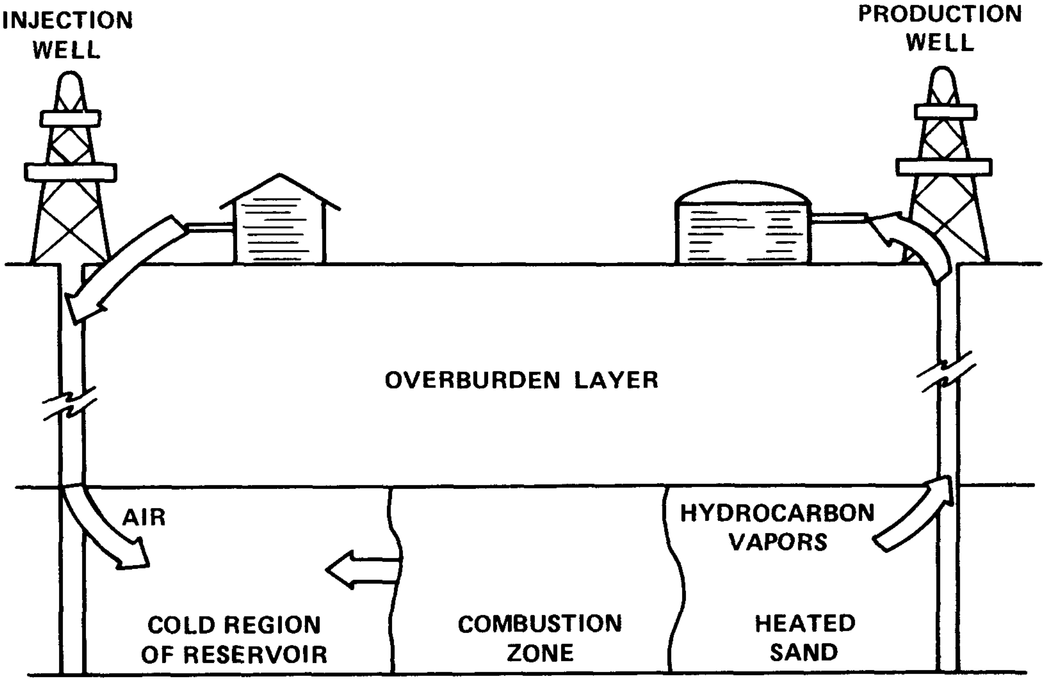
In thermal recovery processes, energy is generated in the form of heat. The heat is supplied by igniting the oil in the formation and sustaining the combustion or partial combustion. The high temperatures generated decrease the viscosity of the oil and make it more mobile. Two types of thermal recovery are the forward-combustion process, in which the combustion front moves with the air flow (Figure 7) and the reverse-combustion process, in which the front moves counter to the direction of air flow (Figure 8). In both cases burning occurs at the interface between air and hot, unburned oil.

Field tests of in situ combustion processes conducted by the Pan American Petroleum Corporation culminated in the development of a combination fire-flood/water-flood process (Reference 18). In the combination process, forward combustion is used to heat a portion of the reservoir to a peak temperature of 1500°F. Following the heating phase, air and water are injected into the formation. The water serves to dissipate the local high-temperature heat, so that a much larger proportion of the reservoir is uniformly heated to about



Source: Reference 1.

Figure 7. SCHEMATIC OF FORWARD COMBUSTION



Source: Reference 1.

Figure 8. SCHEMATIC OF REVERSE COMBUSTION

200°F. At that temperature, the oil becomes more mobile and is produced under the action of the air and hot-water drive.

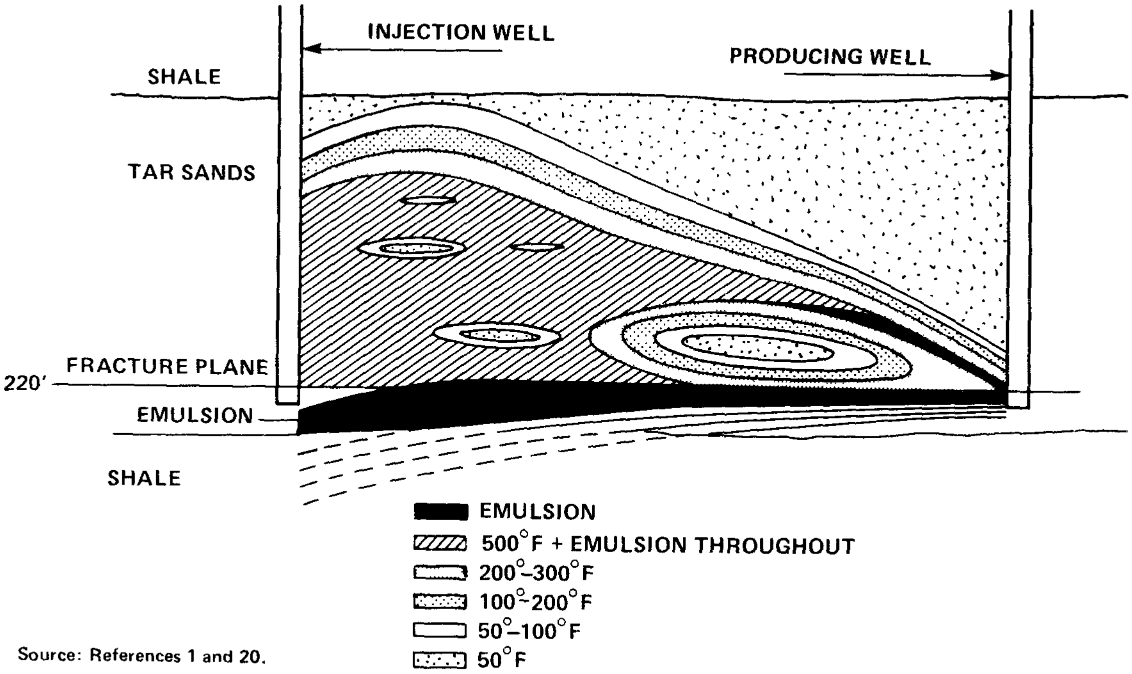
Development of the combined forward-combustion, air/water (COFCAW) process was begun with laboratory work in 1956. From that work, it appeared that forward combustion would not be successful because of the relatively low permeability of the tar sands formation. Reverse combustion, however, appeared to be a useful possibility. These conclusions were confirmed in field trials conducted in 1958-59. In further field trials between 1960-65, however, a second attempt at reverse combustion failed. At that point, it was concluded that the previous tests had been successful because the formation had inadvertently been fractured. Attention was then turned to developing the two-step, forward-combustion, water-flood process.

Field tests of the two-step process were conducted by Muskeg Oil Company (now Amoco Canada, Ltd.) during 1965-68 on the Gregoire Lake Indian Reserve No. 176, 25 mi south of Fort McMurry, Canada. A five-spot well pattern was drilled on a 150-ft square; four production wells were located at the corners of the square, with an injection well at the center.

Overburden depth in this area is approximately 1000 ft, and the tar sands area is 120 ft thick. To begin the combustion and heating phase, the formation was hydraulically fractured. The sands were ignited in July 1966, and forward combustion was continued until May 1967. At that time, the formation had been heated at each of the four production wells. The maximum temperature recorded was 1500°F, and 65 percent of the oil had been heated above 150°F. The wells were shut in for one month and then air injection, water injection, and production were begun. Two of the four production wells experienced mechanical difficulties; the other two wells each produced an average of 63 bbl of oil a day for the following 200 days. The product was 40 percent water by weight.

If the viscous bitumen in a tar sands formation can be made mobile by the admixture of either a hydrocarbon diluent or an emulsifying fluid, then another relatively low-temperature secondary recovery process may be possible. Shell Canada, Ltd., tested an emulsion process in field trials between 1957 and 1962 (Reference 21). Emulsification was preferred over the use of a hydrocarbon diluent because (a) diluent is more expensive than the emulsifying fluid (water) and (b) relatively large amounts of diluent would be required to reduce the viscosity of the highly viscous Athabasca bitumen. Viscosity of a bitumen-in-water emulsion (20-30 percent bitumen) is essentially the viscosity of water.

Field trials were conducted between 1957 and 1959 on the use of a proprietary nonionic surfactant in water. During a somewhat larger and more comprehensive program between 1960 and 1962, a caustic solution (sodium hydroxide in water) and steam-injection combination technique was tested. For this test, a five-spot pattern of wells was drilled, with an injection well at each of the four corners of a square and a producing well in the center. Figure 9 is a cross-section sketch of the experimental arrangement.



Source: References 1 and 20.

Figure 9. IN SITU BITUMEN RECOVERY BY STEAM INJECTION

In the experimental program, the ratio of steam injected to bitumen recovered was about 0.685 ton of steam per barrel of bitumen. At that operating ratio, formation temperatures reached a maximum of 275°F. From the experimental data, Shell Canada concluded that an injection rate of about 0.5 ton of steam per barrel of bitumen would be required on commercial scale. At that operating ratio, formation temperature would be 350°F, and an emulsion of 25-30 percent bitumen in water would be recovered from the producing wells.

A 9-year, $85 million pilot project is scheduled by Shell Canada in the Peace River deposit area near Athabasca, Alberta, Canada. The production scheme is designed especially for the geologic situation existing in that area. The formation occurs at a depth of approximately 1800 ft and averages 90 ft in thickness. The top of the formation is relatively level, having an average dip of only 20 ft per mile. At the base of the formation lies a water saturated zone, which consists of medium- to coarse-grained sand containing minor thin-shale breaks.

The proposed pilot plant will consist of seven, seven-spot patterns having 7-acre spacing and will involve 24-production wells, 7 steam-injection wells, 12 observation wells, 2 fuel-gas wells, and 3 water-disposal wells. The injection wells will be approximately 1930 ft deep, and the production wells will be about 2210 ft deep.

The steam-injection process consists of the following five steps:

- *Step 1:* Inject approximately 1000 to 2000 BPD of steam having a heat content of 1150 Btu per pound until steam breakthrough. This breakthrough usually occurs in about 2 years. During that time, minimal amounts of oil will be produced because the steam will have a tendency to channel along the bottom of the reservoir, leaving the upper oil-rich portions largely untouched.
- *Step 2:* While maintaining steam injection rates at the highest possible level short of fracturing pressure, increase the back pressure in the production well. Approximately 6 months will be required to reach the desired pressure of 800 to 1100 psi in the steam zone.
- *Step 3:* Maintain the desired pressure for approximately 1½ years to allow the upper 81-ft thick, oil-rich zone to be heated by the higher-temperature steam zone.
- *Step 4:* Increase the production rate while allowing the pressure to drop to approximately 250 to 500 psi. This step is expected to start about 4 years after the initial steam injection. The production period is expected to last about 1½ years. If the pressure is reduced too quickly, the oil recovery rate is reduced.
- *Step 5:* Repeat Steps 2, 3, and 4 to produce the remainder of the oil. Although a single, longer-duration pressurization and blow-down cycle would accomplish the same thing, the two-cycle method accelerates oil recovery.

The ratio of steam injected per barrel of bitumen produced is important as far as the economics of an emulsion process are concerned. This importance is apparent from a brief consideration of the theoretical heat requirements. Net heating value of a barrel of bitumen if 6.24 million Btu. One ton of steam represents approximately 2 million Btu as latent heat of vaporation. Thus, a half ton of steam per barrel of bitumen represents (at 100 percent efficiency) a fuel requirement of 16 percent of the bitumen recovered. If, now, the thermal efficiency of the steam drive process is impaired–for instance, by heat losses upward in the formation to the overburden or downward from the formation–the numerator of the steam-to-bitumen ratio will be increased. Conversely, as the grade (i.e., percentage of bitumen) of the tar sands decreases, a larger amount of sand must be heated for each barrel of bitumen recovered. Thus, the steam-to-bitumen ratio will increase. If the expected thermal efficiency is significantly reduced, a relative large and economically significant amount of the recovered bitumen will be required to produce the steam (Reference 1).

APPROXIMATE WATER REQUIREMENTS

Little is currently known about the exact water requirements for tar sands development. However, from this brief description of the in situ processes, it is possible to produce a general range of water requirements for tar sands development. Three levels of development will be considered—test and experimental projects, small-scale pilot projects, and large-scale production facilities. The approximate water requirements for each will be estimated and converted into common hydrologic units of measure for use in comparison with available quantities of water.

First it is necessary to define the size of experimental, pilot, and production projects. Experimental project size is based on the PanAm COFCAW process. This five-well pattern produced 63 BPD per well from two wells, and its product was 40 percent water by weight. Assuming that all four wells could produce at that rate and correcting for the amount of water, a five-well (four producing wells) experiment would produce 151 BPD of bitumen.

The size of pilot facilities is based on the Shell Canada 24-production-well facility. It is assumed that such a facility will also produce at 63 BPD per well and the product will be 40 percent water by weight. (This latter assumption may be optimistic since Shell Canada estimates the product to be 25 to 30 percent bitumen. Its estimates, however, do not include total production of the bitumen/water mixture.) Thus, 907 BPD of bitumen is used for pilot facilities.

No production facility using in situ methods has been developed. Therefore, for comparison purposes, the output of a large, tar sands mining facility will be used. The Greater Canadian Oil Sands facility uses 100,000 tons per day of tar sands (Reference 1). Assuming the product to be 10 percent bitumen, the facility extracts 57,000 BPD, which is used here to define production size.

The best factual data on the water requirements of in situ processes is the Shell Canada figure of 0.685 ton of steam per barrel of bitumen, determined in emulsion steam-injection experiments. Shell Canada estimates that the water requirement could go as low as 0.5 ton of steam per barrel of bitumen. Discussion with staff members at LETC resulted in estimates as low as 0.35 ton of steam per barrel of bitumen (i.e., 2 bbl of water for 1 bbl of bitumen). Since none of the estimates are absolute, water requirements were determined for 2, 5, and 10 bbl for 1 bbl of bitumen for the three sizes of facilities (experimental, pilot, and production).

All of the estimates assume that none of the water required for tar sands development will be available again (i.e., consumptive use of water). If some form of recycling is possible on the water/steam mixture from production wells, the water requirements can probably be reduced 50 percent or more.

The water requirements of the various sizes of facilities are presented in two different ways. First, they are tabulated in barrels per day and acre-feet (AF) per year. Next, the value of acre-feet per year is converted to flow rates of gallons per minute and cubic feet per second. These three units are all commonly used by hydrologists to report water quantity. Reservoir capacity and water rights are often expressed in acre-feet; water well production is commonly measured in gallons per minute; and streamflow statistics are usually provided in cubic feet per second. Table 3 shows the yearly water requirements in barrels per day and acre-feet per year, and Table 4 gives the same values in gallons per minute and cubic feet per second.

Table 3. YEARLY WATER REQUIREMENTS FOR VARIOUS SIZES OF TAR SANDS DEVELOPMENTS ASSUMING 100 PERCENT CONSUMPTIVE USE

Size of Facility	Bitumen Production (BPD)	Steam Required Annually					
		0.35 tons/bbl=2 bbl/bbl		0.87 tons/bbl=5 bbl/bbl		1.75 tons/bbl=10 bbl/bbl	
		BPD	AF/yr	BPD	AF/yr	BPD	AF/yr
Five-Well Experimental	151	302	14.2	755	35.5	1,510	71
24-Well Pilot	907	1,814	85.3	4,535	213	9,070	426
Large-Scale (57,000 BPD) Production	57,000	114,000	5,360	285,000	13,400	570,000	26,800

Table 4. YEARLY WATER REQUIREMENTS FOR TAR SANDS DEVELOPMENT IN STANDARD HYDROLOGIC UNITS

Type of Facility	Steam Requirements (bbl/bbl)	Annual Water Requirements		
		AF/yr	GPM	cfs
Five-Well Experimental	2	14.2	8.8	.02
	5	35.5	22	.05
	10	71	44	.10
24-Well Pilot	2	85.3	53	.12
	5	213	132	.29
	10	426	264	.59
Large-Scale (57,000 BPD) Production	2	5,360	3,323	7.4
	5	13,400	8,300	18.5
	10	26,800	16,600	37.0

IV. WATER RESOURCES NEAR ASPHALT RIDGE AND WHITEROCKS

This section considers in detail the water resources in the vicinity of the Asphalt Ridge and Whiterocks deposits. It first treats the available precipitation and surface water runoff and then presents the water budgets for the currently developed ground and surface waters. Next, the availability of groundwater is investigated. In each section, tar sands development requirements are discussed.

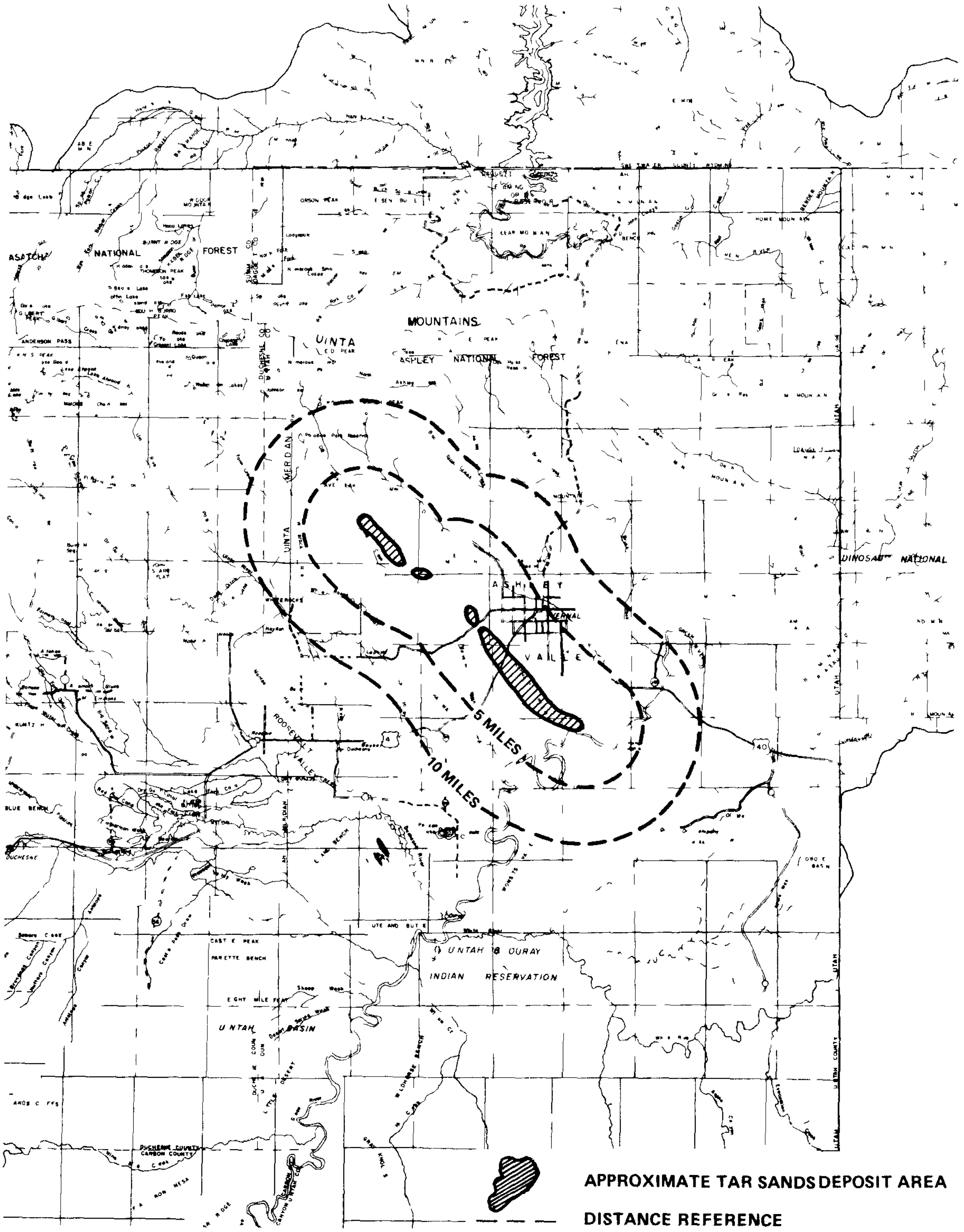
SURFACE WATER

The Asphalt Ridge and Whiterocks tar sands deposits lie within the Uinta River Basin. Considerable information is available on the distribution of precipitation and surface water runoff within the basin. Two reports—by Austin and Skogerboe (Reference 5) and by Hood, Mundroff, and Price (Reference 22)—contain the bulk of the relevant data. The Hood et al. report basically presents data, while Reference 5 presents a thorough hydrologic analysis. Reference 5 is used as a basis in this section. A third report, by Maxwell et al. (Reference 23), gives an excellent picture of water movement in the immediate vicinity of Vernal on the Ashley and Brush Creek systems.

The immediate vicinity of Vernal, Utah, which contains the Asphalt Ridge and Whiterocks tar sands deposits, is illustrated in Figure 10. Also illustrated in the figure are 5- and 10-mi distance reference lines, which give some indication of the distance water might be transported from streams.

The major creeks and rivers that lie within 10 mi of the deposit area are

- Ashley Creek,
- Black Canyon Creek,
- Dry Fork of Ashley Creek,
- Brush Creek,
- Mosby Creek,
- Farm Creek,
- Whiterocks River,
- Uinta River,



Source. Reference 5.

Figure 10. ASPHALT RIDGE TAR SANDS AREAS

- Twelve Mile Wash, and
- Green River.

Of these, only Twelve Mile Wash has not been studied.

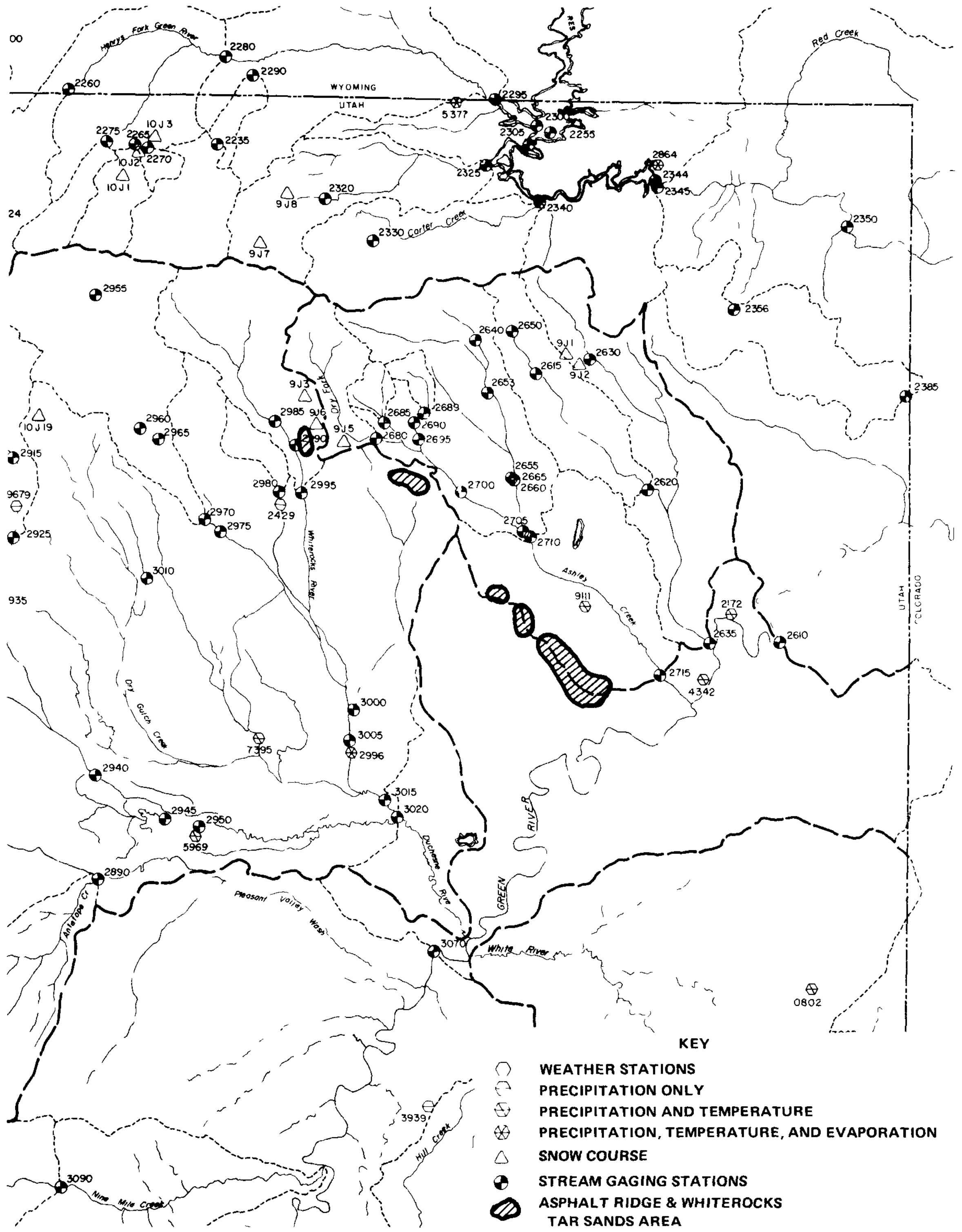
An extensive network of meteorologic and stream gaging stations is maintained in the vicinity of Vernal (Figure 11). The stations that are of concern in terms of identifying water resources for the Asphalt Ridge and Whiterocks River areas are listed in Table 5.

Length of record is an important consideration in hydrologic monitoring. Twenty to 30 years of record is highly desirable for projecting trends and computing averages and standard deviations. The lengths of record for the stream gages in Table 5 are indicated in Figure 12. Thirteen of the 18 stations listed have 20 years or more of records. These stations are the ones on the major streams and are of most interest. In general, streamflow in the area is well defined.

Austin and Skogerboe (Reference 5) divide the major drainage areas in the Asphalt Ridge and Whiterocks areas into smaller "hydrologic subareas" based on the location of the stream gages. These subareas are used in water budget calculations. The hydrologic subareas for the Ashley-Brush drainage basin at the end of Asphalt Ridge and the Uinta Basin drainage area to the west are illustrated in Figures 13 and 14, respectively. All of the subareas in the Ashley-Brush drainage area are of concern to this study and are listed in Table 6. Only five of the subareas in the Uinta drainage area are of concern for this study. They all lie along Asphalt Ridge to the west and are listed in Table 7.

Precipitation is the starting point for all water resource investigations. The quantity of both surface water and groundwater ultimately available depends on the volume and time distribution of precipitation. Austin and Skogerboe (Reference 5) extended the precipitation records in the Vernal area to a 30-year data base and prepared maps illustrating the normal annual precipitation. Maps of precipitation for the Ashley-Brush and Uinta drainage areas are shown in Figures 15 and 16, respectively. The amount of precipitation varies widely, with less than 8 in. in the vicinity of Vernal and nearly 30 in. near the Whiterocks deposits to the north and west.

Austin and Skogerboe (Reference 5) distributed the precipitation available to each hydrologic subarea of each drainage area on both a mean annual and monthly basis. The results are listed in Tables 8 and 9 for the Ashley-Brush and Uinta drainage areas, respectively. From Tables 8 and 9, two significant points are apparent. First, if all the precipitation in the subareas could be captured, each subarea would have almost enough water to support a production-scale tar sands facility [13,400 acre-feet (AF) per year], at a ratio of 5 bbl steam per barrel of bitumen. Such a capture is, of course, infeasible. The second point is the fairly uniform distribution of precipitation through the year. Figure 17 illustrates the monthly and yearly frequency distribution for selected precipitation stations in the vicinity of Asphalt Ridge. In general, there is a 90 to 95 percent probability of 0.2 to



Source: Reference 5.

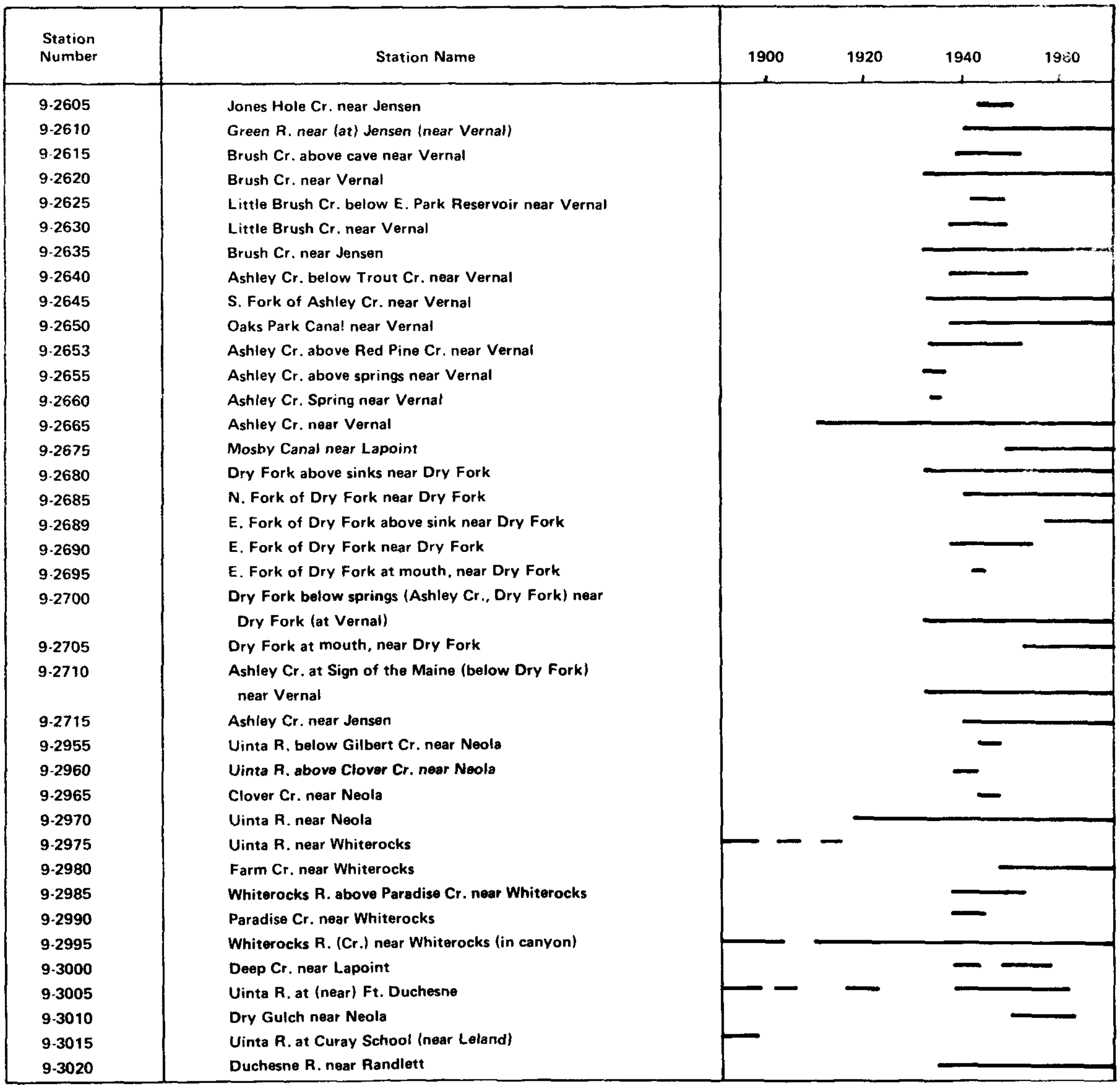
Figure 11. HYDROLOGIC MEASURING STATIONS IN THE UINTA STUDY UNIT

Table 5. LIST OF HYDROLOGIC MEASURING STATIONS IN THE VICINITY OF ASPHALT RIDGE

Station Number	Station Name*
9-2665	Ashley Cr. near Vernal
9-2675	Mosby Canal near Lapoint
9-2680	Dry Fork above sinks near Dry Fork
9-2685	N. Fork of Dry Fork near Dry Fork
9-2689	E. Fork of Dry Fork above sink near Dry Fork
9-2690	E. Fork of Dry Fork near Dry Fork
9-2695	E. Fork of Dry Fork at mouth, near Dry Fork
9-2700	Dry Fork below springs (Ashley Cr., Dry Fork) near Dry Fork at Vernal
9-2705	Dry Fork at mouth, near Dry Fork
9-2710	Ashley Cr. at Sign of the Maine (below Dry Fork) near Vernal
9-2715	Ashley Cr. near Jensen
9-2605	Jones Hole Cr. near Jensen
9-2610	Green R. near (at) Jensen (near Vernal)
9-2615	Brush Cr. above cave near Vernal
9-2620	Brush Cr. near Vernal
9-2625	Little Brush Cr. below East Park Reservoir near Vernal
9-2630	Little Brush Cr. near Vernal
9-2635	Brush Cr. near Jensen
9-2640	Ashley Cr. below Trout Cr. near Vernal
9-2645	S. Fork of Ashley Cr. near Vernal
9-2650	Oaks Park Canal near Vernal
9-2653	Ashley Cr. above Red Pine Cr. near Vernal
9-2655	Ashley Cr. above springs near Vernal
9-2660	Ashley Cr. Spring near Vernal
9-2970	Uinta R. near Neola
9-2975	Uinta R. near Whiterocks
9-2980	Farm Cr. near Whiterocks
9-2985	Whiterocks R. above Paradise Cr. near Whiterocks
9-2990	Paradise Cr. near Whiterocks
9-2995	Whiterocks R. (Creek) near Whiterocks (in canyon)
9-3000	Deep Cr. near Lapoint
9-3005	Uinta R. at (near) Ft. Duchesne
9-3010	Dry Gulch near Neola
9-3015	Uinta R. at Curay School (near Leland)
9-3020	Duchesne R. near Randlett
9-2955	Uinta R. below Gilbert Cr. near Neola
9-2960	Uinta R. above Clover Cr. near Neola
9-2965	Clover Cr. near Neola
9-3070	Green R. near Ouray

*All locations are in Utah.

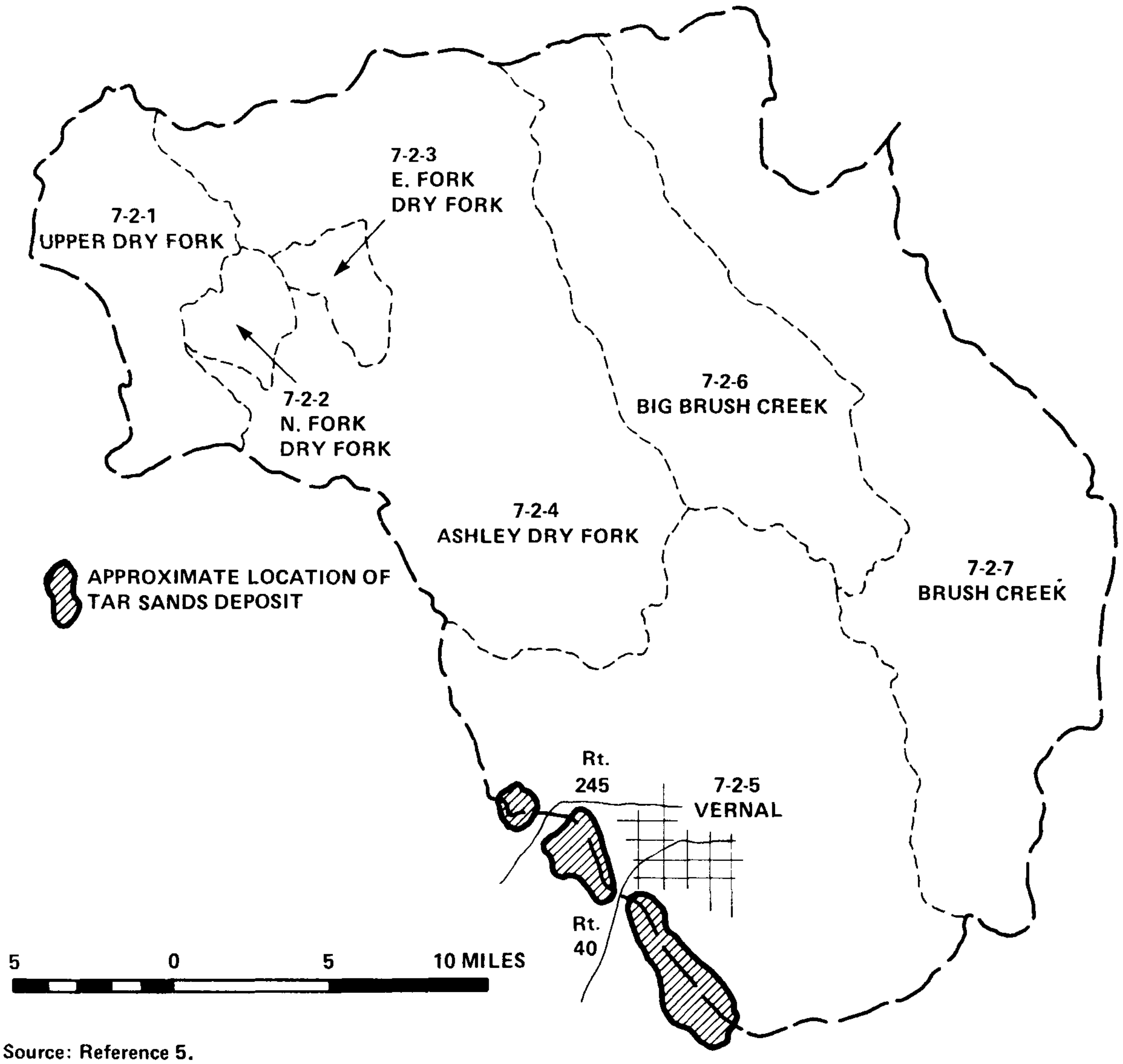
Source: Reference 5.



Station Number	Station Name
9-2605	Jones Hole Cr. near Jensen
9-2610	Green R. near (at) Jensen (near Vernal)
9-2615	Brush Cr. above cave near Vernal
9-2620	Brush Cr. near Vernal
9-2625	Little Brush Cr. below E. Park Reservoir near Vernal
9-2630	Little Brush Cr. near Vernal
9-2635	Brush Cr. near Jensen
9-2640	Ashley Cr. below Trout Cr. near Vernal
9-2645	S. Fork of Ashley Cr. near Vernal
9-2650	Oaks Park Canal near Vernal
9-2653	Ashley Cr. above Red Pine Cr. near Vernal
9-2655	Ashley Cr. above springs near Vernal
9-2660	Ashley Cr. Spring near Vernal
9-2665	Ashley Cr. near Vernal
9-2675	Mosby Canal near Lapoint
9-2680	Dry Fork above sinks near Dry Fork
9-2685	N. Fork of Dry Fork near Dry Fork
9-2689	E. Fork of Dry Fork above sink near Dry Fork
9-2690	E. Fork of Dry Fork near Dry Fork
9-2695	E. Fork of Dry Fork at mouth, near Dry Fork
9-2700	Dry Fork below springs (Ashley Cr., Dry Fork) near Dry Fork (at Vernal)
9-2705	Dry Fork at mouth, near Dry Fork
9-2710	Ashley Cr. at Sign of the Maine (below Dry Fork) near Vernal
9-2715	Ashley Cr. near Jensen
9-2955	Uinta R. below Gilbert Cr. near Neola
9-2960	Uinta R. above Clover Cr. near Neola
9-2965	Clover Cr. near Neola
9-2970	Uinta R. near Neola
9-2975	Uinta R. near Whiterocks
9-2980	Farm Cr. near Whiterocks
9-2985	Whiterocks R. above Paradise Cr. near Whiterocks
9-2990	Paradise Cr. near Whiterocks
9-2995	Whiterocks R. (Cr.) near Whiterocks (in canyon)
9-3000	Deep Cr. near Lapoint
9-3005	Uinta R. at (near) Ft. Duchesne
9-3010	Dry Gulch near Neola
9-3015	Uinta R. at Curay School (near Leland)
9-3020	Duchesne R. near Randlett

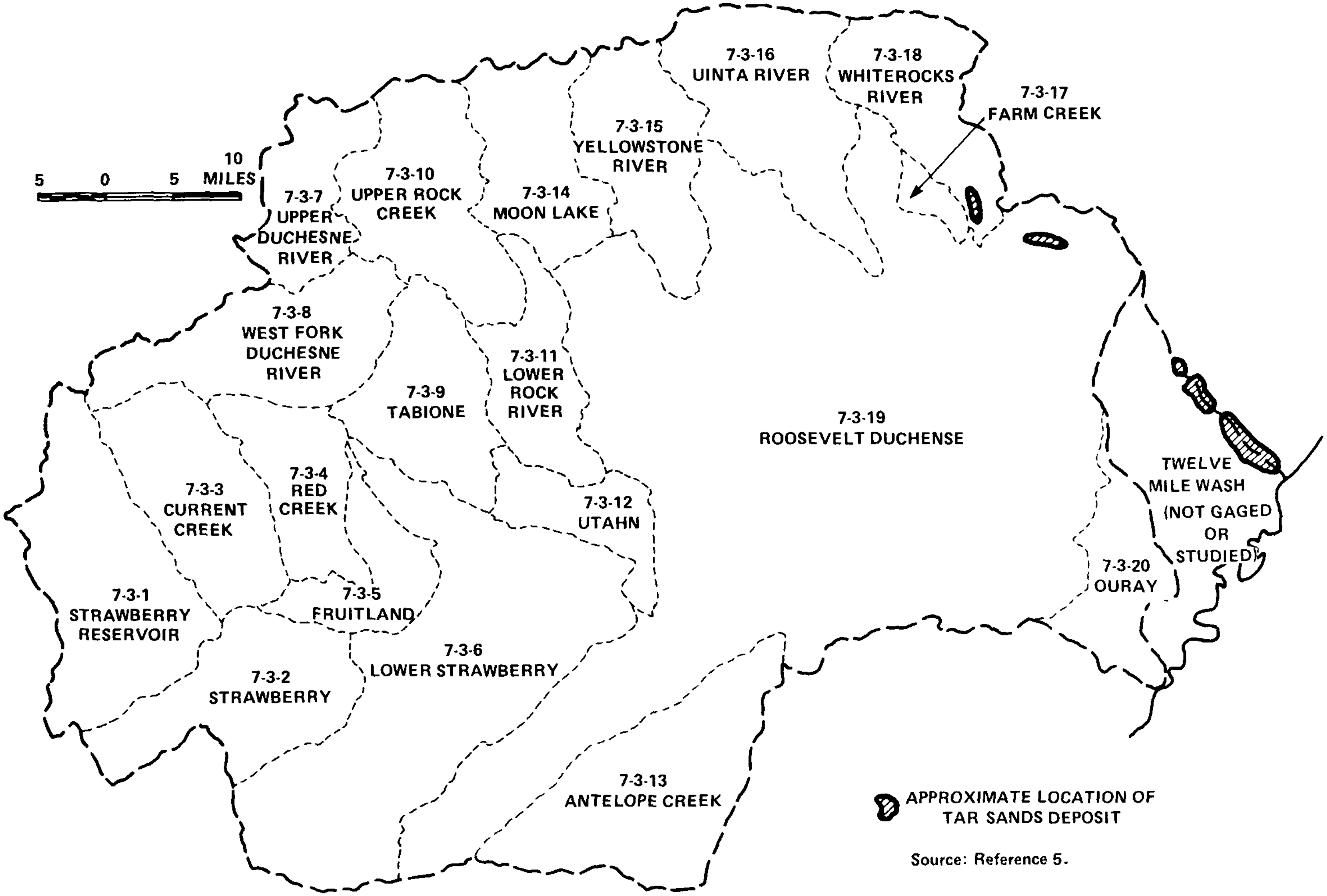
Source: Reference 5.

Figure 12. LENGTH OF RECORD FOR STREAM GAGING STATIONS IN ASPHALT RIDGE AREA



Source: Reference 5.

Figure 13. HYDROLOGIC SUBAREAS IN THE ASHLEY-BRUSH DRAINAGE AREA



Source: Reference 5.

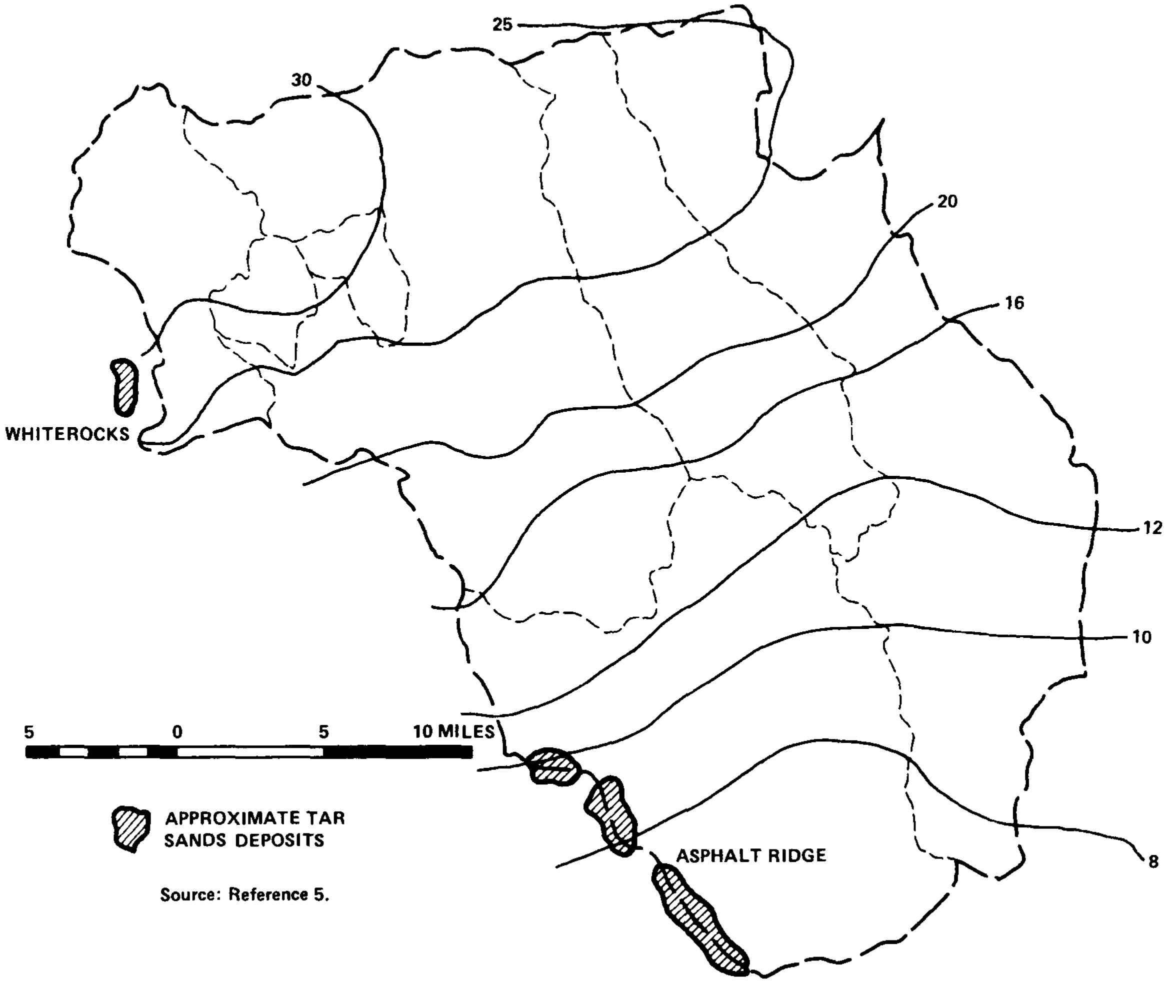
Figure 14. HYDROLOGIC SUBAREAS IN THE UINTA BASIN SUBAREAS

Table 6. HYDROLOGIC SUBAREAS IN THE ASHLEY-BRUSH DRAINAGE AREA

Subarea Number	Description
7 2 1	Upper Dry Fork—the drainage area above the gaging station 9 2680, "Dry Fork above sinks, near Dry Fork "
7 2 2	North Fork of Dry Fork—the drainage area above the gaging station 9 2685 "North Fork of Dry Fork near Dry Fork "
7 2 3	East Fork of Dry Fork—the drainage area above the gaging station 9 2689, "East Fork of Dry Fork above sinks near Dry Fork "
7 2-4	Ashley Dry Fork—the drainage area above the gaging station 9 2710, "Ashley Creek at Sign of the Maine (below Dry Fork) near Vernal," and below the gaging stations 9 2680, "Dry For' above sinks near Dry Fork" 9 2685, "North Fork of Dry Fork near Dry Fork"; and 9 2689, "East Fork of Dry Fork above sinks near Dry Fork "
7 2 5	Vernal—the drainage area above the gaging station 9 2715, "Ashley Creek near Jensen," and below the gaging station 9 2710, "Ashley Creek at Sign of the Maine (below Dry Fork) near Vernal "
7 2 6	Big Brush Creek—the drainage area above the gaging station 9 2620, "Brush Creek near Vernal "
7 2 7	Brush Creek—the drainage area above the gaging station 9 2635, Brush Creek near Jensen " and below the gaging station 9 2620, "Brush Creek near Vernal '

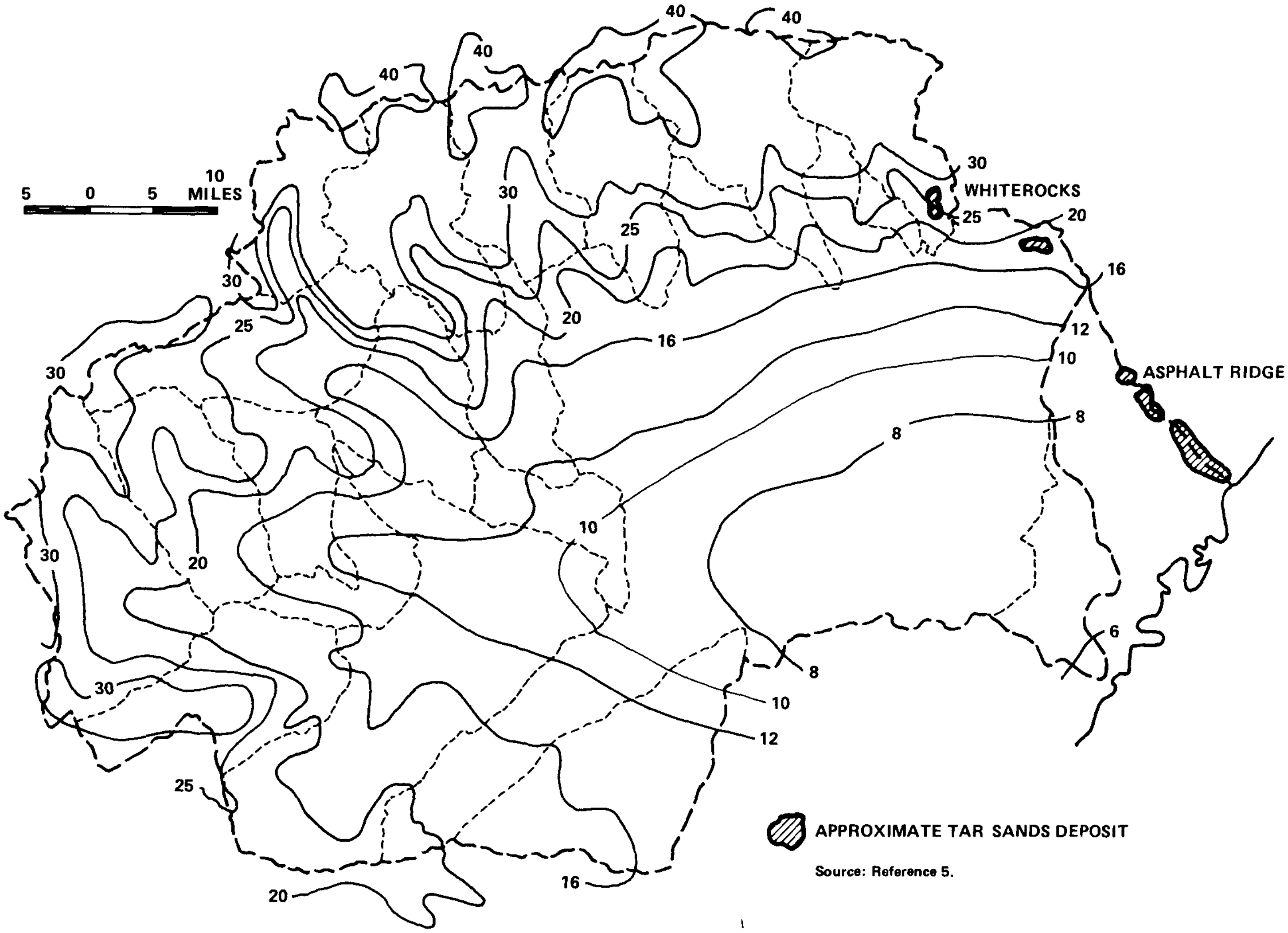
Table 7. HYDROLOGIC SUBAREAS IN THE UINTA DRAINAGE AREA

Subarea Number	Description
7 3 16	Uinta River—the drainage area above the gaging station 9 2970, "Uinta River near Neola "
7 3 17	Farm Creek—the drainage area above the gaging station 9 2080, "Farm Creek near Whiterocks "
7 3 18	Whiterocks River—the drainage area above gaging station 9 2995, "Whiterocks River (Creek) near Whiterocks (in canyon) "
7 3 19	Roosevelt Duchesne—the drainage area above the gaging station 9 3020, "Duchesne River near Randlett," and below the gaging stations 9 2995, "Whiterocks River (Creek) near Whiterocks (in canyon)", 9 2980, "Farm Creek near Whiterocks", 9 2970, "Uinta River near Neola", 9 2925, "Yellowstone Creek near Altonah", 9 2910, "Lake Fork below Moon Lake (West Fork of Lake Fork) near Mountain Home", 9 2775, "Duchesne River near Tabiona"; 9 2795, "Duchesne River at Duchesne", and 9 2890, "Antelope Creek near Dayton "
7 3 20	Ouray—the drainage area above the mouth of the Duchesne River and below the gaging station 9 3020, "Duchesne River near Randlett "



Source: Reference 5.

Figure 15. NORMAL ANNUAL PRECIPITATION FOR THE ASHLEY-BRUSH DRAINAGE AREA, 1931-60



Source: Reference 5.

Figure 16. NORMAL ANNUAL PRECIPITATION FOR THE UINTA BASIN DRAINAGE AREA, 1931-60

Table 8. MEAN MONTHLY AND ANNUAL PRECIPITATION IN EACH HYDROLOGIC SUBAREA OF THE ASHLEY-BRUSH DRAINAGE AREA

Subarea		Oct		Nov		Dec		Jan		Feb		Mar		Apr		May	
		AF	in.	AF	in.	AF	in.	AF	in.	AF	in.	AF	in.	AF	in.	AF	in.
7-2-1	Upper Dry Fk.	6,700	2.84	3,300	1.40	6,000	2.55	5,300	2.25	4,700	1.98	6,000	2.55	6,000	2.55	6,700	2.84
7-2-2	North Fk. Dry Fk.	1,600	3.13	800	1.57	1,400	2.74	1,300	2.55	1,100	2.16	1,500	2.94	1,500	2.94	1,400	2.74
7-2-3	East Fk. Dry Fk.	1,400	2.95	700	1.47	1,200	2.53	1,100	2.31	1,000	2.10	1,200	2.53	1,200	2.53	1,300	2.74
7-2-4	Ashley - Dry Fk.	21,900	2.35	11,000	1.18	19,700	2.11	17,600	1.88	15,400	1.65	19,700	2.11	19,700	2.11	23,600	2.53
7-2-5	Vernal	8,600	.99	5,700	.69	7,300	.89	5,100	.69	4,900	.60	6,400	.78	8,900	1.08	7,500	.91
7-2-6	Big Brush Cr.	8,600	1.87	5,000	1.09	6,300	1.37	5,400	1.18	6,400	1.39	7,200	1.57	9,100	1.98	10,000	2.18
7-2-7	Brush Cr.	15,100	1.73	7,500	.86	11,300	1.29	8,830	1.01	7,500	.86	10,100	1.15	12,600	1.44	13,700	1.57
Totals for Ashley Brush drainage area		63,900	1.85	34,000	.99	53,200	1.55	45,200	1.32	41,000	1.20	52,100	1.52	59,000	1.72	64,200	1.88

Table 8. (Continued)

Subarea		Jun		Jul		Aug		Sep		Oct-Apr		May-Sep		Annual	
		AF	in.	AF	in.	AF	in.	AF	in.	AF	in.	AF	in.	AF	in.
7-2-1	Upper Dry Fk.	6,700	2.84	5,900	2.50	6,700	2.84	6,000	2.55	38,000	16.12	32,000	13.57	70,000	29.69
7-2-2	North Fk. Dry Fk.	1,400	2.74	1,300	2.55	1,400	2.74	1,300	2.55	9,200	18.03	6,800	13.32	16,000	31.35
7-2-3	East Fk. Dry Fk.	1,300	2.74	1,200	2.53	1,300	2.74	1,100	2.30	7,800	16.42	6,200	13.05	14,000	29.46
7-2-4	Ashley - Dry Fk.	23,600	2.53	21,100	2.26	23,600	2.53	21,100	2.26	125,000	13.39	113,000	12.11	238,000	25.50
7-2-5	Vernal	7,500	.91	5,000	.61	8,300	1.01	6,700	.82	47,000	5.72	35,000	4.26	82,000	9.98
7-2-6	Big Brush Cr.	9,500	2.07	9,300	2.07	9,000	1.96	9,000	1.96	48,000	10.45	47,000	10.24	95,000	20.69
7-2-7	Brush Cr.	15,300	1.74	7,600	.87	13,700	1.57	13,700	1.57	73,000	8.14	64,000	7.12	137,000	15.60
Totals for Ashley Brush drainage area		65,300	1.91	51,600	1.51	6,400	1.87	58,900	1.72	348,000	10.17	304,000	8.88	652,000	19.05

Source: Reference 5.

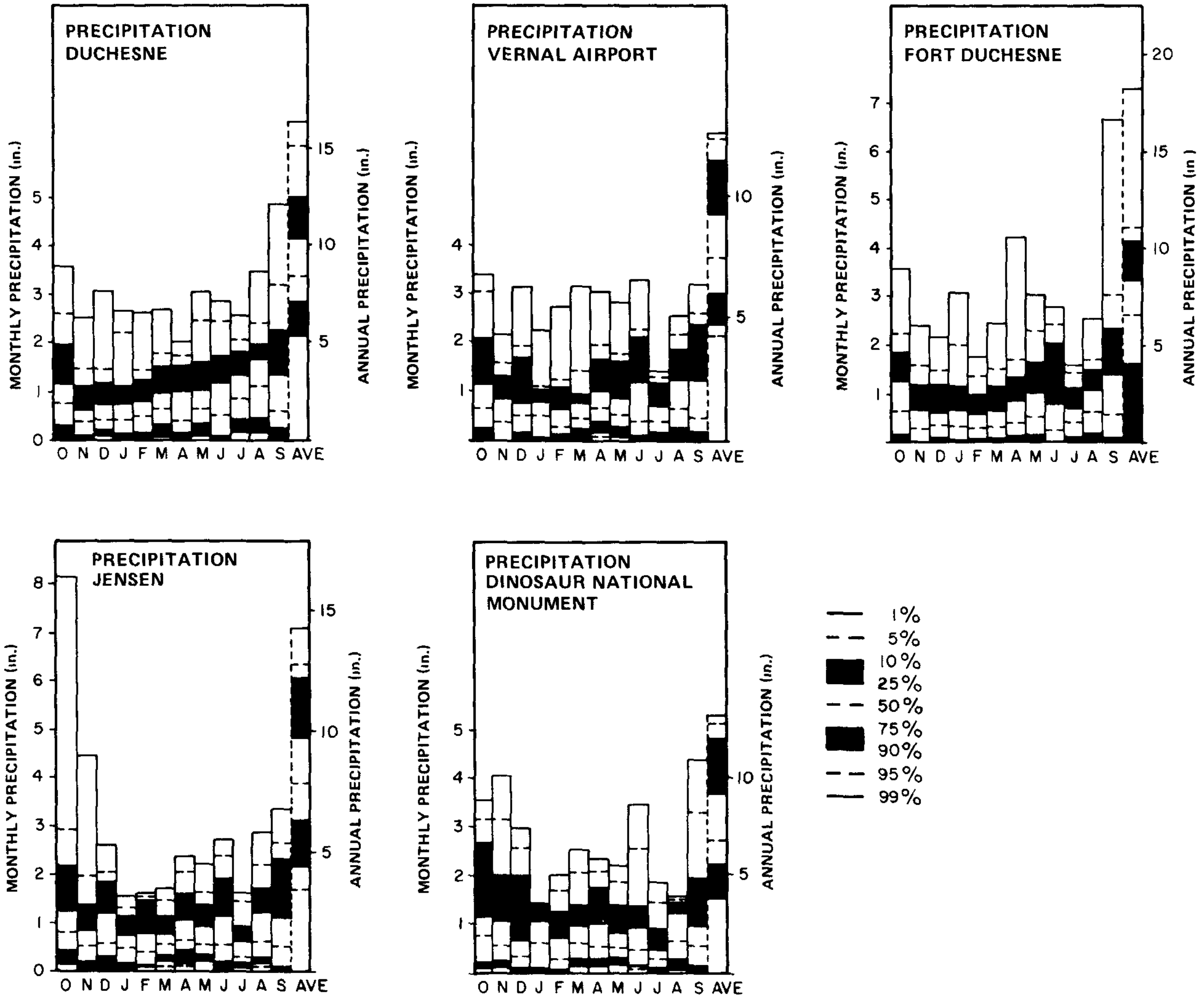
Table 9. MEAN MONTHLY AND ANNUAL PRECIPITATION IN EACH HYDROLOGIC SUBAREA OF THE UINTA BASIN DRAINAGE AREA

Subarea	Oct		Nov		Dec		Jan		Feb		Mar		Apr		May	
	AF	in.	AF	in.	AF	in.	AF	in.	AF	in.	AF	in.	AF	in.	AF	in.
7-3-16 Uinta R.	30,500	3.53	24,400	2.82	21,400	2.48	27,400	3.18	21,400	2.48	21,400	2.48	24,400	2.82	22,300	2.58
7-3-17 Farm Cr.	2,000	2.43	1,000	1.22	1,800	2.19	1,600	1.95	1,400	1.64	1,800	2.18	1,800	2.18	1,800	2.18
7-3-18 Whiterocks R.	19,000	3.13	9,500	1.55	17,000	2.80	15,200	2.50	13,300	2.18	17,000	2.80	17,000	2.80	17,400	2.86
7-3-19 Roosevelt - Duchesne	106,800	1.52	43,500	.76	71,200	1.01	62,300	.88	53,500	.76	53,500	.76	80,200	1.13	88,900	1.26
7-3-20 Quray	3,400	.77	1,700	.39	2,300	.53	2,000	.46	1,700	.39	1,700	.39	2,600	.59	3,200	.73
Totals for Uinta Basin drainage area	401,300	1.97	276,300	1.36	342,800	1.68	351,800	1.73	304,200	1.49	332,500	1.63	338,800	1.66	326,700	1.60

Table 9. (Continued)

Subarea	Jun		Jul		Aug		Sep		Oct-Apr		May-Sep		Annual	
	AF	in.	AF	in.	AF	in.	AF	in.	AF	in.	AF	in.	AF	in.
7-3-16 Uinta R.	22,300	2.58	22,300	2.58	36,500	4.22	19,600	2.28	171,000	19.79	121,000	14.24	294,000	34.03
7-3-17 Farm Cr.	1,800	2.18	1,600	1.93	1,800	2.18	1,600	1.93	11,400	13.79	8,600	10.40	20,000	24.19
7-3-18 Whiterocks R.	17,400	2.86	15,400	2.54	17,400	2.86	15,400	2.53	108,000	17.76	83,000	13.65	191,000	31.41
7-3-19 Roosevelt - Duchesne	88,900	1.27	62,300	.89	88,900	1.27	80,000	1.15	481,000	6.82	409,000	5.84	890,000	12.66
7-3-20 Quray	3,200	.73	2,200	.51	3,200	.73	2,800	.64	15,400	3.52	14,600	3.34	30,000	6.86
Totals for Uinta Basin drainage area	305,500	1.50	277,600	1.36	405,400	1.99	306,000	1.50	2,357,800	11.58	1,621,200	7.96	3,979,000	19.54

Source: Reference 5.



Source: Reference 5.

Figure 17. MONTHLY AND ANNUAL FREQUENCY DISTRIBUTION FOR SELECTED PRECIPITATION STATIONS IN THE UINTA STUDY UNIT

0.3 in. of precipitation at each station each month. An approximately 50 percent chance exists for 0.5 in.

The relative uniformity of the precipitation can also be seen from Table 10, which shows the mean monthly and yearly precipitation for selected stations in the Vernal area.

Table 10. MEAN MONTHLY AND YEARLY PRECIPITATION FOR SELECTED STATIONS IN THE UINTA STUDY UNIT

Stat Number	Station Name	Length of Record	Precipitation (in)												
			Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
[illegible]	Dinosaur Natl Mon	1949 60	0 84	0 74	0 81	0 42	0 41	0 66	0 69	0 61	0 63	0 35	0 71	0 71	7 50
[illegible]	Elkhorn Ashley R S	1931 60	1 26	0 89	0 95	0 92	0 92	1 24	1 22	1 00	0 96	0 99	1 32	1 14	12 99
[illegible]	Ft Duchesne	1931 60	0 76	0 44	0 48	0 48	0 42	0 49	0 60	0 72	0 59	0 50	0 72	0 92	6 16
9 4342	Jensen	1931 60	0 74	0 98	0 70	0 46	0 47	0 55	0 73	0 62	0 71	0 37	0 76	0 75	7 69
9 7391	Roosevelt	1940 66	0 88	0 48	0 69	0 52	0 37	0 57	0 56	0 62	0 81	0 42	0 75	0 77	7 25
9 9111	Vernal Airport	1931 60	0 85	0 53	0 64	0 50	0 46	0 56	0 80	0 67	0 73	0 50	0 82	0 78	7 88

Source: Reference 5.

While the quantity of precipitation is important, the amount that actually runs off and becomes available for use is of primary concern. The mean monthly and annual runoffs for selected gaging stations in the various areas are given in Table 11. The mean runoff volumes were obtained by Austin and Skogerboe (Reference 5) from the historical streamflow record at each gaging station. Thus, the volumes listed in Table 11 serve only as an indication of natural runoff magnitude since the runoff measured at some of the stations has been affected by the works of man at some time during the period of record.

Table 11. MEAN MONTHLY AND ANNUAL RUNOFF FOR SELECTED STATIONS IN THE VERNAL AREA, 1931-60

Station Number	Station Name	Runoff (AF)												
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
9 2620	Brush Cr near Vernal	1,100	930	840	790	730	840	1,730	7,030	5,960	1,650	1,210	990	23,800
9 2710	Ashley Cr at Sign of the Maine near Vernal	3 480	2 600	2,140	1,830	1 530	1,620	3,110	24,480	24,510	8,150	5,170	3,580	82,200
9 2715	Ashley Cr near Jensen	1 600	2,400	2,500	2 500	2 500	2,500	2,600	12,300	12,300	1,200	800	800	44,000
9 2970	Uinta R near Neola	7,600	5 270	4,240	3 560	3,070	3,480	5,090	21,680	32,630	18,110	12,950	9,520	127,200
9 2995	Whiterocks R (Cr) near Whiterocks	4,210	2,840	2,250	1,840	1,590	1,790	3,090	17,850	21,040	9,370	6,980	4,850	77,800
9 3020	Duchesne R near Randlett	17,450	23,210	25 900	25 690	24,860	29,600	29 550	85,950	110,400	23 330	12,500	10,560	419,000

Source: Reference 5.

The mean annual runoff (water yield) for the Vernal area is shown on the map in Figure 18. The physical characteristics of many small watersheds within the study unit were used in accordance with the correlation techniques reported by Bagley, Jeppson, and Milligan (Reference 24) in developing the water yield map. By measuring the area between adjacent water yield lines and multiplying by the average depth for each area, the surface runoff can be determined for any watershed. Any value of surface runoff developed from Figure 18 represents the mean annual flow for the 1931-60 time base.

Very little runoff occurs in the immediate vicinity of Vernal. Less than 1 in. or 53 acre-feet per square mile is available. To the north and west in the Whiterocks area, 8 in. or 427 acre-feet per square mile is available. If the runoff were captured and transported elsewhere, some loss would be expected from seepage and evaporation.

While the precipitation in the Vernal area is distributed fairly uniformly throughout the year, the runoff is not. Significant portions of the precipitation are in the form of snowfall. This snow melts in May and June and accounts for most of the yearly runoff. This condition is illustrated in Figure 19 for the Uinta River near Neola. The histogram shown is typical of all the gages in the area.

Another useful measure of the variability of streamflow is the flow duration curve. It is a cumulative frequency curve (integral of the frequency diagram) that shows the percentage of time during which specified discharges were equaled or exceeded in a given period. Flow-duration curves are useful for determining the probability of future streamflows, and the shape of the curve can be used in evaluating general watershed characteristics. If the curve has been developed from a sufficiently long period of record, the flow-duration curve may be considered a probability curve and used to estimate the percentage of time that a specified discharge will be equaled or exceeded in the future.

Flow-duration curves have been prepared by Jeppson et al. (Reference 25) for most of the gages in the Vernal area. Although these curves are not of concern here, they are useful in detailed design type studies.

To determine the amount of runoff available, detailed information is needed on the spatial distribution of the runoff and the losses from seepage, consumptive use, groundwater, evaporation, and other factors. The water budget for a basin provides these details.

Water budgets for each of the hydrologic subareas in the Asphalt Ridge area are included in the work of Austin and Skogerboe (Reference 5). The essential parts of these water budgets will be presented here, along with the procedure used to derive them. Following the water budgets, the quantity of water at various times in the stream will be compared with potential demand. Water quality will be covered last.

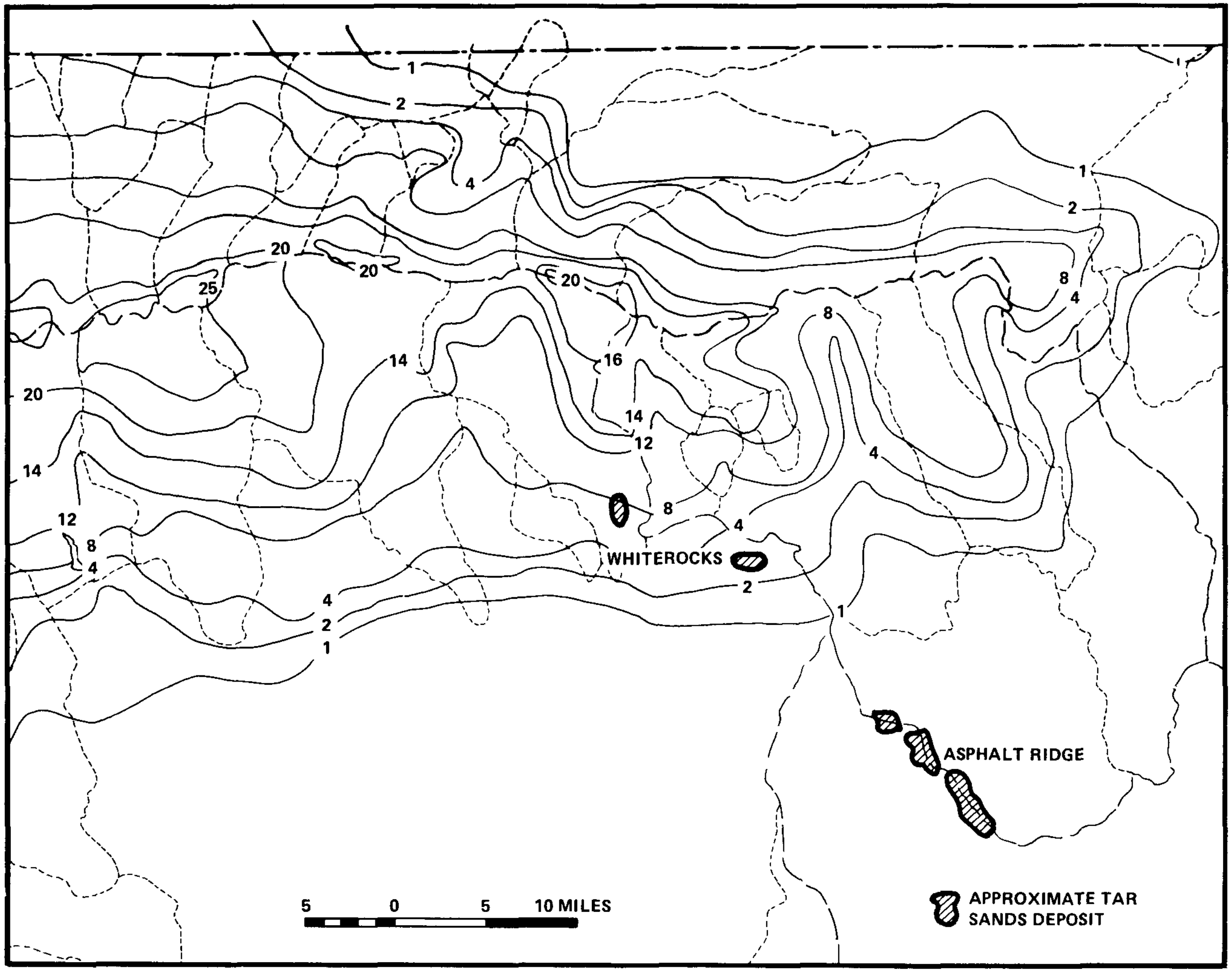


Figure 18. MEAN ANNUAL RUNOFF (in.) IN THE VERNAL AREA, 1931-60

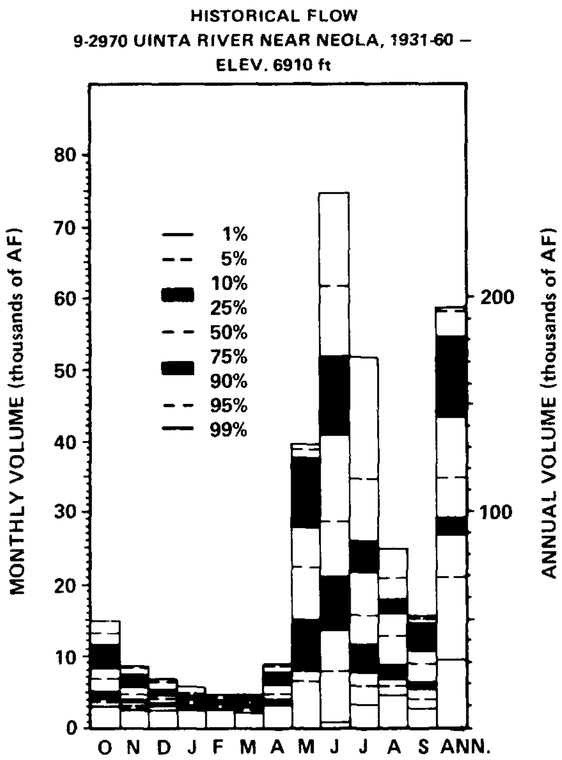


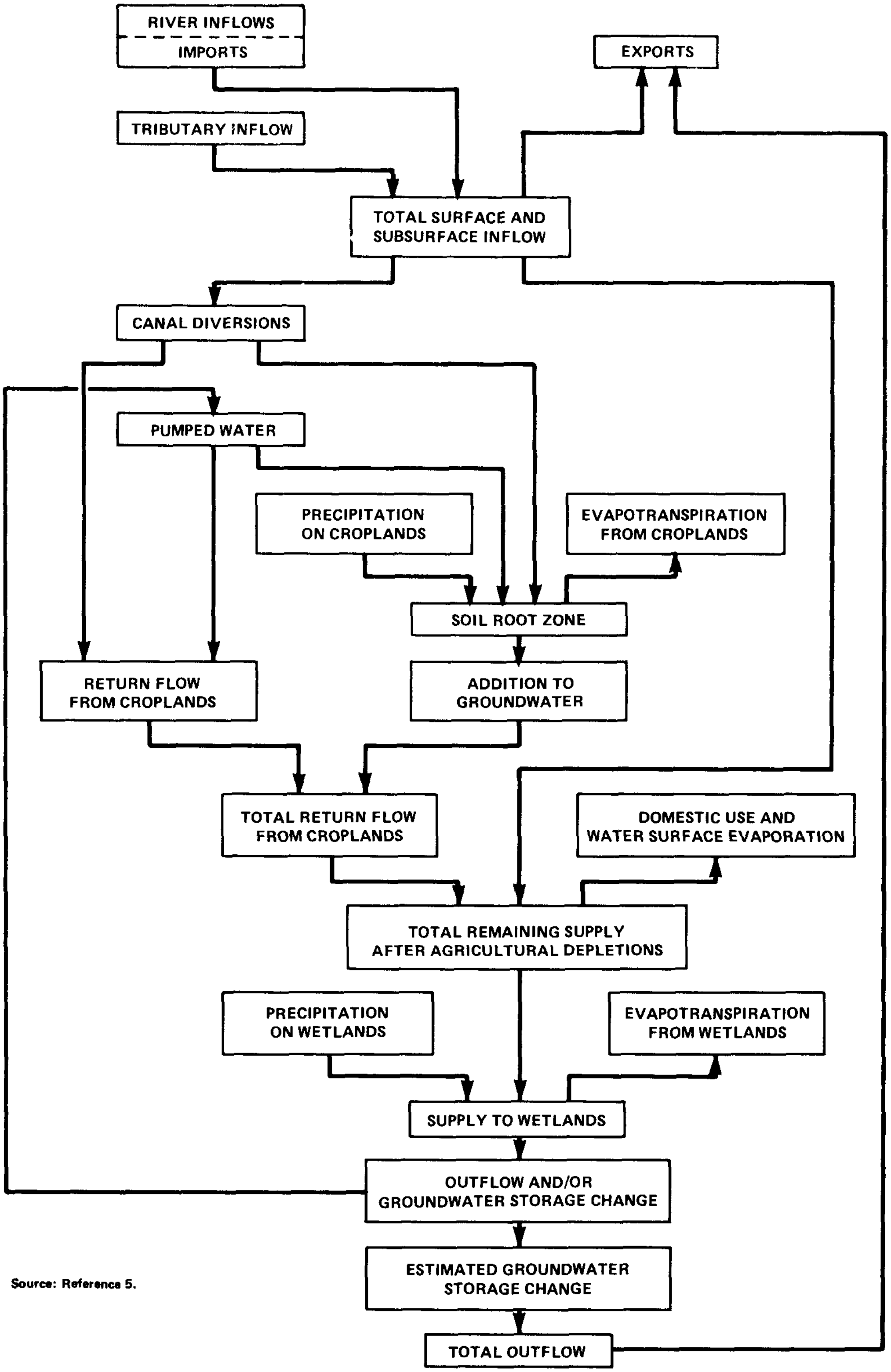
Figure 19. MONTHLY DISTRIBUTION OF FLOW AT A TYPICAL STREAM GAGE IN THE VERNAL AREA

Source Reference 5.

Water Budget Development

Austin and Skogerboe (Reference 5) used a computer program to prepare water budgets from the volumes of data available. The same program was used to prepare budgets for most of the areas containing tar sands deposits. For this reason, a complete description is included here. This description will be referred to rather than repeated when considering the water resources of the other areas.

The amount of available data varies considerably from one subarea to the next. Consequently, the procedure for arriving at a water budget varied according to the type and amount of data available, with a resultant effect on the accuracy of the water accounting. Most water budgets were prepared on a month-by-month basis using the time period for which actual monthly data were available. The month-by-month budgets were then averaged to obtain mean monthly budgets. The mean annual water budget was obtained by averaging the annual accountings obtained for each year having sufficient data. The mean annual budget was adjusted, where necessary, to reflect a 1931-60 mean and was also adjusted for physical conditions existing as of 1960. A flow chart illustrating the water budgeting procedure is shown in Figure 20. (For convenience, the nomenclature used in this description is listed in Table 12.)



Source: Reference 5.

Figure 20. WATER BUDGET FLOW CHART

Table 12. NOMENCLATURE FOR MONTHLY WATER BUDGET

AC1 = acreage of crop (percentage)
AC2 = *acreage of vegetation*
ACU = actual cropland consumptive use
AGSC = crop growth stage coefficient
AGW = addition to groundwater
ASMS = *accumulated soil moisture storage*
BASMS = beginning accumulated soil moisture storage
CC = coefficient to adjust precipitation on cropland
CD = canal diversion
CT = coefficient to adjust temperature
CW = coefficient to adjust precipitation on wetland
DEF = consumptive use deficiency
DWE = domestic uses and water surface evaporation
DWRZ = diverted water to root zone
EFCU = conveyance efficiency
EFOF = efficiency on farm
EFPW = efficiency of pumped water
EXPI = exports subtracted from inflows
EXPO = exports subtracted from outflows
F = Blaney Criddle f
GWSC = groundwater storage change
OF = outflow
PCL = adjusted precipitation on cropland
PCU = potential consumptive use for crop
PCUU = potential consumptive unit use for crop
PDH = percentage of daylight hours
PGSC = *vegetation growth stage coefficient*
PREC = monthly precipitation
PW = pumped water
PWL = adjusted precipitation on wetland
PWRZ = *pumped water to root zone*
RIF = river inflow
RTFLO = return flow from cropland
SEXP = sum of exports
SIF = sum of surface and subsurface inflows
SMC = soil moisture capacity
SPCU = total potential consumptive crop use
SWL = supply to wetland
SWLCU = total wetland potential consumptive use
TAC = total acreage cropland
TAVE = adjusted temperature
TAWL = total acreage wetland
TEMP = monthly temperature
TIF = tributary inflow
TOF = total outflow from system
TRF = total return flows from cropland
TSRZ = total monthly supply to root zone
TSWL = total supply to wetland
WLCU = wetland potential consumptive use
WLCUI = potential consumptive unit use for wetland

Source Reference 5.

The description of the water budget procedure developed by Austin and Skogerboe (Reference 5) is complicated and is included here primarily for reference. The description provides a complete picture of how the data were processed.

The total surface and subsurface inflow to the valley floor of a subarea is obtained by adding the imports from other basins to the river inflows and then adding the tributary inflow (or yield) within the subarea (Figure 20). In the Uinta study unit, the river inflows are obtained from published discharge records collected at stream gaging stations. Since the stream gaging stations are used to report only surface flow, an estimate of the subsurface flow at the outlet of each subarea has been made.

Canal diversions were obtained from river commissioner reports wherever available. The amount of pumped water for each agricultural area was obtained from records of the USGS, U.S. Bureau of Reclamation (USBR), and the Office of the State Engineer.

The total water supply to the soil root zone of agricultural crops is obtained from canal diversions, pumped water, and precipitation on agricultural lands (croplands). The canal diversions were multipled by a conveyance efficiency factor and a farm efficiency factor to determine the amount of water reaching the soil root zone. Estimates of farm efficiency at various locations affected by the Central Utah Project have been prepared by the USBR. Since estimates of pumped water conveyance efficiency were not available, Austin and Skogerboe had to prepare them. The contribution from precipitation was obtained by using actual records of a nearby weather station and adjusting the records using a coefficient to reflect the location of the agricultural lands. In some instances, the records of the weather station were used without correction (coefficient = 1).

The potential consumptive use for each crop was determined by techniques reported in Reference 5. The total potential consumptive use for the agricultural lands in a subarea was obtained by summing the potential consumptive use for each crop.

Soils maps were used in conjunction with crop distributions to arrive at the soil moisture capacity for each agricultural area. Based upon the soils maps, estimates of soil moisture storage capacity were made. Taking into account the depth of roots for each type of crop, an estimate of the volume of water that might be stored in the root zone was determined.

For any single month, the potential consumptive use of water by the croplands is satisfied first by the water supply to the root zone for that month. If the supply to the root zone is *more* than the potential consumptive use, the actual consumptive use equals potential consumptive use and the excess supply fills the root zone. When the root zone is filled to soil moisture capacity, the remaining supply becomes an addition to the groundwater. If the water supply to the root zone is *less* than the potential consumptive water use, the crops must draw on the accumulated moisture previously stored in the soil. If sufficient moisture is stored in the soil to meet the deficiency, the actual consumptive use is equal to the potential consumptive use; the stored accumulation of soil moisture available for the next month is thus reduced by the amount that has been taken from storage (ASMS = BASMS + TSRZ - SPCU). If the deficiency (SPCU - TSRZ) exceeds the amount of stored soil moisture, the actual consumptive use is equal to the sum of the supply to the root zone and the accumulated soil moisture storage at the beginning of the month (ACU = TSRZ + BASMS), thus reducing the amount of stored soil moisture to zero.

The return flow from croplands is equal to the canal diversions of minus the amount supplied to the root zone plus pumped water, minus the amount supplied to the root zone (CD - DWRZ + PW - PWRZ). The total return flow from croplands is the sum of return flows from croplands plus additions to groundwater.

The total surface and subsurface inflow to the subarea minus canal diversions becomes a portion of the water supply available for evapotranspiration by phreatophytes. The total return flows from croplands also become a portion of the water supply to wetlands. Depletions by domestic uses along with water surface evaporation must be subtracted from the water supply contributions to wetlands in order to arrive at a supply to wetlands. This supply is added to the precipitation falling on the acreage of phreatophytes to arrive at the total supply to wetlands. This total supply is depleted by the potential consumptive use by phreatophytes, which is estimated in a manner similar to that used to estimate potential consumptive use for croplands. The remaining water supply is designated as outflow.

The outflow from wetlands must be corrected for any exports at the outlet of the subarea, pumped water, and groundwater storage change in order to determine the total outflow from the subarea along with its proper distribution for each month. Discharge measurements are available for exports at the outflow of each subarea in the Uinta study unit. Since the outlet for each subarea was purposely located at a stream gaging station, surface outflow records are available. Estimates of the subsurface outflow from each subarea have been made utilizing a knowledge of the geology at the stream gaging site along with considerable judgment acquired from field observations, discussions with various professional personnel, and working with available data. Estimates of groundwater storage change have been prepared based upon published records of groundwater levels in the various subareas and taking into account groundwater pumpage.

Surface Water Supplies

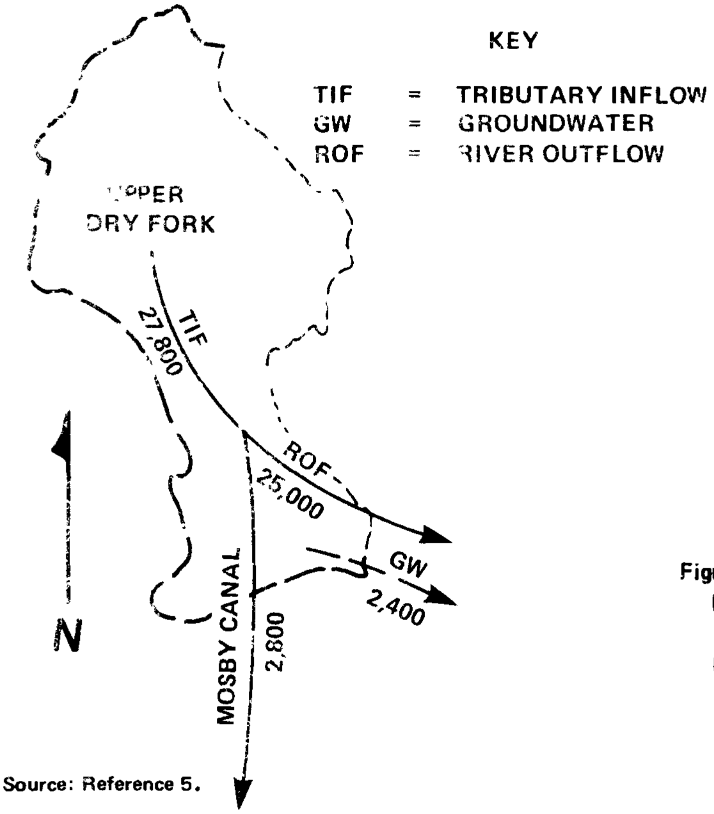
Austin and Skogerboe (Reference 5) compiled water budgets for all the hydrologic subareas (Figures 13 and 14) in the the Ashley-Brush and Uinta drainage areas. Only those in the immediate vicinity of Asphalt Ridge and Whiterocks are reported here. Descriptive figures for each water budget and a table of monthly values are included.

Upper Dry Fork Subarea (7-2-1)

The Upper Dry Fork subarea forms part of the upper drainage of Dry Fork along the south flanks of the Uinta Mountains. The runoff in the Upper Dry Fork subarea is basically from snowmelt and is gaged at USGS Station 9-2680 (Table 5). Water is exported from this subarea through the Mosby Canal to Mosby Creek in the Roosevelt-Duchesne subarea. A flow diagram of the mean annual water budget for the Upper Dry Fork subarea is shown in Figure 21, while the distributions of mean monthly and mean annual flows for the 1931-60 time period are presented in Table 13. The mean monthly and mean annual distributions of the river outflow were obtained from USGS records and by correlation of runoff records with those of USGS Station 9-2995 (Whiterocks River near Whiterocks). The groundwater outflow was estimated from inflow-outflow relationships for the Upper Dry Fork and Ashley-Dry Fork subareas.

North Fork of Dry Fork Subarea (7-2-2)

The North Fork of Dry Fork subarea forms part of the upper drainage of Dry Fork along the south flanks of the Uinta Mountains. The runoff in the subarea is from snowmelt and is gaged at USGS Station 9-2685. The distributions of mean monthly and mean annual



Source: Reference 5.

Figure 21. FLOW DIAGRAM OF THE MEAN AND ANNUAL WATER BUDGET FOR THE UPPER DRY FORK SUBAREA

Table 13. MEAN MONTHLY AND MEAN ANNUAL WATER BUDGET FOR UPPER DRY FORK SUBAREA

Characteristic	Water Budget (AF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Tributary inflow Ungaged inflow	1 800	700	440	380	330	330	820	7,800	8,910	2,690	2,120	1,800	27 800
Total surface inflow	1,500	700	440	380	310	380	820	7,800	8,810	2,690	2,120	1,800	27 800
Exported inflow Mosby Canal	350	0	0	0	0	0	0	230	350	470	820	580	2 800
River outflow Station 9 2680	1 150	700	440	380	310	330	820	7,570	8,560	2,220	1,300	1,220	25,000
Subsurface outflow	100	80	80	90	120	150	240	480	380	340	220	120	2 400
Total surface and subsurface outflow	1 250	780	520	470	480	480	1,080	8,650	8,940	2,560	1,520	1,340	27 400

Source Reference 5.

flows for the 1931-60 time period is listed in Table 14; Figure 22 is a flow diagram of the mean annual water budget for the subarea. The mean monthly and mean annual distributions of the river outflow were obtained directly from USGS records and from USBR estimates for any years during the 1931-60 time period for which records were missing. The groundwater outflow was estimated from inflow-outflow relationships for the North Fork of Dry Fork and Ashley-Dry Fork subareas.

Table 14. MEAN MONTHLY AND MEAN ANNUAL WATER BUDGET FOR NORTH FORK OF DRY FORK SUBAREA

Characteristic	Water Budget (AF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Tributary inflow													
Ungaged inflow	130	80	60	40	30	30	130	1,510	1,370	560	280	180	4 400
Total surface inflow	130	80	60	40	30	30	130	1,510	1,370	560	280	180	4 400
River outflow Station 9 2685	130	80	60	40	30	30	130	1,510	1,370	560	280	180	4 400
Subsurface outflow	40	30	30	40	50	60	100	200	160	140	100	50	1 000
Total surface and subsurface outflow	170	110	90	80	80	90	230	1,710	1,530	700	380	230	5 400

Source Reference 5.

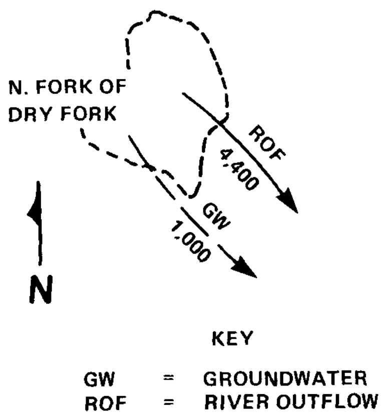


Figure 22. FLOW DIAGRAM OF THE MEAN AND ANNUAL WATER BUDGET FOR THE NORTH FORK OF DRY FORK SUBAREA

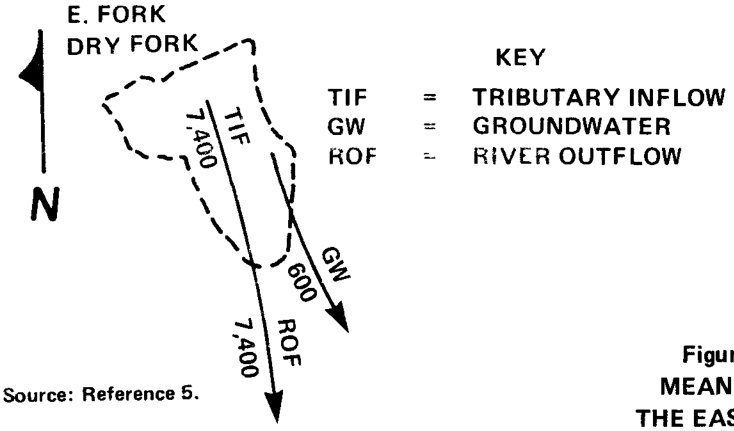
Source: Reference 5.

East Fork of Dry Fork Subarea (7-2-3)

The East Fork of Dry Fork subarea forms part of the upper drainage of Dry Fork along the south flanks of the Uinta Mountains. The runoff in the subarea is from snowmelt and is gaged at USGS Station 9-2689. The diagram in Figure 23 represents the mean annual water budget for this subarea; Table 15 presents the distributions of mean monthly and mean annual flows for the 1931-60 time period. The mean monthly and mean annual distributions of the river outflow were obtained directly from USGS records and by correlating runoff records to obtain data for the years in the 1931-60 time period for which records were missing. The groundwater outflow was estimated from inflow-outflow relationships for the East Fork of Dry Fork and Ashley-Dry Fork subareas.

Ashley-Dry Fork Subarea (7-2-4)

The Ashley-Dry Fork subarea forms the upper drainage of Ashley Creek and the lower drainage of Dry Fork along the south flanks of the Uinta Mountains. The river inflow to the subarea is the river outflow from the Upper Dry Fork, North Fork of Dry Fork, and



Source: Reference 5.

Figure 23. FLOW DIAGRAM OF THE MEAN ANNUAL WATER BUDGET FOR THE EAST FORK OF DRY FORK SUBAREA

Table 15. MEAN MONTHLY AND MEAN ANNUAL WATER BUDGET FOR EAST FORK OF DRY FORK SUBAREA

Characteristic	Water Budget (AF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Tributary inflow													
Ungaged inflow	350	160	100	60	50	80	340	2,240	2,500	850	370	300	7 400
Total surface inflow	350	160	100	60	50	80	340	2,240	2,500	850	370	300	7,400
River outflow Station 9 2689	350	160	100	60	50	80	340	2,240	2,500	850	370	300	7,400
Subsurface outflow	30	20	20	20	30	40	60	120	100	80	50	30	600
Total surface and subsurface outflow	380	180	120	80	80	120	400	2,360	2,600	930	420	330	8 000

Source Reference 5

East Fork of Dry Fork subareas. Immediately below these three subareas, much of the flow goes underground in the area referred to as the "Dry Fork Sinks." Recent dye tests by the USBR (Reference 23) disclosed that most of this flow reappears at the Ashley Creek Springs. Consequently, the subarea boundaries were chosen to include both the Dry Fork Sinks and the Ashley Creek Springs. The Ashley-Dry Fork subarea import flows from the Oaks Park Reservoir by means of the Oaks Park Canal, which conveys storage water to Ashley Creek. The distributions of mean monthly and mean annual flows for the 1931-60 time period are listed in Table 16; Figure 24 is a flow diagram of the mean annual water budget for the Ashley-Dry Fork subarea. Water diverted to cropland during the 1931-60 time period was estimated from 1963-66 diversion records. The consumptive use for the subarea was determined by means of the water budget program described previously in this section. The mean monthly and mean annual distributions for the river outflow, which was measured at stream gaging station 9-2710, were obtained from USGS records.

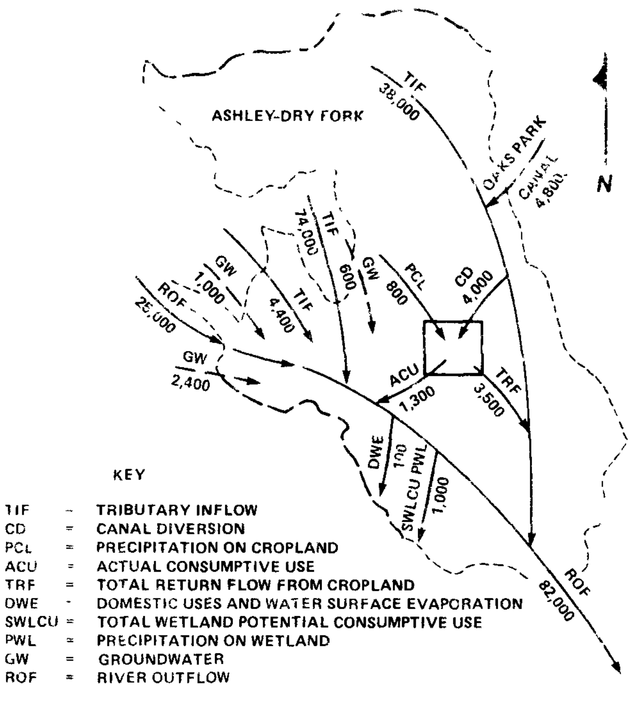
Vernal Subarea (7-2-5)

The Vernal subarea is the lower drainage area of Ashley Creek below stream gaging station 9-2710. The river inflow to the Vernal subarea is the river outflow from the Ashley-

Table 16. MEAN MONTHLY AND MEAN ANNUAL WATER BUDGET FOR THE ASHLEY-DRY FORK SUBAREA

Characteristic	Water Budget (AF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
River inflows													
Station 9 2680	1 150	700	440	380	310	330	820	7 570	8 560	2,220	1 300	1 220	25 000
Station 9 2685	130	80	60	40	30	30	130	1 510	1 370	560	280	180	4 400
Station 9 2690	350	160	100	60	50	80	340	2 240	2 500	850	370	300	7 400
Imported flows													
Station 9 2650	400	0	0	0	0	0	0	0	200	1 700	1 600	900	4,800
Tributary inflow (Station 9 2655)	*1 310*	*730*	*360*	*210*	*130*	*150*	*1 960*	*12 030*	*14,090*	*2 750*	*1 130*	*850*	*35 700*
Ungaged inflow	160	90	80	80	90	100	150	280	310	370	350	240	2 300
Subsurface inflow	170	130	130	150	200	250	400	800	640	560	370	200	4 000
Total *surface and subsurface inflow*	3 670	1 890	1 170	920	810	940	3 800	24 430	27 670	9 010	5 400	3 890	83 600
Diversion to cropland	40	0	0	0	0	0	0	1 300	1 600	630	330	100	4 000
Amount to root zone	20	0	0	0	0	0	0	750	900	320	150	60	2 200
Cropland precipitation	90	70	60	40	50	60	60	70	80	40	80	100	800
Root zone supply	110	70	60	40	50	60	60	820	980	360	230	160	3 000
Cropland PCU	90	0	0	0	0	0	0	200	320	410	330	150	1 500
Root zone supply PCU	20	70	60	40	50	60	60	620	560	50	100	10	1 500
Accum soil moisture	300	320	320	320	320	320	320	320	320	260	230	280	–
Change in soil moisture	20	20	0	0	0	0	0	0	0	-60	30	50	0
Consumptive use deficit	20	0	0	0	0	0	0	0	0	20	100	60	200
Cropland ACU	70	0	0	0	0	0	0	200	310	300	220	110	1 300
Addition to groundwater	20	50	60	40	50	60	60	620	660	30	30	20	1 700
Return flow from cropland	*20*	*0*	*0*	*0*	*0*	*0*	*0*	*550*	*700*	*310*	*180*	*40*	*1 800*
Total of return flows	40	50	60	40	50	60	60	1 170	1 360	340	210	60	3 500
Domestic use/water surface evap	10	0	0	0	0	0	10	10	20	20	20	10	100
Supply to wetland/groundwater	*3 660*	*1 940*	*1 230*	*960*	*860*	*1 000*	*3 850*	*24 290*	*27 410*	*8 700*	*5 260*	*3 840*	*83 000*
Wetland precipitation	110	90	70	50	70	70	80	80	100	50	100	130	1 000
Wetland consumptive use	80	0	0	0	0	0	0	260	410	30	460	260	2 000
Outflow/groundwater change	3 690	2 030	1 300	1 010	930	1 070	3 930	24 110	27 100	8 720	4 900	3 710	82 000
Estimated groundwater change	+220	560	830	820	-600	550	70	+600	+2 650	+80	260	+14	0
River outflow Station 9 2710	3 470	2 590	2 130	1 830	1 540	1 620	4 000	23 510	24 450	8 140	5 160	3 5[illegible]	82 000

Source Reference 5



Source Reference 5

Figure 24. FLOW DIAGRAM OF THE MEAN ANNUAL WATER BUDGET FOR THE ASHLEY-DRY FORK SUBAREA

Dry Fork subarea. The distributions of mean monthly and mean annual flows for the 1931-60 time period are shown in Table 17; Figure 25 is a flow diagram of the mean annual water budget for the Vernal subarea. Water diverted to cropland during the 1931-60 time period was estimated from 1963-66 diversions records, which coincide with the initial operation of the Steinaker Reservoir. This reservoir is an off-channel storage site; waters from Ashley Creek are conveyed to the reservoir by means of the Steinaker Feeder Canal. The water released from Steinaker Reservoir is used for irrigation in the Vernal subarea; the remaining water budgets are for hydrologic subareas to the west of Asphalt Ridge–the Uinta, Farm Creek, Whiterocks, and Roosevelt-Duschesne subareas.

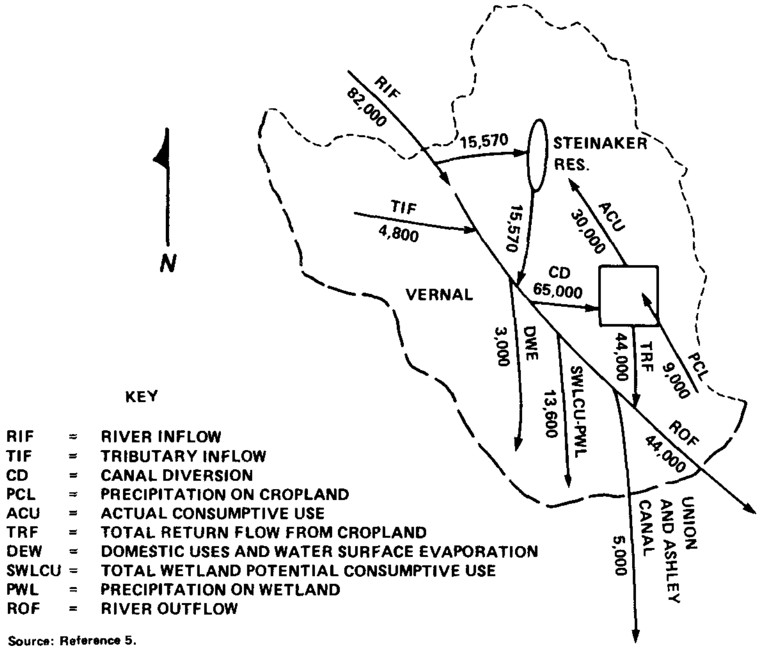
Uinta River Subarea (7-3-16)

The Uinta River subarea forms the upper drainage of the Uinta River along the south slopes of the Uinta Mountains. A flow diagram of the mean annual distribution of the Uinta River subarea is illustrated in Figure 26, while the mean monthly and mean annual distributions for the 1931-60 time period are listed in Table 18. The distribution of river outflow, which is gaged at USGS Station 9-2970, was obtained from USGS records. The 1931-60 distribution of groundwater was estimated from inflow-outflow relationships obtained from water budget programs for the lower subareas in the Uinta Basin drainage area

Table 17. MEAN MONTHLY AND MEAN ANNUAL WATER BUDGET FOR THE VERNAL SUBAREA

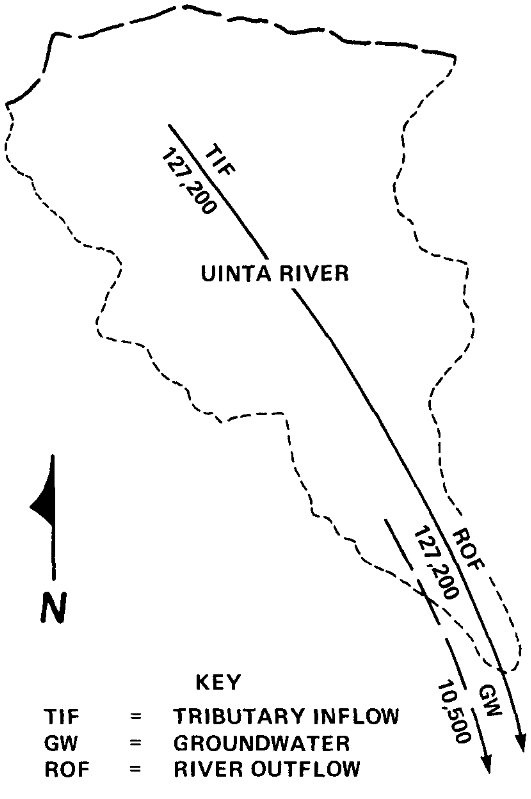
Characteristic	Water Budget (AF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
River inflow Station 9 2710	3,470	2,590	2,130	1,830	1,530	1,620	4,000	23,510	24,450	8,140	5,160	3,570	82,000
Tributary inflow													
Ungaged inflow	210	160	140	140	180	270	450	1,150	1,010	530	350	210	4,800
Steinaker Reservoir													
Net change in storage	210	1,540	1,540	1,260	1,050	1,110	1,380	3,070	4,620	-5,980	-5,610	3,770	0
Total surface inflow	3,890	1,210	730	710	660	780	3,070	21,590	20,840	14,650	11,120	7,550	86,800
Exported flow													
Union and Ashley Up Irr Co Canal diversions	420	0	0	0	0	0	40	1 730	1,300	720	400	390	5,000
Diversion to cropland	3,600	0	0	0	0	0	530	18,310	17,820	12,390	7,110	5,240	65,000
Amount to root zone	1,740	0	0	0	0	0	250	8,780	8,550	9,050	3,410	2,520	31,200
Cropland precipitation	780	730	820	690	630	710	840	800	800	690	780	730	9,000
Root zone supply	2,520	730	820	690	630	710	1,090	9,580	9,350	6,640	4,190	3,250	40,200
Cropland PCU	2,490	0	0	0	0	0	0	6 300	8,370	10,300	6,950	2,890	37,300
Root zone supply PCU	30	730	820	690	630	710	1 090	3,280	980	3,660	2,760	360	2,900
Accum soil moisture	2,000	2,330	2,750	3,040	3,270	3,580	3,970	5,500	3,880	2,620	1,560	2,150	–
Change in soil moisture	150	330	420	290	230	310	390	1,530	1,620	1,260	1,060	590	0
Consumptive use deficit	270	0	0	0	0	0	0	0	0	3,770	2,600	730	7,300
Cropland ACU	2,220	0	0	0	0	0	0	6,300	8,370	6,600	4,350	2,160	30,000
Addition to groundwater	450	400	400	400	400	400	700	1,750	2,600	1,300	900	500	10,200
Return flow from cropland	1,860	0	0	0	0	0	280	9,530	9,270	6,440	3,700	2,720	33,800
Total of return flows	2,310	400	400	400	400	400	280	11,280	11,870	7,740	4,600	3,220	44,000
Domestic use/water surface evap	160	60	50	50	50	130	280	440	530	590	450	210	3,000
Supply to wetland/groundwater	2,020	1,550	1,080	1,080	1,010	1,050	3,200	12,300	13,060	8,690	7,760	4,930	57,800
Wetland precipitation	540	500	570	480	440	400	580	550	540	470	540	500	6,200
Wetland consumptive use	930	0	0	0	0	100	340	3,270	4,270	5 050	3,940	2,100	20,000
Outflow/groundwater change	1,830	2,050	1,650	1,540	1,450	1,440	3 440	9,670	9,330	4,110	4,360	3,330	44,000
Estimated groundwater change	30	350	-850	960	1,050	1,060	840	2,630	2,970	2,910	3,560	2,530	0
River outflow Station 9 2715	1,600	2,400	2 500	2,500	2,500	2 500	2,600	12,300	12,300	1,200	800	800	44,000

Source Reference 5



Source: Reference 5.

Figure 25. FLOW DIAGRAM OF THE MEAN ANNUAL WATER BUDGET FOR THE VERNAL SUBAREA



Source: Reference 5.

Figure 26. FLOW DIAGRAM OF THE MEAN ANNUAL DISTRIBUTION OF THE UINTA SUBAREA

Table 18. MEAN MONTHLY AND MEAN ANNUAL WATER BUDGET FOR THE UINTA RIVER SUBAREA

Characteristic	Water Budget (AF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Tributary inflow													
Ungaged inflow	7 600	5 270	4 240	3 560	3 070	3 480	5 090	21 680	32 630	18 110	12,950	9 520	127,200
River outflow Station 9 2970	7 600	5 270	4 240	3 560	3 070	3 480	5 090	21 680	32 630	18 110	12 950	9 520	127 200
Subsurface outflow	420	370	370	420	520	630	1,050	2 100	1 680	1 470	950	520	10 500
Total surface and subsurface outflow	8 020	5 640	4 610	3 980	3 590	4 110	6 140	23 780	34 310	19 580	13 900	10 040	137 700

Source Reference 5

Farm Creek Subarea (7-3-17)

The Farm Creek subarea is the drainage area of Farm Creek above USGS stream gaging station 9-2980. The mean monthly and annual distributions for the 1931-60 time period are given in Table 19; Figure 27 is a flow diagram of the mean annual distribution of the river outflow, which is gaged at USGS Station 9-2980. These distributions were obtained directly from USGS records and from USBR estimates for those years during the 1931-60 time period for which the records are missing. The 1931-60 distribution of groundwater was estimated from inflow-outflow relationships obtained from water budget programs for the lower subareas in the Uinta Basin drainage area.

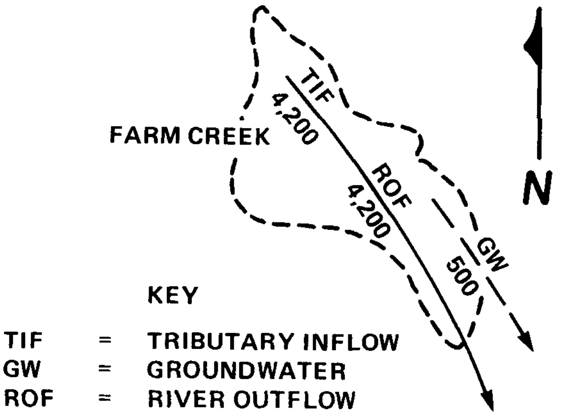
Table 19. MEAN MONTHLY AND MEAN ANNUAL WATER BUDGET FOR THE FARM CREEK SUBAREA

Characteristic	Water Budget (AF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Tributary inflow													
Ungaged inflow	190	200	200	200	200	190	270	1 480	630	260	200	180	4,200
River outflow Station 9 2980	190	200	200	200	200	190	270	1 480	630	260	200	180	4,200
Subsurface outflow	20	20	20	20	20	30	50	100	80	70	40	30	500
Total surface and subsurface outflow	210	220	220	220	220	220	329	1,580	710	330	240	210	4 700

Source Reference 5

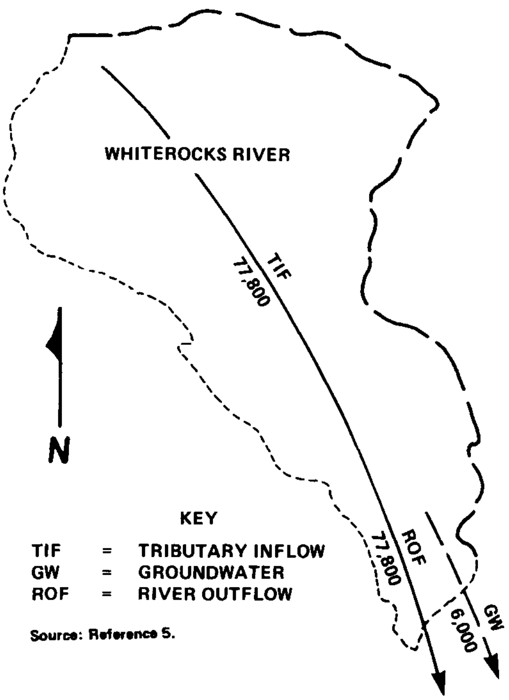
Whiterocks River Subarea (7-3-18)

The Whiterocks River subarea forms the upper drainage of the Whiterocks River, which is located along the south slopes of the Uinta Mountains. A few small reservoirs have been formed by constructing earth-fill dams at the outlets of high-elevation natural lakes in the Uinta Mountains. The flow diagram shown in Figure 28 illustrates the mean annual flow



Source: Reference 5.

Figure 27. FLOW DIAGRAM OF THE MEAN ANNUAL DISTRIBUTION OF THE FARM CREEK SUBAREA



Source: Reference 5.

Figure 28. FLOW DIAGRAM OF THE MEAN ANNUAL DISTRIBUTION OF THE WHITEROCKS RIVER SUBAREA OF THE WHITEROCKS RIVER SUBAREA

distribution for the Whiterocks River subarea, while Table 20 lists the mean monthly and mean annual distributions for the 1931-60 time period. These distributions of the river outflow, which is gaged at USGS Station 9-2995, were obtained from USGS records. The 1931-60 distribution of groundwater was estimated from inflow-outflow relationships obtained from water budget programs for the lower subareas in the Uinta Basin drainage area.

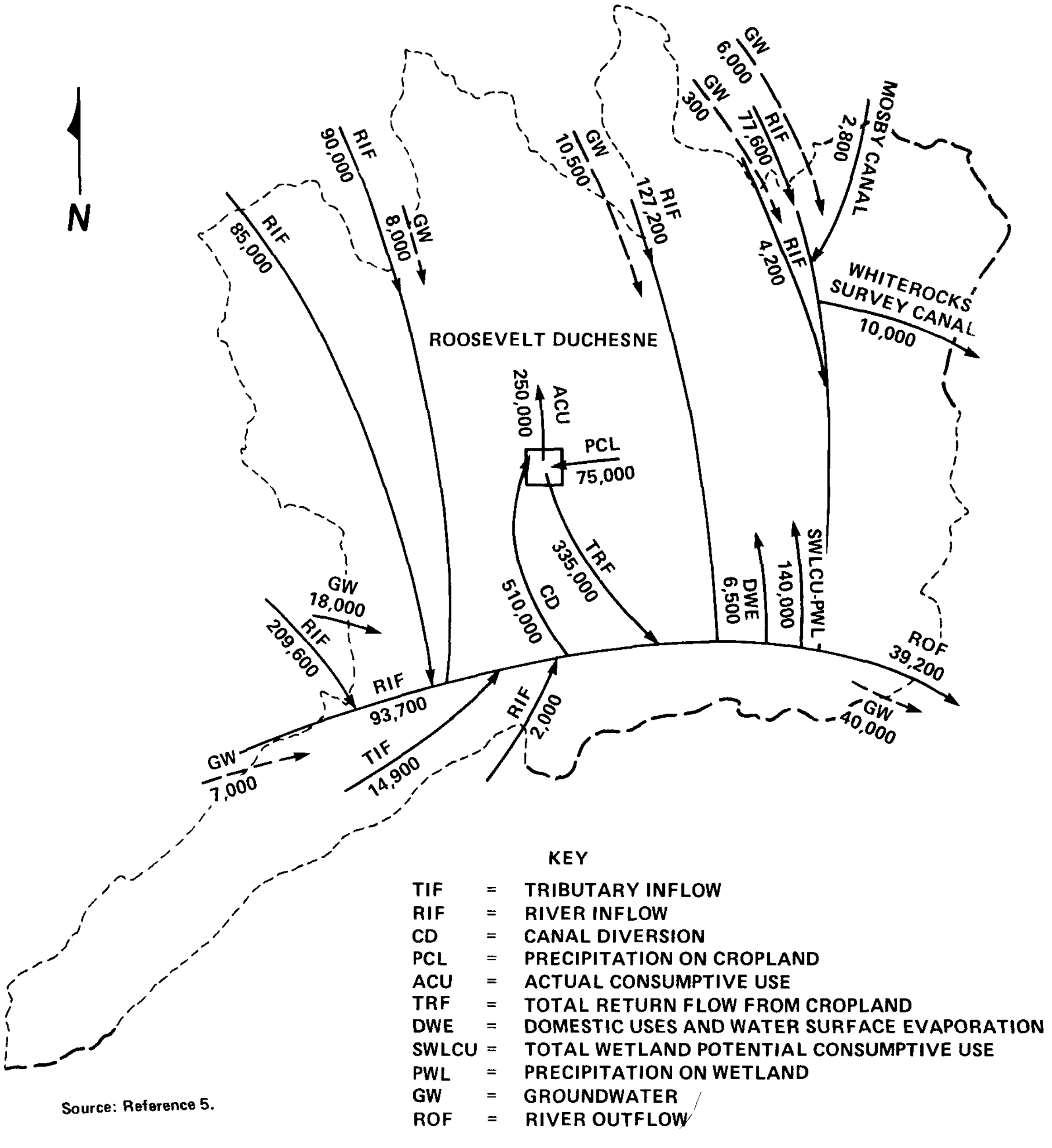
Table 20. MEAN MONTHLY AND MEAN ANNUAL WATER BUDGET FOR THE WHITEROCKS RIVER SUBAREA

Characteristic	Water Budget (AF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Tributary inflow													
Ungaged inflow	4 210	2 840	2 250	1 940	1 590	1 790	3 090	17 850	21 040	9 370	6 980	4,850	77 800
River outflow Station 9 2995	4 210	2 840	2 250	1 940	1 590	1 790	3 090	17 850	21 040	9 370	6,980	4 850	77 800
Subsurface outflow	240	210	210	240	300	360	600	1,200	960	840	540	300	6 000
Total surface and subsurface outflow	4 450	3 050	2 460	2 180	1 890	2 150	3 690	19 050	22 000	10 210	7 520	5 150	83 800

Source Reference 5

Roosevelt-Duchesne Subarea (7-3-19)

The Roosevelt-Duchesne subarea is by far the largest hydrologic subarea in the Uinta Basin drainage area. It contains most of the agricultural lands in the drainage area. The flow diagram shown in Figure 29 represents the mean annual flow distribution for the Roosevelt-Duchesne subarea. The river inflows to the subarea are the river outflows from the Antelope Creek, Lower Strawberry River, Uinta River, Farm Creek, and Whiterocks River subareas. Water is imported into the subarea by way of the Mosby Canal from the Dry Fork subarea in the Ashley-Brush drainage area. The ungaged surface and subsurface inflow to the area was estimated from USBR and USGS reports and from inflow-outflow relationships determined from the water budget program. Water diverted to cropland for the 1931-60 time period was estimated from 1957-64 diversion records. The mean monthly and mean annual distributions of the water budget were determined by dividing the subarea into two budget districts. The first included the land supplied by the Uinta River drainage down to Fort Duchesne and the second was the remainder of the Roosevelt-Duchesne subarea. Although considerable difficulty was encountered in dividing the subarea, the hydrologic input data better described each area. Because of the complexity of dividing the canal diversions, water rights, Indian and non-Indian lands, etc., the water budgets for each district were then compiled into a single water budget representing the entire Roosevelt-Duchesne subarea (Figure 29). The mean monthly and mean annual water budgets for the 1931-60 time period are listed in Table 21. Because of the large area under consideration, the water budgets may not reflect the true picture for each agricultural land area within the subarea. Some lands have ample water supply and good water rights with virtually no consumptive use deficiency except in extremely dry years. Other lands have only limited water supply with poor water rights and, therefore, account for the large consumptive use deficiency in the subarea. The mean monthly and mean annual distributions for the river outflow, which are gaged at Station 9-3020, were obtained from USGS records, which were adjusted according to exports conveyed by the Duchesne Tunnel. The groundwater outflow was estimated from USBR reports and inflow-outflow relationships obtained from the Utah Water Resources Laboratory (UWRL) analog water budgets for the Uinta Basin drainage area.



Source: Reference 5.

Figure 29. FLOW DIAGRAM OF MEAN AND ANNUAL DISTRIBUTION OF THE ROOSEVELT-DUCHESNE SUBAREA

Table 21. MEAN MONTHLY AND MEAN ANNUAL WATER BUDGET FOR ROOSEVELT-DUCHESNE SUBAREA

Characteristic	Water Budget (AF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
River inflows													
Antelope Cr near Myton	130	210	210	190	160	180	200	250	110	100	120	140	2 000
Strawberry River at Duchesne	4 300	4 440	4,370	4,200	4 110	5 710	11,230	26,900	13 420	6 010	4 980	4 030	93 700
Duchesne River at Duchesne	8,990	9 660	9 380	8 700	7 690	8 550	12,230	45 340	62 020	10 790	9 630	7 620	209 600
Lake Fork below Moon Lake near Mt Home	5 000	200	0	0	0	0	2 160	17 520	18 040	21 820	13 840	6 420	85 000
Yellowstone Cr near Altonah	5 360	4 160	3 570	3 170	2 650	2 890	3 970	15 830	25 950	12 910	8 470	6 570	95 500
Unita River near Neola	7 600	5 270	4 240	3 560	3 070	3 480	5 090	21 680	32 630	18 110	12 950	9 520	127 200
Farm Cr near Whiterocks	190	200	200	200	200	190	270	1 480	630	260	200	180	4 200
Whiterocks River near Whiterocks	4 210	2 840	2,250	1 940	1 590	1 790	3 090	17 850	21 040	9 370	6 980	4 850	77 800
Imported flow													
Mosby Canal	350	0	0	0	0	0	0	230	350	470	820	580	2 800
Tributary inflow													
Ungaged surface and subsurface inflow	3,290	2 710	2 780	2 570	3,200	3 600	5 610	14,270	9 750	7 920	5 500	3 700	64 900
Total surface and subsurface inflow	37 090	29 850	26 990	24,950	23 320	27 500	47 080	160 680	187 450	92 700	62 340	42 750	762 700
Exported flow													
Whiterocks-Ouray Canal	1 210	0	0	0	0	80	390	2 010	2 170	1 860	1 150	1 130	10 000
Diversion to cropland	44 570	0	0	0	0	1,270	24 160	99,320	134 600	96 010	64 660	45 410	510 000
Amount to root zone	21 410	0	0	0	0	610	11 600	45,310	61 780	46 120	33 950	24,220	245 000
Cropland precipitation	8,900	3 420	3 510	5 410	5 360	5 810	6,240	7 550	5 120	4 600	9 150	9 930	75 000
Root zone supply	30 310	3 420	3 610	5 410	5 360	6 420	17,840	52 860	66 900	50 720	43 100	34 150	320 000
Cropland PCU	17 630	0	0	0	0	0	0	37 130	57 240	77 450	62 100	33 450	285 000
Root zone supply-PCU	12 680	3 420	3 510	5 410	5,360	6 420	17 840	15 730	9 660	26 730	19 000	700	35 000
Accum soil moisture	20 520	21 440	22 450	24 360	26 220	28 640	40 000	40 000	40 000	21 810	13 540	14 080	
Change in soil moisture	6 440	920	1 010	1 910	1 860	2 420	11 360	0	0	18 190	-8 250	520	0
Consumptive use deficit	760	0	0	0	0	0	0	0	1 130	13 540	14 750	4 820	35 000
Cropland ACU	16 870	0	0	0	0	0	0	37 130	56 110	63 910	47 350	28 630	250 000
Addition to groundwater	7 000	2 500	2 500	3 500	3 500	4 000	6 480	15 730	10 790	5 000	4 000	5 000	70 000
Return flow from cropland	23 160	0	0	0	0	660	12 560	54 010	72 820	49 890	30 710	21 190	265 000
Total of return flows	30 160	2 500	2 500	3 500	3 500	4 660	19 040	69 740	83 610	54 890	34 710	26 190	335 000
Domestic use/water surface evap	260	30	20	20	20	20	30	720	1 210	1 700	1 520	950	6 500
Supply to wetland/groundwater	23 540	32 160	29 480	28 010	26 150	29 680	38 310	129 040	129 570	52 080	30 870	22 310	571 200
Wetland precipitation	4 640	1 830	1 890	2 990	2,820	3 170	3 330	3 990	2 660	2 450	4 860	5 370	40 000
Wetland consumptive use	7 190	60	10	10	20	180	4 550	27 670	36 790	44 900	33 960	24 660	180 000
Outflow/groundwater change	20 990	33 930	31 360	30 990	28 950	32 670	37 090	105 360	95 440	9 630	1 770	3,020	431,200
Estimated groundwater change	480	8 750	4 040	4 060	2 810	1,870	7 050	25 920	7 890	17 510	16 990	12 590	0
River outflow Station 9 3020	16 910	22 780	25 520	25 330	24 540	29,200	28,240	77 040	99 330	20 740	11 560	10 010	391 200
Subsurface outflow	3 600	2 400	1 800	1 600	1 600	1 600	1 800	2 400	4 000	6 400	7 200	5 600	40 000
Total surface and subsurface outflow	20 510	25 180	27 320	26 930	26 140	30 800	30 040	79 440	103,330	27 140	18 760	15 610	431 200

Source Reference 5

Surface Water Availability for Tar Sands Development

With the water budgets established for the drainage areas to the east and west of Asphalt Ridge, it is now possible to consider the adequacy of supplies for tar sands development. Two useful comparisons can be made from the water budget data; the river flows and agricultural diversions (on a monthly basis) will be compared with potential demand. The comparison of agricultural diversions is particularly important since it is likely that water rights for tar sands will have to be purchased from agricultural interests.

Table 22 lists the monthly average streamflows in acre-feet (AF) for the stream gages to the east of Asphalt Ridge; it also lists the withdrawals for agriculture in the Vernal area. These flows must be compared with the potential demand. In Table 3, the following hypothetical demands for water were calculated (based on 5 bbl of water per barrel of oil):

- five-well experimental facility: 35.5 AF/yr = 2.96 AF/mo;
- 24-well pilot facility: 213 AF/yr = 17.8 AF/mo; and
- large-scale production facility: 13,400 AF/yr = 1117 AF/mo.

Table 22. MONTHLY RIVER FLOWS AND AGRICULTURAL DIVERSIONS ASHLEY-BRUSH DRAINAGE AREA

Stream Gaging Station	Monthly Flow (AF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Mo Avg
9 2680	1,150	700	440	380	310	330	820	7,870	8,560	2,220	1,300	1,220	2,108
9 2685	130	80	60	40	30	30	130	1,510	1,370	560	280	180	367
9 2689	350	160	100	60	50	80	340	2,240	2,500	850	370	300	617
9 2650	400	0	0	0	0	0	0	0	200	1,700	1,600	900	400
9 2655	1,310	730	360	210	130	150	1,960	12,030	14,090	2,750	1,130	850	2,975
Diversion to cropland Ashley Dry Fork subarea	40	0	0	0	0	0	0	1,300	1,600	630	230	100	333
9 2710	3,470	2,590	2,130	1,830	1,530	1,620	4,000	23,510	24,450	8,140	5,160	3,570	6,833
Diversion to cropland Vernal subarea	3,600	0	0	0	0	0	530	18,310	17,820	12,300	7,110	5,240	5,410
9 2715	1,600	2,400	2,500	2,500	2,500	2,500	2,600	12,300	12,300	1,200	800	800	3,667

Source Reference 5.

Table 22 shows that adequate surface water exists in the Ashley-Brush drainage area to support experimental and pilot studies. All of the gages in the area indicate monthly average flows sufficient for these activities. This does not imply that for any given month supplies would always be adequate. The randomness of precipitation and runoff would require storage facilities, but water is available. However, this assessment of water availability does not take into consideration the water rights involved. The question of water rights is discussed in Section IX.

The area also appears to have enough surface water to support large-scale production facilities. However, the impact of such facilities on the surface water supply would be substantial. For example, more water would be required than the North Fork of Dry Fork (Station 9-2685) produces on the average, 30 percent of the flow at Ashley Creek near Jensen (Station 9-2715) would be required.

The picture changes somewhat when the available water is decremented by the amount needed for agricultural uses. Diversions to cropland in the Ashley-Dry Fork subarea average 333 acre-feet per month; in the Vernal area they average 5410 acre-feet per month. Actual consumptive uses are 108 and 2500 acre-feet per month, respectively. Thus, a production facility would require 43 percent of the water now consumed by agriculture in the Vernal area. Again, this calculation assumes no recycling of water.

Table 23 lists the monthly average streamflows in acre-feet for the stream gages to the west of Asphalt River in the Uinta Basin drainage area. The withdrawals for agriculture in that area are also listed.

Table 23. MONTHLY RIVER FLOWS AND AGRICULTURAL DIVERSIONS
UINTA DRAINAGE AREA

Stream Gaging Station	Monthly Flow (AF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Mo Avg
9 2970	7,600	5,270	4,240	3,560	3,070	3,480	5,090	21,680	32,630	18,110	12,950	9,520	10,600
9-2980	190	200	200	200	200	190	270	1,480	630	260	200	180	350
9 2995	4,210	2,840	2,250	1,940	1,590	1,770	3,090	17,850	21,040	9,370	6,980	4,850	6,480
Duchesne River at Duchesne	8,990	9,660	9,380	8,700	7,690	8,550	12,230	45,340	62,020	10,790	9,630	7,620	17,466
Diversion to cropland Roosevelt Duchesne subarea	44,570	0	0	0	0	1,270	24,160	99,320	134,600	96,010	64,660	45,410	47,500
Diversion to cropland Lower Strawberry subarea	500	0	0	0	0	0	180	1,480	1,930	990	620	500	517
Diversion to cropland Uinta subarea	1,420	0	0	0	0	0	610	3,440	4,720	3,620	2,390	1,800	1,500

Source Reference 5.

In general, there is more surface water to the west of Asphalt Ridge because of the larger drainage areas of the Uinta and Duchesne Rivers. Again, there is sufficient surface water to support any size of tar sands facility; it is simply a matter of acquiring the necessary water rights.

A comparison of the tar sands facility water requirements with the current water requirements for agricultural use shows that total withdrawal for the Roosevelt-Duchesne, Lower Strawberry, and Uinta subareas is 49,517 acre-feet per month. Of this, 21,716 acre-feet per month is consumed. A production facility for tar sands would represent only 5 percent of the consumptive use of these three subareas.

Surface Water Quality

The quality of water used in tar sands facilities is nearly as important as the quantity. Water containing highly corrosive minerals is difficult to use on a production basis. Such corrosive minerals, however, do not appear to be a problem with the surface water in the Asphalt Ridge area.

Fourteen water quality sampling stations are maintained by the USGS and the USBR in the Vernal area (Table 24). Most of these stations coincide with stream gaging stations.

Table 24. SURFACE WATER QUALITY SAMPLING STATIONS IN THE UINTA STUDY UNIT

1.	Oaks Park Canal near Vernal	8.	Little Brush Cr. near Vernal
2.	Ashley Cr. near Vernal	9.	Brush Cr. near Jensen
3.	Dry Fork R. at mouth near Dry Fork	10.	Uinta R. near Neola
4.	Ashley Cr. at Sign of the Maine near Vernal	11.	Whiterocks R. near Whiterocks
5.	Steinaker Feeder Canal at head	12.	Uinta R. at Fort Duchesne
6.	Ashley Cr. near Jensen	13.	Uinta R. at mouth near Randlett
7.	Brush Cr. near Vernal	14.	Duchesne R. near Randlett

It should be noted here that the amount and quality of water quality data vary widely. The best records are those collected by the USGS at long-term gaging stations. At such stations, information is usually available for a number of parameters on a daily basis. Some stations include water quality monitors that give continuous readouts of temperature, dissolved oxygen, pH, and conductivity. Much of the water quality data, however, is fragmentary. Sediment samples are often collected at random times or only during storm events. The same is true of salinity samples and analyses for trace metals and other constituents. Extreme caution should be used in making judgments on water quality without first examining the data base in detail.

Austin and Skogerboe (Reference 5) report the surface water quality in the Asphalt Ridge area to be reasonably good to excellent based on records from the sample sites listed in Table 24.

The total dissolved-solids concentrations of flow from the Ashley-Brush drainage area increase considerably before they enter the Green River. The quality of upper Brush Creek is good; however, the quality decreases, with an average salinity of 500 ppm at the mouth. The average salinity of the upper drainage of Ashley Creek above the agricultural diversions is below 100 ppm, while at the mouth of Ashley Creek the average concentration is 1800 ppm.

The quality of the waters from the Uinta Basin drainage area is generally quite good. The average salinity in flows above agricultural lands along the south slopes of the Uinta

Mountains is generally less than 50 ppm; this concentration increases to 350 ppm and 700 ppm, respectively, where the Yellowstone and Uinta Rivers enter the Duchesne River. The salinities encountered in the upper drainage of the Duchesne and Strawberry Rivers range from 100 to 200 ppm, but they increase until the average concentrations are 260 ppm and 400 ppm, respectively, at Duchesne. Because of extensive agricultural and wetland depletions, the average salinity increases to 800 ppm at the mouth of the Duchesne River. More detailed records of the water quality are available in Reference 22 and yearly USGS publications.

A detailed water quality study on the Duschesne River Basin was published by Mundorff (Reference 26) in 1977. The purpose of the study was to (a) define the general inorganic chemical characteristics of surface waters in the basin, (b) determine the effects of the material environment and current use on the demand characteristics of the surface water in the basin, and (c) determine the general characteristics of the sediment discharge from the basin. Some of the general conclusions from the study are presented here. Reference 26 contains at short summary of water quality standards, which is also presented here.

Mundorff notes that a relatively small amount of runoff originates in the southern and eastern parts of the basin where the Uinta and Duchesne River Formations of the Tertiary period are predominant, the rocks in some places containing gypsum and other saline evaporites that are relatively soluble. A few observations of thunderstorm runoff in ephemeral streams in such areas indicate that concentrations of dissolved solids were less than 600 mg per liter and that such runoff does not have a significant adverse effect on the chemical quality of the water in the Duchesne River.

A quantitative evaluation of the effects of irrigation on the chemical quality of the Duchesne River could not be made with available data. The coincidence is evident, however, among areas of irrigation, areas of saline soils and poor drainage, areas underlain by the Uinta and Duchesne River Formations, and stream reaches of high dissolved-solids concentrations.

A large increase in dissolved-solids concentrations in a downstream direction was attributed to a large increase in the concentrations of sodium and sulfate. Coupled with this was a downstream change in chemical characteristics from a calcium bicarbonate to a sodium-sulfate type water. These downstream changes generally appear to result from the diversion of large amounts of water having low dissolved-solids concentrations from upstream parts of the basin and the return to or entry into the stream of smaller amounts of water having much higher dissolved-solids concentrations. Planned diversions in the upper part of the basin are reported to increase the dissolved-solids levels in the lower basin.

During periods of low flow, several tributaries to the Duchesne and Strawberry Rivers in the southern part of the Duchesne River Basin have boron concentrations that greatly exceed the limits recommended for various classes of irrigation waters. Boron concentrations as high as 20,000 μg per liter were observed at the mouth of Indian Canyon.

Measured suspended-sediment concentrations as high as 36,200 mg per liter were observed in a small amount of thunderstorm runoff in the southeastern part of the study area. Sediment concentrations greater than 100,000 mg per liter would not be unusual during periods of intense thunderstorm runoff in many of the tributaries that drain areas underlain by the Uinta and Duchesne River Formations in the southern part of the study area.

An estimate of the suspended-sediment discharge of the Duchesne River near Randlett indicates that the discharge was at least 200,000 tons during the 1974 water year, when precipitation in the Duchesne River Basin was much below normal.

As a basis for comparison, several water quality standards are presented. The values reported are taken from Mundorff (Reference 26), who adapted them from U.S. Public Health Service publications.

In general, the standards for water quality are designed to prevent offense to the sense of sight, taste, or smell. Included in the standards are the following chemical substances that should not be present in a water supply in excess of the listed concentrations if other more suitable supplies are or can be made available:

Substance	Concentration (mg/l)
Chloride	250
Sulfate	250
Total dissolved solids	500
Nitrate	45*

*10 mg/l expressed as N.

The following scheme is used to classify water in terms of total dissolved solids and conductivity:

Class	Dissolved Solids (ppm)	Specific Conductance (micromhos/cm at 25°C)
Fresh	0 to 1,000	0 to 1,400
Slightly saline	1,000 to 3,000	1,400 to 4,000
Moderately saline	3,000 to 10,000	4,000 to 14,000
Very saline	10,000 to 35,000	14,000 to 50,000
Briny	More than 35,000	More than 50,000

In general, surface waters in the Asphalt Ridge area are fresh to moderately saline. The presence of large quantities of sediment during storm events indicates that diversion and storage facilities would have to be carefully designed to transport or store the sediment load.

GROUNDWATER

Background

Two types of groundwater resources exist in the study area. The first is shallow water found in the alluvial valley material adjacent to streams and the land surface bedrock. This resource is accessible by shallow wells (about 200 ft deep or less) and is closely related to the streamflow. The second resource is groundwater from deeper bedrock aquifers, and it is usually tapped by deep wells. Bedrock aquifers often recharge hundreds of miles from areas of production and are less sensitive to streamflow.

The two types of groundwater resources are considered separately here. First, the shallow groundwater supply is examined, next the subsurface geology of the Asphalt Ridge area is presented, and then the groundwater in the bedrock aquifers is examined. Groundwater quality is considered after supply-and-demand considerations are discussed.

For more complete understanding of the subsequent discussion, the definitions of several commonly used groundwater terms and the scheme whereby wells are located is presented here. The term *permeability* is generally used to denote the relative ease with which a water-bearing formation can transmit water. The specific measure of permeability is *hydraulic conductivity (K)*. The hydraulic conductivity of a water-bearing material is the volume of water that will move through a unit cross-section of the material in a specific time under a specific hydraulic gradient. *Hydraulic conductivity* (measured in cubic feet per day per square foot, which reduces to feet per day) has replaced the term *field coefficient of permeability* (measured in gallons per day per square foot), formerly used by the USGS. The following ranges of measured or estimated hydraulic conductivity are used in this report:

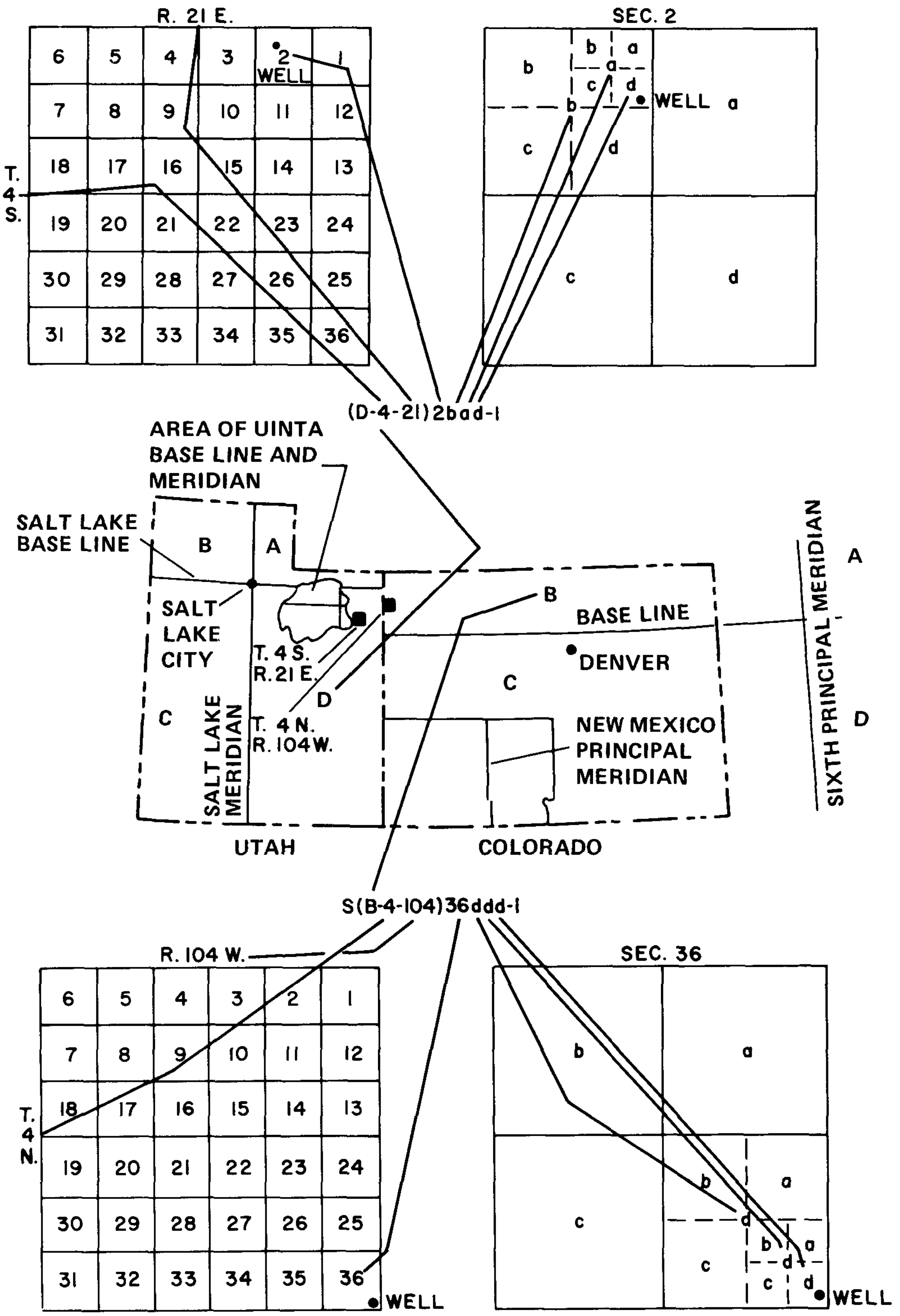
Range	*K* (ft/day)
Very low	less than 0.5
Low	0.5 to 5
Moderate	5 to 50
High	50 to 500
Very high	more than 500

Other commonly used terms are *specific yield, Sy; storage coefficient, S;* and *transmissivity, T.* The specific yield of an aquifer is the ratio of the volume of water that the saturated rock will yield by gravity to its own volume. The definition implies that gravity drainage is complete. *Sy* is related to the storage coefficient. Typical values for *Sy* range from 0.10 to 0.30.

The storage coefficient of an aquifer is a dimensionless number that indicates the volume of water the aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. Under confined conditions *S* is typically small, generally between 0.00001 and 0.001; under unconfined conditions, it is much larger, typically from 0.05 to 0.30.

Transmissivity is the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is specified in cubic feet per day per foot, which reduces to square feet per day. The term *transmissivity* has replaced the term *coefficient of transmissibility* (measured in gallons per day per foot), which was formerly used by the USGS.

Utah's well and spring numbering system, which is awkward and inconvenient, is described in most Utah Department of Natural Resources publications. Briefly, using Reference 27 as a source, the system of number wells and springs in Utah is based on the cadastral land-survey system of the U.S. government. The number designates the well or spring and also describes its position in the land network. By the land-survey system, the state is divided into four quadrants by the Salt Lake base line and meridian, and these quadrants are designated by A, indicating the northeast; B, northwest; C, southwest; and D, southeast. Two numbers, designating the township and range (in that order), follow the quadrant letter, and all three are enclosed in parentheses. The number after the parentheses indicates the section and is followed by three lower-case letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section–generally 10 acres; the letters a, b, c, and d indicate the northeast, northwest, southwest, and southeast quarters of each subdivision, respectively. The number after these lower-case letters is the serial number of the well or spring within the 10-acre tract; the letter S preceding the serial number each subdivision, respectively. The number after these lower-case letters is the serial number of the well or spring within the 10-acre tract; the letter S preceding the serial number denotes a spring. If a well or spring cannot be located within a 10-acre tract, one or two location letters are used and the serial number is omitted. Thus, (D-4-21)2bad-1 designates the first well constructed or visited in the SE¼NE¼NW¼, Sec. 2, T. 4 S., R. 21 E., and (D-5-23)30bc-S designates a spring known only to be in the SW¼NW¼ of the section. Other sites at which hydrologic data were collected are numbered in the same manner, but three letters are used after the section number and no serial number is used. The numbering system is illustrated in Figure 30.



Source: Reference 27.

Figure 30. WELL AND SPRING NUMBERING SYSTEMS USED IN UTAH AND COLORADO

Shallow Groundwater Supplies

The two best references on the shallow groundwater supply in the vicinity of Asphalt Ridge are by Hood (References 27 and 28). Reference 27 deals with general characteristics of aquifers in the northern Uinta Basin area, and Reference 28 is a detailed report on the groundwater in Ashley Valley near Vernal. The presentation here is based primarily on those two reports.

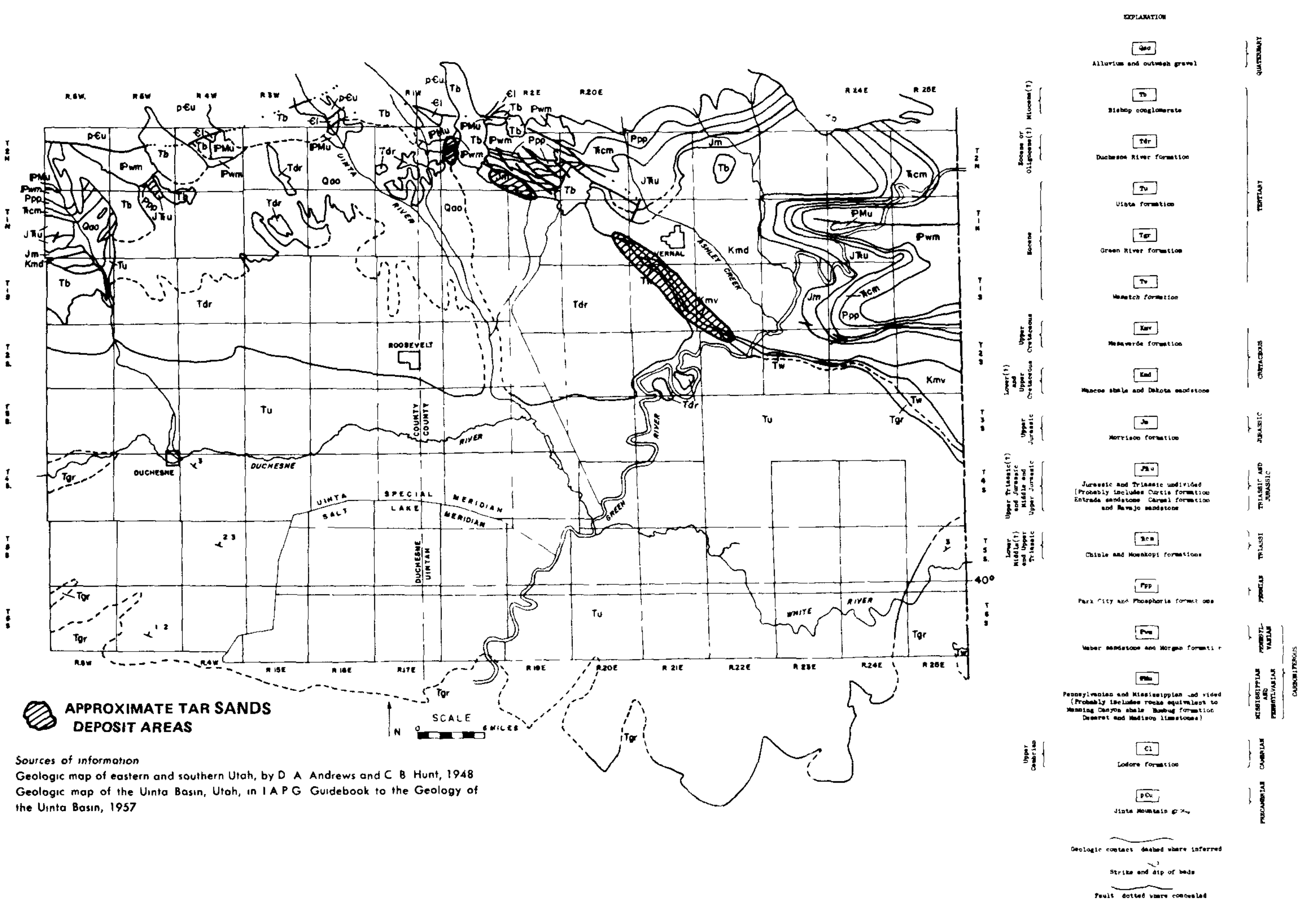
Figure 31 illustrates the surface geology in the Asphalt Ridge area and shows the approximate boundaries of the tar sands areas. Figure 31 is somewhat incomplete. Plate 1 of Reference 27 illustrates a large area of alluvial and glacial deposits around Vernal in Ashley Valley. These deposits are discussed in detail subsequently.

Hood (Reference 27) identifies seven major geologic formations in the Northern Uinta Basin that contain significant amounts of groundwater. Only three of these formations are in the vicinity of Asphalt Ridge; they are the Quaternary glacial deposits and alluvium and the Tertiary Duchesne River and Uinta Formations. Virtually all the surface land to the west of Asphalt Ridge is the Duchesne River Formation. Asphalt Ridge is an outcrop of the Mesaverde Formation. To the east of Asphalt Ridge lies Ashley Valley, which is filled with glacial deposits that overlie the Mancos Shale. The principal features of the three major formations are listed in Table 25.

In Reference 27, Hood discusses the water-producing features of the major geologic formations. Glacial outwash, alluvium of the Pleistocene period, and related coarse-grained deposits comprise the most prolific aquifer in the northern Uinta Basin. These unconsolidated deposits form a continuous sheet of material in such areas as the plain east of Neola where the outwash extends southward beneath the younger alluvium. In other areas, however, the deposits form relatively narrow continuous aquifers in the bottoms of mountain canyons and stream valleys or discontinuous caps on terraces.

For the area studied, values of K range from 2 to 1800 ft per day. The K values of the deposits in mountain canyons range from 10 to 400 ft per day but are mainly in the range from 20 to 80 ft per day. Because the canyon fill is generally thin, most of it has a T value of 1000 ft^2 per day or less, and most wells finished in the canyon fill should have yields of less than 1 cfs.

The glacial outwash in stream valleys has a maximum K of 300 ft per day in the Green River flood plain, about 1000 ft per day in Ashley Valley, and 800 ft per day in the Duchesne River flood plain. The maximum values are reached where sorting is at a maximum; downstream the permeability decreases because the grain size of the glacial material diminishes and the fine-grained debris from adjacent formations is mixed with the glacial material. The Ashley Valley deposits will be discussed in greater detail subsequently.



Sources of information
Geologic map of eastern and southern Utah, by D A Andrews and C B Hunt, 1948
Geologic map of the Uinta Basin, Utah, in I A P G Guidebook to the Geology of the Uinta Basin, 1957

Figure 31. SURFACE GEOLOGY IN VICINITY OF ASPHALT RIDGE

Table 25. DESCRIPTION OF THREE MAJOR LITHOLOGIC UNITS THAT CROP OUT IN THE NORTHERN UINTA BASIN AREA

Erathem	System	Series	Geologic Unit		Character of Material	Hydrologic Characteristics
			Western Part of Basin	Eastern Part of Basin		
CENOZOIC	Quaternary	Pleistocene	Glacial Deposits and Alluvium		Glacial outwash moraines, and undifferentiated deposits of glacial origin (include glaciated ground) Outwash is generally coarse grained and consists of sand, gravel, cobbles, and boulders that underlie and grade into terrace deposits in upland areas Thickness ranges from a few feet on edges of terraces to about 200 ft (60 m) near the mouths of major river canyons These deposits and terrace deposits are discontinuous with those on adjacent benches and stream valleys Beneath stream valleys, outwash forms the basal section of the unconsolidated valley fill thicknesses there rarely exceed 50 ft (15 m) Other glacial deposits are found mainly in canyons or on the mountains, where they are generally poorly sorted veneers on glaciated rock surfaces	Low to very high permeability Glacial outwash and related coarse-grained deposits comprise the most prolific aquifer in the northern Uinta Basin area in localities where the outwash is sufficiently thick to store and transmit water Water is generally under unconfined conditions but locally may be confined or partly confined It comprises the main aquifer in Ashley Valley, on upland slopes and outwash plains (as around Neola and Altamont), beneath the flood plains of the streams (such as the Duchesne and Uinta Rivers), and beneath the floors of the mountain canyons (near their mouths) Values for K are estimated to be in the range of 2 to 1,800 ft/d (0 61 to 550 m/d) Wells near Neola yield as much as 3 ft^3/s (0 0085 m^3/s) The water in the outwash is fresh except where the outwash receives inflow from older rocks, as in the Duchesne River valley below Bridgeland The other glacial deposits have lower permeability, but locally their permeability may approach that of the outwash These less permeable deposits generally act as a recharge medium, but locally they yield some water to springs and act as a transfer medium for water from underlying older rocks The water in these other glacial deposits generally is fresh
	Tertiary	Oligocene (?)	Duchesne River Formation		Shale, mainly red, but including green and other pale colors, siltstone, sandstone, and conglomerate, unconformably underlying younger rocks from near the Colorado state line to near Strawberry Reservoir Coarsest grain sizes found near basin margins where the formation interfingers with other formations In central part of basin, formation grades up from underlying Uinta Formation and consists of interbedded sandstone and shale Sandstone most abundant in lower part and, with conglomerate, in upper part Sandstones are of two basic types—a light colored (generally yellow) channel deposit and a darker, more compact, better cemented interchannel (?) lenticular deposit A few thin beds of sandstone are loose to friable Formation in most areas is slightly to strongly fractured Fractures locally contain secondary deposits of calcium sulfate, as near the Roosevelt Bluebell road east of Dry Gulch Maximum thickness is more than 3,000 ft (910 m)	Very low to very high permeability The horizontal hydraulic conductivity of 19 sandstone samples ranged from 0 000033 to 3 28 ft/d (0 00001 to 1 0 m/d) Total porosity ranged from 7 to 32 percent However, aquifer permeability is enhanced by fracturing, and yields to wells and springs range from less than 1 to more than 300 gal/min (0 06 19 l/s), generally with large drawdown Highest permeabilities generally are near edges of outcrops west of Roosevelt in the central basin, and lowest are in areas north and east of Fort Duchesne Water movement may be impeded locally by gilsonite dikes Near recharge areas, and where the formation is fractured or moderately permeable, the water generally is fresh. At greater depths where the formation is of very low permeability, the water is slightly saline to briny Confined conditions are common in the lower parts of the basin (such as near Roosevelt) artesian heads may exceed 100 ft (30 m) above land surface, but in higher areas of the basin, water levels are below land surface
		Eocene	Uinta Formation		Calcareous shale some limestone, claystone, siltstone and sandstone Fluvial facies in eastern and western ends of basin interfinger with rocks similar in appearance to Duchesne River Formation and with other formations Grades laterally into thinner bedded calcareous lake deposits in center of basin Maximum thickness is nearly 4 000 ft (1 220 m) near center of basin axis	Very low to very high permeability Highest primary permeability of the sandstone seems to approximate that of the median for sandstone in the Duchesne River Formation Bulk of formmation, however, is finer grained than the Duchesne River Formation Permeability is enhanced by fracturing which is evident in many areas for example, Stinking Springs area along Strawberry River in secs 14 and 15, T 4 S R 7 W , Uinta meridian, where the Uinta Formation discharges water from the underlying Green River Formation In most of the area the formation yields only a few gallons per minute of saline water to wells

Source Reference 27

Except in Ashley Valley, the maximum thickness of the stream-valley deposits is about 50 ft and the saturated section generally is no more than about 30 ft. Maximum values for *T*, therefore, should be no higher than 9000 to 24,000 ft^2 per day. Yields of carefully constructed, thoroughly developed, large-diameter wells should be in the range of 1 to 3 cfs. In Ashley Valley, the maximum *T* for a very localized area is about 50,000 ft^2 per day. Sustained maximum well yields for most of the valley, however, should be less than 2 cfs.

Groundwater in most of the glacial outwash, alluvium, and related, course-grained deposits is unconfined; locally it is partially confined by leaky strata near the land surface. The *S* for these deposits was determined at only one locality and ranged from 0.012 to 0.056. The minimum areal value for *Sy* is estimated to be 0.10, or about 10 acre-feet per 100 acre-feet of saturated deposits. Under the existing climatic and streamflow regimen and with the canal irrigation system now in use, it is doubtful that the saturated section will ever be permanently dewatered.

In Reference 27, Hood considered the Duchesne River and Uinta Formations together because they share some common hydrologic and lithologic characteristics and because the lower beds of the Duchesne River Formation in the central part of the area function together with the uppermost sandy beds of the underlying Uinta Formation as a common aquifer. The two formations interfinger at the east and west ends of the basin.

Hydraulic conductivity (*K*) for both formations is small in locations in which the rocks are virtually undisturbed. As a result, the *T* values calculated for many wells range from less than 10 ft^2 per day to a maximum of about 100 ft^2 per day. Most of the partially penetrating, small-diameter wells for which the values were estimated have small yields–less than 10 GPM–and large drawndowns. Values for *K* derived from many wells, however, are a hundred times or more greater than the values derived from rock samples. The higher values of *K* indicate that the formations are fractured.

An estimate of the potential yield of wells is not reliable because each formation has a widely disparate lithology and the effect of fracturing is unpredictable; therefore, a reliable maximum value for *T* cannot be calculated. Based on an aquifer test at Roosevelt, however, where a maximum *T* of 890 ft^2 per day was observed, it is estimated that a deep, large-diameter well could produce about 1 cfs. Considering that artesian conditions prevail in both formations, prolonged pumping of large-yield wells would cause drawdown over a distance measurable in miles.

A review of the water requirements for tar sands development at this point will help to provide an indication of the development that can be supported by a 1-cfs well. This report previously calculated that a five-well experimental facility would require 0.05 cfs (22 GPM) based on 5 bbl of water per barrel of oil with no recycling; a 24-well pilot facility would require 0.29 cfs (132 GPM); and a large-scale production facility would require 18.5 cfs (8300 GPM).

These figures indicate that a single well in each of these geologic formations could probably support experimental or pilot facilities, while several wells would be required to support production facilities. Hood's (Reference 27) indication of large drawdowns in the Uinta and Duchesne Formations, however, indicates that well fields may not be feasible or would have to be carefully designed based on modeling studies.

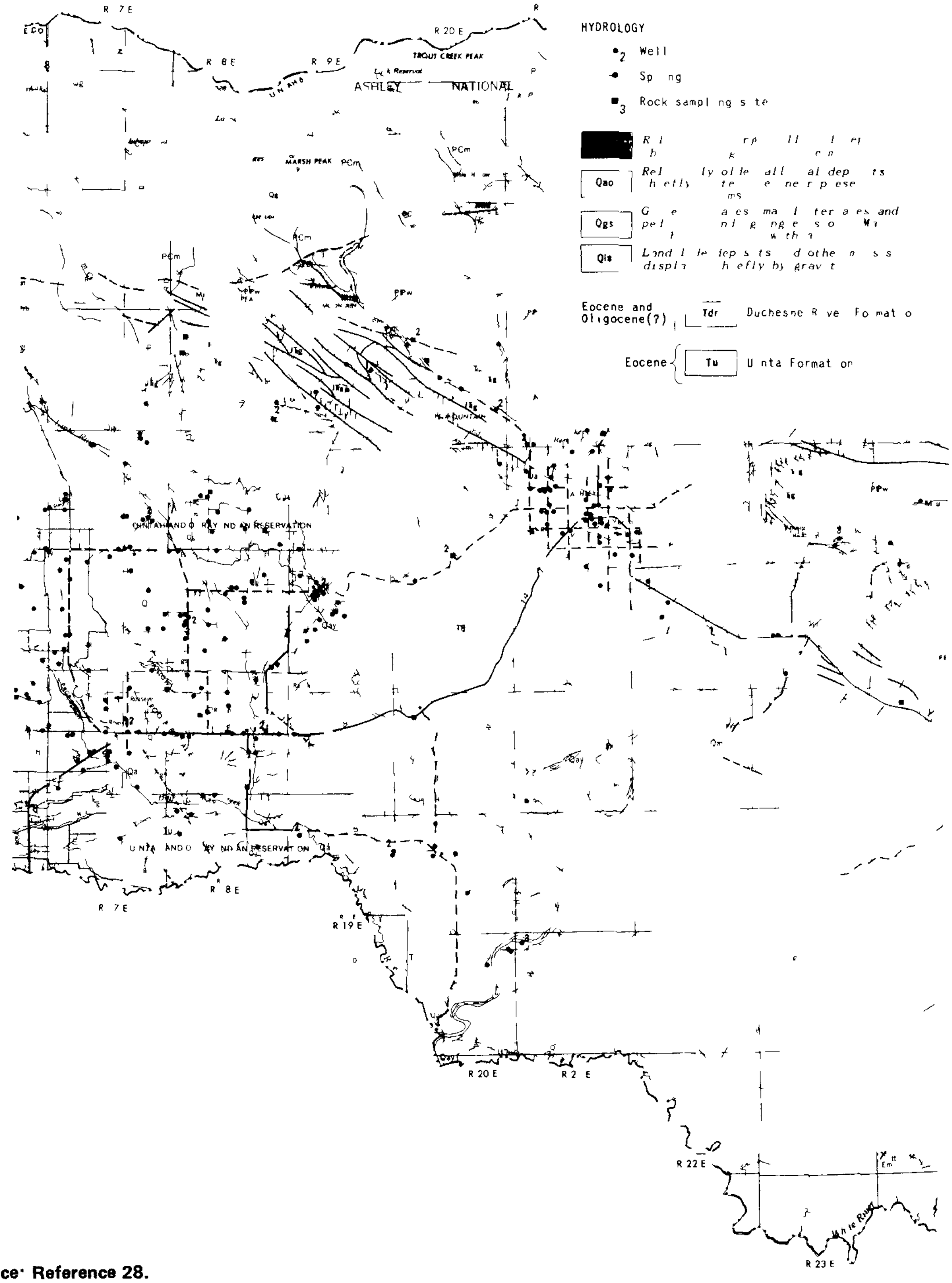
A great many wells have been drilled in the Quaternary alluvium. In the vicinity of Asphalt Ridge, such wells are mostly located in and around Vernal. Almost no wells have been drilled in the Duchesne River-Uinta Formations near Asphalt Ridge. Figure 32 is a geologic map taken from Reference 27 showing the locations of wells and springs in the vicinity of Asphalt Ridge. It shows that the area has a great many wells. Sufficient knowledge has been gained from these wells to allow accurate assessment of groundwater potential to the east of Asphalt Ridge.

The second report by Hood (Reference 28) investigates in detail the shallow groundwater in the Quaternary alluvium around Vernal in the Ashley Valley. Ashley Valley is unique in the northern Uinta Basin area in that it is a relatively isolated hydrologic unit. The small alluvial plain in the valley reaches from the mouth of Ashley Creek Canyon to the edge of the present Ashley Creek bottom land near U.S. Highway 40. The alluvial plain has an area of about 35,000 acres and is almost entirely surrounded by older rocks, mainly of the Cretaceous period. The aquifer underlying the plain consists of fine to very coarse unconsolidated deposits of boulders and other erosional debris believed to be mainly outwash of glacial origin. The deposits were laid down on a surface eroded mainly in the Mancos Shale of the Cretaceous period. The principal source of groundwater in the valley fill is infiltration of surface water; minor sources are infiltration of precipitation and subsurface inflow.

Groundwater recharge is closely related to the amount and duration of streamflow into Ashley Valley. During years and seasons of low streamflow, the recharge is small, and the converse is true during period of high streamflow. The main source of streamflow is Ashley Creek above Ashley Valley. Other streams tributary to Ashley Valley are intermittent and contribute only small quantities of water to the system. Prior to the development of the canal system in Ashley Valley, recharge occurred mainly along the channel of Ashley Creek where the creek enters the valley.

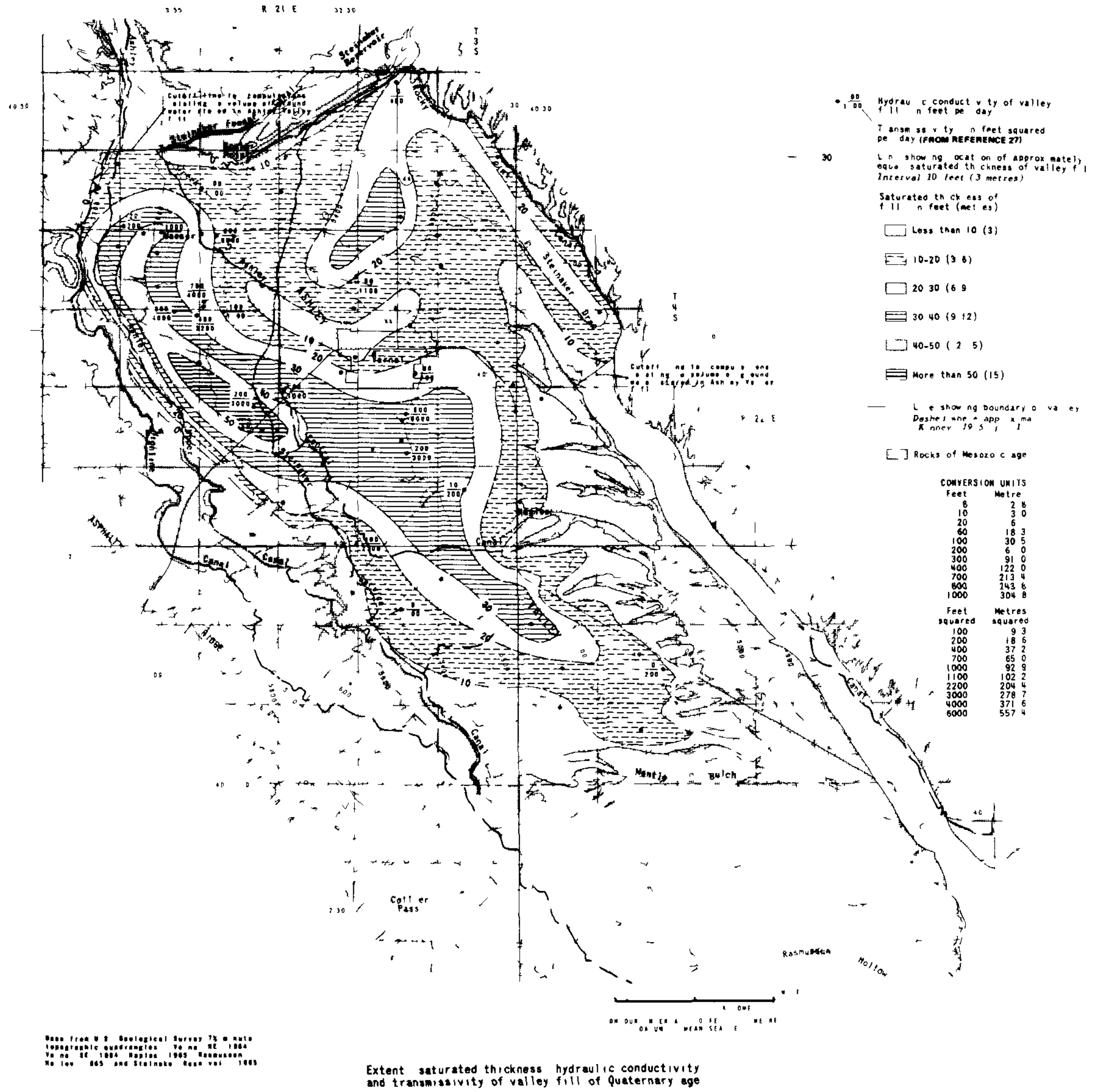
Saturated valley fill (Figure 33) underlies about 25,000 acres of the alluvial plain in Ashley Valley. The remainder of the 35,000 acres of the alluvial plain is an erosion surface on Mesozoic rocks, which has a thin cover of soil and alluvium generally less than 10 ft thick. This discontinuous veneer is not considered to be an effective part of the groundwater reservoir. An additional 1900 acres of saturated valley fill underlies the floodplain of Ashley Creek northwest of U.S. Highway 40 and below the edge of the alluvial plain.

The volume of saturated valley fill in Ashley Valley is about 500,000 acre-feet. The estimated specific yield, Sy, is in the range of 0.10 to 0.15. Thus, the volume of recover-



Source: Reference 28.

Figure 32. LOCATION OF SHALLOW WELLS IN VICINITY OF ASPHALT RIDGE



Source: Reference 28.

Figure 33. EXTENT, SATURATED THICKNESS, HYDRAULIC CONDUCTIVITY, AND TRANSMISSIVITY OF VALLEY FILL OF QUATERNARY AGE

able water in storage amounts to 50,000-75,000 acre-feet, or enough water to supply the irrigation needs for a maximum of 2 years under 1974 irrigation practices.

The calculated volume in storage is a net long-term average and varies seasonally by approximately 10 percent. Prior to the construction of Steinaker Reservoir, the change in storage from a dry year to a wet one was relatively large. Reservoir operation has reduced the long-term fluctuation in storage to some extent, as shown by reduction in long-term fluctuations in groundwater levels.

Figure 33 illustrates the extent and thickness of the alluvial aquifer to the east of Asphalt Ridge. Also illustrated are the many wells considered in Reference 28. Some of the greatest saturated thickness of the aquifer lies along Asphalt Ridge immediately west of Vernal. Hydraulic conductivity in the same area varies from a low of 20 to around 300, i.e., moderate to very high.

Table 26 (from Reference 27) describes some of the hydraulic properties of wells that lie along Asphalt Ridge in the area of greatest saturated thickness. All but one of these wells, (D-4-21) 29bbb-1, has sufficient yield to support an experimental facility. Three—(D-4-21) 16ccb-2, 17aaa-2, and 20dad-1—have sufficient yield for a 24-well pilot facility. Again, a production facility would require a carefully designed well field. A detailed modeling study would be required to avoid impact on agricultural and domestic users.

Quality of Shallow Groundwater

As with surface water, the quality of water quality information on groundwater varies widely. Most quality estimates are made on single samples at random times. Continuous records are virtually nonexistent. Almost no data exist on the quality of shallow groundwater to the west of Asphalt Ridge because there are virtually no wells in that area. Austin and Skogerboe (Reference 5) make brief mention of water quality in the Uinta Formation. This might also be assumed to apply to the Duchesne River Formation. According to Reference 5, the chemical quality of water in the Uinta Formation is determined principally by the lithology of the formation and local recharge conditions. In the central part of the Uinta Basin, the formation is composed predominantly of fine-grained lake deposits that contain large quantities of soluble salts; however, it yields fresh and slightly saline water where local precipitation or runoff from the Uinta Mountains recharges the formation. In the eastern part of the basin, where there is little precipitation, wells may yield fresh or slightly saline water from coarse-grained fluvial deposits that contain few soluble salts.

The quality of water in the alluvial aquifer near Vernal is well defined. Figure 34, taken from Reference 28, illustrates water quality from various shallow wells throughout the Ashley Valley. The shape and shading of areas in the figure indicate relative concentrations of major dissolved constituents. The water samples represented by the shaded areas were mainly fresh (less than 1000 mg per liter of dissolved solids; some were slightly saline (1000-3000 mg per liter); and one was moderately saline (3000-10,000 mg per liter).

Table 26. HYDRAULIC PROPERTIES OF SHALLOW WELLS NEAR ASPHALT RIDGE

Location[a]	Depth[b] (ft)	Casing Diameter (in)	Casing Depth[c] (ft)	Water bearing Material[d]	Thickness of Major Aquifer (ft)	• Length of Well Open (ft)	Well Finish[e]	Yield (GPM)	Pumping Period (hr)	Drawdown[g] (ft)	Specific Capacity[h] (GPM/ft)	Estimated	
												Transmis sivity,[i] T (ft²/day)	Hydraulic Conductivity,[j] K (ft/day)
14cdc 1	24 3	6	23	G	–	–	O	30	2	2 3	15 0	–	–
14cdd 1	100 3	6	17	5U	13	1	X	8	–	14 3	0 57	–	–
15dab 1	30 3	6	13	5R	23	17	P	25	–	4 3	6 25	1 100	60
16bba 2	37 3	5	28	R	–	8	P	30	1	1 3	30 0	6,000	800
16ccb 2	26 3	7	13	5G	6	13	P	100	15	6 3	16 7	4,000	700
17aaa 2	26 3	6	26	5R	12	–	O	60	3	2 3	30 0	–	–
17aab 1	30 3	6	27	G	–	3	X	30	2	4 3	7 5	–	–
17abb 1	52 3	6	44	R	44	6	P	30	–	1 3	30 0	6,000	1,000
20aaa 2	28 6	6	23	G	–	5	P	40	–	4 3	10 0	2,200	400
20aba 1	54 3	6	42	5R	–	12	P	16	1	1 3	16 0	4,000	300
20dad 1	55 3	7	55	G	10	–	O	60	7	5 3	12 0	–	–
21bab 1	30 3	7	20	B	–	10	P	45	–	8 3	5 63	1,100	100
22ada 1	3	6	21	G	–	–	O	30	2	2 3	15 0	–	–
22daa 1	27 3	7	22	G	11	–	O	7	2	4 3	1 75	–	–
23bcc 1	23 3	7	22	G	–	–	O	20	1	4 3	5 0	–	–
23cba 1	26 3	7	22	G	13	–	O	30	2	4 3	7 5	–	–
23cdb 1	25 3	7	25	G	–	–	O	60	4	4 3	15 0	–	–
23dbb 1	18 3	4	18	R	12	–	O	5	–	4 0	1 25	–	–
23dca 1	40 3	6	29	5R	35	11	P	16	2	5 3	3 20	700	60
23ddd 1	20 3	6	20	G	–	–	O	20	2	9 3	2 22	–	–
25ada 1	100 3	6	23	R	23	–	O	20	–	10 3	2 0	–	–
25acb 1	20 3	6	12	G	–	8	F	30	1	1 3	30.0	6,000	800
26dbc 1	58 3	6	28	G	33	12	P	30	2	2 3	15.0	3,000	200
27bbb 1	46 3	6	30	R	–	16	P	40	4	8 3	5 0	1,000	60
28abd 1	67 3	6	52	R	–	15	P	15	3	1 3	15 0	3,000	200
29bbb 1	60 3	7	45	G	15	15	X	6	3	10 3	0 60	–	–
34ddd 1	94 0	4	20	G	6	6	P	10	–	1 3	10 0	2,200	400
36bdb 1	50 3	6	30	G	30	20	P	10	2	8 3	1 25	200	10
(D-4 22)													
30bad 1	30 3	7	12	G	4	18	X	7	2	5 3	1 40	–	–
32bcc 2	22 3	6	22	G	11	–	O	50	5	4 3	12 5	–	–

[a] Location See text for description of numbering system D, well deepened

[b] Depth Code (follows figure for depth), O, measured to nearest foot or less, 1, measured to nearest foot or more 3, reported by driller, 6, reported by source other than driller

[c] Casing depth Depth to bottom of blank casing or top of first perforated interval

[d] Water-bearing material B, unclassified sedimentary rock, C, conglomerate, F, shale, FO, iron-stained fine-grained metamorphic rock, G, gravel, JF, jointed or fractured shale L, limestone, P clay, R, sand and gravel, S, sand, SV, soft sandstone, V, sandstone, XV, crossbedded sandstone, OL, cavernous limestone 3G, medium gravel, 3S, medium sand 3V, medium-grained sandstone, 4C, coarse-grained conglomerate, 4G, coarse gravel, 4R, coarse sand and gravel, 5G, very coarse gravel, 5R, very coarse-grained sand and gravel (includes beds of pebbles, cobbles, and boulders) 6R, clayey sand and gravel, 5U, very coarse-grained unconsolidated sediments, 6S, clayey sand, 7Q, silt 7V silty sandstone, 8F, sandy shale 8L, sandy limestone, 8P, sandy clay

[e] Well finish F, perforated casing with gravel pack G, commercial well screen with gravel pack, O, open end P, perforated W, shored (dug) X, open hole

[f] Pumping period A, 15 minutes or less, B, 15-30 minutes

[g] Drawdown Where shown as 1 foot, most figures are estimated from indication of lesser amount Code (follows figure for drawdown), O, measured to nearest foot or less 1, measured to nearest foot or more, 2, air line measurement, 3, reported by driller, 5, estimated from inaccurate measurement, 6, reported by source other than driller

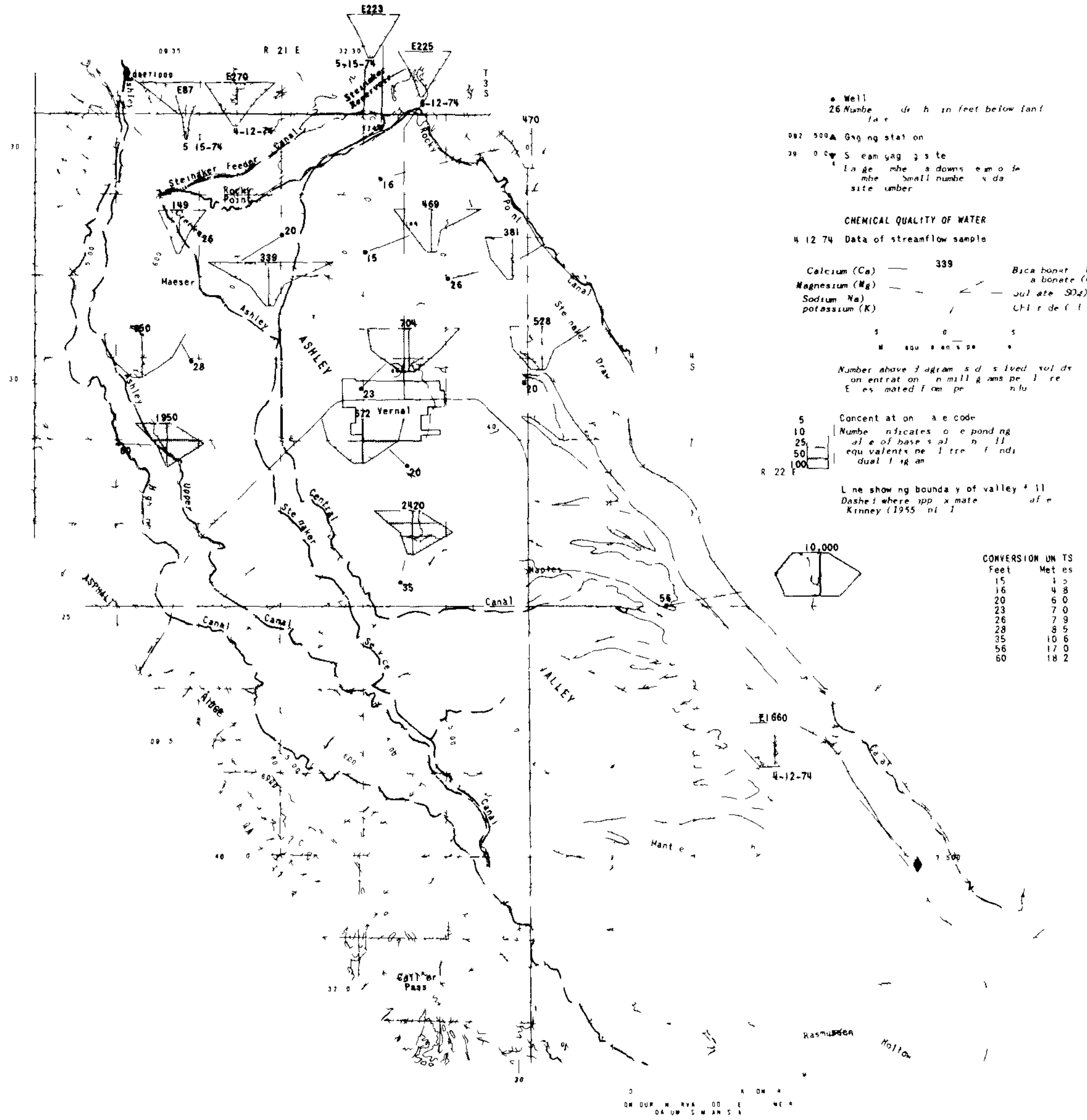
[h] Specific capacity Calculated from yield and drawdown

[i] Estimated transmissivity (T) Estimated by method of Theis, Brown, and Meyer (in Bentall, 1963)

[j] Estimated hydraulic conductivity (K) Calculated by dividing T by either length of well open to aquifer or by thickness of major aquifer

NOTE Individual values of transmissivity that were estimated from values for specific capacity are, at best, approximations Because individual values for hydraulic conductivity are calculated from the estimates for T, those individual values for K also are approximations The principal value of T and K values listed in this table lies in their indication of relative permeability and areas of consistent aquifer characteristics

Source Reference 27



Source: Reference 28.

Figure 34. QUALITY OF WATER IN WELLS IN ALLUVIAL AQUIFERS NEAR ASPHALT RIDGE

The chemical quality of groundwater in Ashley Valley is indicated in Figure 34 by diagrams that represent water from 12 wells, 11 of which discharge water from the valley fill. The driller's log for the twelfth well indicates the formation penetrated may be valley fill, but the well's position in the valley indicates that it probably is finished in rocks of Mesozoic age.

The chemical quality of groundwater in the valley depends on the position of the well with respect to the recharge area, the depth to which the valley fill is penetrated, and the lithologic character of the aquifer. Thus, the lowest concentration of dissolved solids in groundwater in the valley is found where the coarse-grained fill is near the source of recharge. From the area of this well, the dissolved-solids concentration increases toward the south and east.

In the northern part of the valley, the water type changes from calcium bicarbonate to calcium magnesium bicarbonate as the water moves toward Ashley Creek. In this area, the deeper valley fill yields water with a lower concentration of dissolved solids. For this reason, it is believed that most of the increase in dissolved solids occurs in the valley fill near the surface and represents mainly the effects of evapotranspiration and leaching of solids in irrigated fields.

The diagrams in Figure 34 for well water from the southern part of the valley show that magnesium and sulfate concentrations increase as the dissolved-solids concentration increases. The increase in sulfate, in particular, may be due to inflow of groundwater from rocks of Mesozoic age, but it is more probably that most of the gain in sulfate is due to leaching of valley fill that contains debris from the Mesozoic rocks.

U.S. Public Health Service water quality standards recommend 500 mg per liter maximum beneath the Duchesne River and Uinta Formations. Most of the information on these deep aquifers has come from oil and gas exploration.

The following section will consider the groundwater from the deeper aquifers that lie beneath the Duchesne River and Uinta Formations. Most of the information on these deep aquifers has come from oil and gas exploration.

Groundwater from Deep Aquifers

The best documentation on water from the deeper aquifers in the vicinity of Asphalt Ridge is found in Reference 3 by Feltis and Reference 29 by Goode and Feltis. Reference 3 gives a general description of the deep aquifers throughout northeast Utah along with considerable data on wells. Reference 29 concentrates specifically on the oil fields to the south and west of Vernal. Most of the following material is abstracted from these two references.

Before discussing water production directly, an examination of the subsurface geology in the vicinity of Asphalt Ridge will be useful. Figure 35 taken from Reference 3 is a geologic section running approximately north-south through Asphalt Ridge in the vicinity of Vernal. The location of the section is shown in Figure 36, also from Reference 3. Information on the section is derived from oil and gas exploration. The approximate location of the southeast end of Asphalt Ridge is identified in Figure 35.

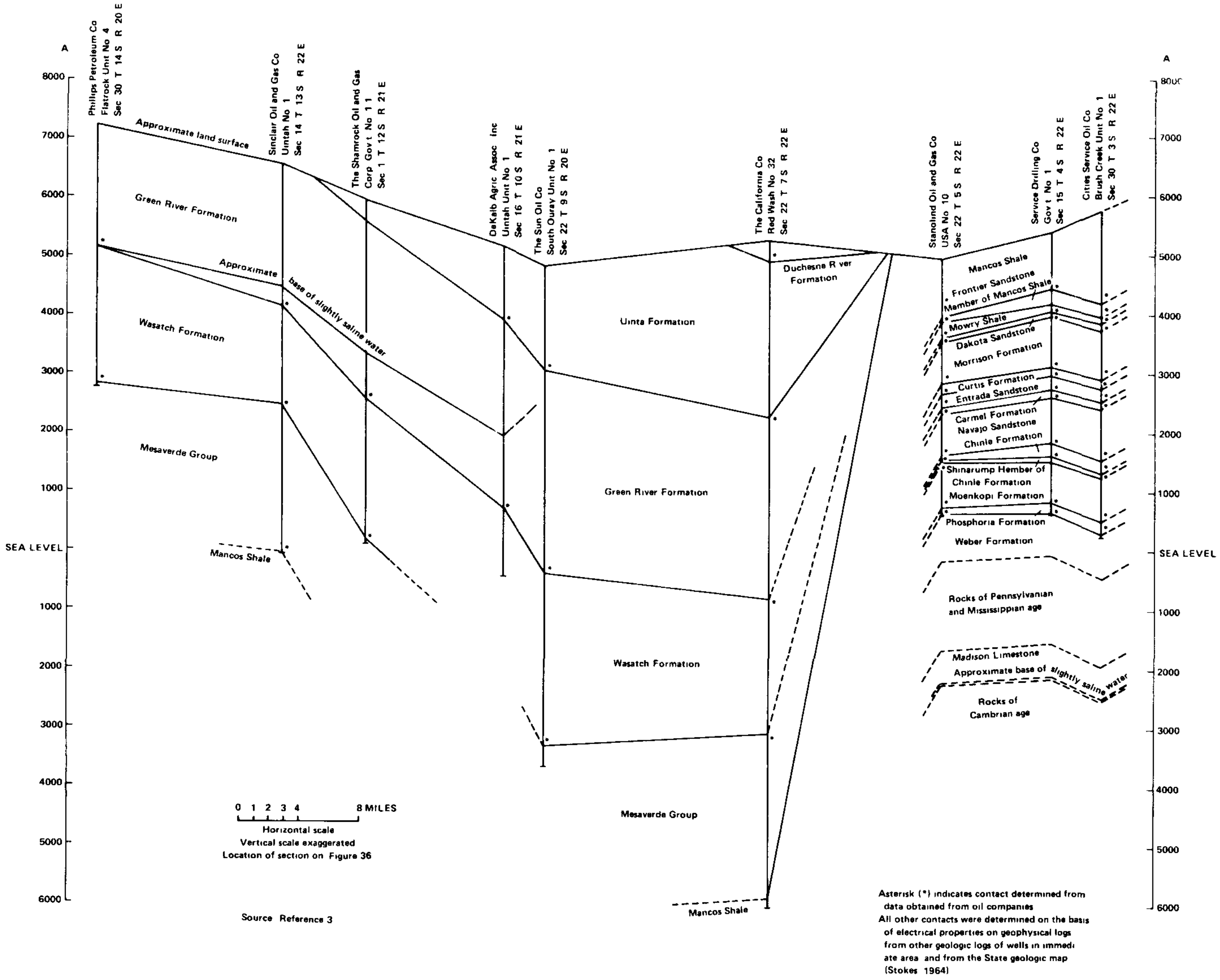
The geologic section (Figure 35) indicates the structural complexity in the vicinity of Asphalt Ridge. The formations that underlie the Quaternary glacial-fill aquifer to the northeast of the ridge are considerably older than the formations to the southwest of the ridge. The southwest facing in back of Asphalt Ridge is primarily of the Tertiary period; the ridge itself is apparently Upper Cretaceous in age; and the underlying formations beneath Vernal are Lower Cretaceous. Two prominent geologic formations—the Green River and Wasatch Formations of the Tertiary period—do not outcrop along Asphalt Ridge. These formations would logically appear as outcrops between the Uinta Formation and Asphalt Ridge, which is an outcrop of the Mesaverde Formation. The formations in the vicinity of Asphalt Ridge dip very steeply to the southwest, making interpretations of the subsurface geology difficult.

Feltis (Reference 3) discusses, in general, the water-bearing properties of the various formations shown in Figure 5. Only those that appear to be viable aquifers will be discussed here. They are the Weber Sandstone, Park City, Frontier Sandstone, Mesaverda Group, Wasatch, Green River, and Uinta and Duchesne Formations. The latter two were discussed previously as the primary surface formation to the southwest of Asphalt Ridge.

The formations that lie to the southwest of Asphalt Ridge will be discussed first. Only four major formations make up the bedrock from the surface to a depth of 12,000 ft (-6000 ft MSL). These four formations are the Uinta, Green River, Wastach, and Mesaverde Group (Figure 35).

Feltis (Reference 3) reports that the Uinta Formation yields water that ranges in chemical quality from fresh to briny. In T. 7 S., Rs. 22 and 24 E., two oil wells yielded water containing 2365 and 898 ppm of dissolved solids, the latter at a rate of 3600 BPD (110 GPM). Two oil wells in T. 9 S., R. 23 E., and T. 4 S., R. 5 W. [Uinta Special Meridian (USM)], yielded water containing 81,200 and 22,914 ppm of dissolved solids, the latter at a rate of 1000 BPD (30 GPM). A spring in the Uinta Formation in T. 1 S., R. 8 W. (USM) yielded water containing 237 ppm of dissolved solids at a rate of 1700 BPD (50 GPM). Three springs in T. 4 S., R. 7 W. (USM) and T. 5 S., Rs. 6 and 7 W. (USM) yielded water containing 7320, 1840, and 2710 ppm of dissolved solids at rates of 680, 6800, and 7800 BPD (20, 200, and 225 GPM).

Water from three water wells in T. 2 S., R. 5 W. (USM) and T. 3 S., Rs. 3 and 8 W. (USM) contained 439, 788, and 4430 ppm of dissolved solids and the well in T. 3 S., R. 3 W. yielded 680 BPD (20 GPM).

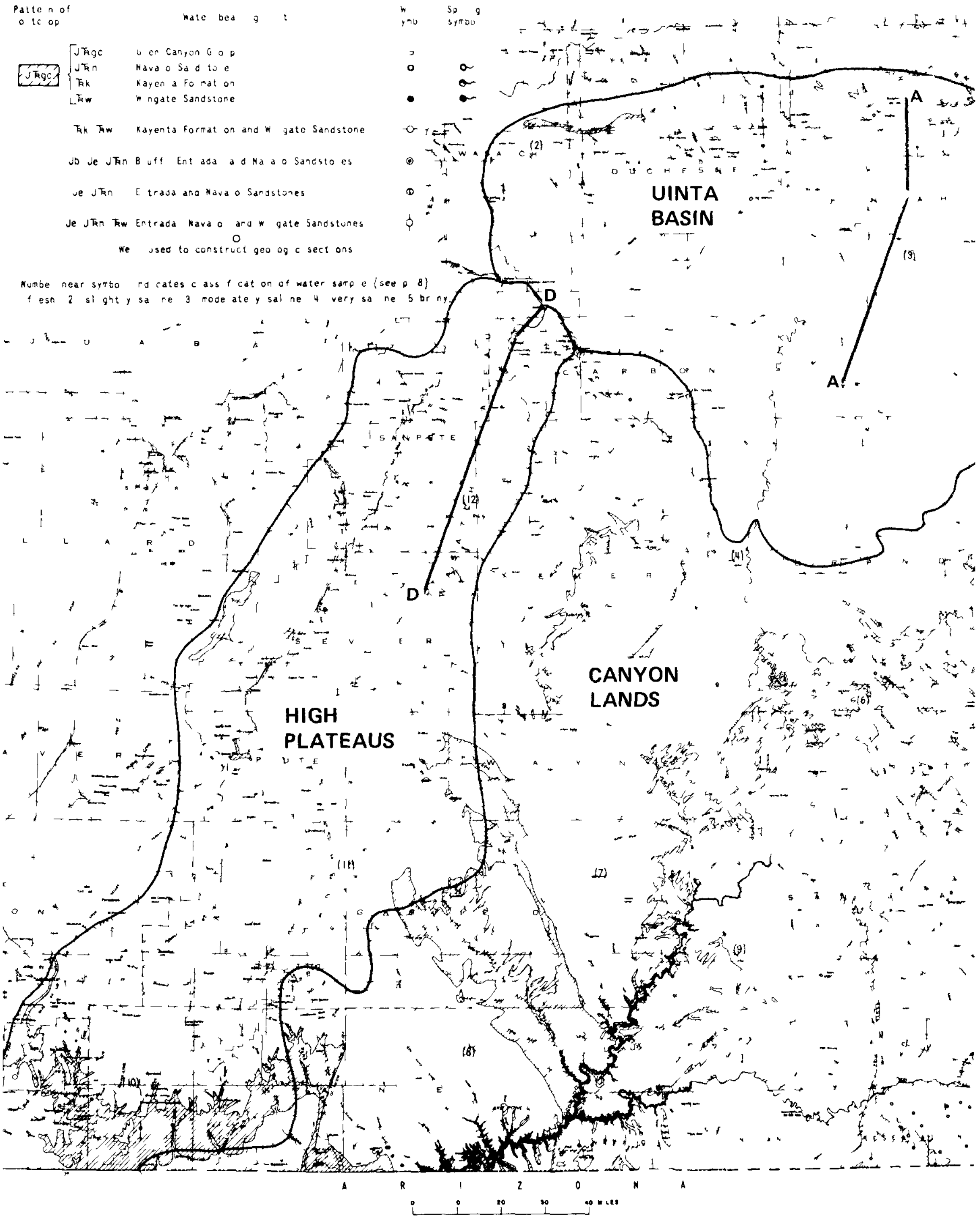


Horizontal scale
Vertical scale exaggerated
Location of section on Figure 36

Source Reference 3

Asterisk (*) indicates contact determined from data obtained from oil companies
All other contacts were determined on the basis of electrical properties on geophysical logs from other geologic logs of wells in immediate area and from the State geologic map (Stokes 1964)

Figure 35. GEOLOGIC CROSS-SECTION A-A' OF THE UINTA BASIN SECTION NEAR VERNAL



Source Reference 3

Figure 36. LOCATION OF GEOLOGIC SECTION THROUGH ASPHALT RIDGE NEAR VERNAL

Little is actually known about the water-bearing properties of the Green River Formation in the immediate vicinity of Asphalt Ridge. Fresh water has been obtained from an oil well in T. 2 N., R. 2 W. (USM). Water from that well contained only 348 ppm of dissolved solids from a depth of 4115 ft. The Green River does not crop out in the central part of the north flank of the Uinta River Basin; therefore, the aquifer in T. 2 N., R. 2 W. (USM) is probably recharged by interformational leakage. Electrical logs from oil wells show the occurrence of fresh and saline water in the Green River in the southeastern and northern parts of the Uinta Basin.

The yield of water from the Green River Formation, as indicated by tests at 17 oil and gas wells, ranges from 17 to 7000 BPD (0.5 to 200 GPM). Two gas wells in Sec. 35, T. 10 S., R. 20 E. and Sec. 17, T. 10 S., R. 22 E. were converted to water wells; in 1964 they flowed at rates of 2700 and 340 BDP (80 and 10 GPM). The largest reported yield of water from the Green River Formation is from an oil well in T. 9 S., R. 24 E. that produced 7200 BPD (220 GPM) from a depth of 1932 ft.

Reference 3 concludes that on the south flank of the Uinta Basin, the Green River Formation is a potential source of fresh or slightly saline water that could be used in the process of oil extraction from bituminous sand and oil shale. A 6000-ft deep well would be required to reach the bottom of the formation near Asphalt Ridge.

Data on the Wasatch Formation in the vicinity of Asphalt Ridge is sketchy at best. Most of the existing knowledge is from outcrops further south and east.

Water from Bedrock

Chemical analyses of 11 water samples collected from the Wasatch Formation in seven oil and gas wells indicate that two of the samples are slightly saline and the other nine range from moderately saline to briny. One of the samples of slightly saline water was obtained from a well in T. 15 S., R. 21 E. The water contained 1966 ppm of dissolved solids, and the aquifer probably is being recharged in the area of relatively high precipitation north of the Roan Cliffs. The other sample of slightly saline water was obtained from a well in T. 1 N., R. 1 E. (USM); it contained 1302 ppm of dissolved solids, and the aquifer probably is being recharged in the subsurface by interformational leakage along the south flank of the Uinta Mountains rather than by direct infiltration in the area of outcrop. Yield data are not available for the seven oil and gas wells. A spring in T. 16 S., R. 17 E. yielded fresh water having 596 ppm of dissolved solids while flowing at a rate of 7650 BPD (225 GPM) in September 1948. Additional smaller springs probably discharge from the Wasatch along the escarpment of the Roan Cliffs. A well 8000 ft deep would be required to penetrate the Wasatch.

Information on the Mesaverde Group is also sketchy. Six chemical analyses of water from four oil wells in the Mesaverde Group show a range of 12,511 to 62,502 ppm of dissolved solids. The wells were in T.9 S., R. 23 E.; T. 10 S., R. 24 E. (two wells); and T. 12 S., R. 14 E.; the reported yield of water from one of the wells in T. 10 S., R. 24 E., was 38 BPD (1 GPM). All three in the Mesaverde Group–one in T. 17 S., R. 17 E. and two in T. 20 S., R. 20 E.–yield water containing 707, 660, and 1090 ppm of dissolved solids, respectively.

Northeast of Asphalt Ridge, immediately below the glacial alluvium, are formations that would require wells 12,000 ft deep to reach water on the southwest side of the ridge. Uppermost of these is the Mancos Shale. Feltis (Reference 3) reports that most of this formation is an unlikely source of fresh water.

Two springs in the Frontier Sandstone member [T. 1 S., R. 8 W. (USM) and T. 4 S., R. 23 E.] each yield about 1 GPM of water containing 786 and 2620 ppm of dissolved solids. The electrical logs of oil wells used in constructing Figure 35 indicate fresh to slightly saline water in the Frontier Sandstone Member.

Reference 3 does not mention any fresh water in the next four formations below the Frontier Sandstone member.

Chemical anlayses are available for water from the Entrada Sandstone on the north flank of the Uinta Basin from a spring in T. 4.S., R. 23 E., and from two oil wells in T. 5 S., R. 22 E., and on the south flank from four gas tests in Tps. 15, 15½, and 17 S., Rs. 22, 23, and 24 E. The spring water is fresh, and the two oil wells yielded water containing 479 and 1165 ppm of dissolved solids at rates of 664 and 375 BPD (19 and 11 GPM). Also on the north flank of the basin, electrical logs of oil wells used in constructing Figure 35 indicate fresh or slightly saline water in the Entrade Sandstone. On the south flank of the basin, water from the Entrada Sandstone is described as salty or briny.

The next water-bearing formation down is the Navajo Sandstone. Reference 3 reports that few wells produce water from the Navajo Sandstone in the Uinta Basin although an aquifer that probably contains fresh or slightly saline water exists along the north flank of the basin. Along that flank, most oil tests that penetrate the Navajo are reported to obtain potable water or water suitable for irrigation. An oil well in Sec. 12, T. 4 S., R. 20 E. had an artesian flow of approximately 2000 BPD (60 GPM) of potable water from the Navajo Sandstone in 1950; however, by 1958 the flow had declined to about 850 BPD (25 GPM). Water from a well in the Navajo Sandstone in T. 4 S., R. 21 E. contained 1894 ppm of dissolved solids, but no yield data on it are available. Two springs in T. 1 N., R. 7 W. (USM) and T. 4 S., R. 23 E. yield water containing 148 and 342 ppm of dissolved solids at estimated rates of 1400 and 70 BPD (40 and 2 GPM). The Navajo Sandstone lies 3500 to 4000 ft below the land surface near Vernal.

No water is reported in the Chinle or Moenkopi Formations. Water from the Phosphoria Formation is produced from oil wells in the Ashley Valley oil field. Reportedly this water originates from the Weber Sandstone, which lies beneath the Phosphoria Formation.

The water from oil wells, abandoned oil wells converted to water wells, and springs in the Weber Sandstone contains dissolved-solids concentrations ranging from about 400 to 2600 ppm. The water in the Weber Sandstone comes from recharge to areas of outcrop in Split Mountain and along the south flank of the Uinta Mountains.

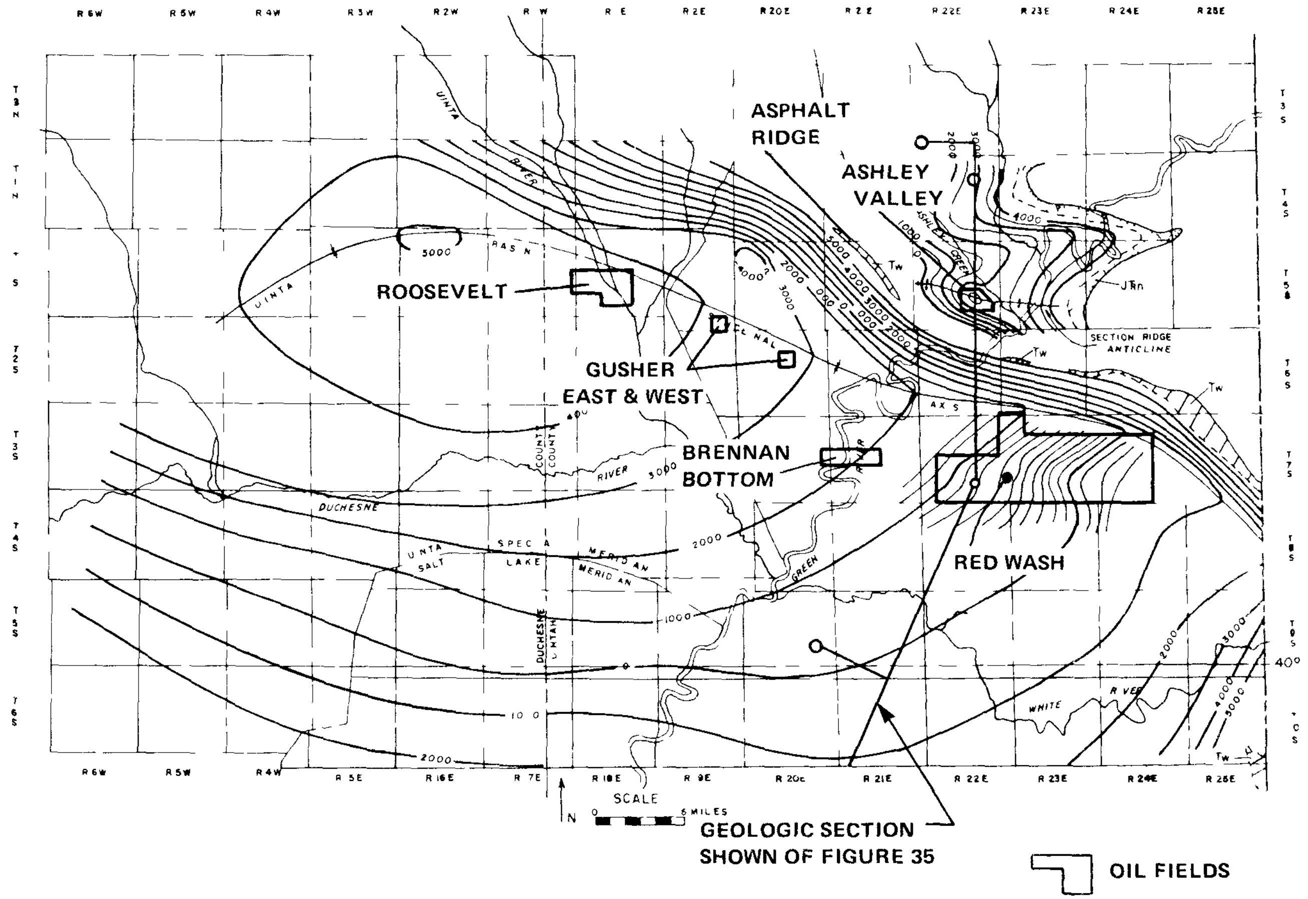
Oil wells in the Ashley Valley oil field produce water from the Weber Sandstone, but some of the water possibly comes from limestone of Pennsylvanian and Mississippian ages that underlies the Weber Sandstone (Reference 29). Normal faults in the oil field could possibly form conduits between the underlying limestones and the Weber Sandstone. Some of the wells in the Ashley Valley oil field are open to both the Weber Sandstone and the overlying Phosphoria Formation, and the concentration of dissolved solids in water from these wells ranges from about 500 to 2600 ppm. During 1964, the 28 oil wells in Ashley Valley oil field produced about 36.5 million bbl of water. Some of the high-volume pumps produce more than 9000 BPD (270 GPM).

According to Reference 3, the Weber Sandstone should be considered as a potential freshwater aquifer all along the northern edge of the basin.

Immediately below the Weber Sandstone are the Madison Limestone and Morgan Formations. Water from warm springs issuing near the top of the Madison Limestone, or possibly at the base of the Morgan Formation in T. 4 S., R. 24 E., flows into the Green River about 2 mi above the mouth of the canyon at Split Mountain. The dissolved-solids content of the water is 942 ppm. In September 1948, the discharge of the springs above river level was estimated to be 6 cfs (2700 GPM or 1500 BPD) and an equal amount or more was believed to discharge directly into the river. The source of water for the springs is probably from the south flank of the Uinta Mountains where the Madison and Morgan Formations crop out. These formations could also be a partial source of the water produced in the Ashley Valley oil field. The Morgan Formation, Madison Limestone, and other limestones of Mississippian age crop out over a wide area along the south flank of the Uinta Mountains, and they all should be considered potential freshwater aquifers along the north edge of the basin. A well approximately 8000 ft deep would be required to penetrate the formation near Vernal.

Reference 29 describes in greater detail the water availability from the formation to the northeast of Asphalt Ridge. It also presents more detail on the subsurface geology in the vicinity of Asphalt Ridge.

Figure 37 taken from Reference 29 gives a detailed look at the structure of the central part of the Uinta Basin. The major oil fields that produce water in the area are indicated. Reference 29 describes the Uinta Basin as an asymmetric downwarped intermountain syncline whose axis is concave southward and generally parallel to the eastward-trending Uinta Mountains to the north. Beds that form the north flank of the syncline dip steeply southward away from the flanks of the Uinta Mountains; beds that form the south flank dip only 1 to 3 deg northward toward the axis of the syncline. In detail this broad synclinal structure



Source: Reference 29.

Figure 37. STRUCTURE MAP OF THE CENTRAL PART OF THE UINTA BASIN

is complicated by local anticlines near and on both sides of the axis. The oil and gas of the principal oil fields (Ashley Valley, Red Wash, and Roosevelt) trapped in these small anticlines. The structure map (Figure 37) shows the configuration of the central part of the Uinta Basin.

The Ashley Valley field is on a 300-ft structural closure on the axis of the westward-plunging Section Ridge Anticline. Oil is produced from the Paleozoic Weber Sandstone and Phosphoria Formationfrom a depth of about 4200 ft.

The Red Wash field is on a gentle northwest-to-west-plunging anticline that is south of and parallel to the axis of the Uinta Basin. Oil production is principally from the Douglas Creek and Garden Gulch Members of the Green River Formation, from depths of 5000 to 6000 ft. The Roosevelt field is on another gentle westward-plunging anticline south of and parallel to the trend of the basin axis. This field is about 10 mi east of the deepest part of the basin. Wells penetrating oil shale in the basal part of the Green River Formationproduce oil from a depth of about 9300 ft. An extensive fracture system provides a reservoir.

Ashley Valley field produces 90 percent of all the water that comes from oil fields in the Uinta Basin. Water yield has increased from nothing in 1948 to 2400 acre-feet in 1960. Yield from individual wells reaches as high as 380 acre-feet per year.

The Weber Sandstone is the principal oil-producing formation in the Ashley Valley field. Extensive fracturing in both the sandstone and the overlying Phosphoria Formation extends the reservoir into the upper formation.

The hydrostatic pressure of the water-drive in the field is sufficient to maintain flowing wells, but pumps were installed on some wells in 1959 and 1960 to increase oil production. The effects of the pumps on water production are not presently known. The strong water drive is probably sustained by surface recharge in outcrop areas north and east of the field.

The water in the Ashley Valley field has a dissolved-solids content ranging from about 500 to 2000 ppm. The water is principally a calcium-sodium-sulfate type, having bicaronate as an additional important constituent. A high sodium content causes much of the water from the Ashley Valley field to be classified as permissible to doubtful for irrigation use. Unless compensated for by gypsum in the soil or in the water, high sodium content in irrigation water causes clayey soils to deflocculate and to become hard and impermeable (Reference 29).

Water obtained from the Roosevelt field is probably most indicative of what might be found to the west of Asphalt Ridge. The indications are not promising. The entire field produced about 20 acre-feet of water in 1960. This was 0.7 percent of the total water production by oil wells in the Uinta Basin. Water produced in the field ranges from moderately saline to saline.

Sutron obtained several recent well records from the Utah State Oil and Gas Conservation Commission in order to investigate deep groundwater in areas outside the defined oil field. These data tended to confirm the observations that have already been presented. That is, wells to the northeast of Asphalt Ridge can penetrate several freshwater aquifers at fairly shallow depths, while those to the southwest will have to go much deeper and will probably find saline water or no water at all. For instance, Maeser Federal #1 well in T. 4 S., R. 20 E. produced 3000 BPD of fresh water from the Nugget Sandstone. An undetermined yield of saline water was found in the Weber Sandstone. Immediately south of the Maeser well across Asphalt Ridge in T. 5 S., R. 21 E., Western Ventures encountered only small amounts of sulphur water at 900 ft in the Uinta Formation. The two wells are within 5 mi of one another.

Groundwater Availability for Tar Sands Development

Some general conclusions can now be made concerning the use of deep groundwater for tar sands development. First, if wells must be drilled for that purpose, or even if rights could be obtained to existing wells, there is little reason to look to the southwest of Asphalt Ridge. All indications are that the only available water would be in the lower part of the Green River Formation and would probably be saline. Wells of 4000 to 6000 ft would be required. To the northeast of Asphalt Ridge fresh water can be found in several of the sandstone formations, particularly the Weber and Navajo. Wells of 4000 ft will penetrate the Navajo and 6000 ft will reach the Weber.

In Reference 29, Goode and Feltis tabulate a number of oil and gas wells that were ultimately completed as water wells. A portion of this tabulation is given in Table 27. All of the wells cited in the table lie within 5 mi of the north end of Asphalt Ridge. In terms of quantity, a single water well in either the Navajo or Weber Sandstone would support a five-well experimental facility for testing in situ recovery techniques (35.5 acre-feet per year required based on 5 bbl of water per barrel of oil). A single water well in the Weber sandstone would support a 24-well tar sands facility (213 acre-feet per year based on 5 bbl of water per barrel of oil). Sizable well fields would be required to support production-scale facilities in either formation (13,400 acre-feet per year required based on 5 bbl of water per barrel of oil). In any case, a modeling study would be recommended to avoid impacting existing wells or overdrawing a new one. The comparisons do not take into account possible recycling, which could significantly reduce requirements. Based on available data, it appears that water obtained from either formation would be fresh to slightly saline.

Table 27. OIL TEST WELLS COMPLETED AS WATER WELLS

Location	Well No.	Producing Formation	Depth of Producing Interval (ft)	Depth of Well (ft)	Production (BPD)
NE¼NW¼SE¼ 28 3S 21E	1	Weber Sandstone	–	2,552	10,000
SE¼SE¼SW¼ 30 3S 21E	2	Weber Sandstone	1,100 - 1,200	–	6,900
NE¼NW¼NE¼ 12 4S 20E	1	Navajo Sandstone	84 - 590	590	2,000
NW¼NW¼NE¼ 12 4S 20E	1-A	Navajo Sandstone	95 - 1,200	2,314 plugged back to 1,200	2,000
NE¼ lot 3 1 6S 23E	1	Weber (?) Sandstone	2,447 - 2,650	2,650	34,000

Source: Reference 29.

V. WATER RESOURCES NEAR HILL CREEK

This section considers in detail the water resources in the vicinity of the Hill Creek deposit. First, the available precipitation and surface runoff are considered. Water budgets are presented for the basins upstream of existing stream gages. Then, the availability of groundwater is investigated.

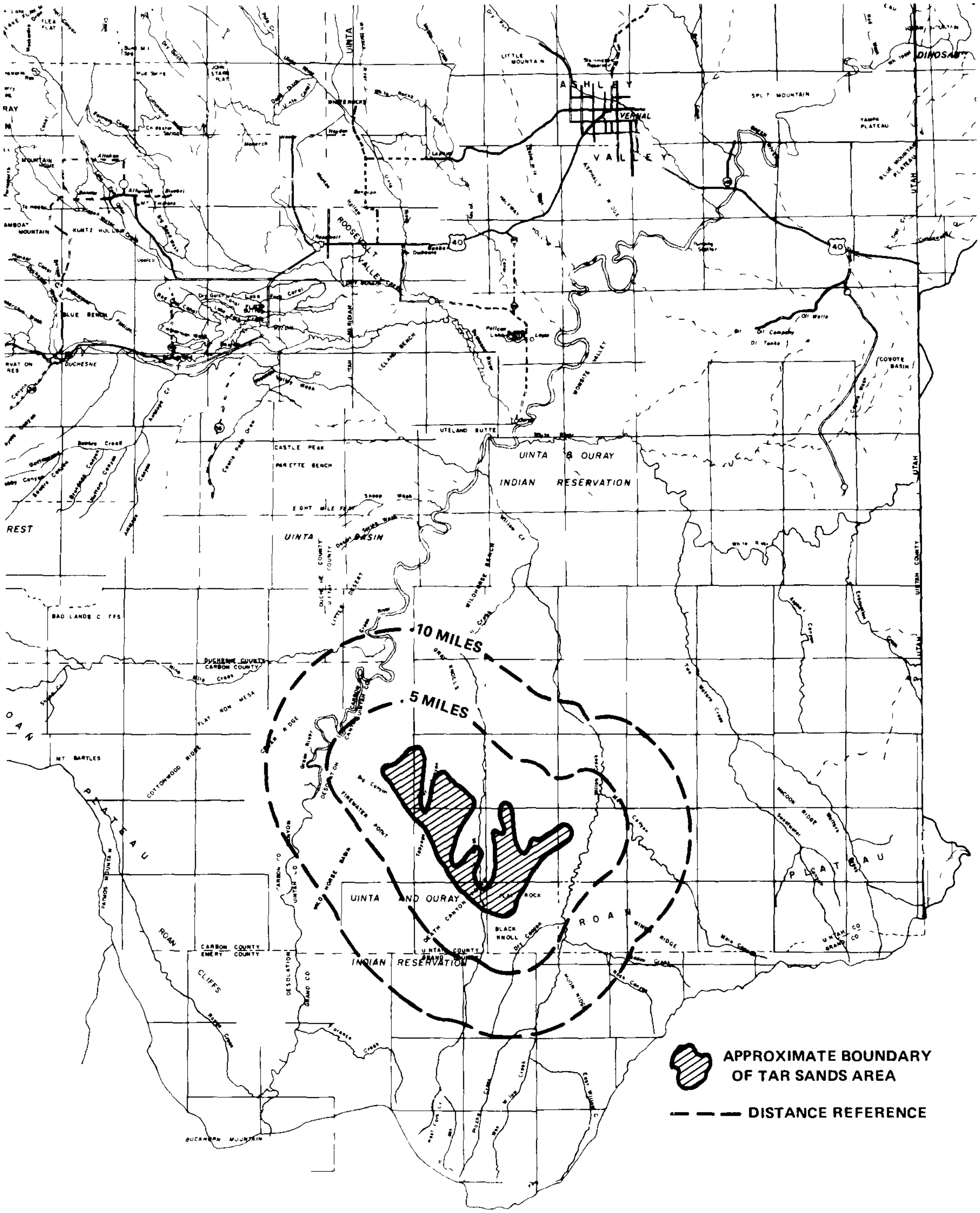
SURFACE WATER

It was noted earlier that the Hill Creek tar sands deposit lies within the south-central portion of the Uinta hydrologic basin. Considerable information is available on the distribution of precipitation and surface runoff within the basin. Two reports contain most of the relevant data: Reference 5 by Austin and Skogerboe and Reference 30 by Price and Miller. Considerable basic data are available in Reference 22 by Hood, Mundorff, and Price. References 5 and 30 contain fairly detailed hydrologic analyses and form the basis for this section of the report.

There are no major cities or towns near the Hill Creek deposit. The general vicinity of the deposit is illustrated in Figure 38, which also shows 5- and 10-mi distance reference line. These reference lines given some indication of distances water might have to be transported from streams

Only two creeks of any significance lie within 10 mi of the deposit areas, Hill Creek and Willow Creek. A number of smaller tributary creeks originate above the tar sands deposit These smaller creeks include

- Main Canyon.
- Meadow,
- Rock Canyon,
- East Willow,
- West Willow,
- Pioche Canyon,
- Dry Canyon, and
- West Fork.



Source: Reference 5.

Figure 38. HILL CREEK TAR SANDS AREA

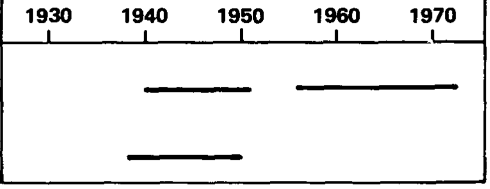
The Green River is within 10 mi of the deposit. The White River is also nearby. The resources of the White River are discussed along with the water supply for P. R. Spring.

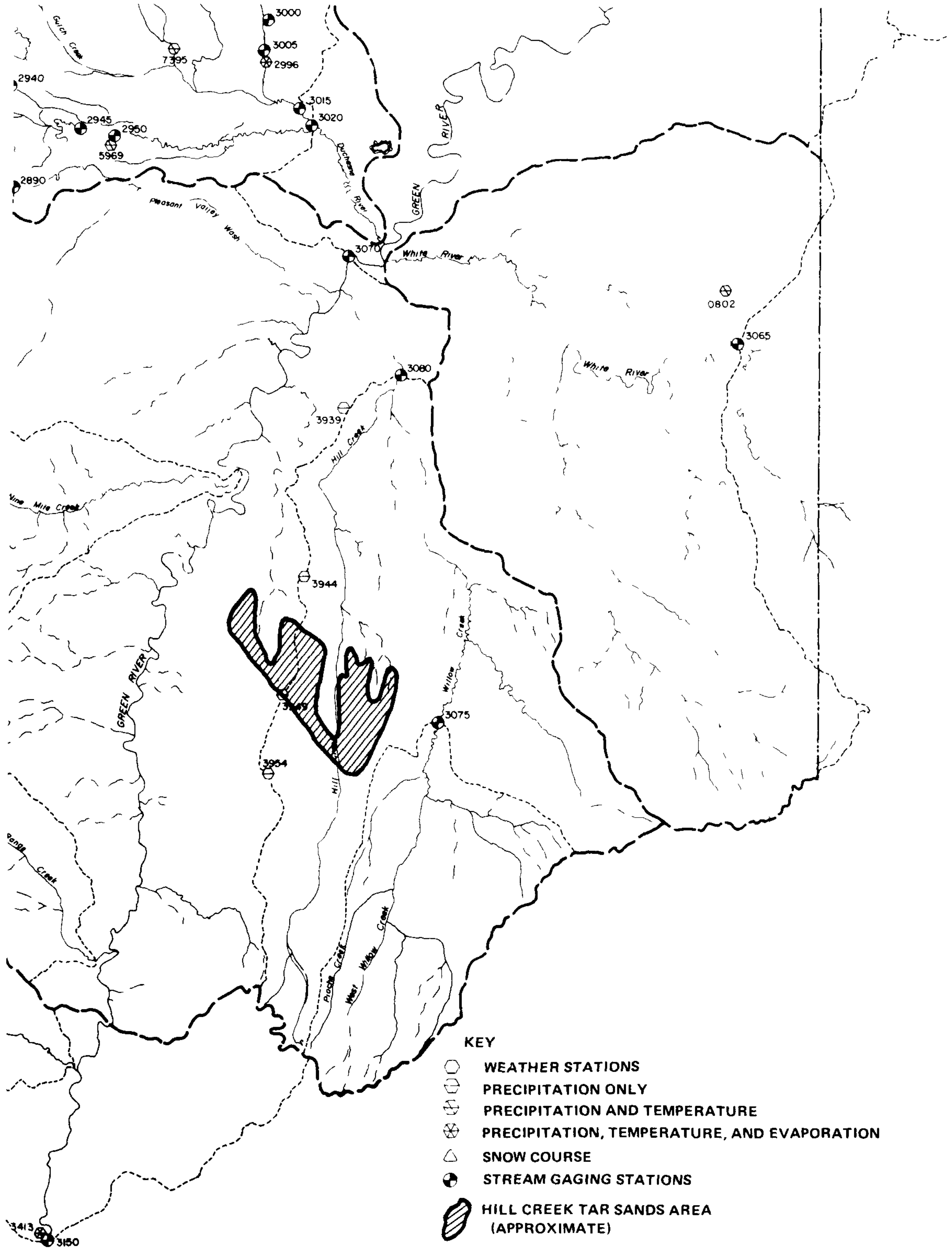
A number of meteorologic and stream gaging stations are maintained in the vicinity of the Hill Creek deposit. These are illustrated in Figure 39. The stations that are important in terms of identifying the water resources for the Hill Creek deposit are listed in Table 28.

Table 28. HYDROLOGIC AND METEOROLOGIC STATIONS IN THE VICINITY OF THE HILL CREEK TAR SANDS DEPOSIT

Station Number	Station Name
	Stream Gaging Stations
9-3075	Willow Creek above diversions near Ouray
9-3080	Willow Creek near Ouray
	Weather Stations
9-3939	Hill Creek No. 1
9-3944	Hill Creek No. 2
9-3949	Hill Creek No. 3
9-3954	Hill Creek No. 4

Length of record is an important consideration in hydrologic monitoring. Twenty to 30 years of record is highly desirable for making projections of trends and computing averages and standard deviations. The length of record for the stream gages in Table 28 are as follows:

Station Number	Station Name	1930 1940 1950 1960 1970
9-3075	Willow Cr. above diversions near Ouray	
9-3080	Willow Cr. near Ouray	

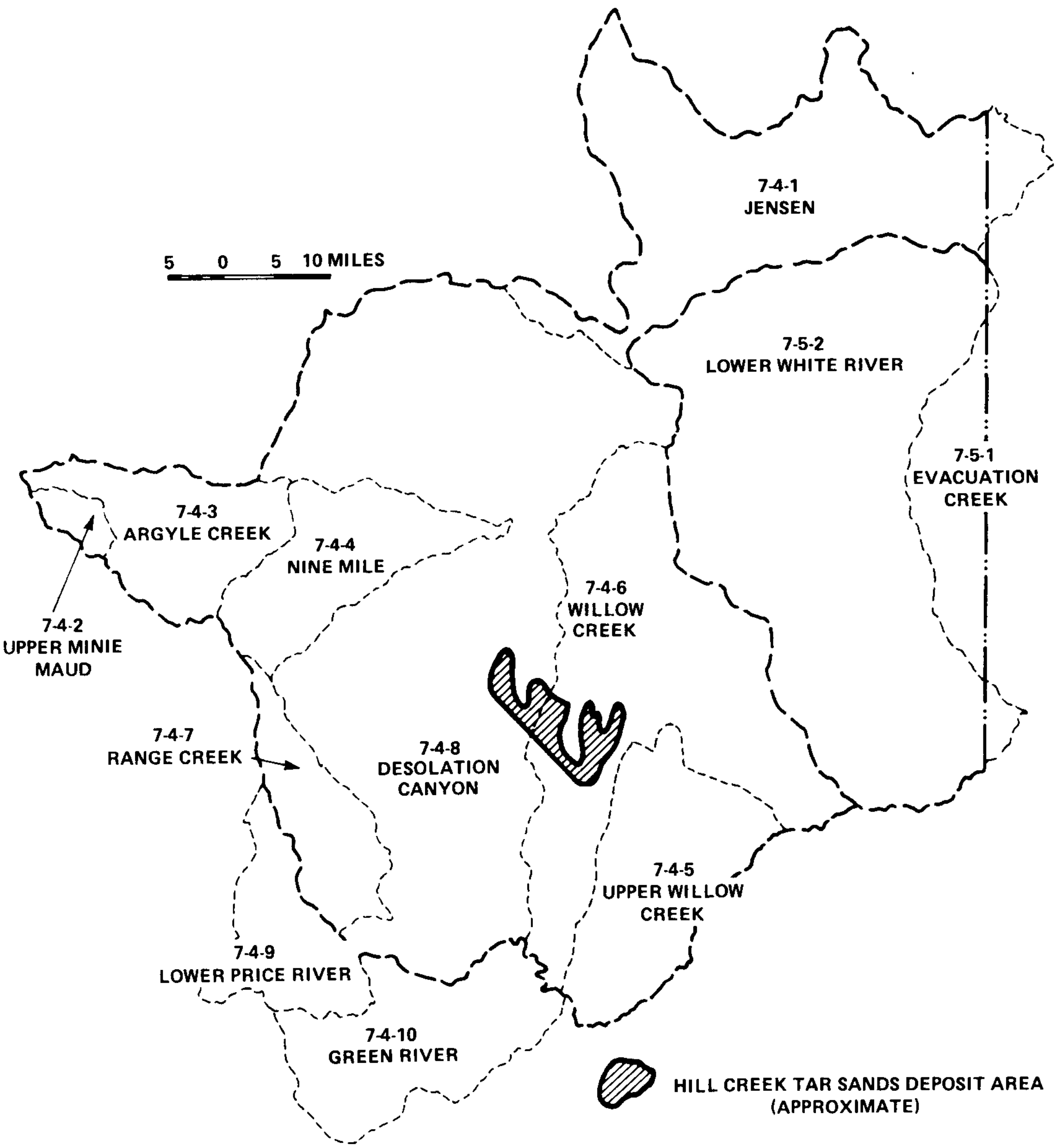


Source: Reference 5.

Figure 39. HYDROLOGIC MEASURING STATIONS IN THE VICINITY OF THE HILL CREEK TAR SANDS DEPOSIT

A significant quantity of data is available only for the station at Willow Creek above diversions. The Hill Creek weather stations have been in operation since the late-1940s. However, in general, precipitation and streamflow in the area have not been defined to any degree.

Austin and Skogerboe (Reference 5) divide the southern Uinta Basin into smaller "hydrologic subareas" based on the locations of the stream gages. These subareas facilitate the creation of water budgets. The hydrologic subareas of concern near the Hill Creek deposits are illustrated in Figure 40.



Source: Reference 5.

Figure 40. HYDROLOGIC SUBAREAS IN THE GREEN AND WHITE DRAINAGE AREAS

Only three of the subareas in the southern Uinta Basin are of concern to this study. These are listed in Table 29.

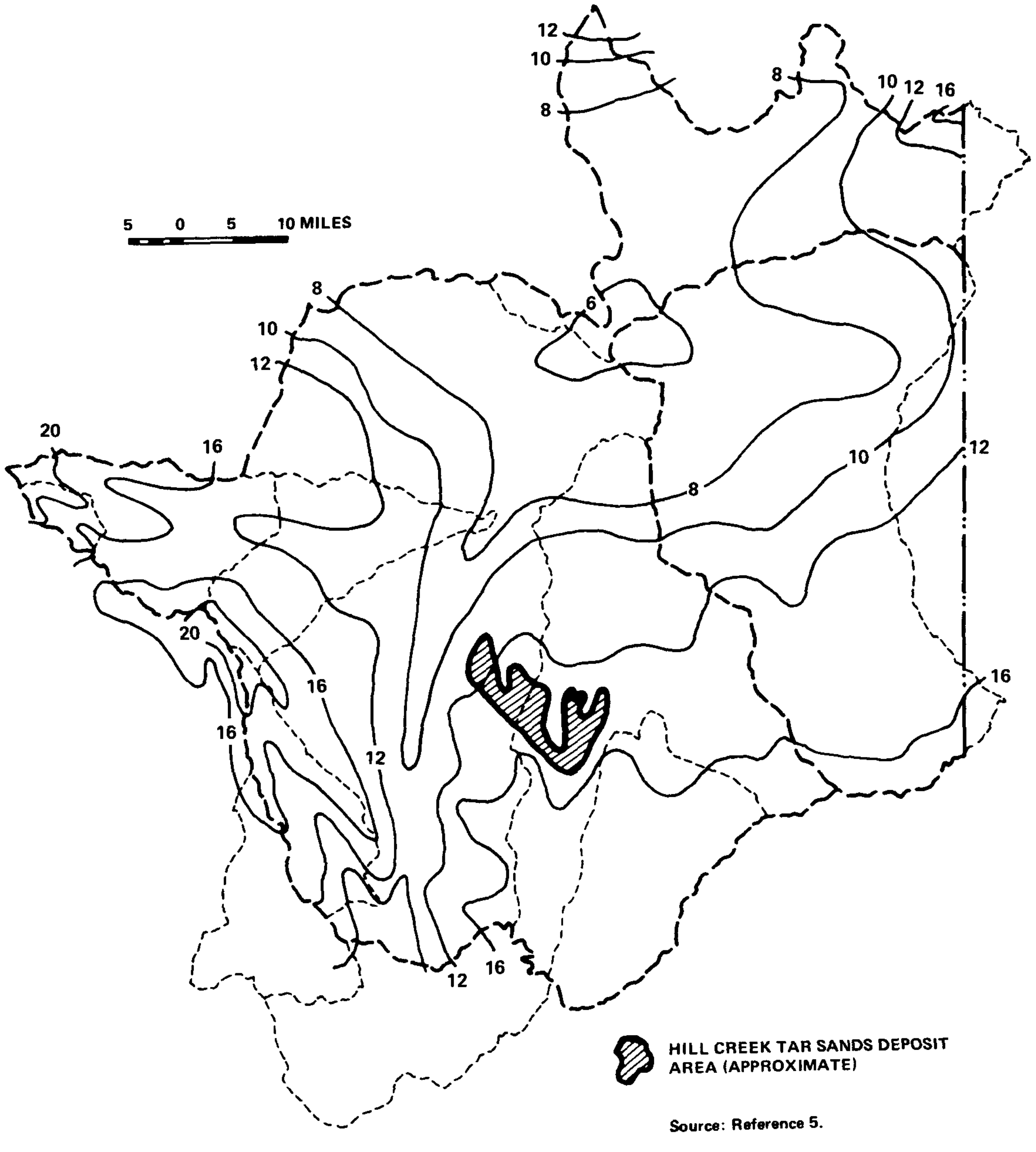
Table 29. HYDROLOGIC SUBAREAS IN VICINITY OF HILL CREEK DEPOSIT

Subarea Number	Decription
7-4-5	Upper Willow Creek—the drainage area above the gaging station 9-3075, "Willow Creek above diversions near Ouray."
7-4-6	Willow Creek—the drainage area above the gaging station 9-3080, "Willow Creek near Ouray," and below the gaging station 9-3075, "Willow Creek above diversions near Ouray."
7-4-8	Desolation Canyon—the drainage area beginning 4 mi above the confluence of the Price and Green rivers, below the mouths of the Range and Nine Mile Creeks, and below the gaging station 9-3070, "Green River near Ouray," and the gaging station 9-3080, "Willow Creek near Ouray."

Precipitation is the starting point for most water resources investigations. The quantity of surface water and groundwater ultimately available depends on the volume and the distribution of precipitation. Austin and Skogerboe (Reference 5) extended the precipitation records in the entire Uinta Basin to a 30-year data base and prepared a set of maps illustrating normal annual precipitation. The precipitation for the Hill Creek area is illustrated in Figure 41. The Hill Creek area receives considerable precipitation compared to the Vernal area. Between 12 and 16 in. falls in the Hill Creek area in a normal year. Since land surface elevations range from 5000 to over 7000 ft, much of the precipitation is in the form of snow.

Austin and Skogerboe (Reference 5) indicate the precipitation available to each hydrologic subarea on both a mean annual and monthly basis. These values are listed in Table 30. Considerable precipitation is available in the three subareas. The maximum estimated water requirement for a production-scale tar sands facility is 10,500 acre-feet per year. Precipitation in all areas exceeds this by a considerable margin.

No readily available information was found on the time distribution of precipitation near Hill Creek. The total distribution for Jensen and the Vernal Airport, as illustrated in Figure 17, appears to be typical. For the Vernal-Jensen sites there is a 90-95 percent probability of 0.2-0.3 in. of precipitation each month. A roughly 50 percent chance exists for a half inch. The precipitation throughout the year is relatively uniform based on the data in Table 30.



Source: Reference 5.

Figure 41. NORMAL ANNUAL PRECIPITATION FOR THE GREEN AND WHITE DRAINAGE AREAS, 1931-60

While the quantity of precipitation is important, the amount that actually runs off and becomes available for use is of greater concern. Price and Miller (Reference 30) analyzed the runoff for the gages in the Hill Creek area. Table 31 lists the mean annual historical runoff for the stations of interest.

Price and Miller also determined the mean monthly streamflow at the two Willow Creek stations. These values are plotted in Figure 42. Typical of the area, the peak runoff

Table 30. MEAN MONTHLY AND ANNUAL PRECIPITAION IN EACH HYDROLOGIC SUBAREA NEAR THE HILL CREEK DEPOSIT

Subarea		Oct		Nov		Dec		Jan		Feb		Mar		Apr		May	
		AF	in.	AF	in.	AF	in.	AF	in.	AF	in.	AF	in.	AF	in.	AF	in.
7-4-5	Upper Willow Cr.	24,700	1.62	21,800	1.43	30,100	1.97	19,100	1.25	21,800	1.43	21,800	1.43	24,700	1.62	17,200	1.13
7-4-6	Willow Cr.	38,500	1.19	34,300	1.06	47,100	1.45	30,000	.93	34,300	1.06	34,300	1.06	38,500	1.19	34,200	1.05
7-4-7	Range Cr.	13,100	1.73	8,300	1.09	8,400	1.10	8,400	1.10	8,400	1.10	10,700	1.40	10,700	1.40	8,700	1.14
7-4-8	Desolation Canyon	74,700	1.09	52,000	.76	59,700	.88	52,100	.76	58,700	.88	52,100	.76	74,700	1.09	53,300	.78

Table 30. (Continued)

Subarea		Jun		Jul		Aug		Sep		Oct-Apr		May-Sep		Annual	
		AF	in.	AF	in.	AF	in.	AF	in.	AF	in.	AF	in.	AF	in.
7-4-5	Upper Willow Cr.	15,100	.99	13,000	.85	25,600	1.68	15,100	.99	164,000	10.75	86,000	5.64	250,000	16.39
7-4-6	Willow Cr.	29,900	.92	25,600	.79	51,300	1.58	30,000	.93	257,000	7.94	171,000	5.28	428,000	13.22
7-4-7	Range Cr.	7,700	1.01	9,800	1.28	13,100	1.72	7,700	1.01	68,000	8.92	47,000	6.16	115,000	15.08
7-4-8	Desolation Canyon	60,900	.88	60,900	.87	83,500	1.20	68,400	.98	425,000	6.22	327,000	4.68	752,000	10.90

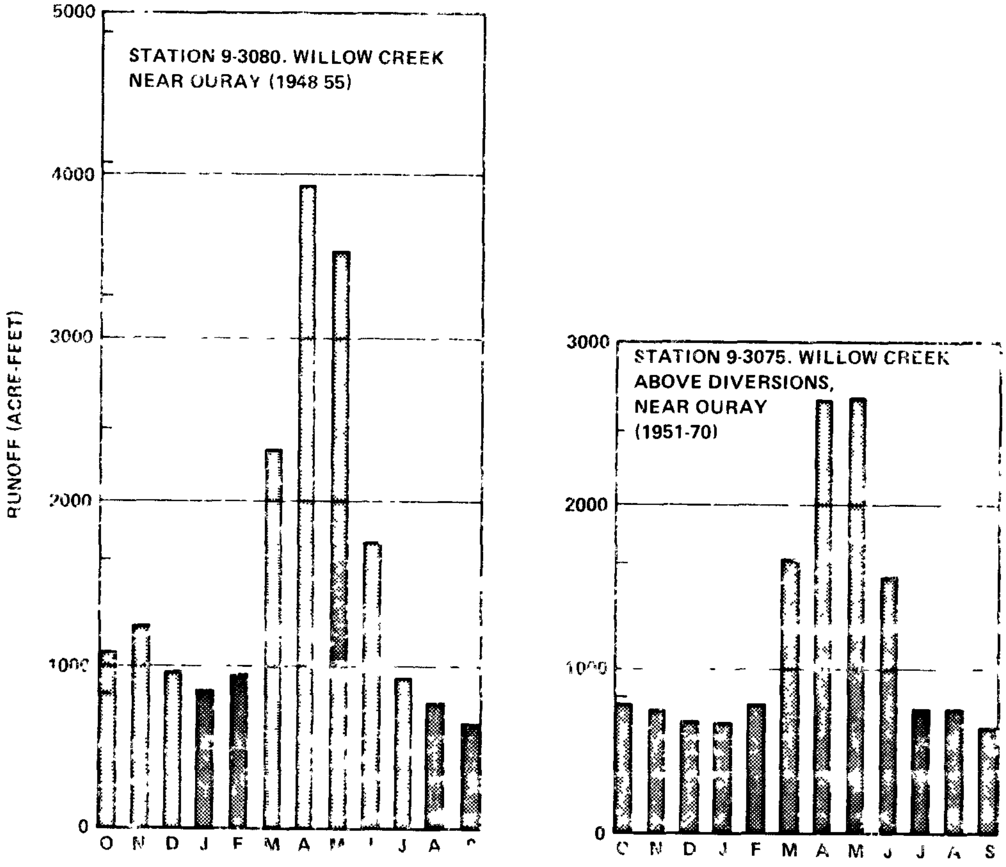
Source: Reference 5

Table [illegible]. STREAMFLOW FOR STATIONS NEAR HILL CREEK

Station Number	Name	Drainage Area mi²	Period of Record*	Average Discharge cfs	AF/yr	Number of Years	Extremes (cfs) Maximum	Date	Minimum	Date
9-[illegible]07[illegible]	Willow Creek above diversions, near Ouray	3	Aug [illegible] Sept 1955 Sept 1957-Sept 1970	1[illegible] 6	4,[illegible]00	18	666	8-6-63	0.3	Aug 21-23, 1960
9-3080	Willow Creek near Ouray	890	July 1947-Sept 1955 (annual max 1961, 1962-68)	[illegible]7.0	19,550	8	[illegible] 2,600	8-27-52 7-31-64	0	several times

Period of record. Stations with records extending to September 1972 were still in operation as of that date.

Source: Reference 3.



Source: Reference 30.

Figure 42. MONTHLY RUNOFF AT STATIONS NEAR HILL CREEK

occurs in April as the winter snowpack melts. Probably the most important thing to note is that flow in Willow Creek is barely adequate to support a tar sands industry requiring 10,000 or more acre-feet of water per year. This initial look at surface water immediately adjacent to the tar sands is not encouraging and this situation will be discussed further following the presentation of the water budget.

The mean annual runoff, or water yield, map for the southern Uinta Basin is shown in Figure 43. By measuring the area between adjacent water-yield lines and multiplying by the average depth for each area, the surface runoff can be estimated for a watershed. In the vicinity of Hill Creek there is very little runoff. Less than an inch runs off any area within 10 mi of the deposits. Based on the data presented in Table 31, a value of 0.89 in. is typical.

In order to determine the amount of runoff available, detailed information is needed on the spatial distribution of the runoff and the losses due to seepage, consumptive use, groundwater, evaporation, and other factors. The water budget for a basin provides these details.

Austin and Skogerboe prepared water budgets for each of the hydrologic subareas near the Hill Creek deposit (Reference 5 and Section IV). The essential parts of these water budgets are presented here. The quantity of water available near Hill Creek is then compared with the requirements for tar sands development. Water quality considerations are presented last.

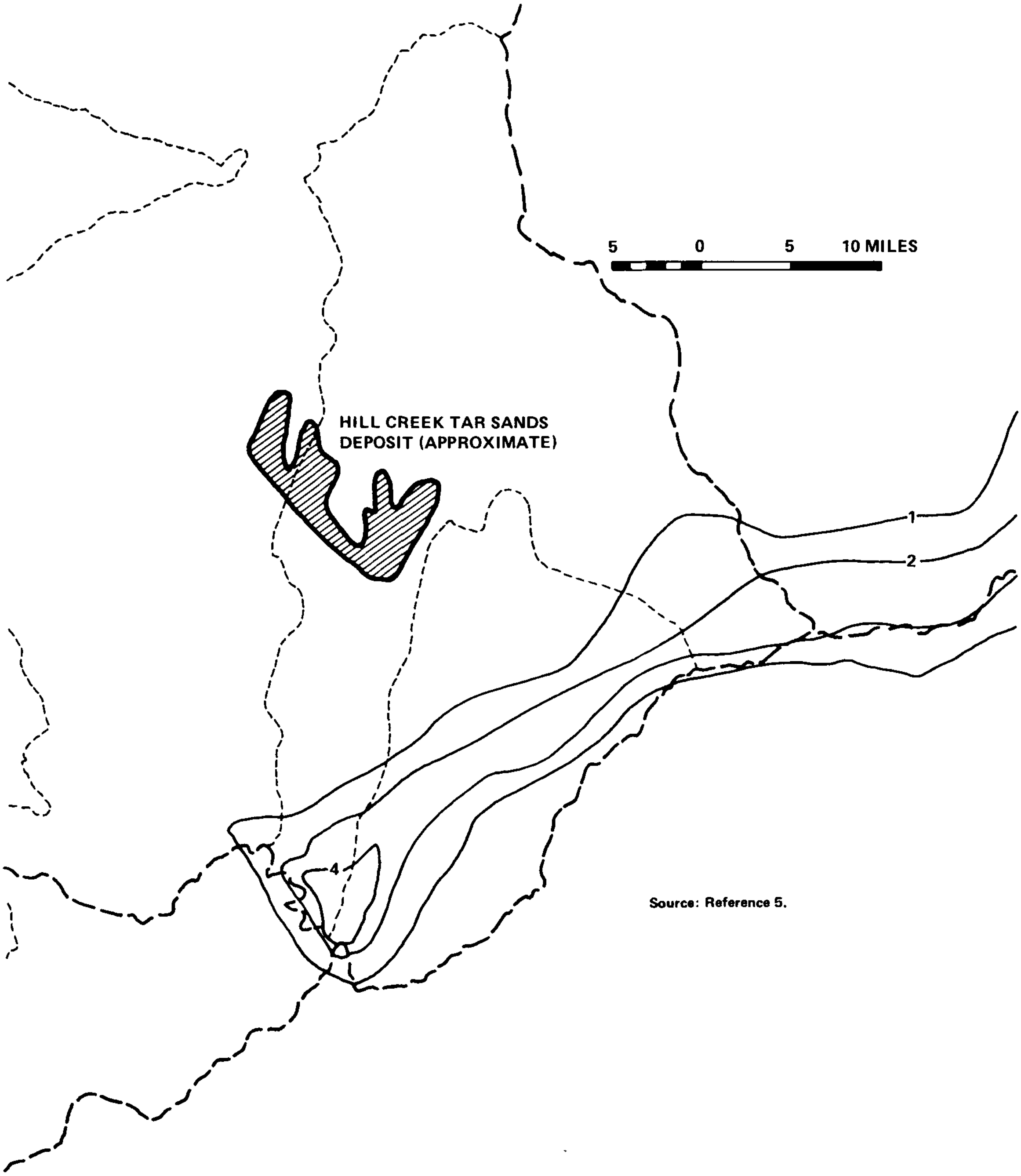
Surface Water Supplies

Upper Willow Creek Subarea (7-4-5)

The runoff from the Upper Willow Creek subarea, which consists of the upper drainage of Willow Creek, is gaged at USGS Station 9-3075, "Willow Creek above diversions near Ouray." The mean annual water budget for the Upper Willow Creek subarea is depicted by the flow diagram in Figure 44; the mean monthly and mean annual flows for the 1931-60 time period are listed in Table 32. The main monthly and mean annual distributions of the river outflow were estimated from USGS records.

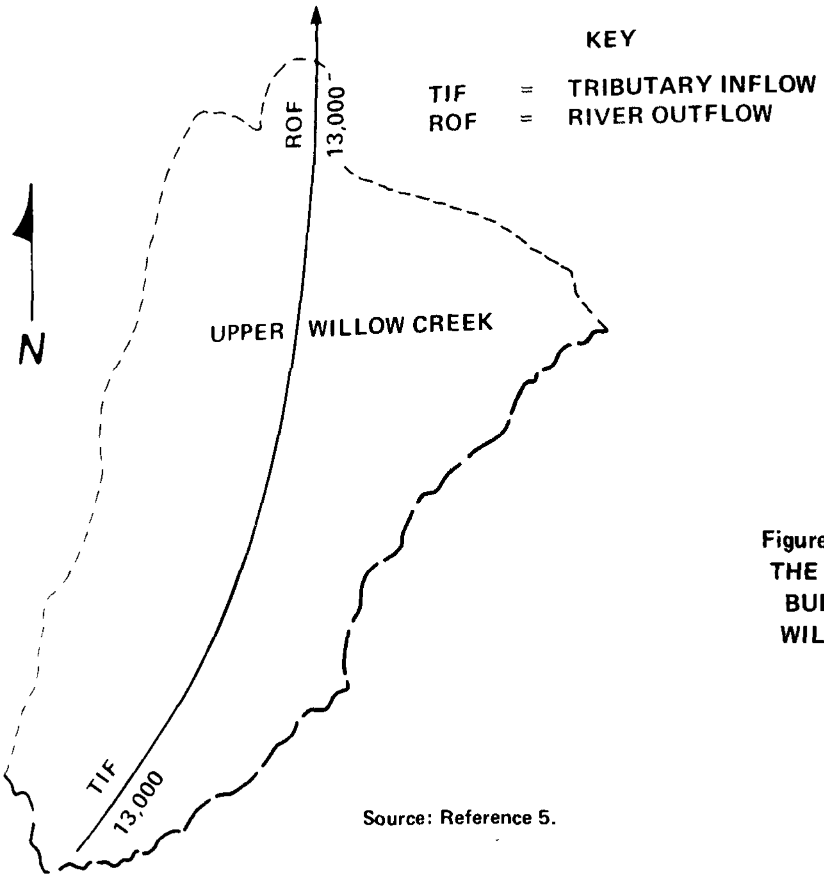
Willow Creek Subarea (7-4-6)

The Willow Creek subarea forms the drainage area along Willow Creek between two USGS stations: "Willow Creek above diversions near Ouray," and "Willow Creek near Ouray." The river inflow to the Willow Creek subarea is the outflow from the Upper Willow Creek subarea, as shown by the flow diagram in Figure 45, which represents the mean annual water budget for the subarea. Table 33 presents the mean monthly and mean annual flows for the 1931-60 time period. The cropland and wetland depletions were computed from the water budget program. The mean monthly and mean annual distributions of the river outflow at USGS Station 9-3080, "Willow Creek near Ouray," were obtained from USGS records.



Source: Reference 5.

Figure 43. MEAN ANNUAL RUNOFF IN VICINITY OF HILL CREEK DEPOSIT



Source: Reference 5.

Figure 44. FLOW DIAGRAM OF THE MEAN ANNUAL WATER BUDGET FOR THE UPPER WILLOW CREEK SUBAREA

Table 32. MEAN MONTHLY AND MEAN ANNUAL WATER BUDGET FOR UPPER WILLOW CREEK SUBAREA

Characteristics	Water Budget (AF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Tributary inflow													
Gaged inflow	780	750	660	670	820	2 120	2,200	1,800	940	730	770	760	13,000
Total surface inflow	780	750	660	670	820	2,120	2,200	1,800	940	730	770	760	13,000
River outflow													
Station No 9 3075	780	750	660	670	820	2 120	2,200	1,800	940	730	770	760	13,000

Source Reference 5

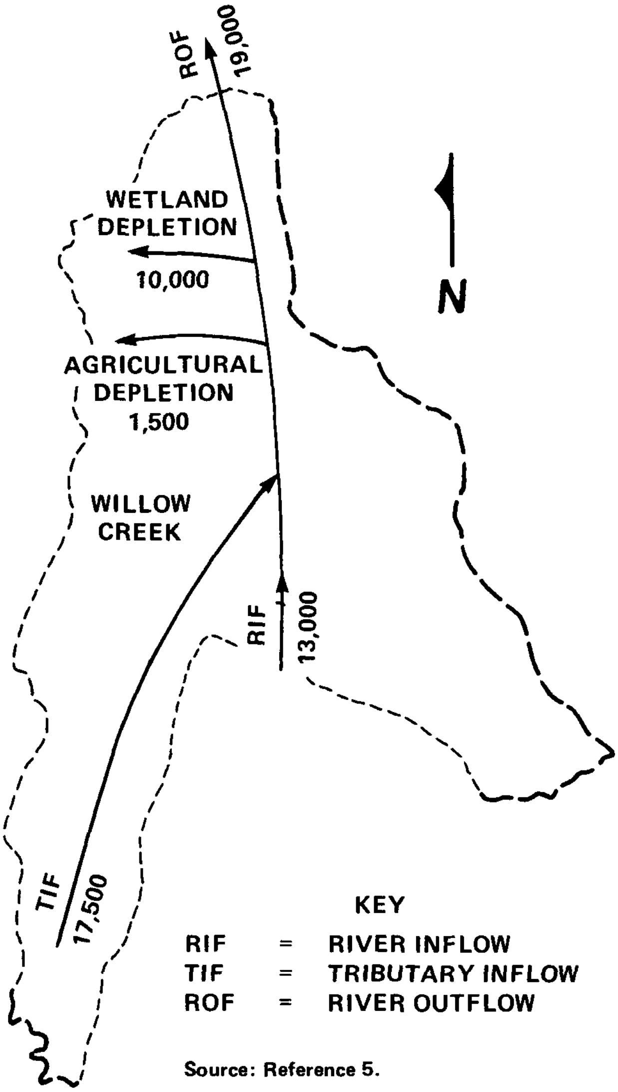


Figure 45. FLOW DIAGRAM OF THE MEAN ANNUAL WATER BUDGET FOR THE WILLOW CREEK SUBAREA

Source: Reference 5.

Table 33. MEAN MONTHLY AND MEAN ANNUAL WATER BUDGET FOR WILLOW CREEK SUBAREA

Characteristics	Water Budget (AF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
River inflow													
Station 9 3015	780	750	660	670	820	2,120	2,200	1,800	940	730	770	760	13,000
Tributary inflow													
Ungaged inflow	700	530	350	350	350	1,250	4,240	3,870	2,030	1,550	1,380	900	17 500
Total surface inflow	1,480	1,280	1,010	1,020	1,170	3,370	6,440	5,670	2,970	2,280	2,150	1,660	30,500
Depletion													
Cropland	90	0	0	0	0	0	80	230	270	350	300	380	1,500
Wetland	800	0	0	0	0	0	250	1,010	2,480	2,050	1,980	1,430	10,000
Outflow and/or groundwater change	590	1,280	1,010	1,020	1,170	3,370	6,110	4,430	220	-120	-130	50	19,000
Estimated groundwater change	390	190		190	240	810	2,210	560	1,480	1,020	-890	580	0
River outflow													
Station 9 3080	980	1,090	950	830	830	2,480	3,900	3,870	1,700	900	780	630	19,000

Source Reference 5

Desolation Canyon Subarea (7-4-8)

The Desolation Canyon subarea is located along the Green River between USGS gaging station "Green River near Ouray," and the Green River at a point about 7 mi below the mouth of Range Creek. The river inflow to the Desolation Canyon subarea is the river outflow from the Jensen, Willow Creek, Nine Mile, and Range Creek subareas. The flow diagram in Figure 46 represents the mean annual water budget for the Desolation Canyon subarea, while the mean monthly and mean annual flows for the 1931-60 time period are presented in Table 34. The amounts and distribution of ungaged inflow, cropland depletions, and wetland depletions were obtained from the analog water budget studies in the Upper Colorado River Basin and the water budget using the land-use survey data. The estimated groundwater change was determined from the water budget using historical flows of the Green River at Ouray and Green River below Range Creek. After the estimated groundwater change was determined, the 1931-60 adjusted distribution at Green River below Range Creek was determined. Therefore, the river outflow at Green River below Range Creek differs from the historical flow in the amount of the changes at Greendale for the 1931-60 time period.

Surface Water Availability for Tar Sands Development

First, it is apparent from the Austin and Skogerboe water budgets that little is known about streamflows immediately to the west of Hill Creek. That is, no gages and little knowledge of flow exists between Hill Creek and the Green River. Several ephemeral streams feed the Green River adjacent to the Hill Creek deposit. These appear to drain areas of 20 to

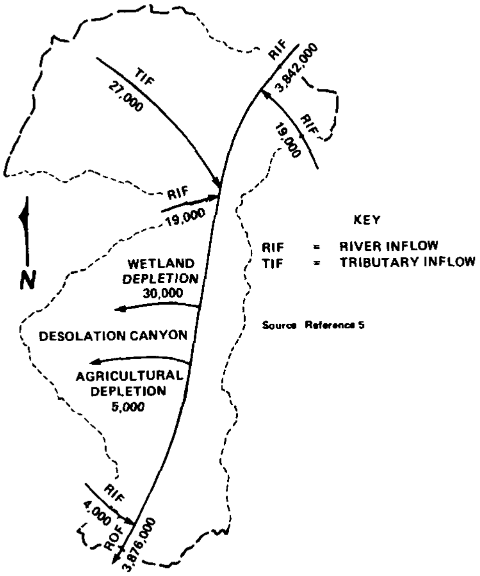


Figure 46. FLOW DIAGRAM OF THE MEAN ANNUAL WATER BUDGET FOR THE DESOLATION CANYON SUBAREA

Table 34. MEAN MONTHLY AND MEAN ANNUAL WATER BUDGET FOR DESOLATION CANYON SUBAREA

Characteristics	Water Budget (AF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
River inflow													
Green River near Ouray	225 250	208 210	149 570	135 550	143 280	219 460	432 970	781 460	778 480	331 880	228 660	207 230	3 842 000
Nine Mile Creek at mouth	790	740	680	610	660	1 330	5 100	5 540	1 400	700	680	770	19 000
Willow Creek near Ouray	980	1 090	950	830	930	2 460	3 900	3 870	1 700	900	760	630	19 000
Range Creek at mouth	80	70	40	40	40	90	670	1 630	870	230	140	100	4 000
Tributary inflow													
Ungaged inflow	1 080	810	540	540	540	2 700	8 100	6 750	1 890	1 620	1 350	1 080	27 000
Total surface inflow	228 180	210 920	151 780	137 570	145 450	226 040	450 740	799 250	784 340	335 330	231 590	209 810	3 911 000
Depletions													
Cropland	250	0	0	0	0	0	0	620	990	1 490	1 130	520	5 000
Wetland	1 150	40	0	0	0	110	340	3 670	5 480	7 880	6 930	4 400	30 000
Outflow and/or groundwater change	226 780	210 880	151 780	137 570	145 450	225 930	450 400	794 960	777 870	325 960	223 530	204 890	3 876 000
Estimated groundwater change	2 000	2 000	1 000	1 000	1 000	2 000	10 000	12 000	1 000	8 000	5 000	3 000	0
River outflow	228 780	212 890	152 780	138 570	146 450	223 930	440 400	782 960	778 870	333,960	228 530	207 890	3 876 000

Source Reference 5

40 mi^2. The yield from individual basins could be estimated from the runoff map, but the quantity would be small and intermittent.

The only apparent sources of surface water in the immediate vicinity of the Hill Creek deposit are Hill Creek and Willow Creek. Hill Creek is not gaged directly, but the quantity attributable to Hill Creek can be inferred from Table 31. The Willow Creek gage near Ouray measures runoff from both Hill Creek and Willow Creek. The drainage area at the gage is 890 mi^2. The drainage area of Willow Creek alone is approximately 60 percent of the total. Therefore, Hill Creek might be expected to yield 40 percent or 7820 acre-feet per year at the mouth. The yield would be less near the tar sands deposit because of increased drainage area. Half of this amount (roughly 4000 acre-feet per year) would be a reasonable estimate. The Willow Creek gage above diversions is immediately adjacent to the tar sands deposit. Its average annual yield is 14,200 acre-feet per year. Both estimates are based on records covering only a limited time period.

Using these estimates, the question of supply for tar sands development can now be addressed. As previously given in Table 3, the following hypothetical demands for water were calculated (based on 5 bbl of water per barrel of oil):

- five-well experimental facility: 35.5 AF/yr = 2.96 AF/mo;
- 24-well pilot facility: 213 AF/yr = 17.75 AF/mo; and
- large-scale production facility: 13,400 AF/yr = 1117 AF/mo.

As stated previously, these estimates assume 100 percent consumptive use and are very conservative.

These figures imply that either Willow Creek or Hill Creek is capable of supporting a large-scale pilot operation. Only Willow Creek is capable of supporting production-scale facilities. The combined flow of both creeks near the tar sands area would appear to be adequate for development of production. The intermittent nature of the runoff would certainly necessitate storage facilities, with corresponding seepage and evaporation losses. Price and Miller (Reference 30) specifically identify Willow Creek as a potential site for development of storage facilities. Caution should be used here, however, because the P.R. Spring deposit lies immediately east of Willow Creek. The flow is not sufficient to support major production in both areas at once without recycling or other conservation measures.

Very little agricultural demand exists in the Willow Creek Basin. Only 1500 acre-feet per year is attributed to agricultural depletion. Considerable wetland depletion (10,000 acre-feet per year) exists. This wetland depletion, if prevented, would nearly support a production-scale tar sands facility.

Given the short length of record available and the fact that Hill Creek is not gaged directly, it would be advisable to use accepted hydrologic techniques to synthesize a record for Hill Creek near the tar sands deposit. This could be done by modeling of the snowmelt, use of correlation techniques, or modeling of the surface water. This kind of study would be essential if storage facilities are to be developed on either Willow Creek or Hill Creek.

In addition to the waters of Hill and Willow Creeks, consideration should be given to transporting water from the White River. The Utah Division of Natural Resources is planning a dam on the White River (Reference 31) to provide water for energy development and irrigation. The planned reservoir capacity is 118,000 acre-feet. The Ute Tribe has irrigation rights to one-third of the capacity. The remainder is to be used for energy development, some of which may be used for tar sands development.

As with all western water, the question of who owns the rights to its use arises. This question is addressed in Section IX.

Surface Water Quality

As stated in Section IV, the amount and quality of water quality data vary widely. The same comments and cautions apply to Hill Creek. Almost no specific water quality information is available for Hill Creek and Willow Creek. Price and Miller (Reference 30) discuss water quality in general and report a few random measurements in Willow Creek and Hill Creek. These measurements were taken in the fall of 1971 and 1972. Extrapolations of these measurements to other times of the year or long time periods would be uncertain. Table 35 presents the results of the measurements.

Table 35. WATER QUALITY SAMPLES IN WILLOW AND HILL CREEKS

Number	12	13	14	15	16	17
Stream	Willow Creek	Willow Creek	Willow Creek	Willow Creek	Hill Creek	Hill Creek
Date of collection	9/27/72	9/28/72	9/28/72	9/2/71	9/2/71	9/2/71
Temperature (°C)	19.0	14.5	12.5	17.0	17.0	16.5
Discharge (cfs)	2.85[a]	0.25[a]	0.08[a]	–	2[b]	1[b]
Chemical content (mg/l)						
Silica	17	11	10	15	18	12
Calcium	59	63	74	62	72	42
Magnesium	51	230	230	190	60	210
Sodium	97	1100	1100	930	34	1000
Potassium	2.6	6.3	5.7	8.7	2.0	6.4
Bicarbonate	396	909	965	831	417	960
Carbonate	0	82	61	0	0	0
Sulfate	240	2500	2500	2300	82	2300
Chloride	9.0	120	120	76	3.8	100
Fluoride	–	–	–	0.4	0.1	0.3
Nitrate plus nitrite as N	–	–	–	0.21	0.00	0.12
Nitrate	–	–	–	–	–	–
Phosphate	–	–	–	0.15	0.15	0.28
Boron	–	–	–	6.50	0.07	5.80
Iron	–	–	–	0.12	0.07	0.02
Manganese	–	–	–	0.04	0.03	0.02
Dissolved solids[c]	670	4560	4580	4000	457	4150
Hardness as calcium carbonate,						
calcium, magnesium	360	1100	1100	940	340	970
noncarbonate	32	220	240	260	2	180
Specific conductance (µ-mho/cm at 25°C)	1010	6000	5970	5190	712	5250
Sodium absorption ratio	2.2	14	14	13	0.8	14
pH	8.2	8.6	8.4	8.3	8.1	8.2

[a] Measured.
[b] Estimated.
[c] Calculated.
Source: Reference 30.

The waters of Willow and Hill Creeks appear to be slightly saline. (Public Health Service standards recommend a limit of 250 mg per liter of chlorides for fresh water; the slightly saline range is from 1000 to 3000 mg per liter.) Dissolved solids and sulfate also exceed the recommended levels of 500 and 250 mg per liter, respectively. The limited results are discouraging, but no definite conclusions should be drawn without a more-detailed sampling program. If use of surface water is seriously considered for developing the Hill Creek deposit, a water-quality monitor should be placed on Hill and Willow Creeks near likely withdrawal sites.

GROUNDWATER

Before discussing groundwater directly, the subsurface geology in the vicinity of the Hill Creek deposit is presented. Accurate determination of the subsurface geology will be an important factor in obtaining groundwater near Hill Creek.

Subsurface Geology

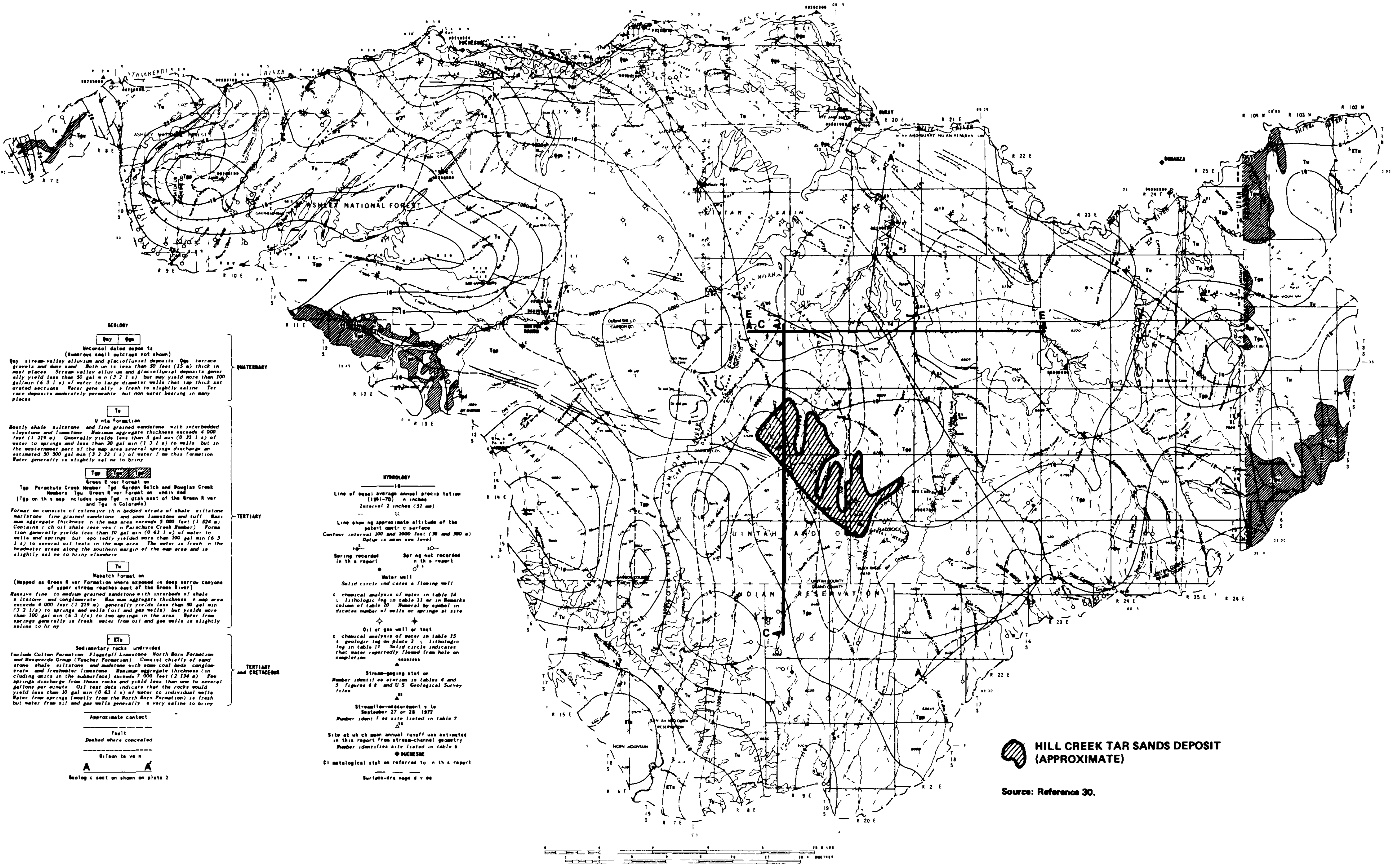
As stated previously, Hill Creek lies in a geomorphological district called the Tavaputs Plateau. This plateau rises slowly to the south from the White River. The predominant surface geologic formation is the Green River. Streams and dry washes are deeply incised in canyons. Canyon depths of 1000 ft are not unusual (Reference 5).

These deeply incised canyons make the groundwater regime considerably different than that which is found near Vernal. The streams in the narrow valleys flow close to bedrock. There is no well-defined, shallow groundwater reservoir as was present in the glacial outwash of the Ashley Valley. The discussion here will concentrate on water in the bedrock aquifers.

Price and Miller (Reference 30) present an excellent geologic map of the southern portion of the Uinta Basin. A portion of this map is given in Figure 47. Superimposed on Figure 47 are the approximate location of the Hill Creek tar sands deposit and the location of two geologic sections developed by Austin and Skogerboe (Reference 5).

The two geologic cross-sections are shown in Figure 48. The subsurface geology is fairly straightforward. The beds underlying Hill Creek dip at shallow angles to the north and are nearly horizontal east and west. The Tertiary Parachute Creek, Garden Gulch, and Douglas Creek Members of the Green River Formation, Mesaverde Formation, and Mancos Shale underlie the Green River Formation at depths of 7000 to 10,000 ft.

Only very sketchy information is available on groundwater from the bedrock in the vicinity of Hill Creek. Feltis (Reference 3) describes the water-bearing properties and water quality of the formations just cited. The deepest formation shown on the cross-section C-C' (Figure 48) is the Mancos Shale. Feltis concludes that the Mancos Shale does not contain fresh water. No information is reported by Feltis on the water-bearing properties of the Mesaverde Group in the vicinity of Hill Creek. One well located considerably north of Hill Creek yielded 1 GPM. Several springs originating in the Mesaverde Formation yield slightly saline water.



GEOLOGY

Qay | Qgs

Unconsolidated deposits
(Numerous small outcrops not shown)

Qay stream-valley alluvium and glaciofluvial deposits. Qgs terrace gravels and dune sand. Both units less than 50 feet (15 m) thick in most places. Stream valley alluvium and glaciofluvial deposits generally yield less than 50 gal/min (3.2 l/s) but may yield more than 100 gal/min (6.3 l/s) of water to large diameter wells that tap thick saturated sections. Water generally is fresh to slightly saline. Terrace deposits moderately permeable but non water bearing in many places — QUATERNARY

Tu

Uinta Formation

Mostly shale, siltstone, and fine grained sandstone with interbedded claystone and limestone. Maximum aggregate thickness exceeds 4,000 feet (1,219 m). Generally yields less than 5 gal/min (0.32 l/s) of water to springs and less than 20 gal/min (1.3 l/s) to wells, but in the westernmost part of the map area several springs discharge an estimated 50-500 gal/min (3.2-32 l/s) of water from this formation. Water generally is slightly saline to briny

Tgp | Tgd | Tgd

Green River Formation

Tgp Parachute Creek Member. Tgd Garden Gulch and Douglas Creek Members. Tgu Green River Formation, undivided
(Tgp on this map includes some Tgd in Utah east of the Green River and Tgu in Colorado)

Formation consists of extensive thin bedded strata of shale, siltstone, marlstone, fine grained sandstone, and some limestone and tuff. Maximum aggregate thickness in the map area exceeds 5,000 feet (1,524 m). Contains rich oil shale reserves (in Parachute Creek Member). Formation generally yields less than 10 gal/min (0.63 l/s) of water to wells and springs, but reportedly yielded more than 100 gal/min (6.3 l/s) to several oil tests in the map area. The water is fresh in the headwater areas along the southern margin of the map area and is slightly saline to briny elsewhere — TERTIARY

Tw

Wasatch Formation

(Mapped as Green River Formation where exposed in deep narrow canyons of upper stream reaches east of the Green River)

Massive fine- to medium grained sandstone with interbeds of shale, siltstone, and conglomerate. Maximum aggregate thickness in map area exceeds 4,000 feet (1,219 m); generally yields less than 50 gal/min (3.2 l/s) to springs and wells (oil and gas wells), but yields more than 100 gal/min (6.3 l/s) to two springs in the area. Water from springs generally is fresh; water from oil and gas wells is slightly saline to briny

KTu

Sedimentary rocks, undivided

Include Colton Formation, Flagstaff Limestone, North Horn Formation, and Mesaverde Group (Tuscher Formation). Consist chiefly of sandstone, shale, siltstone, and mudstone with some coal beds, conglomerate, and freshwater limestone. Maximum aggregate thickness (including units in the subsurface) exceeds 7,000 feet (2,134 m). Few springs discharge from these rocks and yield less than one to several gallons per minute. Oil test data indicate that the rocks would yield less than 10 gal/min (0.63 l/s) of water to individual wells. Water from springs (mostly from the North Horn Formation) is fresh but water from oil and gas wells generally is very saline to briny — TERTIARY and CRETACEOUS

Approximate contact

Fault
Dashed where concealed

Gilsonite vein

A — A'
Geologic section shown on plate 2

HYDROLOGY

16
Line of equal average annual precipitation (1941-70), in inches
Interval 2 inches (51 mm)

Line showing approximate altitude of the potentiometric surface
Contour interval 100 and 1000 feet (30 and 300 m)
Datum is mean sea level

Spring recorded in this report
Spring not recorded in this report

Water well
Solid circle indicates a flowing well

c chemical analysis of water in table 14
L lithologic log in table 11 or in Remarks column of table 10. Numeral by symbol indicates number of wells or springs at site

Oil or gas well or test
c chemical analysis of water in table 15
g geologic log on plate 2. L lithologic log in table 11. Solid circle indicates that water reportedly flowed from hole on completion

09302000
Stream-gaging station
Number identifies station in tables 4 and 5, figures 6-8, and U.S. Geological Survey files

Streamflow-measurement site
September 27 or 28, 1972
Number identifies site listed in table 7

Site at which mean annual runoff was estimated in this report from stream-channel geometry
Number identifies site listed in table 6

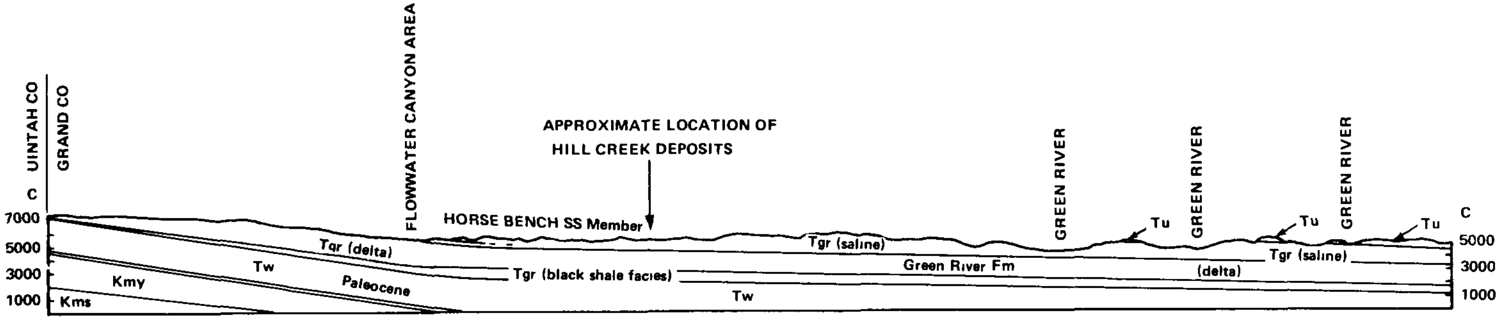
DUCHESNE
Climatological station referred to in this report

Surface-drainage divide

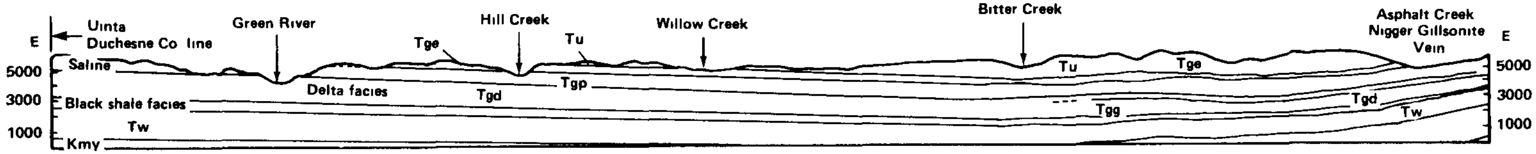
HILL CREEK TAR SANDS DEPOSIT (APPROXIMATE)

Source: Reference 30.

Figure 47. HYDROGEOLOGIC MAP OF THE SOUTHERN UINTA BASIN, UTAH AND COLORADO



Cross-Section C C



Cross Section E E

Source Reference 30

Figure 48. GEOLOGIC CROSS-SECTIONS NEAR HILL CREEK

Water from Bedrock

Feltis reports some data from the Wasatch Formation below Hill Creek. A sample of slightly saline water was obtained from a well in T. 15 S., R. 21 E. The water contained 1996 mg per liter of dissolved solids. The water in the Wasatch at this location probably originates from areas of high precipitation along the cliffs to the south. No well-yield data are reported by Feltis on the Wasatch Formation. In September 1948, a spring in T. 16 S., R. 17 E. yielded fresh water (596 mg per liter of dissolved solids) and had a flow rate of 225 GPM; however, outdated information is of little use.

The chemical quality of the water in the Green River Formation ranges from fresh to briny. Analyses by Feltis (Reference 3) of 73 water samples collected from 51 wells and one spring indicate that four were fresh, 18 were slightly saline, and the remaining 51 were moderately saline to briny. Three of the samples of fresh water came from two wells and a spring, and most of the slightly saline water came from wells on the southern flank of the Uinta Basin. The fresh water was obtained from a gas well in T. 11 S., R. 12 E.; an oil well in T. 14 S., R. 20 E.; and a spring in T. 15 S., R. 23 E. The oil well is very near the Hill Creek deposit. The occurrence of fresh and slightly saline water along the southern flank of the basin suggests that the aquifers are recharged in the area of high precipitation north of the Roan Cliffs.

The yield of water from the Green River Formation as indicated by tests at 17 oil and gas wells, ranges from 17 BPD (0.5 GPM) to 7200 BPD (200 GPM). Two gas wells in Sec. 35, T. 10 S., R. 20 E. and Sec. 17, T. 10 S., R. 22 E. were converted to water wells. In 1964 they flowed at rates of 2700 BPD (80 GPM) and 340 BPD (10 GPM). These wells are 20 to 30 mi north of Hill Creek in the Ashley Valley oil fields. The largest reported yield of water from the Green River is from an oil well in T. 9 S., R. 24 E., which produced 7200 BPD (220 GPM) from a depth of 1932 ft. This well is also 30 mi northeast of Hill Creek.

Feltis (Reference 3) states that on the south flank of the Uinta River Basin the Green River Formation is a potential source of fresh or slightly saline water that could be used in the process of oil extraction from bituminous sand and oil shale. However, wells in the area must be tested further before this statement can be verified.

In both Reference 3 and Reference 22, data on wells and springs near Hill Creek are tabulated. The data are reproduced in Table 36, which includes all the tabulated wells and springs that lie in T. 13 S., Rs. 18 and 19; T. 14 S., Rs. 18-21; and T. 15 S., Rs. 19 and 20.

Table 36. SELECTED DATA ON WELLS AND SPRINGS NEAR HILL CREEK

(a) Records of Selected Petroleum -Test Wells

Location	Name	Year Con-structed	Altitude (ft)	Well Depth (ft)	Depth to Top of Major Aquifer or Water-bearing Zone (ft)	Length of Well Open (ft)	Minor Aquifer or Water-bearing Zone	Temper-ature (°C)	Other Data Available
(D 12-14)13acb-1S	Mobil Sto. Cab. 1	1964	7,591	5,515	8,505	112	211MVRD	–	P
(D-13-23)26acd-1	Skyline Neilson 1	1963	6,460	5,852	2,000	–	–	–	P
(D-14-20) 7adb 1	Phillips Petroleum Flat Rk. 3	1962	7,015	7,300	–	–	–	–	P
30aca-1S	Phillips Petroleum	1962	7,466	4,285	4,530	18	–	–	P
30aca-1S	Hiko Bell Flat Rk. 3	1963	7,466	3,985	3,225	30	–	–	–
30bab 1	Phillips Petroleum Flat Rk. 4	1963	7,210	4,450	1,883	89	–	–	P

(b) Records of Selected Springs

Location	Name or Owner	Altitude (ft)	Discharge (GPM)	Date Measured	Temperature (°C)	Date Measured	Use of Water	Chemical Analysis Available
(D-13-19) 8aa -S	Bureau of Land Management	6,150	0.3E	8/72	–	–	S	P
(D 14-19)33aad-S1	C Brown Spring	7,120	0.5E	9/71	–	9/71	S	P
(D-15-19) 4bba-S1	Secret Spring	7,190	0.1E	9/71	–	9/71	S	P
(D-15-20)15bbd S1	Flat Rock Spring	7,240	0.2M	9/71	17.0	8/71	S	P

(c) Records of Selected Water Wells

Location	Owner	Year Con-structed	Well Depth (ft)	Casing Depth (ft)	Casing Diameter (in.)	Alti-tude- (ft)	Water Level (ft)	Date Measured	Use of Water	Yield (GPM)	Draw down (ft)	Tem-per-ature (°C)	Chemical Analysis Available
(D 14 18) 1bbd 1	Ute Tribe	1964	150 3	14	8	7045 5	68	8/72	S	7	92	13.0	K
(D 14 19) 3cdb 1	Ute Tribe	1960	96 3	65	5	6880 5	80	12/60	S	5	96	–	–
(D 15 20) 3bab 1	Ute Tribe	1960	108 3	60	5	7440 5	52	12/60	S	15	–	–	–
(D-15 20)12cca 1	Ute Tribe	1964	120 3	12	8	7425 5	60	6/64	U	4	60	–	–

Altitude Land surface at spring orifice, above mean sea level, interpolated from topographic maps.
Discharge E, estimated, M, measured, R, reported.
Date Measured Date of temperature measurement also applies to date of water sampling.
Use of Water, P, public supply; U, unused.
Chemical Analysis Available K, specific conductance only; P, partial.

Sources References 3 and 22.

Table 36. SELECTED DATA ON WELLS AND SPRINGS NEAR HILL CREEK (Continued)

(d) Records of Petroleum Springs

Location			Operator or Owner	Name or Number	Producing Formation	Depth to Top of Formation (ft)	Depth to Bottom of Formation (ft)	Interval Sampled (ft)	Yield (BPD/GPM)	Method or Point of Collection	Date of Collection	Temperature (°F)
T	R	Section										
14S	20E	NW¼SE¼NE¼ 7	Phillips Petroleum Co	1	Castlegate Ss	7,037	7,285	7,080 7 180	–	DST 3	9/17/62	
14S	20E	C SW¼NE¼ 30	Phillips Petroleum Co	2	Wasatch Fm	2,390	4 320	3 790 3 820	(See remarks)	(See remarks)	7/13/65	–
					Flagstaff Ls	4 320	4 635	4 530-80	48(R)/1 4	Swab test	12/13/62	
14S	20E	C NE¼NW¼ 30	Phillips Petroleum Co	4	Green R Fm	0	2 100	1 883 1 910	360(R)/11	Swab test	7/22/63	–
15S	21E	CSW¼SE¼ 22	Atlantic Refining Co	22 2	Wasatch Fm	1 610	3 602	3,134-42 3 466-80	– –	DST 1 DST 2	9/26/63 9/28/63	
					Castlegate Ss	5 518	–	5,518-41		DST 4	10/12 53	

(d) Continued

Location			Chemical Content (ppm)													
T	R	Section	Silica	Iron	Calcium	Magnesium	Sodium and Potassium	Bicarbonate	Carbonate	Sulfate	Chloride	Nitrate	Dissolved Solids	Hardness as Calcium Carbonate	Noncarbonate hardness as Calcium Carbonate	Percent Sodium
14S	20E	NW¼SE¼NE¼ 7	–	–	8	2	1,672	964	264	2,150	140	–	4,711	–	–	–
14S	20E	C SW¼NE¼ 30	23	–	614	91	11,900	530	0	1,490	18,300	25	32,700	1,910	1,470	93
			–	–	11	12	2 897	598	360	4,650	320	–	8,245	–	–	–
14S	20E	C NE¼NW¼ 30	–	–	10	7	274 13	366	12	290	32	–	818	–		–
15S	21E	CSW¼SE¼ 22	–	–	20	36	664	149	12	2	1 065	–	1 966	–	–	–
			–	–	80	36	3,766	136	14	7,579	355	–	11,986	–	–	–
			–	–	600	109	11 643	107	0	5,813	14 981		33,253	–		–

(d) Continued

Location			Chemical Content (ppm)				Remarks
T	R	Section	Sodium Absorption ratio (SAR)	Specific Conductance (micromhos/cm at 25°C)	Resistivity (ohmmeter at 68°F)	pH	
14S	20E	NW¼SE¼NE¼ 7	–	–	2 65	9 3	DST 3 recovered 630 ft of water-cut mud (estimated to be 75 percent water)
14S	20F	C SW¼NE¼ 30	119	48 900	–	7 3	Water collected at discharge line to disposal pit after treatment to remove oil Yield was 1 bpd (less than 1 GPM) of water
			–	–	1 02	9 4	
14S	20E	C NE¼NW¼ 30	–	–	9 35	8.7	Fluid level 700 ft unable to lower with swabbing rate of 15 bbl water/hr
15S	21E	CSW¼SE¼ 22	–	–	1 97	8 4	DST 1 recovered 1,482 ft of gas-cut water
			–	–	66	8 6	DST 2 recovered 525 ft of brackish water with sulfur water
			–	–	23	7 3	DST 4 recovered 150 ft of slightly gas-cut muddy water and 950 ft of slightly gas-cut brackish water

Groundwater Availability for Tar Sands Development

It is very difficult to reach any meaningful conclusions on the groundwater supply at Hill Creek with the data available. In particular, the data on yield are meager. One of the first steps in any more-detailed investigation of the Hill Creek wells should be to conduct yield tests on existing wells.

The following quantities of water (based on 5 bbl of water per barrel of oil) are estimated for production-scale tar sands facilities of various sizes:

- five-well experimental facility—22 GPM,
- 24-well pilot facility—132 GPM, and
- large-scale production facility—8300 GPM.

As stated previously, these estimates assume 100 percent consumptive use and are very conservative. These numbers are quite discouraging when compared to the limited data. The largest spring near Hill Creek is estimated to discharge only 0.5 GPM. The largest of the Ute Tribe wells has a yield of 15 GPM; the smallest, 4 GPM. These wells are fairly shallow, less than 100 ft. The yield from oil wells is equally discouraging. A Phillips Petroleum Co. well in T. 14 S., R. 0 E. has the largest reported value—11 GPM. The water in this well ranges from highly saline to brackish. In summary, the groundwater picture at Hill Creek is incomplete and the limited numbers available are not encouraging. No definite conclusions should be drawn, however, without a more-detailed investigation.

The Parachute Creek Member of the Green River Formation lies fairly close to the surface near Hill Creek. Weeks et al. (Reference 32) reported that the Parachute Creek Member is the major aquifer in the Piceance Creek Basin of Colorado. This is approximately 50 mi northeast of Hill Creek. In the Piceance Basin wells in the Parchute Creek Member yield up to 1000 GPM, with 200 to 400 GPM being typical. Only further study can determine if such yields are possible near Hill Creek. The leached zone, which allows such high yields in the Piceance Basin, may not be present in the Uinta Basin.

VI. WATER RESOURCES NEAR P.R. SPRING

This section considers in detail the water resources in the vicinity of the P.R. Spring deposit. First, the available precipitation and surface runoff are considered. Water budgets are presented for the basin above existing stream gages. Then, the availability of groundwater is investigated.

SURFACE WATER

As stated previously, the P.R. Spring tar sands deposit lies within the southeastern part of the Uinta Basin. Considerable information is available on the distribution of precipitation and surface runoff within the basin. The bulk of the relevant data is contained in References 5 and 30. Considerable basic data are also available in Reference 22. Since References 5 and 30 contain fairly detailed hydrologic analysis, they are the basis for this discussion.

There are no major cities or towns near the P.R. Spring deposit. The general vicinity of the deposit is illustrated in Figure 49. Also illustrated are 5- and 10-mi distance reference lines. These lines give some indication of the distance water might be transported from streams.

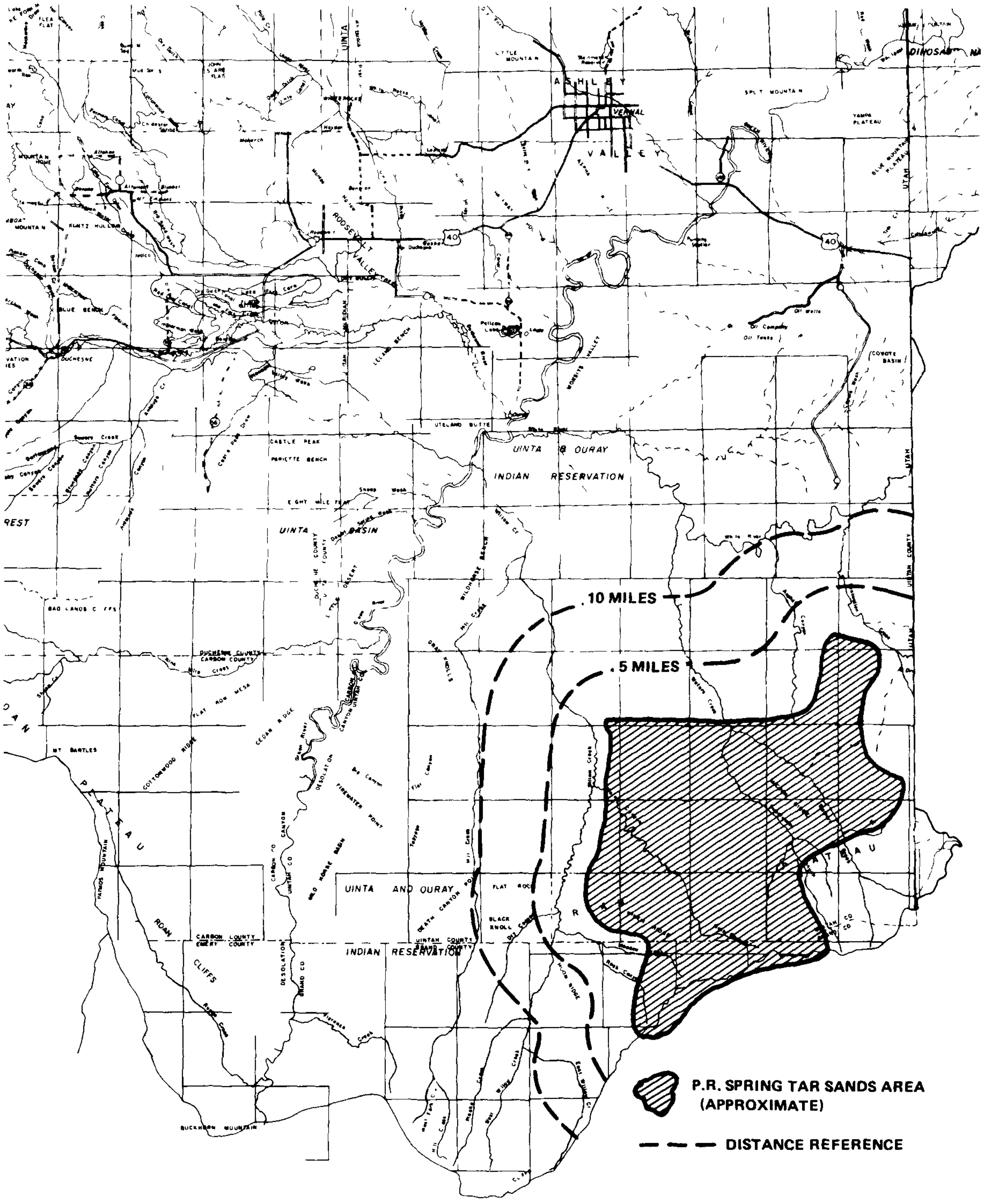
Several creeks originate in or flow through the P.R. Spring tar sands area. The major creeks are

- Evacuation,
- Bitter,
- Sweetwater Canyon,
- Main Canyon, and
- Willow.

Two smaller creeks (Park and Meadow) head in the tar sands area and flow into the upper portion of Willow Creek.

The White River flows 10 mi north of the deposit. The state of Utah owns some water rights on the White River. A discussion of flows there will be included here.

A few meteorologic and stream gaging stations are maintained in the vicinity of the Hill



Source: Reference 5.

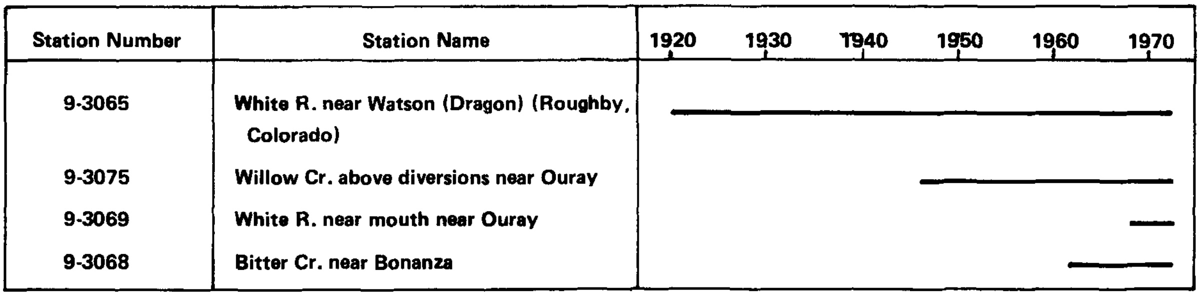
Figure 49. P.R. SPRINGS TAR SANDS AREA

Creek deposit (Figure 50). The stations that are of concern in terms of identifying the water resources for the P.R. Spring deposit are listed in Table 37.

Table 37. HYDROLOGIC AND METEROLOGIC STATIONS IN THE VICINITY OF THE HILL CREEK TAR SANDS DEPOSIT

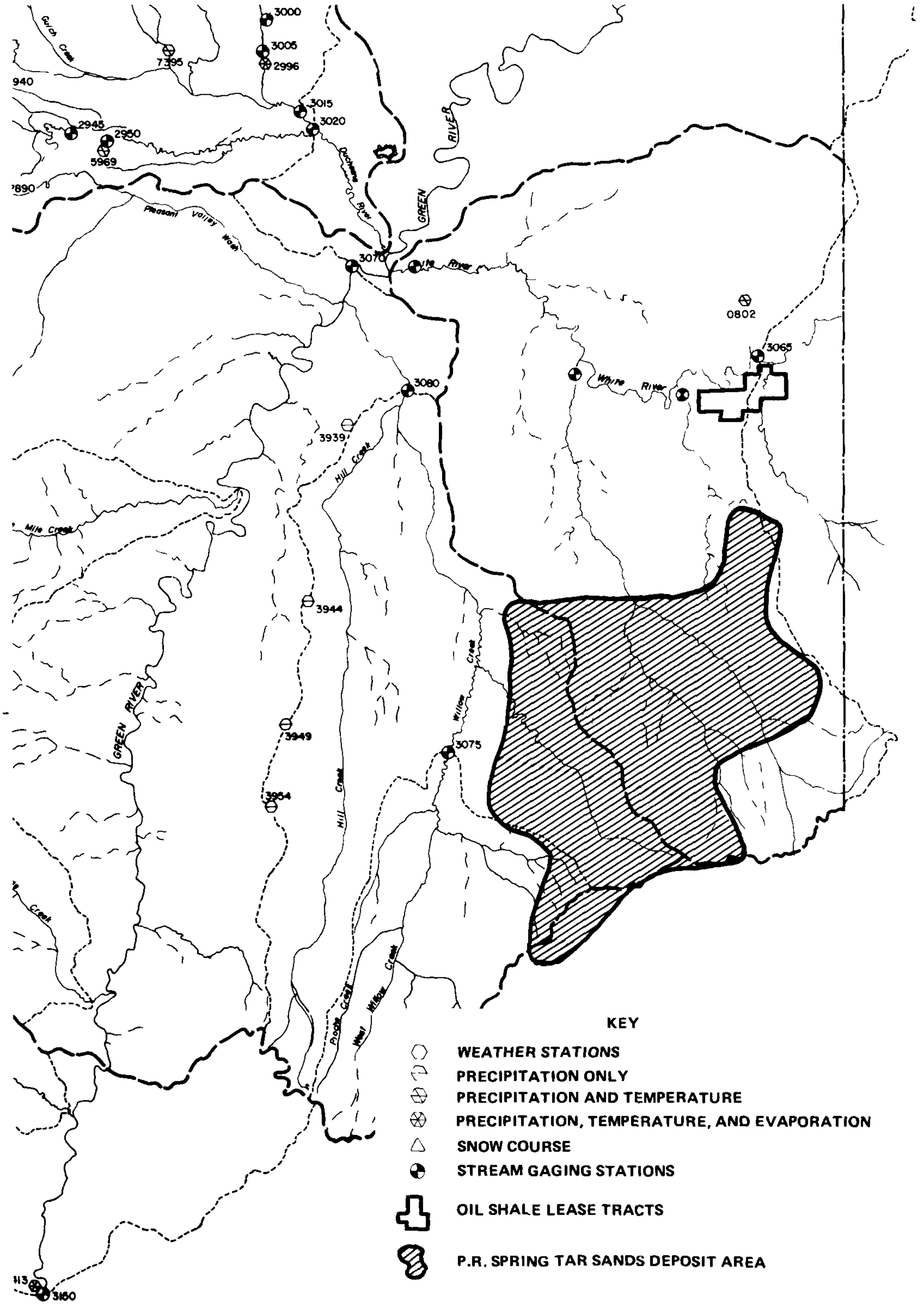
Station Number	Station Name
	Stream Gaging Stations
9-3075	Willow Creek above diversions near Ouray
9-3065	White River near Watson (Dragon)
9-3069	White River at mouth near Ouray, (Apr 1974)
9-3068	Bitter Creek near Bononza (Oct. 1970)
	Weather Stations
9-0802	Bonanza
9-3939	Hill Creek No. 1
9-3944	Hill Creek No. 2
9-3949	Hill Creek No 3
9-3954	Hill Creek No. 4

As stated previously, length of record is an important consideration in hydrologic monitoring; 20-30 years of records are highly desirable for making projections of trends and computing averages and standard deviations. The length of record for the stream gages in Table 37 are as follows:



Station Number	Station Name
9-3065	White R. near Watson (Dragon) (Roughby, Colorado)
9-3075	Willow Cr. above diversions near Ouray
9-3069	White R. near mouth near Ouray
9-3068	Bitter Cr. near Bonanza

Very few of the gaging records near P.R. Spring have long-term, well-defined records. Only the station on the White River near Watson and the one on Willow Creek above diversions have records long enough to be statistically significant. In addition to the gages on Bitter Creek and at the mouth of the White River, the USGS has established a number of gages above the oil shale lease tracts illustrated in Figure 50. Some information is being collected from these; however, it is not included here because it has not yet been published and is not available.



Source· Reference 5.

Figure 50. HYDROLOGIC AND METEROLOGIC MEASURING STATIONS NEAR P.R. SPRINGS TAR SANDS DEPOSITS

The Bonanza weather station has been in operation since 1938. The Hill Creek weather stations also are long term. Precipitation records in the upper portion of the Bitter Creek and Evacuation Creek drainages are poorly defined, however. No gages with any significant length of record exist near their headwaters.

Austin and Skogerboe (Reference 5) divide the southern Uinta Basin into smaller hydrologic subareas based on the location of the stream gages. These subareas facilitate the creation of water budgets. The hydrologic subareas of concern near the P.R. Spring deposit are illustrated in Figure 51.

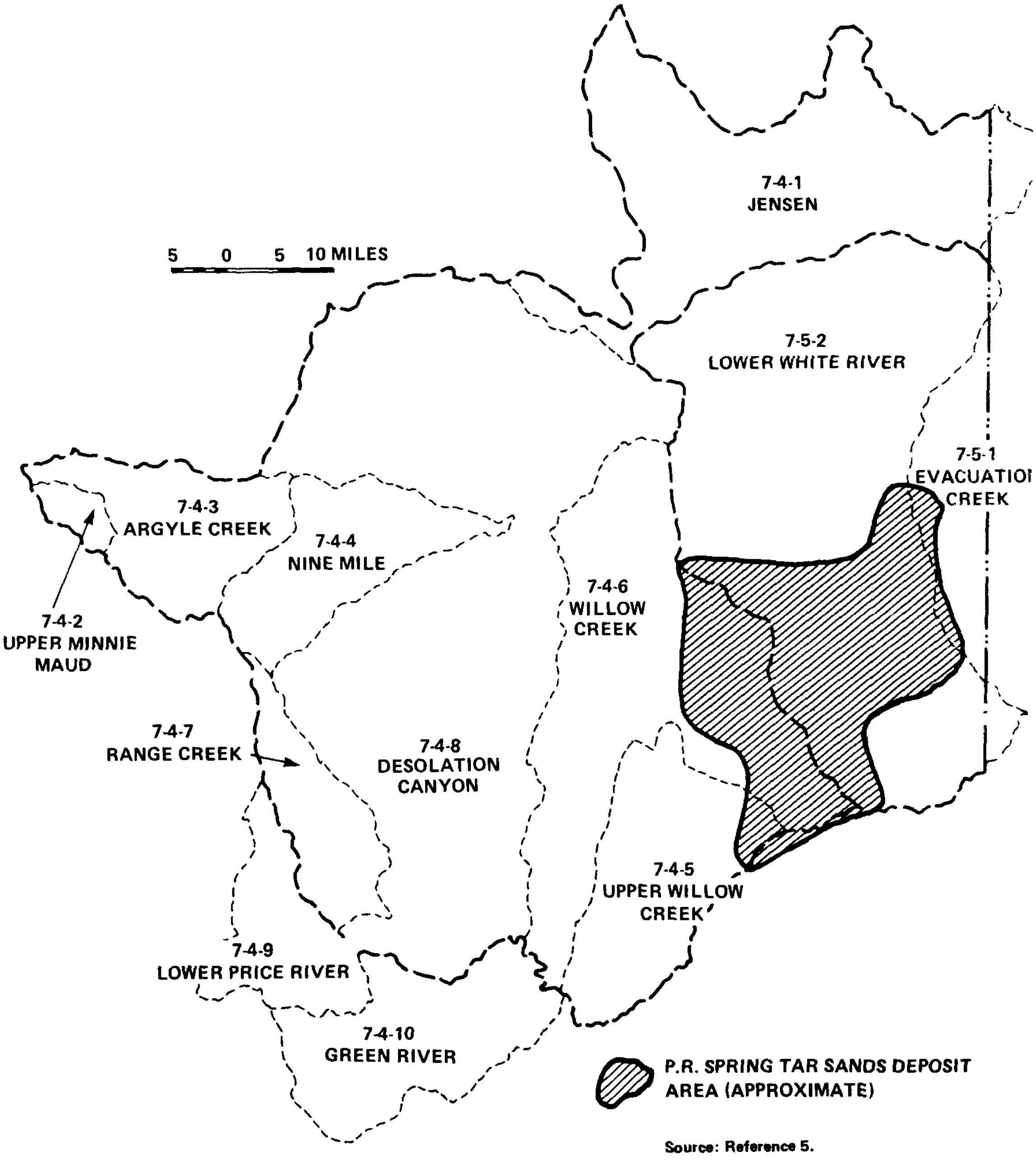
The gaging stations at Bitter Creek and the mouth of the White River were not in operation when Austin and Skogerboe completed their study. Thus, only two subareas in the White River drainage are defined for the vicinity of P.R. Spring. These are listed in Table 38. The Upper Willow Creek drainage is also of interest. The hydrologic subareas are illustrated in Figure 51.

Table 38. HYDROLOGIC SUBAREAS IN VICINITY OF P.R. SPRING DEPOSIT

Subarea Number	Description
7-4-5	Upper Willow Creek—the drainage area above the gaging station 9-3075, "Willow Creek above diversions near Ouray."
7-5-1	Evacuation Creek—the drainage area above the gaging station 9-3065, "White River near Watson (Dragon) (Rangely, Colorado)."
7-5-2	Lower White River—the drainage area above the mouth of the White River and below the gaging station 9-3065, "White River near Watson (Dragon) (Rangely, Colorado)."

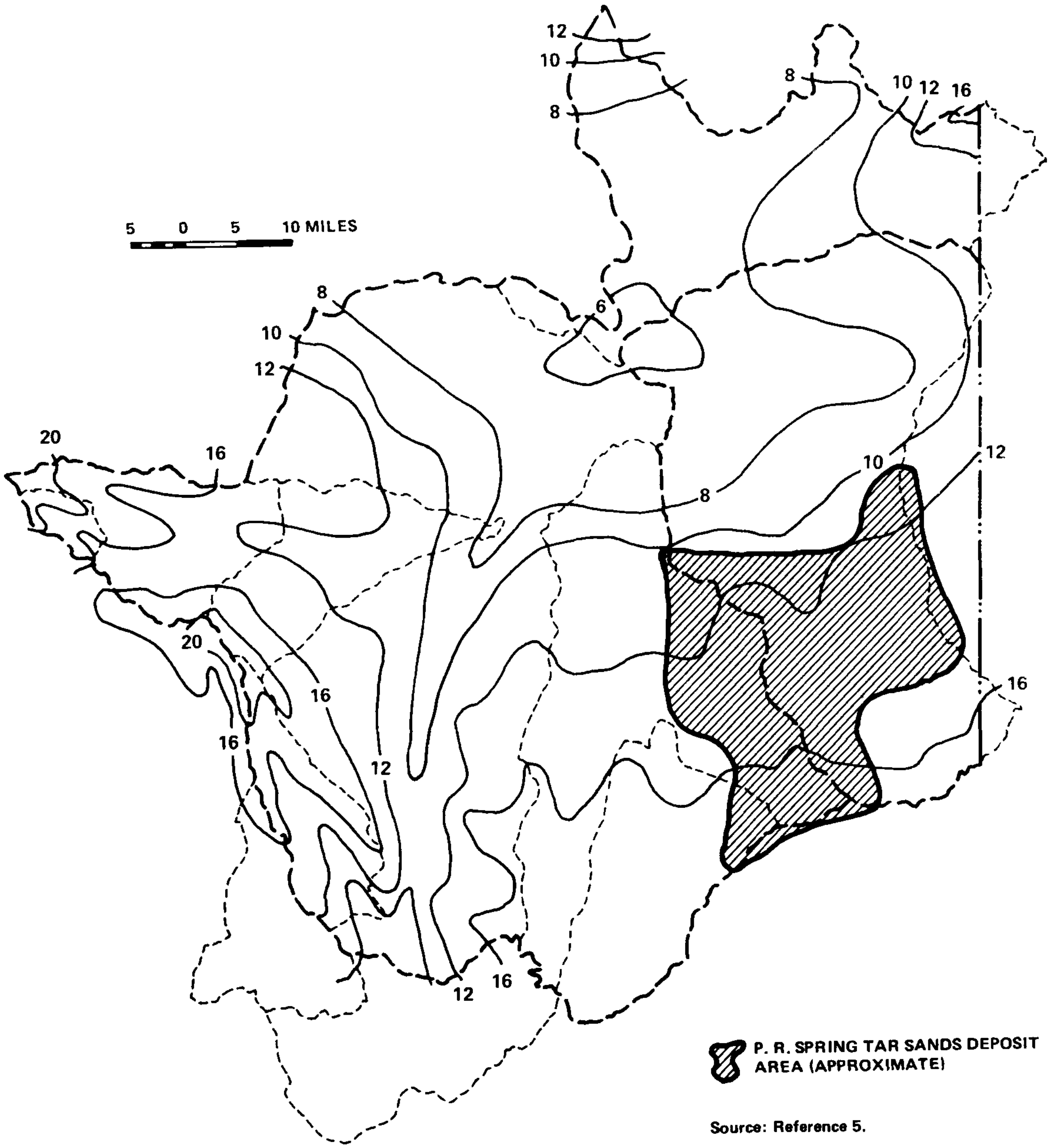
Precipitation is the starting point for most hydrologic investigations. The quantity of surface water and groundwater ultimately available depends on the volume and time distribution of precipitation. Austin and Skogerboe (Reference 5) extended the precipitation records in the entire Uinta River Basin to a 30-year data base and prepared a set of maps illustrating normal annual precipitation. The precipitation in the P.R. Spring area is illustrated in Figure 52.

In a normal year between 12 and 16 in. of precipitation falls in the vicinity of P.R. Spring. Land surface elevations range from 5000 to over 7000 ft. Much of the precipitation is in the form of snowfall.



Source: Reference 5.

Figure 51. HYDROLOGIC SUBAREAS IN THE GREEN AND WHITE RIVER DRAINAGE AREAS



Source: Reference 5.

Figure 52. NORMAL ANNUAL PRECIPITATION FOR THE GREEN AND WHITE RIVER DRAINAGE AREAS, 1931-60

Austin and Skogerboe (Reference 5) distribute the precipitation available to each hydrologic subarea on both a mean annual and monthly basis. The results are listed in Table 39. Considerable precipitation is available in the three subareas. The maximum estimated water requirement for a production-scale tar sands facility was 13,400 acre-feet (AF) per year. Precipitation in all the subareas exceeds this amount by a considerable margin. Unfortunately, only one-tenth or less of what falls actually runs off. This situation will be discussed in a following section.

No readily available information was found on the time distribution of precipitation near P.R. Spring. The writers feel that the time distributions for Jensen and the Vernal Airport illustrated in Figure 17 would be typical. For the Vernal-Jensen sites there is a 90 to 95 percent probability of 0.2 to 0.3 in. of precipitation each month. A roughly 50 percent chance exists for a half inch.

While the quantity of precipitation is important, the amount that actually runs off and becomes available for use is of greater concern. Austin and Skogerboe (Reference 5) determined the mean annual and monthly runoff for the "White River near Watson, Utah," gage. Price and Miller (Reference 30) summarized some information on runoff at the gages at Bitter Creek near Bonanza, White River near Watson, and Willow Creek above diversions. The information from these sources is presented in Table 40.

Price and Miller (Reference 30) also determined the mean monthly runoff for two stream gages on Willow Creek. This analysis is presented in Figure 42. The runoff in Willow Creek peaks in April as the winter snowpack melts. This is typical of streams in the area.

Some information on runoff from ephemeral and intermittent streams near P.R. Spring is also available in Reference 30. These data are summarized in Table 41.

The mean annual runoff or water yield map for the southern part of the Uinta River Basin is shown in Figure 53. By measuring the area between adjacent water yield lines and multiplying by the average depth for each area, the surface runoff can be estimated for a watershed. In the vicinity of P.R. Spring there is little runoff, averaging less than an inch.

The initial look at surface water supplies in the P.R. Spring area is not encouraging. Most of the streams that flow through the deposit area are intermittent. Neither Evacuation Creek nor Bitter Creek average sufficient runoff to support the minimum estimate for production-scale tar sands facilities. Willow Creek appears to have sufficient water, but this would have to be shared with Hill Creek. Supply versus demand will be discussed further following presentation of the water budgets.

In order to determine the amount of runoff available, detailed information is needed on the spatial distribution of the runoff and losses from seepage, consumptive use, groundwater, evaporation, and other factors. The water budget for a basin provides these details.

Table 39. MEAN MONTHLY AND ANNUAL PRECIPITATION IN EACH YDROLOGIC SUBAREA

Subarea		Oct		Nov		Dec		Jan		Feb		Mar		Apr		May	
		AF	in.	AF	in.	AF	in.	AF	in.	AF	in.	AF	in.	AF	in.	AF	in.
7-4-5	Upper Willow Cr.	24,700	1.62	21,800	1.43	30,100	1.97	19,100	1.25	21,800	1.43	21,800	1.43	24,700	1.62	17,200	1.13
7-5-1	Evacuation Cr.	12,200	1.46	5,600	.66	5,600	.66	5,600	.66	5,600	.66	5,600	.66	9,400	1.13	8,600	1.02
7-5-2	Lower White R.	82,900	1.38	38,100	.64	38,100	.64	38,100	.64	38,100	.64	38,100	.64	63,600	1.06	51,600	.86

Table 39. (Continued)

Subarea		Jun		Jul		Aug		Sep		Oct-Apr		May-Sep		Annual	
		AF	in.	AF	in.	AF	in.	AF	in.	AF	in.	AF	in.	AF	in.
7-4-5	Upper Willow Cr.	15,100	.99	13,000	.85	25,600	1.68	15,100	.99	164,000	10.75	86,000	5.64	250,000	16.39
7-5-1	Evacuation Cr.	8,600	1.02	7,400	.88	12,900	1.53	12,900	1.53	49,600	5.89	50,400	5.98	100,000	11.87
7-5-2	Lower White R.	51,600	.86	45,200	.77	77,300	1.29	77,300	1.29	337,000	5.64	303,000	5.07	640,000	10.71

Source: Reference 5.

Table 40. DATA FOR GAGES NEAR P.R. SPRING

(a) Summary of Runoff Data

Station Number	Name	Drainage Area (mi^2)	Period of Record	Average Discharge			Extremes (cfs)			
				cfs	AF/yr	Number of Years	Maximum	Date	Minimum	Date
9 3065	White R near Watson	4,020	Apr 1904 Oct 1906 May Nov 1918, Apr 1923 Sept 1972	700	507,200	49	8,160	7/15/29	53	7/19/34
9 3068	Bitter Cr near Bonanza	324	Oct 1970 Sept 1972	–	–	–	507	8/30/71	0	Many days each year
9 3075	Willow Cr above diversions, near Ouray	300	Aug 1950 Sept 1955 Sept 1957 Sept 1970	19 6	14,200	18	668	8/6/63	3	8/21 23/60

(b) Mean Monthly and Annual (1931 60) Historical Runoff

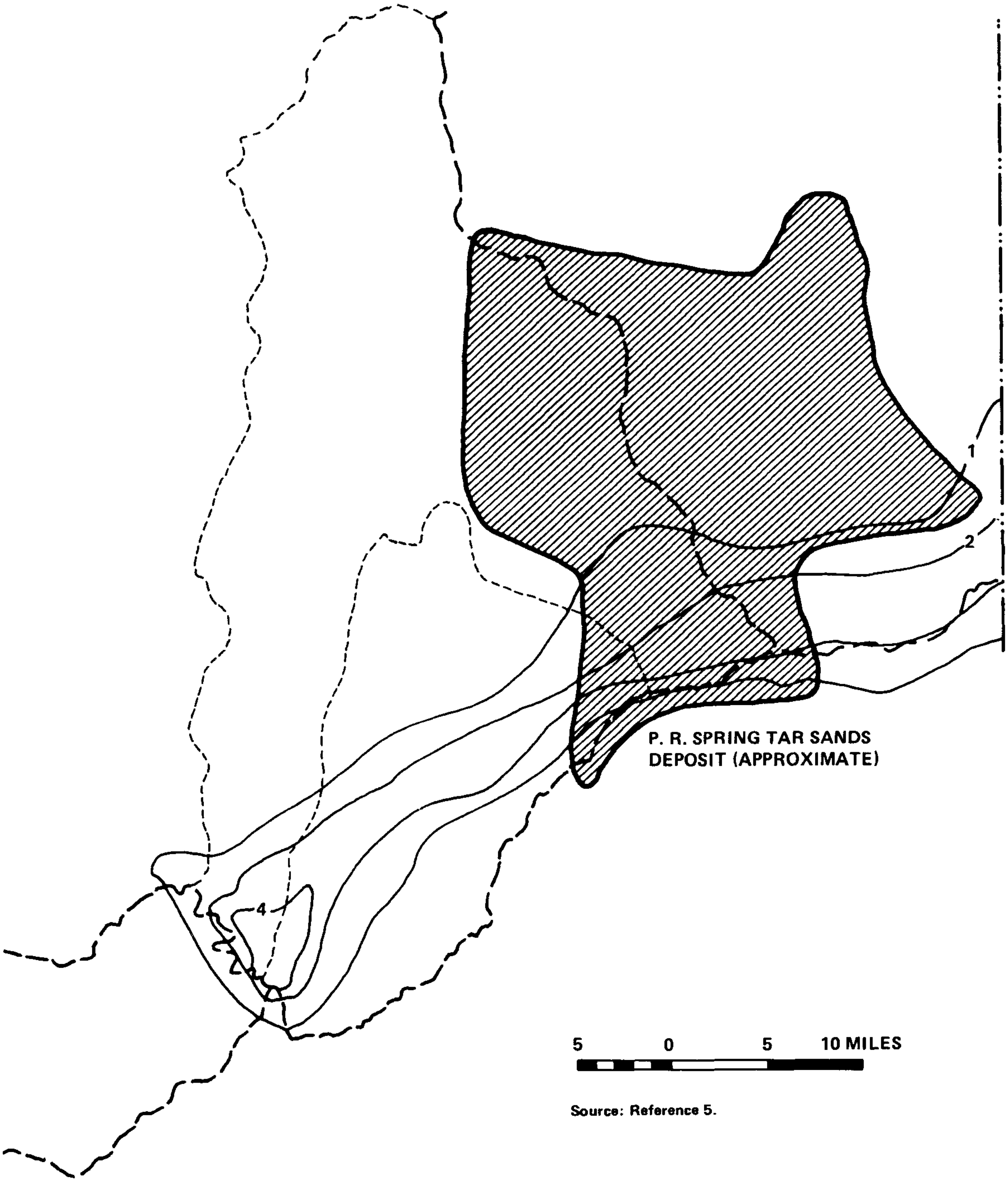
Station Number	Station Name	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
9 3065	White R near Watson (Dragon)	26,340	23,410	21,360	20,570	21,990	34,330	40,290	92,880	107,070	40,280	28,480	24,400	481,200

Table 41. ESTIMATES OF MEAN ANNUAL RUNOFF FOR EPHEMERAL AND INTERMITTENT STREAMS NEAR P.R. SPRING

Name	Type*	Drainage Basin		
		Area (mi^2)	Mean Altitude (ft)	Runoff (AF/yr)
Willow Creek (at gaging Station 9-3075)	P	310	7,650	14,200
Ute Canyon	EI	4.5	6,675	140
Cottonwood Wash	EI	140	5,445	850
Bitter Creek (at gaging Station 9-3068)	EI	320	6,945	800
Evacuation Creek	EI	300	6,560	2,630
Evacuation Creek (upper gage)	EI	220	6,860	780
Park Canyon	EI	32	6,425	10

*Type: EI, ephemeral or intermittent; P, perennial.

Source: Reference 30.



Source: Reference 5.

Figure 53. MEAN ANNUAL RUNOFF NEAR P.R. SPRING TAR SANDS DEPOSIT

Austin and Skogerboe prepared water budgets for each of the hydrologic subareas near the P.R. Spring deposit (Reference 5 and Section IV). The essential parts of these water budgets are presented, followed by the availability of surface water for tar sands development in the P.R. Spring area. Water quality is then discussed.

Surface Water Supplies

Upper Willow Creek Subarea (7-4-5)

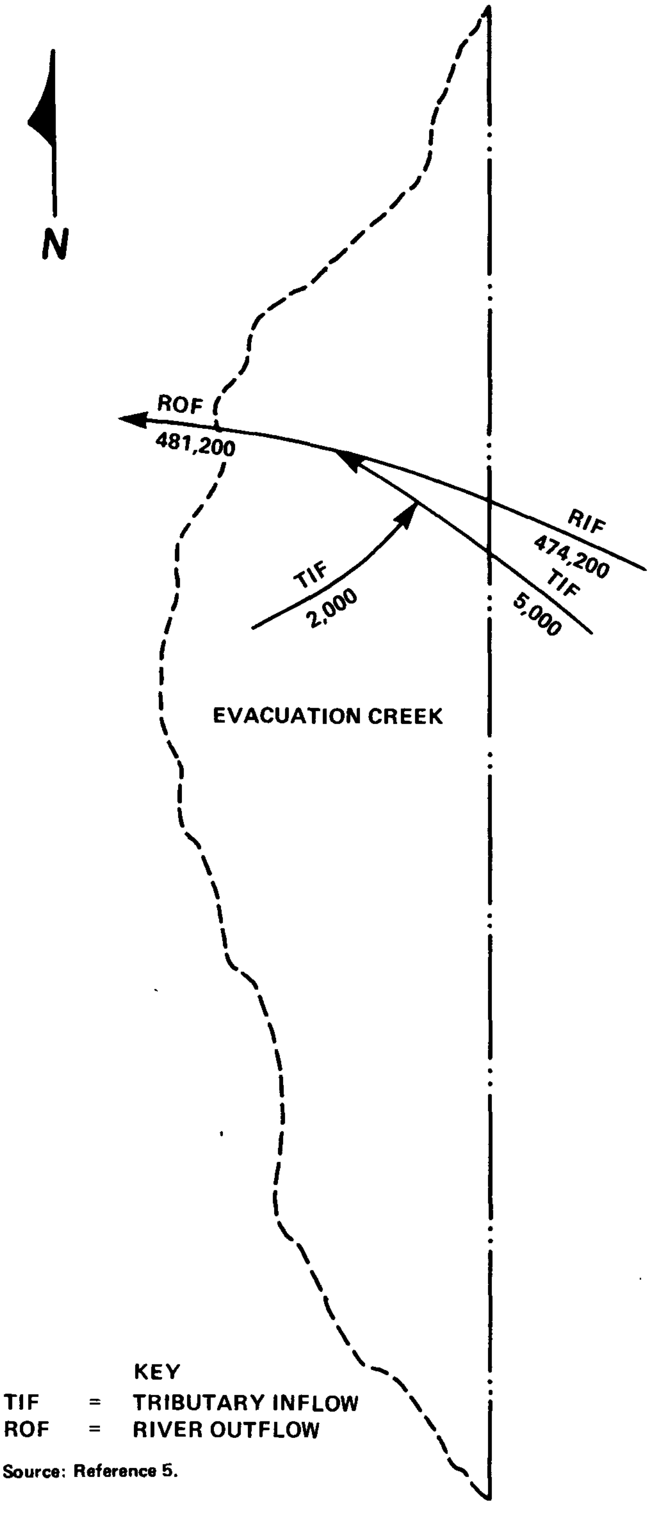
The Upper Willow Creek subarea is described in Section V. The water budget and flow diagram are presented in Table 32 and Figure 44, respectively.

Evacuation Creek Subarea (7-5-1)

The Evacuation Creek subarea is the drainage of Evacuation Creek above "White River near Watson" within Utah. Figure 54 gives a flow diagram of the mean annual water budget for the Evacuation Creek subarea; Table 42 represents the mean monthly and mean annual flows for the 1931-60 time period. The amount and distribution of the tributary inflow were estimated by comparing runoff-precipitation relationships from other adjacent subareas. The river inflow–the White River at the Utah-Colorado boundary line–was estimated from inflow-outflow relationships using USGS records for the river outflow–White River near Watson.

Lower White River Subarea (7-5-2)

The Lower White River subarea is located along the White River from the USGS stream gaging station 9-3065, "White River near Watson," to the mouth of the White River. The river inflow to the subarea is the river outflow from the Evacuation Creek subarea. The mean monthly and mean annual flows for the 1931-60 time period are listed in Table 43; Figure 55 represents a flow diagram of the mean annual water budget for this subarea.



KEY

TIF = TRIBUTARY INFLOW

ROF = RIVER OUTFLOW

Source: Reference 5.

Figure 54. FLOW DIAGRAM OF THE MEAN ANNUAL WATER BUDGET FOR THE EVACUATION CREEK SUBAREA

Table 42. MEAN MONTHLY AND MEAN ANNUAL WATER BUDGET FOR EVACUATION CREEK SUBAREA

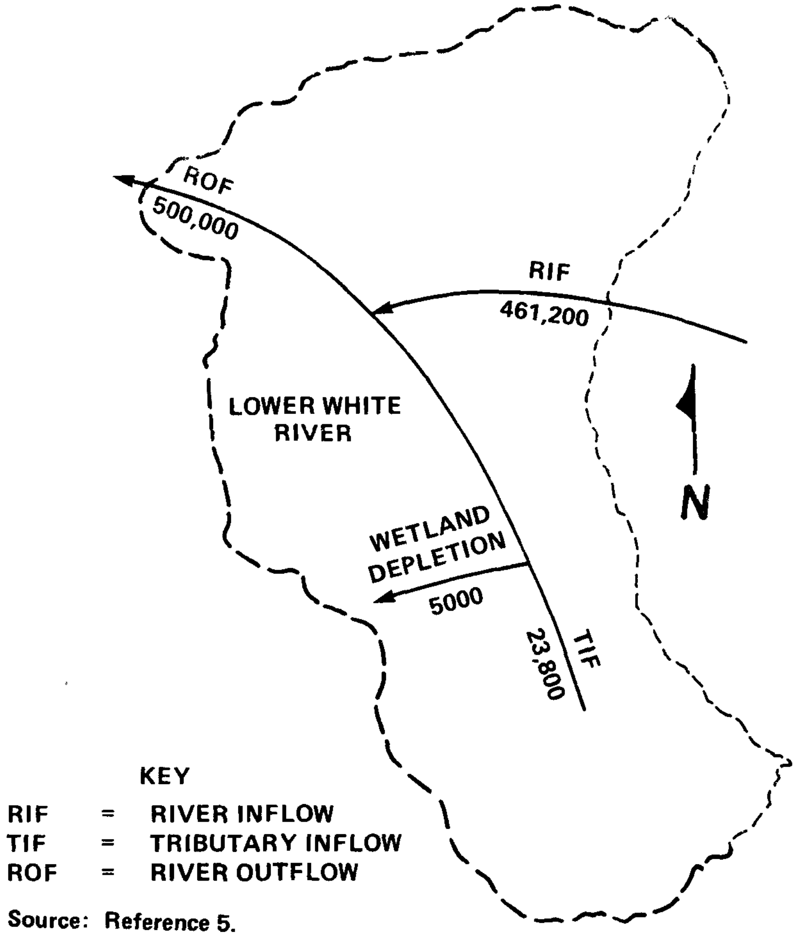
Characteristics	Water Budget (AF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
River inflow													
White R at Utah Colorado line	26 200	23 290	21,300	20 510	21,930	34,180	39 180	90,050	105 560	39 710	28,120	24 170	474 200
Tributary inflow													
Colo drainage of Evacuation Cr	100	90	40	40	40	110	800	1,870	1 080	410	260	160	5,000
Utah drainage of Evacuation Cr	40	30	20	20	20	40	310	760	430	160	100	70	2,000
Total surface inflow	26,340	23,410	21,360	20,570	21 990	34,330	40,290	92,680	107 070	40 280	24,480	24,400	481,200
River outflow													
White R near Watson (Dragon)	26,340	23,410	21,360	20 570	21,990	34 330	40,290	92 680	107,070	40,280	28,480	24,400	481,200

Source Reference 5

Table 43. MEAN MONTHLY AND MEAN ANNUAL WATER BUDGET FOR LOWER WHITE RIVER SUBAREA

Characteristics	Water Budget (AF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
River inflow													
White R near Watson (Dragon)	26,340	23,410	21,360	20,570	21,990	34,330	40,290	92,680	107,070	40,280	28,480	24,400	481,200
Tributary inflow													
Ungaged inflow	1,660	1,190	1,070	1,070	1,190	1,430	2,620	3,820	3,090	2,620	2,140	1,900	23 800
Total surface inflow	28,000	24,600	22,430	21,640	23,180	35,760	42,910	96,500	110,160	42,900	30,620	26 300	505,000
Depletion													
Wetland	190	0	0	0	0	20	60	610	910	1,310	1,160	730	5 000
River outflow													
White R at mouth	27,810	24,590	22,430	21,640	23,180	35,740	42,850	85,890	109,250	41,590	29,460	25,570	500,000

Source Reference 5



Source: Reference 5.

Figure 55. FLOW DIAGRAM OF THE MEAN ANNUAL WATER BUDGET FOR THE LOWER WHITE RIVER SUBAREA

Surface Water Availability for Tar Sands Development

The only major creeks that flow through the P.R. Spring deposit area are Bitter Creek and Main Canyon. Bitter Creek is classified as ephemeral or intermittent. The estimated annual runoff from Bitter Creek is 800 acre-feet per year from 320 mi^2 of drainage area. The estimates for Evacuation Creek from Austin and Skogerboe (Reference 5) and Price and Miller (Reference 30) differ by a factor of two. Stream gage records on both Bitter Creek and Evacuation Creek are short.

The runoff from Willow Creek, immediately to the west of the P.R. Spring deposit, is 13,000 acre-feet per year and is based on substantial amounts of record. The runoff from the White River at Watson is 481,200 acre-feet per year and is also based on substantial records.

As given in Table 3, the following hypothetical demands for water were calculated (based on 5 bbl of water per barrel of oil):

- five-well experimental facility: 35.5 AF/yr = 2.96 AF/mo;
- 24-well pilot facility: 213 AF/yr = 17.75 AF/mo; and
- large-scale production facility: 13,400 AF/yr = 1117 AF/mo.

As stated previously, these estimates assume 100 percent consumptive use and are very conservative.

When these figures are compared to availability, Bitter Creek would support test and pilot facilities but fall short in supporting a production-scale facility by a considerable margin. No data could be found concerning runoff from Main Canyon; however, since it drains considerably less area than Bitter Creek, it is not a likely source of water.

Since it appears that the runoff from the tar sands area itself is not adequate to support production facilities, it will be necessary to consider other sources. As stated previously, Willow Creek was identified by Price and Miller (Reference 30) as a potential location for water development. The measurement of 13,000 acre-feet per year at the stream gage adjacent to the P.R. Spring area nearly meets the estimated water needs for a production-scale facility (13,400 acre-feet per year). However, this water would be obtained at the expense of Hill Creek. Unless recylcing on the order of 50 percent were achieved, any water withdrawn from Willow Creek for use at the P.R. Spring tar sands area would reduce the water available for use at the Hill Creek tar sands area.

It is difficult to conclude anything about water availability from Evacuation Creek. Based on the lowest estimate of runoff (2600 acre-feet per year), it could support pilot and test facilities; based on the best case (7000 acre-feet per year), it could support half of a production facility. However, some type of runoff modeling or record extension should be performed before reaching any conclusions. Data gathered by USGS for development of Utah's oil shale lease tracts will be helpful in this regard.

Careful hydrologic studies would have to be undertaken before either Evacuation Creek or Bitter Creek could be used as water supplies. Because the runoff is highly intermittent, water supplies would have to be stored and the large losses caused by evapoartion and seepage would have to be calculated.

The flow of the White River at Watson (481,200 acre-feet per year) is more than enough to support production at any level. However, rights to the water would be difficult and/or expensive to obtain. The Utah Department of Natural Resources is planning to construct a dam on the White River (Reference 31) that would provide water for energy development and irrigation. Planned reservoir capacity is 118,000 acre-feet. Of this amount, the Ute Indian Tribe has irrigation rights for one-third. Of the remainder, which is allocated for energy development, some may be used for tar sands projects. The water would have to be transported, however, to the upper reaches of the deposit area, over a considerable distance and over an elevation difference of 2000 ft.

Surface Water Quality

As stated in Section IV, the amount and quality of water quality data vary widely. The same comments and cautions apply to the P.R. Spring area. Almost nothing is known about the water quality of any of the streams near P.R. Spring, with the exception of the White River. Price and Miller (Reference 30) report a single measurement for Bitter Creek at a flow of 1 cfs and a single measurement for Evacuation Creek at a flow of 0.05 cfs. Both were low in chlorides and fairly high in sulfates. The Bitter Creek sample contained 7240 mg per liter of dissolved solids, over 3000 of which were in the form of calcium and magnesium. The Evacuation Creek sample contained 3900 mg per liter of dissolved solids, 1100 of which were in the form of calcium and magnesium. Price and Miller reported on a number of samples from Willow Creek in September 1971 and 1972 (Table 35 and Reference 30). These samples indicate the water to be slightly saline and high in dissolved solids and hardness.

The USGS maintains a water quality monitor on the White River at Watson. Daily water quality information has been available since 1950. Values of temperature, pH, conductivity, and dissolved oxygen are recorded continuously. The water in the White River is generally fresh, with conductivities from 400 to 800 being typical. Hardness values of 250-350 mg per liter are typical. Values of pH range from 7.5 to 8.3.

The water quality of the streams near P.R. Spring cannot be judged without more-detailed information than is currently available.

GROUNDWATER

Before discussing groundwater directly, the subsurface geology in the vicinity of the P.R. Spring deposit must be presented. Accurate determination of the subsurface geology is essential to obtaining groundwater near P.R. Spring.

Subsurface Geology

P.R. Spring lies in a geomorphological district called the Tavaputs Plateau. This plateau rises slowly to the south from the White River. The predominant surface geologic formation is the Green River. Streams and dry reaches are deeply incised in the plateau. Canyon depths of 1000 ft are not unusual, as indicated in Reference 5.

The deeply incised canyons make this groundwater region considerably different than that which is found near Vernal. The streams in the narrow valleys flow close to bedrock. There is no well-defined, shallow groundwater reservoir as was present in the glacial outwash of Ashley Valley. Therefore, this discussion concentrates on water in the bedrock aquifers.

Price and Miller (Reference 30) present an excellent geologic map of the southern portion of the Uinta Basin. A portion of this is reproduced in Figure 56. Superimposed on Figure 56 are the approximate location of the P.R. Spring tar sands deposit and the location of two geologic sections, developed by Austin and Skogerboe in Reference 5.

The two geologic cross-sections are reproduced in Figure 57. The subsurface geology is fairly straightforward. The beds underlying P.R. Spring dip at shallow angles to the north and are nearly horizontal east and west under much of the deposit area. Toward the east, along the Colorado border, the beds dip westward, with several of the deeper formations outcropping along Asphalt Creek and Evacuation Creek.

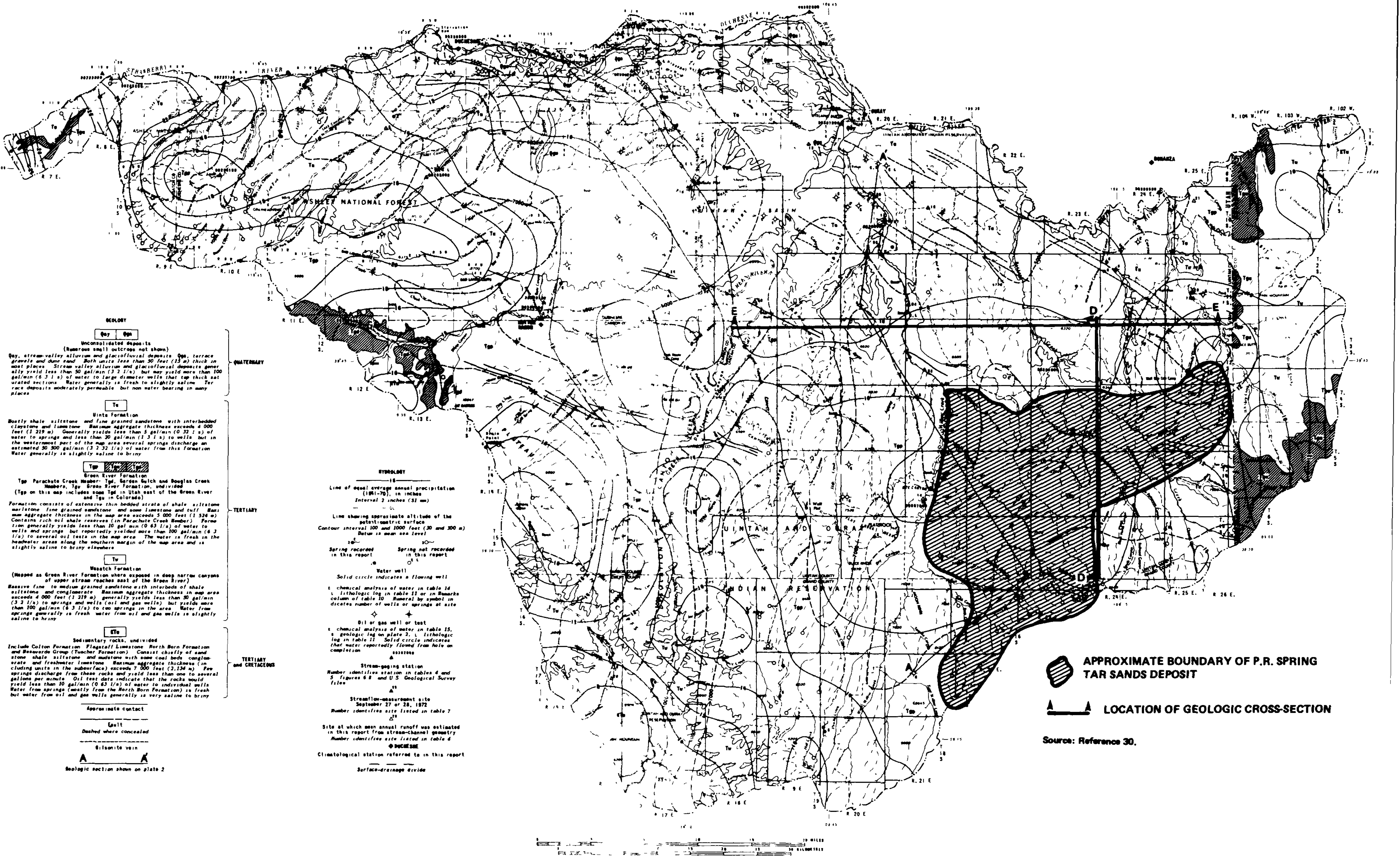
The Tertiary Parachute Creek, Garden Gulch, and Douglas Creek Members of the Green River Formation are the primary surface formations in the tar sands area. Care should be used in viewing cross-section E-E', which shows the Uinta Formation on the surface. Cross-section E-E' lies slightly to the north of the tar sands area (Figure 56). The Wasatch, Mesaverde, and Mancos Shale Formation lie beneath the Green River, in descending order. Although not shown in the figure, the Dakota Sandstone lies beneath the Mancos Shale.

Only very sketchy information is available on groundwater from bedrock in the vicinity of P.R. Spring. Feltis (Reference 3) describes the water-bearing properties and water quality of these formations.

The deepest formation shown on the cross-section D-D' is the Mancos Shale. Feltis (Reference 3) concludes that the Mancos Shale does not contain fresh water. No information is reported by Feltis on the water-bearing properties of the Mesaverde Group in the vicinity of P.R. Spring. One well considerably north of P.R. Spring yields 1 GPM. Several springs originating in the Mesaverde Group yield slightly saline water.

Water from Bedrock

Feltis (Reference 3) reports some data from the Wasatch Formation below P.R. Spring. A sample of slightly saline water was obtained from a well in T. 15 S., R. 21 E. The water contained 1996 mg per liter of dissolved solids. The Wasatch Formation probably recharges in the area of high precipitation along the cliffs to the south of P.R. Spring.

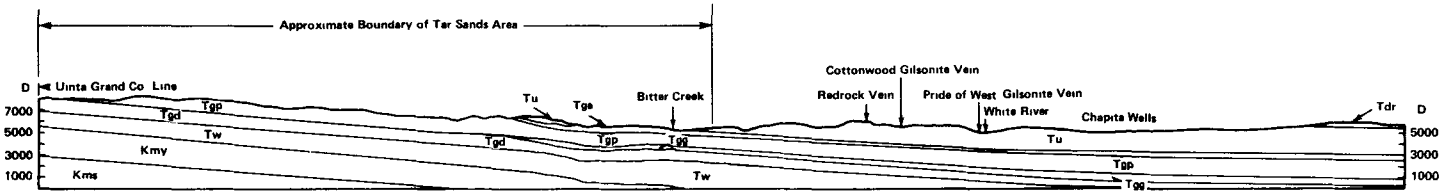


▨ APPROXIMATE BOUNDARY OF P.R. SPRING TAR SANDS DEPOSIT

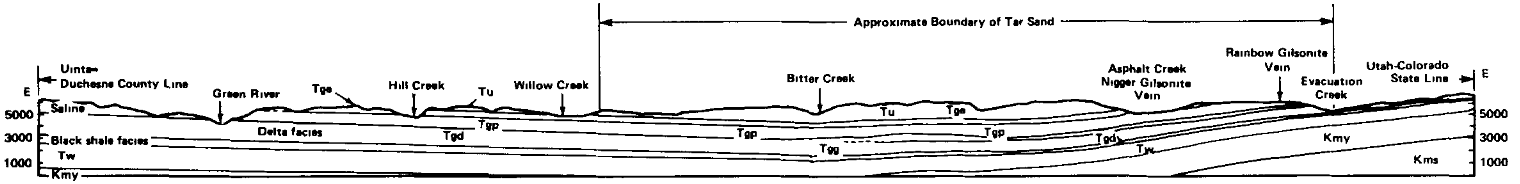
A———A' LOCATION OF GEOLOGIC CROSS-SECTION

Source: Reference 30.

Figure 56. GEOLOGIC MAP [illegible] SOUTHERN PORTION OF THE UINTA BASIN



Cross Section D D



Source Reference 5

Cross Section E E

Figure 57. GEOLOGIC CROSS-SECTIONS IN VICINITY OF P.R. SPRING TAR SANDS DEPOSIT

Feltis (Reference 3) concludes that the Green River Formation is a potential source of water for oil extraction from tar sands along the southern flank of the Uinta Basin. There are very few data to support this conclusion in the P.R. Spring area. There are virtually no water yield data from wells near P.R. Spring. Most yield data on the Green River Formation come from the Ashley Valley and Red Wash oil fields 20 to 30 mi north.

The chemical quality of the water in the Green River Formation ranges from fresh to briny. Analyses by Feltis (Reference 3) of 73 water samples collected from 51 wells and a spring indicate that 4 were fresh, 18 were slightly saline, and the remaining 51 were moderately saline to briny. Three of the samples of fresh water came from two of the wells and the spring. Fresh water from the spring (T. 15 S., R. 23 E.) contained 381 ppm of dissolved solids. Most of the slightly saline water came from wells on the southern flank of the Uinta Basin. The occurrence of fresh and slightly saline water along the southern flank of the Uinta Basin. The occurrence of fresh and slightly saline water along the southern flank of the basin suggests that the aquifers are recharged in the area of high precipitation north of the Roan Cliffs.

Tests at 17 oil and gas wells yielded water at the rate of 17 BPD (0.5 GPM) to 7200 BPD (200 GPM). Two gas wells in Sec. 35, T. 10 S., R. 20 E. and Sec. 17, T. 10 S., R. 22 E. were converted to water wells, and in 1964 these wells had flow rates of 2700 BPD (80 GPM) and 340 BPD (10 GPM), respectively. The largest reported yield of water from the Green River is from an oil well in T. 9 S., R. 24 E., which produced 7200 BPD (200 GPM) from a depth of 1932 ft. However, none of these values should be assumed for the P.R. Spring area.

References 3, 22, and 30 contain tabulated data on wells and springs near P.R. Spring. These data are reproduced in Table 44 for all the reported wells and springs that lie in T. 13 S., Rs. 21-26 E.; T. 14 S., Rs. 21-26 E.; T. 15 S., Rs. 21-23 E.; T. 16 S, Rs. 22-23 E.; and T. 17 S., R. 22 E.

Records of active and discontinued wells were obtained from the Utah State Oil and Gas Conservation Commission. A well in T. 17 S., R. 23 E. encountered fresh water in the Dakota Sandstone at a depth of 6608 ft. No yield data were given. A well in T. 17. S., R. 22 E. also encountered water in the Dakota Sandstone. A well in T. 17 S., R. 21 E. reported an undetermined quantity of salt water at a depth of 9730 ft. The formation was not identified.

A sizable gas field lies 6 to 10 mi south of P.R. Spring in the Grand Valley, outside of the Uinta Basin. Oil and gas wells in T. 17. S., Rs. 24-26 E. report water in the Dakota Sandstone and other formations. These wells are 2000 to 3000 ft deeper than those near P.R. Spring.

It is difficult to reach any meaningful conclusions on the groundwater supply at P.R. Spring with only the available data. In particular, data on the yield of the various forma-

Table 44. DATA ON SELECTED SPRINGS, WELLS, AND OIL AND GAS WELLS NEAR P.R. SPRINGS

(a) Records of Selected Wells

Location	Owner	Year Con-structed	Well Depth (ft)	Casing Depth (ft)	Casing Diam-eter (in.)	Well Finish	Alti tude- (ft)	Water Level (ft)	Date Water Level Measured	Use of Water
(D 13 21)15ddc 1	Willis Stevens	1961	52	52	6	P	5,590	35	4/61	U
(D-13 21)22aab 1	Willis Stevens	1961	40	15	5	P	5,600	10	4/61	U
(D-14-22)25baa 1	Willis Stevens	1956	200	–	4	–	7,205	–	–	U
(D-14-22)26aca 1	Willis Stevens	1959	150	–	–	–	7,080	–	–	U

(b) Records of Selected Petroleum-Test Wells

Location	Name	Year Con-structed	Altitude (ft)	Well Depth (ft)	Depth to Top of Major Aquifer or Water-bearing Zone (ft)	Length of Well Open (ft)
(D-13-23)26acd-1	Skyline Neilson 1	1963	6,460	5,852	2,000	–
(D-15-21)22dcc 1	Atlantic Fed. 22-2	1963	7,420	5,700	3,134 5,518	8 23
(D-15-22)36dac-1	Texaco Fence Canyon 1	1967	7,690	10,348	9,232	117

(c) Records of Selected Springs

Location	Name or Owner	Altitude of Land Surface (ft)	Geologic Source	Rate (GPM)	Discharge Temper- (°C)	Date	Use	Remarks and Other Data Available
(D 13-23)27acd-S1	–	6,180	Tgp	<.5	–	4/12/72	–	Undeveloped; probably intermittent and used by live stock
(D 13-25)13add S1	Mud Spring	6,475	Tw	Dry	–	9/1/71	U	Formerly used for domestic and stock supply
(D 16-22)23dcd-S1	Cedar Camp Spring	7,900	Tgp	5	–	7/2/60	D, S	Piped to stockwatering trough, discharge measured by U.S. Bureau of Land Management
(D-14-22)25cac S1	Pine Spring	7,060	Tgp	4.5m	8 0	8/9/65	S	Piped to stockwatering trough, discharge measured by U.S. Bureau of Land Management
(D-14 24)21ccc-S1	Unknown	6,580	Tgp	10	10.0	9/12/72	S	Piped to stockwatering trough
(D 15-23)36ddd-S1	P R Spring	8,010	Tgp	5 6m	8.5	9/17/64	S	Piped to stockwatering trough, discharge measured' by U.S. Bureau of Land Management
(D 15-23)7bcc-S1	Unknown	7,438	Tgp	.2m	10 5	9/23/73	S	Piped to stockwatering trough

(d) Records of Selected Springs

Location	Name or Owner	Altitude (ft)	Discharge (GPM)	Date Measured	Temperature (°C)	Date Measured	Use of Water	Chemical Analysis Available
(D 13-23)27acd-S1	Seep	6,180	0.4E	4/72	10.5	4/72	–	P
(D-13-25)13add-S1	Mud Spring	6,475	–	–	–	–	–	–
(D-13-25)29bab-S1	Indian Spring	7,050	2E	9/71	14.5	9/71	S	P
(D-14-22)25cac-S1	Pine Spring	7,060	4M	8/65	8.0	4/72	S	P
(D-14 24)21ccc-S1	–	6,580	10E	9/72	10 0	9/72	S	P
(D-15-23)36ddd-S1	P.R. Spring	7,950	1M	9/64	8.5	9/64	S	P
(D-16-22)23dcd-S1	Cedar Camp Spring	7,900	5M	7/60	–	–	S	–

Table 44. DATA ON SELECTED SPRINGS, WELLS, AND OIL AND GAS WELLS NEAR P.R. SPRINGS (Continued)

(e) Records of Selected Wells and Springs

Location			Operator or Owner	Name or Number	Producing Formation	Depth to Top of Formation (ft)	Depth to Bottom of Formation (ft)	Interval Sampled (ft)	Yield (BPD/GPM)	Method or Point of Collection	Date of Collection	Temperature (°F)
T	R	Section										
15S	21E	C SW¼SE¼ 22	*Atlantic Refining Co*	*22 2*	*Wasatch Fm.*	1,610	*3,602*	3,134-42	–	DST 1	9/26/63	–
								3,466-80	–	DST 2	9/28/63	–
					Castlegate Ss	5,518	–	5,518-41	–	DST 4	10/12/63	–
15S	22E	W½NE¼SE¼ 36	Texaco, Inc	1	Entrada Ss	9,194	9,360	9,232 9,349	100(R)/3	Swab test	4/60	–
15S	23E	SE¼SE¼ 36	–	P.R. Spring	Green R Fm	0	–	–	34/1(M)	Flow	9/17/64	47
15½S	23E	NE¼SW¼SE¼ 33	Texaco, Inc.	3	Morrison Fm	8,100	8,706	8,630	–	–	–	
13S	23E	SE¼SW¼NE¼ 26	Skyline Oil Co.	1	Green R Fm	0	2,170	2,000	–	–	6/60	–

(e) (Continued)

Location			Chemical Content (ppm)											
			Silica	Calcium	Magnesium	Sodium and Potassium	Sulfate	Chloride	Nitrate	Dissolved Solids	Hardness as Calcium Carbonate	Noncarbonate Hardness as Calcium Carbonate	Percent Sodium	Sodium Absorption Ratio (SAR)
T	R	Section												
15S	21E	C SW¼SE¼ 22	–	20	36	664	2	1,065	–	1,966	–	–	–	–
			–	80	36	3,766	7,579	355	–	11,986	–	–	–	–
			–	600	109	11,643	5,813	14,981	–	33,253	–	–	–	–
15S	22E	W½NE¼SE¼ 36	–	5,115	534	28,237	72	54,000	–	88,052	–	–	–	–
15S	23E	SE¼SE¼ 36	17	65	36	17	94	2 8	0.5	381	312	64	11	4
15½S	23E	NE¼SW¼SE¼ 33	–	–	–	–	–	–	–	–	–	–	–	–
13S	23E	SE¼SW¼NE¼ 26	40.8	10.4	7 1	261	423	17	–	1,086	–	–	–	–

(e) (Continued)

Location			Chemical Content (ppm)			Remarks
			Specific Conductance (micromhos/cm at 25°C)	Resistivity (ohmmeter at 68°F)	pH	
T	R	Section				
15S	21E	C SW¼SE¼ 22	–	1 97	8.4	DST 1 recovered 1,482 ft of gas-cut water
			–	.66	8.6	*DST 2 recovered 525 ft of brackish water with sulfur water.*
			–	.23	7.3	DST 4 recovered 150 ft of slightly gas-cut muddy water and 950 ft of slightly gas-cut brackish water
15S	22E	W½NE¼SE¼ 36	–	10	7 3	Swabbed 4¼ bbl/hr of water from 8,800 ft with fluid level standing at 8,000 ft
15S	23E	SE¼SE¼ 36	606	–	7.7	
15½S	23E	NE¼SW¼SE¼ 33	–	–	–	
13S	23E	SE¼SW¼NE¼ 26	–	–	–	

tions are meager. An excellent first step in the detailed study of P.R. Spring would be to conduct pump tests.

Groundwater Availability for Tar Sands Development

The following quantities of water (based on 5 bbl of water per barrel of oil) are estimated for production-scale tar sands facilities of various sizes:

- five-well experimental facility–22 GPM,
- 24-well pilot facility–132 GPM, and
- large-scale production facility–8300 GPM.

As stated previously, these estimates assume 100 percent consumptive use and are very conservative. No data exist to compare to these estimates. As stated in Section V, several wells owned by the Ute Tribe near Hill Creek produce from 5 to 15 GPM. These wells, located in the Green River Formation, are very shallow (less than 100 ft). Yields this low are barely capable of supporting test facilities. A Texaco well in T. 15 S., R. 22 E. produced 3 GPM from the Entrada Sandstone; again, this yield is too low to be useful.

One encouraging note can be found in the data on the springs provided in Table 44. Note that six of seven springs originate in the Parachute Creek Member of the Green River Formation. Weeks et al. (Reference 32) report that the Parachute Creek Member is the major aquifer in the Piceance Creek Basin of western Colorado. This aquifer is less than 30 mi to the northeast of P.R. Spring. The Piceance Basin wells in the Parachute Creek Member yield up to 1000 GPM, with 200 to 400 GPM being typical. Only detailed exploration will determine if such yields are possible near P.R. Spring. The leached zone present in the Piceance Basin may not be present in the Uinta Basin.

VII. WATER RESOURCES NEAR SUNNYSIDE

This section describes in detail the water resources in the vicinity of the Sunnyside deposit. First, the available precipitation and surface runoff are considered. Water budgets are presented for the basin above existing stream gages. Then, the availability of groundwater is investigated.

SURFACE WATER

As stated previously, the Sunnyside tar sands deposit lies along the boundary between the Uinta and Price hydrologic basins. Only a small quantity of surface water originates in the Uinta Basin near Sunnyside; thus, most of this section is concerned with the Price River drainage.

The major portion of the information in this section comes from Reference 33, which is a hydrologic inventory of the Price River Basin developed by the Utah Division of Water Resources. Information on the Uinta Basin was obtained from References 5 and 23. A recent USGS publication by Waddell (Reference 34) describes some recent data collection activities of the USGS in the vicinity of Sunnyside.

The immediate vicinity of Sunnyside, Utah, and the approximate boundaries of the tar sands area are illustrated in Figure 58. Reference lines for 5- and 10-mi distances are provided to indicate the distance over which water might be transported from streams.

There are few streams of any significance in the vicinity of the Sunnyside deposit. The major ones are the Price River, Icelander Creek, and Grassy Trail Creek in the Price Basin and Minnie Maud Creek and Nine Mile Creek in the Uinta Basin. Of these five, only Minnie Maud Creek and the Price River have been gaged. The flow for both Icelander and Grassy Trail Creeks is classified as ephemeral/intermittent.

The gaging station and hydrologic measuring station network maintained by the USGS and other agencies in the vicinity of the Sunnyside deposit is illustrated in Figure 59. The

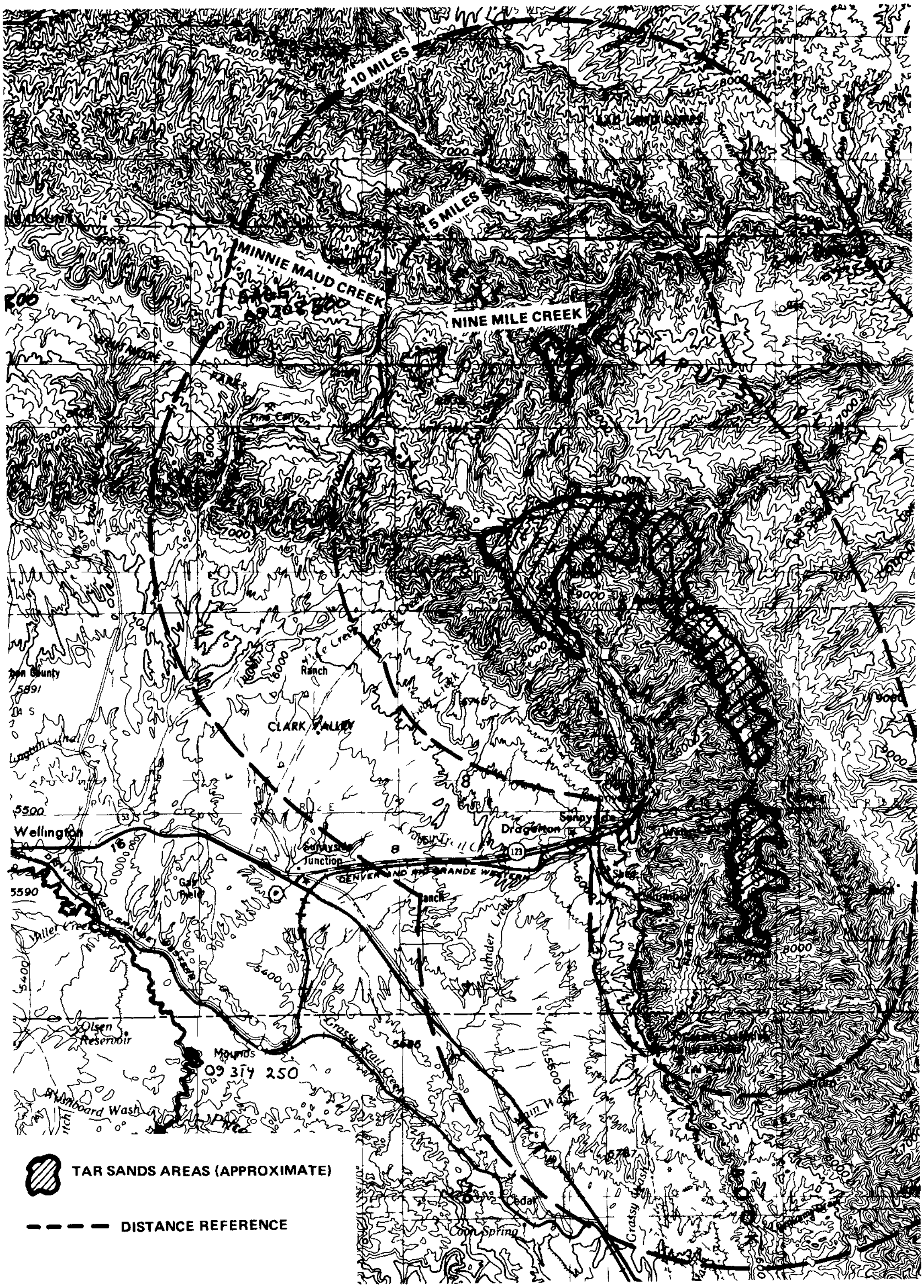
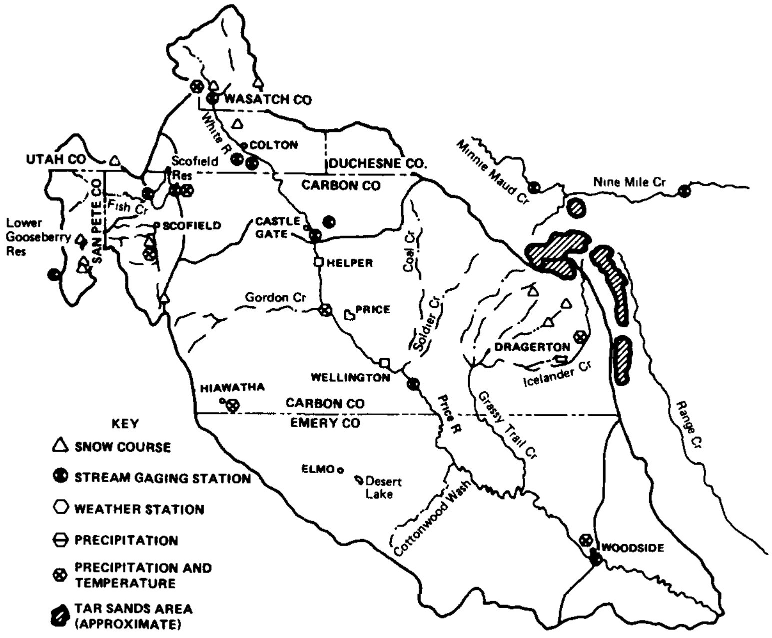


Figure 58. SUNNYSIDE TAR SANDS AREAS



Source Reference 33

Figure 59. PRICE RIVER BASIN HYDROLOGIC MEASURING STATIONS

stations of concern in terms of identifying water resources for the Sunnyside area and the period of record for each station are as follows:

Station Number	Type of Record	Station Location	1910	1920	1930	1940	1950	1960	1970
9-9629	Precipitation	Woodside				—	—		
9-3117	Streamflow	Price R. near Soldier Summit						—	—
9-3140	Streamflow	Price R. near Wellington					—	—	—
9-3145	Streamflow	Price R. at Woodside	—			—	—	—	—
9-3085	Streamflow	Minnie Maud Cr. near Myton					—	—	—
9-3145	Chemical Quality	Price R. at Woodside	—	—	—	—	—	—	—
9-3145	Dissolved Solids	Price R. at Woodside	—	—	—	—	—	—	—

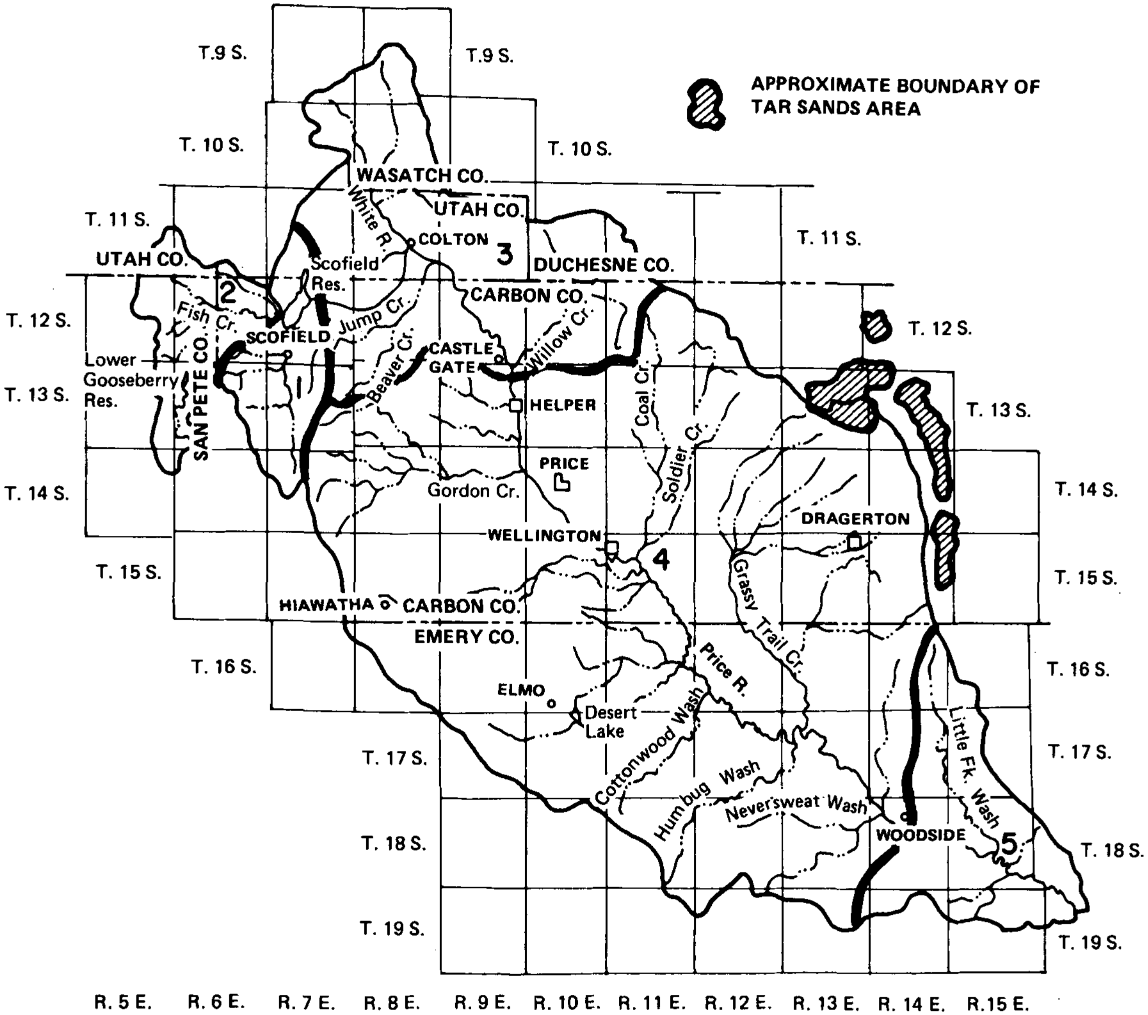
As stated previously, length of record is an important consideration in hydrologic monitoring. Virtually all the stations discussed in this section have been recording for 20 years or more. This is considered an adequate base for making long-term decisions. The streamflow of the major stream and precipitation are both well defined.

The Price River Basin has been divided into smaller hydrologic subareas, based on the location of the stream gages. These subareas are used in water budget calculations. The five subareas of the Price Basin, listed in Table 45, are illustrated in Figure 60. Also listed in Table 45 are two subareas from the Uinta Basin that are of interest here.

Table 45. HYDROLOGIC SUBAREAS IN THE PRICE AND UINTA BASINS NEAR SUNNYSIDE

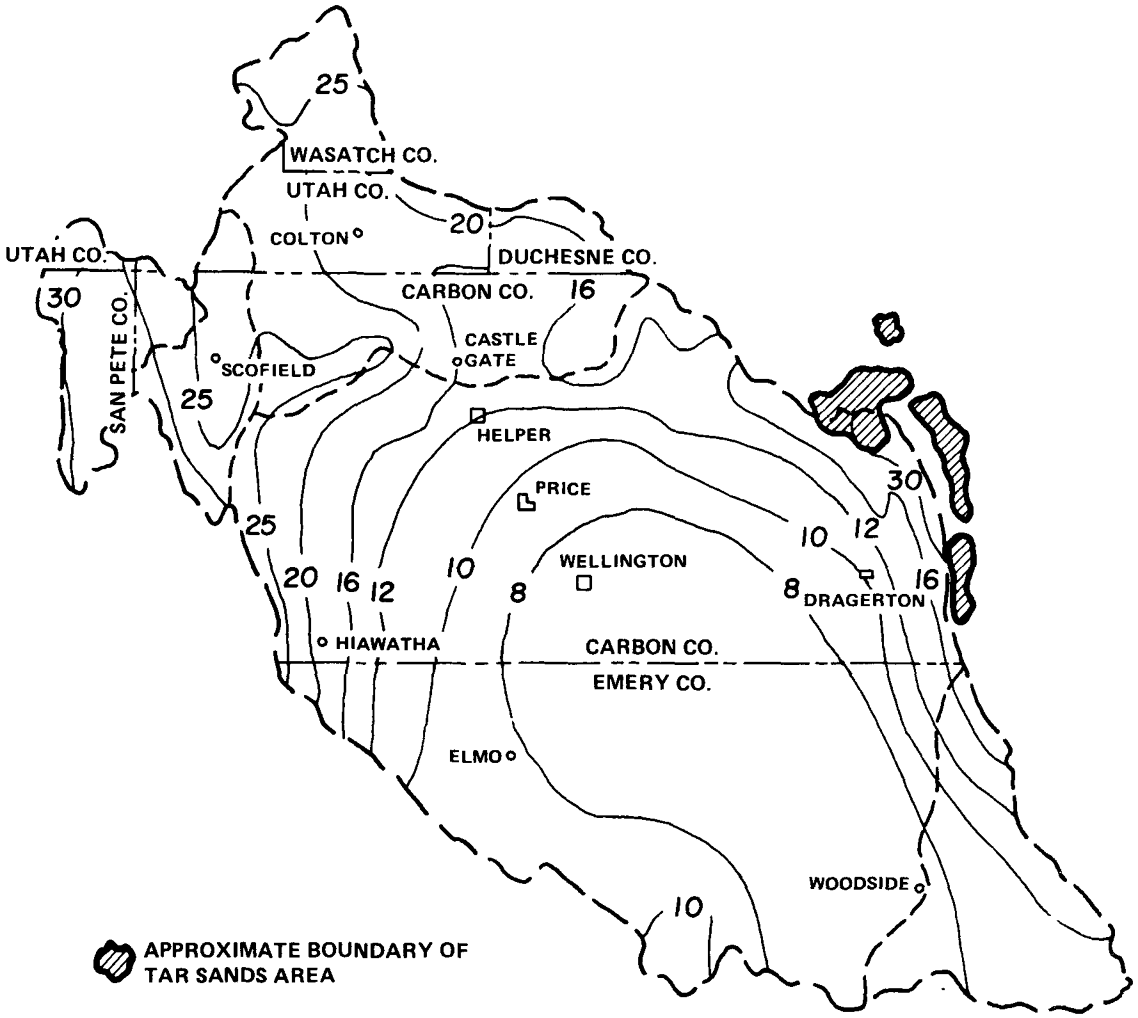
Subarea Number	Description
8-1-1	Scofield– the drainage area above the gaging station 9-3115, "Price River near Scofield" and below the gaging station 9-3105, "Price River above Scofield."
8-1-2	Fish Creek–the drainage area above the gaging station 9-3105, "Price River above Scofield."
8-1-3	Colton–the drainage area below the gaging station 9-3115, "Price River near Scofield," and above the gaging station 9-3130, "Price River at Heiner."
8-1-4	Price–the drainage area below the gaging station 9-3130, "Price River at Heiner," and above the gaging station 9-3145, "Price River at Woodside."
8-1-5	Lower Price–the drainage area between the gaging station 9-3145, "Price River at Woodside," and the Green River.
7-4-2	Upper Minnie Maud–the drainage area above the gaging station 9-3085, "Minnie Maud Creek near Myton."
7-4-3	Argyle Creek–the drainage area above the gaging station 9-3090, "Minnie Maud Creek at Nutter Ranch, near Myton," and below the gaging station 9-3085, "Minnie Maud Creek near Myton."

Precipitation is the starting point for most water resources investigations. The quantity of both surface water and groundwater ultimately available depends on the volume and time distribution of precipitation. A hydrologic inventory by the Utah Division of Water Resources (Reference 33) extended the precipitation records in the Price River Basin to a long-term data base. Figure 61 shows the normal annual precipitation (Reference 33). As Reference 33 shows, precipitation is heaviest from fall through spring (September through April), and much of this precipitation is in the form of snowfall. Approximately 20 in of precipitation per year falls in the immediate vicinity of the Sunnyside deposit. The amount of precipitation diminishes rapidly as the elevation decreases to the southwest.



Source: Reference 33.

Figure 60. HYDROLOGIC SUBAREAS IN THE PRICE RIVER DRAINAGE AREA

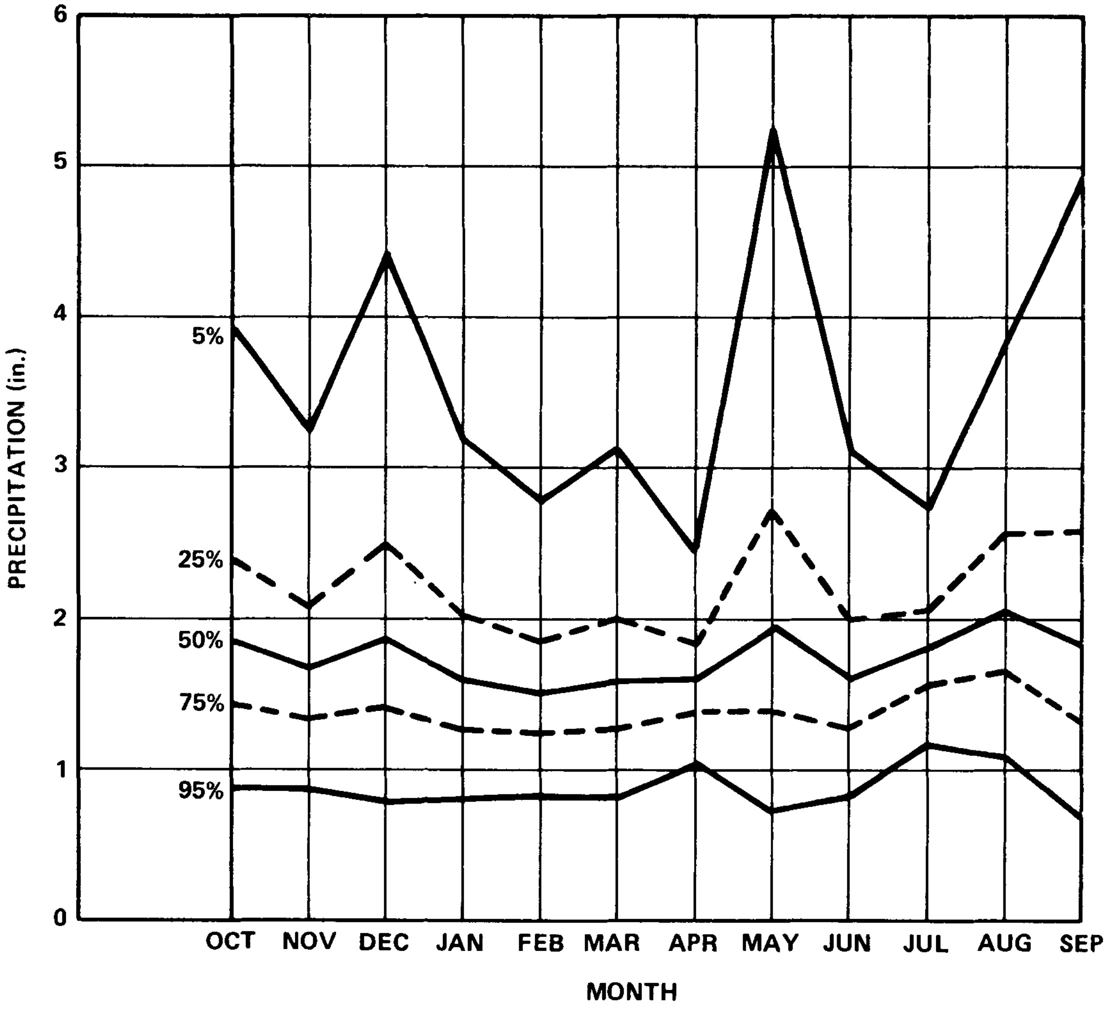


Source: Reference 33.

Figure 61. NORMAL ANNUAL PRECIPITATION IN THE PRICE RIVER DRAINAGE AREA

Several other descriptions of the distribution of the precipitation in the Price River Basin over time are given in Reference 33. Figure 62 shows the monthly precipitation frequency distribution at the Price Game Farm Station and the mean monthly and annual precipitation atthe Price Game Farm and Woodside stations. These values are listed in Table 46.

The monthly precipitation frequency distribution is quite interesting. It indicates that a 50 percent probability of normal amounts of precipitation is quite standard throughout the year. Extreme precipitation events (5 percent probability) occur most often in May and December.



Source: Reference 33.

Figure 62. MONTHLY PRECIPITATION FREQUENCY DISTRIBUTION
PRICE GAME FARM STATION

Table 46. MEAN MONTHLY AND MEAN ANNUAL PRECIPITATION AT STATIONS IN THE PRICE RIVER DRAINAGE AREA

Station Number	Station Name	Precipitation (in.)												
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
9-7015	Price Game Farm	0.96	0.64	0.88	0.73	0.65	0.66	0.61	0.70	0.70	0.90	1.11	0.83	9.24
9-9629	Woodside	0.88	0.73	0.48	0.50	0.37	0.39	0.64	0.52	0.48	0.49	0.91	0.66	7.05

Source: Reference 33.

While the quantity of precipitation is important, the amount that actually runs off and becomes available for use is of greater concern. The mean monthly and annual runoffs at selected gaging stations in the vicinity of Sunnyside are listed in Table 47. These values [in acre-feet (AF)] were obtained from References 5 and 33 as well as from historical records at each gaging station.

Table 47. MEAN MONTHLY AND MEAN ANNUAL RUNOFF AT STATIONS IN THE PRICE RIVER DRAINAGE

Station Name	Period of Record	Runoff (AF)												
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Price R. near Wellington	1950-58	1,957	1,673	1,451	1,381	1,675	2,623	8,743	17,149	8,378	3,180	4,268	2,157	56,635
Price R. at Woodside	1946 78	4,493	3,593	2,505	1,909	3,036	7,617	10,568	15,301	7,355	5,007	7,753	6,297	75,439
Price R. near Heiner	1934-78	2,635	1,069	742	591	714	2,289	9,725	20,863	13,410	11,167	7,436	5,042	75,743
Minnie Maud Cr near Myton	1957-78	80	70	30	30	30	90	640	1,490	870	330	210	130	4,000
Minnie Maud Cr. at Nutter Ranch near Myton	1960-70	530	450	420	380	410	750	2,510	3,530	1,470	560	490	500	12,000

Source References 5 and 33.

The mean annual runoff, or water yield, map for the Price River Basin is illustrated in Figure 63. By measuring the area between adjacent water yield lines it is possible to estimate runoff from specific areas. According to Reference 33, predictions based on this procedure are somewhat optimistic and should be used with caution.

Considerable runoff (nearly 4 in., or 212 acre-feet per square mile) is estimated in the vicinity of the tar sands deposit. However, while the frequency distribution for precipitation is fairly uniform throughout the year, the same is not true of runoff. Streamflow frequency distribution for the Price River near Heiner and at Woodside are illustrated in Figures 64 and 65. Large amounts of precipitation are obtained as the snow melts in the spring, with April and May being the months of peak runoff. Thus, storage facilities are required to provide water continuously throughout the year; a small reservoir should provide enough water for test facilities.

In order to determine the amount of runoff available, detailed information is needed on the spatial distribution of the runoff and losses from seepage, consumptive use, groundwater, evaporation, and other factors. The water budget for a basin provides these details. The procedure used is presented in Reference 5 and Section IV.

Water budgets for the hydrologic subareas in the Sunnyside area are presented in Reference 33; only the Price subarea is discussed here. In addition, water budgets based on the

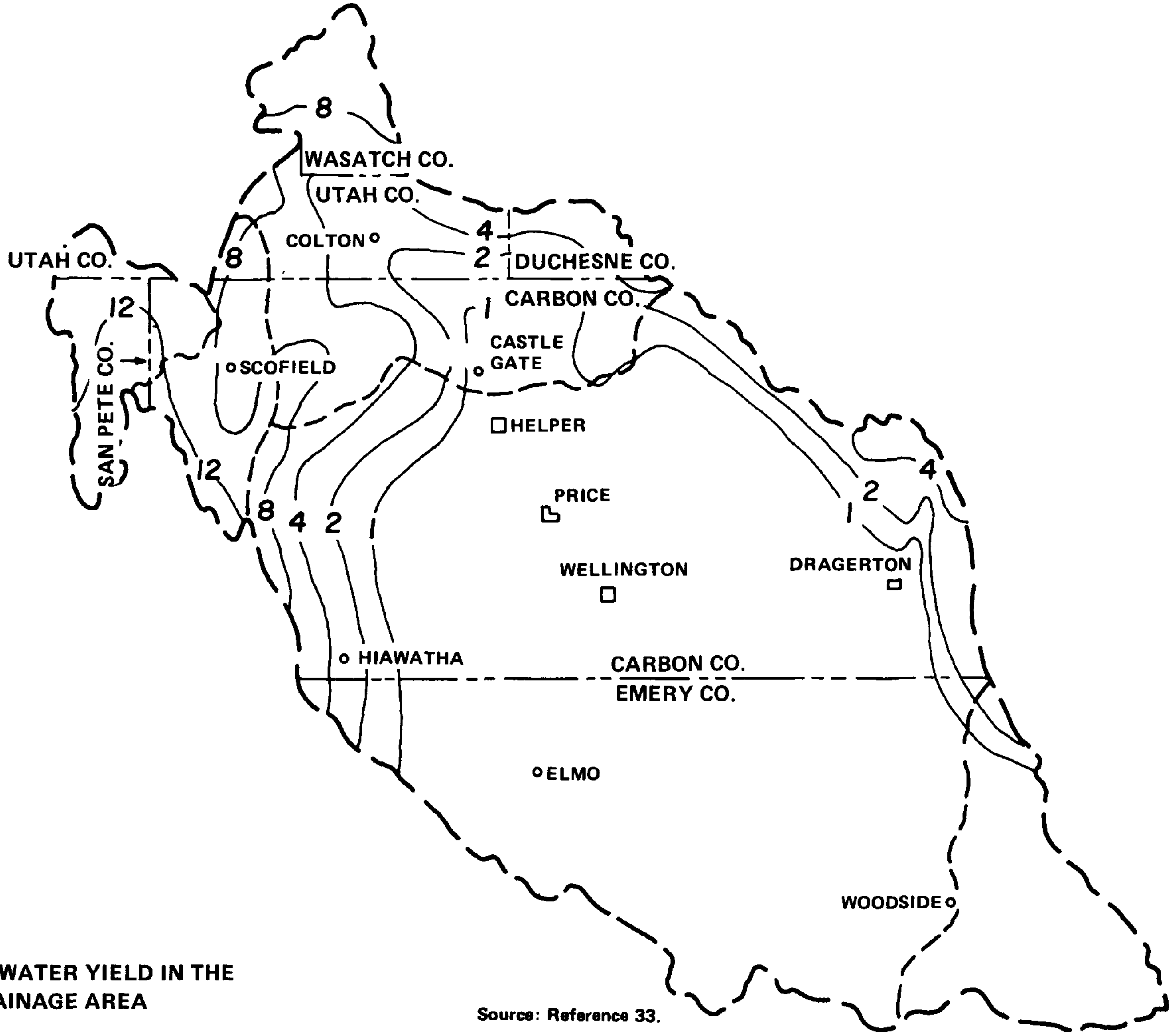
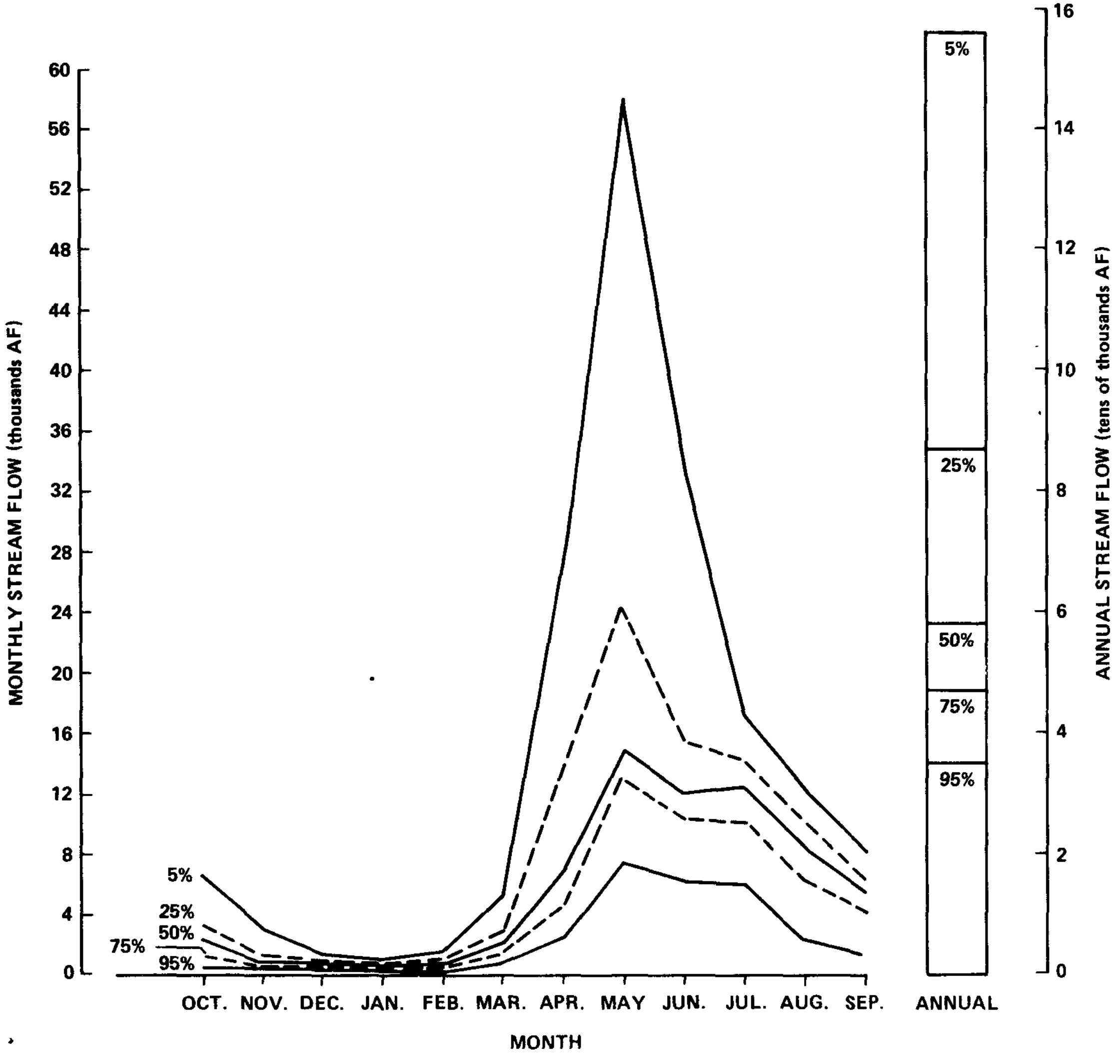


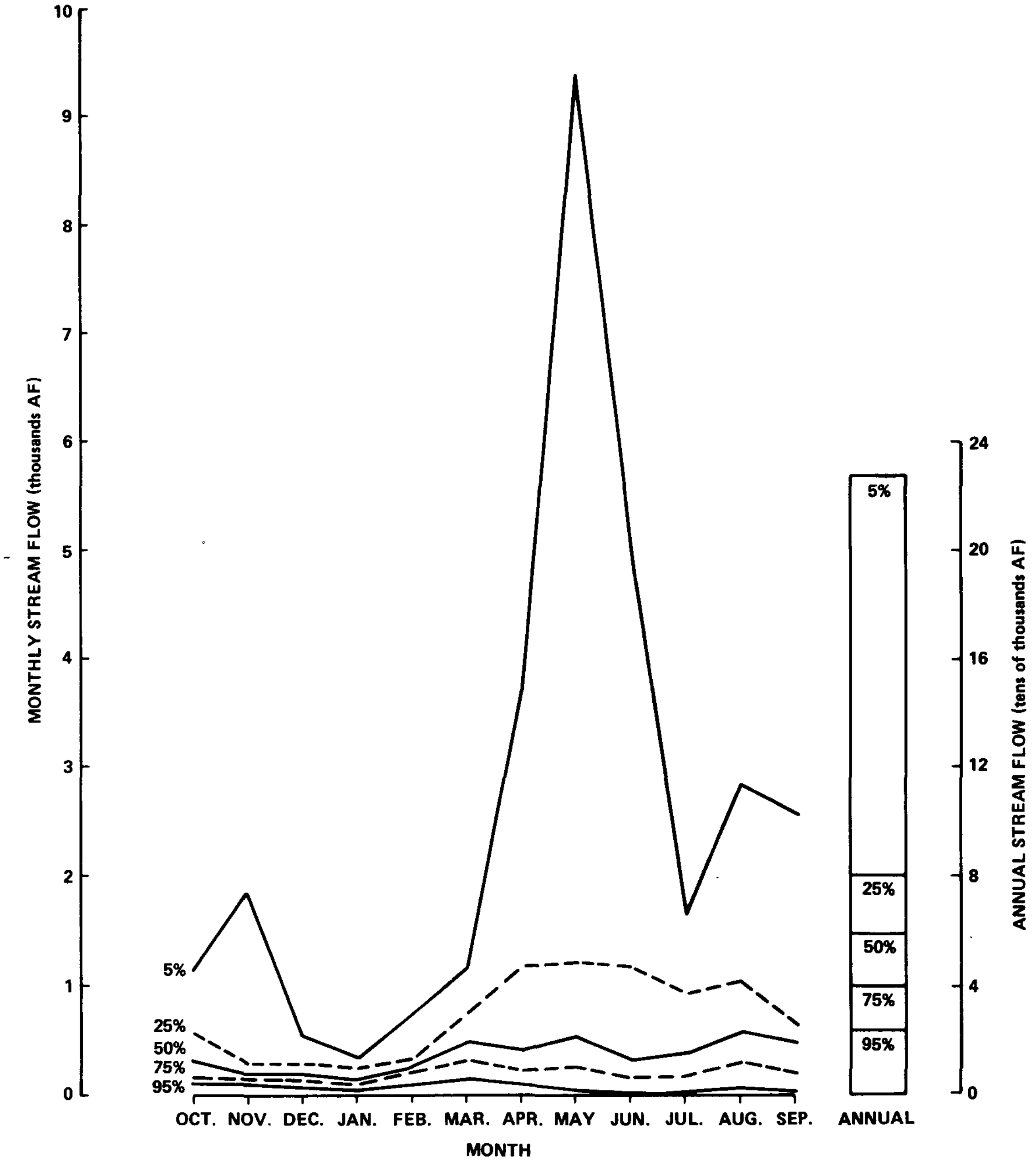
Figure 63. MEAN ANNUAL WATER YIELD IN THE PRICE RIVER DRAINAGE AREA

Source: Reference 33.



Source: Reference 33.

Figure 64. STREAMFLOW PROBABILITY (BASED ON RANKING) FOR PRICE RIVER NEAR HEINER



Source: Reference 33.

Figure 65. STREAMFLOW PROBABILITY (BASED ON RANKING) FOR PRICE RIVER AT WOODSIDE

gages along the Minnie Maud and Nine Mile Creeks are presented. Following the presentation of the water budgets, the water quality of these subareas will be considered.

The Utah Division of Water Resources conducted the mapping of the water-related land use during the summer of 1966 (Reference 33). Recent aerial photographs of the area obtained from the U.S. Department of Agriculture were used as a base in making the survey. The photos were taken into the field and the land use was identified on the photos using land-use indexes. Table 48 lists the different crop and phreatophyte acreages found in the drainage basin and their respective index designations.

Surface Water Supplies

Price Subarea (8-1-4)

The gaging station "Price River at Heiner" measures the river inflow to this hydrologic subarea. The mean yearly flow of the Price River at this point is 75,743 acre-feet. There is an annual import from the Colton subarea of 3033 acre-feet, which provides all the culinary water for the Price and Helper areas.

Also, 24,738 acre-feet of water is imported from Huntington Creek in the San Rafael River Basin. All of the diversions to cropland (92,467 acre-feet per year to the Elmo area) occur in this subarea. This is the only irrigation import to the area. This diversion record was arrived at by summing the diversions contained in the Price River Commissioners' Report. The Emery County import was based on the amount of shares owned by the residents of the area in the Price River drainage.

The total river outflow from this subarea is measured at the gaging station called "Price River at Woodside." The mean annual flow is 75,434 acre-feet. For areas that were not covered by gaged drainages, the yields were computed by the yield maps, which were adjusted to balance the budget.

The mean annual water budget for the Price subarea is depicted by the flow diagram in Figure 66. The mean monthly and mean annual water budget figures are listed in Table 49.

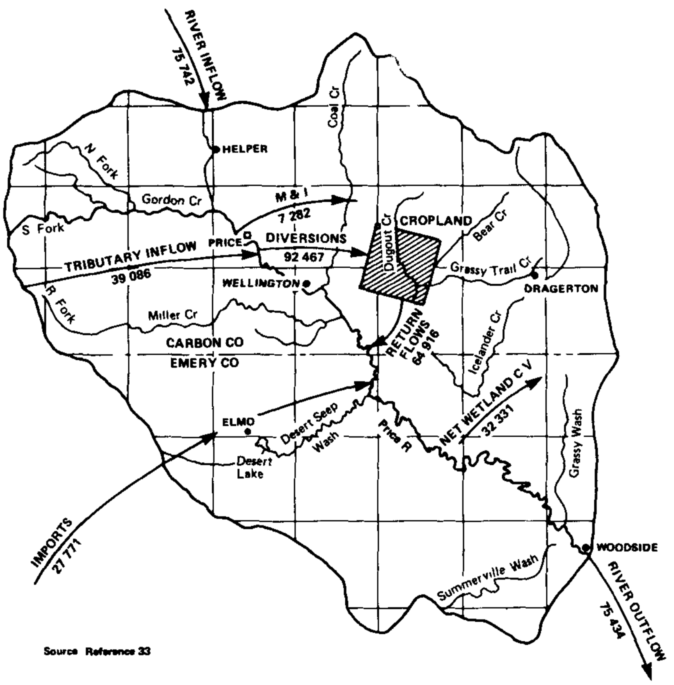
Upper Minnie Maud Subarea (7-4-2)

The Upper Minnie Maud subarea forms part of the upper drainage of Nine Mile Creek. The runoff from the subarea is gaged at USGS Station 9-3085, "Minnie Maud Creek near Myton." The mean monthly and mean annual flows for the 1931-60 time period are given

Table 48. SUMMARY OF WATER-RELATED LAND USE IN THE PRICE RIVER BASIN

Classification Symbol	Description	Price Subarea
A 1	Corn	1,049
A 2	Sugar beets	1,117
A 3	Potatoes	25
A 4	Peas	12
A 6	Truck crop	11
A 7	Barley	3,140
A 8	Oats	560
A 9	Wheat	879
A 10	Alfalfa	9,200
A 12	Cultivated grass and hay	867
A 13	Pasture	6,375
A 14	Wetland pasture	2,593
A 15	Native grass pasture	128
A 16	Orchard	104
Subtotal		25,293
L 1	Light cottonwood	388
M 1	Medium cottonwood	572
D 1	Dense cottonwood	250
L 2	Light salt cedar	104
M 2	Medium salt cedar	467
D 2	Dense salt cedar	86
L 3	Light willows	25
M 3	Medium willows	256
D 3	Dense willows	116
4	Rushes and cattail	219
L 5	Light greasewood	2,534
M 5	Medium greasewood	4,767
D 5	Dense greasewood	646
L 6	Light sagebrush	331
M 6	Medium sagebrush	1,151
D 6	Dense sagebrush	400
M 7	Medium streamside brush	27
D 7	Dense streamside brush	9
L 8	Light grasses and/or sedges	267
M 8	Medium grasses and/or sedges	757
D 8	Dense grasses and/or sedges	297
Phreatophytes		13,669
Grand Total		39,129

Source Reference 33



Source Reference 33

Figure 66. PRICE SUBAREA

Table 49. MEAN MONTHLY AND MEAN ANNUAL WATER BUDGET FOR PRICE SUBAREA

Characteristics	Water Budget (AF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
River inflow													
Price River at Heiner	2 635	1 069	742	591	774	2,289	9 725	20 862	13 410	11 167	7 436	5 042	75 742
Imports													
Canals	857	623	584	516	566	692	1 638	6 517	6 164	3 648	2 373	1 205	25 383
Domestic lines	199	199	199	198	198	198	198	199	199	200	200	200	2 388
Tributary inflow	3 811	2 789	839	627	1 600	4 956	2 055	2 153	2 961	3 942	6 571	6 785	39 086
Total inflow	7 502	4 680	2 361	1 932	3 138	8 135	13 617	29 731	22 734	18 957	16 580	13 232	142 599
Diversion to cropland	4 004	2 222	475	475	475	1,275	7 010	22 181	20 159	16 601	10 377	7 213	92 467
Amount of root zone	1 281	711	152	152	152	408	2,243	7 098	6 451	5 312	3 321	2 308	29 589
Cropland precipitation	2 023	1 138	1 846	1 538	1 391	1 391	1 308	1 497	1 371	1,897	2 340	1 750	19 490
Root zone supply	3 304	1 849	1 998	1 690	1 543	1 799	3 551	8 595	7 822	7 209	5 661	4 058	49 079
Cropland PCU	2 391	0	0	0	0	0	1 754	7 606	12 320	14 419	10 820	6 536	55 874
Root zone supply PCU	912	1 849	1 998	1 690	1 543	1 799	1 797	989	-4 498	7 210	-5 159	2 478	-6 768
Accumulated soil moisture	912	2 761	4 759	6 449	7,992	9 791	10 539	10 539	6 041	0	0	0	0
Change in soil moisture	912	1 849	1 998	1 690	1 543	1 799	1 797	989	-4 498	7,210	5 159	-4 478	0
Consumptive use deficiency	0	0	0	0	0	0	0	0	0	1 169	5 159	2 478	8 806
Cropland consumptive use	2 392	0	0	0	0	0	1 754	7 606	12 320	13 250	5 661	4 058	47 041
Total return flow	2 723	1 511	323	323	323	867	5 816	16 072	13 708	11 289	7 056	4 905	64 916
Domestic/industrical use	607	607	607	607	607	607	607	607	607	607	607	607	7 283
Wetland precipitation	1 094	675	998	831	752	752	707	809	741	1 025	1 264	946	10 594
Wetland consumptive use	2 215	444	95	95	95	255	1 955	8 523	9 063	9 056	6 163	4 966	42 925
Outflow	4 493	3 593	2 505	1 909	3,036	7 617	10 568	15 301	7 355	5 007	7 753	6 297	75 434
River outflow													
Price River at Woodside	4 493	3 593	2 505	1 909	3 036	7 617	10 568	15 301	7 355	5 007	7 753	6 297	75 434

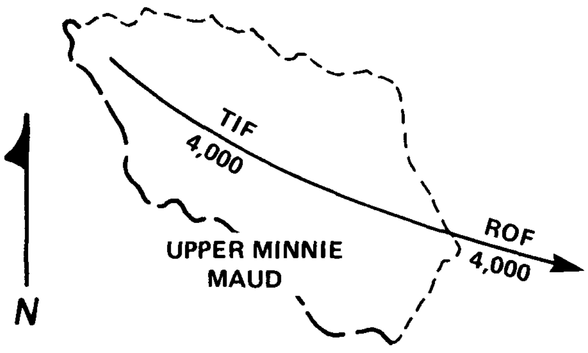
Source Reference 33

in Table 50; Figure 67 is a flow diagram of the mean annual water budget for the Upper Minnie Maud subarea. The mean monthly and mean annual distribution of river outflow for Minnie Maud Creek was obtained from the USGS records.

Table 50. MEAN MONTHLY AND MEAN ANNUAL WATER BUDGET FOR UPPER MINNIE MAUD SUBAREA

Characteristics	Water Budget (AF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Tributary inflow													
Ungaged inflow	80	70	30	30	30	90	640	1,490	870	330	210	130	4,000
Total surface inflow	80	70	30	30	30	90	640	1,490	870	330	210	130	4,000
River outflow													
Minnie Maud Cr near Myton	80	70	30	30	30	90	640	1,490	870	330	210	130	4,000

Source Reference 5



KEY

TIF – TRIBUTARY INFLOW

ROF – RIVER OUTFLOW

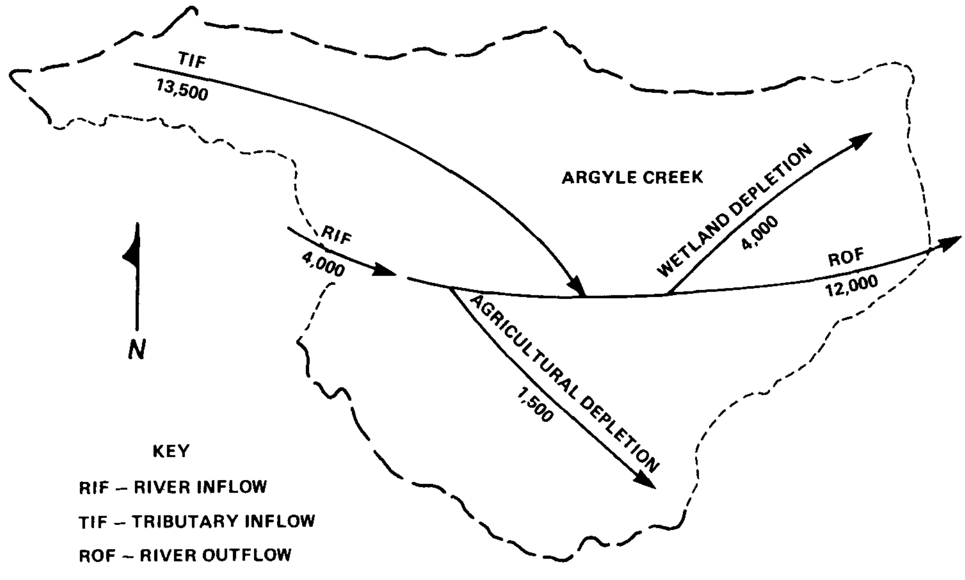
Source: Reference 5.

Figure 67. FLOW DIAGRAM OF THE MEAN ANNUAL WATER BUDGET FOR THE UPPER MINNIE MAUD SUBAREA

Argyle Creek Subarea (7-4-3)

The Argyle Creek subarea forms part of the upper drainage of Nine Mile Creek. The river inflow is the river outflow from the Upper Minnie Maud subarea. The runoff is gaged at USGS Station 9-3090, "Minnie Maud Creek at Nutter Ranch near Myton." A flow diagram of the mean annual water budget for the Argyle Creek subarea is shown in Figure 68;

Table 51 represents the mean monthly and mean annual flows for the 1931-60 time period. The 1931-60 cropland and wetland depletions were obtained from the water budget program of Austin and Skogerboe (Reference 5). The mean monthly and mean annual distributions of river outflow for Minnie Maud Creek were obtained from USGS records.



Source Reference 5

Figure 68. FLOW DIAGRAM OF THE MEAN ANNUAL WATER BUDGET FOR THE ARGYLE CREEK SUBAREA

Table 51. MEAN MONTHLY AND MEAN ANNUAL WATER BUDGET FOR ARGYLE CREEK SUBAREA

Characteristics	Water Budget (AF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
River inflow													
Minnie Maud Creek near Myton	80	70	30	30	30	90	640	1,490	870	330	210	130	4,000
Tributary inflow													
Ungaged inflow	380	240	260	250	260	490	2,240	4,410	2,740	1 050	730	450	13,500
Total surface inflow	460	310	290	280	290	580	2,880	5,900	3,610	1,380	940	580	17,500
Depletions													
Cropland	70	0	0	0	0	0	0	270	360	390	260	150	1 500
Wetland	150	0	0	0	0	0	300	660	930	860	670	430	4,000
Outflow and/or groundwater change	240	310	290	280	290	580	2,580	4,970	2,320	130	10	0	12,000
Estimated groundwater change	290	140	130	100	120	170	70	1,440	850	-430	-480	-500	0
River outflow													
Minnie Maud Cr at Nutter Ranch near Myton	530	450	420	380	410	750	2,510	3,530	1,470	560	490	500	12,000

Source Reference 5

Surface Water Availability for Tar Sands Development

In the immediate vicinity of the Sunnyside tar sands deposit there are only three streams: Nine Mile Creek, Range Creek, and Icelander Creek. While numerous small creeks exist, they are all ephemeral and not generally worth considering as water supplies.

The flow in Nine Mile Creek can be accurately determined from the stream gage "Minnie Maud Creek near Myton." Minnie Maud Creek, which forms the upper portion of the Nine Mile Creek drainage, lies well within 5 mi of the tar sands deposit. The flow in Minnie Maud Creek averages 7000 acre-feet per year. It varies from a high of 1400 acre-feet per month in May to a low of 30 acre-feet per month in the winter. A second gage, "Minnie Maud Creek at Nutter Ranch near Myton," on the Nine Mile Creek/Minnie Maud system was operated for a short time above Gate Canyon. This gage was also within 5 mi of the tar sands area. The flow of Nine Mile Creek at this location is 12,000 acre-feet per year, ranging from a high of 3530 acre-feet per month to a low of 380 acre-feet per month.

No gaging records are available on Icelander Creek. Range Creek, which originates in the tar sands area, has only intermittent flow and was not gaged. Austin and Skogerboe (Reference 5) used correlation techniques to estimate the quantity of flow. They report an annual flow of 4000 acre-feet with a monthly flow range of 40 to 1630 acre-feet. These figures are for the mouth of the stream at the Green River. Because of the reduced drainage area, flows near the tar sands area would be only 20 to 30 percent of these values.

A crude estimate of the flow in Icelander Creek can be obtained from the drainage area and the water yield (mean annual runoff) map. The drainage area at Sunnyside is roughly 35 mi^2 and the average yield for the area is approximately 2 in. per year. Thus, a total annual runoff of 3700 acre-feet would be a reasonable estimate of the runoff from Icelander Creek at Sunnyside. Again, this value would be considerably less near the tar sands area because of reduced drainage area.

The only major river near the Sunnyside deposit is the Price River. The flow in the Price River is accurately established by gages above Heiner and at Woodside. (Another gage was established near Wellington in 1972, but as yet, the USGS has not published data on long-term averages at that gage.) On the average, 75,743 acre-feet of water flow into the Price subarea at Heiner and 75,434 acre-feet of water flows out at Woodside. A very dry year occurred in 1976, with a total flow of only 30,250 acre-feet being measured at Wellington.

Using the above values, the question of supply for tar sands development can now be addressed. As given in Table 3, the following hypothetical demands for water were calculated (based on 5 bbl of water per barrel of oil):

- five-well experimental facility: 35.5 AF/ yr = 2.96 AF/mo;

- 24-well pilot facility: 213 AF/yr = 17.75 AF/mo; and
- large-scale production facility: 13,400 AF/yr = 1117 AF/mo.

As stated previously, these estimates assume 100 percent consumptive use and are very convervative.

Based on these values, the flow in the Nine Mile Creek/Minnie Maud system is not quite adequate to continuously support production-level activities. Without recycling, little or nothing would be left for other uses. Thus, storage facilities would be required. However, in order to capture sufficient volumes of water, the storage facilities would have to be at elevations of no more than 6000 ft and considerable pumping would be required to bring the water up to the deposit area.

Range and Icelander Creeks probably do not produce sufficient water for more than large-scale pilot operations, especially if storage facilities were developed high in the drainage basin. No definite conclusions can be drawn on these two streams without further gaging activity or a modeling study to accurately determine the runoff near areas of interest.

The Price River could easily support any level of activity. It is at a considerable distance from the deposit and much lower in elevation. The impact of production facilities on the Price River would be considerable in dry years. In 1976, the estimated water requirement for production facilities would have been more than one-third of the total flow for that year, as measured at Wellington.

Surface Water Quality

As stated in Section IV, the amount and quality of water quality data vary widely. These same comments and cautions apply to the Sunnyside area. Considerable information is available on the quality of water in the Price River. Data include suspended sediment, dissolved oxygen, specific conductance, pH, and sampling for various chemical constituents.

Water quality information on the other streams of interest is almost totally lacking. Random samples of specific conductance and temperature are available for Minnie Maud Creek; no data are available for Icelander Creek and Range Creek. A fairly detailed analysis of the water quality data on the Price River is available in Reference 33. This is summarized here in the following paragraphs.

Suspended sediment is not a serious problem in the upper Price River drainage, but in the lower drainage area the problem becomes more serious, with recorded concentrations as high as 64,800 ppm. A table of suspended sediment concentration versus discharge is presented in Reference 33. In general, concentrations vary with flow. Insufficient data are available to compute a yearly average level or total load.

Dissolved solids present more of a direct effect on man. Drinking water, industrial water, and agricultural water are all affected by dissolved solids. Water samples obtained by the USGS from various gaging stations along the Price River at approximately the same time of day show the following concentrations of dissolved solids:

- above Scofield: 180 ppm,
- at Heiner: 226 ppm,
- at Wellington: 1190 ppm, and
- at Woodside: 2110 ppm.

The water at Wellington, near the tar sands area, does not meet the U.S. Public Health Service standard for drinking water (no more than 500 ppm of dissolved solids), but it is at an aceptable level for stock watering. Table 52 lists the chemical quality for various discharges at Woodside, the only station on the river for which long-term records have been kept. As indicated by the table, the concentration of dissolved solids varies with discharge and location on the river. In general, the water quality of the Price River near the tar sands area is marginal. The high levels of dissolved solids and salinity might have an adverse impact on the potential use of this water in industrial processes.

A detailed analysis of water quality in the Price Basin is contained in Reference 12. This analysis was part of a major study of the water quality in the Price Basin for the state of Utah under the auspices of the USGS. The conclusions coincide fairly well with those in Reference 33.

Mundorff (Reference 12) divides the Price Basin into upper, central, and lower portions. The upper basin is that part of the Price River Basin upstream from Heiner; the central basin lies between Heiner and the junction of the Price River and Desert Seep Wash; and the lower basin is downstream from Desert Seep Wash. The upper basin is the major source of this water is mainly snowmelt, which is stored in Scofield Reservoir. The water has a low-sodium (alkali) and a medium salinity content. From the headwaters to about the junction with Spring Canyon Creek, the Price River generally has a dissolved-solids content of less than 400 mg per liter, which is of the calcium bicarbonate type. Beginning at the junction of the Price River and Spring Canyon Creek, inflow to the Price River is mainly from marine shales of the Cretaceous period. At Wellington, which is near the center of the basin, the dissolved-solids content ranges between about 500 and 2400 mg per liter. At Woodside, which is about 22 mi upstream from the mouth, the weighted-average dissolved-solids concentration (strongly sodium sulfate) was generally between 2000 and 4000 mg per liter during the 1952-69 period.

The water quality of the Price River is lowered considerably as the stream crosses the central basin. The deterioration is the result of both geologic and human factors. From November through April, little water is released from Scofield Reservoir, and the upper basin contributes little water to the Price River. However, during such periods of low flow,

Table 52. CHEMICAL QUALITY OF WATER AT "PRICE RIVER AT WOODSIDE" GAGING STATION

Relation between water discharge and chemical quality of water at selected stations in the Green division. Data are for the water years 1914-57 adjusted to 1957 conditions.

Mean Discharge (cfs)	Chemical Constituents (parts per million)								Dissolved Solids (residue at 180° C)			Hardness as Calcium Carbonate		Percentage of Sodium	Specific Conductance (micromhos at 25° C)	Sodium absorption ratio
	Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Sulfate	Chloride	Boron	Parts per Million	Tons per AF	Tons per Day	Calcium, magnesium	Non-carbonate			
4,310	92	34	62	1.9	267	250	14	0.11	598	0.81	6,960	369	150	27	870	1.4
2,940	94	38	74	2.6	267	295	16	.12	630	.86	5,000	390	172	29	910	1.6
2,320	95	40	83	3 1	268	330	17	.12	662	.90	4,150	402	182	31	960	1 8
1,580	98	47	100	3.9	268	400	18	.12	742	1.01	3,170	438	218	33	1,050	2.1
1,050	102	54	122	4.7	268	490	21	.13	870	1.18	2,470	476	256	35	1,220	2.4
665	107	64	155	5.6	270	600	25	.14	1,070	1.46	1,920	530	308	39	1,480	2.9
348	124	85	224	6.8	272	860	33	.17	1,500	2.04	1,410	659	436	42	1,980	3.8
149	160	135	365	8.0	283	1,430	48	.23	2,420	3.29	974	954	722	45	3,000	5 1
102	183	165	470	8.5	290	1,800	59	.26	3,000	4.08	826	1,130	896	47	3,650	6.1
74	205	190	558	8.8	303	2,100	68	.29	3,530	4 80	705	1,290	1,040	48	4,200	6.8
62	217	205	603	9.0	320	2,250	73	31	3,830	5.21	641	1,380	1,120	48	4,500	7.1
52	230	220	660	9.2	335	2,440	78	.33	4,100	5.58	576	1,480	1,200	49	4,800	7.5
44	240	234	710	9.3	345	2,600	83	.35	4,320	5.88	513	1,560	1,280	50	5,000	7.8
36	255	250	760	9.4	349	2,780	88	.37	4,580	6.23	445	1,660	1,380	50	5,300	8.1
25	280	278	830	9.8	351	3,120	97	.42	4,950	6.73	334	1,840	1,550	50	5,700	8.6
11	325	320	960	10	352	3,600	105	.51	5,380	7.32	160	2,130	1,840	49	6,050	9.1
6.8	340	330	970	10	354	3,700	105	58	5,400	7.34	99	2,200	1,910	49	6,100	9 0
5.2	345	330	980	11	355	3,800	106	.61	5,400	7.34	76	2,220	1,930	49	6,100	9 1
4.4	350	335	980	11	360	3,800	107	.64	5,400	7.34	64	2,250	1,960	48	6,100	9.0
116	151	118	327	6.6	288	1,240	43	.21	2,110	2.87	662	862	626	45	2,600	4.8

Source Reference 33; data obtained from "Water Resources of Upper Colorado River Basin," Geological Survey Professional Paper 441, 1965.

irrigation return flow and untreated sewage continue to enter the river. From about May to October, major releases are made from Scofield Reservoir, but during this period a large part of the flow is diverted from the Price River into major irrigation canals in the upstream part of the central basin. Untreated sewage and appreciable amounts of irrigation return flow of poor quality enter the Price River downstream from points at which most of the flow is diverted from the river. Thus, during most of the year the central basin of the Price River consists of relatively small amounts of water of good quality from the upper basin to which are added variable amounts of irrigation return flow, waste discharges from municipalities, and natural flow from tributaries that drain areas of marine shales. Although some deterioration in the chemical quality of the Price River probably would be caused by either an absence of stream regulation or agricultural irrigation in the central basin, the deterioration is intensified by the presence of both factors.

GROUNDWATER

Before discussing groundwater directly, the subsurface geology in the vicinity of the Sunnyside deposit must be presented. Accurate determination of the subsurface geology is essential to obtaining groundwater near Sunnyside.

Sunnyside lies in a geomorphological district called the West Tavaputs Plateau. The plateau rises slowly to the south from the Duchesne River, which flows parallel to the axis of the Uinta Basin Geosyncline. The predominant surface formation is the Green River. Streams and washes are incised in canyons, with depths of 1000 ft not unusual (Reference 5).

Streams in the narrow canyons of the Tavaputs Plateau flow close to bedrock. Very little alluvium exists in the canyon floors to support shallow groundwater. Only in the broad Price River Valley is there any significant alluvial material to support shallow groundwater.

The shallow groundwater in the Price River Valley is discussed first, followed by the deep subsurface geology of the Sunnyside area. Then, the data on water from the bedrock aquifers is discussed.

Upon fairly close examination there appears to be no significant use of shallow groundwater in the Price River Basin near Sunnyside. This is emphasized by the fact that the USGS does not report well observations in Carbon or Emery Counties. The results of a detailed investigation into the water resources near Sunnyside (Reference 34) are not yet available in published form.

The only published use of groundwater anywhere in the Price Basin is in a 33-mi^2 area to the west of Colton. This area is bounded on the north and west by Utah Highway

96 and on the south and east bv the Price River. This area is considerably north and west of the tar sands deposit. At present, approximately 6000 acre-feet of groundwater from this area is collected from springs and seeps and then is used for culinary purposes in the Price-Helper area. Some springs have also been developed for stock watering. The Utah Power and Light Company has also drilled two wells near Colton for use during periods of high electricity demand.

Tests were performed on both wells near Colton in an attempt to determine the drawdown under continuous pumping. Free flow was also measured at these wells. During 1953-62, well number one averaged 170 GPM with a head 12 ft above the land surface. In 1962, well number two discharged 270 GPM with a head 14 ft above the ground surface. Well one was pumped at 1100 GPM for 126 days and the maximum drawdown was 230 ft, well two was pumped at 1600 GPM for 8 hr and the drawdown was 180 ft. The area yielding the groundwater contains the Price River and the Flagstaff, Blackhawk, North Horn, and Colton Formations. The Flagstaff and the North Horn Formations are the chief aquifers.

The stream valley alluvium below Price is underlain by the Mancos Shale Formation. The high bicarbonate and sodium sulfate content contaminate the groundwater, rendering it useless for everything except limited watering of Stock(Reference 33).

Subsurface Geology

The Sunnyside-Dragerton area of the Price River Basin has been the subject of considerable geologic interest. Major coal seams are present in the face of the Roan and Book Cliffs. The tar sands deposit has also attracted considerable interest.

In 1928, Clark developed a detailed geologic map of the Castlegate, Wellington, and Sunnyside Quadrangles (Reference 35). In 1948, Holmes et al. developed an extremely detailed map of the geology within a few miles of Sunnyside (Reference 36). The Holmes map is very detailed, including deposits of only few inches thick. Most of the geologic information presented here is based on Reference 35.

Figure 69 (in pocket at end of report) shows a portion of the geologic map of the area, including geologic cross-sections of the Sunnyside area (Reference 35). In the broad Price River Valley, the surface is primarily the Mancos Shale Formation. The Morrison Sandy Shale is beneath the Mancos. The Mancos Shale is locally overlain by thin Quarternary gravel and alluvium. Because of the close contact between the Mancos Shale and the gravels, the quality of the shallow groundwater in the Price Valley is poor, as mentioned previously.

Atop the Mancos Shale are the Price River Formation and several coal beds. These form the face of the Book Cliffs. The Wasatch Formation lies unconformably over the Price River Formation and is topped by the larger of the Green River Formations at the high elevations of the Tavaputs Plateau.

Water from Bedrock

The best reference on groundwater from the deep rock formations is again the work by Feltis (Reference 3). As with the shallow groundwater, there are few wells in the area and little information. The comments made by Feltis on each of the underlying formations are discussed, beginning with the lowest formation, the Morrison, and proceeding upward in elevation to the Green River.

The Morrison Formation, which lies at a depth of about 6000 to 8000 ft below the tar sands area, is the lowest of the formations. No wells are specifically identified with the Morrison in the Sunnyside area. In San Juan County, wells in the Morrison have yielded 2 GPM, and yields from wells in Grand County are also reported as 2 GPM or less. The level of dissolved solids in the water from the Morrison Formation ranges from 2000 to 25,000 mg per liter, slightly saline to brackish.

A thin bed of Dakota Sandstone lies between the Morrison Formation and the Mancos Shale. Wells and springs in this area are reported to yield fresh to slightly saline water. Wells located in areas considerably distant from Sunnyside have reported yields as high as 15 GPM.

The largest formation underlying the Sunnyside area is the Mancos Shale. Unfortunately, it is one of the poorest aquifers. Feltis (Reference 3) has stressed that the fine-grained texture and the abundance of water-soluble salts prevent the Mancos Shale Formation from being a viable source of fresh water. The level of dissolved solids in the water samples from several sandstone members of the Mancos Shale ranges from 4000 to over 50,000 mg per liter.

Feltis does not provide any information on the formations above the Mancos Shale in the Canyon Lands district, which he considers in his discussion of the Uinta Basin. No information on the water-bearing properties of the Price River Formation and the associated coal beds is presented in Reference 3.

The Wasatch Formation is the second major formation in the Sunnyside area. Feltis speculates that the Wasatch Formation recharges in the area of high precipitation along the Roan Cliffs. This is in the immediate vicinity of the tar sands deposit. Wells in the Wasatch Formation yield water that is slightly saline to briny; however, no yield data were found for the vicinity of Sunnyside.

At the highest elevation in the vicinity of Sunnyside is the Green River Formation. Because of the high elevation and the thinness of the material in this area, it is unlikely to be a water source at this location. In other areas of Utah, the water of the Green River ranges from fresh to briny. The yield from wells in the Green River Formation varies considerably, reaching as high as 220 GPM in the Ashley Valley oil fields.

Few data on oil and gas exploration wells near Sunnyside are available. Seven wells are reported in Reference 3 and one well in Reference 22. These wells are listed in Table 53. No yield data are available and the quality of water reported under "remarks" is not encouraging.

Table 53. OIL AND GAS EXPLORATION WELLS NEAR SUNNYSIDE

Location			Operator or Owner	Number	Producing Formation	Depth to Top of Formation (ft)	Depth to Bottom of Formation (ft)	Interval Sampled (ft)	Remarks
T	R	Section							
14S	9E	S½NW¼NE¼ 29	Amerada Petroleum Co	1	Ferron Ss Mbr of Mancos Sh	2,664	3,023	At 2,756	Sample collected while drilling with air
								At 2,806	Sample collected while drilling with air
					Tununk Sh Mbr of Mancos Sh	3,023	3 416	At 3,054	Sample collected while drilling with air
								At 3,325	Sample collected while drilling with air
15S	10E	C NE¼NE¼ 26	Shell Oil Co	1	Mississippian sed rocks	8,950	10,763	10,068 10 165	—
15S	11E	NE¼SE¼SW¼ 12	Carbon Dioxide and Chemical Co	2	Navajo Ss	3,095	3,114	3 095 3,114	Carbon dioxide well Water sample bailed from hole at 2,320 ft under pressure by using temperature observation machine
15S	12E	SW¼SW¼SW¼ 7	Pan American Petroleum Corp	1	Mississippian sed rocks	7,042	8,154	7,433 7,986	DST 1 recovered very cloudy water, dark brown organic filtrate
15S	12E	SE¼SW¼SW¼ 8	Shell Oil Co	1 A	Redwall Ls	7,970	9,130	8,323	
					Elbert Fm	9,130	–	9,174	DST 1 A recovered 6,750 ft of slightly gassy, slightly muddy salt water with trace of oil and sulfurous odor
15S	12E	15	–	–	Mancos Sh	0	–	0-30	Dug well, 30 ft deep Analysis includes 0.2 ppm fluoride
16S	9E	W½NE¼NW¼ 12	Pure Oil Co	1 A	Redwall Ls	9,800	11,125	10,117 10,259	DST 2 recovered 450 ft of heavy gas-cut mud (carbon dioxide) and 360 ft of salt water
16S	12E	C NE¼NW¼ 1	Cities Service Oil Co	1	Sinbad Ls Mbr of Moenkopi Fm	4,014	–	4,014-83	DST 3 recovered 80 ft of slightly sulfur gas-cut mud, 90 ft of sulfur water-cut mud, and 450 ft of sulfur water
					Mississippian sed rocks	6,372	–	7,831 7,930	DST 5 recovered 270 ft of gas (carbon dioxide) and salt water-cut mud and 1,910 ft of gas-cut (carbon dioxide) salt water from Deseret (?) Formation
16S	12E	C NE¼NW¼ 4	Equity Oil Co	2	Sinbad Ls Mbr of Moenkopi Fm	4,141	–	4,138-75	Analysis includes 2,410 ppm magnesium as magnesium carbonate and 180 ppm free carbon dioxide
								4,138 75	Analysis includes 2,680 ppm magnesium as magnesium carbonate and 210 ppm free carbon dioxide

Source References 3 and 22

The records of the Utah Oil and Gas Conservation Commission contain data on several wells that could not be found in published sources. One well in T. 12 S., R. 15 E. that penetrated the North Horn Formation lies in the Uinta Basin north of Minnie Maud Creek. No water was reported. On the other hand, a Reserve Oil Co. well in T. 12 S., R. 16 E. yielded 50 bbl of water per hour (40 GPM) from the Green River Formation and 75 bbl of fresh water per hour (55 GPM) from the Wasatch Formation. An oil well in Farnham Dome, 10 mi southwest of Sunnyside, yielded water at a depth of 3250 ft. No yield or quality estimates were provided. A wildcat well in T. 12 S., R. 12 E. produced 5 to 10 bbl per hour (4-8 GPM) of fresh water from the North Horn Formation and 35 to 40 bbl per hour (25-30 GPM) from the Price River Formation. This well was capped as a shallow-water well at the request of the leasee. At three other wells, located in T. 13 S., R. 14 E.; T. 13 S., R. 15 E.; and T. 12 S., R. 14 E., significant water was reported in the sandstone of the Green River and Wasatch Formations. No yield or quality information was provided.

While only limited data are available on wells in this area, a considerable number of springs are present. Several springs in the Uinta Basin are reported by Hood, Mundorff, and Price (Reference 22), and a number of others are reported by Connor and Mitchell (Reference 37). The springs reported in Reference 22 are listed in Table 54. The springs reported in Reference 37 are listed in Table 55. Yield data and information on the producing formation have not been published.

Table 54. RECORDS OF SELECTED SPRINGS

Location	Name of Owner	Altitude[a] (ft)	Aquifer	Discharge[b] (GPM)	Date Measured[c]	Temperature (°C)	Date Measured	Use of Water[d]	Chemical Analysis Available[e]
(D 11 15)15DBR-S1	–	6 660	124PCCK	0 9E	3/72	–	3/72	–	P
(D 11 17)20ACA-S1	–	5,600	124PCCK	0 9E	3/72	–	3/72	–	P
(D 11 18)20CBA-S1	–	4 800	124PCCK	1E	3/72	8 0	3/72	–	P
(D 12 21)19RDD S1	Sulphur Spr	5 335	124PCCK	20E	8/71	19 5	8/71	U	P
(D 13 14)24ADB-S1	Pan Am Oil Corp	8,275	124PCCK	–	–	–	7/66	–	P
(D 16 16)31AAA-S1	Waldo Wilcox	5,590	111ALVM	15E	4/64	11 0	4/72	I	–
(D 16 16)32DDA-S1	Waldo Wilcox	5,430	124WSTC	150E	4/72	11 0	4/72	I	P
(D 16 17) 3C -S	Camel Rock Spr	–	124WSTC	225R	9/48	–	9/48	–	P
(D 16 18)24BCD-S1	Pinto Spr	7,925	124PCCK	0 2E	8/71	–	8/71	S	P
(D 16 22)23DCD-S1	Cedar Camp Spr	7 900	124PCCK	5M	7/60	–	–	S	–
(D 17 16)10CAC-S1	Waldo Wilcox	5 040	125NRHR	6E	4/72	–	–	H	–
(D 17 16)10CCA-S1	Waldo Wilcox	5 040	125NRHR	6E	4/72	–	4/72	H	P
(D 17 16)15BAC-S1	Waldo Wilcox	5,030	125NRHR	1E	4/72	11 5	4/72	U	–
(D 17 17)20CCC-S1	–	4,240	211MVRD	–	–	–	9/48	–	P

[a] Altitude Land surface at spring orifice, above mean sea level

[b] Discharge E estimated, M, measured, R reported

[c] Date measured Date of temperature measurement also applies to date of water sampling

[d] Use of water H household or domestic I, irrigation S, stock U, unused

[e] Chemical analysis available P, partial

Source Reference 22

The springs reported in Reference 37 are listed in Table 55. Yield data and information on the producing formation have not been published.

The data from springs in Range Creek Canyon (Table 54, wells D-16-16 and D-16-17) give some encouragement for finding water on the Wasatch and North Horn Formations. The North Horn Formation apparently outcrops at the Uinta Basin side of the Book Cliffs. It does not show on any geologic maps found. It apparently lies between the Mancos Shale and the Wasatch Formation and is Tertiary in age. Feltis (Reference 3) provides some information on the North Horn Formation.

A water well in the North Horn Formation (T. 11 S., R. 8 E.) yielded water containing 310 ppm of dissolved solids (Reference 3, Figures 16 and 17 and Table 4). The well flowed at a rate of 9200 BPD (270 GPM) and was pumped at a rate of 54,000 BPD (1600 GPM).

A water well in T. 14 S., R. 4 E. yielded water, containing 344 ppm of dissolved solids, at a flow rate of 1700 BPD (50 GPM) and pumped rate of 24,000 BPD (700 GPM). The well is reportedly completed in sandstone in the North Horn Formation.

Table 55. SPRINGS

Well Coordinate Number	Owner	Dimensions (in.)	Depth (ft)	Type of Spring	Use
(D-12-9)36c	Town of Helper	–	–	spring	PS
(D-13-7)5 (Scofield Spr.)	Town of Scofield	–	–	spring	PS
(D-13-8)1c	Utah Carbon Coal Co.	–	–	spring	dom.
(D-13-8)27	Coal City	120x120	20	dug	dom.
(D-13-9)9	Liberty Fuel Co.	60x 60	60	dug	PS
(D-13-9)15 (Clear Cr. Spr.)	Town of Helper	–	–	spring	PS
(D-13-10)21	Kenilworth Mine	–	–	spring	Ind.
(D-14-9)1	Price Country Club	–	–	spring	none
(D-14-10)	H.D. Balafota	–	–	well	stock
(D-14-14)32	Spring Canyon Coal Co.	–	–	spring	baths
(D-14-14)32	Kaiser Steel Co.	–	–	spring	PS
(D-15-8)8	Lion Coal Corp.	–	–	spring	none
(D-15-8)8	Lion Coal Corp.	–	–	spring	none
(D-15-8)33 (So. Fork Spr.)	U.S. Fuel Co.	–	–	spring	PS
(D-15-10)12a		–	–	spring	none
(D-15-10)30	G.F. Oliver	–	–	well	dom.
(D-15-14)6cbd-1 A-15168	Geneva Steel Co.	8 dia.	40	drilled	dom.
(D-15-17) (Flat Canyon Seep)		–	–	seep	none
(D-15-17) (Flat Canyon Spr.)		–	–	spring	none

Source: Reference 37.

Five springs in T. 11 S., Rs. 7 and 8 E. and T. 12 S., R. 8 E. yielded water containing from 256 to 562 ppm of dissolved solids. Two of the springs yielded 100 and 680 BPD (3 and 20 GPM, respectively). Data for one of the springs in T. 11 S., R. 7 E. are given in Table 4 of Reference 3.

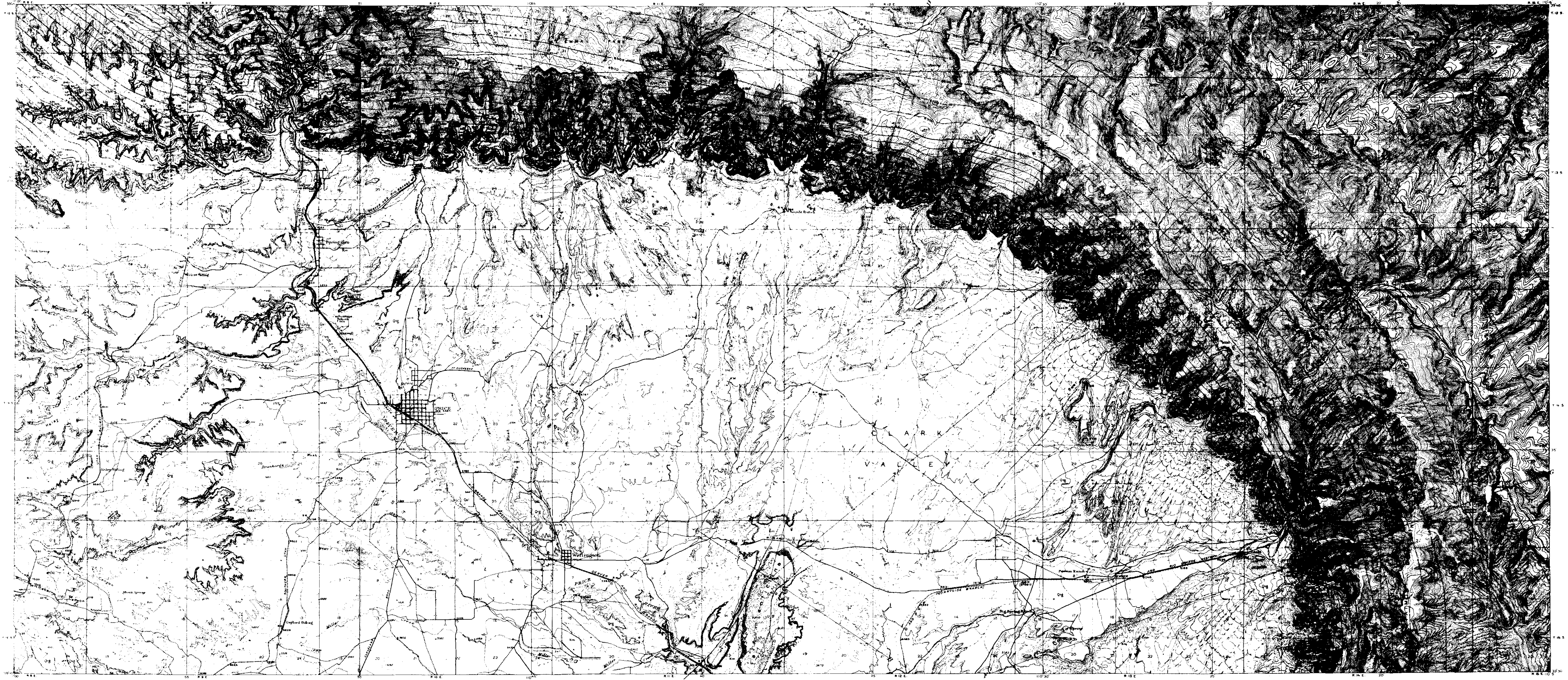
Groundwater Availability for Tar Sands Development

The following quantities of water (based on 5 bbl of water per barrel of oil) are estimated to be the amount for production-scale tar sands facilities of various sizes:

- five-well experimental facility—22 GPM,
- 24-well pilot facility—132 GPM, and
- large-scale production facility—8300 GPM.

As stated previously, these estimates assume 100 percent consumptive use and are very conservative.

The limited data suggest that groundwater may not be a viable source of supply in the Sunnyside area. The only encouraging information is the fair yield from springs in the North Horn and Price River Formations. These springs yield reasonably fresh water at rates high enough to support pilot-scale facilities in some cases. No definite conclusions on the groundwater supply should be drawn without further investigation. Yield data from the few oil and gas wells available would be helpful. Better determination of the deep subsurface geology would also be helpful. The structures beneath the Mancos Shale in the Sunnyside area could be better defined through careful examination of well logs.



Base from U. S. G. S. maps of Castlegate, Wellington and Sunnyside quadrangles

Geology by Frank R. Clark

GEOLOGIC MAP AND SECTIONS OF THE CASTLEGATE, WELLINGTON, AND SUNNYSIDE QUADRANGLES, UTAH

Scale 1/62500

1 ½ 0 1 2 3 4 5 Miles

1928

EXPLANATION

QUATERNARY

Alluvium

Terrace gravel

UNCONFORMITY

TERTIARY

Eocene

Green River formation

(Mainly grayish-drab fine-grained thin-bedded sandstone and sandy shale, in places calcareous, with some dark-brown shale [illegible] carbonaceous matter)

Wasatch formation

(Mainly coarse-grained sandstone, conglomeratic in places, sandy shale, and several beds of conglomerate and impure limestone. Yellowish and greenish at base; shaly, red and pinkish in middle part; gray [illegible] sandstone with greenish and purplish [illegible] shale in upper 1800 feet)

UNCONFORMITY

CRETACEOUS

Upper Cretaceous

Mesaverde group

Price River formation

(Mainly sandstone, shale, and sandy shale, of gray to buff color, with Castlegate sandstone member (Kcg) massive gray to buff sandstone, at base)

Blackhawk formation with Aberdeen sandstone member (Ka) at or near base

(Gray to buff sandstone and sandy shale interbedded with coal. Includes, in descending order Upper Sunnyside (Us), Lower Sunnyside (ls), Rock Canyon (rc), Fish Creek (fc), Gilson (g), and Kenilworth (k) coals and Castlegate (cg) and Spring Canyon (sc) coal groups. At or near base massive cliff-forming Aberdeen sandstone member (Ka), 100 to 200 feet thick. In eastern part of area the Aberdeen interfingers with Mancos shale (Km))

Star Point sandstone (Ksp)

(Basal formation of Mesaverde group interfingering with tongues of Mancos shale (Km). At top the Spring Canyon tongue (Ksc), massive sandstone 150 feet thick; in middle the Storrs tongue (Ks), thick-bedded sandstone underlain by sandy shale with shale at base; at base the Panther tongue (Kp), which is to east a band of impure limestone concretions and thin beds of sandstone and sandy shale and to west is thicker (100 to 185 feet), coarser, and harder)

Mancos shale

(Dark-drab or bluish marine shale and sandy shale (Km), with three prominent sandstone members in lower part: Emery sandstone member (Ke); Garley Canyon sandstone member (Kgc); and Ferron sandstone member (Kf). Upper part interfingers with sandstone tongues of Mesaverde formations (Ka, Ksc, Ks, and Kp).)

Dakota (?) sandstone

(Chiefly well-indurated sandstone, in places conglomeratic)

UNCONFORMITY

CRETACEOUS (?)

Lower Cretaceous (?)

Kmo

Morrison formation

(Variegated sandy shale and sandstone with thin beds of indurated conglomerate)

Outcrops of coal beds

(Figures show location of measured sections, shown on plates, or in text)

U D

Faults

(Solid where location is certain, broken where inferred U, upthrown side; D, downthrown side)

⚒

Coal mine

‡

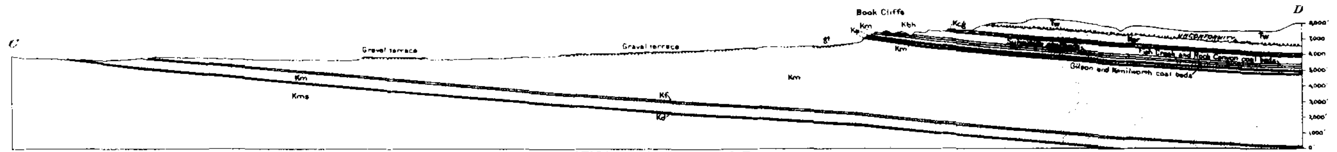
Local coal mine

6000

(Structure contours on upper Sunnyside coal bed in Wellington and Sunnyside quadrangles; on Castlegate coal in Castlegate quadrangle. Interval 100, [illegible] and 500 feet. Datum sea level)

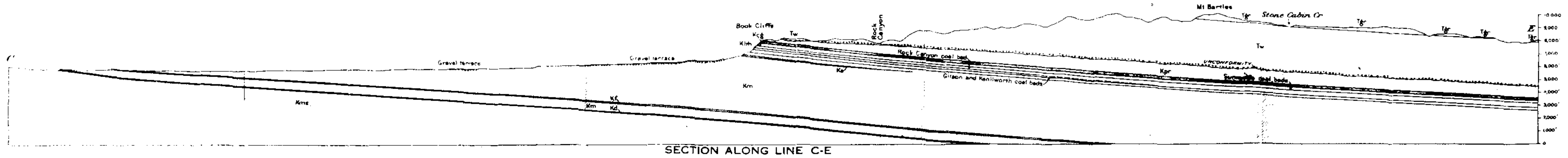
15°

Dip and strike of beds

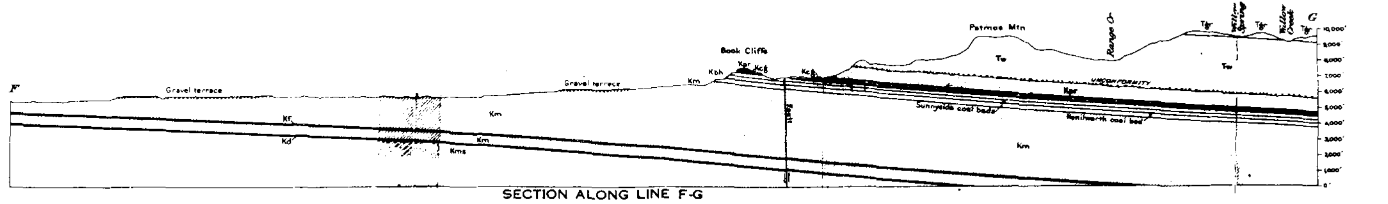


SECTION ALONG LINE C-D

SECTION ALONG LINE A-B



SECTION ALONG LINE C-E



SECTION ALONG LINE F-G

Figure 69

VIII. WATER RESOURCES NEAR TAR SAND TRIANGLE

This section considers in detail the water resources in the vicinity of the Tar Sand Triangle deposit. First, the available precipitation and surface runoff are considered. Water budgets are presented for the basin above existing stream gages. Then, the availability of groundwater is investigated.

SURFACE WATER

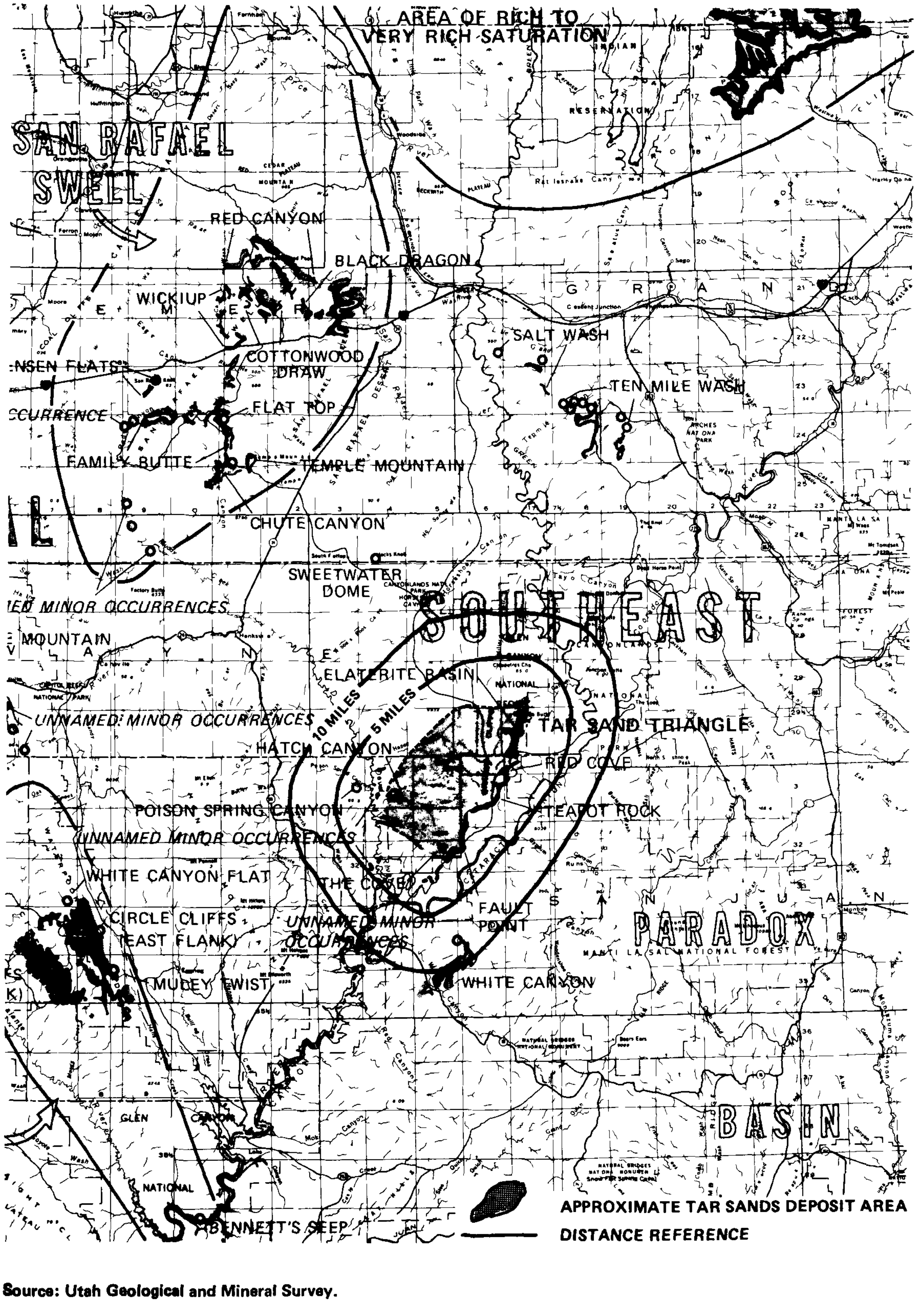
As stated previously, the Tar Sand Triangle area lies near the junction of the Dirty Devil River Basin with the Colorado River. Water from the Dirty Devil Basin would probably be used for development. While the Colorado River could also provide ample water, a complex series of interstate agreements are involved in the rights to its use. Therefore, this discussion concentrates on water from the Dirty Devil Basin. In addition to the annual USGS publications of water resource records, the only available reference is a hydrologic inventory of the Dirty Devil Basin by the Utah Department of Natural Resources (Reference 38). Most of the following discussion is taken from that reference source.

There are no major cities or towns near the Tar Sand Triangle deposit. The deposit lies mostly within the Glen Canyon National Recreational Area and immediately west of Canyon Lands National Park. Access to the area for development is severely restricted.

The vicinity of the tar sands deposit is shown in Figure 70. Reference lines for 5- and 10-mi distances are provided to indicate the distances over which water might be transported.

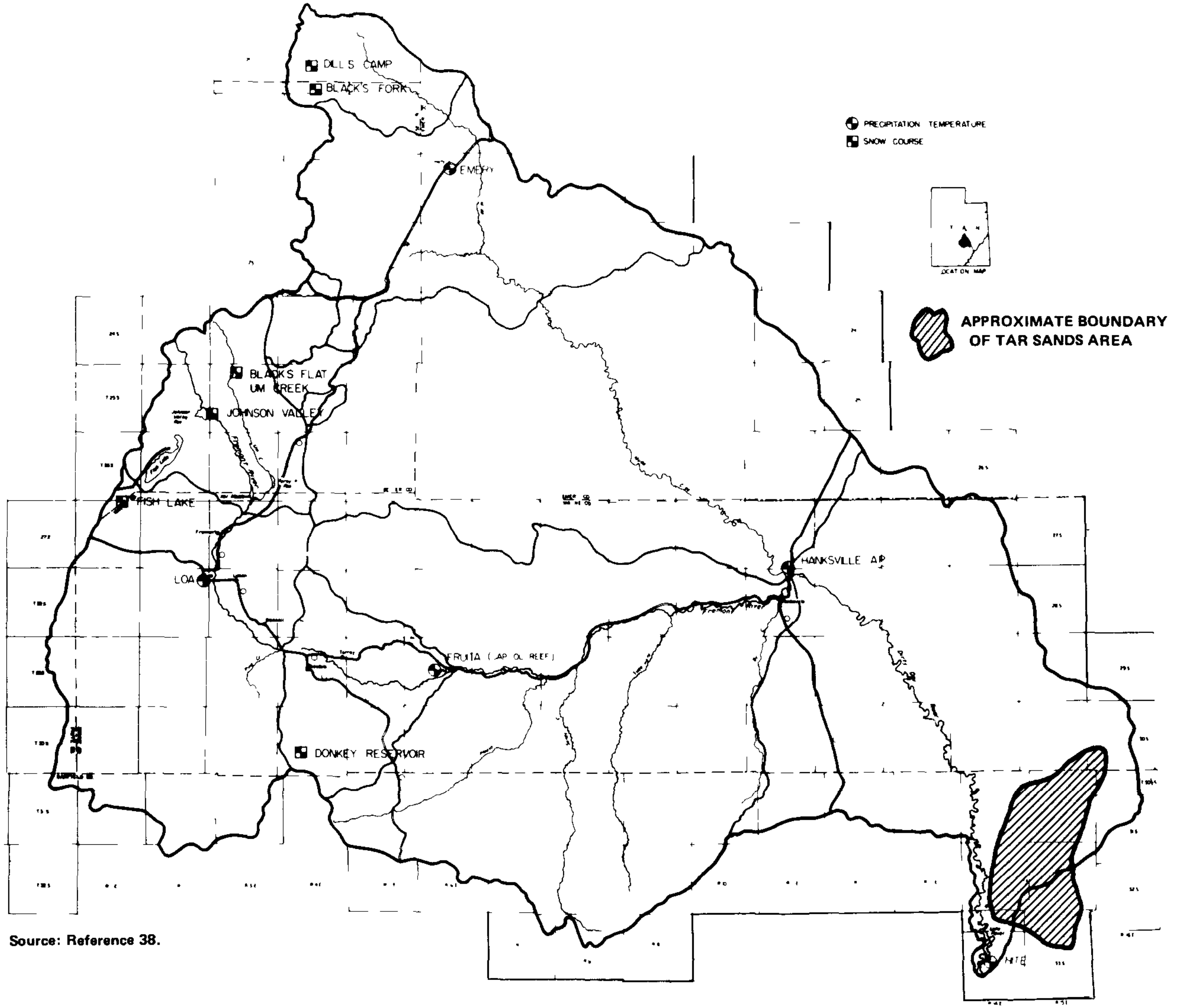
Only two creeks originate in the Tar Sand Triangle area: Happy Canyon, which flows west into the Dirty Devil River, and Millard Canyon, which flows northeast into the Green River. While the Green (discussed previously in this report), Colorado, and Dirty Devil Rivers are all within 10 mi of the tar sands deposit, only the Dirty Devil River is considered as a water source for tar sands development in this area.

Only a few stream gage and meteorologic stations are maintained near the Tar Sand Triangle. The meteorologic stations in the Dirty Devil Basin are illustrated in Figure 71; the stream gaging stations are illustrated in Figure 72. Figure 73 shows the stations and lengths of records (an important consideration in hydrologic monitoring) for the stations near the Tar Sand Triangle. Twenty to 30 years of records are desirable in defining trends and standard deviations. The gage station "Dirty Devil River near Hite" is still active but is now



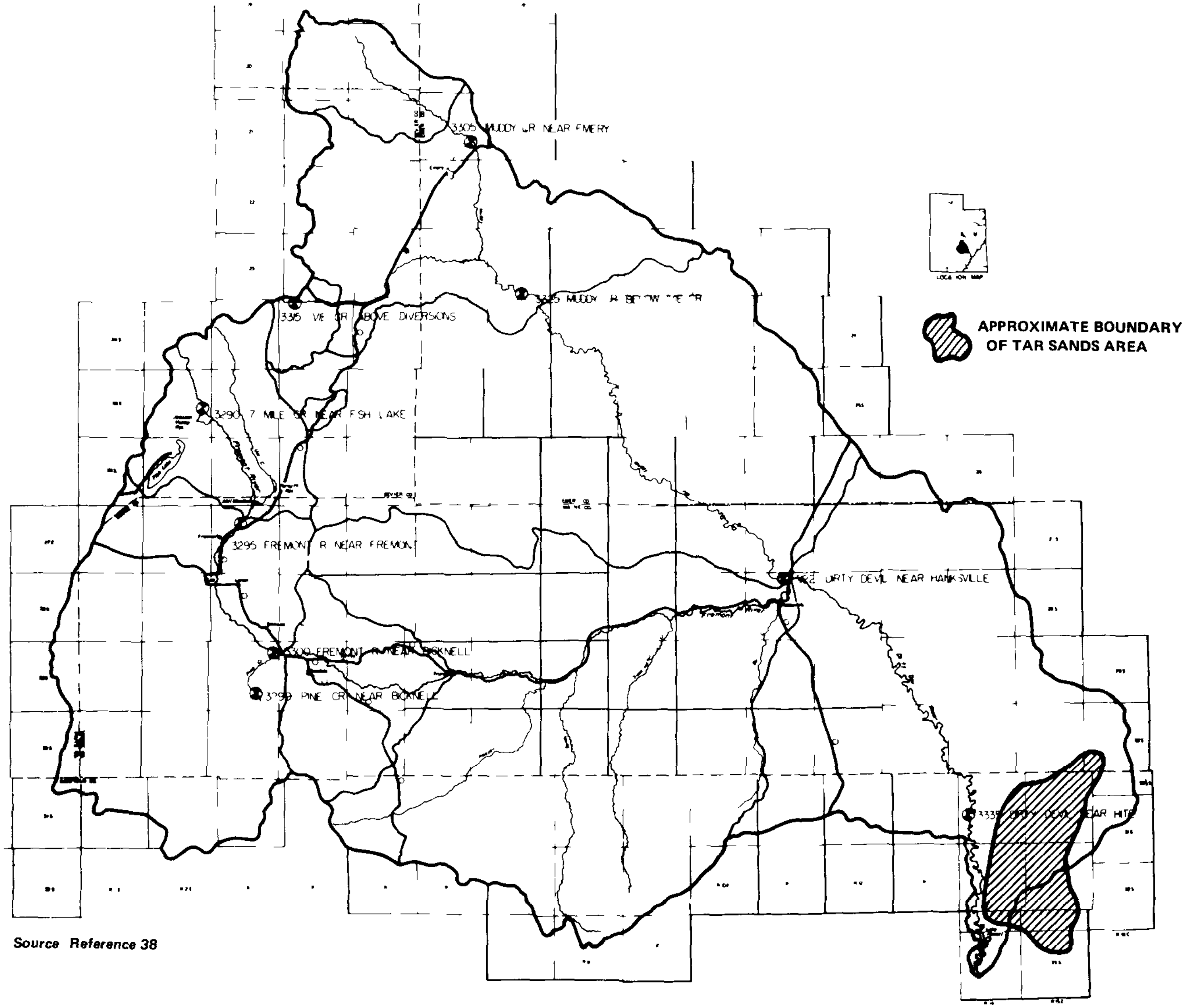
Source: Utah Geological and Mineral Survey.

Figure 70. TAR SAND TRIANGLE DEPOSIT AREA



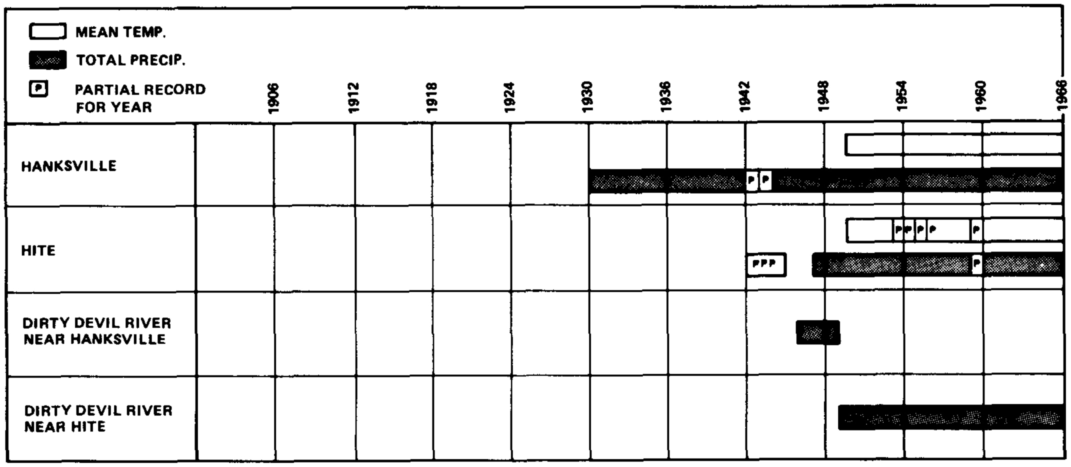
Source: Reference 38.

Figure 71. DIRTY DEVIL RIVER BASIN PRECIPITATION AND TEMPERATURE STATION LOCATIONS



Source Reference 38

Figure 72. DIRTY DEVIL RIVER BASIN STREAMFLOW GAGING STATION LOCATIONS



Source: Reference 38.

Figure 73. LENGTH OF RECORD FOR STREAM GAGES AND PRECIPITATION STATIONS NEAR TAR SAND TRIANGLE

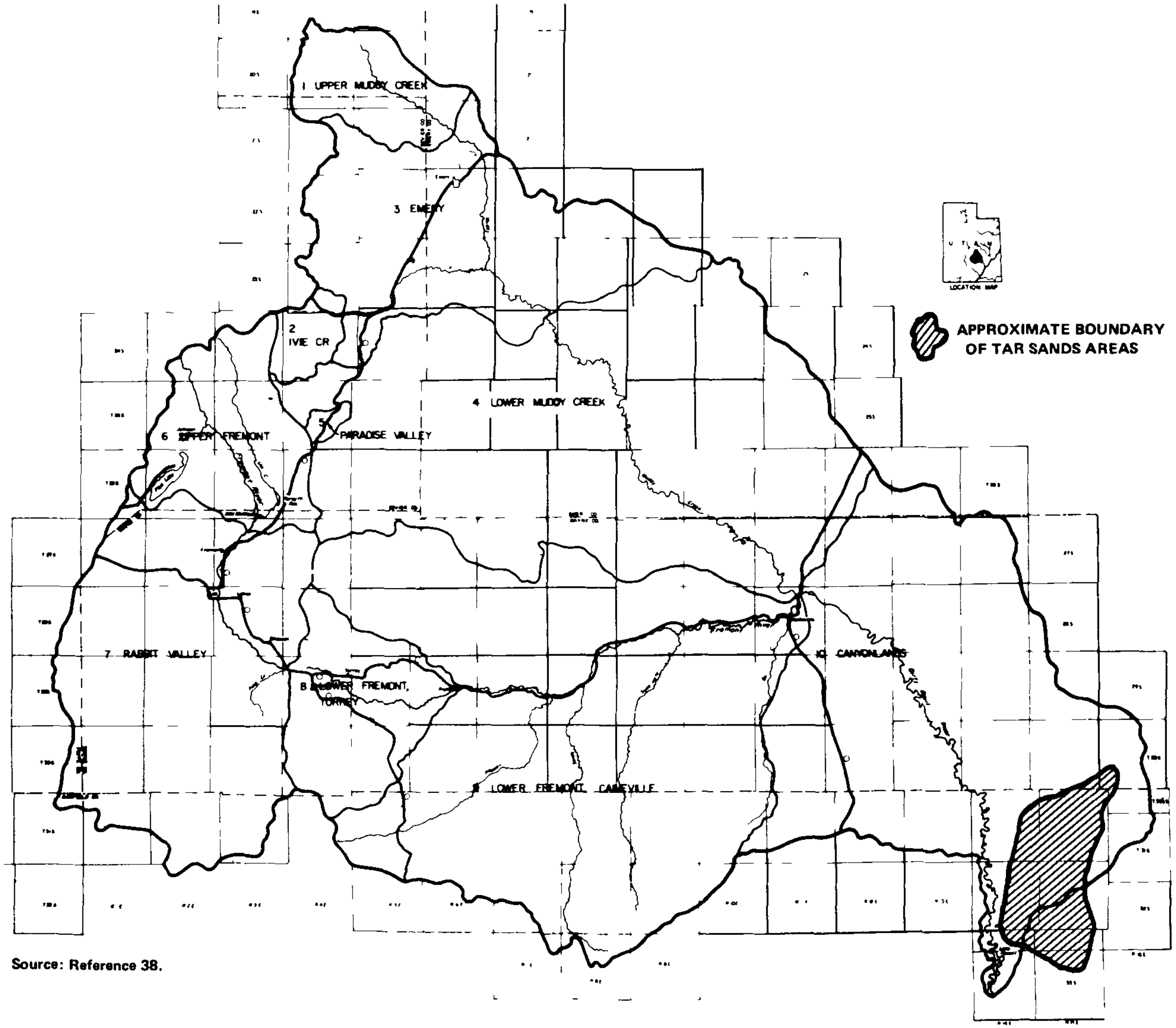
called "Dirty Devil River above Poison Springs Wash near Hanksville." Over 30 years of records are available there. The flow in the Dirty Devil River is well defined. Precipitation is well defined at Hite and Hanksville.

The Utah Department of National Resources divides the Dirty Devil Basin into a number of smaller hydrologic subareas based on the location of stream gages. These subareas facilitate the creation of water budgets. The hydrologic subareas of the Dirty Devil Basin are illustrated in Figure 74. Only Subarea 10, Canyon Lands, is of concern here.

Precipitation is the starting point for most water resources investigations. The quantity of surface water and groundwater ultimately available depends on the volume and the distribution of precipitation. Figure 75 is a map of the normal annual precipitation in the Dirty Devil Basin (Reference 38). A maximum of 10 in. of precipitation falls on parts of the Tar Sand Triangle area. Because the land surface elevations range from 5000 to nearly 7000 ft, at least part of this precipitation is in the form of snow.

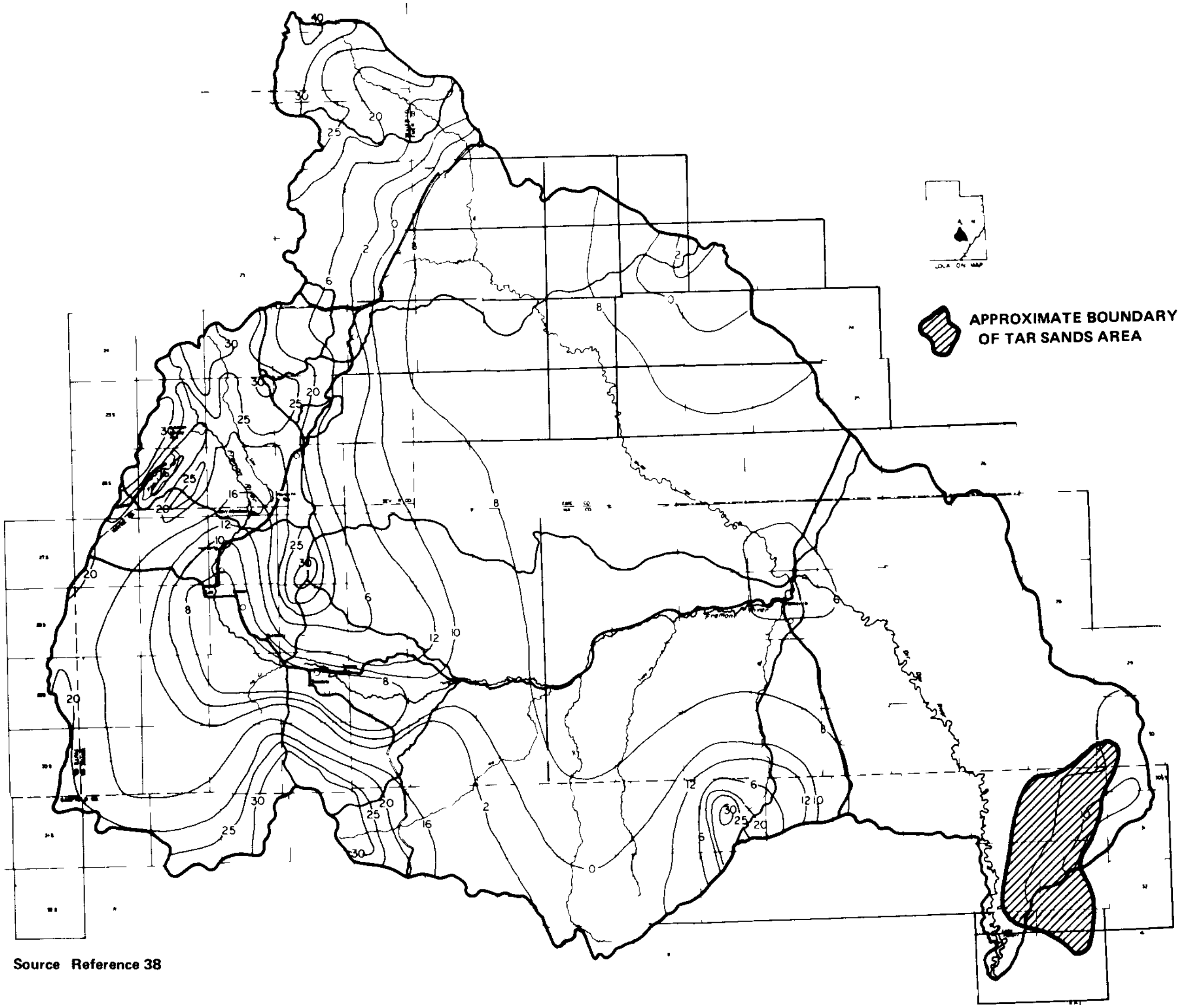
The time distribution of precipitation is an important consideration. Locations at which the precipitation is erratic over time require storage facilities so that the supply of water can be continuously available. The precipitation frequency distribution for Hanksville is illustrated in Figure 76. There is roughly a 50 percent chance of 1.25 in. of precipitation each month. Extreme events (5 percent chance) occur most often in August and October.

While the quantity of precipitation is important, the amount that actually runs off and becomes available for use is of greater concern. The Utah Department of Natural Resources (Reference 38) lists the mean annual flow of the Dirty Devil River at Hite as 73,890 acre-feet (AF) per year. This is roughly 5½ times the estimated requirements (13,000+ acre-feet



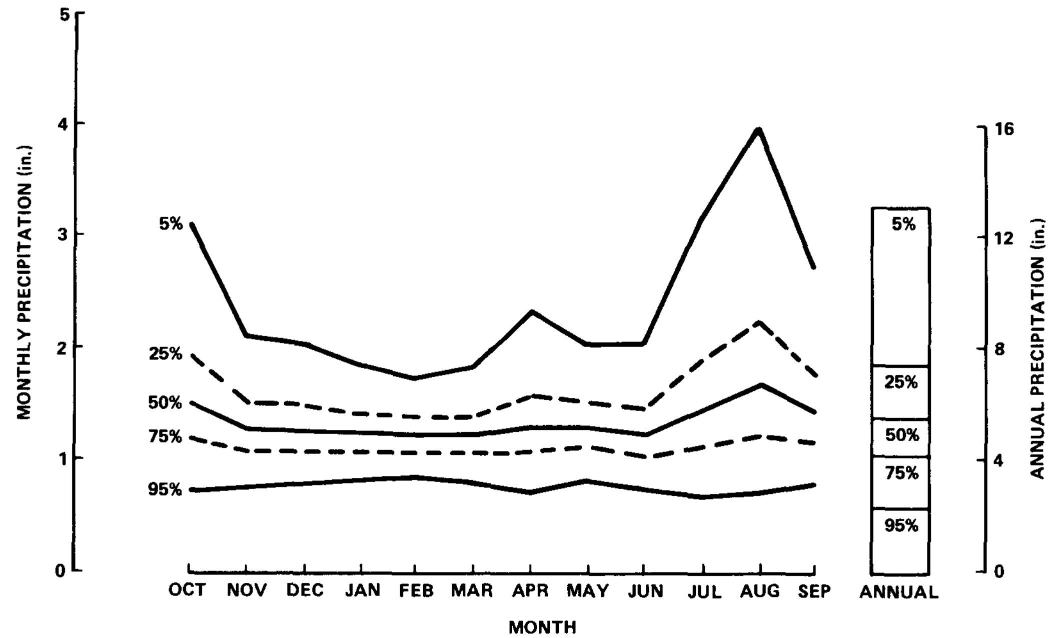
Source: Reference 38.

Figure 74. DIRTY DEVIL RIVER BASIN HYDROLOGIC SUBAREAS



Source Reference 38

Figure 75. DIRTY DEVIL RIVER BASIN NORMAL ANNUAL PRECIPITATION



Source: Reference 38.

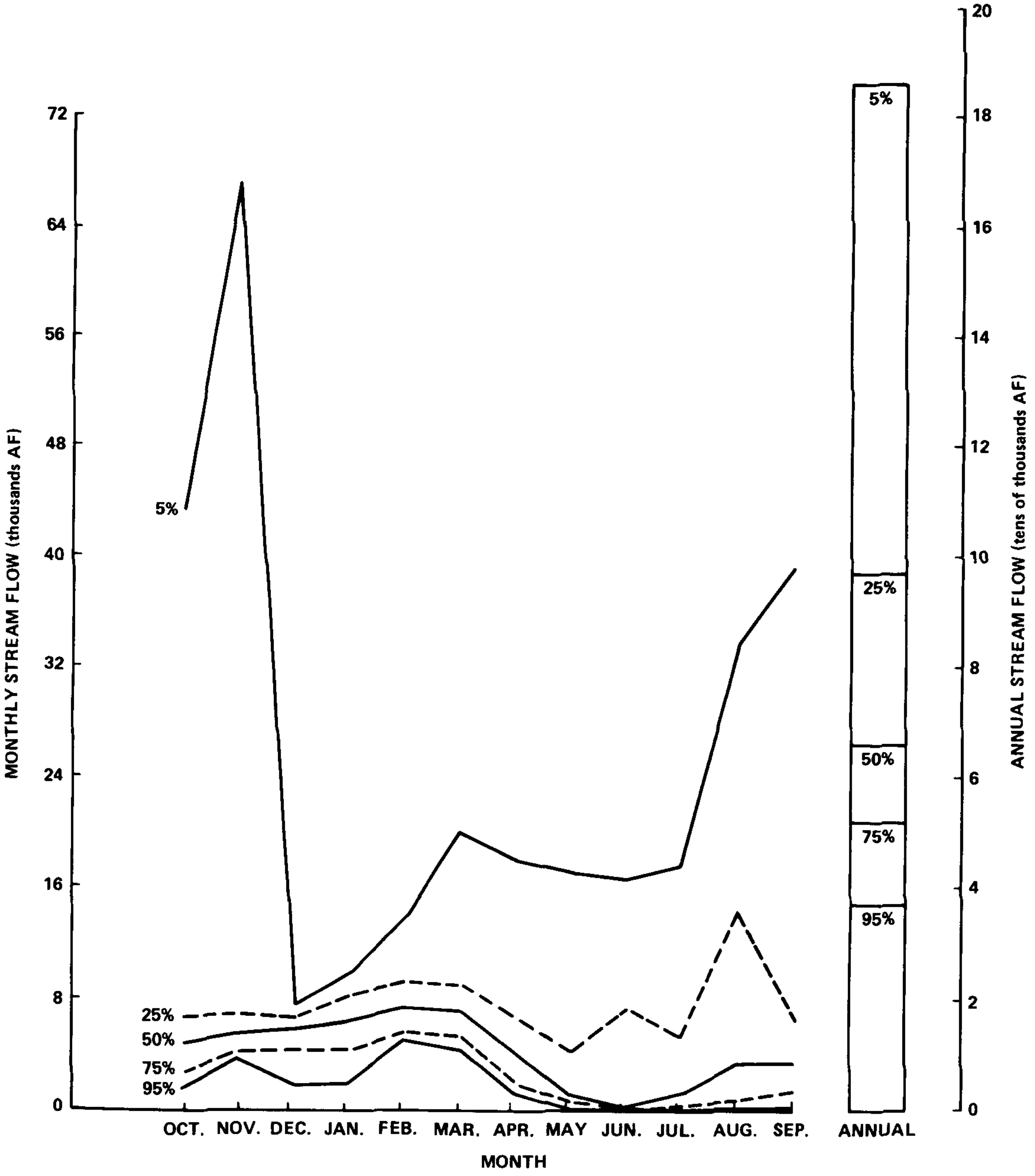
Figure 76. PRECIPITATION FREQUENCY DISTRIBUTION AT HANKSVILLE STATION (P-0832)

per year) for a production-scale tar sands facility (based on 5 bbl of water per barrel of oil). Reference 38 also provides some information on the distribution of the annual runoff with time. Figure 77 illustrates the streamflow probability for the station on the Dirty Devil River near Hite. There is a 95 percent probability of a 38,000-acre-feet per year flow in any given year. Most of the runoff occurs in February and March, with very little in June and July. Extreme events tend to occur in September and November.

The water yield map for the Dirty Devil Basin is presented in Figure 78. Less than an inch of runoff is estimated to occur anywhere near the tar sands deposit. The water yield map can be used to establish rough limits on the amount of water that originates in the ungaged streams in the tar sands area. Assuming a reasonable, typical amount of rainfall to be about 0.5 in. and given that the drainage area of Happy Canyon is 72 mi^2 (roughly two townships) and that of Millard Canyon is 36 mi^2 (roughly one township), these areas would yield roughly 1920 acre-feet and 960 acre-feet of water, respectively. Even if the total runoff could be stored, it would only be sufficient to support a pilot-level tar sands facility.

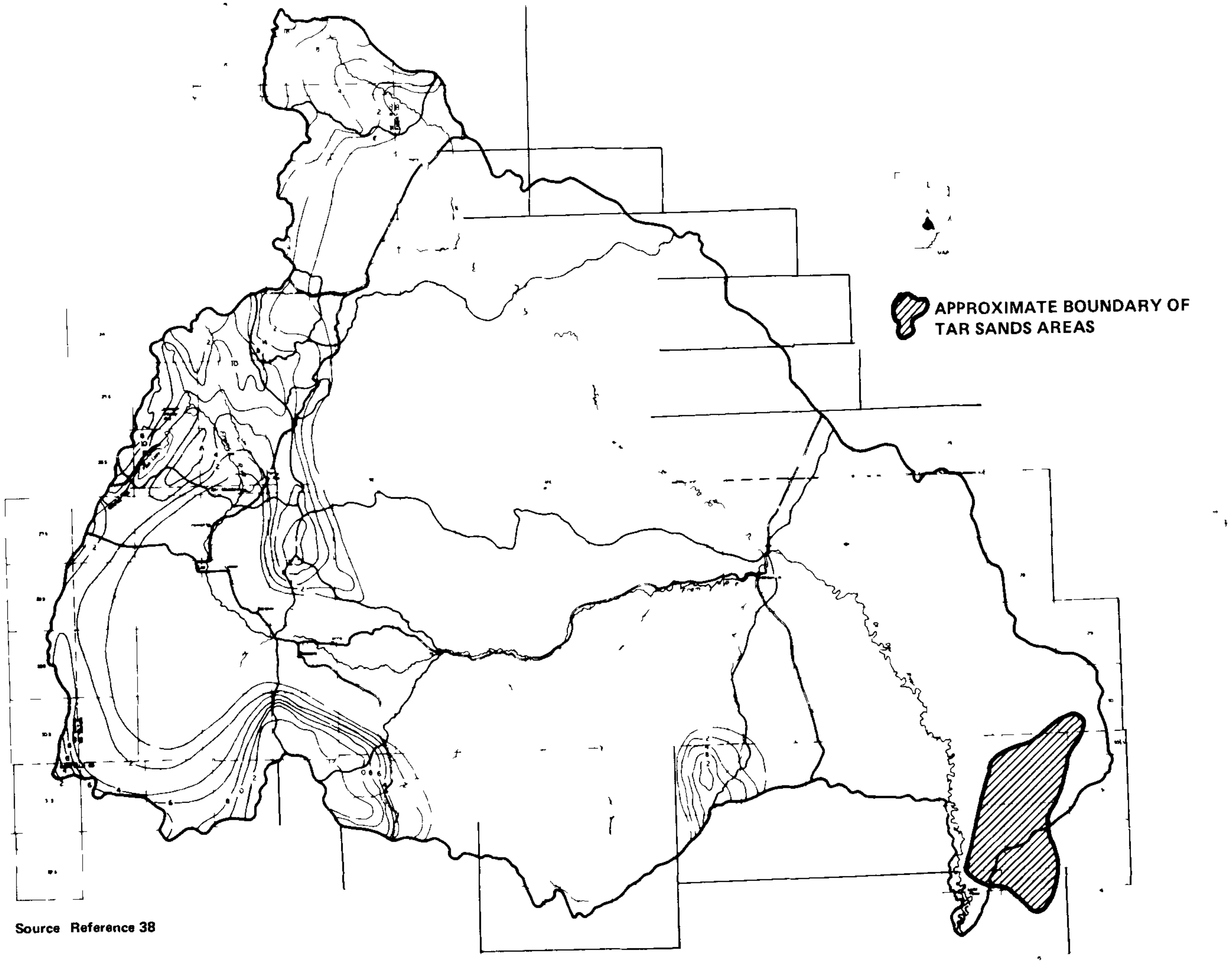
only be sufficient to support a pilot-level tar sands facility.

In order to determine the amount of runoff available, detailed information is needed on the spatial distribution of the runoff and losses from seepage, consumptive use, groundwater, evaporation, and other factors. The water budget for a basin provides these details.



Source: Reference 38.

Figure 77. STREAMFLOW PROBABILITY OF DIRTY DEVIL RIVER NEAR HITE



Source Reference 38

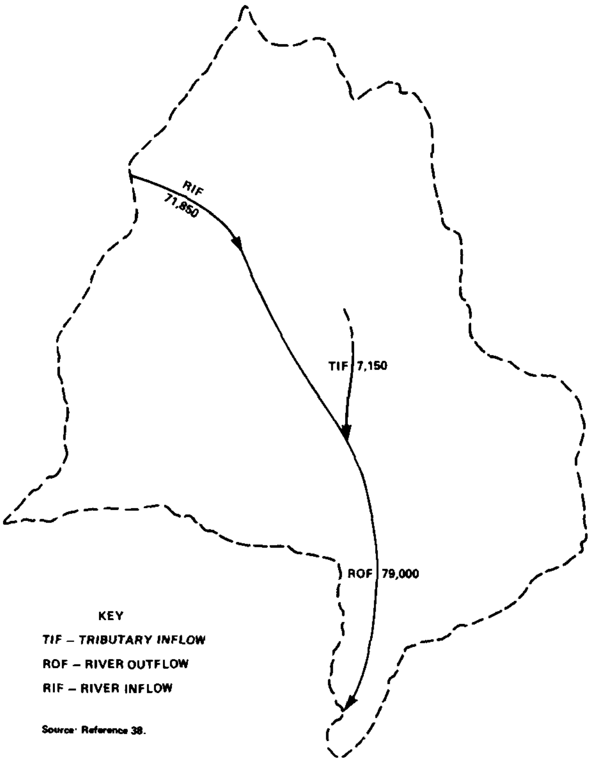
Figure 78. DIRTY DEVIL RIVER BASIN MEAN ANNUAL WATER YIELD

The procedure used is presented in Reference 5 and Section IV. Reference 38 gives the water budgets for the entire Dirty Devil Basin; only the water budget for the Canyon Lands subarea is discussed here.

Surface Water Supplies

The Canyon Lands subarea covers the 852 mi^2 of drainage between the confluence of the Fremont River and Muddy Creek, and the mouth of the Dirty Devil River near Hite; the flow diagram is shown in Figure 79. There are no agricultural or industrial activities in this subarea.

Table 56 describes the water budget for this subarea. Inflow consists of precipitation, estimated flow of the Fremont River at Hanksville, and unmeasured inflow from Muddy Creek at Hanksville*; the outflow is closely gaged by the flow of the Dirty Devil River near Hite. The outflow into the Colorado River is an estimate.



Source: Reference 38.

Figure 79. FLOW DIAGRAM OF MEAN ANNUAL WATER BUDGET FOR THE CANYON LANDS SUBAREA

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*A USGS gage was established on Muddy Creek at Hanksville after the Utah Department of Natural Resources conducted its hydrologic inventory (Reference 38).

Table 56. MEAN ANNUAL WATER BUDGET FOR CANYON LANDS SUBAREA

Characteristics	Water Budget (AF)
River inflow	71,850
Tributary inflow (unmeasured)	7,150
River outflow (estimated)	79,000

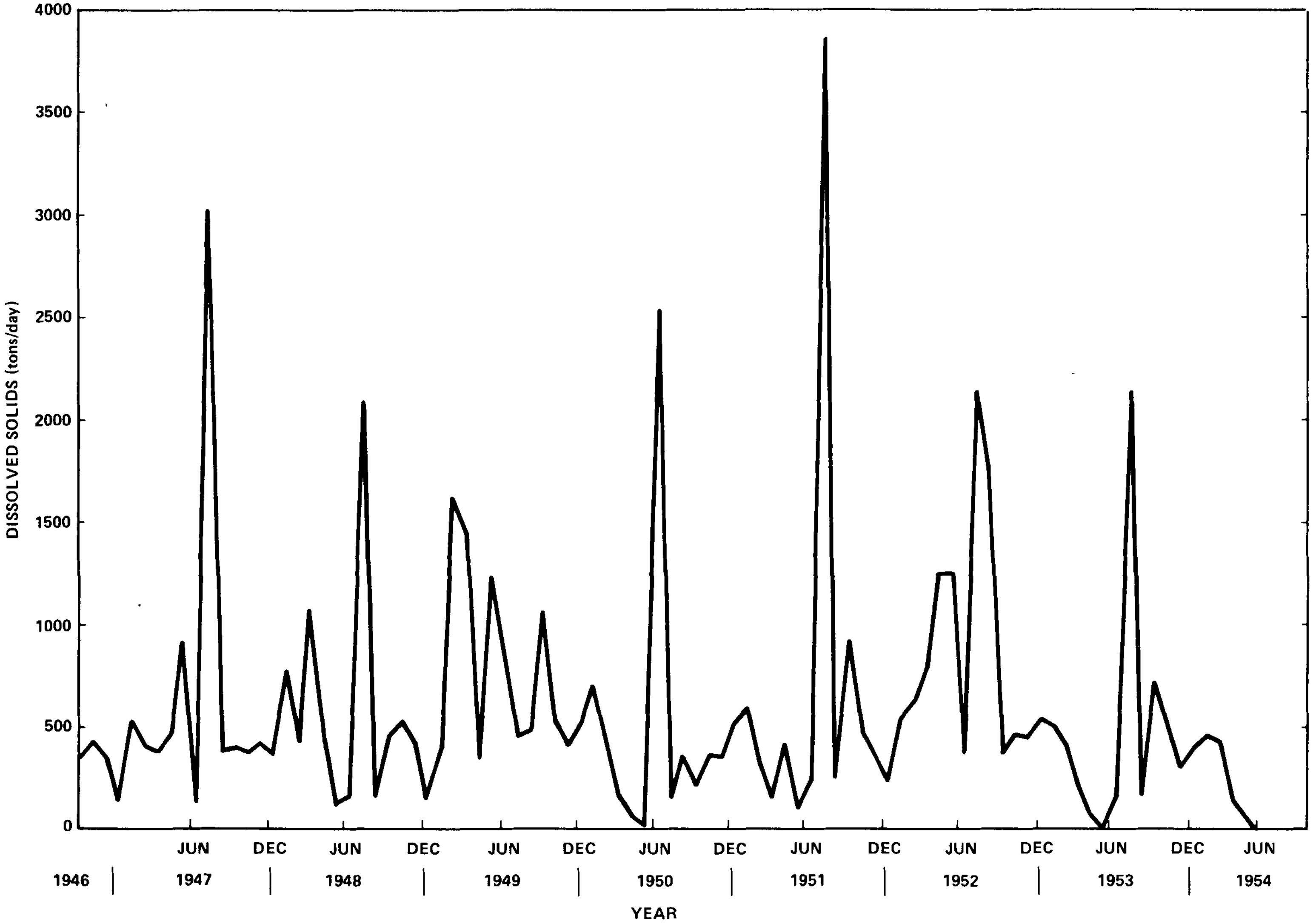
Surface Water Availability for Tar Sands Development

Water for use in production-level tar sands development facilities in the Tar Sand Triangle area must be withdrawn from one of three rivers, the Dirty Devil, Colorado, or Green. While sufficient water to supply a production-scale facility flows in all three rivers, use of the Green and Colorado Rivers involves complex water rights problems and, thus, they cannot be considered as probable sources. The question of water rights is discussed in Section IX.

The estimated yield of the ungaged tributaries in the tar sands area is probably adequate to support pilot-level operations; however, storage facilities would be required. Since development of such storage facilities in an ungaged area is risky, some form of gaging or modeling program would have to be undertaken to determine the exact amount of water available, taking into account the expected losses from evaporation and seepage when stored.

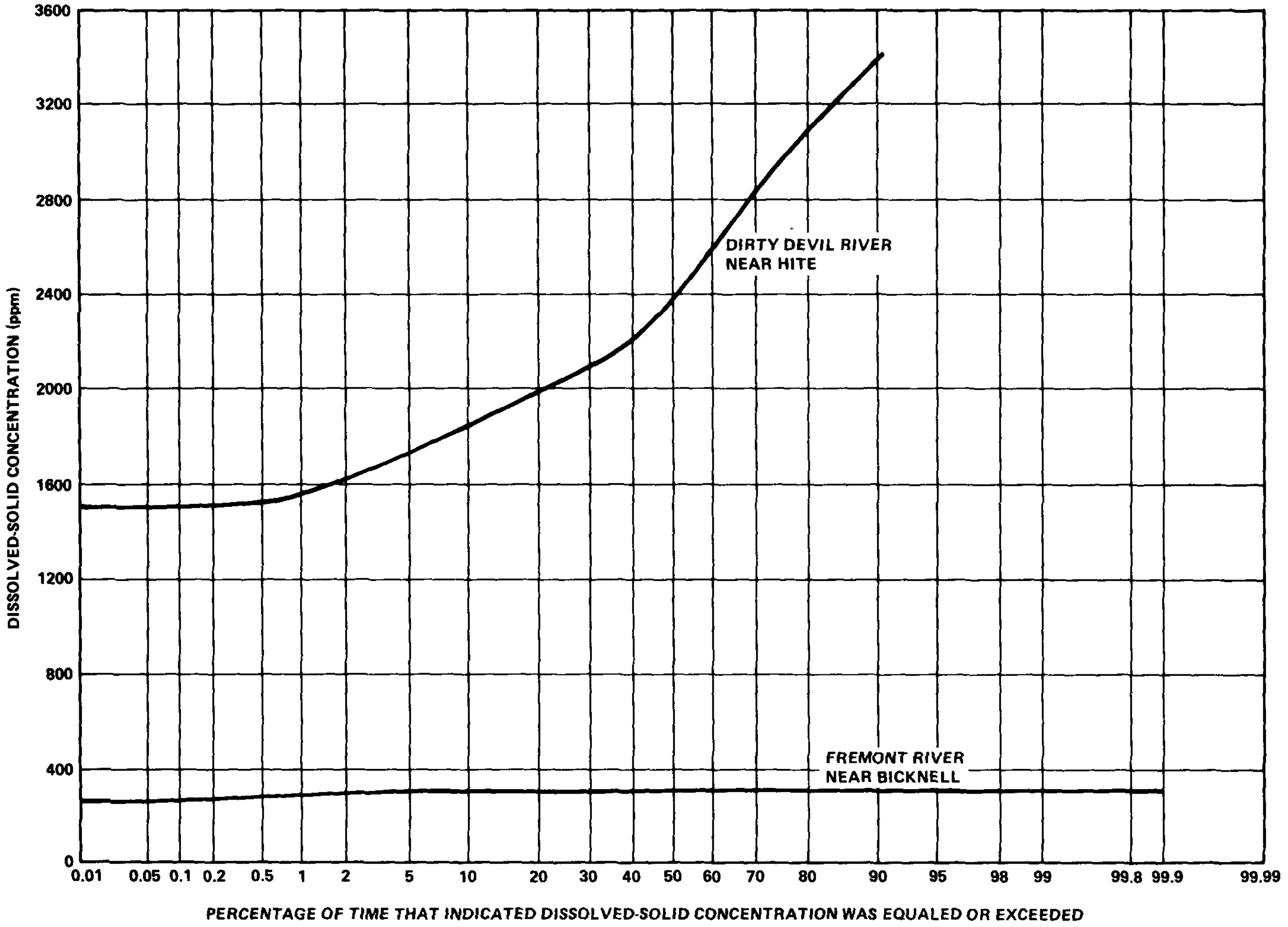
Surface Water Quality

As stated in Section IV, the amount and quality of water quality data vary widely. The same comments and cautions also apply to the Tar Sand Triangle area. Very little is known about the quality of water in the Dirty Devil River. Currently, the USGS collects random observations of temperature and specific conductance at Hanksville. In previous years, suspended sediment records and water quality samples for total dissolved solids have been collected. The most common quality measurements are total dissolved solids (TDS) in units of parts per million and tons per day (which requires simultaneous discharge measurements). Figure 80 shows TDS measurements at the Hanksville station on the Dirty Devil River. The USGS has prepared TDS duration data for the Fremont River near Bicknell and the Dirty Devil River near Hite. These data are plotted in Figure 81.



Source: Reference 38.

Figure 80. TOTAL DISSOLVED SOLIDS IN DIRTY DEVIL RIVER NEAR HANKSVILLE



Source: Reference 38.

Figure 81. TOTAL DISSOLVED SOLIDS DURATION (YEAR)

ceeds 2400 mg per liter. The Public Health Service standard recommended for drinking water and water supplies used by common carriers is no more than 500 mg per liter. This value is exceeded at Hite 100 percent of the time. No data have been published on the chemical content of the dissolved solids in the Dirty Devil River.

GROUNDWATER

There is a dearth of published information on groundwater near the Tar Sand Triangle. There is not even much information on the subsurface geology of the area. Most of the information in the following presentation comes from Reference 3, Reference 37, and USGS Bulletin 951 (published in 1947). Even the Utah State Oil and Gas Conservation Commission and the State Engineer could not provide any additional information.

Reference 38 states that most of the groundwater resources in the Dirty Devil Basin are in Rabbit Valley, which is near the upper end of the Fremont River and over 60 mi from the Tar Sand Triangle area.

Subsurface Geology

A limited picture of the subsurface geology of the Tar Sand Triangle area is presented in USGS Bulletin 951. Plate 1 of that bulletin presents a geologic section of the Canyon Lands area, which runs north and south through a portion of the Tar Sand Triangle. This section is reproduced as Figure 82. The surface geology varies from Jurassic to Permian in age. The tar sands lie in the White Rim Sandstone, which is of the Permian period. Cambrian rock structures appear to underlie the Pennsylvanian in an unconformable manner.

Water from Bedrock

Feltis (Reference 3) states that groundwater data are not available for many areas in the Canyon Lands principally because no water wells have been drilled to determine the quantity of water and because such data were not collected during oil and gas exploration.

Recharge to bedrock aquifers in the Canyon Lands occurs when permeable formations crop out along the flanks of the Abajo, Henry, and La Sal Mountains, along the flanks of folds such as the Comb Ridge Monocline, San Rafael Swell, or Waterpocket Fold, and on the wide expanse of flat-lying aquifers that are exposed between the major structural elements. Except near the mountains, however, the amount of recharge is generally small because of the low level of annual precipitation that normally occurs.

Also included in Reference 3 is a formation-by-formation analysis of the water-bearing properties of the Canyon Lands subarea. The most promising water producers are summarized here. The information primarily pertains to the area around T. 30 S., R 16 E., where the tar sands lie.

Chemical analyses of water from the Rico Formation are available for water from five springs and one well. Three springs in T. 33 S., R. 15 E. yielded water containing 1220, 3920, and 4770 ppm of dissolved solids, respectively. The water flowed at rates of about 70, 510, and 850 BPD (2, 15, and 25 GPM), respectively. A water well in T. 35 S., R. 15 E. yielded water containing 310 ppm of dissolved solids at a rate of 350 BPD (10 GPM).

Two water wells in the Cedar Mesa Sandstone member in T. 41 S., R. 16 E. and T. 43 S., R. 14 E. yielded water of 1890 and 656 ppm of dissolved solids, respectively. The flow rates were about 100 and 70 BPD (3 and 2 GPM), respectively. Seven springs in Tps. 36, 37, and 42 S., Rs. 16-18 E. in the sandstone in San Juan County yielded water at rates generally less than 170 BPD (5 GPM). The level of dissolved solids ranged from 298 to 596 ppm. The Cedar Mesa Formation is exposed to recharge in much of the tar sands area, which may increase its potential as an aquifer there.

A water sample from an oil well in the Organ Rock Tongue in T. 29 S., R. 10 E. contained 4487 ppm of dissolved solids. Two springs, one in T. 43 S., R. 16 E. and another in T. 34 S., R. 14 E., yielded water containing 944 and 375 ppm of dissolved solids, respectively. The flow of the former was less than 3 BPD (0.1 GPM), but the latter flowed at a rate of about 1000 BPD (30 GPM).

The dissolved-solids content of water from six oil wells in the White Rim Sandstone member in the west-central Canyon Lands section ranged from 2045 to 6045 ppm of dissolved solids. Some of the tar sands in the Triangle area are in the White Rim Sandstone. It is probably not a likely aquifer.

In T. 24 S., R. 13 E., water sampled at two depths in an oil well in the Moenkopi Formation contained 12,472 and 15,999 ppm of dissolved solids. The latter sample was obtained with a reported yield of 94 BPD (2.8 GPM). In T. 24 S., R. 14 E., however, another oil well yielded water from the Moenkopi Formation that contained only 4187 ppm of dissolved solids. Two springs in T. 35 S., Rs. 13 and 14 E. yielded water containing 1700 and 1860 ppm of dissolved solids, respectively. Their respective flow rates were 15,300 BPD (450 GPM) and 1700 to 13,700 BPD (50 to 400 GPM). Another spring in T. 31 S., R. 14 E. yielded water containing 2355 ppm of dissolved solids. A spring in T. 20 S., R. 11 E. yielded water containing 2250 ppm of dissolved solids, its flow rate was 680 BPD (20 GPM).

In T. 24 S., R. 13 E., an oil well in the Sinbad Limestone yielded water containing 18,125 ppm of dissolved solids. In oil wells in T. 29 S., Rs. 10 and 12 E. the Sinbad yielded water containing 4437 and 9130 ppm of dissolved solids, with the latter at a flow rate of 432 BPD (13 GPM). A water sample collected from the Kaibab Limestone, the Sinbad Lime-

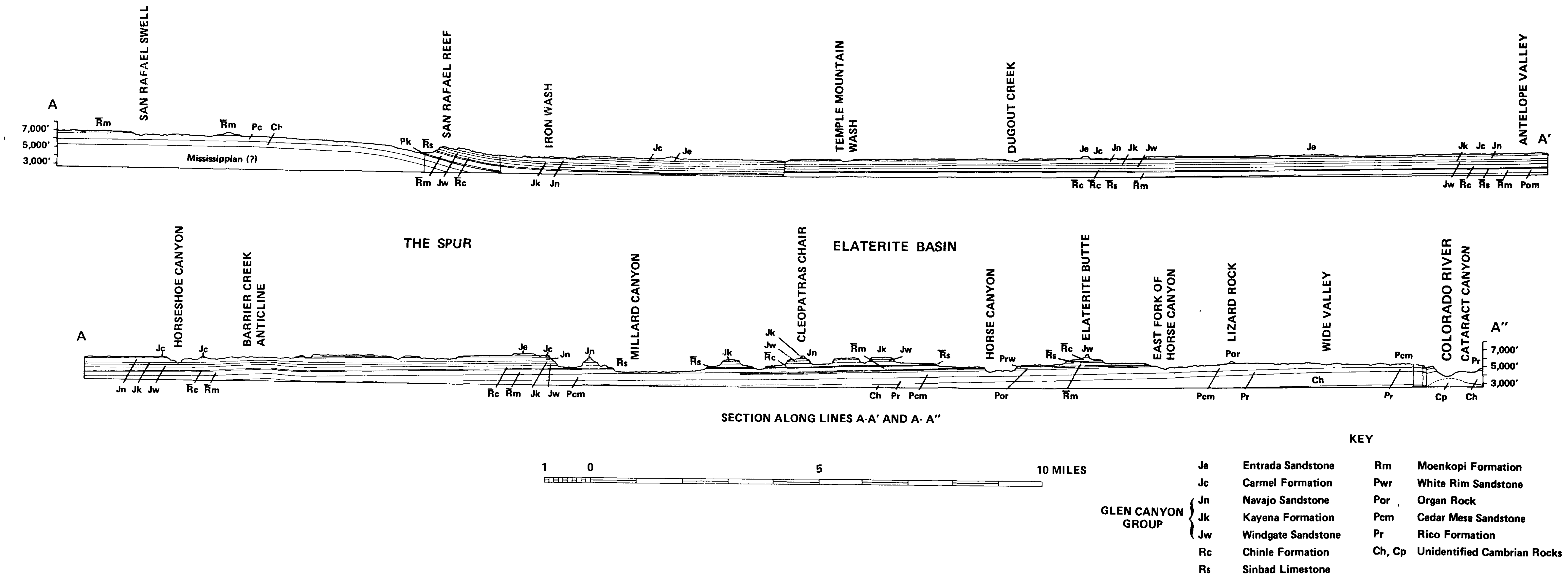


Figure 82. GEOLOGIC SECTION
OF THE CANYON LANDS AREA

stone Member, and undifferentiated beds in the Moenkopi Formation in an oil well in T. 29 S., R. 11 E. contained 6167 ppm of dissolved solids.

The quality of water from the Chinle Formation has not been tested near Tar Sand Triangle. In other areas it is very saline to briny. The Glen Canyon Group consists of the Wingate Sandstone, the Kayenta Formation, and the Navajo Sandstone. This widespread sequence of predominantly sandstone is one of the most important aquifers in the Canyon Lands section because it generally yields fresh water to springs, and in many areas it yields water to wells that is at least suitable for livestock.

In T. 23 S., R. 21 E.; T. 30 S., R. 24 E.; T. 31 S., R. 23 E.; and T. 43 S., R. 24 E., water wells yielded water from the Wingate Sandstone that contained about 300 to 400 ppm of dissolved solids. The yield of two of the four wells was 70 and 140 BPD (2 and 4 GPM). Sixteen springs in the Wingate yielded water containing 133 to 914 ppm of dissolved solids, with the flow rates ranging from 17 to 3840 BPD (0.5 to 113 GPM). In T. 26 S., R. 7 E., water from an oil well in the Wingate contained 4079 ppm of dissolved solids. Water produced from a well that taps the Wingate and also the Entrada and Navajo Sandstones is discussed in the section on the Entrada Sandstone. Recharge to the Wingate is restricted by the overlying, relatively impermeable Kayenta Formation. Where fracturing and faulting extend through the Glen Canyon Group, however, water moves downward from the Navajo Sandstone through the Kayenta Formation into the Wingate Sandstone.

The Kayenta Formation generally acts as a barrier to the vertical movement of groundwater rather than as an aquifer. Many springs in the Glen Canyon Group issue at the base of the Navajo Sandstone or near the top of the Kayenta Formation because the more impermeable rock of the Kayenta Formation restricts or stops the downward flow of water. Three springs in the Kayenta (in T. 31 S., R. 15 E.; T. 39 S., R. 11 E.; and T. 42 S., R. 12 E.) yielded water containing 220, 115, and 144 ppm of dissolved solids, respectively. The flow rates were 70 BPD (2 GPM) or less.

Most water wells in the Glen Canyon Group draw water from the Navajo Sandstone, probably because it is the shallowest and most permeable formation in the group. Twenty-one water wells in the Navajo Sandstone yielded water containing from 171 to 7250 ppm of dissolved solids, with flow rates ranging from 70 to 45,400 BPD (2 to 1335 GPM). Ten wells drilled in the Navajo Sandstone in Arizona and Utah to supply water at the Glen Canyon Dam construction facility in Arizona yielded water containing from 216 to 1814 ppm of dissolved solids. The flow rates ranged from 1200 to 45,400 BPD (35 to 1335 GPM).

Chemical analyses of water from 14 springs in the Navajo Sandstone showed a range of dissolved solids from 129 to 354 ppm. The yields of the springs range from less than 34 BPD (1 GPM) to 1700 BPD (50 GPM). Most of the springs yield 340 BPD (10 GPM) or less.

The Carmel Formation has yielded water that ranges from fresh to moderately saline. In most areas, however, the Carmel forms an aquiclude above the Navajo Sandstone. An example of this is the Blanding Basin, where the water in the Navajo Sandstone is confined under artesian pressure by the overlying Carmel Formation.

The Entrada Sandstone has yielded fresh water in some areas and saline water in others. The water from six wells in eastern San Juan County contained 360 to 801 ppm of dissolved solids, that from seven wells in Emery, Kane, and Wayne Counties contained 380 to 3500 ppm, and that from two wells in Grand County contained 9470 and 14,300 ppm.

Data for eight wells indicate that yields from the Entrada Sandstone range from about 85 to 40,000 BPD (2.5 to 1200 GPM). Five of these wells are in San Juan County, and their yields average 4860 BPD (143 GPM). The Entrada is the highest formation in the Tar Sand Triangle, and it is probably not an aquifer.

Table 57 lists specific information from wells identified by Feltis (Reference 3) in the Canyon Lands area. Wells that are within a reasonable distance of the Tar Sand Triangle are included in the table. Again, these wells lie near T. 30 S., R. 16 E.

A well indicated in Table 57 in T. 28 S., R. 11 E. that yielded 13 GPM is near Hanksville. There is a considerable difference between the Entrada Sandstone there and the small amounts sitting atop the Tar Sand Triangle.

Reference 37 contains some information on wells and springs near Hanksville. Most of the data are over 20 years old and no yield numbers are given.

Groundwater Availability for Tar Sands Development

The following quantities of water (based on 5 bbl of water per barrel of oil) are estimated to be the amount for production-scale tar sands facilities of various sizes:

- five-well experimental facility–22 GPM,
- 24-well pilot facility–132 GPM, and
- large-scale production facility–8300 GPM.

As stated previously, these estimates assume 100 percent consumptive use and are very conservative.

When compared with the measured yields of springs in the Tar Sand Triangle, none of the springs yields even enough for test development.

The information given by Feltis (Reference 3) is more encouraging. The Cedar Mesa and Moenkopi Formations are both exposed to the surface over a considerable area near Tar Sand Triangle. Several streams and creeks flow over the Cedar Mesa. Based on yield

Table 57. OIL WELLS AND SPRINGS NEAR TAR SAND TRIANGLE

Location			Operator or Owner	Name or Number	Producing Formation	Depth to Top of Formation (ft)	Depth to Bottom of Formation (ft)	Interval Sampled (ft)	Yield (BPD/GPM)	Remarks
T	R	Section								
28S	11E	NW¼SE¼SE¼ 16	E E Stone	1	Entrada Ss	0	–	305 340	See Remarks	Reported flow on 5 29 62 was 13 GPM (440 BPD) Analysis includes 0 22 ppm boron and 0 3 ppm fluoride
28S	14E	SE¼NE¼SW¼ 22	A Ekker	Robbers Roost Spring	Carmel Fm	0	–	–	34/1(R)	Analysis includes 0 12 ppm boron and 0 3 ppm fluoride
28S	15E	NW¼NW¼SE¼ 21	A Ekker	Blue John Spring	Entrada Ss	0	–	–	34/1(R)	Analysis includes 0 07 ppm boron and 0 3 ppm fluoride
28S	15E	SE¼SE¼SE¼ 29	–	Granary Spring	Entrada Ss	0	–	–	–	
28S	18E	NW¼NE¼NW¼ 12	Pan American Petroleum Corp	1	Mississippian sed rocks	5,497	6,092	5 507 90 5,652 5,825	– –	DST 5 recovered 3,150 ft of salty sulfur water DST 6 recovered 3 600 ft of black sulfur water
30S	16E	NW¼NE¼NE¼ 3	–	French Spring	Navajo Ss	0	–	–	34/1(R)	Analysis includes 0 01 ppm boron and 0 1 ppm fluoride
31S	14E	NE¼SE¼ 23	–	Lower North Hatch Spring	Moenkopi Fm	0	–	–	–	Analysis includes 33 ppm iron and aluminum
31S	14E	SW¼NW¼ 36	–	Tonto Mill Site Spring	Shinarump Mbr of Chinle Fm	0	–	–	–	
31S	15E	9	–	Two Pipe Spring	Kayenta Fm	0	–	–	17/0 5(E)	Spring is on south side of ridge above North Hatch Canyon
31S	15E	NW¼SE¼NW¼ 19	Superior Oil Co	22 19	Paradox Fm	2,750	3,780	2,839 64	–	DST 1 recovered 270 ft of slightly mud-cut water
29S	15E	NW¼NW¼SE¼ 14	A Ekker	Trail Spring	Navajo Ss	0	–		17/0 5(R)	Analysis includes 0 01 ppm boron and 0 1 ppm fluoride
29S	15E	S½SE¼NE¼ 20	Continental Oil Co	1	Mississippian sed rocks	6 603	–	6,685 6,846	–	DST 4 recovered 900 ft of muddy water and 680 ft of black sulfur water

Source Reference 3

values from other locations, perhaps 5-10 GPM could be obtained from wells in either of these formations. While low, such yields would at least support test activities. The Moenkopi Formation has yielded quantities of water sufficient to support test facilities. Several springs less than 30 mi from the Tar Sand Triangle have yielded quantities from 20 to 400 GPM. Only actual exploration for water in the Tar Sand Triangle area will provide the data needed for a meaningful assessment. A reasonable expectation is that several of the formations would yield 5 to 10 GPM. Based on current data, groundwater supplies seem inadequate to support production facilities.

IX. LEGAL, SOCIAL, AND OTHER FACTORS

INTRODUCTION

In addition to the issues of water availability, quality, and current use, other factors such as legal restraints, population trends, and current plans for development of each area must be considered. This section of the report summarizes some of these other critical factors that could limit the use of water for tar sands development even though sufficient quantities are available.

LAWS GOVERNING WATER RIGHTS

Trelease (Reference 39) presents one of the best descriptions of the various types of water rights regarding surface water. Trelease contrasts the riparian doctrine of the eastern states, where water is abundant, with the appropriative doctrine of eighteen western continental states, including Alaska. Both types involve property interest created by or obtained under state law, but they have very different characteristics. While most states recognize only one type or the other, in several states both types exist. Utah recognizes only the appropriative type of water rights law.

Riparian rights are governed for the most part by common law. The major feature of riparian rights is that the owners of land bordering upon a stream have equal rights to the use of the water. The basic rule states that each landowner whose property borders a stream is entitled to the natural flow of the stream as its passes his land, undiminished in quantity and unimpaired in quality. Use of the water is limited to the stream bank. The principal commercial use of water was to turn the wheels of mills or factories and the water was to be passed down from one mill dam to the next. Today, the rule is more often interpreted as meaning that each riparian may make a reasonable use of the water consistent with like uses by the others. This interpretation permits some uses that may deplete the stream. Another important principle of the riparian rights is that the right to the water exists whether the use is made or not; hence, a riparian owner can initiate a use at any time and insist that the other users accommodate his use or that a share of the water be allotted to him.

On the other hand, the basic principles of water rights based on the prior-appropriation doctrine are that (a) the beneficial use of water, not ownership of the land, is the basis of the right to water and (b) priority of use, not equality of right, is the basis of the division of water among appropriators when there is not enough for all. The place of use is not limited to the stream bank; with few exceptions, the water can be used anywhere it is needed. An appropriation is always stated in terms of the right to take a definite quantity of water. The appropriations are confirmed and authorized by state and territorial decisions and statutes, and insofar as made on the public domain, by federal statutes. In Utah, water rights are kept on file in the Office of the State Engineer.

Thus, on a typical stream in a western state, there are many appropriators, each of whom was granted a water right at a different time. While there may be water for all when the mountain snowpacks melt and the stream is high, the quantity of water decreases during the dry summer. As the quantity decreases, the diversion works of the appropriators are shut off in inverse order of priority. The newest diversion is the first stopped, and the first one is never stopped. The right of the senior appropriator extends both upstream and downstream. He may take water needed by a junior appropriator below him, while the junior appropriator upstream must permit the water to go past his point of diversion when it is needed to supply the senior rights. There is no prorationing in times of scarcity. Thus, the burden of shortage falls on the most recently added appropriations.

Laws regarding groundwater form a somewhat different pattern. Groundwater, usable water under the surface of the Earth, is found in aquifers, porous formations such as gravel or sandstone, holding a substantial amount of water and permitting it to move through the formation. Although aquifers are usually fed by seepage from the surface, and often discharge water into springs and streams, groundwater in aquifers is so physically different from water in streams that historically it has been treated differently. Initially, the landowner was regarded as owning the water underneath his land and was permitted to extract whatever quantity he could. Then, a number of state courts imposed requirements that the owner's use of goundwater must be reasonable; some applied a rule of correlative rights similar to riparian doctrines of reasonable sharing. Many states have superimposed substantial statutory regulation on the exercise of these common law doctrines. A number of western states, including Utah, now have statutes adapting rules of prior appropriation to groundwater.

IMPACT OF WATER RIGHTS ON THE TAR SANDS DEVELOPMENT

Unfortunately, most surface waters in Utah are over-appropriated, and in any given year some users receive no water. Thus, in order to develop the tar sands areas discussed in this report, the developers will probably have to buy rights from established users with high-priority appropriations. In regard to this issue, the Office of the State Engineer in Utah has made the following statement to the Sutron Corporation:

> "Because there are applications to appropriate water in excess of Utah's allocation of water from the Colorado River, water rights for development in these areas which are in the Colorado drainage would have to be acquired from

> prior applicants who have approved applications near the areas to be developed. However, it may be difficult to find owners who would part with their approved applications covering sufficient quantity of water for development of the tar sands. Also, finding a source of water for any extensive development may be difficult especially in the Tar Sand Triangle area where little surface water is apparent and underground sources are unknown.
>
> "It appears that water for processing tar sands would have to come primarily from Colorado and Green Rivers or their tributaries if appropriate water rights could be acquired.
>
> "This is generally the situation on water rights and resources in these areas. To get the clear and concise picture of water rights and resources which you desire would require extensive research and exploration of specific locations."

However, before attempting to acquire any water rights, each potential development site must be carefully analyzed for water requirements so that an adequate water supply can be purchased from appropriators with sufficiently high priority to ensure a continuous supply.

Considerable information on specific water rights in the Vernal area is available in Reference 40. Some of the history of how the rights were established is also presented. Rights to the flow of Ashley Creek were adjudicated and a decree made in November 1897 in the Fourth Judicial Court of Utah. The decree apportioned the entire flow of the creek among the water users; several companies and numerous individuals were each awarded a certain portion of the total flow. Water under the various 1897 rights is now almost entirely distributed through six canals and ditches, the total diversion capacity of which has been accepted in operating practices over many years as 500 cfs. The 1897 decree, then, while ostensibly covering the entire flow of Ashley Creek, is in practice limited to 500 cfs The approximate percentages of the 1897 rights conveyed by each canal and ditch are as follows:

- Ashley Upper Canal (including Colton Ditch): 36,
- Ashley Central Canal (including Hardy Ditch): 34,
- Rock Point Canal: 20,
- Island Ditch: 7,
- Steinaker Ditch: 2, and
- Dodds Ditch: 1.

Percentages shown for the Ashley Upper Canal and Ashley Central Canal include water acquired from these canals by the municipal water systems and now diverted into a pipeline from Ashley Spring, located above the canal intakes and above the "Sign of the Maine" gage. Rights for the use of Ashley Creek flows for irrigation have been decreed since the original decree of 1897, primarily for use of flood waters and return flows from irrigation.

In addition to the 1897 water rights, the State Engineer, in 1912, granted an application that entitled Highline Canal to 182 cfs of the Ashley Creek runoff near the head of Ashley Valley after the runoff reaches 500 cfs. Moreover, water users under the Union and River Canals in the lower part of Ashley Valley hold rights to return flows and flood waters of Ashley Creek. These rights were obtained by application in 1909 and 1911, respectively, and were adjudicated by court decree in 1915. The decree provides for primary rights of 10 6/7 cfs to the Union Canal Company, 5 5/7 cfs to the River Irrigation Company, and 6/7 cfs to other minor users. It further provides for secondary rights totaling 35 1/10 cfs.

A number of applications have been filed with and approved by the State Engineer to store water on Ashley Creek and its tributaries and on other nearby streams for use as needed in the Vernal area. The State Engineer's approval of an application gives the applicant permission to proceed with the construction of works and use of water, but a final certificate of appropriation is issued only after proof of appropriation is made. The certificate of appropriation is issued only for the amount of water applied for or the amount of water beneficially used, whichever is less. No certificates of appropriation have yet been issued on storage rights for the Vernal area although four small reservoirs have been constructed on tributaries of Ashley Creek and one on Brush Creek under rights granted by approved applications. These four reservoirs, plus one on Brush Creek, are

- Long Park (Ashley Creek) – application right for 500 acre-feet,
- Twin Lakes (Ashley Creek) – application right for 360 acre-feet,
- Goose Lake (Ashley Creek) – application right for 150 acre-feet,
- Mirror Lake (Ashley Creek) – application right for 100 acre-feet, and
- Oaks Park (Brush Creek) – application right for 7500 acre-feet.

All of the storage reservoirs are operated for the benefit of the Ashley Valley Reservoir Company although some of the rights are held by government agencies pending repayment of loans granted for construction. The capital stock of the Ashley Valley Reservoir Company and, in turn, its reservoir water were distributed in 1956 among Ashley Valley irrigators and municipalities as listed in Table 58.

The Utah Power and Light Company has by application to the State Engineer acquired a right to use 55 cfs of water from Ashley Creek for its hydroelectric power plant on that stream. Water rights for the municipal water system have been acquired by the purchase of irrigation water.

In addition to the water rights previously mentioned, prior to construction of Steinaker Reservoir some applications were approved by the State Engineer to cover additional high flows of Ashley Creek for storage or direct use. No works were constructed to utilize the water, however, and proofs of appropriation were not made. The applicants apparently

Table 58. CAPITAL STOCK OF ASHLEY VALLEY RESERVOIR

Stockholder	Shares Owned	
	Number	Percentage of Total
Steinaker Ditch	108.00	0.5
Highline Canal	4,407.46	19.6
Ashley Upper Canal	9,991.50	44.4
Ashley Central Canal	5,235.52	23.3
Rock Point Canal	1,165.76	5.2
Island Ditch	20.00	0.1
Municipal System (Vernal, Maeser, and Naples)	1,564.55	6.9
Total	22,492.79	100.00

did not intend to pursue their filings to completed appropriations and abandoned them in favor of the Vernal unit, a project that would result in greater water resource development and greater benefits to the water users (discussed in the following subsection). Some of these applications were cleared from the records.

No good historical information was located on water rights proceedings in the White, Price, and Dirty Devil Basins. A fairly complete compilation of water rights in all the basins of concern to this study (including Ashley Creek and the Duchesne River) is available in Reference 41. Reference 41 was compiled by the Utah Department of Natural Resources, Divisions of Water Resources and Water Rights. All of the water rights to quantities greater than 1.0 cfs are listed by priority for each of the hydrologic subareas identified earlier in this report. These compilations were considered to be too lengthy for inclusion in this report. However, this list should be used in determining the names of right holders with sufficiently high priority to guarantee water for tar sands development; such a list would be of use at a later time when negotiations are undertaken to purchase the necessary water.

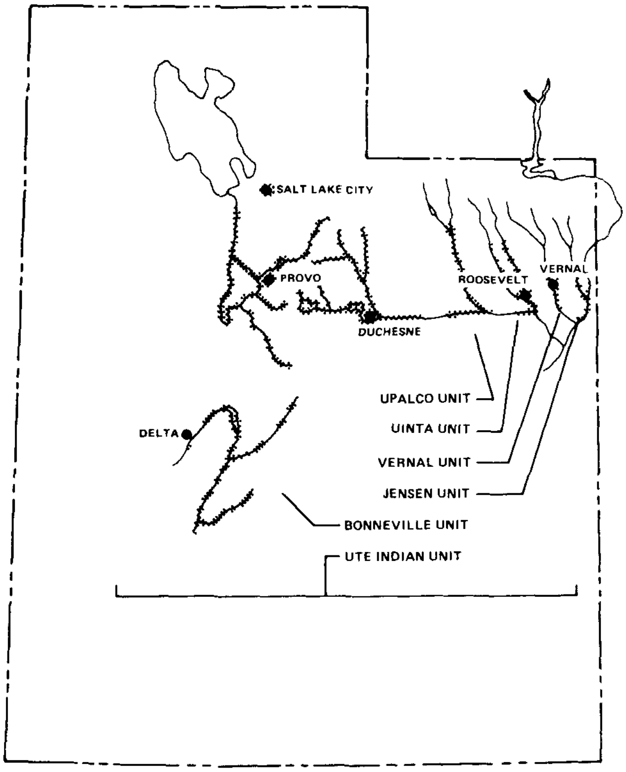
A high-priority item in any further investigation of the tar sands areas should be a complete delineation of the water rights on streams and groundwater. It is conceivable that no rights have ever been filed for remote areas such as Happy Canyon or Millard Canyon. It would be wise to file rights now on any available surface water even if development is years away.

PLANNED WATER DEVELOPMENT

In addition to the legal framework, tar sands development must take place within the bounds of other water resource developments. The USBR has a number of planned development projects that will redistribute available water between stream basins and drastically change the time distribution of the flow. The impact of these projects will have to be carefully considered, particularly when considering surface water as a source of supply. Several of the projects currently under consideration or under construction are discussed here.

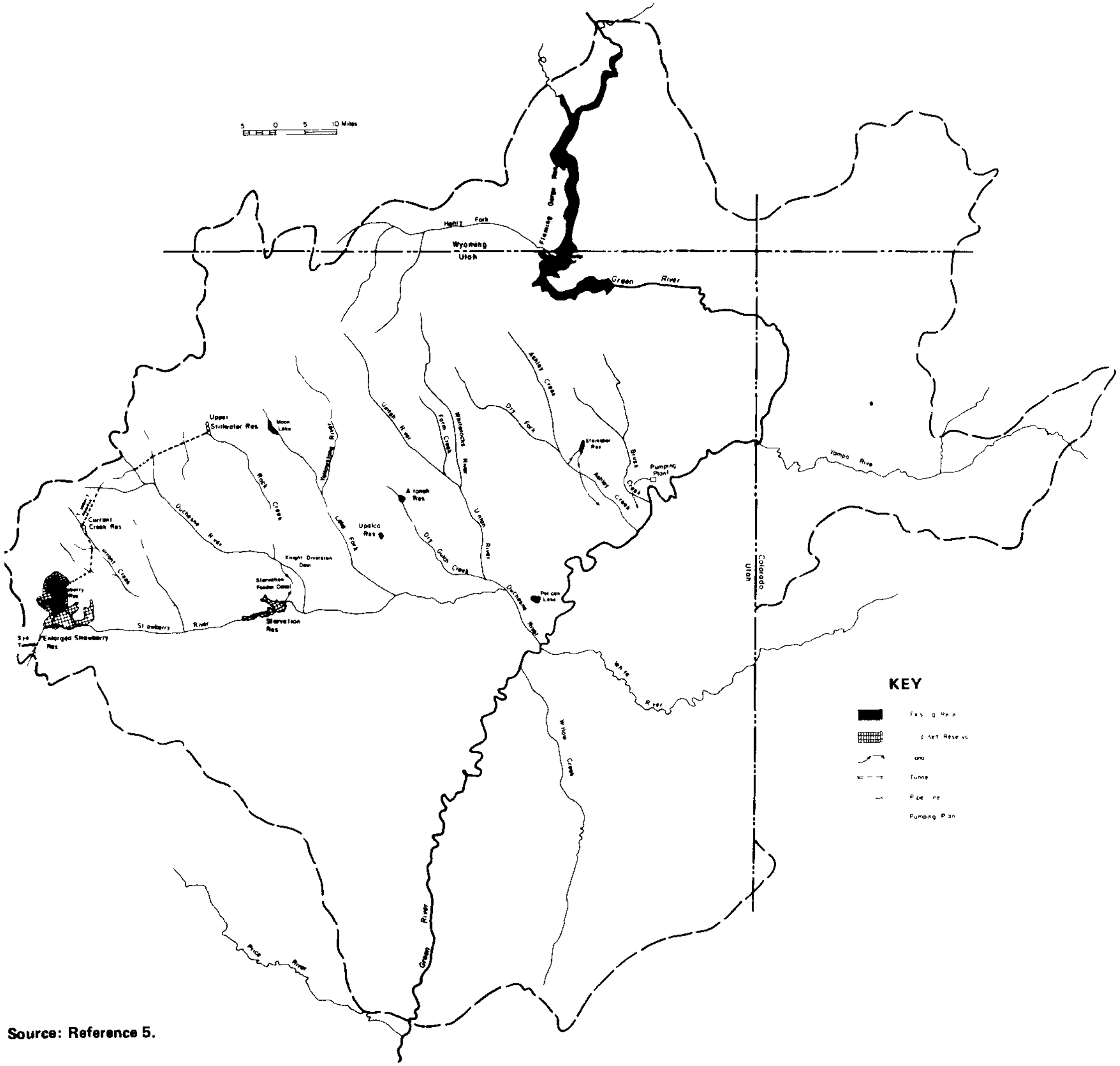
Asphalt Ridge-Whiterocks Area

Several existing and planned projects have potential impact on the use of surface water for tar sands development in the Asphalt Ridge (Vernal) area. These projects are described in detail in Austin and Skogerboe (Reference 5). Austin and Skogerboe based their work on a 1968 USBR report (Reference 42). The various portions of the Central Utah Project are illustrated in Figure 83. A more-detailed picture of the project near Asphalt Ridge is shown in Figure 84.



Source References 5 and 42

Figure 83. UNITS OF THE CENTRAL UTAH PROJECT



Source: Reference 5.

Figure 84. WATER RESOURCES DEVELOPMENT IN THE UINTA BASIN

The Central Utah Project, located in the central and east-central part of Utah, is being developed to utilize the state's allocated share of the Colorado River. The project will develop additional storage for increased water use in the Uinta Basin drainage area and will provide large amounts of additional water to the Wasatch Front, where population and industrial development are rapidly expanding.

The initial phase of the Central Utah Project consists of unit projects at Vernal, Bonneville, Upalco, and Jensen. While three of these unit projects (Vernal, Jensen, and Upalco) are local developments in the Uinta Basin drainage area, they have no physical ties to each other or to the Bonneville unit. This initial phase represents the Central Utah Project's contribution to the Colorado River Storage Project, which was authorized for construction by Congress in 1956, and makes the Central Utah Project the largest participant in that storage project.

The Vernal unit, located in the Vernal subarea, has been completed except for drainage facilities. This project unit provides supplemental water for about 15,000 acres of land in Ashley Valley through the storage of Ashley Creek water in the offstream Steinaker Reservoir. Fort Thornburgh Diversion Dam on Ashley Creek diverts water into the Steinaker Feeder Canal, which conveys the water to Steinaker Reservoir. The Steinaker Service Canal transports the storage water from Steinaker Reservoir to existing irrigation canals in the subarea for delivery to agricultural lands. Recreation and fishery facilities have been provided at Steinaker Reservoir.

The Jensen unit is located mainly in the Jensen subarea along the Green River from Brush Creek to the mouth of Ashley Creek. This project unit will develop 22,700 acre-feet of water. About 18,000 acre-feet will be used for municipal and industrial purposes in the Vernal area; the remaining 4700 acre-feet will be used for irrigation of lands along Brush Creek and in the vicinity of Jensen. The major features of this unit will be the Burns Pumping Plant on the Green River and Tyzack Dam, Reservoir, Pumping Plant, and Aqueduct. Tyzack Reservoir on Big Brush Creek will provide benefits in the form of recreation facilities, fish and wildlife, and flood control.

The Upalco unit, located northwest of Roosevelt in the Roosevelt-Duchesne subarea, will increase the water supply by approximately 20,500 acre-feet for supplemental irrigation of Indian and non-Indian lands. About 42,610 acres (15,070 acres of Indian land and 27,540 acres of non-Indian land) will receive project supplemental water. The project will provide recreation facilities, fish and wildlife areas, flood control, and area redevelopment. Taskeech Dam, Reservoir, Feeder and Service canals and the Boneta Diversion Dam will be major features of the Upalco unit.

The Bonneville unit, now under construction, is the largest and most complex unit of the initial phase of the Central Utah Project. Under the initial phase, water resources in the Uinta Basin drainage area will be stored for supplemental supplies within the drainage area and substantial amounts will be diverted into the Utah Lake drainage area. Supplemental service water will be supplied to approximately 26,000 acres of land in the Uinta Basin drainage area. Lands along the Duchesne River suitable for irrigation will be served before exporting any water to the Bonneville Basin. Water storage for Duchesne River lands below Duchesne will be provided in the Starvation Reservoir being constructed on the lower Strawberry River. Supplemental water for Duchesne River lands above Duchesne will be provided by exchanges from Starvation Reservoir. The reservoir will have a total capacity of 167,310 acre-feet, 152,330 acre-feet of which will be active. Water from Strawberry River and its tributaries below the proposed Soldier Creek Dam and from the Duchesne River will be diverted at Knight Diversion Dam (located about 5 mi upstream from Duchesne) into the Starvation Feeder Conduit (2 mi, 300 cfs) for storage in the Starvation Reservoir.

Collection and conveyance of divertible Uinta Basin water for transbasin diversion into the Utah Lake drainage area will be accomplished through the 37-mi Strawberry Aqueduct and enlargement of the Strawberry Reservoir. Streams between Rock Creek and Strawberry Reservoir will be intercepted by the aqueduct. Two small regulating reservoirs--the Upper Stillwater Reservoir (30,000 acre-feet) on Rock Creek and the Currant Creek Reservoir (15,000 acre-feet) on Currant Creek–will be constructed as part of the collection system. The Soldier Creek Dam (240 ft high) on Strawberry River, 7 mi below the existing Strawberry Dam, will increase the active capacity of Strawberry Reservoir from 270,000 acre-feet to 700,000 acre-feet.

The ultimate phase of the Central Utah Project, as proposed by the USBR, consists of the Uinta and Ute Indian units. The Uinta unit, as approved, will develop flows of the Uinta and Whiterocks Rivers north of Roosevelt for irrigation, municipal and industrial use, recreation, fish and wildlife enhancement, and flood control. Storage regulation will be provided in the Uinta Reservoir on Uinta River and in the Whiterocks Reservoir on Whiterocks River. Project water will be supplied to 34,152 acres of supplemental service and 7818 acres of full service to Indian-owned land and to about 11,000 acres of supplemental service to non-Indian-owned land. About 1000 acre-feet of municipal and industrial water will be reserved for use in the Roosevelt area. Planning has begun on the Ute Indian unit, which is to be the largest single unit of the Central Utah Project. The Ute Indian unit is essentially an enlargement of the Bonneville unit. It includes diversion of water from the Flaming Gorge Reservoir for use in the Uinta Basin and for replacement of some water diverted for municipal use in the Bonneville Basin.

The impact of the complex projects described above on surface water rights is clearly described in the USBR project reports on the Vernal and Jensen units (References 40 and 42). The discussion on water rights from these two reports is presented here to illustrate the type of legal proceedings that may be required to obtain water for tar sands development.

During early investigations for the Jensen Reclamation Project, the USBR recognized the need to file a water rights application for the project in compliance with Utah water laws. Application No. 17558 was filed on April 23, 1946, to appropriate 30 cfs of water from Big Brush Creek for the irrigation of 3500 acres of presently irrigated land and 1500 acres of new land. This application also proposed to store 10,000 acre-feet at the Tyzack Reservoir site to supplement the direct flow rights. It provided for storage of water during high runoff years to be used during low runoff years. The application was approved March 17, 1961, and is still valid.

When investigations were initiated for the Central Utah Project in the Uinta Basin, the Jensen Reclamation Project became the Jensen unit of the Central Utah Project. In developing the Jensen unit plan, it was determined that the 10,000 acre-feet applied for originally would be inadequate for the proposed Tyzack Reservoir. An application (No. 30414) to store 4 million acre-feet of Green River water in Flaming Gorge Reservoir was filed. Under this application, 500,000 of the 4 million acre-feet was to be used for the Central Utah Project in the Uinta Basin. On February 21, 1969, the USBR filed an application to segregate 40,000 acre-feet of the water appropriated by Application No. 34014 for use by the Jensen unit. At the same time, a change of application was filed; this change called for water from Big Brush Creek to be stored in the Tyzack Reservoir. The segregation application (No. 30414-a) was approved by the State Engineer on July 8, 1969, and change application (No. a-5769) was approved July 9, 1969.

Water to be pumped from the Green River to Jensen unit lands is covered by two water rights applications. Application No. 34015 covers the appropriation of 50 cfs, and Application No. 34016 as amended by Change Application No. a-5767 is for 100 cfs. Both applications were submitted to the Utah State Engineer on August 7, 1958, and approved on March 17, 1961. Application No. 34016, as originally filed, was to pump water from Green River for lands in the vicinity of Ouray; however, it was found that the area near Ouray did not need the water and that additional capacity was needed at the Burns Pumping Plant. Thus, Change Application No. a-5767 was filed to change the area to the Jensen unit. Change Application No. a-5767 was filed February 18, 1969, and approved by the State Engineer on May 5, 1969.

The Utah Division of Wildlife Resources has the right to pump 5 cfs from the Green River for waterfowl propagation at the Stewart Lake Waterfowl Management Area. This right was obtained under Application No. 28853, which was approved on Feburary 24, 1958. Water under this right would be furnished through project works.

An action was initiated by the Utah State Engineer (Civil Case No. 3070) in the Fourth Judicial Court of Utah, in and for Duchesne County, to adjudicate all water rights for surface water and groundwater in the drainage area of the Uinta Basin. On March 20, 1956, the court ordered the State Engineer to make a proposed determination of water rights in connection with this action. The State Engineer served summonses, secured the filing of claims by the water users, completed hydrographic surveys, prepared a priority schedule, and prepared a proposed determination of the perfected water rights within the drainage area covering the Jensen unit. This proposed determination was submitted to the court by the State Engineer on June 1, 1969. The drainage area covering the Jensen unit is known as the Ashley division, Brush Creek subdivision of the Uinta Basin. The priority schedule has been affirmed by the court. This priority schedule of rights established by the above proceedings will be a key element in obtaining rights for tar sands development near Vernal.

The USBR reports on the Jensen unit contain considerable useful information on projected water usage trends and population trends near Vernal. Considerable emphasis is given to shale oil production and its impact on these trends. Because of the variables and problems involved in the oil shale industry, three levels of shale oil production were used by the USBR to establish the range of impact. The USBR claims that these production levels, as given in Table 59, are consistent with those outlined by the Department of Interior in its November 1974 task force report for "Project Independence" to the Federal Energy Administration.

Table 59. PROJECTED LEVELS OF SHALE OIL PRODUCTION IN UTAH

Year	Projected Levels of Production (BPD)		
	Prototype	Moderate Commercial	Accelerated Commercial
1980	100,000	100,000	100,000
1985	200,000	200,000	300,000
1990	200,000	300,000	500,000
1995	200,000	400,000	500,000
2000	200,000	500,000	600,000

Projected employment figures for each level of development were estimated by using construction and plant operation employee numbers as a base and then adding service and support employees to get a total oil shale employment figure. The number of households was ascertained by dividing the number of employees by the average jobs per household (1.37 according to 1970 census) and multiplying by the average number of persons per household to arrive at total oil shale population. Table 60 presents the procedures and factors used.

Projecting the distribution of the oil shale employees throughout the area is difficult. Normally, about two-thirds of the new population would be expected to locate in Ashley Valley and the remainder elsewhere in the basin. It is anticipated that a portion of the new population for oil shale development would settle along the White River near Bonanza.

The projected population increase and the estimated new municipal and industrial water requirements to year 2000 for three levels of shale oil production are summarized in Table 61. The water requirement for municipal use is based on an estimated rate of 225 gallons per capita per day [0.25 acre-feet (AF) per year] for the increased population. The new water requirement for the industrial component is based on moderate expansion of

Table 60. ESTIMATED EMPLOYMENT FOR THREE LEVELS OF SHALE OIL PRODUCTION IN THE UINTA BASIN

Production Level	Year	Plant Cap. under Const. (BPD)	Plant Const. Employees	Plant capacity (BPD)	Plant Operation Employees[a]	*Total* Shale Oil Employment (jobs avail.)	Service and Support Employment[b]	Total Jobs	Number of Households[c]	Shale Oil Population[d]
Prototype	1975	–	200	–	–	200	300	500	365	1,400
	1980	100,000	1,750	100,000	2,360	3,610	5,415	9,025	6,590	24,400
	1985	100,000	850	200,000	4,720	5,570	8,355	13,925	10,160	37,600
	1990	–	–	200,000	4,720	4,720	7,080	11,800	8,615	31,900
	1995	–	–	200,000	4,720	4,720	7,080	11,800	8,615	31,900
	2000	–	–	200,000	4,720	4,720	7,080	11,800	8,615	31,900
Moderate commercial	1975	–	200	–	–	200	300	500	365	1,400
	1980	100,000	1,250	100,000	2,360	3,610	5,415	9,025	6,590	24,400
	1985	100,000	1,250	200,000	4,720	5,970	8,955	14,925	10,950	40,300
	1990	100,000	1,250	300,000	6,380	7,630	11,445	19,075	13,920	51,500
	1995	100,000	1,250	400,000	8,500	9,750	14,625	24,375	17,790	65,800
	2000	100,000	1,250	500,000	10,630	11,880	17,820	29,700	21,680	80,200
Accelerated commercial	1975	–	200	–	–	200	300	500	365	1,400
	1980	200,000	2,500	100,000	2,360	4,860	7,290	9,650	7,040	26,000
	1985	200,000	2,500	300,000	6,380	8,880	13,320	19,700	14,380	53,200
	1990	100,000	1,250	500,000	10,630	11,890	17,820	28,450	20,770	76,800
	1995	100,000	1,250	500,000	10,630	11,880	17,820	28,450	20,770	76,800
	2000	100,000	1,250	600,000	12,740	13,990	20,990	33,730	24,620	91,100

[a] "Project Independence," Task Force Report, U.S. Dept. of the Interior, Nov. 1974, Tables F-3 and H-5.

[b] Ratio of basic employees to service-support employees 1:1.5.

[c] 1970 Census of Population: 1.37 jobs per household.

[d] 1970 Census of Population: 3.7 people per household.

Table 61. ESTIMATED NEW MUNICIPAL AND INDUSTRIAL WATER REQUIREMENTS

Year	Level of Shale Oil Production	Projected Population		Estimated Population Increase	New Water Requirements (AF)		
		Ashley Valley Area[a]	Population Base (1973)		Municipal (M)[b]	Industrial (I)	Total M+I
1975	Prototype	16,500	14,300	2,200	600	0	600
	Moderate commercial	16,500	14,300	2,200	600	0	600
	Accelerated commercial	16,900	14,300	2,600	700	0	700
1980	Prototype	32,600	14,300	18,300	4,600	0	4,600
	Moderate commercial	33,300	14,300	19,000	4,800	1,300	6,100
	Accelerated commercial	35,100	14,300	20,800	5,200	1,300	6,500
1985	Prototype	34,000	14,300	19,700	4,900	100	5,000
	Moderate commercial	35,600	14,300	21,300	5,300	2,700	8,000
	Accelerated commercial	42,400	14,300	28,100	7,000	4,900	11,900
1990	Prototype	30,000	14,300	15,700	3,900	100	4,000
	Moderate commercial	39,000	14,300	24,700	6,200	2,900	9,100
	Accelerated commercial	46,900	14,300	32,600	8,200	5,100	13,300
1995	Prototype	32,200	14,300	17,900	4,500	100	4,600
	Moderate commercial	47,100	14,300	32,800	8,200	3,500	11,700
	Accelerated commercial	49,100	14,300	34,800	8,700	5,700	14,400
2000	Prototype	34,500	14,300	20,200	5,100	200	5,300
	Moderate commercial	54,200	14,300	39,900	10,000	3,500	13,500
	Accelerated commercial	56,100	14,300	41,800	10,500	5,700	16,200

[a] Projected population for Ashley Valley includes 1973 base population plus normal growth of 2 percent annually, an appropriate portion of the oil shale population, and a minor increase associated with expansion of other natural resource development.

[b] Estimated at 0.25 acre-feet per capita.

[c] If either tar sands or phosphate requires additional water, this figure would be very conservative.

development of phosphate, gilsonite, petroleum, natural gas, and tar sands deposits located in or near the Jensen unit area.

P.R. Spring-Hill Creek Area

Shale oil production will clearly have an impact on tar sands development in the P.R. Spring-Hill Creek area. Utah's two pilot oil shale leases lie between the tar sands areas and the mouth of Evacuation Creek on the White River. As previously mentioned, the major water project in the Hill Creek-P.R. Spring area is the White River Dam proposed by the Utah Department of Natural Resources. Approximately two-thirds of the 118,000 acre-feet of storage will be available for oil shale and tar sands development. Some additional information on water requirements for oil shale development is presented here to establish the magnitude of the competing need.

Table 62 presents some estimates of oil shale mining water requirements. The estimated minimum water requirement is nearly the same as the estimate for a production-scale tar sands facility (13,000+ acre-feet per year). The maximum requirement is over 2.5 times

Table 62. SHALE OIL PRODUCTION WATER REQUIREMENTS FOR 100,000-BPD UNDERGROUND MINE

Line	Water Requirements	
	Average (GPM)	Annual Average (AF)
Practical minimum requirement:		
Process plant	5,960	9,700
Processed shale dust control and irrigation, and other undefined uses	1,000	1,600
Other losses, including seepage and evaporation	1,040	1,700
Total minimum requirement	8,000	13,000
Practical maximum requirement:		
Minimum requirement		13,000
Add: raw water for 100% water cooling the process and utility plants		8,750
Add: contingency, 20%		4,250
Total maximum requirement		26,000

as much. To give these numbers some perspective, the mean annual discharges of streams in the P.R. Spring-Hill Creek area are as follows:

- White River: 481,200 acre-feet per year,
- Evacuation Creek: 7000 acre-feet per year,
- Bitter Creek: 800 acre-feet per year,
- Willow Creek: 13,000 acre-feet per year, and
- Hill Creek: 4000 acre-feet per year.

Note also that the USBR anticipates the development of a major community as a result of the work at Bonanza. This community will also have substantial water requirements.

Other potential water uses in the P.R. Spring-Hill Creek area are listed in Table 63. Many of the uses listed are not specific to one area. The numbers give some idea of the magnitude of potential competing demands.

Table 63. WATER CONSUMPTIVE USE RATES FOR ENERGY CONVERSION AND TRANSPORTATION PROCESSES

Energy System	Water Needs
Steam-electric nuclear	
Evaporative cooling	17,000 AF/yr/1000 m W unit
Pond	12,000 AF/yr/1000 m W unit
River	4,000 AF/yr/1000 m W unit
Wet-dry radiator	2,000 AF/yr/1000 m W unit
Steam-electric coal	
Evaporative cooling	15,000 AF/yr/1000 m W unit
Pond	10,000 AF/yr/1000 m W unit
River	3,600 AF/yr/1000 m W unit
Dry radiator	2,000 AF/yr/1000 m W unit
Geothermal	48,000 AF/yr/1000 m W unit
Refineries	39 gal/bbl crude
Oil shale	7,600 to 18,900 AF/yr/100,000-BPD plant
Coal gasification	10,000 to 45,000 AF/yr/250 million-cfs/day plant
Coal liquification	20,000 to 130,000 AF/yr/100,000-BPD plant
Coal slurry pipeline	20,000 AF/25 million tons coal (1 cfs will transport about 1 million tons/yr)

Source Western States Water Council, 1974

Sunnyside Area

Only vague, general information has been published concerning water development near the Sunnyside deposit. Reference 33 contains most of the useful facts.

In 1896, the Mammoth Reservoir Company was formed with the intended purpose of developing the waters of the Price River. The rights of this company were purchased in 1900 by a group of farmers wishing to make a transmountain diversion into the San Pitch Basin. However, the company ran into financial problems, and the rights of the Mammoth Company were sold to the Irrigated Lands Company, which in 1911 was reorganized into the Price River Irrigation Company. This company finally began construction of a dam; however, when the dam was only half completed, it failed.

The next storage project on the Price River was the Scofield Dam. This project was completed in 1926 under the authority of the Price River Water Conservation District. The next spring the dam partially failed and storage was restricted by the State Engineer until a new dam was build further downstream in 1947. This new reservoir has a capacity of 74,000 acre-feet, of which 8000 acre-feet is dead storage.

A number of small ponds are the only storage facilities that exist in the tar sands area. These ponds are either for stock watering or for short-term irrigation supply.

Tar Sand Triangle Area

No published information was found concerning water resource development near Tar Sand Triangle. There is irrigation in areas upstream along the Dirty Devil and Fremont Rivers and Muddy Creek.

WATER USAGE AND POPULATION TRENDS

In a soon-to-be released report by Utah State University (Reference 43), figures are given on population and water-use trends throughout the state. When published, the final report will be quite useful. It contains population statistics for most of the major cities and towns in Utah and regression equations that may be used to project municipal and industrial demand at future dates. The preliminary report did not clearly define the variables in the regression equations and the table containing the figures on projected water demand to the year 2020 was not yet completed. The population projections were complete and are reproduced in Table 64.

Table 64. BASELINE POPULATION PROJECTIONS FOR MULTICOUNTY DISTRICTS (MCDs) AND TOWNS NEAR TAR SANDS AREAS*

Areal Unit	Projected Population						
	1960	1970	1980	1990	2000	2010	2020
<u>Uinta Basin Association of Governments</u>:	19,925	20,649	37,130	34,550	44,700	51,600	58,600
Daggett County	1,164	666	1,030	970	1,210	1,400	1,550
Manila	329	266	370	350	470	500	550
Duchesne County	7,179	7,299	14,280	13,260	17,170	19,840	22,530
Roosevelt	1,812	2,005	4,700	4,350	5,600	6,500	7,500
Duchesne	770	1,094	2,300	2,100	2,750	3,200	3,700
Uinta County	11,582	12,682	21,820	20,320	26,320	30,360	34,520
Vernal	3,655	3,908	6,950	6,450	8,350	9,650	11,150
<u>Southeastern Association of Governments</u>:	42,066	37,078	51,240	61,280	74,000	86,200	98,300
Carbon County	21,135	15,647	21,520	26,170	31,080	36,200	41,280
Price City	6,802	6,218	8,700	10,400	12,550	14,650	16,700
Emery County	5,546	5,137	9,220	10,200	13,320	15,520	17,690
Green River	1,075	1,033	1,200	1,300	1,750	2,050	2,300
Grand County	6,345	6,688	7,690	9,340	11,100	12,930	14,750
Moab	4,682	4,7903	7,150	8,500	10,300	12,000	13,700
San Juan County	9,040	9,606	12,810	15,570	18,500	21,550	24,580
Monticello	1,845	1,431	2,050	2,450	3,000	3,450	3,950

*Projections beyond 1990 for MCD are based on trend extrapolation using the 1970 Census of Population estimates and Alternative Future Zero (Office of the State Planning Coordinator, 1975) as the data base. Projected county and city populations were estimated by disaggregating the projected MCD populations consistent with their 1976 proportions. These proportions were taken from Utah Facts (Utah Industrial Development Information System, 1977) and special census reports.

Source: Reference 43.

X. SUMMARY OF WATER AVAILABILITY AND RECOMMENDATIONS

INTRODUCTION

This section summarizes the findings of water availability in the tar sands regions (Sections IV through VIII) and recommends areas in which additional data and further study are needed before the development potential of the area can be ascertained. Water availability, as discussed here and in Sections IV through VIII, refers to the existence in the area of sufficient water for tar sands development, based on the requirements given in Section III. Water availability, however, does not imply that the legal right to use that water exists. As discussed in Section IX, in Utah water rights are established by the state on a priority basis through the filing of claims. At present, with the possible exception of groundwater, the water rights already granted exceed the quantity of water available. Thus, it will be necessary for tar sands developers to purchase existing high-priority rights in order to ensure sufficient supplies. The price of these rights is one issue that will require further study before a decision can be made regarding the cost/effectiveness of developing the regions.

ASPHALT RIDGE-WHITEROCKS

Surface Water

The mean annual discharges (in acre-feet) for the streams near Asphalt Ridge and Whiterocks are

Dry Fork R. above Sinks near Dry Fork	25,296
N. Fork of Dry Fork R. near Dry Fork	4,404
E. Fork of Dry Fork R. above sinks near Dry Fork	7,404
Oaks Park Canal near Vernal	4,800
Ashley Cr. above springs near Vernal	35,700
Ashley Cr. at Sign of the Maine	81,996
Ashley Cr. near Jensen	44,000
Uinta R. near Neola	127,200
Farm Cr. near Whiterocks	4,200
Whiterocks R. near Whiterocks	77,760
Duchesne R. at Duchesne	209,600.

Specific data on current water origin and use for hydrologic subareas in the Asphalt Ridge-Whiterocks area are given in Table 65.

Table 65. SUMMARY OF CURRENT WATER AVAILABILITY AND USE IN THE ASPHALT RIDGE-WHITEROCKS AREA

Characteristics	Subarea (acre-feet per year)								
	Upper Dr Fk.	N. Fk Dry Fk	E Fk Dry Fk	Ashley Dry Fk.	Vernal	Uinta	Farm Creek	Whiterocks	Roosevelt Duchesne
River inflow	27,800	4,400	7,400	1,700	82,000	–	–	–	695,000
Tributary, imported, and ungaged inflow	27,800	4,400	7,400	1,990	4,800	127,200	4,200	77,800	67,700
Net reservoir flow	–	–	–	–	–	–	–	–	–
Exported flow	2,800	–	–	–	5,000	–	–	–	10,000
Diversion to agriculture	–	–	–	100	65,000	–	–	–	510,000
Cropland consumptive use	–	–	–	110	30,000	–	–	–	250,000
Additions to groundwater	–	–	–	*20*	*10,200*	–	–	–	*70,000*
Return flow from agriculture	–	–	–	40	33,800	–	–	–	265,000
Domestic use and evaporation	–	–	–	10	3,000	–	–	–	6,500
Wetland consumptive use	–	–	–	260	20,000	–	–	–	180,000
River outflow	25,000	4,400	7,400	3,570	44,000	127,200	4,200	77,800	391,200
Subsurface outflow	2,400	1,000	600	140	–	10,500	500	6,000	40,000

There is no doubt that sufficient water flows out of the valleys of both the Ashley and Duchesne Rivers to meet the water requirements of tar sands development. However, not all of the individual streams have sufficient flow to support a production-level facility. For example, while the North Fork of Dry Fork has insufficient water to support a production-level facility, only 30 percent of the flow of Ashley Creek near Jensen would be needed for such an activity.

Competition with existing uses is another factor. A production-level facility near Vernal would require 43 percent of the water presently used for agriculture, whereas only 5 percent of the water consumed by agriculture in the Duchesne River Basin would be required.

The quality of the water is also important; in fact, the worst problem in this area is the fairly high level of salinity, with some boron also present in the water content.

An important issue is the time that would be required to extract bitumen from the tar sands. The Asphalt Ridge-Whiterocks deposits are collectively estimated to contain from 1165 million to 1450 million bbl of bitumen. Assuming a 30 percent recovery rate, it would require 17 to 21 years to extract all of the bitumen. Larger production facilities could accomplish this in less time; however, the number of production facilities will depend on the availablility of the water and the price of water rights. For example, four such facilities would require all the flow of Ashley Creek, and it is highly unlikely that all the water could be used for one purpose even if the cost of the rights were not prohibitive.

The figures presented here do not account for the completion of the Jensen unit of the Central Utah Project, which will bring additional water to the Vernal area. Nor does this study address the question of whether some of this additional water could be used for tar sands development.

Groundwater

The Vernal area is unique among the tar sands areas in that it sits atop a sizable shallow groundwater reservoir. A number of shallow wells (less than 200 ft) in the glacial alluvium produce water at sufficient rates to support pilot-level tar sands facilities. A carefully designed well field could probably support production-scale facilities. A model would be required to determine any adverse impact on other groundwater users in the area. Water rights for a well field may be considerably easier to obtain than surface water rights. The quality of water from the alluvium is good. Fresh to slightly saline water can be expected.

There appears to be no viable source of groundwater from bedrock aquifers to the southwest of Asphalt Ridge. Only the Green River Formation contains water, and it is probably very saline.

To the northeast of Asphalt Ridge, fresh water can be found in several of the underlying sandstone formations, primarily the Weber and Navajo. Wells 4000 to 6000 ft deep would be required. One to two wells in either formation would probably support a pilot-scale facility. A carefully designed well field could probably support a production facility, but again a model would have to be developed to determine its feasibility.

Specific Recommendations

Based on the available data, water for tar sands development near Asphalt Ridge could be obtained in several ways. Surface water could be obtained from either Ashley Creek or the Duchesne River. Although the impact would be less on the Duchesne River than on Ashley Creek, water from the Duchesne River would have to be transported over a considerable distance. A considerable amount of water could also be obtained from shallow aquifers near Vernal and from deep bedrock aquifers.

Very little additional hydrologic data will be required for tar sands development in the Asphalt Ridge-Whiterocks area; sufficient data are available to develop alternative plans for using surface water, shallow groundwater, or deep groundwater. The following specific activities are recommended:

- An analysis of current and pending water rights in the Ashley and Duchesne Basins in relation to tar sands development should be undertaken. Water rights holders with sufficiently high priority to guarantee adequate supplies should be identified in anticipation of future purchases of the necessary rights.

- Specific tar sands development sites should be identified.
- Alternative water development plans should be prepared for each site. These plans should include study of
  - likely diversion points for surface water;
  - required storage facilities;
  - potential sources of water rights and their cost;
  - potential well field locations for shallow or deep groundwater wells and modeling studies to assess their impact;
  - costs associated with the development of various water sources, including costs of pipelines, pumping, storage, and other factors; and
  - impact of tar sands development on other planned water resource uses.

HILL CREEK

Surface Water

No gages exist and little is known about streamflows immediately to the west of Hill Creek between Hill Creek and the Green River. Several ephemeral streams join the Green River adjacent to the Hill Creek deposit. These streams appear to drain areas of 20 to 40 mi^2. Yields from individual basins could be estimated from the runoff map, but would be small and uncertain. Table 66 presents the currently available data on surface water sources and use for the hydrologic subareas near Hill Creek.

The only apparent sources of surface water near the Hill Creek deposit are Hill Creek and Willow Creek. Although Hill Creek is not gaged directly, the flow near the deposit area is estimated to be roughly 4000 acre-feet per year. Additional water might be available from a dam on the White River that is proposed by the Utah Department of Natural Resources.

The "Willow Creek above diversions" stream gage is immediately adjacent to the tar sands deposit. It has an average annual yield of 14,200 acre-feet per year. Both estimates are based on short periods of record.

Willow Creek and Hill Creek are each capable of supporting large-scale pilot operations, but only Willow Creek is capable of supporting a production-level facility. The combined flow of both creeks near the tar sands area appears to be adequate to support a production-level facility. The intermittent nature of the runoff would certainly necessitate

Table 66. SUMMARY OF CURRENT WATER AVAILABILITY AND USE IN THE HILL CREEK AREA

Characteristic	Subarea (acre-feet per year)		
	Upper Willow Creek	Willow Creek	Desolation Canyon
River inflow	–	13,000	3,884,000
Tributary, imported, and ungaged inflow	13,000	17,500	27,000
Net reservoir flow	–	–	–
Exported flow	–	–	–
Diversions to agriculture	–	–	–
Cropland consumptive use	–	1,500	5,000
Additions to groundwater	–	–	–
Return flow from agriculture	–	–	–
Domestic use and evaporation	–	–	–
Wetland consumptive use	–	10,000	30,000
River outflow	13,000	19,000	3,876,000
Subsurface outflow	–	–	–

storage facilities, which would involve associated seepage and evaporation losses. Caution should be used here, however, because the P.R. Spring deposit lies immediately east of Willow Creek and the flow is not sufficient to support major production in both areas at once without recycling or other conservation measures.

Very little agricultural demand exists in the Willow Creek Basin. Only 1500 acre-feet per year is attributed to agricultural depletion. However, considerable wetland depletion (10,000 acre-feet per year) exists. If this wetland depletion were prevented, it alone would almost support a production-level tar sands facility.

Since Hill Creek is not gaged directly and the length of record for the area is short, a record for Hill Creek near the tar sands deposit should be synthesized through modeling or correlation techniques. Such a study is essential if storage facilities are to be developed on either Willow or Hill Creek. In the absence of sufficient water from Hill or Willow Creek, the only alternative would be to obtain water from the White River.

Limited samples indicate that the waters of Willow and Hill Creeks are too saline for public supply, although no definite conclusions could be drawn from the limited data.

Groundwater

There is no potential shallow groundwater supply near the Hill Creek deposit. Insufficient information exists to draw any conclusions about the deep groundwater supply. Typical oil and gas wells in the area yield barely enough water to support test tar sands facilities. Several of the underlying formations are good aquifers in other parts of the Uinta Basin. Pump tests on existing oil wells are highly recommended.

Specific Recommendations

Based on the data available, the best means of providing water for tar sands development are storage on Willow and/or Hill Creeks or from a proposed dam on the White River. However, before plans can be made regarding the Hill Creek area, additional hydrologic data will be required. The surface water supply is poorly defined and hardly anything is known of the groundwater supply. The following activities are specifically recommended:

- The actual flow in Hill Creek near the tar sands deposit should be determined. This could most readily be done by
  - using existing weather records to model rainfall and snowmelt runoff, or
  - establishing a gage site near the deposit area for several years.
- The safe yield of Willow and Hill Creeks should be analyzed, and locations for storage facilities should be determined.
- The losses to be expected in storage facilities should be determined.
- The water rights to the White River and Willow and Hill Creeks should be examined in detail. Water rights holders with sufficiently high priority to guarantee supplies for tar sands development should be identified in anticipation of future purchase of these rights. Particular attention should be given to federal water rights since Hill Creek is part of the Ute Indian Reservation.
- Discussions should be held with the USBR concerning water availability and development on the lower White River Basin.
- Logs of wells in the Hill Creek area should be examined in detail and a good subsurface geology map developed.
- Pump tests should be conducted and quality samples taken on existing abandoned oil and gas wells if possible.
- A limited drilling program to search for water should be considered after the subsurface geology is established. (Core drilling may be required just to establish the geology.)
- A good water quality monitoring program should be undertaken to better determine the nature of the surface runoff.

- Preliminary recommendations for obtaining the necessary water for tar sands development should be developed.
- An interest in obtaining water from the proposed dam on the White River should be expressed in writing to the Utah Department of Natural Resources.

P.R. SPRING

Surface Water

P.R. Spring lies between Evacuation Creek and Willow Creek near the points at which they join the White River. The only major creeks that flow through the P.R. Spring deposit area are Bitter Creek and Main Canyon Creek. Table 67 presents the currently available data on surface water sources and use for the hydrologic subareas near P.R. Spring.

Table 67. SUMMARY OF CURRENT WATER AVAILABILITY AND USE IN THE P.R. SPRING AREA

Characteristics	Subarea (acre-feet per year)		
	Upper Willow Creek	Lower White River	Evacuation Creek
River inflow	–	481,200	474,200
Tributary, imported, and ungaged inflow	13,000	23,800	7,000
Net diversion flow	-	–	–
Exported flow	–	–	–
Diversions to agriculture	–	–	–
Cropland consumptive use	–	–	–
Additions to groundwater	–	–	–
Return flow from agriculture	–	–	–
Domestic use and evaporation	–	–	–
Wetland consumptive use	–	5,000	–
River outflow	13,000	500,000	481,200
Subsurface outflow	–	–	–

Bitter Creek has an estimated annual runoff of 800 acre-feet and is classified as ephemeral-intermittent. Nothing could be found concerning runoff from Main Canyon Creek. Since it drains considerably less area than Bitter Creek, however, it is not a likely source of water for tar sands development. Stream gage records on both Bitter Creek and Evacuation Creek are short. The estimated runoff for Evacuation Creek ranges from 2600 to 7000 acre-feet per year. The estimate for Willow Creek, immediately west of the P.R. Spring deposit, is 13,000 acre-feet per year. This runoff volume is based on substantial amounts of record. The White River at Watson yields 481,200 acre-feet per year. The records on the White River are also substantial.

Bitter Creek would support test and pilot facilities if storage facilities were available but would fall considerably short of the water supply required for a production-level facility.

Willow Creek was identified by Price and Miller (Reference 30) as a potential location for water development. The stream gage adjacent to the P.R. Spring area indicates a flow of 13,000 acre-feet per year, which is adequate to support a production-level facility. However, unless recycling on the order of 50 percent were achieved, any water withdrawn from Willow Creek would reduce the amount available to the Hill Creek area.

It is difficult to conclude anything about water availability from Evacuation Creek. Based on the low end of the estimated range (2600 acre-feet per year), it appears that Evacuation Creek could support pilot and test facilities. Based on the best-case estimate (7000 acre-feet per year), Evacuation Creek could probably support a half-sized production-level facility. Some type of runoff modeling or record extension should be used before any definite conclusions are reached. Data gathered by USGS for development of Utah's pilot oil shale lease tracts will be helpful in this regard.

Careful hydrologic studies would have to be undertaken to use either Evacuation Creek or Bitter Creek as water supplies. Since the runoff is highly intermittent, storage facilities would be required, and the losses from evaporation and seepage would have to be considered.

There is no question that the flow of the White River at Watson (481,200 acre-feet per year) is adequate to support production at any level. It is certain also that rights to the water would be difficult and/or expensive to obtain. The considerable distance and large increase in elevation (up to 2000 ft) of the area would pose problems in transporting the water to the upper reaches of the deposit area. The Utah Department of Natural Resources is planning a dam on the White River for development of energy and irrigation of Indian lands (Reference 31). Two-thirds of the planned storage capacity of 118,000 acre-feet will be used for energy development.

Groundwater

There is no potential source of shallow groundwater in the P.R. Spring area. Almost no data from deep wells exist for comparison to estimated requirements. The Ute Tribe owns several very shallow wells (less than 100 ft) in the Green River Formation near Hill Creek. These wells produce 5-15 GPM. Yields this low are barely capable of supporting test facilities. A Texaco well in T. 15 S., R. 22 E. produced 3 GPM from the Entrada Sandstone—a yield too low to be useful.

One encouraging note can be found, however. Six of seven springs in the P.R. Spring area originate in the Parachute Creek Member of the Green River Formation. Weeks et al. (Reference 32) report that the Parachute Creek Member is the major aquifer in the Piceance Creek Basin of western Colorado. This is less than 30 mi to the northeast of P.R. Spring. In the Piceance Basin, wells in the Parachute Creek Member yield up to 1000 GPM, with 200 to 400 GPM being typical. Only detailed exploration will determine if such yields are possible near P.R. Spring. The leached zone present in the Piceance Basin may not be present on the Uinta Basin.

Specific Recommendations

Based on the available data, the best means of providing water for development of tar sands are storage on Willow and/or Hill Creek and the proposed White River Dam. Note that use of water from Willow or Hill Creek will impact development at the Hill Creek deposits. However, additional hydrologic data and analysis will be required for intelligent planning in the P.R. Spring area. Data on the surface water supply are inadequate and hardly any data on the groundwater supply exist. The following activities are specifically recommended:

- Accepted hydrologic techniques should be used to obtain better estimates of the flows of Evacuation and Bitter Creeks. Data collected by USGS for oil shale development in this area may be helpful. Modeling of rainfall-snowmelt runoff may be required or additional stream gages established.
- The safe yield of Evacuation Creek, Bitter Creek, and other small streams should be analyzed in terms of water storage.
- Potential storage sites should be selected and storage-associated losses estimated.
- The water rights in the area (particularly Willow Creek, Evacuation Creek, Bitter Creek, and the White River) should be examined in detailed. Water rights holders with sufficiently high priority to guarantee supplies for tar sands development should be identified in anticipation of future purchase of these rights.
- Water development in the lower White River Basin should be discussed with the USBR.
- Logs from wells in the P.R. Spring area should be examined in detail and a good subsurface geology map developed.
- Pump tests should be conducted and quality samples taken on existing abandoned oil and gas wells if possible.

- A limited drilling program to search for water should be considered once the subsurface geology is established. (Core drilling may be required to establish the geology.)
- A water quality sampling program should be undertaken to more accurately determine the quality of surface runoff.
- Preliminary recommendations for obtaining the necessary water for tar sands development should be developed.
- An interest in obtaining water from the proposed dam on the White River should be expressed in writing to the Utah Department of Natural Resources.

SUNNYSIDE

Surface Water

In the immediate vicinity of the Sunnyside tar sands deposit there are only three small streams: Nine Mile Creek, Range Creek, and Icelander Creek. While there are numerous other small creeks, all of them are ephemeral and not generally worth considering as water supplies for tar sands development. The Price River is the only major stream in the area. Surface water availability and current use are summarized in Table 68 for the hydrologic subareas near Sunnyside.

Table 68. SUMMARY OF CURRENT WATER AVAILABILITY AND USE IN THE SUNNYSIDE AREA

Characteristics	Subarea (acre-feet per year)		
	Price	Upper Minnie Maud	Argyle Creek
River inflow	75,742	–	4,000
Tributary, imported, and ungaged inflow	66,857	4,000	13,500
Net reservoir flow	–	–	–
Exported flow	–	–	–
Diversions to agriculture	92,467	–	–
Cropland consumptive use	47,041	–	1,500
Additions to groundwater	–	–	–
Return flow from agriculture	–	–	–
Domestic use and evaporation	7,283	–	–
Consumptive use	42,925	–	4,000
River outflow	75,434	4,000	12,000
Subsurface outflow	–	–	–

The flow in Minnie Maud Creek averages 7000 acre-feet per year. It varies from a high of 1400 acre-feet per month in May to a low of 30 acre-feet per month in the winter. The gage, "Minnie Maud Creek at Nutter Ranch near Myton," on the Nine Mile Creek-Minnie Maud system, was operated for a short time above Gate Canyon. The flow in Nine Mile Creek at this location is 12,000 acre-feet per year, ranging from a high of 3530 acre-feet per month to a low of 380 acre-feet per month.

No gaging records are available on Icelander Creek or Range Creek, an intermittent stream originating in the tar sands area. The estimated annual flow is 4000 acre-feet, with a range in monthly flow from 40 to 1630 acre-feet. These figures are for the mouth of the stream at the Green River. Flows near the tar sands area would be only 20 to 30 percent of these values because of the reduction in drainage area. The total yearly runoff from Icelander Creek at Sunnyside probably amounts to 3700 acre-feet.

The only major river near the Sunnyside deposit is the Price. The flow in the Price River is accurately established by gages above Heiner, near Wellington, and at Woodside. The gage at Wellington was established in 1972, and the USGS has not published an average flow there as yet. However, the total flow in 1976 was 30,250 acre-feet. At Heiner, 75,743 acre-feet of water flowed into the Price subarea; the outflow at Woodside was 75,434 acre-feet.

These values imply that the flow in the Nine Mile Creek-Minnie Maud system might be barely adequate to support production-level activities. Little or nothing would be left, however, for other uses. Storage facilities would be necessary in order to maintain a steady water supply. In order to capture sufficient volumes of water, the storage facilities would be at an elevation of no more than 6000 ft. Considerable pumping would be required to bring the water up to the deposit area. Losses from evaporation and seepage would be significant.

Range and Icelander Creeks probably do not yield sufficient water for more than large-scale pilot operations. This is particularly true if storage facilities were developed high in the drainage basin. No definite conclusions should be drawn regarding these two streams without additional gaging or a modeling study to accurately determine the runoff near areas of interest.

The Price River could easily support any level of activity. However, it is at a considerable distance from the deposit and much lower in elevation. The impact of production-level facilities on the Price River would be considerable in dry years. In 1976, the estimated water supply needed for a production-level facility would have used one-third of the total yearly flow at Wellington.

Considerable information is available on the quality of water in the Price River. Data include suspended sediment, dissolved oxygen, specific conductance, pH, and sampling for various chemical constituents. However, water quality information on the other streams of interest is almost totally lacking. Random samples of specific conductance and temperature are available for Minnie Maud Creek. No data are available for Icelander and Range Creeks.

Water in the Price River contains a very high level of dissolved solids and considerable suspended sediment. Both could be a problem when using the water in tar sands processes.

Groundwater

Shallow groundwater in the lower areas along the Price River is unusable because of contact with the Mancos Shale Formation. The total dissolved solids content is too high for any practical applications. The North Horn, Price River, and Wasatch Formations appear to be potential sources of water for at least test-level facilities. Additional data would be required to form any meaningful conclusions.

Specific Recommendations

Based on the available data the Price River must be considered as the most viable source of water for tar sands development. The only alternative appears to be storage on the Nine Mile-Minnie Maud Creek system.

No further data are required on the flow or quality of the Price River, but supplemental data and analysis will be required to obtain a complete picture of the water resources in the tar sands area. Specifically, the following are recommended:

- The water rights to the Price River and Minnie Maud, Nine Mile, Icelander, and Range Creeks must be clearly determined. Water rights holders with sufficiently high priority to guarantee supplies for tar sands development should be identified in anticipation of future purchase of these rights.
- The flow in the Price River should be analyzed to determine if regulation would be required to ensure stable supplies.
- Data collection and analytical programs should be undertaken to define the flows in Range and Icelander Creeks. These programs might include
    - establishing stream gages,
    - rainfall-snowmelt runoff models, and
    - correlation techniques.
- Limited programs should be undertaken to determine the quality of runoff in Minnie Maud, Nine Mile, Range, and Icelander Creeks.
- Logs of the wells in the area should be examined and an up-to-date subsurface geology map developed.
- Pump tests should be conducted on existing abandoned oil and gas wells.

- The location of potential storage facilities, particularly on Minnie Maud Creek, should be determined and the yield and losses should be more-accurately estimated.
- Preliminary recommendations for obtaining water for tar sands development should be developed.

TAR SAND TRIANGLE

Surface Water

Only two creeks (Happy Canyon and Millard Canyon) originate in the Tar Sand Triangle area. The Dirty Devil, Green, and Colorado Rivers are all within reasonable distances of the tar sands deposit. Current surface water availability and use for the Canyon Lands hydrologic subarea is summarized in Table 69. As indicated in the table, little is known about this area.

Table 69. SUMMARY OF CURRENT WATER AVAILABILITY AND USE IN THE TAR SAND TRIANGLE AREA

Characteristics	Canyon Lands Subarea (acre-feet per year)
River inflow	71,850
Tributary, imported, and ungaged inflow	7,150
Net reservoir flow	–
Exported flow	–
Diversions to agriculture	–
Cropland consumptive use	–
Additions to groundwater	–
Return flow from agriculture	–
Domestic use and evaporation	–
Wetland consumptive use	–
River outflow	79,000
Subsurface outflow	–

The mean annual flow of the Dirty Devil River is 73,890 acre-feet per year. It is rare when it does not run dry for one or two months each summer. Reasonable estimates of runoff for the Happy Canyon and Millard Canyon Creeks are only 1920 and 960 acre-feet per year, respectively.

Therefore, the only means of obtaining water for production-level facilities in the Tar Sand Triangle area is to withdraw water from the Dirty Devil, Colorado, or Green River. However, while sufficient water flows in all three for production-level facilities, the water rights to the usage of these rivers would have to be purchased from current holders.

The estimated yield of the ungaged tributaries in the Tar Sand Triangle area is probably adequate to support pilot-level operations but would certainly require storage facilities. involving associated evaporation and seepage losses. Development of such storage facilities at ungaged sites would be risky without some form of gaging or modeling program to determine the exact amount of water available.

Very little is known about the quality of water in the Dirty Devil River. Currently, the USGS collects random observations of temperature and specific conductance at Hanksville. In previous years, suspended sediment records and water quality samples for total dissolved solids have been collected.

As indicated in Section VIII, the Public Health Service recommends that the level of dissolved solids in drinking water and water supplies used by common carriers be no more than 500 mg per liter. At Hite, the level of dissolved solids exceeds 2400 mg per liter half the time and is always higher than the Public Health Service standards. No data have been published on the chemicals that comprise the dissolved solids in the Dirty Devil River.

Groundwater

Little specific information on groundwater near the Tar Sand Triangle is available. The Cedar Mesa and Moenkopi Formations are both exposed to the surface over a considerable area near Tar Sand Triangle. Several streams and creeks flow over the Cedar Mesa. Based on yield values from other locations, perhaps 5-10 GPM could be obtained from wells in either of these formations. While low, such yields would at least support test activities. The Moenkopi Formation has yielded quantities of water sufficient to support test facilities. Several springs less than 30 mi from Tar Sand Triangle have yielded quantities from 20 to 400 GPM. Only actual exploration for water in the Tar Sand Triangle area will permit meaningful assessment; however, yields of 5 to 10 GPM from several of the formations would be a reasonable expectation. Based on current data, it is not expected that groundwater supplies in this area could support production-level facilities.

Specific Recommendations

Based on the limited data available, the only sources of water for significant tar sands development are the Dirty Devil, Colorado, and Green Rivers. The following specific recommendations are made regarding the water supply in this area:

- The water rights in the Dirty Devil Basin should be examined in detail. Water rights holders with sufficiently high priority to guarantee an adequate water supply for tar sands development should be identified in anticipation of future purchase of these rights.
- The locations of any possible springs in this area should be explored and specific rock formations associated with them identified. The yield of each spring should be determined.
- A subsurface geology map should be developed, possibly using a core drilling program as a basis.
- A limited drilling program for groundwater should be conducted if spring yield looks promising.
- Ways to store water from the Dirty Devil River for use in the Tar Sand Triangle should be examined.

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