UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PLAN FOR A STUDY OF PART OF THE JICARILLA APACHE INDIAN RESERVATION

Open-File Report 77-756

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By J. L. Kunkler and A. G. Scott

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INTRODUCTION

In October 1973 the Albuquerque Area Office of the U.S. Bureau of Indian Affairs requested the U.S. Geological Survey to make a study of the ground and surface-water resources of the portion of the Jicarilla Apache Indian Reservation that is located within the watershed of the Rio Chama (fig. 1).

Specific items requested to be included in the study were:

(a) <u>Ground water</u>

(1) Estimated ground-water flow within the project area.

(2) Potential yields of wells drilled to various depths within the project area.

(3) Estimate of ground water in storage within the project area.

(4) Temperature of water.

(5) Quality of water.

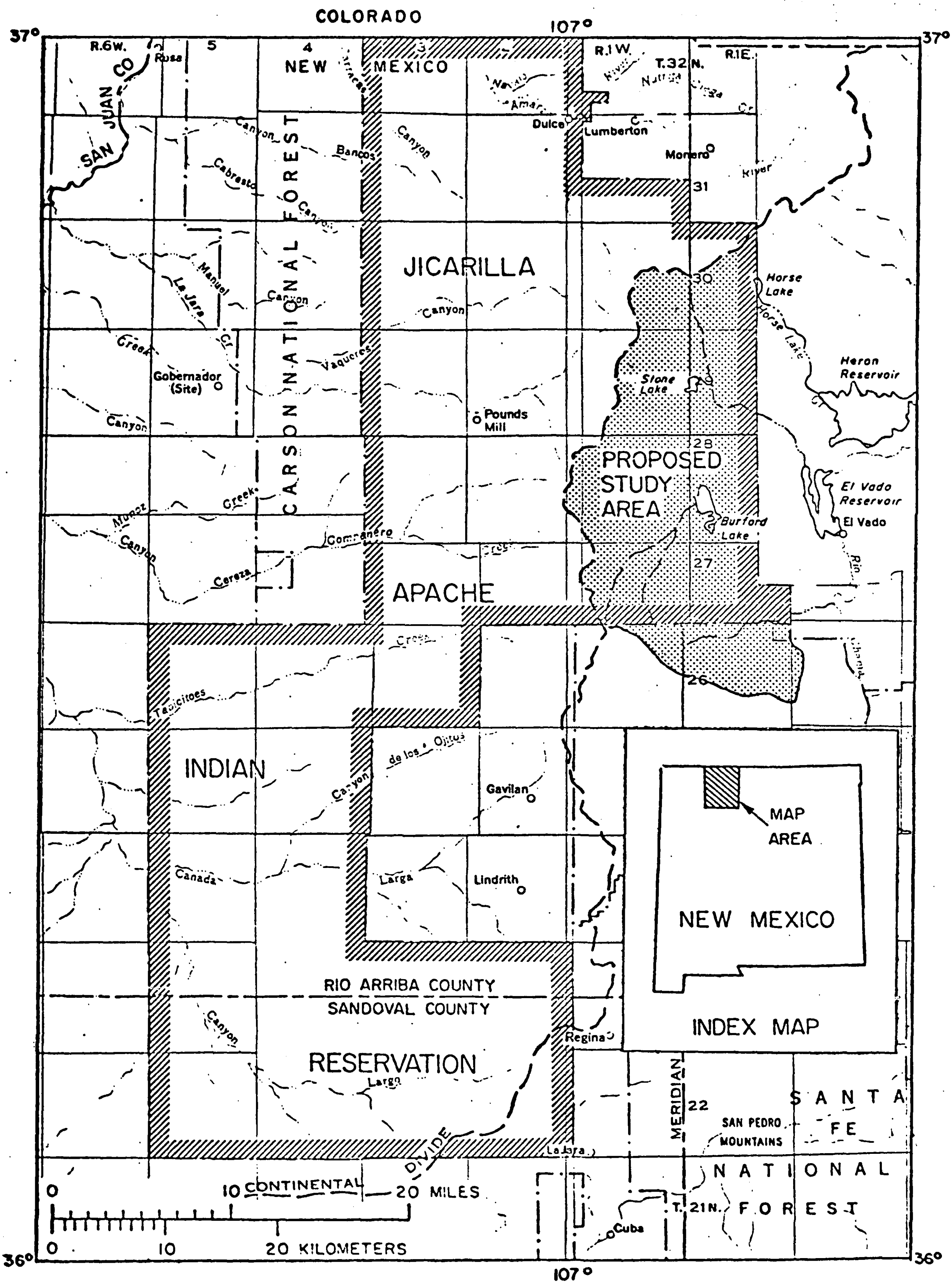

Figure 1.--Location of Jicarilla Apache Indian Reservation and proposed study area.

PURPOSE OF STUDY

Water-resources studies have never been made in this area. The area is somewhat remote and access to certain parts may be difficult. The existence and availability of data needed for a water-resources study is not known.

Thus, the Geological Survey requested the Bureau of Indian Affairs to sponsor a short-term planning study to investigate certain parameters of the proposed project area so that a determination could be made as to the problems involved in making a water-resources study that will meet the objectives outlined. The planning study would also determine a reasonable time-frame for the proposed study, manpower needs, and study costs.

(b) Surface water

(1) Estimated average annual flow at four specified stream locations (Surface-water yields would be estimated for high, low, and average conditions).

(2) Quality of water

The Bureau of Indian Affairs indicated that the Jicarilla Tribe is interested in developing potential fish hatcheries, and that special emphasis should be placed on analyzing surface and ground-water data in regard to its suitability for fish hatchery use.

LOCATION AND DESCRIPTION OF AREA

The proposed study area lies east of the Continental Divide in Rio Arriba County, New Mexico (fig. 1). The area covers about 200 square miles, of which about 175 are within the boundaries of the Jicarilla Apache Indian Reservation; the remainder of the study area is just south of the reservation on the Santa Fe National Forest within the drainage area of Arroyo del Puerto Chiquito.

Altitudes of land surface range from 7,000 feet in the southeast part of the area to about 9,000 feet in the northeast part. Normal annual precipitation ranges from 16 to 20 inches, of which about half falls between May and September. Summer temperatures are moderate, probably never exceeding 95°F; but winters are rigorous with mean monthly temperatures below freezing.

There are few permanent habitations. The largest center of population appears to be around Stone Lake Lodge, but employees of the lodge live in Dulce. The sparse population is greatly increased during fishing and hunting seasons when the average daily population may reach several hundred.

The principal use of the land is for grazing stock and big game. Income is derived from camping, fishing, and hunting fees. This area is one of the most famous on the North American continent for big game hunting. Field-dressed deer weighing more that 250 pounds are common, and the Jicarilla Indians boast of many Boone and Crockett Club records on deer and elk antlers. Stone Lake has been stocked with trout that apparently grow faster than normal and is consequently well-known to sportsmen in the southwest.

TOPOGRAPHIC FEATURES

The proposed study area lies within and along the eastern boundary of the San Juan structural basin. Elongate north and south-trending cuestas and valleys form the principal topographic feature (fig. 2).

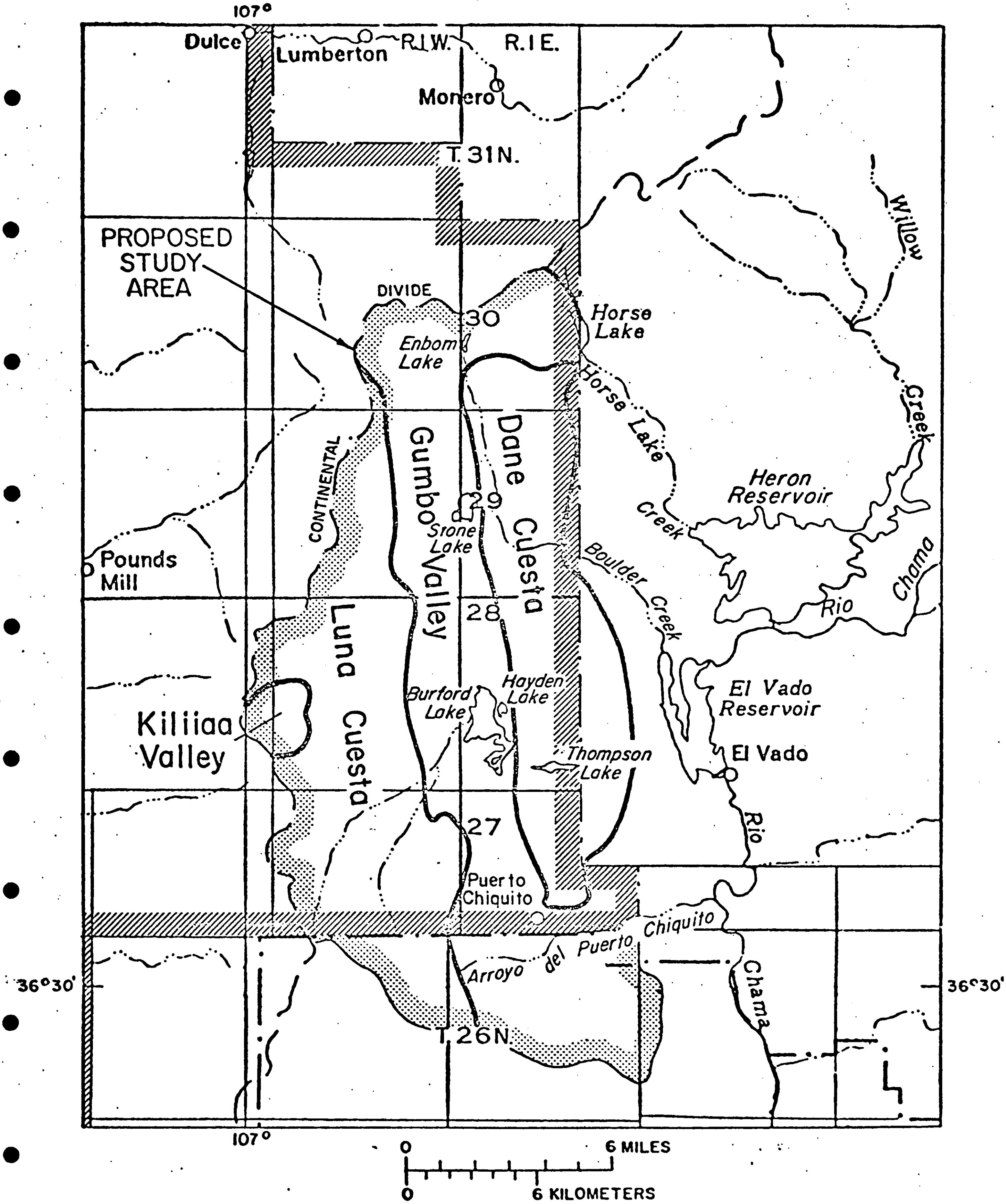

Figure 2.--Principal topographic features of proposed study area.

DANE CUESTA

This area is bounded on the east by a prominent westward-dipping homocline or cuesta. The uppermost rocks of this feature are sandstone. North of Stone (or Boulder) Lake this cuesta becomes the dip slope of the northwest-plunging Horse Lake anticline. The reservation boundary north of Horse Lake lies mostly on a valley of shale, but the northeast corner encroaches upon the dip slope of another northwest-trending anticline.

There are local names for parts of the feature just described. From the southern boundary of the reservation north of La Puerta Grande it is called Pound Mesa: from La Puerta Grande north to Boulder Gap or Boulder Creek it is called Apache Mesa; from Boulder Gap north to Horse Lake it is called Horse Mesa. For purposes of this study the entire ridge is named Dane cuesta.

The floors of canyons cutting through Dane cuesta are generally smooth but incised at places by gulleys. Landslides are obvious at many places and the floors of the canyons may be composed in part of landslide debris.

GUMBO VALLEY

Dane cuesta is separated from a parallel cuesta to the west by a strike valley on the shale. This valley, containing several natural and manmade lakes and combinations thereof, in this report is named Gumbo valley.

The relief on this valley is great for a shale valley and at places well-defined stream channels are conspicuously absent. Some of the relief is due to ridges of shale topped with well-rounded stream gravels that are more resistant to erosion than the shale. At other places no explanation has been found for the relief; however, this problem might be easily resolved from field observations.

The existence and persistence of the three natural lakes now known as Horse, Stone, and Burford Lakes appears anomalous. These lakes have been known since the Escalante expedition of 1776 when the size of Horse Lake (Laguna de Olivares) was estimated as one-quarter league in length and 200 varas in width more or less (Dane 1960a, p. 118). It probably is geologically significant that this estimate conforms closely with the present dimensions. These lakes are plotted with sufficient detail on the Miera y Pacheco (1778) map to leave little doubt that they are the same; moreover, this map shows no outlets for these lakes. A later map by Wheeler (1887) shows the same lakes in their same relative positions with an outlet only for Stone Lake.

Stream channels into these lakes are generally poorly developed, leading to the suspicion that the effective surface drainage is less than indicated on topographic maps and probably insufficient to account for the amount of water in storage. The diary of Escalante contains also an interesting statement about the quality of water in Horse Lake: "Although its water has not a very pleasant taste, it is fit to drink". (Dane, 1960a, p. 118).

The pristine hydrology of two of these lakes, Stone and Horse, has been altered recently by artificial earthworks that are apparently designed to increase their storage capacities. Water is released from Horse Lake for use on a nearby ranch. Horse Lake now has a well-defined outlet; Stone and Burford Lakes do not. However, a well-developed stream channel appears in Boulder Creek canyon about a mile below a point where Stone Lake might have overflowed at times.

The southern end of Gumbo valley is characterized by well-developed stream channels and a small prominence reported to be an anticline (Baltz and others, 1960, p. 29). Several pump jacks in this area indicate the existence of a small oilfield.

LUNA CUESTA

To the west of Gumbo valley is a second unnamed cuesta that herein is named Luna cuesta. The rocks forming this cuesta are composed of sandstone and shale.

A large delta shaped valley in Luna cuesta at the head of Cisneros canyon is named herein Kiliiaa valley. The origin of this valley in secs. 19, 29, and 30, T.28 N., R.1 W., and in secs. 24 and 25, T.28 N., R.2 W., is not known, but its topography indicates that it might have ground-water potential.

PREVIOUS INVESTIGATIONS

Judging from a perusal of geologic literature this area has been less intensely studied than the surrounding area. A very voluminous bibliography can be compiled of papers and studies in the San Juan and Chama basins, but most of these papers contain little or nothing of interest for the proposed water-resources study.

The first trained geologist to visit the area probably was Professor J. S. Newberry (1876) who passed through in 1859 with the Macomb expedition. From a camp near El Vado he made his famous sketch of La Puerta Grande.

The best source of geologic information and reference to studies in this area is in the Guidebook of the 11th Field Conference of the New Mexico Geological Society (1960). This guidebook contains several papers on the geology of the area, a geologic map by Smith and Muehlberger (in pocket) showing outcrops of major geologic formations, numerous faults and structure contours for the base of rocks of Cretaceous age. A geologic roadlog is given by Baltz and others, p. 27. Several papers describe fossils and give descriptions of the geology surrounding the area.

A paper by Dane (1960a, p. 113) describes early explorations of the area, and a second by the same author (1960b, p. 63) provides descriptions of the Dakota Sandstone and Mancos Shale along with graphic sections and diagrammatic cross sections that are useful in planning and drilling wells.

In addition, the New Mexico Geological Society plans field trips in this general area in the fall of 1974 during the 25th Annual Field Conference. It is supposed that the guidebook for this conference will contain more valuable papers.

A map compiled by Dane (1947) shows outcrops of major geologic formations, major tectonic features, and structure contours for the base of the Mesaverde Formation (Group).

The geology and fuel resources of rocks on Luna cuesta were investigated by Fassett and Hinds (1971). Various maps, data, and references in this publication should be useful.

The geology and mineral resources of Rio Arriba County are discussed by Bingler (1969). This paper gives a description of titanium deposits near Stinking (Burford) Lake. It includes a geologic map with less detail than those previously mentioned.

Much is known of the subsurface geology from studies to the east where older rocks lie on the surface. Muehlberger (1967) gives the geology of the Chama Quadrangle, and Landis and Dane (1967) give a geologic map of the Tierra Amarilla Quadrangle. Maps in these publications also show types of surficial deposits such as landslides, terrace, moraine, and gravel deposits that may be helpful in understanding the geomorphology of Gumbo valley.

Still further to the east are areas studied by Doney (1968) and Muehlberger (1968). Both publications contain detailed geologic maps that also show surficial recent geologic deposits.

A geologic map of southern Archuleta County, Colorado, has been published by Wood and others (1948) which shows major structural features of the area. Several graphic sections of subsurface geology are given.

The hydrodynamics and geochemistry of aquifers in the San Juan basin have been studied by Berry (1959). His thesis may contain clues for prospecting for good quality ground water.

Water-resources studies adjacent to but outside the area are not numerous. The principal study is that of Baltz and West (1967), but some of the studies of Project Gasbuggy (Koopman and Ballance, 1967a, and b) may contain useful ground-water information.

Two unpublished reports prepared by private consultants contain information on water resources. Neither of these papers is available to the public. It appears that neither is based on extensive basic data collection. Many of the interpretations and conclusions are generalized and probably based on extrapolations of studies in surrounding or adjacent areas. The latest of these reports which contain most of the information in the first should be available within a few months.

Virtually all of the area is covered by two 15 minute quadrangle maps (Boulder Lake, N. Mex. and Lumberton, N. Mex.-Colo., published by the U.S. Geological Survey, 1955). Maps with more detail have been published by the Bureau of Indian Affairs (1969). Aerial photos (1970) of the entire area are available with a scale of approximately 5 inches per mile.

TEST HOLE AND WELL DATA

Records show that more than 30 test holes and oil wells have been drilled in this area; moreover, many more test holes have been drilled in the surrounding areas. A perusal of the records shows that most of the holes within the study area were drilled about 1962.

Few of the wells and test holes penetrate rocks older than Dakota Sandstone, but one was drilled to rocks of Precambrian age in sec. 33, T.28 N., R.1 W. The elevation of this well is given as 7,335 feet which indicates a location in La Puerta Grande south of Thompson Lake. This location would indicate that the well was "spudded in" near the top of the Mancos Shale. Depths to the tops of various formations in feet are given in the following table:

Dakota Sandstone	1,810
Morrison Formation	2,070
Todilto Limestone	2,730
Entrada Sandstone	2,825
Chinle Formation	3,070
Permian (rocks)	3,550 or 4,500
Pennsylvanian (rocks)	5,150
Schist (Precambrian)	5,860

Various well logs are available from some of the test holes and wells; however, with the exception of gamma ray logs, these records tend to be discontinuous with depth.

Due caution and skepticism should be exercised in studies of these records. A hasty review shows that some of these test holes or wells have penetrated formations or members of formations that are not recognized in surface exposures.

There has been much recent subsurface exploration in the vicinity of the proposed study area by various exploration companies. Atlantic Richfield Co., Denver, Colo. has done much of the exploration. The Chief Geologist, Mr. Roger Markham (oral communication) advises that 600 to 800 test holes have been drilled in the area and most have bottomed in the Morrison Formation. Other exploration companies such as United Nuclear, Albuquerque, N. Mex., Western Nuclear, Casper, Wyo. and Denver, Colo., may also have test-hole data.

Several of the test holes drilled by the Atlantic Richfield Co. were left open for exploitation as water supplies. Records of these holes are in the files of the Office of the New Mexico State Engineer, Santa Fe (R. L. Borton, oral communication).

A considerable body of data relating to ground-water resources of the San Juan basin exists in files of the office of the Chief Geologist, El Paso Natural Gas Co., Farmington, N. Mex. A few of these data were examined briefly during December 1972 in connection with another study of the U.S. Geological Survey. The chemical analyses of ground water show the presence of good quality water even at great depths in some parts of the basin. It must be cautioned, however, that many of these data are from oil and gas wells where environmental conditions are unusual.

There are records of some springs and water wells in files of the office of the Bureau of Indian Affairs, Dulce. That part of these records available for study shows little information of value.

DESCRIPTION OF WATER RESOURCES

Despite its moderate precipitation, this area is one of meager water resources; moreover, much of the water supply is of restricted value because of its salinity and its chemical composition. Most of the surface water is in lakes in Gumbo valley. Chemical analyses of these waters have been furnished by the Bureau of Indian Affairs and values of specific conductance are given in the following table:

Specific conductance (micromhos) of lake waters in Gumbo valley

Date (approximate)	Stone Lake	Hayden Lake	Enbom Lake	Burford Lake
May 17, 1967	3,200	1,300	720	8,000
June 25, 1968	2,880	940	-	5,440
July 31, 1968	2,740	840	-	-
Sept. 9, 1968	2,710	880	-	-
Nov. 5, 1968	2,800	1,060	-	-
June 17, 1969	2,300	870	650	2,950
Aug. 19, 1969	2,370	840	670	2,320
Nov. 18, 1969	2,360	920	560	-
Feb. 9, 1970	1,270	1,020	660	-
Aug. 31, 1971	2,610	1,610	900	-
Apr. 23, 1973	1,580	800	1,170	-
July 25, 1973	2,230	-	-	1,500
Aug. 27, 1973	2,340	870	1,160	-

It is noted that salinities, a function of the specific conductance, vary widely with time and place, but do not approach values for saturated brines (approximately 200,000 micromhos). This condition demands a surface or subsurface outlet for the lakes. From a study of the chemical analyses, it appears that only calcium carbonate precipitates from these lakes. Hydrogen sulfide is evolved from most if not all of the lakes at various times.

The only other surface waters observed during a brief examination of the area were small streams in Boulder Creek and in an arroyo at Puerto Chiquito and outflow from Horse Lake. There is no stream channel in the floor of La Puerta Grande.

STATE OF HYDROLOGIC KNOWLEDGE OF AREA

The hydrologic knowledge in this area is of several types, some more reliable than others. In part, it is intuitive based on knowledge from other areas, some is rumor or hearsay, and a small part is fact. Our purpose is to state what we know, what we have heard, what we suspect; and let others decide how extensively this knowledge should be enlarged. This proposal, therefore, will contain several options for studies. Each succeeding option will require more effort and hopefully will result in more knowledge and benefits.

1. Surface water--only one gaging station has been operated which encompasses drainage from the proposed area of study. About 18 percent of the drainage area at this station, 08284300, Horse Lake Creek above Heron Reservoir near Parkview, is within the study area. This station has been operated from October 1962 to the present time. In addition, two other gaging stations are presently operated on Willow Creek which is adjacent to the study area. These records are published annually in the U.S. Geological Survey series of reports entitled "Water-Resources Data for New Mexico."

It is possible to estimate characteristics of surface-water flow by using data from the above stations, however, the estimates would be poor. Because the climate and geologic environment are so variable, the quality of surface-water runoff would be difficult to estimate with confidence.

2. Ground water--nothing is definitely known of the amount of ground water in storage. It is safe to predict that the amount is enormous, but that most cannot be extracted with present technology. There is more than 4,000 feet of shale underlying the area, and most of this material is probably saturated. The porosity of shale is variable; but if it is assumed to be about 50 percent, a simple calculation shows that the amount of ground water in this source alone would be sufficient to cover the entire area to an average depth of 2,000 feet. The amount of ground water in storage that can be extracted is much less, perhaps only a small fraction of the amount stored in the shales.

In general, neither the rate nor direction of ground-water movement is known. Typically, it is assumed that ground-water movement is toward discharge areas, but these areas are not known. It is assumed that the rate of ground-water movement in aquifers below the sandstones of the Mesaverde Group is very slow, perhaps no more that a few feet or inches per century.

Nothing is known of the temperature of ground water in this area.

Estimates of yields and quality of water from various aquifers are given by Berry (1957, unpublished report). These estimates appear to be reasonable, based on information available at the time; however, additional information has come from various sources and will result probably in revision of some of these estimates. Berry believed that the greatest yields of ground water are possibly from wells finished in the Entrada Sandstone. His estimate that wells penetrating this formation might yield as much as 300 gallons per minute seems reasonable. His assessment of the aquifer in the Dakota Sandstone may be somewhat pessimistic. This should be a poor aquifer, yet in the Chama basin it has produced some wells with good yields and excellent quality of water. Some of these wells are very near recharge areas and are in fault zones, but others are not.

The Mancos Shale may yield potable water at places. According to Harley Parr, New Mexico State Highway Department (oral communication), a well finished in this formation provided a water supply for the U.S. Bureau of Reclamation's construction camp during the boring of the Azotea tunnel. He reports also that other wells penetrating the Dakota Sandstone and Morrison Formation produced potable water.

The sandstones of the Mesaverde Group probably are not good sources of ground water. Three wells have been drilled recently into these sandstones in search of a water supply for Stone Lake Lodge. According to Glen Hammock of Gordon Herkenhoff and Associates, Albuquerque, N. Mex. (oral communication), these wells yielded only small amounts of poor-quality water. One well produced some hydrogen sulfide and was abandoned. The well now in use produces water with enough dissolved iron to create a poor taste and to badly stain porcelain fixtures in the lodge. Hammock believes that wells finished in these sandstones will yield less than 20 gallons per minute.

The Lewis Shale is not likely to provide an aquifer; however, E. C. Beaumont, Consulting Geologist, Albuquerque, N. Mex. (oral communication) has mapped extensive joint patterns on the surface of this formation. If there is extractable water in the Lewis Shale, it is probably in fractures. Hammock believes that water in the Lewis Shale will be of poor quality (oral communication).

Several springs are shown on Dane cuesta on topographic quadrangle sheets. According to Glen Hammock (oral communication) some of these springs yield enough water to furnish a water supply to Stone Lake Lodge. He believes that these springs are potentially the best source of water in the study area. The recharge areas for these springs are small, probably not larger than a few square miles, hence the question of whether they will provide a water supply throughout periods of sustained droughts is debatable. Chemical analyses, furnished by the U.S. Bureau of Indian Affairs, of water from some of these springs shows specific conductances in the range of 500-670 micromhos, indicating that this is probably the best quality ground water in the area.

PLAN FOR WATER-RESOURCES STUDY

To accomplish the objectives, as outlined by the U.S. Bureau Indian Affairs, of a water-resources study of part of the Jicarilla Apache Indian Reservation, it is proposed that a study covering a time period of 1 year be initiated, the fieldwork to be accomplished during one summer season. Such studies can be conducted by personnel of the U.S. Geological Survey, when funds become available. A hydrologist with knowledge of geology and ground water and a hydrologist with knowledge of surface water will be needed on a part-time basis.

The following techniques and outlines of studies are recommended:

1. Estimated ground-water flow within the project area.

Any estimate of ground-water flow will be given with a low confidence of accuracy. The estimate will depend upon a clarification of the objective. If an estimate is to be given of only the amount of ground water flowing across the reservation boundary, the problem is simpler than estimating flow at all parts of the reservation.

Some fieldwork will be needed to determine areas of recharge and discharge of ground water. The area of recharge for various aquifers will be a significant factor in these estimates.

Estimates can be refined only by drilling and test pumping in more wells.

2. Estimates of potenial yields and quality of water from various aquifers.

It is doubtful that the estimate of yields can be improved very much over those given by Berry in his unpublished report (op. cite) without a large effort in data collection. More data are available on the quality of water in various aquifers, hence this part of the estimate can be refined.

These estimates could be refined by developing and measuring the flow from springs periodically. This type of study should precede planning of permanent utilization of springs on Dane cuesta.

A study of the hydrology of the major lakes in Gumbo valley should provide better estimates for yields and quality of water in sandstone aquifers of Dane cuesta. A description of this study is given in a subsequent section.

These estimates can be refined by drilling and test pumping various aquifers, and it is recommended that thought and planning begin toward achieving this objective. We agree with Berry that, insofar as possible, test drilling should be done in cooperation with the drilling of oil and gas wells.

3. Estimates of ground water in storage within the project area.

These estimates will be based on the assumption that sediments are saturated. An average porosity will be assumed for each type of rock, and the estimate will be based on the thickness porosity and areal extent of each type of rock. These estimates will be poor unless data can be accumulated to refine them. The refinements would be from studies of porosity logs from test wells.

4. <u>Estimates of the temperature of ground water in various aquifers</u>.

This estimate will be based partly on the temperature of water from springs and wells. Temperature logs of deep test holes or wells would greatly improve the confidence of the estimates. If temperature logs cannot be found or made, the estimates will be based on normal thermal gradients determined elsewhere.

5. <u>Estimate of surface water outflow from the reservation</u>.

A. <u>Mean annual flow</u>--The following two options will provide estimates of the long-term mean annual flow from the study area. The second option would improve the estimate.

(1) It has been shown in previous studies that the size and geometry of alluvial stream channels are related to the amount of water carried by the channel (Moore, 1968). Make measurements of stream channels at reservation boundary and utilize to estimate mean annual flow. In addition extend data from existing nearby gaging stations to study area on the basis of drainage areas.

(2) Install a continuous-recording stream gage at the reservation boundary on Boulder Creek. In addition, make monthly streamflow measurements at the other channels which leave the reservation. The gage should be operated for a period of 5 years and the monthly measurements made for 2 years. These data can be used to correlate with a nearby long-term gaging station and should provide a very good estimate of long-term mean annual outflow from the reservation.

B. Peak flow--Flood-flow characteristics of these streams can be estimated with existing data.

C. Low flow--The following options are offered for estimates of low flow.

(1) Visual inspection of the streams and records from nearby gages indicate that these streams are dry much of the time. Without additional data this is about as much as can be said about low-flow characteristics.

(2) To provide a confident estimate of the low-flow characteristics of these streams would require periodic observations of flow. This would be accomplished by monthly measurements of flow for a period of 2 years and then correlation with nearby station records.

6.--Quality of surface water.

The quality of surface water in arroyos and lakes will range through a wide spectrum of types and salinities depending upon the geologic environment, weather conditions, type of runoff, etc. No satisfactory estimates can be made without data collection. It is proposed to collect water samples from various sites.

To accomplish the outlined objectives all pertinent literature on the geology and hydrology of the area will be studied. Topographic maps will be integrated into the best possible base map. Water wells in the area will be investigated. Staff gages will be installed in the principal lakes. One or more rain gages will be operated. Weirs will be installed at selected springs. A final report will be prepared and submitted to the Bureau of Indian Affairs for approval to release to the open file.

The estimated cost of the proposed study is $18,000. The cost of this planning study was $2,000, which is included in the total estimated cost--thus an additional $16,000 will be needed for the water-resources study.

If a better definition of mean annual flow and low flow is needed, it is suggested that item A-2 and item C-2 be considered. A continuous-recording stream gage on Boulder Creek would cost an estimated $2,500 to install. Cost of operation would be $2,500 per year. Monthly streamflow measurements in other channels would cost $1,800. Total cost for 5 years of operation would be $16,800. If such a stream gage were operated, refined low-flow characteristics would also be provided. Without the stream gage operations described in item C-2 could be provided at a cost of $2,700. It is suggested that if it is decided that better definition of mean annual and low-flow characteristics is needed that the proposed study be made at the lower level and that the refined data and interpretations be prepared in the form of an addendum to the water-resources study report.

SUGGESTED STUDIES

Several studies are suggested that might provide data for a variety of water problems, some of which are not specifically mentioned in the letter requesting this study.

1. Exploration for new ground-water supplies.

Several options are given for this study. Exploratory efforts should be directed toward the least expensive supply for a given need. If the need arises for a supply of 200 or more gallons per minute, the only source is in the Entrada Sandstone. Wells tapping this aquifer would be 3,000+ feet in depth; but due to piezometric pressures, the pumping lift would be much less.

The Dakota Sandstone can be tapped along the eastern edge of the reservation at several places where the wells would be about 2,000 feet deep. Wells tapping this aquifer should be as near as possible to the recharge areas to the east. It is recommended that these wells penetrate the sandstones at the top of the Morrison Formation because the upper part of the Dakota Sandstone is probably quartzite and carbonaceous shale. Only the lower sandstone of the Dakota Sandstone and upper sandstones of the Morrison Formation (Burro Canyon?) are likely to produce good water. If possible these wells should be drilled in or near fault zones. Yields would probably not exceed 50 gallons per minute; however, these yields would probably be sustained for many years.

Wells penetrating the sandstones of the Mesaverde Group should furnish enough water for stock, and at places this water might be barely good enough for human consumption. Depths would vary from a few hundred to perhaps 1,000 feet.

Wells drilled into the aquifers on Luna cuesta might yield enough water for some purposes; however, it is doubtful if these aquifers could yield more than 100 acre-feet per year under sustained pumping.

There is probably some ground water in shallow aquifers in Gumbo valley, but it would be difficult to find, the yields would be small, and the quality of most would be poor.

2. A study of the hydrology of the major lakes in Gumbo valley.

This study would consist of monitoring precipitation, lake stages, chloride concentrations, and other chemical properties of the water at various sites around the lakes. From these data, evaporation rates, recharge rates from surface and ground water, and losses to ground water aquifers under the lakes would be culculated. Additional benefits would be better estimates of quality of water in the sandstones of the Mesaverde Group, and some estimates of the long-term effect of pumping ground water from these sandstones.

It is expected that the data on this study might be very valuable to other studies relating to improving the habitat for fish. For example, it is very likely that the pH and alkalinity measurements would be useful in diagnosing the reasons for intermittent turbility in the lakes.

The U.S. Geological Survey has a seismic capability. Seismic profiles can be made of the subsurface, and these can be used to contour the bottoms of the lakes. Ideally, the thickness and depths of various types of sediments underlying the lakes can be determined.

The seismic capability could be used also to determine bedrock configuration in other areas and this would greatly improve estimates on the direction of ground-water movement. It would provide more data for estimates of ground water storage, and help in delineating favorable areas for ground-water prospecting.

According to F. C. Koopman, U.S. Geological Survey, Albuquerque, New Mex. (oral communication), the field data for about 1 mile of seismic profile can be collected in one day, and another day of effort is needed to process the records. Koopman believes that seismic profiles sufficient to contour Burford Lake can be made with about 5 man-days effort.

3. The measurement of water levels in wells.

Only a few wells are present in the area, and little is known about them. If sufficient data can be collected on depths, pumping rates, etc., and if it is possible to measure their water levels, a long-range program of periodic measurement of water levels might be established. Such data on water levels is valuable in determining the amount of water in storage, recharge to aquifers, and effect on the aquifers of possible future water withdrawals.

If these suggested studies were included in the water-resources study, it is believed that the study could still be completed within 1 year. The additional cost of the suggested studies is estimated at $7,000.

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