United States Department of the Interior

GEOLOGICAL SURVEY
WATER RESOURCES DIVISION
Room 227, Federal Building
705 North Plaza Street
Carson City, Nevada 89701

August 3, 1984

MEMORANDUM

TO: Members of the Carbonate Terrane Society

FROM: Terry Katzer, Nevada Office Chief, WRD, Carson City, NV

SUJBECT: Carbonate Terrane Study

In response to our last meeting, we have prepared the enclosed project proposal for a 10-year investigation of the entire Carbonate Terrane, which will serve as a point of discussion for our August 13th meeting. We have probably overlooked some elements, however, I'm sure they will fall into place during the course of the study. There is a large degree of uncertainty on projecting cost for ten years. For one thing, the inflation rate is unknown. Also, the budget, while it may seem ambitious, may in all actuality, be deficient. Another large item not estimated here are the costs of an exploratory drilling program with subsequent development/production drilling; these costs will probably dwarf all the investigative cost. And finally, we realize that ultimately, the availability of funds will be a controlling factor in the investigative process.

To briefly summarize the proposal, it is important to understand that the water resources of the carbonate terrane are not well defined, for the data are sparse, and the hydrology and geology are complex. It will take a lot of money and a long time to arrive at some reasonable understanding of the system. Unless this understanding is reached, the development of carbonate water is risky, and the resultant effects may be disastrous for the developers and current users.

Water resource planning based on a scientific understanding of the hydrology will have many benefits. From the Las Vegas Valley water users perspective, it will mean knowing that the additional water for their expanding needs is really available, and that it will be possible to quantify that additional water.

From the perspective of the current water users throughout the Carbonate Terrane, including the potential White Pine Power Project users, it will mean ensuring a safeguard on their already appropriated ground-water rights, and it will allow the allocation of unallocated waters to proceed toward a much better defined perennial yield.

From the State's perspective, an understanding of the system will allow its optimum management for the benefit of all the people. From the Federal agencies perspective and, in particular the Department of Interior's Water and Science, an understanding of the system is essential prior to beginning resource development.

See you on Monday, August 13 at 10:00 a.m. in Rick Holmes' shop.

Terry

Terry Katzer

Enclosure

TK:tf

PROJECT PROPOSAL
for
INVESTIGATION OF CARBONATE-ROCK AQUIFERS IN
EASTERN AND SOUTHERN NEVADA

U.S. Geological Survey
Water Resources Division
Carson City, Nevada

July 1984

PROJECT PROPOSAL
for
INVESTIGATION OF CARBONATE-ROCK AQUIFERS IN
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Problem

Most of the known water resources of Nevada, which includes virtually all surface water and most of the ground water in basin-fill reservoirs, are used or appropriated to (or beyond) the extent of current estimates of their perennial yield. For development to continue in some of the more intensely developed basins, "new" sources of water or new methods of managing the existing sources will be necessary. In this context, the aquifers of the deep carbonate rocks of eastern and southern Nevada are often cited as potential "new" sources of water. At the same time, the hydrology of the Carbonate Terrane, and in particular the carbonate-rock aquifers, is the least understood in the Great Basin. Large-scale and long-term investigations will be needed to overcome this knowledge deficiency.

This proposal is not the first to consider a comprehensive investigation of the hydrology of the Carbonate Terrane in Nevada (fig. 1). Area-wide studies have been conducted by four different organizations to date (area-wide here indicates an interest in the Carbonate Terrane as a whole or at least over an area large enough to include more than one of the major regional flow systems within the Terrane). The organizations are 1) the Desert Research Institute (Mifflin, 1968, Hess and Mifflin, 1978), 2) the U.S. Air Force (M-X Multiple Protective Shelter Water Resources Program 1983), 3) the U.S. Geological Survey (Great Basin Regional Aquifer System Analysis, Harrill and others, 1982), and 4) the U.S. Bureau of Reclamation (Southern Nevada Deep Carbonate Aquifer Study, 1984). Each of the studies by these organiza-

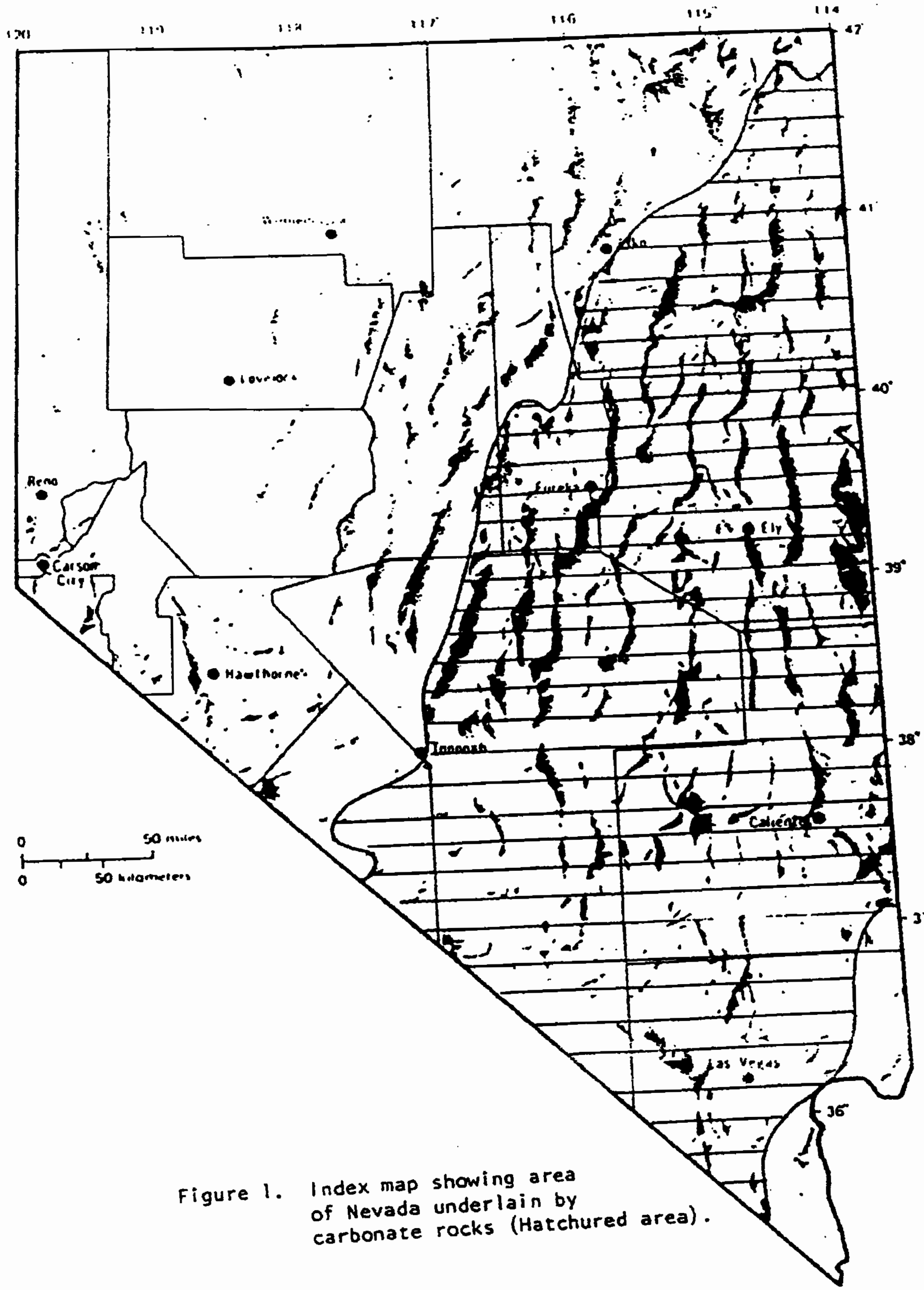

Figure 1. Index map showing area of Nevada underlain by carbonate rocks (Hatchured area).

tions was concerned with the development of appropriate and feasible methods for the investigation of the hydrology of the Terrane, and to varying extents, each is concerned with the development of well-constructed plans for long-term studies to support and (or) assess development of the resources of the deep carbonate-rock aquifers

The large-scale investigations have been, and will continue to be, built on smaller scale studies. Important among the small-scale investigations are studies that have dealt primarily with the delineation and description of individual regional flow systems. These include 1) the early studies of the White River flow system by Maxey and Eakin (1949) and Eakin (1966); 2) the numerous studies in the area between, and including, the Nevada Test Site and Death Valley by Hunt and Robinson (1960), Eakin and others (1963), Winograd and Thordarson (1975), and Classen (1983); and, 3) the investigations of the geohydrology of Central Nevada associated with the Atomic Energy Commission's Central Nevada Test Area (Fiero and Illian, 1968 and 1969). Numerous studies of the hydrology of individual or small groups of basins have also been conducted by both private and public organizations and will provide their conceptual foundations to planned large-scale studies. Major sources of information for comprehensive investigations come from outside the hydrologic profession. Deep drill-hole information has been collected in the course of drilling deep test wells for oil exploration, and much of the geophysical data in the Carbonate Terrane was developed in support of mineral exploration.

The Carbonate Terrane of eastern and southern Nevada lies in an area in which local climates are primarily dependent on altitude. Annual preciptation totals range from less than 3 inches in some of the southern valleys (e.g., Amargosa Desert and Death Valley) to greater than 30 inches in some of the highest mountain ranges in the northeast (e.g., the Ruby Mountains). Precipitation on most valley floors range from 5 to 12 inches per year (Hardman, 1936). The most humid parts of the Carbonate Terrane, with local exceptions, lie in the vicinly of 38 degrees latitude where the valley floors are often more than 5,000 feet above sea level. The Utah and southern Nevada parts of the Terrane are the most arid. The temporal distribution of precipitation in the region is dependent on which of several storm tracks are influential in a particular area, but generally precipitation on valley floors throughout much of the Terrane is relatively evenly distributed between the winter and summer (Quiring, 1965, figures 2 and 3). Summer precipitation occurs mostly during thunderstorms.

Water deposited by precipitation within the Carbonate Terrane or on the bordering mountain blocks is the only water, so far as is known, that recharges the hydrologic systems of the Carbonate Terrane. Most of the precipitation on the valley floors is evaporated or transpired without entering the ground-water systems of either the basin-fill aquifers or the deep carbonate-rock aquifers. Thus, most of the recharg to basins and deep carbonate-rock aquifers is presumed to derive ultimately from precipitation in the mountains in and adjacent to the Carbonate Terrane. The processes by which this recharge occurs are poorly understood. In some basins, for example southern Ruby Valley (Johnson 1980, pages 17-180) and the Ash Meadows flow system (Winograd and Thordarson, 1975, page 92), recharge to the basin-fill aquifers, and to carbonate-rock aquifers, is believed to occur primarily as deep percolation of water into and through the mountain block materials. In other valleys and systems, for example the Amargosa Desert (Claasen, 1983, page 1), much of the recharge appears to have occurred primarily as a result of the percolation of surface runoff from snowmelt in the adjacent mountains, and took place in flood channels along alluvial fans and the basin floor during wetter climatic conditions 12,000 to 18,000 years ago. The percent of recharge water following one of these paths or the other must depend to a large extent on the topography and large-scale permeability of the mountain block.

Flow patterns within the basin-fill reservoirs of the Carbonate Terrane can be complex, but most often entail flow from the recharge areas at the base of the moutain blocks "down" the basin to one or more discharge areas. The water at these discharge areas either 1) evaporates at a playa or free-water surface fed by springs, 2) is evapotranspired by phreatophytes where the water table is relatively near land surface, 3) flows into another basin or flow system, or 4) leaves the system through some combination of the above modes of discharge. The location of these discharge areas within a basin is determined by some combination of geologic, topographic, and hydraulic factors.

The hydraulic and hydrologic connections between the basin-fill reservoirs and underlying carbonate-rock aquifers are poorly understood at this time. Studies in Ash Meadows (Bateman and others, 1972; Bateman and others, 1974) and in the Upper Moapa Valley (Maxey and others, 1966) have shown that in some cases very intimate connections between the two aquifers may exist while in other cases, the aquifers may behave as independent systems. The factors that may ultimately control the extent of interconnections are the presence of aquitards between the two types of aquifers and the extent to which hydraulic gradients exist which might induce interaquifer flow. The aquitards that may occur in this context are — in order of increasing age — layers of fine-grained sediments within the basin fill, thick layers of lava-flow materials, and (or) tuffs of Tertiary age, and fine-grained consolidated rocks (for example, the siltstones and shales of Mesozoic age that overlie some Paleozoic sections). Where such aquitards lie between the basin-fill aquifers and underlying carbonate-rock aquifers over a large area, flow and hydraulic connection between the two systems may be prevented or greatly modified.

The connection between the ground-water systems of mountain blocks and adjacent basin-fill aquifers -- and between adjacent basins through the intervening mountain blocks -- is also controlled at least in part by the presence of aquitards and by the existence of favorable hydraulic gradients. Where the normal faulting that created the basin and range topographically has left Tertiary volcanics or some poorly permeable unit along a large portion of the contact surface between the mountain block and basin-fill sediments, the capacity for recharge water that has percolated deep into the mountain block to leak into and recharge the basin-fill aquifers may be severely impaired. The presence of such an aquitard, or the presence of an intrusive body or other type of aquitard beneath the mountain block may also prevent inter-basin flow though the mountain block. Another barrier to interbasin flow that has been suggested in several cases is the presence of a mound of recharge water beneath mountain blocks (Eakin, 1963, page 15). Beneath ranges that receive a substantial amount of deep percolating recharge water, the hydraulic heads may be raised above the head in either of the adjacent valleys. As a result, water cannot flow towards or through the mountain block from either of the valleys. The amount of deep-percolating recharge necessary to create a hydraulic barrier must depend on the permeability of the mountain block (Eakin, 1966, pages 268-269; Mifflin, 1968, pages 15-20).

Mountain blocks at depth are not hydrologically distinct geologically from the carbonate rock as a whole. The exposed part of the mountain block is the same lithogically, as that part of the block of consolidated rock underlying the area. As such mountain-block hydrology at depth is no different from the hydrology of the consolidated rock beneath the basins. Both are dominated by the secondary and tertiary porosity -- and resulting permeability -- of the consolidated rocks. Secondary porosity is the porosity associated with fractures in the aquifer medium. Tertiary porosity is the porosity associated with dissolution features such as caves and modified fractures. Tertiary porosity and permeability is limited to the carbonate rocks, and, at depths where overburden pressures may tend to seal simple fractures, may be the most important avenue of ground-water flow (Eakin, 1966, pages 266 and 268). Dissolution of carbonate rock is generally concentrated near the water table or in the unsaturated portions of the carbonate rocks, where the water is still unsaturated with respect to the carbonate minerals. Within a short distance of entering carbonate rocks, the ground waters of the Carbonate Terrane are fully saturated with respect to those minerals. Caves occur most often in the mountain blocks and in specific parts of the Paleozoic section, but solution features may be present at great depth (Hess and Mifflin, 1978, pages 26-31).

The physics of flow of ground water through secondary-permeability terranes is such that water flow is very easy along the path of the fracture and solution features, and difficult perpendicular to these features. At a small scale then, flow direction need not parallel the local or regional hydraulic gradients. At large scales, depending on the degrees to which the fracture patterns are isotropic and sufficiently random, flow directions may or may not parallel large-scale hydraulic gradients. Instead, large-scale flow and discharge patterns may tend to parallel major structural features. This results in conditions in which large hydraulic gradients can persist with little actual flow.

Ground-water flow within the Carbonate Terrane at regional scales depends on the presence of fracture zones, the occurrence of intrusives and other local geologic barriers, the impacts of large-scale linear geologic features such as the Cortez Rift, the locations of topographic lows and other discharge areas, recharge distribution, and the configuration of aquitards and aquifers. Many large springs are associated with major faults in the carbonate terrane, and faults can act to expedite flow or act as barriers to flow (e.g., Winograd and Thordarson, 1975, pages 81 and 29). Ground-water discharge areas are commonly found in the areas that are lowest topographically, whether in a basin, a regional system or on the side of a mountain block. Recharge distribution can result in hydraulic barriers and ultimately drive the flow systems.

Given the myriad possible avenues of hydrologic connection between the various aquifers and flow systems and the uncertainties of recharge and discharge mechanisms and processes, an investigation of the hydrology of the carbonate-rock aquifers in Nevada is undoubtedly a difficult undertaking. Additional complicating factors include:

- Basic hydrologic data (ground-water levels in both the basin-fill and carbonate-rock aquifers, flow measurements for important springs, and flow measurements for major streams) are scarce or infrequently obtained in much of the area.
- Secondary hydrologic and other data, such as hydraulic parameters, geophysical and geochemical data, are lacking in many areas.
- Only a small number of wells and drill holes tap the deep carbonate rocks.
- The geology of the Great Basin in general, and the Carbonate Terrane in particular, is complicated.

- Uncertainties and inaccuracies exist in current methods of estimating ground-water inflow and recharge.
- Uncertainties and inaccuracies exist in current methods of estimating ground-water outflow and evaporative discharge.
- The geometry, properties, and boundaries of the carbonate-rock and basin-fill reservoirs are generally unknown, and definition of these properties can be expensive and difficult.
- Climatic conditions today are inadequately defined (particularly at higher altitudes) and conditions during the development of the flow paths within the deep-rock aquifers and flow paths are even more uncertain.
- Limited stresses on the water resources of the area under current development conditions, allow hydrologists information only on the narrow band of system responses to natural conditions.
- The relationship between geothermal systems and the deep carbonate-rock aquifers and ground-water flow systems is not well understood.
- The area underlain by significant carbonate-rock sequences in Nevada is over 40,000 square miles of sparsely populated land, and includes 106 hydrographic areas and basins.

A comprehensive investigation of the hydrology of the Carbonate Terrane will have to be at least ambitious enough to deal in some manner or other with each of these complications and uncertainties.

Objective

The objective of the proposed project is to understand the hydrology, specifically the ground-water hydrology, of the Carbonate Terrane of the Great

Basin. Initially the project will concentrate on delineating, defining, describing, and understanding the carbonate-rock aquifers and associated flow systems in eastern and southern Nevada.

Approach

A comprehensive long-term program of investigation of the Nevada Carbonate Terrane will have to be based on a series of related and interdependent shorter term small-scale studies designed to address and resolve, insofar as possible, specific problems. Because of the large number of hydrologic problems that exist and the scope, remoteness, and complexity of the Carbonate Terrane, it is unlikely that a single, large-scale comprehensive study of the Carbonate Terrane as a whole could be pursued or even funded at appropriate levels by any one of the interested agencies and organizations. It is unlikely that all of the interested agencies taken together could pursue an adequate plan of study unless the issues and investigations are pursued on a more local level. A rational program of investigation requires the division of studies among limited, but key, subareas of the Carbonate Terrane; critical hydrologic processses; and those agencies most capable of pursuing it. The choice of study areas must be based on hydrologic continuity, on relative uniformity of conditions and processes, on interest in development of the resources or processes specific to an area, and on logistical feasibility. They must be scaled to include some significant part of a regional or subregional flow system so that problems of true interest--e.g. interbasin flow mechanisms and the yield potential of the carbonate-rock aquifers—are addressed.

Initially these studies may be conducted independently, concurrently, or in tandem, as time, manpower, and resources allow. Even in the early stages there will be a need for a large-scale overview and integration of all hydrologic and geologic interpretations with an eye toward transfer of information, regionalization of interpretations, and analysis of topics that are inherently too large-scaled to fall within the scope of any of the subarea studies. At some point the regionalization must be funded as a major project in its own right.

Principal methods available for continuing and future investigations of the Carbonate Terrane are: (1) geophysical studies to locate hydraulic boundaries, define rock properties, and delineate aquifer geometries, (2) interpretation of geochemical data to define the sources and histories of waters encountered in the carbonate-rock aquifers and surrounding media, (3) re-evaluation of water budgets for basins and mountain blocks in the Carbonate Terrane, and the development of more innovative methods of developing these budgets, (4) evaluation of physical and chemical analyses of deep wells and regional springs, (5) analysis of the lineaments and large-scale structural features of this part of the Great Basin, (6) geomorphic analysis of major landforms to assist in determining past hydrologic environments, (7) investigations of paleoclimates and their significance to current and future conditions, as well as to the history and geography of cavern development, and (8) analysis of hydraulic, lithologic, geophysical, and chemical data from deep wells and other holes.

Geophysical methods of study that may prove very useful include seismic refraction and (or) reflection surveys surface and downhole gravity measurements, and aeromagnetic surveys. Seismic methods may be used to identify major faults and geometries of local geologic structures. Gravity may be used to estimate depths to consolidated rock beneath valley-fill materials and density of consolidated rocks (and hence, indirectly, fracture density). Interpretation of aeromagnetic data may allow detection of metamorphic structures and intrusive bodies that may act as hydraulic barriers. Interpretation of chemical, temperature and isotopic variations along (and among) flow systems can be useful in delineating and assessing the limits and potential of those flow systems (Mifflin, 1968, pages 31-39; Johnson, 1980; Claasen, 1983). Linements analyses can be accomplished using Landsat imagery, and may be useful in identifying hydrologically significant structural features such as local shear zones with their attendant fracture systems or brecciation.

As basin and mountain block water budgers are better defined a level of confidence in the amounts of water that are flowing through the carbonate-rock aquifers and the connections between this water and the waters of the basin-fill aquifers may be developed. Improvement of these estimated budgets will require development of more accurate and precise estimates of rates of recharge and discharge.

Determination of piezometric heads at springs associated with the carbonate-rock aquifers and wells open to the carbonate rocks helps to define flow directions and can be useful in identifying hydraulic connections between rock units. Regional springs and deep wells also provide the main avenue for determination of chemical conditions in the deep rock aquifers.

Geomorphic research focused initially on the White River system will place the landforms of that area into a geomorphic/geologic time series that broadly defines its complex history in terms of paleohydrology. The mapping and age dating of soils, surficial geology, and stratigraphy will provide the means for the ultimate quantification of the landscaping processes. This will involve gathering the appropriate soil surveys made by the Soil Conservation Service and interpreting these findings in a geomorphic-hydrologic perspective. Additionally, all geologic and geomorphic (if available) literature will be put into a common data base. After this evaluation is made, areas will be selected for a second phase of intense investigation based on their importance in understanding todays hydrologic flow system. The second phase studies will be site specific (one valley at a time) and involve very detailed mapping and corresponding age dating. As a data base is built in one area, chronologies will be extended to other appropriate areas, and in this fashion, the entire White River system will be analyzed. During this second phase, areas outside the White River system may require similar efforts if it seems important to understand a cause-effect relationship that bears on the White River system.

Paleoclimate research is of significance because of the long travel times for water in regional systems; for example in the White River flow system water as much as 10,000 to 20,000 years old are encountered (Alan Welch, U.S. Geological Survey, personal communication, 1984). Understandng of the conditions under which this water was recharged, flowed, and discharged may depend on the development of histories of climate in the Great Basin. These factors may, in turn, influence assessments of the renewability of the waters of the carbonate-rock aquifers.

Finally, the most direct, but generally most expensive method of investigation of the carbonate-rock aquifers is drilling of deep holes into the rocks. The information gained at each hole is only a small increment of the total information required for the rational development of the aquifers, but the cost of drilling and properly teting holes limits the number of deep holes that will be available. Thus, the wells that are drilled have to be placed and designed carefully to maximize their scientific worth. This will require packer tests on each porosity zone encountered to determine productivities and specific aquifer properties; development of careful lithologic logs based on cuttings and careful, detailed borehole geophysical measurements; and determinations of water chemistries and rock properties by stratigraphic unit.

Major tasks to be performed in conducting a comprehensive investigation of the hydrology of the carbonate terrane will include:

1) Basic data collection, compilation and analysis;
2) Research on key hydrologic processes and parameters, and development of specific methods for system definition;
3) Investigation and analysis of conditions and processes in important subareas;
4) Delineation and definition of flow systems and resources of the carbonate terrane; and
5) Regionalization of results.

Data Collection

Crucial to the study of the carbonate terrane is the development and continuation of historical records of hydrologic conditions in the area. Current data collection efforts are inadequate to define the hydrologic conditions throughout the area. Basic data collection programs will be initiated and (or) extended, as resources permit, to measure:

--Streamflow from important watersheds and springs

--Ground-water levels in each basin

--The chemistry of water in all parts of the carbonate terrane (surface water and ground water)

--Precipitation rates at all altitudes encountered in the carbonate terrane

--Other climatic parameters as necessary to estimate of evapotranspiration under conditions encountered in the carbonate terrane, and

--Land- and water-use data, as well as water supply sources and rates. Figure 2 shows the location of continuous streamflow and springflow gaging stations operating in and near the carbonate terrane. Installation and maintenance of these additional gaging stations will bring the level of surface-water discharge data in the carbonate terrane up to minimum regional levels. Specific surface-water gaging sites will be chosen to be representative of regional runoff characteristics, to help define specific basin and interbasin water budgets, and (or) to provide data for the delineation of mountain-block or regional-spring hydrology.

Figure 3 shows the location of continuous ground-water level gaging stations and regularly monitored wells in the carbonate terrane. Relatively few continuous gaging stations are necessary on a regional scale to define the slow and fast response cycles of ground-water levels, but regular measurement of a larger number of wells is desirable. Much more important is the canvassing of basins to update and improve the areal coverage provided by the historical database. This canvassing provides well locations, well descriptions, and water-level data at new and existing wells in many basins that otherwise would not be available to future investigations. Canvassing of basins should be repeated approximately every three to five years. The entire southern half of the carbonate terrane, excepting Las Vegas and the Nevada Test Site, should be canvassed soon to fill this data requirement.

Geochemical interpretations of the sources and histories of waters in the carbonate terrane are, of course, dependent on the availability of chemical, physical, and isotopic analyses of samples from an adequate number and distribution of sources. The U.S. Geological Survey Great Basin Regional

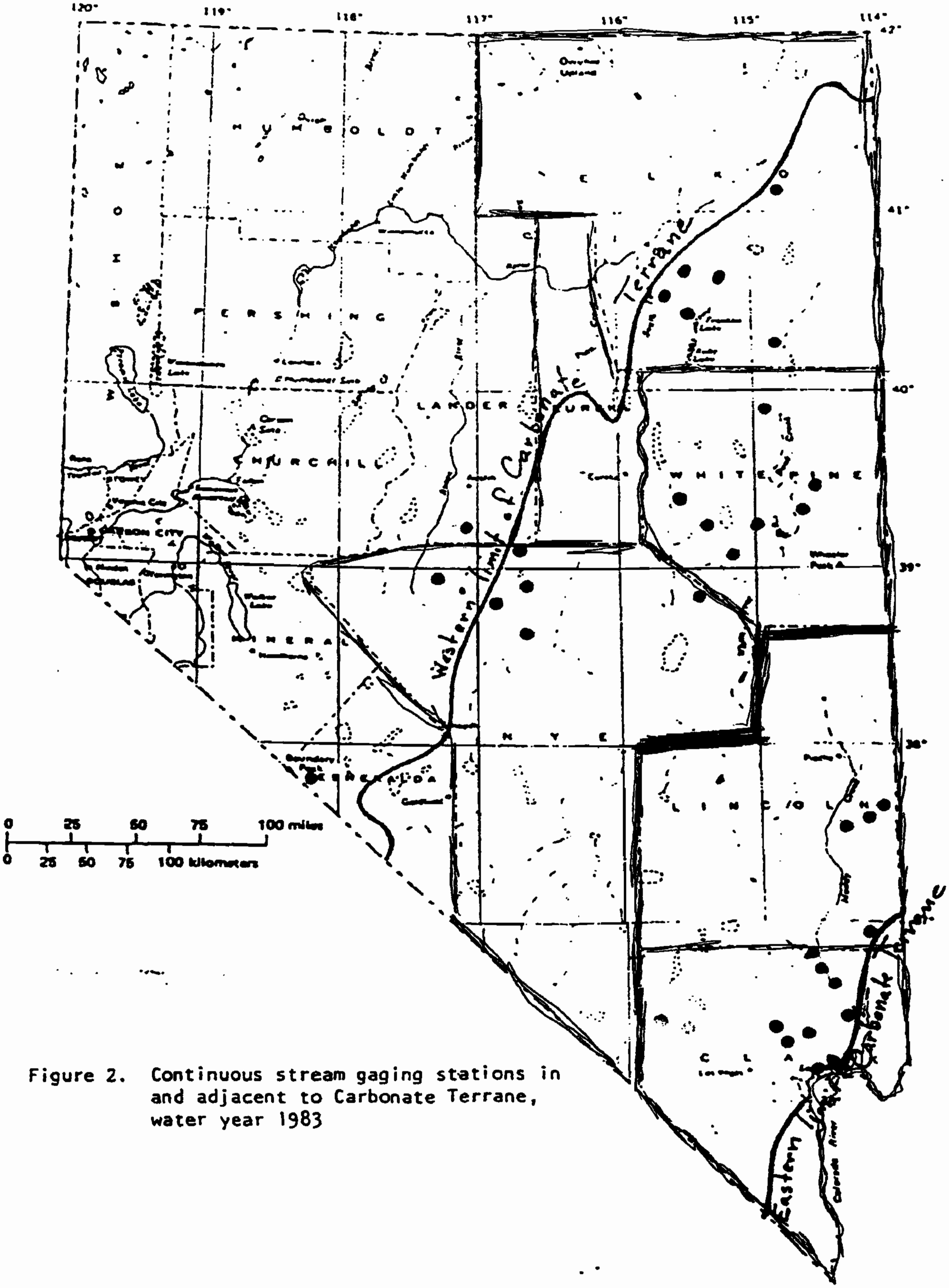

Figure 2. Continuous stream gaging stations in and adjacent to Carbonate Terrane, water year 1983

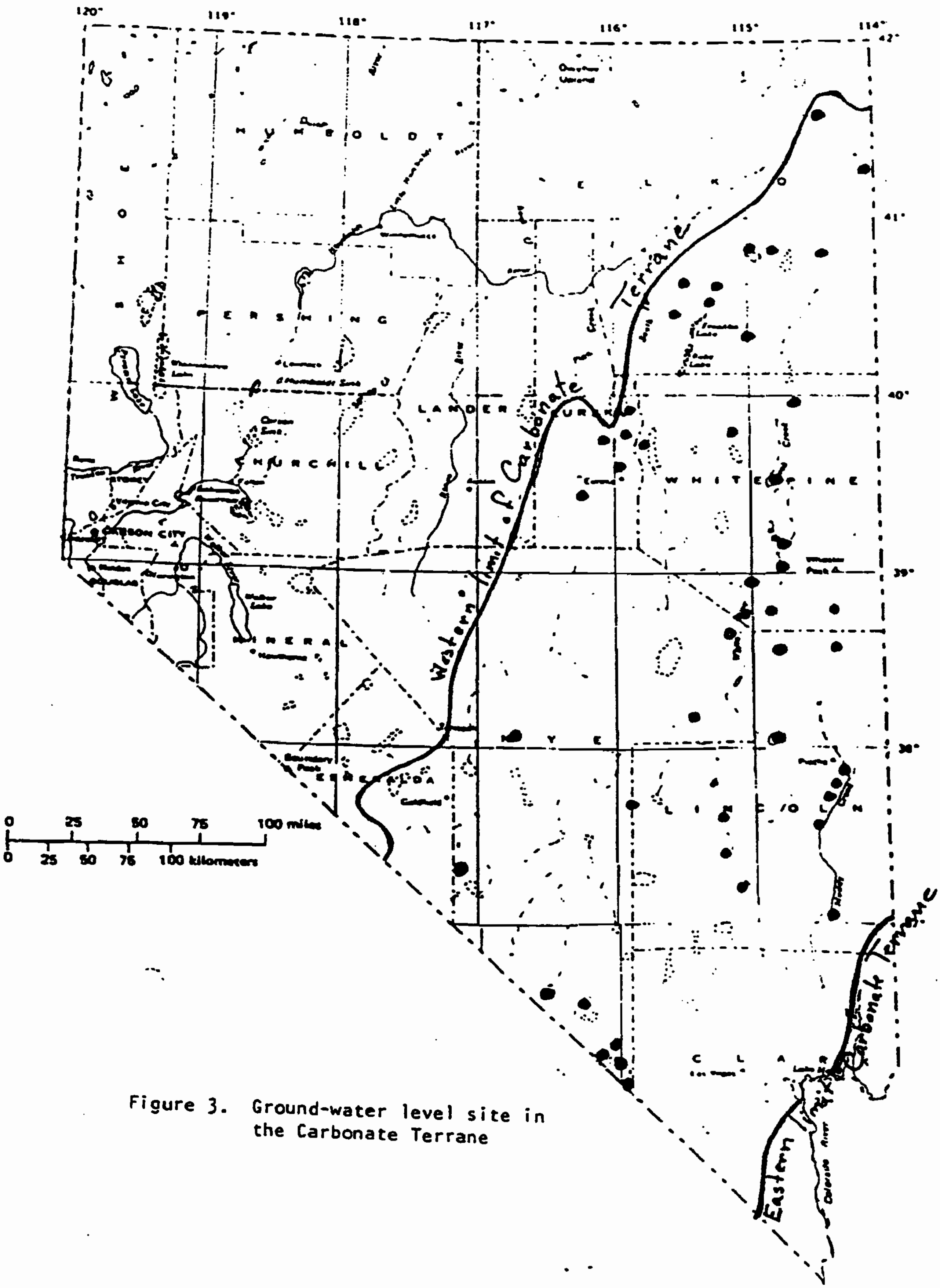

Figure 3. Ground-water level site in the Carbonate Terrane

Aquifer System Analysis has collected a wealth of chemical and isotopic data on the major regional springs of the carbonate terrane. Reliable chemical and isotopic data for water from the streams, mountain-block streams, and basin-fill ground waters of the carbonate terrane are not so readily available, and should be augumented as part of the basic data collection program.

A key factor in the development of recharge estimates is the estimated precipitation rates in areas that act as recharge centers. The areal distribution of precipitation stations is probabaly adequate at valley-floor elevations in the Carbonate Terrane. At high altitudes, where most of the precipitation takes place, however, coverage needs considerable improvement. Recent installation of ten high-altitude precipitation storage gages in eastern Nevada has raised the upper limit on precipitation measurements in that area from about 8,500 to 10,500 feet. Figure 4 shows the distribution of high-altitude precipitation measurement sites in the carbonate terrane.

A key parameter in the development of discharge estimates for water budgets is the rate of evapotranspiration by phreatophyes, from bare soil, and from free water surfaces. At present, precise measurements to estimate these rates are being made only in southwestern Nevada, near Beatty and at the Nevada Test Site. A wide variety of climatic, vegetative, and topographic conditions in the carbonate terrane limit the transfer value of these data collection efforts. The basic data collection program will therefore include the installation and maintenance of at least ten additional measurement sites, selected for wide areal coverage, coverage at a wide range of elevations, and for coverage of the entire range of ecologic settings encountered in the

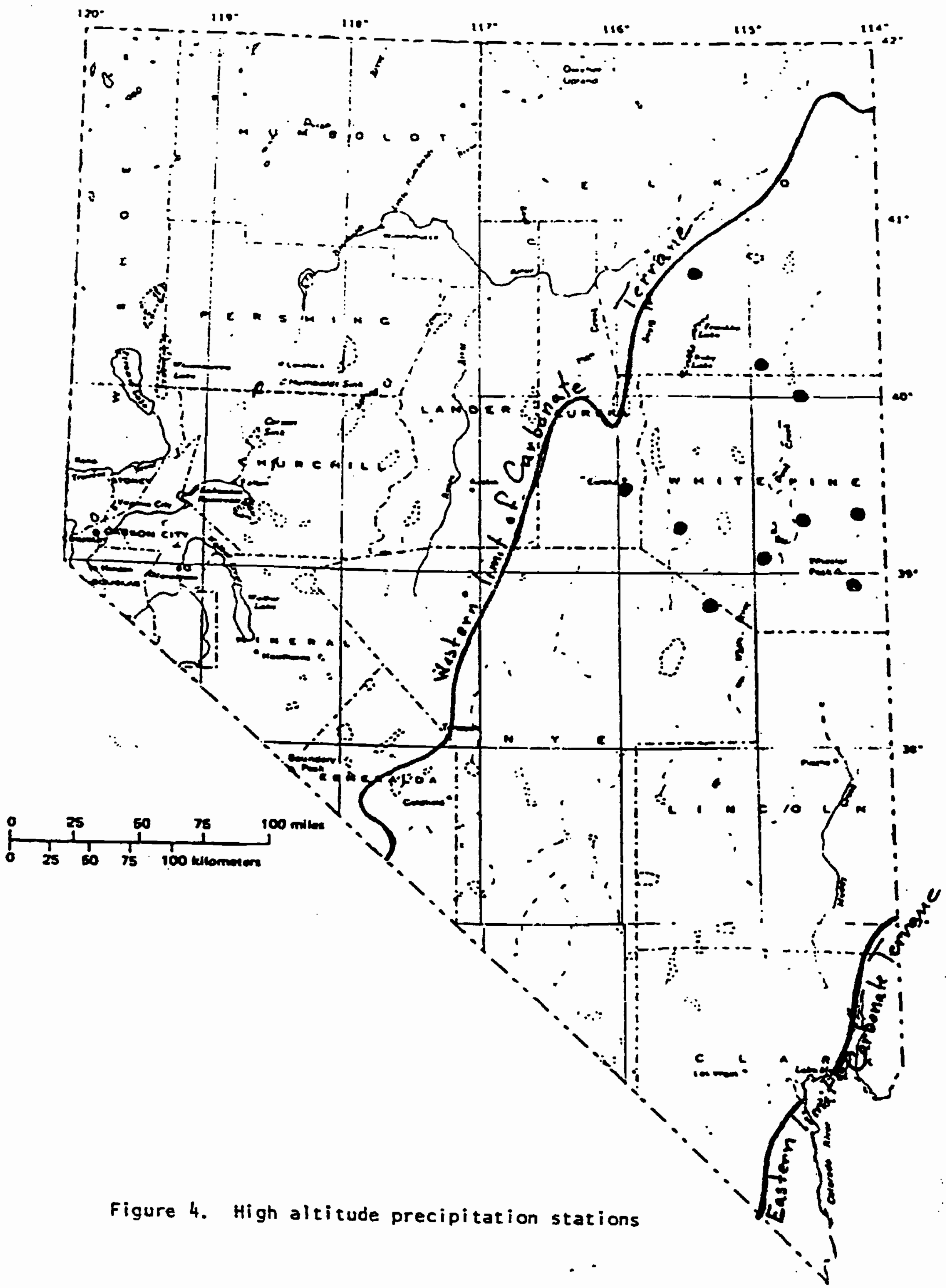

Figure 4. High altitude precipitation stations

Carbonate Terrane.

Finally, land-use and water-use data and measurements are necessary to the definition of water budgets in the carbonate terrane. Current efforts in this area are generally limited to efforts by the State Engineer to document water use in valleys that are either designated (restricted development) or approaching that status. Such efforts would be useful in essentially all of the developed basins in the area. It is probably not necessary that data be collected every year (except in the heavily impacted valleys that would be monitored anyway under current policy), rather collection could be integrated with the ground-water levels canvasing discussed above on a three- to five-year cycle.

It is crucial that each of these components of the basic data collection be granted a long-term commitment of funding and staffing independent of other parts of the comprehensive investigation. A single year or even several years of data in any of these areas will be of limited use. The various data networks should be implemented as soon as possible and will be reviewed periodically. Improvements to the networks are to be a goal of these reviews and, where necessary or appropriate, reductions or expansions of the networks will be implemented.

Critical hydrologic processes and paramenters that require investigation and research in the carbonate terrane are:

--Local, basin-wide, and deep-rock recharge processes.

—Evapotranspiration under that range of topographic, ecologic, and climatic settings encountered in the Carbonate Terrane.

—Role and definition of geologic barriers to ground-water flow.

—determination of hydraulic properties of shallow basin-fill aquifers, deep, basin-fill aquifers, carbonate-rock aquifers, and the other aquifers and aquitards in the area.

Research conerning proper application and interpretation of the following methods will also be necessary:

--Correlation of surface geophysical measurements to aquifer geometry.

--Correlation of borehole geophysical meaurements, lithologies, and well test results to aquifer/aquitard hydraulic properties.

--Correlation of selected isotopic and geochemical parameters to flow-path delineation and flow-rate estimation.

--Definition of water budgets more precise and accurate than the current reconnaissance estimates.

--Correlation of lineament analyses with regional, geologic, structural, and hydrologic features.

Research in these areas will utilize historical data, data developed under the basic data program, and specially collected data as necessary, and will be associated with ongoing investigations where possible to ensure that the efforts are tied very closely to the issues at hand. At the same time, the research will be designed for wide-spread application of results.

The carbonate terrane might be divided into key areas as follows in general order of hydrologic interest and priority:

--Southern Nevada

--Nevada Test Site, Nellis Gunnery and Bombing Range, and Amargosa Desert area

--East-central Nevada in the vicinity of White Pine County

--Diamond Valley/Kobeh Valley area

--Pahrump Valley

--Central Nevada -- (a) the Railroad Valley, (b) Kobeh-Monitor Valley, and (c) Clayton Valley multibasin flow systems

--Areas peripheral to the carbonate terrane -- (a) Big Smoky Valley and (b) the basins of the Humboldt River drainage within the carbonate terrane

—The upper White River flow system

--North-eastern Nevada -- the Great Salt Lake Desert flow system

Figure 5 indicates the nine general areas referred to above.

The southern Nevada area is listed as a high interest and priority area because it includes the discharge areas of several major regional flow systems, and interest in developing the water of the carbonate-rock aquifers is greatest in that area. The Test Site Amargosa Desert area includes three flow systems whose boundaries and interactions are still uncertain after more than 20 years of hydrologic investigations. Information concerning regional flow is greatest there as a result of these long-term hydrologic investigations. The White Pine County area is a high-altitude part of the cabonate terrane (figure 5) with basins and mountains that are generally subhumid. Much of the recharge in the carbonate terrane is localized there. The Diamond Valley - Kobeh Valley area is of interest because it provides an opportunity to observe the effects of stressing the basin-fill aquifers in one of the basins of the carbonate terrane. Diamond Valley is experiencing a considerable overdraft condition under current pumping regimes (Harrill, 1968). Pahrump Valley provides another opportunity to observe the workings of carbonate-terrane hydrology under stressed conditions and has the advantage that several excellent studies in the area provide a basis for future investigations (Harrill, 1982). The moderate-size interbasin flow system of central Nevada are of interest because their connections to surrounding major flow systems is not completely defined and because they may provided clues to

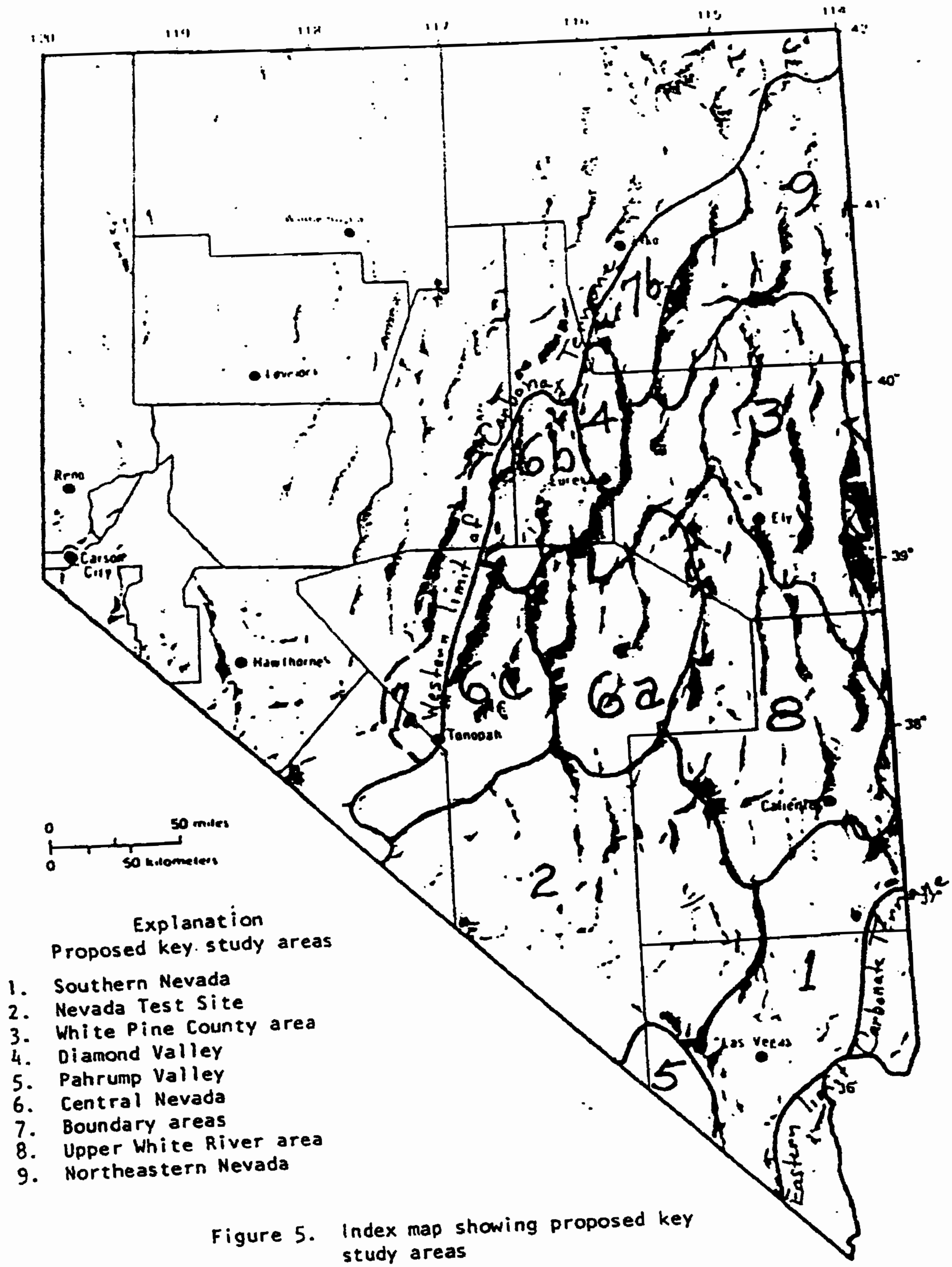

Figure 5. Index map showing proposed key study areas

the workings of carbonate-rock aquifer hydrologies at a more manageable scale than the larger flow systems. Studies along the periphery of the carbonate terrane will be, at least in part, designed to help define what are the true hydrologic boundaries of the carbonate terrane and (or) the carbonate-rock aquifer system. Finally, the northern two-thirds of the White River flow system and the basins of north-eastern Nevada are the headwaters of two of the major flow systems in the carbonate terrane of eastern Nevada.

The key area investigations should address the following issues:

—Geologic structural setting

--Recharge conditions, process and rates

—Ground water occurrence and movement in basin-fill reservoirs

--Ground water occurrence and movement in consolidated-rock reservoirs

—Physical and geologic controls on ground-water movement

--Ground-water discharge conditions, processes and rates

—Aquifer/aquitard geometries

--Hydrologic barriers and controls on ground-water movement

--Mountain-block recharge/mountain-block runoff processes and rates

--Water Budgets

—Analysis and observation of impacts of resource development

—Special topics important in the individual areas

Simulation analysis will be used as necessary and warranted; both as a tool for testing the feasibility of conceptual models and as an investigative and, potentially, a predictive tool for integrating information on the working of the flow system.

Exploratory drilling can be expected to play an important role in several of these studies.

REFERENCES CITED

Bateman, R.L., Mindling, A.L., Naff, R.L., and Joung, J.M., 1972, Development and management of ground-water and related environmental factors in arid alluvial and carbonate basins in southern Nevada: University of Nevada, Desert Research Institute Publication 18, 43 p.

Bateman, R.L., Mindling, A.L., and Naff, R.L., 1974, Development of ground water in relation to preservation of desert Pupfish in Ash Meadows, southern Nevada, University of Nevada, Desert Research Institute H-W 17, 39 p.

Claasen, H.C., 1983, Sources and mechanisms of recharge for ground water in the west-central Amargosa Desert, Nevada -- A geochemical interpretation: U.S. Geological Survey Open-File Report 83-542, 61 p.

Eakin, T.E., 1963, Ground-water appraisal of Dry Lake and Delamar Valleys, Lincoln County, Nevada: Nevada Department of Conservation and Natural Resources - Reconnaissance Report 18, 26 p.

Eakin, T.E., 1966, A regional interbasin ground-water system in the White River area, southeastern Nevada: Water Resources Research 2(2), pp. 251-271.

Eakin, T.E., Schoff, S.L., and Cohen, Philip, 1963, Regional hydrology of a part of southern Nevada - A reconnaissance: U.S. Geological Survey TEI-833, open-file report, 40 p.

Fiero, G.W., Jr., and Illian, J.R., 1968, Regional Hydrology of the Hot Creek-Little Smoky Valley flow systems, Nye County, Nevada, Interim Report: University of Nevada, Desert Research Institute, Miscellaneous Report 6, 20 p.

Fiero, G.W., Jr., and Illian, J.R., 1969, Section B regional ground water flow systems of central Nevada: University of Nevada, Desert Research Institute, Miscellaneous Report 5, 218 p.

Harrill, J.R., Welch, A.H., Prudic, D.E., Thomas, J.M., Carman, R.L., Plume, R.W., Gates, J.S., and Mason, J.L., 1983, Aquifer systems in the Great Basin of Nevada, Utah, and Adjacent States: A study plan: U.S. Geological Survey Open-File Report 82-445, 49 p.

Hess, J.W., and Mifflin, M.D., 1978, A feasibility study of water production from deep carbonate aquifers in Nevada: University of Nevada, Desert Research Institute, Publication No. 41054, 125 p.

Hunt, C.B., And Robinson, T.W., 1960, Possible interbasin circulation of ground water in the southern part of the Great Basin, in Short papers in the geological sciences: U.S. Geological Survey Professional Paper 400-B, p. B273-274.

Johnson, C.A., 1980, Environmental controls on occurrence and chemistry of groundwater in a carbonate terrane of eastern Nevada: University of Nevada, Desert Research Institute Publication No. 41066, 101 p.

Maxey, G.B., and Eakin, T.E., 1949, Ground water in White River Valley, White Pine, Nye, and Lincoln Counties, Nevada: Nevada State Engineer's Office, Water Resources Bulletin 8, 59 p.

Maxey, G.B., Mindling, A.L., and Domenico, P.A., 1966, Ground water in Upper Muddy River Basin: University of Nevada, Desert Research Institute Miscellanous Report 3, 28 p.

Mifflin, M.D., 1968, Delineation of ground-water flow systems in Nevada: University of Nevada, Desert Institute, Technical Report H-W 4, 89 p.

Quiring, R.F., 1965, Annual precipitation amount as a function of elevation in Nevada south of 38.5 degrees latitude: Las Vegas, U.S. Weather Bureau Research Station, 14 p.

U.S. Air Force, 1983, M-X multiple protective shelter water resources program - Nevada: A summary: presented to the Nevada Statewide Advisory Committee on Water Resources (January 21, 1983), 18 p.

Winograd, I.J., and Thordarson, William, 1975, Hydrogeologic and hydrochemical framework, south-central Great Basin, Nevada - California, with special reference to the Nevada Test Site: U.S. Geological Survey Professional Paper 712-C, 126 p.

Program elements and budget summary FY85-89

Program element	TOTAL	Total
Data networks		
Surface water	$1,250,000	
Ground water	$750,000	
Water quality	$750,000	
Precipitation	$400,000	
Data compilations	$200,000	
Data management	$400,000	
		$3,750,000
Hydrogeologic Studies		
Geophysics	$400,000	
Geophysics Data	$50,000	
Lineaments/Fractures	$240,000	
Stratigraphy	$160,000	
		$850,000
Hydrologic Studies		
Recharge mechanisms	$360,000	
Discharge/Evapotrans	$540,000	
Recon drilling	$270,000	
Well testing	$110,000	
Hydraulic properties	$75,000	
Aquifer geometry	$160,000	
Paleoclimates	$620,000	
Paleohydrology	$415,000	
Environ. science	$150,000	
Water budget eval.	$415,000	
Geologic barriers	$320,000	
Aquifer interconnect	$360,000	
Water use	$300,000	
		$4,095,000
Geochemical Studies		
General geochem	$465,000	
Isotopes	$160,000	
		$625,000
Area Studies		
White R Sys.	$260,000	
Diamond Valley	$360,000	
Steptoe Valley	$220,000	
Central Nevada	$400,000	
Terrane boundary	$360,000	
		$1,600,000
Program Management	$800,000	
		$800,000
Regional Synthesis	$400,000	
		$400,000
Total	$12,120,000	$12,120,000

Program elements and budgets for Carbonate Terrane Program FY85-89

Program element	FY85	FY86	FY87	FY88	FY89	FY90	FY91	FY92	FY93	FY94	TOTAL	Total
Data networks												
Surface water	$125,000	$125,000	$125,000	$125,000	$125,000	$125,000	$125,000	$125,000	$125,000	$125,000	$1,250,000	
Ground water	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$750,000	
Water quality	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$750,000	
Precipitation	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$400,000	
Data compilations	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$200,000	
Data management	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$400,000	$3,750,000
Hydrogeologic Studies												
Geophysics	$50,000	$50,000	$80,000	$80,000	$80,000	$60,000					$400,000	
Geophysics Data	$30,000	$20,000									$50,000	
Lineaments/Fractures	$80,000	$60,000	$40,000	$40,000	$20,000						$240,000	
Stratigraphy		$40,000	$40,000	$40,000	$40,000						$160,000	$850,000
Hydrologic Studies												
Recharge mechanisms	$40,000	$80,000	$80,000	$80,000	$80,000						$360,000	
Discharge/Evapotrans	$40,000	$100,000	$80,000	$80,000	$80,000	$80,000	$80,000				$540,000	
Recon drilling	$30,000	$60,000	$60,000			$60,000	$60,000				$270,000	
Well testing	$10,000	$30,000	$30,000			$20,000	$20,000				$110,000	
Hydraulic properties		$15,000	$20,000	$40,000							$75,000	
Aquifer geometry		$30,000	$50,000	$80,000							$160,000	
Paleoclimates	$60,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000			$620,000	
Paleohydrology	$50,000	$65,000	$80,000	$80,000	$80,000	$60,000					$415,000	
Environ. science	$50,000	$50,000	$50,000								$150,000	
Water budget eval.				$40,000	$80,000	$80,000	$80,000	$75,000	$60,000		$415,000	
Geologic barriers					$40,000	$80,000	$80,000	$60,000	$60,000		$320,000	
Aquifer interconnect					$40,000	$80,000	$80,000	$80,000	$80,000		$360,000	
Water use			$80,000	$80,000	$40,000	$20,000	$20,000	$20,000	$20,000	$20,000	$300,000	$4,095,000
Geochemical Studies												
General geochem	$65,000	$50,000	$75,000	$75,000	$60,000	$40,000	$20,000	$60,000			$465,000	
Isotopes		$40,000	$60,000	$60,000							$160,000	$625,000
Area Studies												
White R Sys.			$40,000	$80,000	$80,000	$60,000					$260,000	
Diamond Valley				$40,000	$80,000	$80,000	$80,000	$80,000			$360,000	
Steptoe Valley	$80,000	$80,000	$60,000								$220,000	
Central Nevada					$80,000	$80,000	$80,000	$80,000	$80,000		$400,000	
Terrane boundary					$40,000	$80,000	$80,000	$80,000	$80,000		$360,000	$1,600,000
Program Management	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$800,000	$800,000
Regional Synthesis						$80,000	$80,000	$80,000	$80,000	$80,000	$400,000	$400,000
Total	$1,040,000	$1,305,000	$1,460,000	$1,430,000	$1,455,000	$1,515,000	$1,295,000	$1,150,000	$915,000	$555,000	$12,120,000	$12,120,000

All costs in 1984 dollars [illegible]