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THE HUMBOLDT RIVER RESEARCH PROJECT, NEVADA

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ABSTRACT

The drainage basin of the Humboldt River, an area of about 16,200 square miles, ranges from a few to about 300 miles wide. The river flows westward from near the east boundary of Nevada to the Humboldt «Sink», a broad flat basin where the water is lost by evaporation. All of the water in the river previously estimated to be recoverable, including the flood flows, has been appropriated by users for many years. Development of the water resources of the Basin for the most efficient use is in a primary stage. Irrigation practices are not highly advanced except in a few scattered localities and in the distribution area of Rye Patch Reservoir, the only major constructed control on the river.

The long-range objective of the Research Project is to determine all water that may be made available for beneficial use in the Basin and to recommend efficient methods to accomplish optimum utilization of water resources. Secondary objectives include development of methods of evaluation and utilization and analysis of local developmental, scientific, and legal problems related to the overall water resources picture.

The chief amount of additional water that may be developed for beneficial use is that presently wasted by phreatophytes and other causes of evapotranspiration. In addition, water presently available for use may be more efficiently managed to increase the benefits from it. Development of additional water and more efficient management of present supplies may depend primarily on ways and means of withdrawing and recharging ground water.

Since it was not possible to study adequately the whole Basin at once, a reach of the River in the Winnemucca area, believed to be a well-defined hydrologic province, was selected in which to begin investigations. The primary aims in this initial phase of the Project include:

1. Development of methods and procedures for evaluating the magnitude of the components of the hydrologic cycle in a semi-arid basin.
2. Determination of geologic and geomorphic controls on water resources of the Basin, especially those related to movement, storage and availability of water.
3. Determination of consumptive use of water by crops, native useful vegetation, and non-beneficial vegetation.
4. Determination of the amount of water presently non-beneficially used by phreatophytes or otherwise being wasted that can be salvaged. Also devising and testing methods for the replacement of non-beneficial plants with beneficial ones.
5. Evaluation of the economics of modifying present farm practices or other water use in the Basin to increase the values of crops and products and thus the efficiency of water use.

To accomplish these complex aims two State agencies, two Universities, and six Federal agencies are cooperating on the Project. Progress on the work after two years of operation are reported in this paper.

RÉSUMÉ

Le bassin de drainage de la Humboldt River s'étend sur une surface d'environ 16.200 miles carrés avec une largeur allant de quelques miles à environ 300. La rivière s'écoule vers l'ouest depuis un point près de la frontière orientale du Névada jusqu'en Humboldt «Sink», un large bassin plat dans lequel l'eau se perd par évaporation. Toute l'eau de la rivière considerée comme récupérable, y compris l'écoulement des crues, a été utilisée depuis de nombreuses années par les usagers. Le développement des ressources hydrologiques du bassin de façon efficace n'est qu'à son stade préliminaire. L'irrigation n'est pas très avancée sauf dans quelques localités dispersées et dans le domaine de distribution du «Rye Patch Reservoir», le seul ouvrage contrôlant la rivière.

Le but final du projet de recherche est la détermination de la quantité d'eau utilisable dans le bassin et la recommandation de méthodes efficaces pour l'utilisation optimum des ressources hydrologiques. En outre, l'eau utilisable actuellement pourrait être distribuée de façon plus efficace. Le développement de ressources supplémentaires et une meilleure utilisation de celles disponibles pourrait dépendre des méthodes utilisées pour l'exploitation et la recharge des eaux souterraines.

Comme il n'a pas été possible d'étudier de façon adéquate l'ensemble du bassin, un affluent de la rivière dans la région de Winnemucca, considéré comme une province hydrologique bien définie a été choisie comme endroit des premières recherches. Les buts principaux de cette phase initiale du project sont les suivants :

1. Développement des méthodes et procédés pour évaluer l'ampleur des composants du cycle hydrologique dans un bassin semi-aride.
2. Détermination des facteurs géologiques et géomorphologiques qui contrôlent les ressources hydrologiques du bassin, en particulier ceux liés au mouvement, accumulation et obtention de l'eau.
3. Détermination de la consommation en eau des récoltes et de la végétation locale utilisable ou non économiquement.
4. Détermination a la quantité d'eau qui n'est pas utilisée actuellement de façon rentable par les phréatophytes ou qui est perdue pour d'autres raisons et qui pourrait être récupérée. Choix et mise à l'essai de méthodes pour le remplacement de plantes non utilisables par d'autres économiquement utilisables.
5. Evaluation des conditions économiques qui seraient liées à une modification des méthodes actuelles de culture ou d'utilisation de l'eau du bassin de façon à augmenter la valeur des récoltes et par là l'efficacité de l'emploi de l'eau.

Pour accomplir ces buts complexes, deux agences d'État, deux universités et six agences fédérales coopèrent au projet. Les résultats obtenus après deux ans d'activité sont exposés dans le présent rapport.

1. Introduction

The amount of usable water severely limits the development and population of all arid regions in the world. At the same time overcrowding of humid regions is resulting in demand for more occupation of arid zones. Also, demands increase yearly for production of foodstuffs and other staples for which large parts of the arid zones are highly adaptable, apart from water shortage. Further, many semi-arid and arid regions are more pleasant and healthful places in which to live than presently highly populated areas.

The move toward aride zones is graphically illustrated in many parts of the world, for example, the colonization of North Africa by Europeans during the nineteenth and the early part of the twentieth century and migration to the Southwest United States from both the Eastern and the Pacific Coasts in the last thirty years. This population shift has resulted in development of acute or chronic water shortages and not infrequently in critical depletion of both surface and ground-water supplies. Some of the areas discussed in other parts of this symposium, especially the Central Valley of Arizona and parts of Tunisia, illustrate depletion of water supplies in arid zones.

Nevada communities have felt the pressures of growing population and developing agriculture and industry. Withdrawals of ground water in southern Nevada have exceeded perennial recharge for more than a decade. Only nearby Lake Mead and the convenient presence of a war-time built pipeline into Las Vegas Valley have allowed a rational and efficient basis for continued increasing use of water by the expanding population.

Northern Nevada has not been severely affected by such rapid population growth

but its imminence is readily discernable. In order to avoid overdevelopment and consequent depletion, and to utilize efficiently all available water, the Nevada Department of Conservation and Natural Resources has initiated a program to evaluate the water resources of the State. Any effort to attain this objective necessarily includes study of the Humboldt Basin, for more water is potentially available here than in any other basin in Nevada.

This paper describes the program and projects which have been initiated in order to gain knowledge of the hydrology and to develop methods of utilization of the water resources of the Humboldt Basin. Secondary objectives include development or discovery and application of scientific methods in arid-zone hydrology. In order to exemplify steps toward these objectives, general description of known facts pertinent to understanding hydrogeology and hydrology of the Basin is included. Work on the Project has been described in two progress reports published in 1960 and 1961 (Nevada State Department of Conservation and Natural Resources, 1960, 1961). Previous studies in the Basin include primarily ground-water investigations in Paradise, Reese River, and Lovelock Valleys and in the vicinity of Elko reported by Loeltz, Phoenix, and Robinson (1949); Waring (1918), Robinson and Fredericks (1946), and Fredericks and Loeltz (1951).

The Humboldt River Basin is about one-third of the area of northern Nevada, on the order of 16,200 square miles. The river flows about 260 miles from head to mouth and from the northeast to the southwest across the Basin. The headwaters are in the high Ruby Range and in somewhat lower country to the north on the north and east sides of the Basin. Most of the stream flow originates here and only small contributions of water flow into the channel farther downstream.

The crests of the higher ranges throughout the Basin are characterized by an alpine or sub-alpine climate; the mountain slopes and valleys in the headwaters regions between elevations of from 5,000 to 8,000 feet, by a semi-arid climate; and the lower areas from the latitude of Beowawe westward, by an arid climate. The pattern of the Humboldt River is that of a gaining stream flowing over relatively impermeable rocks from the uppermost headwaters to a point just below Palisade and of a losing stream, crossing areas floored alternately by permeable alluvial fill and less permeable bedrock, from Palisade to Humboldt "Sink". Within this pattern the stream gains and loses at several places west of Palisade as a result of variation in permeability of the bed and other factors, but these gains and losses are small compared to the overall loss by evapotranspiration.

Archeology, history, and legend attest that the Humboldt River valley has been a well-known oasis occupied by humans since prehistoric times. The Pre-Columbian Indians perennially occupied the valley. Explorers and trappers of European and American origin visited and described the river and environs early in the nineteenth century and, somewhat later, important way-stations were built along the river on the wagon trail to California. The valley was settled by miners and stockmen during the latter half of the nineteenth century. Construction of the transcontinental railroads stimulated settlement, exploitation of mineral resources, and use of water resources. Basically, the economy has remained unchanged since the turn of the century. Stock-raising and mining are still predominant industries.

Influx of settlers resulted in friction and litigation over use of water. During the thirties surface-water rights were adjudicated (Mashburn and Mathews, 1943) resulting in an effective, if perhaps temporary, settlement of such problems. At present all surface water and nearly all ground water are considered legally appropriated despite the fact that large quantities of water are wasted by evapotranspiration and smaller quantities flow into the barren wastes of the Humboldt "Sink".

The chief use of water in the Basin is irrigation, accomplished by flooding methods during the spring melt in the upper reaches and by more efficient methods in the

Lovelock area. Here, during the thirties, the Rye Patch Reservoir, the only major control structure in the Basin, was built by the U.S. Bureau of Reclamation to store water for irrigation purposes. Under present practices, two or more dry years in succession result in major losses of crops and resultant depressive effects on the economy. Major floods occur about once in ten years and periods of low flow occur two to three years out of ten, resulting in a "feast or famine" situation that restricts production and population growth to limits far below the potential that might be achieved by more efficient physical control, management, and use of water resources. The problems involved, then, center around (1) control and modulation of the river flow utilizing both ground and surface water in a pattern that will allow most efficient use without long-range depletion; (2) management of physical controls so that they support methods of utilization; and (3) economical utilization of water made available by the physical controls. This latter problem not only involves application of technical and scientific methods and tools but may require tundamental changes in the economy in order to financially justify construction of controls and employment of management.

2. The nature of the project

Preliminary evaluation of these problems indicates that no single organization or agency in the United States possesses all of the tacilities and, more important, the trained personnel to cope with the numerous and complex problems involved. Accordingly, the Director of the Nevada Department of Conservation and Natural Resources, with the advice of officials from several organizations, called upon the following agencies to handle the specific problems indicated (Nevada State Department of Conservation and Natural Resources 1960 and 1961):

1. Department of Conservation and Natural Resources, State of Nevada. General organization, administration, coordination and general support of the Project; support for supplementary weather stations and experimental plots, compilation and publishing of Project reports.
2. Bureau of Mines, State of Nevada. Geophysical work and some phases of the geologic work.
3. Departments of Geology, University of Nevada, University of Illinois. Most phases of the geology.
4. Desert Research Institute, University of Nevada. Some phases of hydrogeology and studies of evaporation.
5. U.S. Weather Bureau, Department of Commerce. Hydroclimatology.
6. Max C. Fleischman College of Agriculture, University of Nevada. Land and water use problems for agriculture.
7. Agricultural Research Service, U.S. Dept. of Agriculture. Some phases of evapotranspiration studies and chemical quality of water, land and water use.
8. Soil Conservation Service, U.S. Dept. of Agriculture. General mapping and aerial photography, mapping of phreatophytes, soil studies, land use problems.
9. U.S. Geological Survey, U.S. Dept. of the Interior. Collection, compilation, and analysis of basic hydrologic data, test-well drilling, some evapotranspiration studies.
10. Bureau of Land Management, U.S. Dept. of the Interior. Land tenure and land use problems.
11. Bureau of Reclamation, U.S. Dept. of the Interior. Support for evapotranspiration studies and assistance in planning for flood and other controls.

A detailed study of the whole Basin would not only result in expense beyond the foreseeable resources of State and cooperating Agencies but might also lead to duplication of work or to intensive studies in areas where they might not be needed

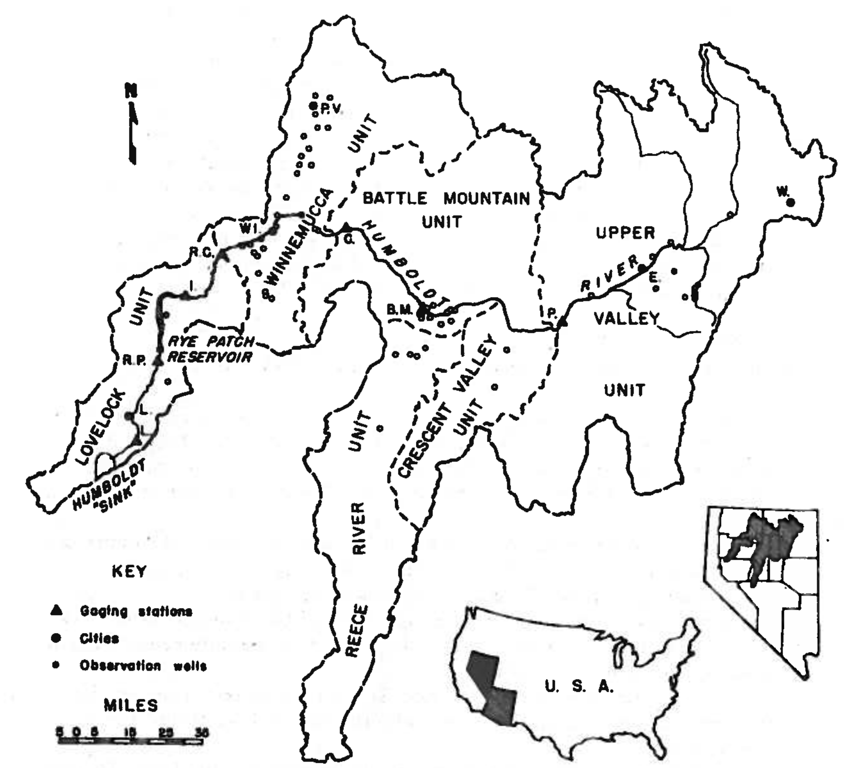

Fig. 1 — Hydrologic units, Humboldt Basin.

to attain desired results. Therefore it was decided to designate units of the Basin which would be more amenable to study and to select one unit for intensive investigation. It is believed that this procedure will result in development of methods and knowledge in early phases of the Project that will allow for more rapid, accurate, and perhaps less intensive study for remaining units. Accordingly, the following units, shown on Figure 1, have been designated, chiefly on the basis of hydrologic characteristics:

1. *The Upper Valley unit* extending from the uppermost headwaters of the Humboldt River to Palisade.
2. *The Battle Mountain unit* which extends from Palisade to the Preble Narrows near Comus.
3. *The Winnemucca unit* from Preble Narrows near Comus to Rose Creek and including the drainage basin of the Little Humboldt River and Grass Valley.
4. *The Lovelock unit* from Rose Creek to the Humboldt "Sink".
5. *The Reese River Valley unit.*
6. *The Carico Lake — Crescent Valley unit.*

The first four units include reaches of the Humboldt River whereas the last two are within the drainage basin but are not known to contribute surface water or significant quantities of ground water to the river (Waring, 1918, p. 110).

Considerable geologic and hydrologic study previous to development of this

Project had been accomplished in the Winnemucca unit. It indicated that local problems of substantial interest to the State Engineer and others might be solved by intensive study, problems that might not be solved unless they were studied in great detail. This plus other favorable factors including geographic location, size, variety of phenomena, and sympathetic interest of residents resulted in selection of the Winnemucca unit for the first phase of intensive study. Active field work in the unit was initiated in 1959 and will probably continue through 1963. Ultimately all units will be studied in more or less detail. Preliminary studies were initiated in the Battle Mountain Unit in 1960 and will continue in 1961. Meanwhile, a reconnaissance survey of the Humboldt River Basin under Section 6 of U.S. Public Law 566 allowing for the planning of control structures on small watersheds has been initiated and will undoubtedly result in making available useful data.

3. Summary and preliminary analysis of work accomplished to date

Although the Project is in its initial stages, study of various areas of work have resulted in knowledge that is of substantial value and interest. This information relates primarily to general features of the Basin and of the various units with some detailed data available for the Winnemucca unit. Briefly, the work accomplished includes:

1. Photography and topographic mapping of most of the Basin at suitable scale. Only a small part of the Basin remains unmapped.
2. Compilation of a generalized geologic map of the Basin.
3. Compilation and preliminary analysis of available hydroclimatic data.
4. Compilation and preliminary analysis of stream-flow measurements, water-well records, and other hydrologic data.
5. Detailed geologic and hydrologic field study is essentially completed in the Winnemucca unit, although some observations will continue for at least two field seasons.
6. Detailed evapotranspiration studies are progressing in this Unit. The Agricultural Research Service, the U.S. Geological Survey and Bureau of Reclamation, and the State Department of Conservation and Natural Resources have emplaced lysimeter tanks to study losses from native plants. In conjunction with lysimeter tanks, a weather station has been installed. The tanks have not been in place long enough to yield usable data.
7. The Soil Conservation Service has initiated surveys of areas of various phreatophytes. With this and the anticipated information from the lysimeters it is hoped that use of water by nonbeneficial plants can be determined. Studies will be conducted to discover and test useful vegetation to replace nonbeneficial phreatophytes.

The geologic work has resulted in compilation of a generalized geologic map of the Basin (fig. 2) which more or less effectively outlines lithologic controls on occurrence and movement of water. From this map it is evident that the surface lithology of the Upper Valley unit is essentially bedrock with only small areas of alluvium except in reaches of the southern tributaries, Pine and Huntington Creeks. Even in these valleys the alluvial deposits are thin and superficial except locally and, hydrogeologically, differ little from Tertiary sediments. Thus, the Upper Valley unit is characterized by highlands composed of intrusives, rocks of Paleozoic age, and volcanics and sediments of Tertiary age. The valley areas are floored primarily with Tertiary sediments and thin alluvium.

The highlands in the other units are essentially like those in the Upper Valley unit, differing primarily in containing less Tertiary sediments and intrusives. Also

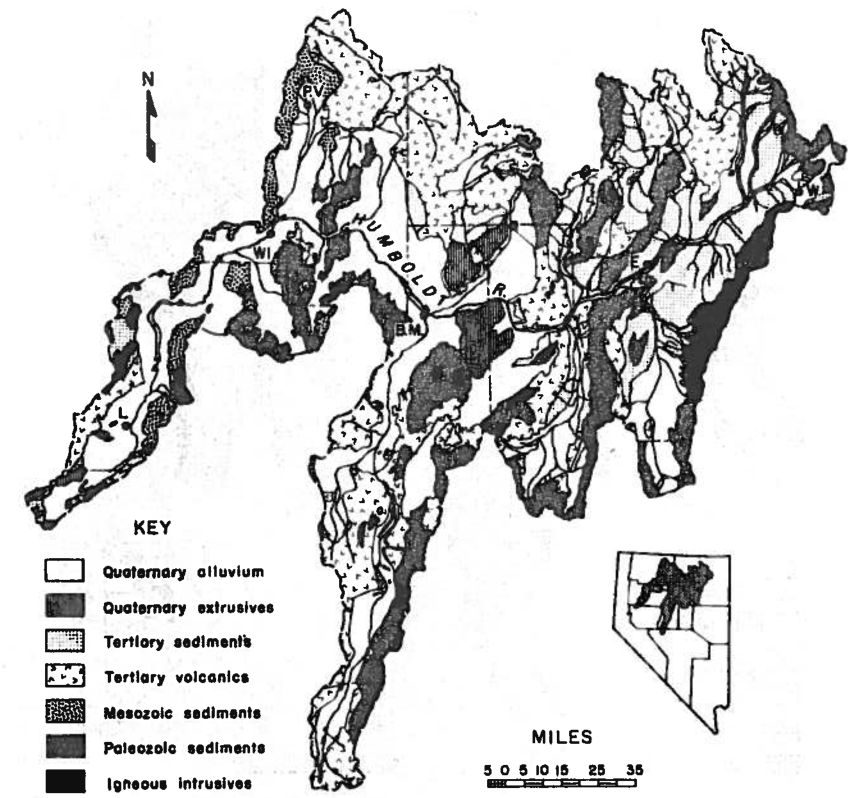

Fig. 2 — Geology of the Humboldt Basin. Compiled from maps of the U.S. Geological Survey and the Nevada State Bureau of Mines.

Mesozoic as well as Paleozoic sediments form a prominent part of the highlands. The valleys of downstream units comprise a proportionately larger fraction of total area and contain more and thicker alluvial fill. Hydrogeologically this is significant because the permeable alluvial-filled basins offer large volumes of storage space for ground water and appreciably affect flow of the river and its tributaries. Variations in geology and pattern of mountain ranges interspersed with broad alluvium-filled basins are diagnostic factors in designation of units and sub-units of the Basin.

Another factor is the distribution of precipitation shown in Figure 3. The map was compiled by George Hardman of the Nevada Department of Conservation and Natural Resources and is based upon all known sources of precipitation data, including conventional long-period weather stations, temporary stations and snow-survey courses. As shown in figure 3, the Upper Valley unit is a more or less typical semi-arid province with the annual precipitation ranging from 8 to more than 20 inches and with large areas in which the precipitation exceeds 12 inches. Precipitation decreases westerly and the western side of the Basin is arid with large areas of less than 5 inches of annual precipitation.

Figure 3 also illustrates the topography of the Basin quite accurately because

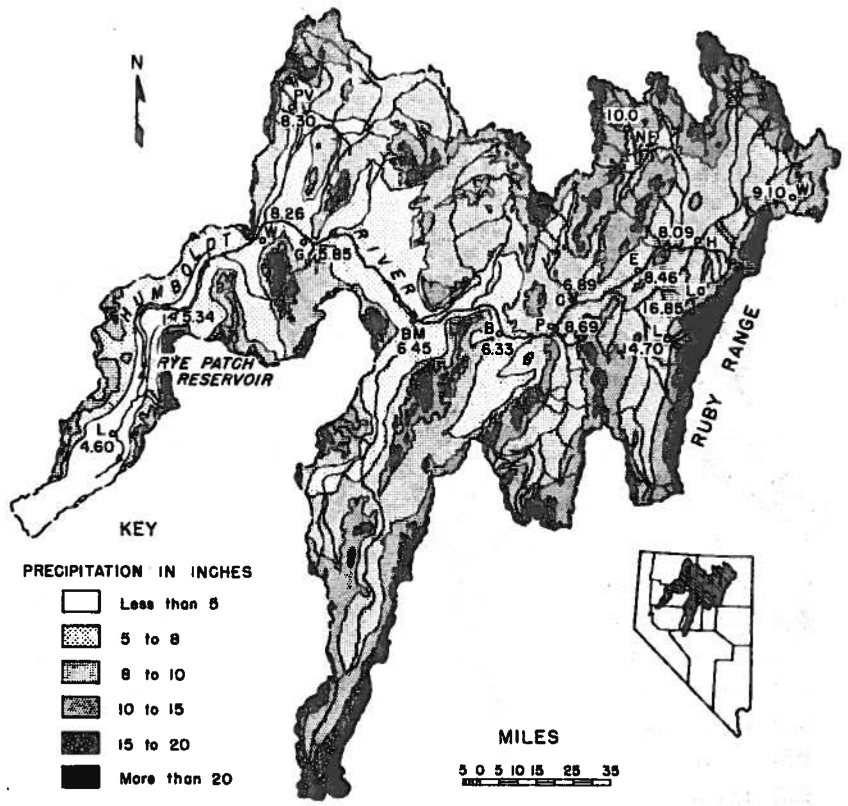

Fig. 3 — Distribution of Precipitation, Humboldt Basin. Compiled by George Hardman, Assistant Director, Rept. of Conservation and Natural Resources, State of Nevada.

amount of precipitation depends considerably upon elevation. Thus, the dark areas are regions of high elevation ranging from about 9,000 to over 11,000 feet, the white areas are on the order of 4,000 to 6,000 feet and other areas are intermediate in elevation.

The combined effects of distribution of precipitation and lithology result in broad hydrologic variations. For example, the Humboldt River is a gaining stream in the Upper Valley unit and a losing stream farther westward primarily because of these factors and the added factor of increased evaporation opportunity to the west. Also, changes in flow of the river and in storage in ground-water reservoirs within the Winnemucca unit probably result in large part from the distribution of differing lithologies.

The detailed geologic and hydrologic work in the Winnemucca unit has given us considerable insight into these problems. In order to remain within the limitations of space and time allotted for this paper only a summary of the work and its results is possible.

Figure 4 is a detailed geologic map of the central part of the Winnemucca unit. This area, in which mapping of surficial geology is essentially completed, presents

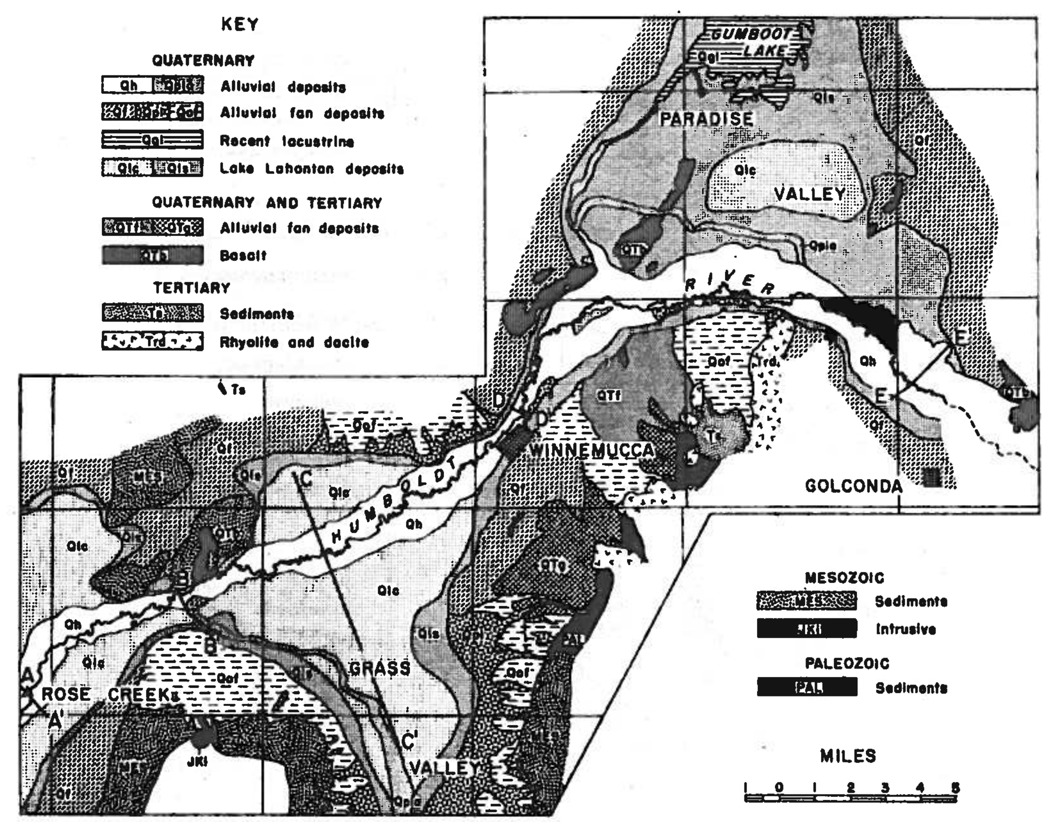

Fig. 4 — Geology of the Winnecuma unit, Humboldt Basin, Nevada. Geology by John W. Hawley, William E. Wilson and Keros Cartwright.

a good example of necessary detail of geologic mapping deemed adviseable for analysis of water resource problems. In addition to this mapping, much shallow subsurface analysis has been accomplished as illustrated in profiles shown in figures 5 and 6. Much of this detail in mapping and analysis was made possible by a test-drilling program conducted by the U.S. Geological Survey in which 160 shallow wells (a few feet to 117 feet deep) were bored, primarily in the river channel and environs. The shallow drilling program has resulted in much valuable knowledge. Drilling information is the basis for determination of specific yield of shallow sediments and other valuable hydrologic determinations, a primary aim of the Geological Survey study. It has confirmed the presence, extent, and thickness of an important sand and gravel aquifer which underlies the river channel from Golconda to Rose Creek. Further results of test-drilling include more intimate knowledge of the river channel materials and other sediments and their mutual relationships. These results show that the standard of detailed mapping is justified in this area in order to solve hydrologic problems. They also demonstrate the need for deeper test drilling to assist in outlining extent, distribution, and characteristics of deeper aquifers in the alluvial fill.

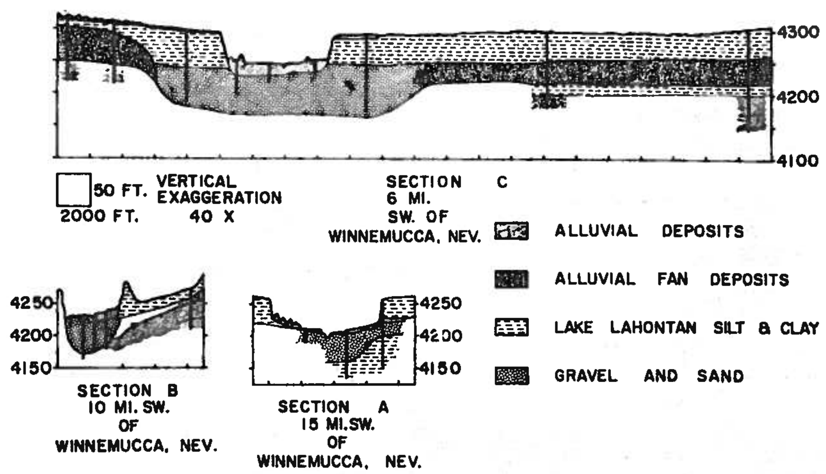

Fig. 5 — Geologic profiles A, B, and C, Winnemucca unit. Modified from work by John W. Hawley, Wm. E. Wilson and Keros Cartwright.

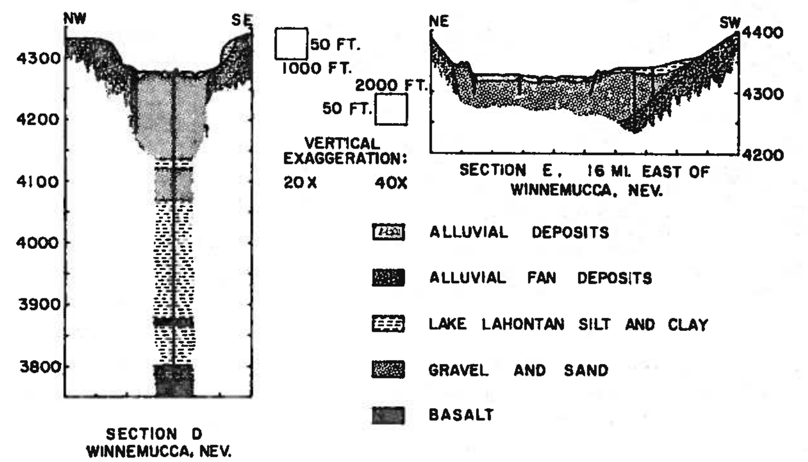

Fig. 6 — Geologic profiles D and E, Winnemucca unit. Modified from work by John W. Hawley, Wm. E. Wilson, and Keros Cartwright,

In conjunction with detailed geologic and geohydrologic studies the Geologica Survey has made a number of stream measurements in reaches of the river between Comus and Rose Creek to assist in determining relationships of stream flow, groundwater, and geologic controls. Preliminary data show that the river is a losing stream during high flow but that it gains and loses in different reaches across the unit (figure 7) during low flow. Preliminary piezometric-surface maps of ground water show verifying relationships, and study is now progressing to relate the geological data with this pattern. It is hoped that detailed study along these lines will result in an explanation for variations in losses from the river between Comus and Rose Creek.

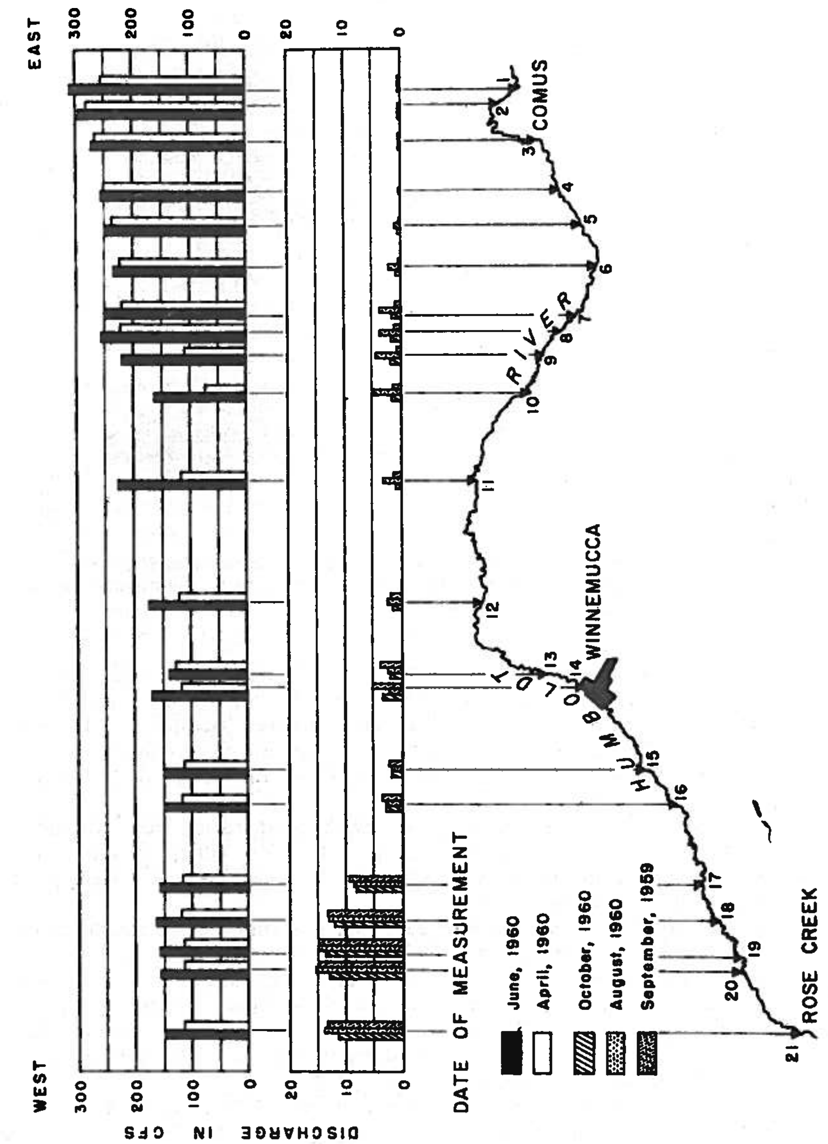

Fig. 7 — Stream Flow, Humboldt River. Compiled from measurements made by the U.S. Geological Survey.

Some generalizations can be made regarding stream flow and regimen from presently available data. Initial studies of available streamflow records give a gross estimate of the distribution and quantity of water potentially available from the Humboldt River and its tributaries. Figure 8 shows hydrographs of stream flow plotted on a logarithmic scale at four gaging stations on the river between Palisade

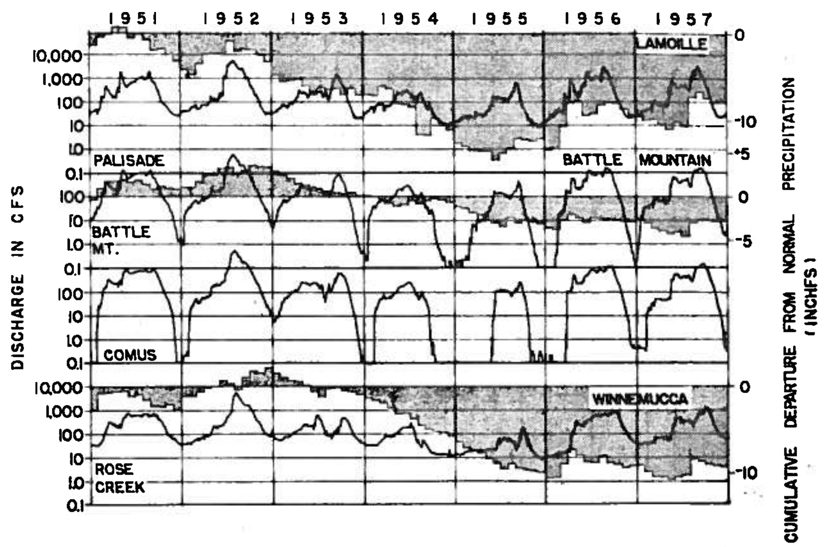

Fig. 8 — Hydrographs of the Humboldt River at four stations and C D from N P from three stations. Compiled from records of the U.S. Geological Survey and the U.S. Weather Bureau.

and Rose Creek, about 16 miles west of Winnemucca. The hydrographs, showing daily flow in cubic feet per second, were selected for a more or less representative period which includes both high and low stages between October 1, 1951 and September 30, 1957. Thus, not only seasonal but long-term fluctuations of stream flow are shown. Several fundamental characteristics of the nature of the stream flow appear:

1. Most of the stream-flow is snow melt normally appearing from November to January, cresting in the late spring, and rapidly falling off during the months of June and July to a base flow that is sometimes only a fraction of a percent of flood flow.
2. A consistent loss occurs between each gaging station from Palisade downstream. This will be discussed in succeeding paragraphs.
3. Where the stream flows over bedrock or other impermeable sediments as at Palisade and Rose Creek, it is perennial, even in low years, whereas at stations in alluvial areas where considerable bed loss can occur, the stream flow drops to little or nothing during considerable periods in the summer, as at Battle Mountain and Comus.
4. Long-term variations in peak flow are great, ranging from as much as 5,930 cubic feet per second during the record high in 1952 to only 330 cubic feet per second during a near-record low crest in 1954 at Palisade. Considerable variations in base flow also occur. Comparable relationships are shown at other stations.

Since the river is essentially uncontrolled throughout its course from the headwaters to Imlay, even simple and unsophisticated analyses such as these illustrate the nature of the river and of the primary water resources problem—a regimen consisting of one to three, more or less destructive floods in each decade interspersed by perhaps the same number of low flow years with resulting drouth conditions. The

effects of drouth are especially severe when dry years occur in succession as they did in 1954 and 1955 and in 1959 and 1960.

The linear-scale block diagrams in figure 8 give cumulative departure from normal monthly precipitation for three stations. Close correlation between stream flow and precipitation is evident from comparison of these diagrams with stream flow. Further, the diagrams indicate that the period 1951 to 1957 was one of deficient precipitation within the period of record, especially in the headwaters area of the river where nearly all streamflow originates. Values for normal monthly and annual precipitation is given in Table 1 for comparison.

The diagrams in figures 9, 10, and 11 give values of annual discharge in acre-feet plotted on a logarithmic scale at stations from Palisade downstream. With these values are block diagrams on a linear scale showing apparent stream losses in acre feet from station to station for the period 1949 to 1960. During this period, the only one with relatively complete records on which to evaluate these losses, streamflow and losses are probably somewhat lower than actual long range values because flow averages for the period are somewhat lower than flow averages for longer periods of record. For example, average annual flow at Palisade over a period of 53 years averages 257,000 acre-feet and for the 12-year period the average is 240,500 acre-feet; at Comus for a period of 46 years it is 200,800, for the 12 years, 173,085; at Rye Patch for 46 years it is 144,100, for the 12 years, 130,500. Table 2 gives values on which the graphs in figures 9, 10, and 11 are based.

The values given in the table and figures are adjusted for total inflow and outflow at and below each gaging station. Thus, flow of Pine Creek and Rock Creek are added to Palisade, and flows of Kelly and Evans Creeks and estimates of underflow from Paradise and Grass Valleys are added to Comus. Losses in Paradise and Grass Valley, Reese River Valley (Waring, 1918, p. 110), and in the Rock Creek drainage area above the gaging station are not considered here since they do not appreciably affect, or are affected by stream flow in the main valley. The graphs and table show that during the twelve-year period losses averaged about 72,000 acre-feet annually between Palisade and Battle Mountain, 26,000 acre-feet between Battle Mountain and Comus, 24,000 acre-feet between Comus and Rose Creek, 8000 acre-feet between Rose Creek and Imlay, 26,500 acre-feet from Rye Patch Reservoir (Imlay to Rye Patch), and 42,000 acre-feet below Lovelock. Thus, the total average annual losses along the River, exclusive of the Upper Valley Unit approximate 198,000 acre-feet.

Several subsidiary factors are also shown by figures 9, 10, and 11. For example, losses between Palisade and Comus show an expectable pattern of low loss during low flows and high loss during high flows. However, between Comus and Rose Creek a different pattern appears. Losses seem to decrease with increasing flows and increase with decreasing flows with some lag. In one year, 1958, a gain between the stations is indicated. This problem is now being studied and undoubtedly answers will be forthcoming. It is believed that water stored in larger quantities in groundwater aquifers during high flows may return slowly to the river during drouth periods.

In figure 11, the losses between Imlay and Rye Patch chiefly represent evaporation from the Reservoir. Preliminary calculations show that the rate of evaporation on this basis may be on the order of three to four feet annually.

Not all losses determined above can be considered available for recovery because some water is now beneficially used and some is and inevitably will be economically unrecoverable. The amount of water beneficially used in the Basin below Palisade, in addition to that withdrawn from the Rye Patch Reservoir, is difficult to determine. However, on the basis of available information perhaps 60,000 acre-feet are used for crops and for domestic and stock purposes. This estimate is based on the assumption that the use of water from Rye Patch Reservoir is an acceptable standard of beneficial use.

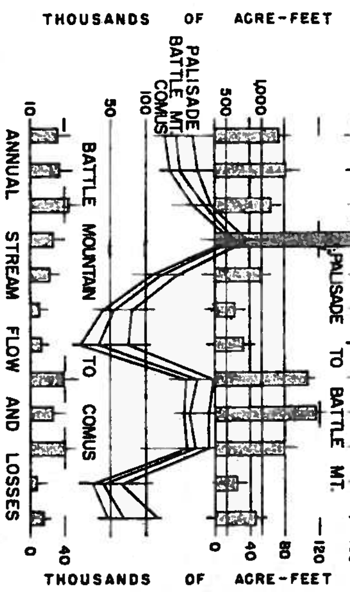

Fig. 9 — Annual stream flow and losses, Humboldt River, Nevada. Compiled from records of the U.S. Geological Survey.

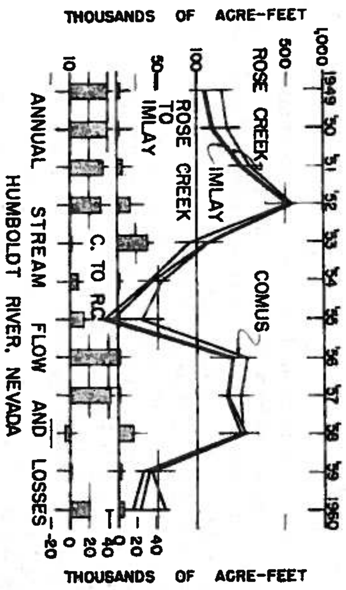

Fig. 10 — Annual stream flow and losses, Humboldt River, Nevada. Compiled from records of the U.S. Geological Survey.

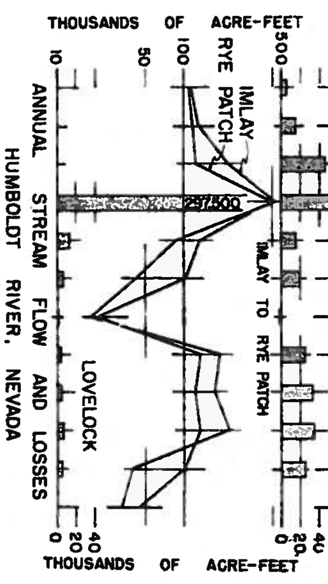

Fig. 11 — Annual stream flow and losses, Humboldt River, Nevada. Compiled from records of the U.S. Geological Survey.

TABLE 1

Normal monthly and annual precipitation at four stations in the Humboldt Basin. Compiled from records from the U.S. Weather Bureau.

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Lamoille	1.46	1.56	2.01	2.67	2.17	1.48	.74	.50	.76	1.48	1.61	1.72	18.16
Battle Mountain	.79	.71	.65	.75	.80	.54	.18	.15	.27	.53	.57	.77	6.71
Lovelock	.82	.71	.54	.53	.46	.62	.13	.14	.20	.54	.42	.65	5.76
Winnemucca	.96	1.01	.86	.83	.84	.79	.31	.18	.34	.79	.84	1.00	8.75

Water known to be lost for essentially any further use includes reservoir losses at Rye Patch, on the order of 26,500 acre-feet and that part of the water which flows into the Humboldt "Sink" in return flow from irrigation in the vicinity of Lovelock, about 4,500 acre-feet. The remainder of the flow downstream from Lovelock is flood water which cannot presently be controlled by the Reservoir, and constitutes perhaps as much as 300,000 acre-feet every ten years. This water, or a large fraction of it could conceivably be intercepted and stored upstream and is considered available for recovery.

In summary, about 91,000 acre-feet of water plus that used from Rye Patch Reservoir (130,000 acre-feet) is not available for recovery, leaving approximately 100,000 acre-feet of water as the potentially recoverable losses between Palisade and Humboldt "Sink" (Table 3).

TABLE 3

Inventory of water losses, water beneficially used or not recoverable, and water potentially available in the Humboldt Basin below Palisade. Potentially available water does not include all potential return flow.

From	To	Water losses	Water Beneficially Used	Water not Recoverable	Water Potentially Available
Palisade	Battle Mtn.	72,000		?	
Battle Mtn.	Comus	26,000		?	
			60,000	?	70,000
Comus	Rose Creek	24,000		?	
Rose Creek	Imlay	8,000		?	
Imlay	Rye Patch	26,500	130,500	26,500	0
Passing	Lovelock station	42,000		4,500	37,500
	Total	198,500	190,500	31,000	107,500

Comparison of this value with the roughly estimated beneficial use of river water in the Basin today, about 130,000 acre-feet from Rye Patch Reservoir and 60,000 acre-feet in the Valley between Palisade and the Reservoir, indicates that something on the order of 50 per cent more water is available for recovery. This estimate does not include water that might be salvaged or more efficiently used if material changes are made in the economy of the Basin.

The purpose of this simple analysis is primarily to show the variety and magnitude of problems being considered by the Project. Its results are most certainly not to be considered as dependable for justifying construction of controls, employment of management, or for recommending changes in the economy. On the other hand, the results are deemed to justify further research to determine more dependable values for guidance in development of the Basin.

TABLE 2

Annual stream flow and losses in acre-feet at gaging stations in the Humboldt Basin. All measurements from records of the U.S. Geological Survey.

Water Year	Palisade, Rock Cr., & Pine Cr.	Battle Mtn.	Losses between Palisade and Battle Mtn.	Comus	Losses between Battle Mtn. and Comus	Losses — Battle Mtn. Unit	Comus, misc. creeks and underflow	Rose Creek	Losses — Winnemucca Unit	Imlay	Losses — Rose Creek to Imlay	Rye Patch Station (also represents use from Reservoir)	Losses-Rye Patch Reservoir (Imlay minus Rye Patch)		Lovelock	Losses — Lovelock Unit	Total Losses — Humboldt Basin below Palisade
													Unadjusted	Adjusted for changes in storage			
1949	254,610	181,200	73,410	148,500	32,700	106,110	158,500	118,500	40,000	115,600	2,900	111,000	4,600	21,050	—	—	—
1950	281,500	199,000	82,500	164,900	34,100	116,600	174,900	135,000	39,900	132,400	2,600	118,300	14,000	20,590	—	—	—
1951	368,680	302,700	65,980	257,700	45,000	110,980	267,700	232,700	35,000	226,600	6,100	124,500	102,100	45,750	—	—	—
1952	760,750	587,100	173,650	558,500	28,600	202,250	568,500	535,800	32,700	522,200	13,600	408,600	113,600	52,980	—	—	—
1953	186,300	134,300	52,000	112,100	22,200	74,200	122,100	120,100	2,000	87,810	32,290	135,700	47,890	14,950	297,500	364,080	599,030
1954	77,350	53,980	23,370	43,590	10,390	33,760	53,590	44,270	9,320	41,050	3,220	103,000	61,850	19,960	11,940	59,180	135,380
1955	70,890	39,460	31,430	27,530	11,930	43,360	37,530	21,840	15,690	18,830	3,010	21,170	2,340	1,776	5,840	29,020	72,100
1956	386,130	278,800	107,330	240,200	38,600	145,930	250,200	197,200	53,000	193,400	3,800	137,700	55,700	25,296	1,350	2,584	61,634
1957	353,090	239,800	113,290	213,500	26,300	139,590	223,500	180,800	42,700	177,700	3,100	123,000	54,700	33,130	3,760	32,856	231,786
1958	348,840	269,000	79,840	228,800	40,200	120,040	238,800	243,200	4,400	226,500	16,700	135,200	91,300	35,160	4,150	40,380	222,670
1959	62,390	41,870	20,520	34,910	6,960	27,480	44,910	42,650	2,260	38,330	4,420	103,000	64,770	25,180	6,620	58,480	174,120
1960	102,760	62,170	40,590	46,800	15,370	55,960	56,800	36,290	20,510	31,510	4,780	44,730	13,220	—	5,350	34,950	64,690
12-yr. Av.	271,107	199,105	71,992	173,085	26,029	98,021	183,085	159,029	24,056	150,994	8,043	130,491	20,494	26,570	42,063	77,691	198,753

2014 Losses Between Comus and Imlay
Total 33,351 Ac/ft.

4. Methods of recovery and regulation

In view of present limitations on our knowledge, discussion of all possible methods of recovery and regulation of water in Humboldt Basin is premature, however, important aspects of the problem and some consideration of them can be profitably mentioned. On the basis of available analyses and data, the key to recovery and beneficial use of a considerable amount of water obviously lies in regulation of river-flow by some method or combination of methods of storage. Additional recovery, perhaps the bulk of it, may be accomplished by diversion of water to beneficial uses from use by non-beneficial phreatophytes and other evapotranspiration losses.

Development of additional storage in surface reservoirs has been under study by various agencies and is now being considered by members of the Project. The river basin study to determine small drainage storage sites will yield much needed information. Studies by State and Federal Agencies aimed at locating and determining feasibility of large reservoirs have shown that few sites, chiefly in the Upper Valley unit, are available and that these are limited in potential utility by a very small cost-benefit ratio. Further, development of surface storage would result in increased evaporation losses which might materially offset advantages gained. Quantitative limitations of this method are under study but have not been determined.

Possible methods of diverting evapotranspiration losses to beneficial use are also under study. Preliminary steps to solve this problem have been described in a foregoing part of this paper.

Conjunctive use of surface flow and ground-water storage as a method of recovery and regulation is being carefully considered. One large ground-water reservoir in the Winnemucca unit and the probability of another of almost similar size in the Battle Mountain unit, both of which underlie or are adjacent to the river, afford possible storage sites. Presently estimated volume that might be made available for storage is on the order of at least 500,000 acre-feet. At present these ground-water reservoirs are saturated to river level and only during times of high flow is storage in them advantageously used, apart from limited withdrawals for irrigation, municipal and domestic purposes. Carefully controlled withdrawal of large quantities of ground water, perhaps as much as 400,000 acre-feet in the Winnemucca Unit, might result in a water-level decline on the order of 40 to 50 feet and would make available enough storage space to accommodate nearly two years of average flow of the river. Adequate data for estimates are not yet available but storage on the order of one-half to two-thirds of this capacity might be developed in the Battle Mountain unit.

If water levels in ground-water reservoirs of the Winnemucca and Battle Mountain units could be maintained at depths exceeding 25 feet, evaporation opportunity would be greatly reduced since the stored water would be underground and out of reach of the most wasteful of the non-beneficial phreatophytes.

Presently we need more physical facts on geometry and lithology of these aquifers and more knowledge of recharge processes and methods. Recharge basins in southern California are being successfully used to inject water in underground reservoirs. Rates as high as one foot per day are not uncommon. Therefore, members of the Project will continue to study and evaluate conjunctive use of surface and ground water in the Humboldt Basin. Probably this method offers the most promising potential to recover the greatest amount of water now lost to evapotranspiration and flood run-off and to modulate river flow.

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