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GEOLOGICAL SURVEY

PLANNING AND DESIGN OF STUDIES FOR RIVER-QUALITY ASSESSMENT IN THE TRUCKEE AND CARSON RIVER BASINS, CALIFORNIA AND NEVADA

By Jon O. Nowlin, William M. Brown III,
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CONVERSION FACTORS

The inch-pound system is used in this report. For those who prefer metric units, the conversion factors for the terms used in this report are listed below:

Multiply	By	To obtain metric units
acre-ft (acre-feet)	0.001233	hm^3 (cubic hectometers)
acre-ft/yr (acre-feet per year)	0.001233	hm^3/yr (cubic hectometers per year)
acres	0.4047	hm^2 (square hectometers)
ft (feet)	0.3048	m (meters)
ft^3/s (cubic feet per second)	0.02832	m^3/s (cubic meters per second)
gal (gallons)	3.785	L (liters)
inches	25.4	mm (millimeters)
lb (pounds)	0.454	kg (kilogram)
Mgal/d (millions of gallons per day)	3785	m^3/d (cubic meters per day)
mi (miles)	1.609	km (kilometers)
mi^2 (square miles)	2.590	km^2 (square kilometers)

Use the following to convert degrees Fahrenheit (°F) to degrees Celsius (°C):
(°C) = 5/9 (°F -32)

ABBREVIATIONS

BOD - Biochemical oxygen demand
DO - Dissolved oxygen
Landsat - Any of three satellites that collect radiometric data used to produce a variety of images of the Earth's surface.
mg/L - milligrams per liter
NAWDEX - National Water Data Exchange, administered by the U.S. Geological Survey.
NH_3-N - Ammonia nitrogen
NO_2-N - Nitrite nitrogen
NO_3-N - Nitrate nitrogen
STORET - Storage and Retrieval system of the U.S. Environmental Protection Agency.
WATSTORE - National Water Data Storage and Retrieval system of the U.S. Geological Survey
"208" - Section 208 of Public Law 92-500 specifying studies of nonpoint-source pollutants.

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ABSTRACT

In October 1978 the U.S. Geological Survey began an assessment of river quality in the Truckee and Carson River basins, California and Nevada. The objectives are (1) to identify the most significant resource-management problems concerning water quality in the two basins, (2) to develop and apply methods to rationally assess these problems, and (3) to communicate the results to the responsible managers and the public in an effective and timely manner.

Six major elements of the assessment to be completed by October 1981 are (1) a detailing of the legal, institutional, and structural development of water resources in the basins and the current problems and conflicts; (2) a compilation and synthesis of the physical hydrology of the basins; (3) development of a special workshop approach to involve local management in the direction and results of the study; (4) development of a comprehensive streamflow model encompassing both basins to provide a quantitative hydrologic framework for water-quality analysis; (5) development of a water-quality transport model for selected constituents and characteristics on selected reaches of the Truckee River; and (6) a detailed examination of selected fish habitats for specified reaches of the Truckee River.

The assessment planning process reviewed all major known and expected water-quality problems in the two basins. The six elements selected to be included in the study left several significant issues that were beyond the scope of the assessment budget, time frame, and manpower. The assessment team proceeded to design studies to consider three of those issues: (1) a study to assess regional water-quality loadings, with emphasis on loadings to specified reaches of the Truckee River; (2) an intensive investigation of the quality of urban runoff in a major metropolitan area (Reno) and the effectiveness of alternative practices for urban runoff management; and (3) a dual study to assess water-quality loadings in the Carson River basin and to model limnological processes in a major reservoir (Lahontan) fed by both the Truckee and Carson Rivers. These proposals are discussed in supplements to this report.

The specific techniques to be applied to each study element range from qualitative assessments to detailed monitoring and development of mathematical models. In building the basic framework to develop techniques, the basins were viewed as a single hydrologic unit because of interconnecting diversion structures. The framework comprises 13 hydrographic subunits, a number sufficient to allow an assessment of major, immediate water-quality problems without being unwieldy for modeling and sampling efforts. The six major study elements and the three proposed supplementary studies were developed upon and thereby interrelated through this framework. The process of designing the study, therefore, emphasized the integration of seemingly disparate elements into a consistent, functional whole.

Successful completion of the principal assessment involves effective communication of results to local managers and the public. In addition to six formal reports, the project staff is preparing base maps, photomosaics, computer data files, mathematical models, a bibliography, and audiovisual presentations that will be readily available to local users. Periodic workshops, news releases, and public presentations will highlight progress and inform users of new materials.

INTRODUCTION

The Truckee and Carson River basins compose a region of 7,257 mi^2 spanning the California-Nevada State line in western Nevada (fig. 1). Within the basin are the Reno-Carson City area (Nevada's second largest socioeconomic center), recreational developments surrounding Lake Tahoe, and some of the most productive agricultural lands in Nevada.

Purpose and Scope

The purpose of this report is (1) to state the objectives of the Truckee-Carson River-Quality Assessment (hereafter referred to as the assessment), (2) to outline the work elements in the project, and (3) to describe the methods to be used to communicate the results.

The assessment was started in October 1978. This study is one of a series of multidisciplinary projects patterned after a prototype study on the Willamette River basin, Oregon (Rickert, Hines, and McKenzie 1976a), to develop and apply methodologies for effective assessment of river-quality problems. The assessment encompasses the Truckee River basin from the outlet of Lake Tahoe to the mouth at Pyramid Lake, and the entire Carson River basin (fig. 2). Objectives of this study are (1) to identify the most significant resource-management problems affecting, or affected by, water quality in the two basins, (2) to develop and apply methodologies to rationally assess some of these problems, and (3) to communicate the assessment results to the responsible managers and the public at large in an effective and timely manner. The emphasis of the assessment process will be to focus the research on components of the river system most relevant to present and future planning and management problems and to develop practical tools for predicting the most probable impacts of alternative management actions on the river system.

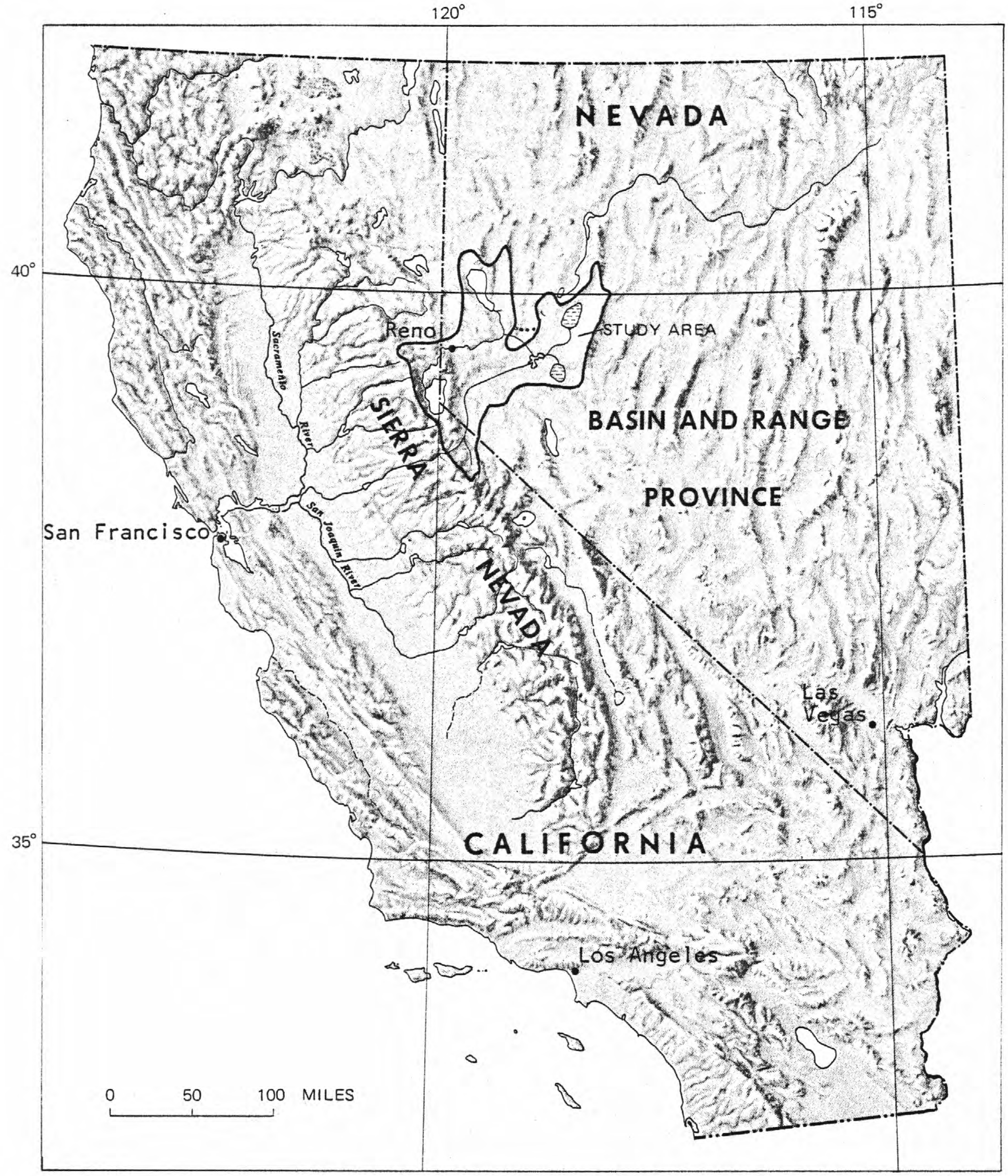

FIGURE 1.--Location of the Truckee-Carson River system.

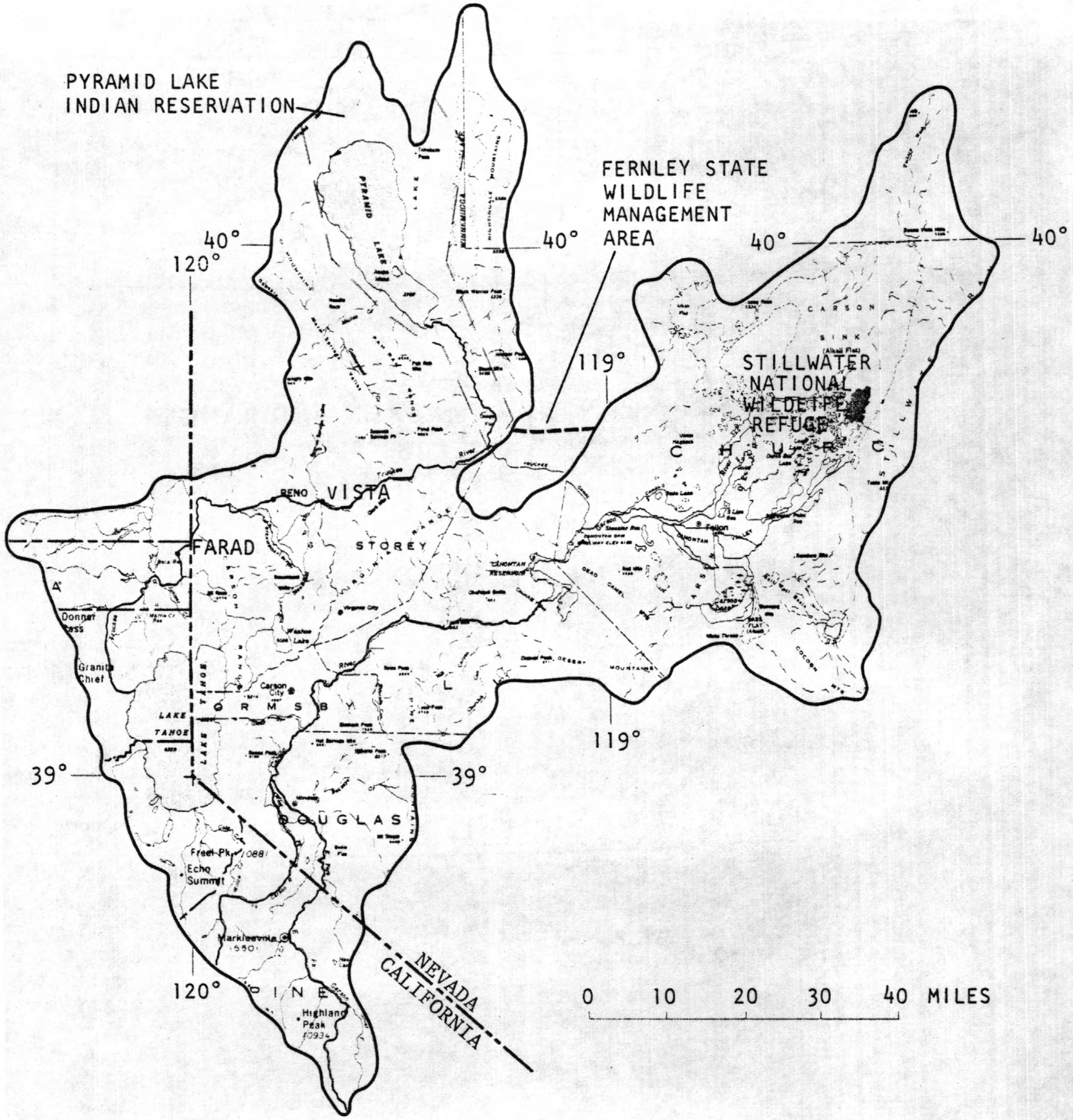

FIGURE 2.--Principal topographic features of the Truckee and Carson River basins.

Description of the Project Area

Physical Setting

Physical geography.--The headwaters of the two basins are on the east slope of the Sierra Nevada, a large mountain block that extends for 400 mi along the eastern border of California. Altitudes in the headwaters exceed 10,000 ft in both the Truckee and Carson basins. The lowest parts of the river basins are in the Basin and Range Province of Nevada with altitudes of 3,795 ft (Pyramid Lake, 1977) and 3,845 ft (Carson Sink). The Sierra Nevada is characterized physiographically by a massive fault block that is dissected by deep canyons. In contrast, the Basin and Range Province is characterized by broad valleys and isolated mountain blocks.

Both the Truckee and Carson basins are topographically closed. The Truckee River basin, which has a drainage area of 3,119 mi^2, terminates at Pyramid Lake; surface-water inflow to the lake discharges by evaporation from the lake surface. The Carson River basin, with a drainage area of 4,138 mi^2, terminates in the desert of Carson Sink; any residual surface water is consumed by evapotranspiration.

Climate.--Climate in the basins is controlled by the orographic barrier of the Sierra Nevada. As the prevailing westerly winds laden with moist Pacific air ascend the Sierra slopes to altitudes where temperatures are lower, condensation causes abundant snow and rain during the winter and spring. Most of the precipitation in the mountains is in the form of snow, with more than 90 percent of the annual precipitation at altitudes above 8,000 ft consisting of snow. The average annual snowfall in the Sierra Nevada amounts to more than 20 ft, with as much as 65 ft falling in some years (Houghton and others, 1975).

Relatively little moisture passes to the east side of the Sierra and into the Basin and Range Province. As the winds descend the east slope, they are warmed and consequently are able to evaporate moisture from the ground. The Basin and Range Province therefore is arid. The average annual precipitation is about 11 inches at Carson City and 7 inches at Reno. In contrast, precipitation is more than 90 inches for some high-altitude areas in the Sierra Nevada. Farther east near Fallon, the average annual precipitation is less than 5 inches. The seasonal distribution of precipitation is uneven. About 30 percent of the annual precipitation at Reno is in the form of snow. Most rainfall occurs in the spring and late autumn, and an average of less than 1 inch of rain falls in Reno from July through October.

Streamflow.--Most streamflow in the Truckee and Carson basins is derived from snowmelt in the headwaters in the Sierra Nevada. Withdrawals and diversions of water for agricultural and municipal uses are concentrated in the valleys in the lower parts of the basins; consequently streamflow generally decreases with distance from the mountain front. Comparative streamflow statistics for major gaging stations in the basins for water years 1970-77 are shown in table 1. For example, the average annual discharge for that 8-year period was 577,000 acre-ft for the Truckee River at Farad, Calif., near the eastern limit of the Sierra Nevada, and 574,000 acre-ft at Vista, Nev., about 30 mi downstream from Farad and below municipal and agricultural diversions and returns in the Truckee Meadows. The average flow at Vista was slightly less than at Farad, even though the drainage area is about 53 percent greater at Vista than at Farad. Table 1 presents a similar picture of decreasing flows in a downstream direction in the Carson River basin.

Water is transferred from the Truckee River basin to the Carson River basin at several locations. Wastewater generated in urban areas along the shore of Lake Tahoe is exported to the upper Carson River basin. The annual export was about 8,600 acre-ft in 1978. Water diverted from the lower Truckee River is transferred to the Carson River basin through the Truckee Canal for irrigation use near Fallon. The annual average diversion in recent years was about 193,000 acre-ft, or about 35 percent of the annual flow of the Truckee River at the point of diversion.

The quality of water in both the Truckee and Carson Rivers deteriorates downstream. In the headwaters of the Carson River basin, the average dissolved-solids concentration is about 60 mg/L and the average nitrate-nitrogen concentration is 0.05 mg/L. Immediately above Lahontan Reservoir, in contrast, average dissolved-solids and nitrate-nitrogen concentrations are about 280 and 0.25 mg/L, respectively. Similarly, in the upper Truckee River below Lake Tahoe, average dissolved-solids and nitrate-nitrogen concentrations are 60 and 0.2 mg/L, whereas near Pyramid Lake the values are 220 and 0.3 mg/L.

Lakes, reservoirs, and wetlands.--The Truckee River basin contains two large lakes--Tahoe and Pyramid. Lake Tahoe lies at an altitude of 6,225 ft in the Sierra Nevada. The surface area of the lake is 191 mi^2, and its average depth is 1,000 ft (Crippen and Pavelka, 1970). Although some concern has been expressed as to the future quality of water in Lake Tahoe, the present quality is excellent. The concentration of dissolved solids is about 60 mg/L and the suspended-solids concentration is 3 mg/L.

Pyramid Lake, the largest body of water lying completely within Nevada, had a surface area of 171 mi^2 at its 1977 stage and an average depth of 190 ft. The lake is a remnant of ancient Lake Lahontan, a vast body of water that during the last glacial epoch covered a large part of western Nevada. Before the start of transbasin diversion of water from the Truckee River in 1905, the altitude of the surface of Pyramid Lake was 3,870 ft and the dissolved-solids concentration was about 3,900 mg/L. The 1977 altitude of the lake was 3,795 ft, and the concentration of dissolved solids was approximately 5,200 mg/L. Historical changes in altitude for the lake are shown in figure 3. The lake is the sole habitat of the Cui-ui, a unique lakesucker listed as an Endangered Species by the Federal Government and found nowhere else in the world. The lake is also one of the few habitats of the Lahontan cutthroat trout, specimens of which exceeded 40 lb prior to an abrupt decline in the fishery in the 1930's. The giant trout have been restocked in the lake in recent years through hatchery operation but are currently listed as a Threatened Species.

In addition to a control structure on the outlet from Lake Tahoe, flows in the Truckee River are regulated by five reservoirs in the headwaters (fig. 4). Prosser Creek Reservoir and Martis Creek Reservoir provide regulation for principal tributaries to the Truckee River, and Independence Lake, Stampede Reservoir, and Boca Reservoir lie in series on a single tributary. Flow exiting Donner Lake, a natural lake, is controlled to a limited extent by a small weir at the lake outlet.

Lahontan Reservoir, which at maximum stage has a surface area of 25 mi^2, is located in the Carson River basin (fig. 2). The reservoir stores water from the Truckee and Carson Rivers to irrigate agricultural lands near Fallon. Both rivers flow through urban areas, where sewage-treatment facilities and storm sewers contribute to degradation of water quality. Additionally, agricultural lands along the rivers are irrigated by river water, and return flows further degrade the quality of the river. As a result of point and nonpoint upstream loadings, Lahontan Reservoir in recent years has experienced severe algal growths and dissolved-oxygen depletion.

The Carson River terminates in the Carson Desert, which includes brackish-water wetlands with a surface area of about 60 mi^2. Historically, these wetlands received water directly from the river. Presently, most flow in the Carson River is diverted for agricultural use, leaving agricultural return flows as the major source of water for the wetlands. These wetlands include the Stillwater National Wildlife Refuge, a major stopping point for wildfowl in the North American Flyway. The refuge management is concerned about increasing salinity of the waters and possible insecticide and herbicide contamination from agricultural return flows.

TABLE 1. - Annual mean streamflow in the Truckee and Carson River basins, 1970-77

[Discharge statistics for period October 1969 to September 1977 (1970-77 water years) to provide a common basis for comparison between stations with different periods of record. Percentiles are for those discharges that occurred less than the indicated percentage of the period 1970-77]

Gaging station (fig. 5)		Drainage area (mi^2)	Mean annual discharge		Normal annual mean (ft^3/s)			Remarks
			Cubic feet per second	Acre-feet per year	25th per-centile	50th per-centile	75th per-centile	
				Truckee River basin				
10337500	Truckee River at Tahoe City, Calif.	507	295	214,000	197	310	374	Regulated outflow from Lake Tahoe.
10346000	Truckee River at Farad, Calif.	932	797	577,000	647	817	985	Includes releases from five lakes or reservoirs.
10348000	Truckee River at Reno, Nev.	1,067	663	480,000	495	690	854	Upstream municipal and agricultural diversions.
10350000	Truckee River at Vista, Nev.	1,431	793	574,000	624	834	996	Upstream municipal return flows and agricultural diversions and return flows.
10351300	Truckee Canal near Wadsworth, Nev.	--	267	193,000	217	263	327	Diversion to the Newlands irrigation project.
10351400	Truckee Canal near Hazen, Nev.	--	197	143,000	146	205	246	Upstream agricultural diversions. Truckee River inflow to Lahontan Reservoir.
10351600	Truckee River below Derby Dam, near Wadsworth, Nev.	1,676	601	363,000	304	524	708	
10351650	Truckee River at Wadsworth, Nev.	1,728	533	386,000	326	556	751	Upstream ground-water accretions from agricultural surface and subsurface return flows.
10351700	Truckee River near Nixon, Nev.	1,827	541	392,000	333	569	753	Upstream ground-water accretions. Gage used by water managers to estimate flows to Pyramid Lake.

TABLE 1. - Annual mean streamflow in the Truckee and Carson River basins, 1970-77--Continued

Gaging station (fig. 5)		Drainage area (mi^2)	Mean annual discharge		Normal annual mean (ft^3/s)			Remarks
			Cubic feet per second	Acre-feet per year	25th percentile	50th percentile	75th percentile	
				Carson River basin				
10309000	East Fork Carson River near Gardnerville, Nev.	356	324	235,000	189	381	414	Outflow from the Sierra Nevada.
10310000	West Fork Carson River at Woodfords, Calif.	65.4	93	67,400	54	109	121	Outflow from the Sierra Nevada.
10310500	Carson River near Carson City, Nev.	886	351	254,000	181	427	467	Upstream agricultural diversions and return flows. Includes 8,600 acre-ft of treated effluent from Lake Tahoe basin.
10312000	Carson River near Fort Churchill, Nev.	1,302	322	233,000	148	395	445	Upstream agricultural diversions and return flows and municipal return flows.
10312150	Carson River below Lahontan Reservoir near Fallon, Nev.	1,801	497	360,000	409	498	517	Releases for agriculture in Newlands Project include Carson River and Truckee River water.
10312280	Carson River below Fallon, Nev.	--	19	13,800	304	524	708	Upstream agricultural diversions and return flows.

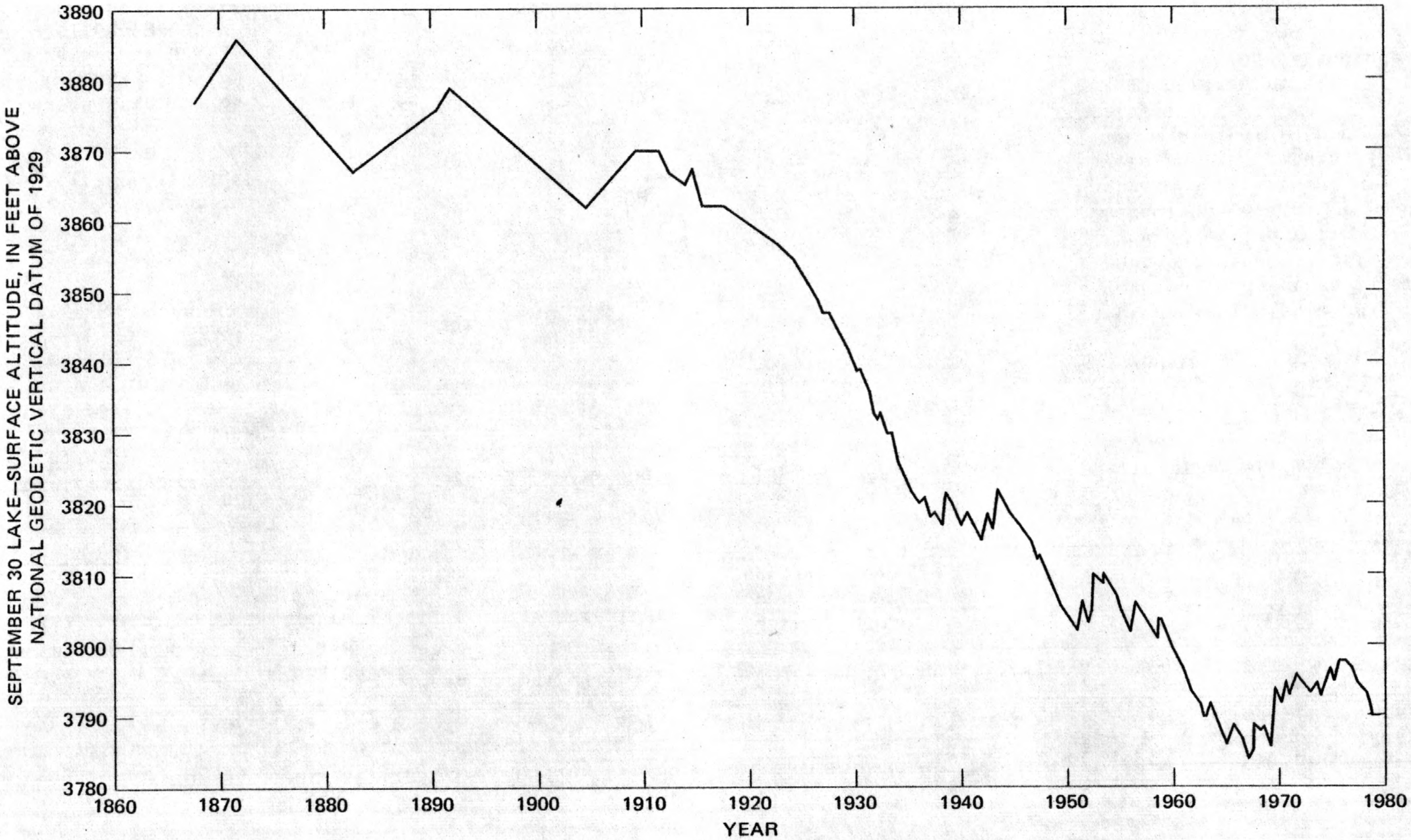

FIGURE 3.--Water-surface fluctuations of Pyramid Lake, 1867-1979. (Modified from Harris, 1974). Records prior to 1911 are fragmentary.

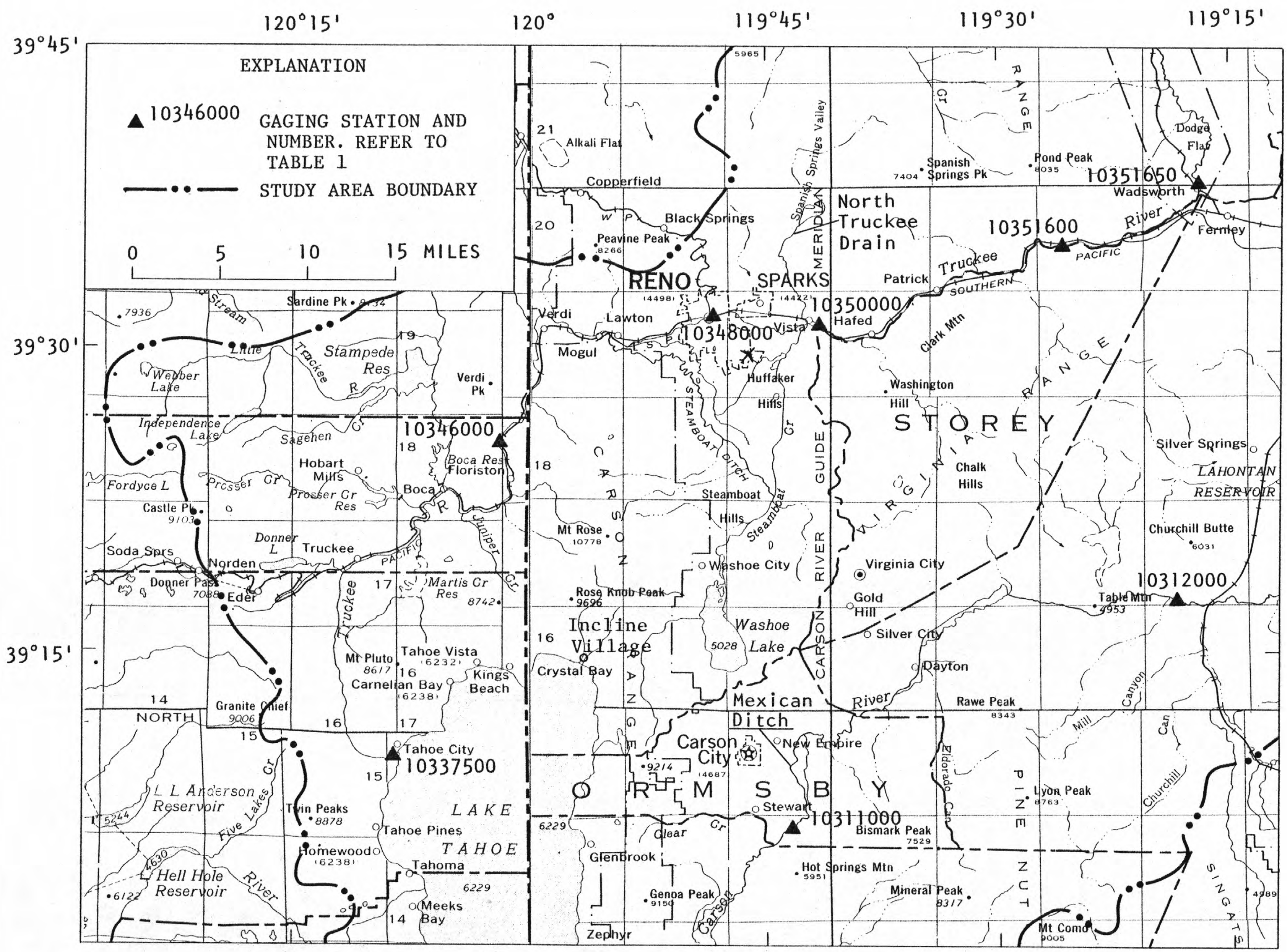

FIGURE 4.--Gaging-station locations and principal reservoirs on the upper Truckee River in the west-central part of study area.

Socioeconomic Setting

The Truckee-Carson River system supports an economy based on recreation, government, and agriculture. The gaming industry represents an important economic factor in the Reno area (population about 150,000) and the Lake Tahoe area (average year-round population about 50,000). In the Lake Tahoe area, a substantial part of the economy is based on winter skiing and summer water-based recreation, and summer population commonly exceeds 150,000 people. Government employment is an important economic factor in Carson City (population about 30,000), the capital of Nevada. The economic base of the Fallon (population about 12,000) and Gardnerville (population about 6,000) areas is irrigated agriculture.

The gaming industry in the Lake Tahoe and Reno areas is expanding rapidly. In recent years, industry income has been increasing at the compound rate of about 25 percent per year. Concomitantly, the population of both the Truckee and Carson River basins has been rapidly increasing. Because of a shortage of housing in the Lake Tahoe and Reno areas, the impact of this population increase has been felt throughout the basins. A significant number of people commute from residences in the Carson River basin to employment in the Lake Tahoe and Reno areas; to a lesser extent, the opposite is also true.

Not all the recent increase in population is due to expansion of the gaming industry. Many retired people are moving to Nevada, attracted by low taxes, a mild, sunny climate, and other amenities of Western desert living. Nevada is also experiencing growth via the general and persistent migration of people from the Northeastern and Midwestern States to the southern and western parts of the United States.

Water-Resources Problems

Demands on water-supply and wastewater facilities.--Rapid economic development in both the Truckee and Carson River basins has greatly increased demands on water supplies and wastewater-treatment facilities. Moratoriums or quotas on residential or commercial building recently have been used in both the Reno and Carson City areas to limit development until water-supply and waste-treatment facilities can be expanded to meet the demands of past growth. Secondary expansion has occurred in rural areas of the two basins in response to overflow from the more densely developed areas. Land and water use in many areas is changing from historical patterns of irrigated agriculture to urban and residential development. Planned strategies for water use and wastewater treatment will have important long-term impacts on river quality and economic development.

Water-rights conflicts.--Water rights have been in and out of litigation in the Carson River basin since 1871 and in the Truckee River basin since 1913. The oldest active case on record in the U.S. Federal Court system is the United States versus Alpine Land and Reservoir Co. This suit over assignment of priority for water rights in the Carson River above Lahontan Dam was filed in 1925 and did not go to court until June 1979. Current litigation in the Carson River basin is centered on establishing priority and assigning rights for water stored in Lahontan Reservoir for the Newlands irrigation project below Fallon. Conflict in the Truckee River basin involves operating criteria for reservoir management, diversions, and Indian claims for Truckee River water now being diverted to Lahontan Reservoir for use in the Newlands project.

Threatened and Endangered Species.--The Cui-ui lakesucker (*Chasmistes cujus*) and the Lahontan cutthroat trout (*Salmo clarki henshawi*) reside in Pyramid Lake, and prior to about 1930 they both spawned in the Truckee River. Sedimentation, primarily due to logging practices in the early 1900's, and decreased flows resulting from upstream diversions blocked the lower Truckee River to spawning runs of the fish in the 1930's, and populations in Pyramid Lake declined severely in succeeding years. The Pyramid Lake Indian Tribe and the U.S. Fish and Wildlife Service are dedicated to reestablishing both fisheries.

Egg studies have indicated that the fish will not reproduce under current water-quality and flow conditions in the lower river. In addition, the stage of Pyramid Lake has declined more than 90 ft in the past 70 years, primarily due to upstream water diversions (fig. 3). The resulting increase in salinity threatens the long-term survival of the fish.

Water-quality standards.--Water-quality standards have been proposed for the protection of cold-water salmonids throughout the Truckee River basin and for alternating cold and warm water fisheries in reaches of the Carson River above Lahontan Reservoir. The proposed standards for the Truckee River above Reno reflect the desire to protect the present quality from further degradation due to future development. Controversy in the Truckee River below Reno involves potential costs of waste treatment adequate for protecting the river in order to reestablish the historical runs of Lahontan cutthroat trout. At issue in the Carson River basin is the question of whether the improvement in quality required by standards for protecting fish is physically attainable or economically justifiable in an area historically devoted to agricultural land uses.

PROJECT PLANNING

Effective communication between resource scientists, planners, and managers is an essential key to the utility of an environmental assessment. A fundamental goal of the Truckee-Carson assessment is to develop methods to provide technically sound and timely information to decisionmakers. To achieve this, the scientist must understand the planner's information needs; his legal, monetary, and time constraints; and the level of his ability to comprehend scientific information. The manager must understand that the level of scientific knowledge limits the scientist's ability to deliver quantitative resource assessments, and that each assessment method has inherent strengths and weaknesses. Both scientists and managers need to realize that valid data and sound analyses, rather than complicated analytical schemes, form the foundation of a reliable resource assessment.

Assessment Workshops

Previous Geological Survey river quality-assessments have developed informal lines of communication with concerned planners and managers over a period of several months. The Truckee-Carson study began by directly involving administrators, managers, planners, and scientists concerned with resource development in the two basins in an intense, cooperative, interactive effort to establish a common perspective of problems in the two basins by holding a workshop at Lake Tahoe in October 1978. Specific objectives of this workshop were to (1) rank the pertinent water-resources problems in order of importance to management, (2) set practical bounds for consideration of potential management responses to those problems, (3) indicate areas of critical needs for more information on the resources, and (4) establish effective and continuing communication among the workshop participants. Details of the workshop process may be found in the discussion of the assessment workshops work element in the section "Basinwide Studies."

TABLE 2. - Assessment prioriti

	Truckee River	Carson Riv
Issues	Priorities for investigation	
1. Alternatives for advanced waste treatment	1	1
2. Impact of urban runoff	2	3
3. Impact of agricultural runoff	3	2
4. Reestablishment of species	--	--
5. Relevance of water-quality standards	--	--
Major water-quality factors	Relative concern	
Sediment/turbidity	Major	Major
Temperature Major	Moderate	
Dissolved oxygen	Moderate	Major
Dissolved solids	Major	Minor
Nutrients	Major	Major
Minor elements/metals	Moderate	Moderate
Pesticides	Moderate	Moderate
Flow regimen	Major	Major

The initial workshop resulted in a preliminary identification of five critical water-quality problems:

1. Evaluation of alternatives for advanced waste treatment.
2. Assessment of the impact of urban runoff.
3. Assessment of the impact of agricultural runoff.
4. Reestablishment of Threatened and Endangered Species.
5. Determination of the relevance of proposed water-quality standards.

As shown in table 2, relative rankings for issues 2 and 3 varied with the basin under consideration. Issues 4 and 5 were identified as being important but no consensus was reached as to their relative ranking. Table 2 also contains a list of water-quality factors that the workshop participants considered to be important in evaluating the five critical issues.

developed in the Truckee-Carson workshop

Truckee River basin	Carson River basin
Critical reaches	
Lake Tahoe-Farad, Reno-Pyramid Lake	Stateline-Lahontan Reservoir
Reno-Pyramid Lake	Carson City-Lahontan Reservoir
Reno-Pyramid Lake	Stateline-Lahontan Reservoir Stillwater Refuge
Reno-Pyramid Lake	--
Lake Tahoe-Pyramid Lake	Stateline-Lahontan Reservoir
Critical reaches	
Reno-Pyramid Lake	Stateline-Carson City
Reno-Pyramid Lake	Stateline-Carson City
Reno-Pyramid Lake	Stateline-Lahontan Reservoir
Lake Tahoe-Pyramid Lake	Stateline-Lahontan Reservoir
Lake Tahoe-Pyramid Lake	Stateline-Lahontan Reservoir
Lake Tahoe-Pyramid Lake	Carson City-Stillwater Refuge
Reno-Pyramid Lake	Stateline-Stillwater Refuge
All	All

Review of Critical Issues

Following the October 1978 workshop, the project staff reviewed past and present studies and reports on water-quality problems in the basins and continued discussions with various interested agencies as to their information needs. General conclusions at the end of this review were:

1. Although numerous studies have been made in the Truckee-Carson system, no one source contains an accurate, consistent compilation of basic hydrologic information for the two basins. Existing reports often conflict with each other with respect to key measurements such as drainage areas and river mileage. Water-quality data from different sources have often been lumped together and analyzed without regard to inconsistent sampling points and differing methods of sample collection and analysis.

2. Most previous studies of water-quality problems have considered legal and institutional constraints on management of water quantity in the system as rigid boundaries to the hydrologic system. Such constraints preclude an independent analysis of natural variability in river hydrology and associated quality.

3. Estimates of water-quality loadings from urban and agricultural nonpoint sources have been based on inadequate data sets, usually derived from routine monitoring programs that give little or no consideration to the streamflow at the time of sampling.

4. Analysis of alternatives for advanced waste-treatment facilities have generally been based on descriptive summaries of water-quality data rather than on quantitative assessments and have not discussed impacts on Pyramid Lake and Lahontan Reservoir.

5. Although water-quality control in the lower Truckee River is predicated upon protection of habitat for Lahontan cutthroat trout and the Cui-ui lakesucker, fundamental questions still remain concerning the adequacy of river habitat for the fish.

Selected Project Elements

The study priorities developed in the October 1978 workshop were evaluated by the project staff with respect to available technologies, time, funds, and manpower constraints on the assessment. Selection criteria included the degree of relevance to current problems and issues faced by water-resource managers in the two basins and the expected probability of success within the constraints of the project.

From this evaluation a program was developed that consists of three levels of work with a total of six major elements (table 3). The first level of work is to compile and synthesize data on stream hydrology, water quality, and the development and management of the water resources of the two basins. This work will result in two reports intended to serve as a comprehensive and cohesive framework for the development of the remaining study elements and as background material for future water-quality studies in the basins. The second level of work encompasses studies designed to generate new information of basinwide scope. This work will result in a series of communication workshops and a hydrologic model of the two-basin system. The third level of work will include detailed water-quality studies for selected reaches of the Truckee River. This work will result in predictive water-quality models for those reaches and an analysis of several physical and chemical factors affecting the spawning habitats of migratory fish in the Truckee River.

TABLE 3. - Study elements for the Truckee-Carson River-Quality Assessment

Level of investigation	Study elements
I Establishing the institutional and hydrologic framework	1. Historical development--A summary of the structural, institutional, and legal development of the water resources to provide background for evaluating potential alternatives for water-quality management.
	2. Hydrologic characteristics--A comprehensive compilation and graphical summary of the hydrologic characteristics of key subunits of the basins to provide a hydrologic reference for detailed studies.
II Basin-wide studies	3. Assessment workshops--Interactively developing simple qualitative models of the water-resources system to develop alternatives for assessment and to promote communication between planners, managers, and resource scientists.
	4. Streamflow model--Development and application of a quantitative streamflow model covering both basins to analyze the regional input of institutional, hydrologic, and structural boundaries on the rivers' flow regimens.
III Intensive studies of selected reaches of the Truckee River	5. Predictive water-quality transport models--Development and application of mathematical models of transport of temperature, dissolved oxygen, and nitrogen species from Reno to Pyramid Lake and Lake Lahontan.
	6. Spawning habitat studies--A detailed investigation of the quality in the river and bed materials in conjunction with in situ egg reproduction studies.

Study Techniques

The assessment will consider the work elements in a manner similar to that outlined for the Willamette study (Rickert and others, 1976b):

1. Identify the significant water-quality problems of major importance in the basin.

2. Analyze the hydrology, including detailed definition of river-channel geometry.

3. Select assessment methods appropriate to each problem.

4. Collect the data relevant to each problem by intensive investigations and synoptic river surveys.

5. Analyze the data for cause-and-effect relationships; formulating and calibrating models, or other predictive methods, by which changes in river-quality parameters can be projected; and verifying the predicted results against observed river conditions.

6. If agreement between the predicted and observed river conditions is reasonable, then make forecasts of the impacts of various planning alternatives on river quality.

7. Finally, present the results of river-quality assessment in a usable manner, understandable to planners and decisionmakers for their establishing of priorities and investments in the various possible solutions to problems.

The specific techniques to be applied to each study element range from qualitative assessments to detailed monitoring and development of mathematical models and are discussed in detail in following sections.

Important Water-Quality Issues Not Covered by the Assessment

The selection of elements to be included in the study was a necessary compromise between those issues defined to be of crucial importance and the limitations imposed by the finite resources of the project. Because the assessment is part of a national demonstration program, the selection process also stressed those elements having the greatest potential for developing new methods. These methods should have significant value for transfer to other river systems with similar hydrologic environments. Elements considered but not included for these reasons include:

1. Regional determination of annual and seasonal nonpoint loadings derived from urban and agricultural land uses.

2. Examination of the potential impact of growth in and near the Lake Tahoe Basin on water quality in the upper Carson and Truckee Rivers.

3. Assessment of the impacts of nutrient loadings from the Truckee River on the biota of Pyramid Lake.

4. Assessment of impacts of nutrient loadings from the Truckee Canal and Carson River on the biota of Lahontan Reservoir.

5. Assessment of the impact on stream quality of changing from agricultural to urban land uses.

6. Regional synoptic assessment of the impacts of land use on sedimentation, using remote sensing methods developed by Brown and others (1979).

7. Evaluation of the impact of proposed land application of sewage effluents on the quality of ground and surface waters.

8. Assessment of the occurrence and distribution of trace elements and heavy metals in stream sediments (similar to that of Rickert and others, 1977).

9. Evaluation of the impact of the quality of agricultural return flows on wildlife habitats in the Fernley and Stillwater refuges and Carson Pasture.

Among the several topics considered for study and dropped in the selection process, the two judged to be of particular importance are assessments of the assimilation capacities of Pyramid Lake and Lahontan Reservoir. All water-quality management alternatives in the Truckee and Carson basins will ultimately affect either the input flows or loads to these two receiving bodies, and yet there is insufficient information to assess the impacts of such changes on the water quality and biota of the lakes.

Whereas determination of the water-quality dynamics within the lakes is beyond the scope of this project, such a determination is crucial for intelligent management of the water resources of either the Carson or Truckee Rivers. Development of the necessary understanding of cause-and-effect relationships on the lakes will require (1) an intensive data-collection program specifically designed to establish these relationships and (2) developing quantitative models on the complex dynamics within the lake ecosystems.

Intensive water-quality investigations have been conducted on Pyramid Lake (Sigler and Kennedy, 1978), but the results cannot be evaluated as they are being held confidential pending disclosure in current litigation. Very little work has been done in the past concerning water quality in Lahontan Reservoir; however, an intensive 2-year descriptive study that will provide basic data on the biology and water quality of the reservoir was begun in 1979 by the Desert Research Institute (Reno, Nev.).

Studies Proposed to Supplement the Assessment

As an outgrowth of the assessment planning, the following three studies were identified as being particularly needed to complement the assessment, and three projects were designed to consider the problems:

1. Assessment of regional water-quality loadings, with emphasis on loadings to the Truckee River from the Reno-Sparks urban area to Pyramid Lake and Lahontan Reservoir.

2. Intensive investigation of both the quality of urban runoff in the Reno area and the effectiveness of practices for urban runoff management.

3. Assessment of water-quality loadings in the Carson River basin, development of a model of the limnological processes in Lahontan Reservoir, and evaluation of the effects of water-quality loadings.

Proposals for the projects to deal with these issues are discussed in more detail in Supplements A, B, and C to this report.

INSTITUTIONAL AND HYDROLOGIC FRAMEWORK

The first level of work for the assessment is to document the current institutional and hydrologic controls on the management of water resources in the Truckee-Carson basins. The bounds within which planners and managers consider management alternatives are determined largely by an institutional framework that is the result of years of historical development. The physical responses of the water resources to alternative strategies are determined by the basic hydrology of the system; that hydrology often is the result of man's activities superimposed on a system that has naturally evolved over thousands of years. The assessment will explore these controls in two publications: (1) A summary of the history of water-resources development and the evolution of the resulting institutional and legal controls, and (2) a summary of the basic hydrology of the two river basins.

Hydrologic History

Purpose and Scope

The historical development of water resources in the Truckee-Carson system is complex. Although many good reviews of water development have been published, no one source summarizes the patterns of development in both basins with respect to the evolution of the current institutional framework and associated conflicts. The assessment will provide such a review, concentrating on three themes: (1) The history of the development of water resources, (2) a review of the evolution of legal and institutional constraints on water development and management, and (3) a summary of current water conflicts.

The history of water-resources development will review historical patterns of water use and structural modifications to the hydrology in key subunits of the two basins. Emphasis will be placed on documenting alterations to stream hydrology in the attempt to modify the natural magnitude, frequency, and distribution of flows in a water-short system.

The legal and institutional review will explore how historical conflicts between competing water uses such as the ranching and milling interests on the Carson River have evolved into the current legal and institutional constraints on water allocation and management. This discussion will provide a background for understanding the basis of current conflicts over water management and how those legal and institutional constraints affect alternatives being considered for water-quality management.

The discussion of current conflicts will include how recent major changes in the area's economy and concomitant changes in land and water use have placed severe stress on both water availability and water quality. The historical perspective developed in preceding sections will be used to provide background for the various alternatives being considered by managers and planners to alleviate these problems.

Presentation of Results

The historical overview of the development of water resources and related legal and institutional constraints on water management will be compiled and published. The perspective of water-resource problems developed in this report will be integrated throughout the study. The history of the development of structural alterations to the stream systems in key subunits of the study area will directly relate to several components of the report on hydrologic characteristics discussed in the following section. These two reports will be complementary; the historical report will discuss in its text several topics treated in a graphical or tabular manner in the second report.

Hydrologic Characteristics

The Truckee and Carson River basins, because of their interconnecting diversion structures, are considered as a single hydrologic unit. Therefore it is desirable to consider the hydrologic characteristics of the basins to account for the interconnections and to provide a comprehensive framework for hydrologic study and design of sampling networks. The initial step toward these actions is to compile the basic hydrologic information in a format geared to the interconnected system. This format will guide the assessment team in their work and provide water-resource planners and managers with a collation of information that heretofore either has been widely dispersed or has provided only fragmented views of the total system. The foundation for this format would come from previous studies that have yielded good information on various hydrologic topics.

Selected Subunits

On the basis of water-quality considerations, the Truckee and Carson River basins will be divided into 13 principal subunits (fig. 5). The boundaries of these subunits generally conform to published hydrographic boundaries for consistency with previous work (Rush, 1968). However, an additional boundary between subunits L and M was determined specifically for this study to separate the irrigated agricultural lands surrounding Fallon from the wildfowl habitats of Stillwater National Wildlife Refuge and Carson Lake (fig. 2). Basically this boundary connects the points where water flows out of the agricultural areas. These points were determined by inspection of aerial photographs showing agricultural activity and diversions in August 1977. Nevertheless, much of the boundary is somewhat arbitrary and does not conform to the precision with which the other boundaries were determined. The northern boundary of subunit D represents a sink with inflow mainly from agricultural runoff originally derived from the Truckee Canal. Thus, subunit D is hydrologically connected to the Truckee River via the Canal. Some water from the western part of subunit D may reenter the Truckee River as ground-water inflow near Wadsworth.

The remaining boundaries were determined by using the most current topographic maps and data available from the U.S. Geological Survey in January 1979. The boundaries were drawn on 1:24,000- and 1:62,500-scale maps, and the areas enclosed were determined to be accurate within 1 percent with respect to the standard accuracy of the maps. The details of the hydrographic boundary and area determinations will be presented in a future publication.

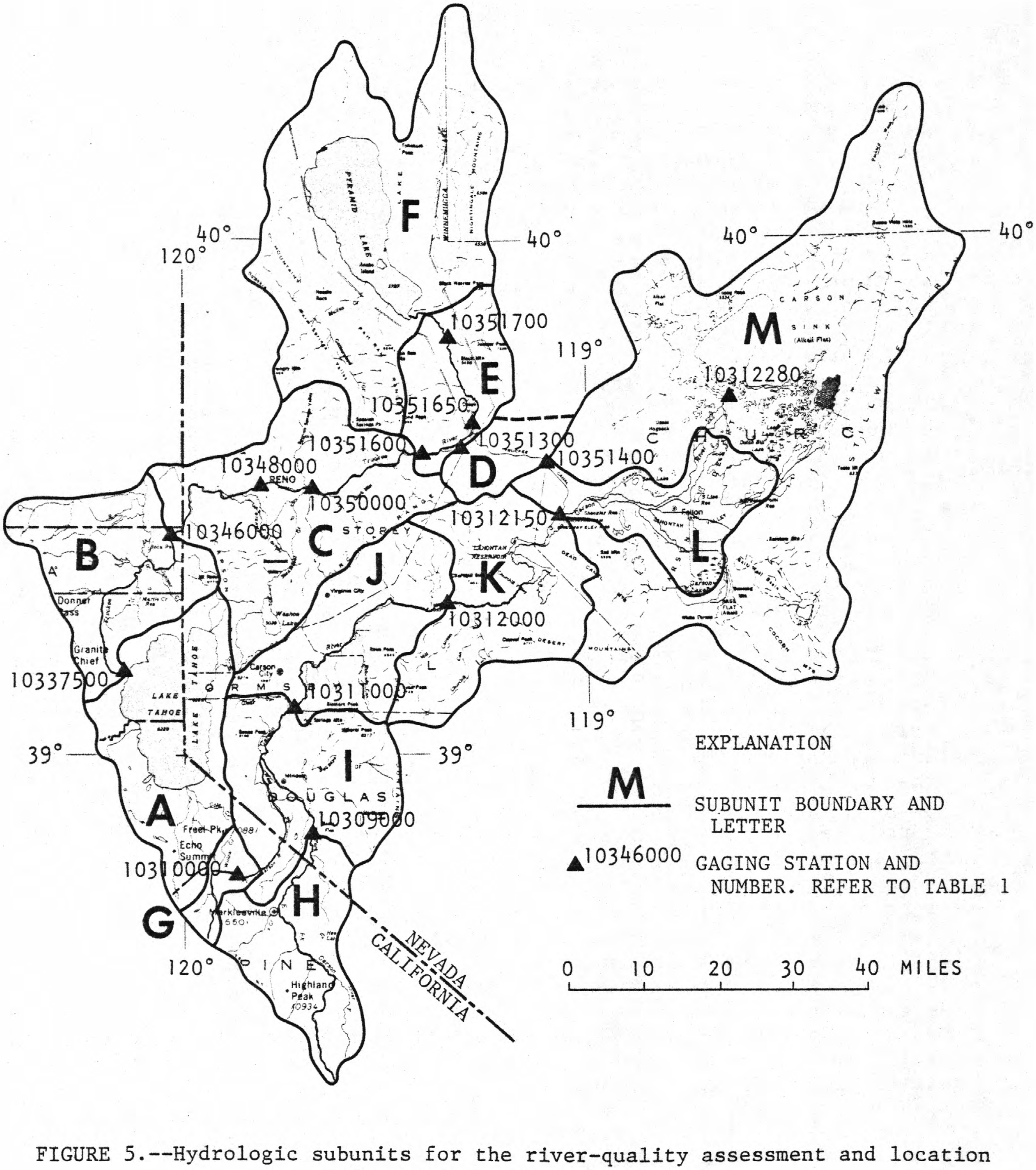

FIGURE 5.--Hydrologic subunits for the river-quality assessment and location of existing gaging stations.

The subunit scheme was developed by the assessment team with substantial input from attendees of the assessment study planning workshop (page 29). This scheme was selected to account for the general intents, purposes, and time restrictions common to river-quality assessment studies. There are not so many subunits that sampling and modeling efforts will become unwieldy, yet the number of subunits is sufficient to allow an assessment of the major immediate river-quality problems in the basins. The subunits are defined in such a way that their further subdivision for special purposes in the study or in the future can be made with relative ease. In table 4, the subunits are described in terms of the physiographic, land-use, and hydrologic elements to be considered by the assessment team. This subunit division will be the basis for the format of basic hydrologic considerations that will be used in the remaining work elements.

Table 4 summarizes the numerous elements that reflect the current processes, problems, and data needs relative to water quality in each subunit. The table therefore can be considered as an outline representing a synthesis of current thinking about water quality in the basins and as a guide to defining precisely the tasks of the study team. The scope and execution of these tasks are then developed in the remainder of this report.

Presentation of Results

The hydrologic characteristics of the Truckee and Carson River basins will be presented in a report consisting of text and three map sheets. Sheet 1 will contain a map of the study area showing subunit boundaries, monitoring station locations, major diversion structures, sewage treatment plant discharge locations, ground-water basin boundaries, and such additional data as the boundaries of irrigated agriculture. These and other features will be plotted on a U.S. Geological Survey 1:250,000-scale topographic map prepared expressly for this study (see section on "Base Materials"). Sheet 1 will also contain detailed river profiles of major reaches of the rivers, an index map, and appropriate explanations and tabulations of data featured on the map. Sheet 2 will contain expanded planimetric maps of the Truckee River from Floriston to Pyramid Lake, the Carson Valley and vicinity, and the Fallon Agricultural area. These maps will show a variety of features such as points of diversion and return flows, sampling stations, and the points at which water-quality standards are applied. Hydrographic data will be shown in conjunction with a specially prepared perspective block diagram of the study area to be shown on sheet 3. The text will include page-sized maps, schematics, and other illustrations. The report will include tables of pertinent supplemental data such as the stream-gaging and water-quality monitoring history of the study area and tabulations of physiographic data such as drainage area, river miles, and stream slope for selected points on the rivers.

TABLE 4. - Hydrologic subunits and associated characteristics for project planning

[Subunit boundaries are shown in figure 5]

Subunit symbol and name	Subunit area (square miles)	Representative gaging station and number	Significant physiographic and land-use characteristics, and management practices affecting water quality	Hydrologic characteristics pertinent to water-quality assessment
A Lake Tahoe	507	Truckee River at Tahoe City, Calif. 10337500	Abundant snowfall on lake surface that occupies 38 percent of subunit area; snowmelt runoff from natural slopes that is low in both dissolved and suspended material; point- and non-point-source pollutants assimilated in the massive lake and do not reach outlet in appreciable quantities; export of municipal sewage generated within subunit; increasing residential and transient population producing additional sewage to be exported.	Historical, legislated, and alternative release schedule for flow at lake outlet dam; quantity, quality, and disposition of sewage flow diverted to subunits B and I; quality of flow at lake outlet dam as a base condition for assessment of downstream water-quality in Truckee River.
B Upper Truckee River	426	Truckee River at Farad, Calif. 10346000	Runoff controlled by five major reservoirs and releases at Lake Tahoe outlet; point-source effluent from subunit discharged into alluvium of Truckee River; non-point source pollutants derived from highway surface runoff (U.S. Interstate Highway 80 along river).	Historical, legislated, and alternative schedules for combined reservoir releases and resultant flows at Truckee River at Farad; water-quality constituents of these flows; quantity and quality of treated discharge as seepage through alluvium into Truckee River.
C Middle Truckee River	744	Truckee River at Vista, Nev. 10350000	Numerous power, agricultural, and municipal water-supply diversions; nonpoint-source pollutants derived from urban and agricultural land in Truckee meadows and Spanish Springs Valley; point-source effluent from Reno-Sparks sewage treatment plant reaching Truckee River by way of Steamboat Creek; geothermal springs that discharge mineral salts into Steamboat Creek; urbanization of land on flood-prone alluvial fans, requiring structural measures to control flooding and retain sediment.	Number, type, and capacity of diversions and the ultimate disposition of diverted flow; quantity and quality of flow returned to the Truckee River as urban and agricultural runoff; quantity and quality of sewage treatment plant discharge; occurrence and type of events producing urban storm runoff, flooding, and sedimentation.

TABLE 4. - Hydrologic subunits and associated characteristics for project planning--Continued

Subunit symbol and name	Subunit area (square miles)	Representative gaging station and number	Significant physiographic and land-use characteristics, and management practices affecting water quality	Hydrologic characteristics pertinent to water-quality assessment
D Fernley area (Truckee Canal)	103	Truckee Canal near Hazen, Nev. 10351400	Agricultural diversion of Truckee River into canal and thence to diversions from canal in Fernley area.	Canal capacity and history of diversions into canal from Truckee River; quantity of leakage from canal into the Truckee River between Derby Dam and Wadsworth; quality, quantity and ultimate disposition of flow diverted from the canal; occurrence and magnitude of rainfall on basins in the subunit contributory to the canal.
E Lower Truckee River	261	Truckee River near Nixon, Nev. 10351700	Release flows and overflows at Derby Dam; diversions at Numana Dam; hydraulic gradient controls effected by Numana and Marble Bluff Dams and volcanic bedrock in the vicinity of the Nixon gage; impact of grazing and other activities that distrub riparian vegetation along channel banks.	Channel geometry for selected reaches; historical habitats and conditions for spawning of migratory fish; particle-size distribution of channel bed material; types and concentrations of pollutants attached to bed material in spawning areas; schedule of flows resulting from releases and overflows at Derby Dam plus ground-water inflow between Derby Dam and Wadsworth; release and diversion schedules for Numana and Marble Bluff Dams; quantity and particle-size distribution of sediment discharged during flushing of sediment at Derby Dam.
F Pyramid Lake	1,181	Pyramid Lake near Nixon, Nev. 10336500	Management of Truckee River diversions at Derby Dam; urban and agricultural discharges to river, particularly downstream from Reno; evaporation rate of lake that generally exceeds inflow; increasing salinity of lake with declining lake level.	Lake-surface altitude and lake salinity relative to Truckee River flows; tendency of lake level to rise or fall during Pleistocene and Holocene epochs; geometry and composition of bed of deltaic reach of Truckee River and fishway diversion at Marble Bluff Dam; aspects of fishery that is dependent on a maximum salinity and access to the Truckee River for spawning.

TABLE 4. - Hydrologic subunits and associated characteristics for project planning--Continued

Subunit symbol and name	Subunit area (square miles)	Representative gaging station and number	Significant physiographic and land-use characteristics, and management practices affecting water quality	Hydrologic characteristics pertinent to water-quality assessment
G Upper West Fork, Carson River	65	West Fork Carson River at Woodfords, Calif. 10310000	Snowmelt runoff from mountainous and alpine meadow terrain that is mostly above 6,000 ft; control of flows are minor; small ranches, campgrounds, and small recreational cabin communities account for limited sewage discharge into river.	Quantity and quality of flows at Woodfords as base conditions for assessment of hydrologic budget and extent of downstream water-quality degradation.
H Upper East Fork, Carson River	356	East Fork Carson River near Gardnerville, Nev. 10309000	Snowmelt runoff from mountainous terrain that provides about 75 percent of annual flow in the Carson Valley; flow slightly regulated by several small reservoirs; agricultural runoff and sewage inputs from Markleeville, Calif., vicinity; acid mine drainage from Bryant Creek; proposed major water-storage structure (Watasheamu Dam) near Horseshoe Bend.	Quantity and quality of flows at Gardnerville gage as base conditions for assessment of hydrologic budget and extent of downstream water-quality degradation; alternative flow regimen imposed by proposed operations of Watasheamu Dam.
I Carson Valley	464	Carson River near Carson City, Nev. 10311000	High flows of West and East Forks that pass through southern parts of subunit and thence to main Carson River virtually uncontrolled; lower flows regulated by numerous agricultural diversions; agricultural return flow by surface conveyances and ground-water seepage; treated sewage discharges from subunit A that enter Carson Valley at three points; treated sewage of Minden-Gardnerville area that discharges to river; rapid suburban expansion creating diffuse sources of septic-tank discharge to the aquifer; channel alterations leading to channel bank and bed erosion.	Number, type, and capacity of diversions and the ultimate disposition of diverted flows; quantity, quality, and disposition of sewage discharges; generalized description of the surface- and ground-water hydrology of the Carson Valley in consideration of ongoing and potential heavy development of urban-suburban communities; quantity and quality of agricultural return flows; occurrence and type of events producing flooding of East and West Forks and small streams draining steep mountain face of the west side of the subunit; sediment-transport relations for reaches of principal streams subject to aggradation or degradation.

TABLE 4. - Hydrologic subunits and associated characteristics for project planning--Continued

Subunit symbol and name	Subunit area (square miles)	Representative gaging station and number	Significant physiographic and land-use characteristics, and management practices affecting water quality	Hydrologic characteristics pertinent to water-quality assessment
J Eagle and Dayton Valleys	417	Carson River near Fort Churchill, Nev. 10312000	Nonpoint-source pollutants derived from urban-suburban land in the Eagle Valley; point-source effluent from three treatment plants; diversions and return flows for riparian agriculture along Carson River; mercury-contaminated stream sediments resulting from pre-1900 milling of gold and silver ores; diffuse sewage discharge into ground water and thus the river from small communities in Dayton Valley.	Quantity and quality of urban-suburban runoff from Eagle Valley; quantity, constituents, and ultimate disposition of treatment-plant discharges; number, type, and capacity of agricultural diversions; generalized description of the surface- and ground-water hydrology in consideration of ongoing development of urban-suburban communities; samples of stream sediments to monitor mercury contamination.
K Churchill Valley (Lahontan Reservoir)	498	Carson River below Lahontan Reservoir, near Fallon, Nev. 10312150	Diversion of flows into Lahontan Reservoir through the Truckee Canal; storage and release of flows at Lahontan Dam; inflow of Carson River; evaporation rate of lake.	Quantities and constituents of flows of the Truckee Canal and Carson River; area-elevation-capacity and evaporation characteristics of the reservoir; historical release schedule and spills at dam; alternative potential release schedules based upon alternative upstream inputs; description of the impact of water storage on the surrounding ground-water system.
L Fallon Agricultural area	([1])	No representative station	Agricultural diversions from Truckee Canal and releases from Lahontan Reservoir; usage of shallow fresh ground-water lens for municipal and domestic water supply; high water table resulting from seepage of diverted flows into the ground.	Number, type, and capacity of diversions and ultimate disposition of diverted flows; locations, area, and volume of principal water bodies; generalized description of origin and characteristics of shallow aquifer; quantities of evapotranspiration from irrigated fields.

TABLE 4. - Hydrologic subunits and associated characteristics for project planning--Continued

Subunit symbol and name	Subunit area (square miles)	Representative gaging station and number	Significant physiographic and land-use characteristics, and management practices affecting water quality	Hydrologic characteristics pertinent to water-quality assessment
M Stillwater-Carson Lake	([1])	No representative station	Irrigation runoff, seepage, and spills from Lahontan Reservoir routed to Carson Lake and the Stillwater National Wildlife Refuge. These are major feeding and breeding areas for large numbers of migratory wildfowl agricultural uses in subunit L and storage in subunit K that affect quantity of water reaching wildlife areas.	Points of surface inflow into Carson Lake and the Stillwater National Wildlife Refuge; location, area, and volume of principal water bodies; generalized hydrologic description of the sinks for comparison of altered and natural conditions; trends in enlargement or shrinkage of water bodies favored by wildfowl; quantity and quality of water available to wildlife area under alternative upstream flow regimens.

[1]Area to be determined during this study. The combined areas of subunits L and M equal 2,338 square miles.

BASINWIDE STUDIES

Assessment Workshops

Purpose and Scope

Previous Geological Survey assessments have developed informal lines of communication with concerned planners and managers over a period of several months. The Truckee-Carson Assessment has attempted, through a workshop technique, to directly involve administrators, managers, planners, and scientists concerned with resource development in the two basins in the intense, cooperative, interactive effort to establish a common perspective of water-resources problems.

Approach

The assessment workshop is a technique developed by the Institute of Resource Ecology of the University of British Columbia in the course of formulating methods for adaptive environmental assessment and management (Holling, 1978). These methods were derived from the Institute's involvment in environmental impact assessments dealing with a wide range of resource problems in a number of international settings.

The institute developed the workshop technique as an alternative to two commonly accepted approaches to environmental assessments: (1) the formalization of structured assessment procedures, or (2) the creation of large interdisciplinary teams to tackle resource-management problems. The first approach, establishing a formal series of independent work tasks and consulting contracts, usually has had only minor provisions for coordination and integration of the separate elements and often has omitted consideration of cross-disciplinary interactions. In contrast, the interdisciplinary team approach has attempted to promote communication among disciplines, often involving large groups, big budgets, and long time frames. This approach, however, has not always been successful. Individual studies within disciplines often tend to become bogged down in research details irrelevant to key management problems, activities among team members often become uncoordinated, and products of large interdisciplinary teams often include highly complex models that defy understanding by either the modelers or client decisionmakers.

In contrast to either formally structured, single-discipline or large-team approaches to environmental analysis and management, the workshop process uses a technique involving a smaller "core-team" of scientists. These scientists interact with a wider group of experts and managers during a series of short-term, intensive workshops, using the construction of a simple systems model as a focus of discussion. The institute has found that a small interdisciplinary group of people working with a specific goal (model) in a well-structured atmosphere over a short period of time has several advantages over other assessment approaches. The group is forced to recognize that not all elements of the hydrologic or economic systems being examined are of equal importance, and that value judgments have to be made about the relative importance of various aspects of the problems being considered. The scientists present are restrained from their tendency to subdivide problems into increasingly finer levels of detail and specialization that may totally miss major management concerns. The managers and administrators in the workshop become familiar with some of the basic assumptions and limitations involved in representing complex problems by quantitative models. Success of this process, however, can be achieved only if appropriate people are involved in the workshop groups. The key participants are (1) disciplinary specialists; (2) methodologists familiar with modeling techniques; and (3) managers and decisionmakers who ultimately will use the assessment products.

The workshop model is a device used to focus the discussions of the group and to structure the course of the workshop. In interdisciplinary discussions which do not have such a focus, much time is wasted in general discussions of what is "important" to particular interests or individuals. When these factors are brought into the open and quantified as part of a systems model, their relative importance can be judged by all the workshop participants. Some specialists find that modeling workshops can become painful; many factors that they subjectively have assumed to be "important" turn out to be irrelevant for predictive purposes.

The workshop model is not an end in itself, and, as a tool for focusing communication, its predictions do not need to be precise. The workshop model should never be more detailed than necessary to capture the essential behavior of the system being studied, because an overly complex model is unlikely to be understood by decisionmakers, and the probability of making a wrong and critical assumption in the formulation of a model increases rapidly with the number of variables being considered.

The first assessment workshop was held in October 1978 at the beginning of the project-planning process. Specific objectives of the workshop were (1) to rank the water-resource problems in order of importance to the participants, (2) to set practical bounds for consideration of potential management responses to those problems, (3) to indicate areas of critical needs for more information on the resources, and (4) to establish effective and continuing communication between the workshop participants. The list of priorities developed in the workshop was then used by the assessment team as a basis for further project planning (page 15).

A second workshop in December 1979 was used to evaluate the structure of the detailed hydrologic and water-quality models being developed in other elements of the assessment (below and page 34).

Communication of Results

The application of the workshop modeling process to the assessment will be documented in a section of the summary report in the project (table 6).

Hydrologic Model

Purposes

A model that routes flows through the basins will serve three main purposes. First, it would predict the changes in reservoir and lake levels and in streamflows that would result from changes in management decisions. Second, it would translate synthesized flow records downstream to assess the impact of man on the flow regime. Third, it would provide the basis on which transport of water-quality constituents must be calculated. Knowledge of both flow and transport is necessary to evaluate the response of the hydrologic system to alternative water-quantity and water-quality management schemes.

Review of Existing Models

As described below, at least four flow models have been built for parts of the basins. Each of these models has served specific purposes. The broader scope and spatial coverage of the assessment suggests the construction of a more general flow model. Whether this model is a new model constructed by adapting available general models to the problem, or is an extension of one of the existing models requires a more detailed comparison of the existing models with assessment needs. A simple model is desirable because it is more easily understood, has less stringent data requirements and fewer assumptions, and is more likely to be used. The least-detailed model required to adequately describe the flow dynamics will be used.

Desert Research Institute (Butcher and others, 1969; Fordham and Butcher, 1970; and Fordham, 1972) developed a combined flow model and optimization routine to maximize beneficial use of the surface water of the basins. The model is based on partially reconstructed records at a number of sites for the period 1925 to 1967. The flow model accounts for gains and losses of water in most reaches of the basins by assuming a monthly mass balance. The principal uncertainties are the monthly ground-water storage changes in the Truckee Meadows area, the amount of spillage from the Truckee Canal into the lower Truckee River, and the timing and amounts of diversions, returns, and ungaged inputs in Carson and Dayton Valleys. The model has two shortcomings for the assessment. First, it does not incorporate Stampede and Martis Creek Reservoirs, built since the model was developed. Second, it does not disaggregate the West and East Forks of the Carson River, a requirement for considering proposed reservoirs on the East Fork.

The U.S. Bureau of Reclamation constructed a similar model excluding Pyramid Lake but including proposed reservoirs in the upper Carson River basin. The model serves as a tool for deriving operating criteria for the proposed reservoirs and predicting modified monthly flows downstream. Although the Reclamation model is more current, the Desert Research Institute model contains a more general formulation of the Truckee Meadows hydrology. Otherwise the two models have similar uncertainties.

Linsley and Kraeger (Sierra Club Pyramid Lake Task Force, 1975), on behalf of a Sierra Club Task Force, constructed a flow model with monthly time steps for the basins from the Fort Churchill gage downstream on the Carson River and from the Vista gage downstream on the Truckee River. The model's principal inadequacy is its limited spatial coverage.

Gupta and Afaq (1974) constructed a flow model of the Truckee River from Tahoe City to Nixon, using explicit and implicit finite-difference solutions to the unsteady flow equations. They concluded that the accuracy of model predictions was highly dependent upon the accuracy of lateral (tributary and diversion) flow data, data which are not generally collected. Because this model is spatially limited, has data requirements difficult to satisfy, and requires hourly time-steps, it is inappropriate for the assessment.

A model which covers the entire basins and disaggregates the basins as indicated in figure 6 is desirable to evaluate the impacts of management alternatives on flows and water quality in the Truckee-Carson system. In each of these subunits the flow model should consider only the necessary components of those flow components shown schematically in figure 6.

Consideration of up to 50 years of simulation time may be necessary to evaluate the responses of the hydrologic system to some alternatives. Simulation for such a long period will require that the model be reasonably simple if it is to be run many times. To be useful to managers, the model will have to predict monthly or weekly flows. Careful consideration of the tradeoffs between accuracy and simplicity will be necessary before a time-step can be chosen.

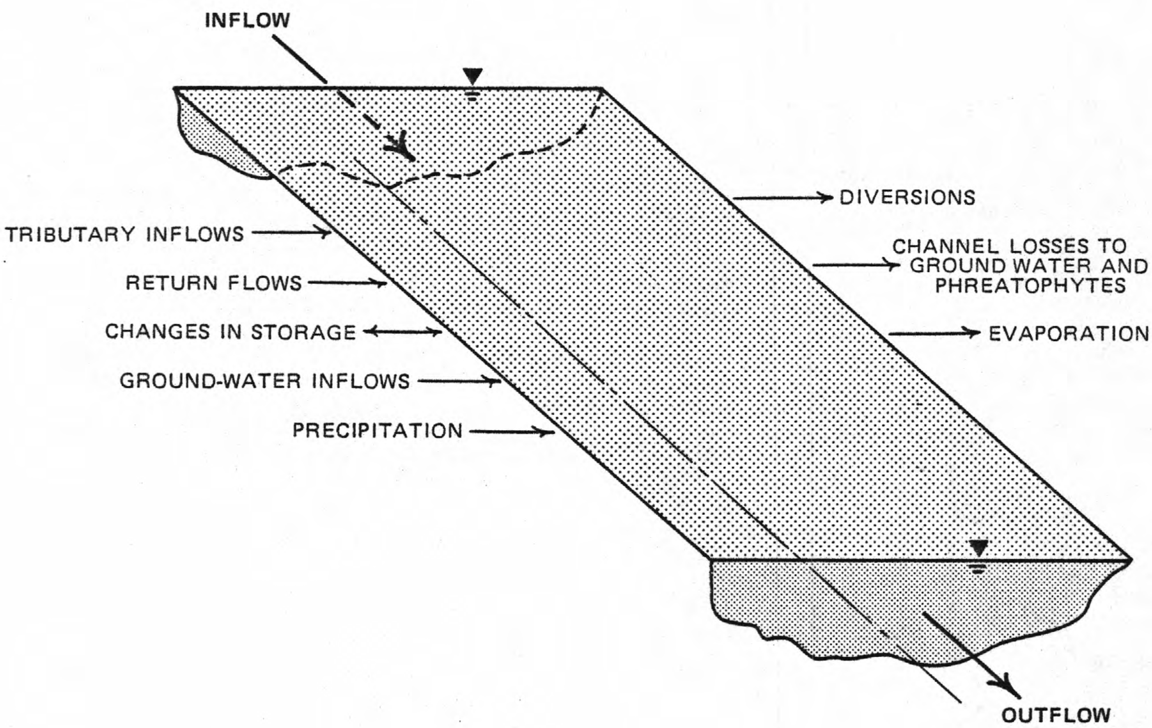

FIGURE 6.--Schematic diagram of an example model reach and components of flow.

Possible Model Equations and Data Requirements

The uses of the model will dictate what level of detail will be necessary in computing flows in time and space. The time-step, spatial resolution, and basin geometry will in turn demand that a particular set of flow equations be modeled. The mass balance (continuity) equation will be used in some form; whether or not the flow (momentum) equation will be used is yet to be determined.

The more detailed flow models require more extensive flow and channel-geometry data than the less detailed models. The most detailed models require upstream and downstream flow records, relations between depth and cross-sectional area, reach lengths, channel slopes, lateral inflows and outflows, and channel roughnesses. The least-detailed models require only upstream flows and lateral inflows and outflows. Data requirements for the flow model to be used will lie somewhere in between.

Communication of Results

A U.S. Geological Survey publication will be prepared to describe the basic hydrology of the two basins, the formulation and development of the hydrologic model, and the results of selected runs on the model. The completed model, with documentation on its assumptions and appropriate applications, will be made available to all interested agencies.

INTENSIVE STUDIES OF SELECTED REACHES OF THE TRUCKEE RIVER

Predictive Water-Quality Models

Major river quality issues in the Truckee-Carson system result from the designation of fishery habitats for Salmonid species as a primary beneficial use to be protected by water-quality standards. Problems exist in meeting published criteria for temperature, un-ionized ammonia, nitrates, nitrites, dissolved oxygen, and trace metals. A critical question for water-quality planners is the issue of how applicable published criteria are to this specified hydrologic system. Published criteria for Salmonid protection are so strict for many parameters that the stated concentration limits may never be technically or economically achievable. Scientific information is needed to define cause-and-effect-relationships that determine river-quality and how that quality actually impacts the resources in the lower river.

A number of intensive studies have been performed on the Truckee River from Reno to Derby Dam in conjunction with planning wastewater facilities and areawide water-quality management. The data from these studies provide a series of static observations of water quality in time but do not provide managers with quantitative means to evaluate the effects of management alternatives on the resource. A predictive water-quality transport model for the Truckee River from Reno to Pyramid Lake and for the Truckee Canal from Derby Dam to Lahontan Reservoir will be of great value for assessment of the impacts of future river-quality planning and management alternatives on the water resources. The prediction of water temperatures and concentrations of dissolved oxygen and various forms of nitrogen, in response to water-quality and flow-management alternatives, will be valuable to fishery managers. Such predictions may be used in judging the probabilities of success and potential costs of various rehabilitation strategies for the lower river.

Water-Quality Characteristics to be Modeled

Critical factors of concern to those evaluating the waste-treatment alternatives and options for fishery management will be modeled, including:

1. Water temperatures.
2. Concentrations of dissolved solids.
3. Dissolved-oxygen (DO) concentrations.
4. Concentrations of the inorganic nitrogen species (nitrate, nitrite, and ammonia) and total phosphorus.

Model Development

The ultimate success of a water-quality model must be measured by the degree of its acceptance and use. A balance must be met between simplicity for ease of use and understanding and the complexity and sophistication required to achieve the desired predictive accuracy. The assessment will attempt to use the simplest models that can be successfully calibrated and verified against observed river-quality conditions. Rather than develop new models for the study, existing steady-state transport models will be examined for applicability to the Truckee system and modifications made as required.

Hydrologic analysis--Hydrologic analysis for the transport models will concentrate on definition of the probability and duration of the modeled flow regimens and the development of time-of-travel curves based on stream geometry and dye studies.

The critical periods with respect to flow are late-summer droughts when water-quality conditions are extreme and the period from March to June when the Lahontan cutthroat trout and Cui-ui lakesucker would be in the river to spawn. Existing streamflow data form an inadequate basis for statistical analyses due to incompatible periods of record between sites and the effects of adding hydraulic structures at different times to the system. Two sets of synthetic records will have to be compiled for hydrologic analysis for input to the transport models: (1) A time series of records reflecting flows that would have occurred if all existing structures had been operated under current criteria for the entire period of record, and (2) a series representing flows that would have occurred if the system had been left in its natural state for the entire period of record. The previously described hydrologic model (p. 31) will be used to generate these records.

Time-of-travel and dispersion information are needed for computation of transport and dilution of nutrients and oxygen demands. Estimates of travel time may be derived from flow models or from dye-tracer studies. Dispersion estimates may be made from flow and concentration data or can be derived from carefully conducted dye studies. A previous dye study conducted in the reach from Reno to Derby dam found time-of-travel estimates derived from flow records to compare favorably with the dye measurements for high-flow conditions (O'Connell and others, 1962). The assessment will use both hydrologic data and dye studies to compute time of travel downstream from Reno for representative high and low flows.

Reaeration rates--Reaeration rates are often the most important and, at the same time, the least understood factors in the preparation of a dissolved-oxygen model. Gas tracers have successfully been used to experimentally determine reaeration rates that have been, in terms of model performance, equal to or superior than those derived from empirical equations or hydraulic analysis (Tsivoglou, 1967, and Rathbun and Grant, 1978). The shortcoming of this technique is that the relative inefficiency with which the tracers are dissolved in the stream limits the length of the observed reach to less than 5 miles. Budget and personnel constraints will limit field measurements of reaeration to two or three segments of the Truckee River below Reno. Segments will be selected that are hydraulically respresentative of the remainder of the lower river and that also coincide with historical spawning beds of the Lahontan cutthroat trout. Reaeration measurements will be made during periods when the trout would be expected to be active in the river (March to June) as well as during low-flow periods.

Collection and analysis of water-quality data--An intensive data collection and analysis program is planned to develop, calibrate, and verify the water-quality models. Model verification will also be attempted by using data sets from previous studies, notably the 1977 monitoring conducted for the cities of Reno and Sparks during extreme low flows (Pacific Environmental Laboratory, 1979).

The river below Reno will be divided into three reaches:

1. Steamboat Creek to Derby Dam (18.6 mi)
2. Derby Dam to Marble Bluff Dam (34.9 mi)
3. Derby Dam to Lahontan Reservoir (Truckee Canal, 31.7 mi).

An intensive study will be conducted during two critical periods; March to June and during late summer low flows. Samples will be collected at 4 to 6 sites in each reach every 2 hours during a 24- to 48-hour period. Determinations will be made for dissolved oxygen, water temperature, specific conductance, and pH. Additional samples will be collected every 4 hours and analyzed for BOD, NH_3-N, NO_2-N, NO_3-N, ortho- and total phosphorus, and chlorophyll. Twice-daily samples will be collected at North Truckee Drain, Steamboat Creek, at the discharge of the Reno-Sparks sewage plant, and at Vista prior to the start of the intensive surveys to establish antecedent input loading.

BOD analyses will be run for a 20-day duration to determine reaction rates and "ultimate" BOD's. Both inhibited and uninhibited BOD's will be run to assess the effects of nitrification on the reaction rates.

Interpretation and Presentation of Results

The model will be used as a tool to predict the effects of various proposed advanced waste treatment processes for the Reno area on river quality in the Truckee River downstream from Reno and in the Truckee Canal. The predictions and the model should aid management in evaluating alternative management proposals and water-quality standards. The model will be documented in a Geological Survey publication discussing water quality in the Truckee River.

Spawning Habitat Studies

Problem Statement

The Truckee River below Reno historically provided both spawning and nursery habitat for the Lahontan cutthroat trout and the Cui-ui lakesucker. A variety of factors, including water pollution, reduced flows due to agricultural diversions, blockage of fish migration by diversion structures, overharvesting, and siltation of the Truckee River delta at Pyramid Lake, have resulted in the decimation of native Lahontan cutthroat trout and Cui-ui lakesucker populations. Neither fish has successfully spawned in the Truckee River since the 1930's, when siltation due to reduced flows and the resultant lowering of Pyramid Lake blocked the mouth of the river to spawning runs. By the early 1940's the Lahontan cutthroat trout had become extinct in Pyramid Lake and the Cui-ui lakesucker population had greatly declined. The Cui-ui lakesucker was listed as an Endangered Species in 1967. The Lahontan cutthroat trout was listed as Endangered in 1970 and subsequently reclassified to Threatened in 1975 due to improved success in maintaining populations through hatchery operations.

As part of a program to assess the feasibility of reestablishing the fishery in the Truckee River, the U.S. Fish and Wildlife Service has conducted studies of the hatching success and survival of fry of Lahontan cutthroat trout at a number of sites both above and below Reno (U.S. Fish and Wildlife Service, 1966; Johnson and others, 1971; McBrayer and Ringo, 1975; and Bailey and Scoppettone, 1979). These studies have documented 99- to 100-percent mortalities for eggs or fry at all potential spawning sites studied below Reno. Cause-and-effect relationships between observed egg and fry mortalities and various water-quality characteristics have not been adequately documented. Speculation on the causes of egg mortalities have centered on:

1. The effects of high water temperatures.
2. Low intragravel dissolved-oxygen concentrations due to clogging of the gravels by fine sediments and (or) the presence in the sediments of high concentrations of oxygen-demanding substances.
3. Toxic effects of trace elements or organic contaminants in the bed sediments.

A fourth possibility that has not previously been considered is the effects of ground-water inflow into the streambed. The reach of the Truckee River from Derby Dam to Nixon is known to be receiving substantial ground-water inflow by seepage from the Truckee Canal and agricultural return flows (Van Denburgh, and others, 1973). Ground water is commonly low in dissolved oxygen and, in most of the reach of the lower Truckee River, is also much higher in dissolved solids than the river water.

Information on the potential cause-and-effect relationships between river quality and Lahontan cutthroat trout egg and fry mortalities is needed to fully evaluate the impact of river quality and quantity management alternatives on the lower Truckee River. Detailed information on potential spawning habitats in the Truckee River below Derby Dam is critical to the effort of the Fish and Wildlife Service and the Pyramid Lake Indian Tribe to reestablish the fishery in the lower river. The Fish and Wildlife Service is proposing to initiate another series of egg reproduction studies and has requested assistance from the assessment project in designing and executing water-quality monitoring during the studies.

Approach

In the spring of 1980, the U.S. Fish and Wildlife Service will construct artificial redds (spawning beds) for the implantation of Lahontan cutthroat trout eggs at several locations in the Truckee River, including at least one site above Reno where successful reproduction was observed in previous studies. Two egg reproduction experiments will be conducted at each site; one in the early spring (March) before water temperatures are likely to exceed critical levels and the second during the generally accepted historical spawning period of April to June.

The Geological Survey will monitor water quality at three sites; one site above Reno and two sites below Reno that previously had experienced high egg mortalities. At each site, intensive monitoring will be conducted to determine the quality of the bed materials, the intragravel fluids, and the stream water. Characteristics to be monitored and sampling frequencies are shown in table 5. The constituents and properties selected for chemical analysis are those known to be present in the Truckee River from previous studies and to be either toxic to aquatic life or likely to create an oxygen demand in the sediments.

TABLE 5. - Monitoring characteristics for the fishery habitat study

	Bed materials[1]	Intergravel fluids	Stream water[2]	Ground water
Basic sampling schedule	Duration of study[3]	Weekly	Weekly	Duration of study[3]
Field determinations				
Flow	--	--	X	--
Velocity	--	--	X	--
Temperature[3]	--	X	X	X
pH[4]	--	X	X	X
Specific conductance[4]	--	X	X	X
Dissolved oxygen[4]	--	X	X	X
Laboratory determinations				
Sediment concentration	--	X	X	--
Particle-size distribution	X	X	X	--
Ammonia nitrogen	X	X	X	X
Nitrite nitrogen	X	X	X	X
Nitrate nitrogen	X	X	X	X
Organic nitrogen	X	X	X	X
Organic carbon	X	X	X	X
Biochemical oxygen demand	X	X	X	X
Cadmium	X	X	X	X
Copper	X	X	X	X
Iron	X	X	X	X
Lead	X	X	X	X
Mercury	X	X	X	X
Zinc	X	X	X	X
Arsenic, chromium, and manganese	X	X	X	X

[1]Chemical analysis to be run on the clay-silt (0.020-mm) sized fractions.

[2]Stream samples may be deleted if comparable data for the site are available from another study element of the assessment.

[3]Continuous thermograph at each site.

[4]On-site determinations. One 24-hour diel study (hourly samples) of intragravel and stream waters will be performed at each site in addition to weekly samples.

Bed materials will be sampled three times (prior to the construction of the redds, and at the midpoint and the end of the study), using techniques described by McNeil and Ahnell (1964). Particle-size analyses will be performed on bed materials covering the range from 0.002 to 152 mm. Most toxic minor elements and organics tend to concentrate in the fine-grained portions of fluvial sediments. To provide a uniform basis for comparison of chemical analyses of bed sediments between sites, those analyses will be performed on the clay-silt sized (less than 0.020 mm) fractions of the bed materials.

Intragravel fluids will be sampled once prior to construction of the redds and weekly during the study. Initial samples will be collected with a peristaltic pump from a well point driven into the gravels. Samples during the study will be collected by using plastic standpipes modified from designs by Terhune (1958), Gangmark and Bakkala (1958), and Coble (1961).

Stream-water samples will be discharge-integrated, using standard techniques (Guy and Norman, 1970). The presence of ground-water inflow to the bed sediments will be tested by adapting techniques developed for the measurement of ground-water seepage into lakes (Lee, 1977). Ground-water seepage, if present, will be sampled at the beginning, midpoint, and end of the study, using techniques described by Lee and Hynes (1978).

Interpretation and Presentation of Results

The data collected will be statistically analyzed for significant differences in water quality between sites and in comparison with observed egg and fry mortalities. The data will be tested for relationships between the dissolved-oxygen regimen in the gravels and sediment transport and deposition in the river. The results of the water-quality monitoring will be presented in a Geological Survey report.

COMMUNICATION OF THE ASSESSMENT RESULTS

Mutual understanding between resource scientists and planners is most easily attained by conducting resource assessments as joint ventures from beginning to end. The effective approach begins with joint delineation of public policies, long-range goals, and problems; continues with exploration of study methods; proceeds with joint evaluation of planning assumptions and an examination of alternatives to be tested; and ends with an iterative process of evaluation, discussion, and the application of results.

The effectiveness of the Truckee-Carson assessment will be judged on three bases: (1) The quality of the scientific analyses, (2) the effectiveness of communicating those results, and (3) the timeliness of producing the planned products. The communication media to be used in this study include intensive modeling workshops, public meetings, formal Geological Survey publications, journal articles, and information memorandums and news releases. In addition, individual products of the study, such as base materials, computer data bases, and mathematical models will be made available for use by resource planners and managers.

Publications

An important element of the assessment will be the formal presentation of the study results. Reports on the assessment will be designed so that the results can be easily and quickly understood, with emphasis on the graphical presentation of results. The principal reports will be produced through formal Geological Survey report series (table 6).

TABLE 6. - Report products planned for the assessment

Study element	Report topic	Probable publication format
All	Assessment workplan	Open file
Historical development	Hydrologic history and development of the Truckee and Carson River basins	Circular
Hydrologic characteristics	Hydrologic characteristics of selected subunits of the Truckee and Carson River basins	Professional Paper
Assessment workshops	Application of adaptive environmental assessment techniques to project planning and coordination for the Truckee-Carson River-Quality Assessment	Open file
Hydrologic model	Hydrologic analysis in support of water-quality assessment of a water-short region	Circular
Water-quality studies and summary	An assessment of water-quality constituent transport in selected reaches of the Truckee River and Truckee Canal using predictive models; an investigation of water quality related to spawning habitat for the Lahontan cutthroat trout, Truckee River basin; and methods for the assessment of critical water-quality problems in a water-short region, Truckee and Carson River basins	Circular

Additional open-file reports may be produced to quickly disseminate intermediate results of the project. Short technical papers and journal articles may also be used to communicate details of study elements to the scientific community. Informal updates on the progress of the study will be made through local press releases and information memorandums. Table 7 shows the tentative schedule for the completion of individual elements and reports for the study.

Public Presentations

The assessment workshops (page 29) will provide an effective means of direct communication with a limited audience of concerned managers and planners. Although the study does not intend to hold public meetings as is commonly done by "208" planning groups and other public planning agencies, members of the assessment team will be available upon request to make presentations of the study results at various public meetings.

Two audiovisual programs about the assessment will be produced. One will be a short program of 15-20 minutes and the other will run for 50-60 minutes. The shorter program will be a slide-tape package that can be readily duplicated and sent to interested users for viewing at their own convenience. The longer program will be a slide package for use with live narration by members of the project staff. Both programs will use only well-composed and technically excellent color slides depicting features of the study area, graphical study results, and other illustrations. The programs will be developed during the course of the study and revised as the study progresses. The first run of the long program was made in December 1979, at the second assessment workshop. Completion of the shorter, packaged program is scheduled for March 1981, after most of the project results are available.

Other Media

Computer Data Files

The Geological Survey's WATSTORE data system includes three hydrologic data files that will be used to store, retrieve, and statistically and graphically process data collected during the assessment:

1. The Daily Values File accommodates daily data such as mean water discharges, total daily rainfall.

2. The Unit-Values File stores data collected at uniform time intervals up to 2,880 observations per day per item, such as rainfall and runoff collected during a storm event or water-quality data from an automatic digital monitor.

TABLE 7.-- Schedule for completion of study elements

STUDY ELEMENTS	1978			1979												1980												1981								
Work element	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
ASSESSMENT WORK PLAN	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X															
PROJECT DESIGN	X	X	X	X	X	X	X	X	X	X																										
First workshop	X																																			
Project planning	X	X	X	X	X	X	X	X	X	X																										
Review and revision				X	X	X	X	X	X	X																										
REPORT WRITING				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X															
Draft report				X	X	X	X	X	X																											
Typing and illustrations									X	X																										
Colleague reviews										X	X	X	X	X																						
Response to reviews													X	X	X	X	X	X	X																	
Typing revisions																		X	X	X																
Final draft																					X															
HISTORICAL DEVELOPMENT																X	X	X	X	X	X	X	X	X	X	X	X	X	X							
REPORT WRITING																X	X	X	X	X	X	X	X	X	X	X	X	X	X							
Research literature																X	X	X	X	X	X															
Outline																			X	X																
Expanded outline																				X	X															
Draft report to reports section																							X	X												
Typing manuscript																								X	X											
Colleague reviews																									X	X	X									
Response to reviews																											X	X								
Typing revisions																												X	X							
Final draft																													X							

TABLE 7.-- Schedule for completion of study elements--Continued

STUDY ELEMENTS Work element	1978			1979												1980												1981								
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
HYDROLOGIC CHARACTERISTICS	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x							
COMPILE BASIC DATA	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x															
Prepare base maps	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x															
Delineate drainage areas			x	x	x	x	x	x	x																											
Determine river miles									x	x	x	x																								
Prepare stream profiles										x	x	x	x	x	x	x	x																			
Compile hydrologic data													x	x	x	x	x	x	x	x	x															
Analyze flow statistics																x	x	x	x	x	x															
Inventory hydrologic structures																x	x	x	x	x	x															
REMOTE SENSING								x	x	x	x	x	x	x	x	x	x																			
Obtain Landsat images								x	x																											
Photo interpretation									x	x	x	x	x	x	x	x	x																			
Compile and draft													x	x	x	x	x																			
REPORT WRITING												x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x							
Outline												x	x																							
Expanded outline													x	x																						
Graphics													x	x	x	x	x	x	x	x																
Draft report to reports section																	x	x	x	x	x	x														
Typing manuscript																						x	x	x												
Colleague reviews																									x	x	x									
Response to reviews																											x									
Typing revisions																												x								
Final draft																													x							

TABLE 7.-- Schedule for completion of study elements--Continued

STUDY ELEMENTS Work element	1978			1979												1980												1981								
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
HYDROLOGIC MODEL							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MODEL DEVELOPMENT							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X													
Review existing models											X	X	X	X	X	X	X	X	X	X	X	X	X													
Select model configuration																		X	X	X	X	X	X													
Determine data characteristics																		X	X	X	X	X	X													
Construct data set																		X	X	X	X	X	X													
Program model																			X	X	X	X	X	X	X											
Connect with graphics																			X	X	X	X	X	X	X											
Calibrate																									X	X										
Test																										X	X									
MODEL APPLICATION																							X	X	X	X	X	X	X							
Formulate test scenarios																									X	X	X	X	X							
Run scenarios																												X	X							
REPORT WRITING																							X	X	X	X	X	X	X	X	X	X	X	X	X	X
Outline																							X	X												
Expanded outline																								X	X											
Draft report to reports section																									X	X	X	X								
Typing manuscript																												X	X							
Colleague reviews																														X	X	X				
Response to reviews																																X	X	X		
Typing revisions																																			X	
Final draft																																				X
ASSESSMENT WORKSHOPS	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
WORKSHOPS	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X																					
First workshop	X																																			
Modification of model					X	X																														
Preparation for second workshop											X	X																								
Second workshop															X																					

TABLE 7.-- Schedule for completion of study elements--Continued

STUDY ELEMENTS	1978			1979												1980												1981								
Work element	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
ASSESSMENT WORKSHOPS--Continued	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
REPORT WRITING[1]																															X	X	X	X	X	X
Outline																															X					
Expanded outline																																X				
Draft report to reports section																																	X			
Typing manuscript																																	X			
Colleague reviews																																	X	X		
Response to reviews																																		X	X	
Typing revisions																																			X	X
Final draft																																				X
WATER-QUALITY STUDIES AND SUMMARY	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
REVIEW HISTORICAL DATA				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X																	
Inventory and compile				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X																	
Analyze hydrology				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X																	
Analyze loadings															X	X	X	X	X																	
Analyze temperatures				X	X	X	X	X	X	X																										
DATA COLLECTION	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X									
Design field program			X	X	X	X	X									X	X	X	X																	
Install monitors														X	X	X	X	X	X	X																
High-flow synoptics								X	X											X	X	X														
Data reduction and analysis										X	X	X	X									X	X	X												
Low-flow synoptics												X	X										X	X	X											
Data reduction and analysis													X	X	X	X									X	X	X	X								
Time-of-travel fieldwork								X	X			X	X	X	X		X	X	X				X	X												
Data reduction and analysis									X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X										
Reaeration fieldwork													X	X						X	X	X														
Data reduction and analysis															X	X	X					X	X	X	X											

[1]Production of a report is contingent upon completion of hydrologic model element. Report writing schedule is therefore subject to revision.

TABLE 7.-- Schedule for completion of study elements--Continued

STUDY ELEMENTS	1978			1979												1980												1981								
Work element	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
WATER-QUALITY STUDIES AND SUMMARY--Continued	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
WATER-QUALITY MODELS														X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
Review and select models														X	X	X	X	X	X	X																
Modify and test																						X	X	X	X	X	X									
Calibrate																							X	X	X	X	X	X	X							
Verify																												X	X	X	X					
Prepare scenarios																								X	X	X	X	X	X							
Run scenarios																																X	X			
FISH HABITAT STUDY														X	X	X	X	X	X	X	X	X	X	X	X											
Design data collection														X	X	X																				
Install redds																	X	X																		
Data collection																	X	X	X																	
Data reduction and analysis																		X	X	X	X	X	X	X	X											
REPORT WRITING																						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Outline																						X														
Expanded outline																							X													
Draft report to reports section																								X	X	X	X	X								
Typing manuscript																												X	X							
Colleague reviews																														X	X	X				
Response to reviews																																	X	X		
Typing revisions																																		X	X	
Final draft																																				X

3. The Water-Quality File stores water-quality data and associated measurements. Each water-quality value is referenced to sampling site, date and time of sampling or measurement, and a unique parameter code identifying the type of data and methods of collection and analysis. Data stored in this file are automatically transferred to the STORET system of the Environmental Protection Agency for parallel storage.

In addition, the Geological Survey's NAWDEX (National Water Data Exchange) computer files will be used to inventory data collection sites in the study area. Information stored in this system includes site locations, identification of agencies collecting the data, and the types of data and frequency of collection. Information stored in all these Geological Survey data bases will be available for use by planners and managers concerned with the resources of the Truckee-Carson basins.

Base Materials

The standard base map for the study will be a 1:250,000-scale topographic map prepared by the U.S. Geological Survey expressly for the study. The map will be a composite of five 1:250,000-series quadrangle maps, each separated into drainage, topographic, cultural, and open-water overlays so that a minimum five-color (including black) rendition of final products is possible. Each of the five quadrangle maps will be checked and revised to assure consistent and up-to-date cultural and hydrographic information throughout the composite. After revision, blackline clear-film positives will be obtained for each separation for the composite map. The blackline positives will then be spliced together and extraneous information outside the study area boundary masked. Finally, composites will be obtained, using appropriate screening of each overlay and color to enhance hydrologic features and allow the additional overlay and enhancement of new information.

Additional base maps at scales of 1:500,000 and 1:5,000,000 will be prepared for use as index maps and for reduction to page-size basin maps for miscellaneous purposes.

An orthophotomosaic composited from four 1:500,000-scale enhanced Landsat images will be prepared for the location of major water bodies, diversions, and areas of high water table. Near-infrared-band imagery will constitute the base for this product which will then be overlaid with visible-band imagery that accentuates the desired features. Cultural information similar to that shown in figure 1 will be composited with the imagery to complete the final product.

Enhanced composite Landsat color images as 1:500,000-scale paper prints and 1:1,000,000-scale color transparencies have been ordered for use in preparing visual aids for audiovisual presentations on the study. These products may also be used in the proposed Professional Paper and other reports to illustrate features of the study area.

All map and photographic materials will be available for inspection by interested people.

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SUPPLEMENT A--PROJECT PROPOSAL FOR THE ASSESSMENT OF WATER-QUALITY LOADINGS IN THE TRUCKEE AND CARSON RIVER BASINS

The following study was originally designed as part of the Truckee-Carson River-Quality Assessment but was dropped because of budgetary and manpower constraints. The Carson River part of the loading study described below was begun in November 1979 as part of an investigation of the water quality of Lahontan Reservoir (Supplement C). The Truckee River part was not funded as of January 1980.

Recently completed "208" studies in the Truckee and Carson River basins have focused attention on the problems of assessing impacts of point and nonpoint pollutant loads on the respective river systems (Washoe Council of Governments, 1978; Carson River Basin Council of Governments, 1978). Adequate data are lacking in both systems to evaluate nonpoint source loadings with respect to dominant land uses and to quantify the impact of such loadings on the receiving waters. Without such analyses, planners and managers cannot predict the effects of rapidly changing land uses on river quality, nor can they rationally assess the effectiveness of alternatives under consideration for treatment of point and nonpoint sources of pollution. To consider the effects of point and nonpoint source loadings on water quality, specific problems in the basins were itemized and an approach was developed to assess some of them.

Loading from Point Sources

The major point discharges of treated sewage are listed in table 8. These discharges contribute to the overall loading of the two rivers and ultimately to the loading of Pyramid Lake and Lahontan Reservoir. There are two principal point sources in the Truckee River basin: (1) Tertiary-treated sewage effluent from sources on the north shore of Lake Tahoe and in the upper Truckee River subunit are discharged into alluvium along the river near the mouth of Martis Creek, and (2) secondary-treated sewage effluent from the Reno-Sparks urban area is discharged into Steamboat Creek just upstream from its confluence with the Truckee River (fig. 7).

TABLE 8. - Major point discharges of treated sewage

Name	Treatment	Quantity (Mgal/d)	Source	Point of discharge	Hydrologic subunit
Truckee River basin					
Tahoe-Truckee Sanitation Agency	Tertiary	2.9	West and north shore Lake Tahoe; Truckee	Subsurface adjacent to Truckee River and Martis Creek.	Lake Tahoe and upper Truckee River
Reno-Sparks joint wastewater	Secondary	18.6	Reno-Sparks area	Steamboat Creek, tributary to Truckee River.	Middle Truckee River
Carson River basin					
South Tahoe Public Utility District	Tertiary	3.5	South Shore Lake Tahoe	Indian Creek Reservoir in headwaters of Carson River. Used for irrigation.	Upper West Fork Carson River and Carson Valley
Minden-Gardnerville Sanitation District	Secondary	.7	Towns of Minden and Gardnerville and adjacent area	Martin Slough adjacent to East Fork Carson River. Used for irrigation.	Carson Valley
Douglas County Sewer Improvement District (Round Hill)	Secondary	1.2	Southeast Lake Tahoe	1968 to 1979 direct to East Fork Carson River. Since 1979, to Williams Slough area for irrigation.	Carson Valley
Incline Village General Improvement District	Secondary	3.0	Northeast Lake Tahoe	Seasonal land application for irrigation or direct to Carson River at north end of valley.	Carson Valley
Carson City	Secondary	2.2	Carson City and adjacent area	1.3 Mgal/d used seasonally for irrigating golf course; remainder through Mexican ditch to Carson River 5 mi downstream from Carson City	Eagle and Dayton Valleys

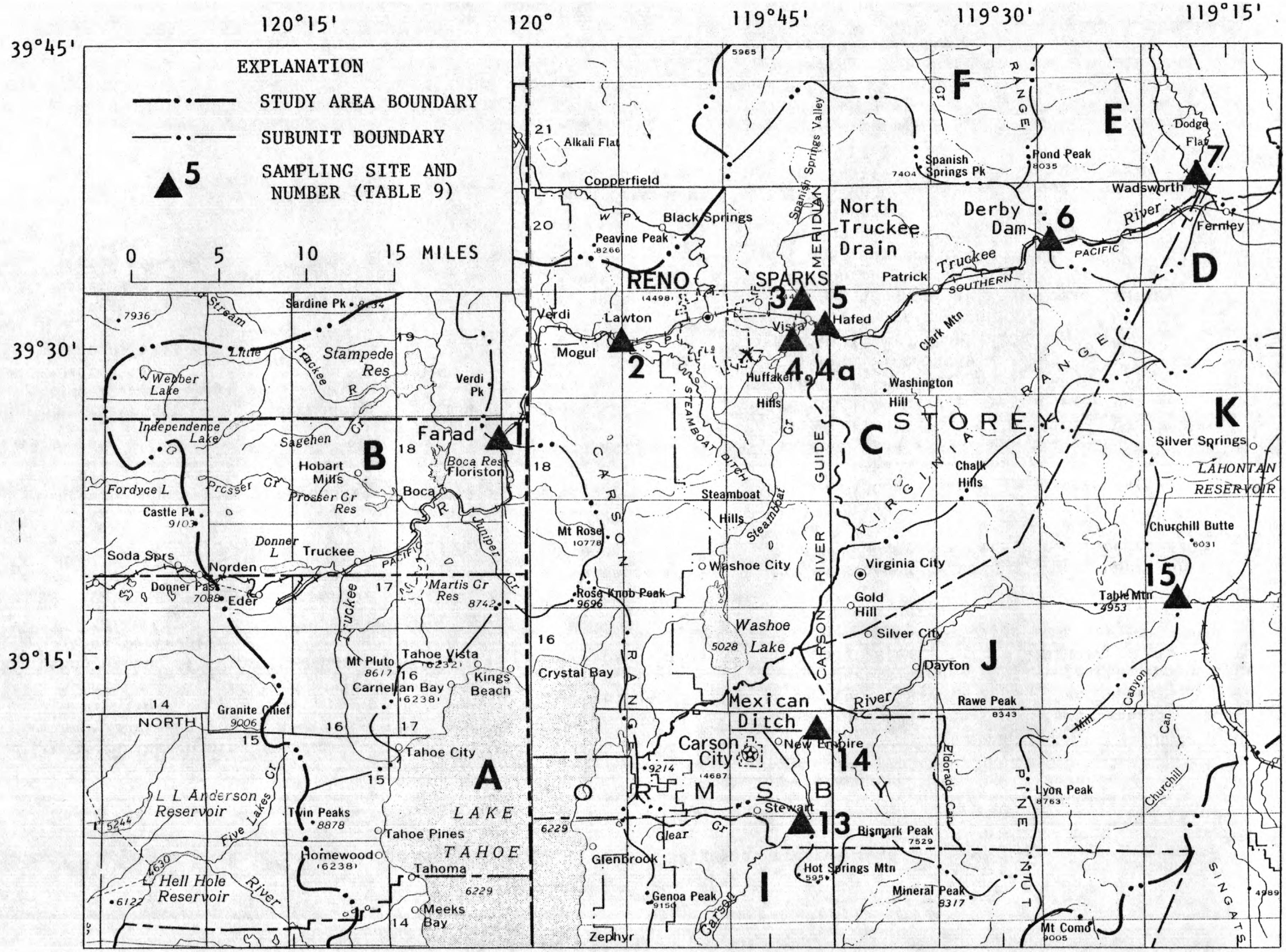

FIGURE 7.--Location of subunits B, C, and J, and water-quality sampling sites in the west-central part of study area. Compare with figure 5.

During the spring and summer, much of the treated effluent discharge in the Carson River basin is applied to the irrigation of pastures and alfalfa fields. Tertiary-treated sewage effluent from the South Lake Tahoe urban area is stored for recreational use in Indian Creek Reservoir and released for irrigation along Indian Creek and in adjacent areas (fig. 8). Secondary-treated sewage effluent from the Minden-Gardnerville urban area is discharged into Martin Slough and thence to local agricultural irrigation or to the East Fork of the Carson River. Secondary-treated sewage effluent from urban areas along the eastern shore of Lake Tahoe is applied to agricultural fields on the west side of the Carson Valley during the growing season and discharged directly into the East Fork and main Carson River channels during winter months. About one-third of secondary-treated sewage effluent from Carson City is used for irrigating a golf course and the remainder is discharged into Mexican Ditch above its confluence with the Carson River.

Loading from Nonpoint Sources

In the Truckee River basin, sources of nonpoint loadings include commercial and residential development in the Lake Tahoe and Upper Truckee River subunits, highway runoff along Interstate 80 in the Truckee Canyon reach above Reno, and storm runoff and septic-tank effluents from rapidly expanding urban development in the Middle Truckee River subunit. Nonpoint sources of major concern in the Carson River basin are agricultural return flows in the Carson Valley and Fallon Agricultural subunits and booming urban development in the Carson Valley and Eagle-Dayton Valley subunits. Mining wastes are of concern in the Upper East Fork of the Carson River, where Bryant Creek has become contaminated by acid wastes from tailings at an abandoned sulfur mine, and in the Carson River from Dayton to Lahontan Reservoir, where streambed sediments are known to be enriched in mercury from the milling in the 1800's of gold and silver ores from the Comstock Lode (Van Denburgh, 1973; Richins and Risser, 1975). Release flows from Prosser, Martis Creek, and Boca Reservoirs may transport medium to high concentrations of fine sediment particles, floccules, and colloids that cause turbidity in the Truckee River. Derby Dam has been a source of sediment that was flushed under the gates into the river channel downstream, resulting in severe damage to the benthic biota (Koch and Hainline, 1976) and probable degradation of trout habitat (Bailey and Scoppettone, 1979).

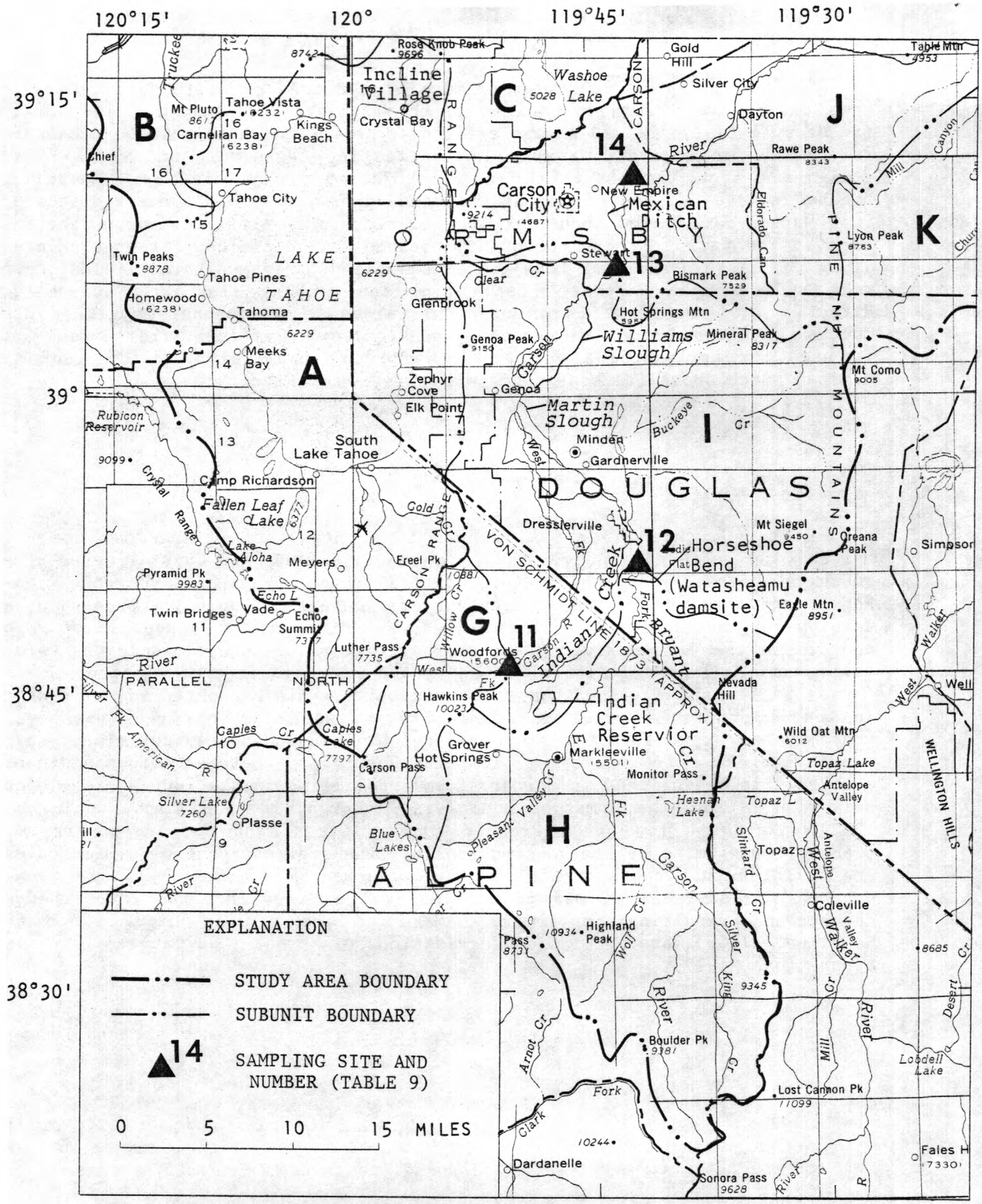

FIGURE 8.--Location of subunits A, G, H, and I, principal locations of sewage discharge, and water-quality sampling sites in the south-central part of study area. Compare with figures 5 and 9.

Approach

The known point and nonpoint sources of water-quality constituents suggest an intensive sampling program for many sites in both basins. In the Truckee River basin, an ideal program would focus on the determination of annual constituent loads derived from the upper Truckee and middle Truckee River subunits and the disposition of those loads as they are transported to Pyramid Lake, or to Lahontan Reservoir via the Truckee Canal. Efforts in the Carson River basin would be concentrated primarily on loads derived from the Carson Valley and Eagle-Dayton Valley subunits to determine impacts upon the river and Lahontan Reservoir. The assessment of loads discharged from the Fallon Agricultural subunit is also implied. Where possible, existing data on water-quality constituent loadings will be integrated with newly collected data.

The assessment team conducted a review of alternative sampling strategies to determine a realistic program that would yield useful results within the time and budget constraints of the study. This review led to the following conclusions:

1. Sampling programs to distinguish between urban and agricultural point and nonpoint source loadings in the Carson Valley and middle Truckee River subunits cannot be developed within the study constraints. The distribution system of diverted flows, including point-source sewage discharges, is such that widespread synoptic monitoring is required to relate land-use activities to water-quality loadings.

2. A comprehensive evaluation of sources, magnitudes, and effects on the Truckee River of urban runoff in the middle Truckee River subunit was also deemed to be beyond the scope of the assessment. However, a program to consider these issues was designed as an outgrowth of the assessment planning and is described in Supplement B.

3. In the Fallon Agricultural subunit water-quality constituents were considered to be much less important than the total quantity of water discharged to the Stillwater-Carson Lake subunit. Thus effort to determine the loads in that water was deemed unwarranted.

4. The principal receiving waters, with respect to water-quality standards and the accumulation of constituents, are Lahontan Reservoir, Truckee River downstream from the Reno-Sparks urban area, and Pyramid Lake. Therefore, the adopted sampling strategy emphasizes the study of constituent loadings to these waters.

5. The adopted sampling strategy provides a sound basis for additional efforts beyond this study. Once the constituent types and total loadings delivered to the principal receiving waters are determined, the value of defining the ultimate sources of the constituents can be readily assessed.

Sampling Strategy and Locations

The sampling strategy developed for the assessment of water-quality loadings in the Truckee and Carson River basins is a regional approach based on the hydrologic subunits previously discussed (p. 22). This approach has two objectives: (1) The accurate determination of annual and seasonal loads of sediment, dissolved solids, and nutrients contributed to the receiving waters of Pyramid Lake and Lahontan Reservoir, and (2) by virtue of site location, a preliminary definition of regional sources for the observed loads to optimize the direction of future studies in the basins.

Seventeen sampling sites were considered for assessing the sediment, nutrient, and organic loadings to Lahontan Reservoir, Truckee River downstream from the Reno-Sparks urban area, and Pyramid Lake. These sites are shown in figure 9 and described in table 9. Nine sites are located to represent flux across subunit boundaries, and eight sites are located to measure flow and constituents moving within subunits.

For the middle Truckee River subunit, two sites will be sampled to determine the gross inputs and outputs of constituents. Inputs will be described by the results of sampling on the Truckee River at Farad (site 1), and outputs will be determined by measurements on the Truckee River at Vista (site 5). To determine the contributions of urban and agricultural runoff and to isolate the discharges from the Reno-Sparks sewage treatment plant (STP), samples will be taken from the Truckee River at Mayberry Avenue bridge below Lawton (site 2), North Truckee Drain just upstream from its confluence with the Truckee River (site 3), and Steamboat Creek upstream and downstream from the STP (sites 4 and 4a).

Measurements at sites 3 and 4 will reflect the aggregate of urban and agricultural nonpoint source loadings from the Truckee Meadows. Further distinction between those loadings will be determined by a proposed intensive urban runoff study described in Supplement B.

For the lower Truckee River subunit (fig. 10), three sites will be sampled to determine gross inputs and outputs of constituents (fig. 8). Inputs will be described by the results of sampling on the Truckee River just downstream from Derby Dam (site 6) and at Wadsworth (site 7). The two sites are required because flow records show a significant increase in the average annual flow between the sites (table 1), perhaps indicating agricultural return flows from subunit D and leakage from the Truckee Canal to the river. Outputs will be described by the results of sampling at Marble Bluff Dam (site 9). Site 8 will be used as a base station for comparisons with historical data because of its lengthy and continuing operation as a sampling site for many water-quality constituents under other programs.

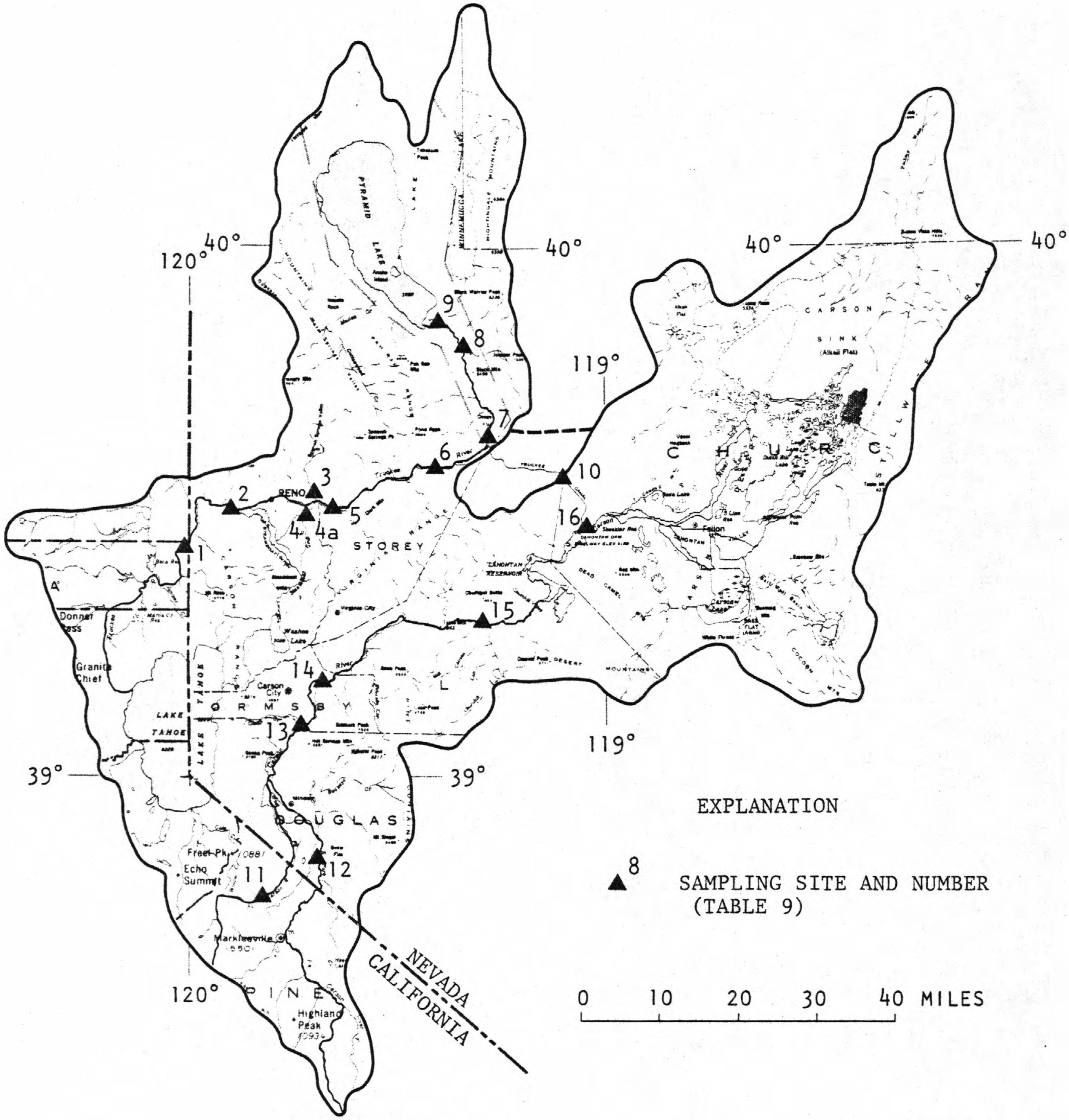

FIGURE 9.--Sampling sites for assessing sediment, nutrient, and organic loadings to Lahontan Reservoir, Truckee River downstream from the Reno-Sparks urban area, and Pyramid Lake.

TABLE 9. - Sites selected for water-quality sampling

Site (fig. 9)	USGS station number	Station name	Reason for selection	Hydrologic subunit (See fig. 5)	Drainage area[1] (mi^2)	Sampling frequency
1	10346000	Truckee River at Farad, Calif.	Background quality of water; existing gaging and water-quality station	On boundary between upper Truckee (B) and middle Truckee River (C)	932	Biweekly[2]
2	10347500	Truckee River at Mayberry Ave. below Lawton, Nev.	Upstream from major point and non-point sources of pollution from the cities of Reno and Sparks	Middle Truckee (C)	about 1,000	([3])
3	10348250	North Truckee Drain at Sparks, Nev.	Tributary to the Truckee River; transports urban and agricultural return flows from Reno-Sparks area	do.	108	([3])
4	10349990	Steamboat Creek at Kimlick Lane at Reno, Nev.	Tributary to the Truckee River and transports agricultural return flows above input of treated wastes from the cities of Reno and Sparks	do.	246	([3])
4a	10349995	Reno-Sparks sewage-treatment plant, Nev.	Secondary effluent from Reno and Sparks	do.	--	([3])
5	10350000	Truckee River at Vista, Nev.	Just downstream from Reno-Sparks area and upstream from major diversion; gaging station	Middle Truckee (C)	1,431	([3])
6	10351600	Truckee River below Derby Dam, near Wadsworth, Nev.	Just downstream from trans-basin diversion to Truckee Canal; gaging station	On boundary between middle (C) and lower Truckee (E)	1,676	([3])
7	10351650	Truckee River at Wadsworth, Nev.	Streamflow accretion (canal leakage and return flows) gaging and water temperature station	Lower Truckee (E)	1,728	([3])
8	10351700	Truckee River near Nixon, Nev.	Just upstream from Numana diversion dam; gaging and water-quality station	Lower Truckee (E)	1,827	Monthly[4]

See footnotes at end of table.

TABLE 9. - Sites selected for water-quality sampling--Continued

Site (fig. 9)	USGS station number	Station name	Reason for selection	Hydrologic subunit (See fig. 5)	Drainage area[1] (mi^2)	Sampling frequency
9	10351775	Truckee River at Marble Bluff Dam, Nev.	Terminal station to Pyramid Lake in Truckee River basin	On boundary between lower Truckee (E) and Pyramid Lake (F)	1,937	([3])
10	10351400	Truckee Canal near Hazen, Nev.	Inflow station from Truckee River to Lahontan Reservoir in Carson River basin; gaging station	Truckee Canal (D)	--	([3])
11	10310000	West Fork Carson River at Woodfords, Calif.	Input to Carson Valley subunit; existing gaging station	Upper West Fork Carson River (G)	65	([2])
12	10309000	East Fork Carson River near Gardnerville, Nev.	Input to Carson Valley subunit; existing gaging station	Upper East Fork Carson River (H)	356	([2])
13	10311000	Carson River near Carson City, Nev.	Output from Carson Valley; existing gaging station	On boundary between Carson Valley (I) and Eagle-Dayton (J) Valley	886	([2])
14	10311400	Carson River at Deer Run Road near Carson City, Nev.	Includes effluent and urban runoff from Carson City; existing gaging station	Eagle-Dayton Valley (J)	958	([2])
15	10312000	Carson River near Fort Churchill, Nev.	Inflow station from Carson River to Lahontan Reservoir; gaging and water-quality station	On boundary between Eagle-Dayton Valley (J) and Churchill Valley (K)	1,302	([3,4])
16	10312150	Carson River below Lahontan Reservoir, near Fallon, Nev.	Outflow station from Lahontan Reservoir; gaging station	Fallon Agricultural (L)	1,801	([3])

[1]See table 1 for comparative streamflow statistics.
[2]Biweekly as a National Water-Quality Surveillance Station (NWQSS).
[3]Sampling frequency related to hydrologic events: See text, p. 59.
[4]Monthly as a National Stream-Quality Accounting Network (NASQAN) station.

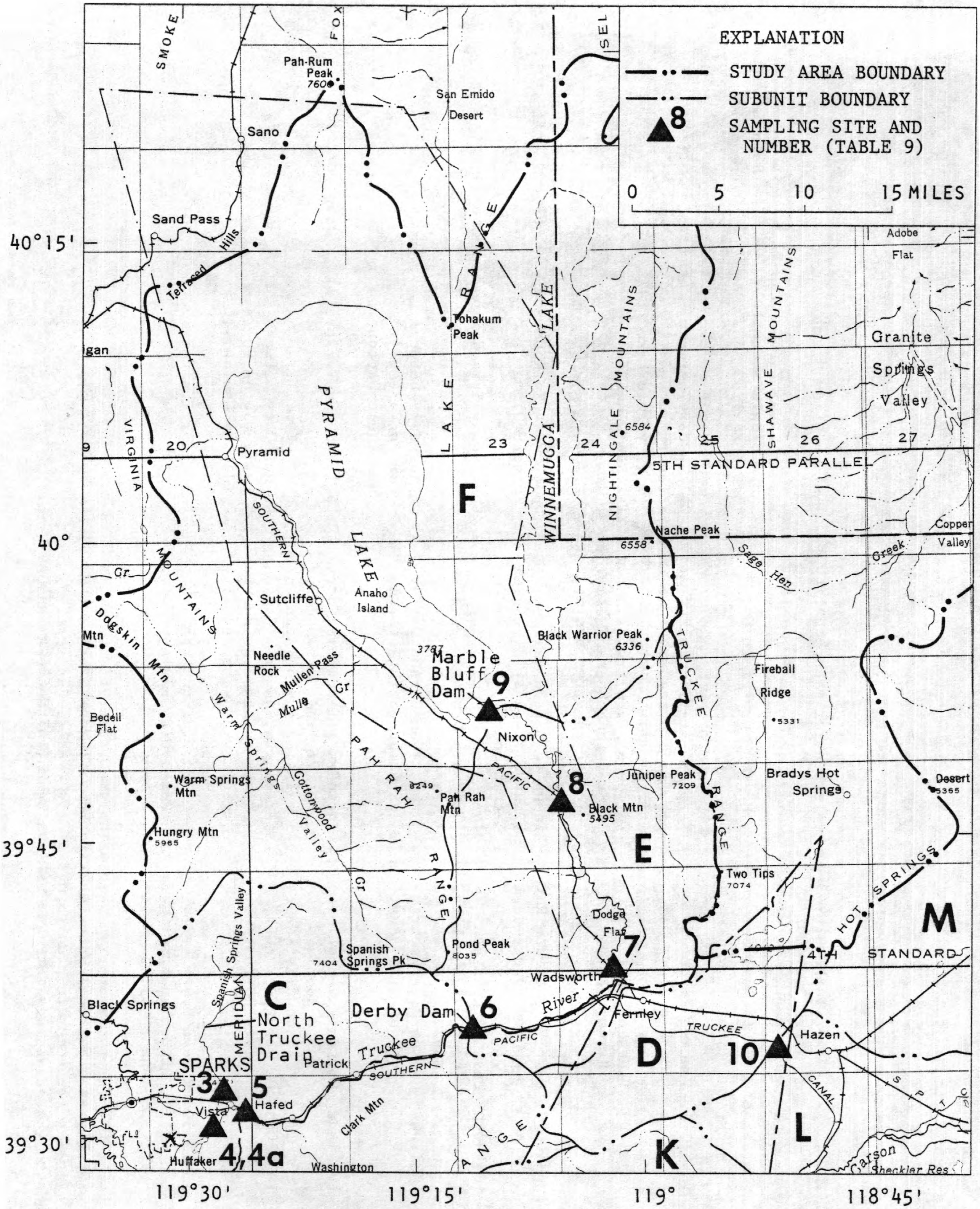

FIGURE 10.--Location of subunits D, E, and F, and water-quality sampling sites in the north-central part of study area. Compare with figure 5.

For the Carson Valley subunit (fig. 8), three sites will be sampled to determine inputs and outputs of loadings. Inputs will be described by measurements of the West Fork Carson River at Woodfords (site 11) and the East Fork Carson River near Gardnerville (site 12). Outputs will be described by measurements at Carson River near Carson City (site 13), which will reflect point and nonpoint discharges in the subunits. Data to be collected on point discharges from sewage treatment plants (table 8) will be used to estimate the total point discharges and to disaggregate point from nonpoint discharges. No attempt will be made to distinguish between urban and agricultural nonpoint sources within the subunit. In the Eagle-Dayton Valleys subunit, measurements on the Carson River at Deer Run Road near Carson City (site 14) will reflect the urban nonpoint source loadings from the Carson City metropolitan area. For the Churchill Valley (Lahontan Reservoir) subunit (fig. 11), gross inputs and outputs of constituents will be determined by using sampling at three sites (fig. 9). Inputs will be described on the basis of sampling the Truckee Canal near Hazen (site 10) and the Carson River near Fort Churchill (site 15). Outputs will be determined from samples of releases from Lahontan Reservoir into the Carson River downstream (site 16).

Flow Conditions for Sampling

Water-quality and quantity measurements will be made during a wide range of flow conditions, with emphasis on extreme events. The basic sampling frequency will vary with hydrologic conditions.

Sampling will be most intense during spring runoff peaks, the period usually between April 15 and June 15, when multiple high flows occur due to snowmelt runoff and rainfall. During this period it is desirable to sample the highest flows that potentially carry the greatest quantities of certain constituents, such as suspended sediment. Samples also will be obtained during major rains, general rainstorms that affect large parts of the study area and produce severe flood conditions (usually in winter or spring), as in the case when relatively warm rains fall upon and melt a snowpack. Attempts also will be made to sample runoff from summer thunderstorms.

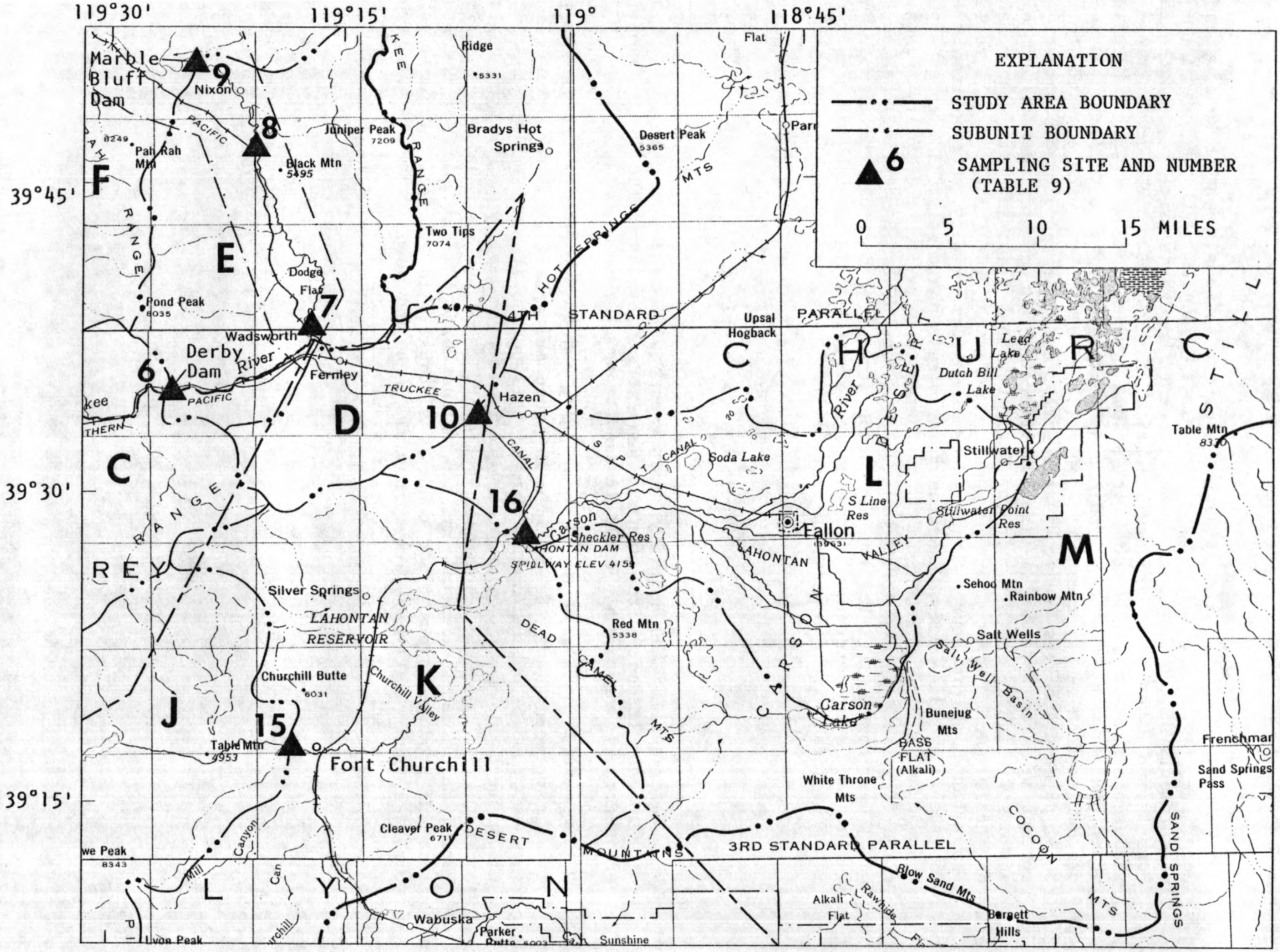

FIGURE 11.--Location of subunits D, E, and L, parts of subunits K and M, and water-quality sampling sites in the east-central part of study area. Compare with figure 9.

Sample Collection and Analysis

Field and laboratory analyses of samples will include the characteristics given in table 10. Concentrations of the major nutrients (nitrogen, phosphorus, and carbon) will be determined for both the dissolved and "total," or whole-water, phases so that the amount of these materials transported in suspension may be calculated. This information, together with suspended sediment concentrations and particle-size data, will give insight on the relationships between sedimentation and other water-quality problems.

Previous work has indicated an uptake of nutrients by aquatic plants in the Truckee River (Pacific Environmental Laboratory, 1979). Concern has been expressed that aquatic vegetation may be only a seasonal "sink" in the river system and that those nutrients incorporated in plants recycle into the water and ultimately are transported to the receiving waters. Effort will be expended in the study to sample large detrital matter (0.25-inch diameter) not normally collected by suspended-sediment samplers, to assess the importance of such organic debris to the total annual nutrient flux.

Interpretation and Presentation of Results

The basic results of the water-quality data collection program will be development of curves that relate stream constituents and sediment particle size to discharge, computation of stream-constituent loads to and from selected river reaches and to Lahontan Reservoir, determination of yields (quantity per unit area) to relate river quality to regional land-use practices, and tabulation of baseline water-quality data.

Annual loads will be computed for the measured constituents by using the transport flow-duration curve method described by Miller (1951) and Colby (1956). Curves will be developed by relating concentrations to discharges. For concentrations that do not correlate well to discharge, other techniques will be explored, such as computing load increments by multiplying mean concentrations for a period of time by the time interval and summing the increments of load thus derived (Stamer and others, 1978).

The results of the study will be included in a report describing (1) annual loads transported in the study reaches, (2) the effects of point and nonpoint discharges on river quality in those reaches, and (3) observed relationships between regional land uses and river quality.

TABLE 10. - Schedule of analyses for assessment of water-quality loadings

Water-quality determination	Sampled phase: Dissolved[1]	Suspended[2]	Whole-water[3]	Analytical methods
Field measurements				
Stage	--	--	--	Recorder or staff gage
Discharge	--	--	--	Rating curve or current-meter measurement
Temperature	--	--	X	Mercury thermometer or electronic thermistor
Specific conductance	--	--	X	Electronic meter
pH	--	--	X	Electronic meter
Alkalinity	--	--	X	Electrometric titration
Laboratory measurements				
Sediment				
Concentration	--	--	X	Evaporation at 110°C (Guy, 1969)
Particle size	--	--	X	Sieve, bottom-withdrawal, or pipette (Guy, 1969)
Dissolved solids	X	--	--	Evaporation at 185°C (Skougstad and others, 1979)
Nutrients				
Nitrogen (as N)				(Skougstad and others, 1979)
Total	X	X	X	
Organic	X	X	X	
NH_4	X	X	X	
NO_2	X	X	X	
NO_3	X	X	X	
Phosphorus (as P)				(Skougstad and others, 1979)
Total	X	X	X	
Orthophosphate	X	X	X	
Oxygen demand				
Ultimate biochemical oxygen demand	--	--	X	Graphical extrapolation of 20-day carbonaceous biochemical oxygen demand analyses (Stamer and others, 1979)
Organic carbon	X	X	X	Infrared carbon analyzer (Goerlitz and Brown, 1972)
Biologic				
Phytoplankton				(Greeson and others, 1977)
Total biomass	--	--	X	
Chlorophyll A	--	--	X	
Chlorophyll B	--	--	X	

[1]Field pressure filtration (peristaltic pump) through membrane filters with 0.45-micrometer nominal pore size.

[2]All except organic carbon: difference between whole-water and dissolved concentrations. Organic carbon: residue on silver membrane filter with 0.45 micrometer pore size.

[3]Discharge-integrated samples using standard suspended-sediment sampling techniques (Guy and Norman, 1970).

SUPPLEMENT B--PROJECT PROPOSAL FOR AN INTENSIVE INVESTIGATION OF URBAN RUNOFF IN THE TRUCKEE MEADOWS

Problem

Recent studies sponsored by the Washoe Council of Governments indicate that, on a short-term basis during storms, urban runoff in the Truckee Meadows area is the predominant source of pollutant loading to the Truckee River (URS Company, 1977, 1978). Expected urban growth in the Truckee Meadows may increase stormwater runoff loadings to the Truckee River, and conversion of lands from agricultural to urban use will change the urban contribution to total loads. This situation may be ameliorated by the introduction of stormwater management practices, such as streetsweeping and sediment detention basins.

Little quantitative information is available to evaluate the impact of stormwater runoff on the water quality of the Truckee River. While it is generally agreed that urban growth will increase loadings, reliable quantitative predictions of its impact cannot be made from existing data. Furthermore, data are not available to evaluate the effectiveness of implemented or proposed management alternatives.

Objectives

In general, the objective of the study is to provide local managers with data and methods of analyses suitable to support stormwater management decisions. More specifically, the objectives of the study are:

1. To develop a data base for typical urban drainage basins in the Truckee Meadows. Data will consist of rainfall, runoff, water quality, and other environmental factors.

2. To determine the magnitude and frequency of stormwater pollutant loadings of critical constituents contributed from each drainage basin sampled.

3. To develop methods for estimating stormwater pollutant loadings for ungaged drainage basins in the Truckee Meadows.

4. To test the effectiveness of stormwater management alternatives such as streetsweeping and sediment detention storage.

Approach

The study will be conducted over a period of 4½ years. The first 2 years will be devoted to the first three objectives, which relate mostly to collecting data and developing methods for predicting the urban stormwater pollutant loadings to the Truckee River. The remainder of the time will be devoted to refining earlier work and to obtaining data needed to evaluate the effectiveness of selected wastewater management alternatives.

The early months of the study will be spent, in part, in designing a data network to fulfill the study objectives. The data network will consist of drainage basins instrumented for the acquisition of precipitation, runoff, and water-quality data. The design objective is to provide a representative and transferable data base. Essential network design elements will be number, size, and land-use characteristics of the drainage basins and duration of data collection. The data network is planned to consist of four instrumented drainage areas. In the first phase of the study, three drainage basins will be selected to represent distinct, homogeneous land uses such as single-family residential, multiple-family residential, and commercial. The fourth drainage basin will be selected to represent a mixture of land uses and will include within its boundaries at least one of the three homogeneous basins. The rationale for this design is that the homogeneous drainage can be used to isolate processes related to a particular land use, and the nonhomogeneous drainage basin can be used to study the integrated effects of a mixture of land uses.

Several strategies are possible for the design of the data network to meet the objective of the second phase of the study, to evaluate the effectiveness of wastewater management alternatives. One possibility is to move the instrumentation to new drainage basins and implement and evaluate different management alternatives on nearly identical drainage basins. Another possibility is to continue collecting data for a drainage basin after implementation of a new wastewater management scheme. A third possibility is some combination of the first and second.

With these general concepts of the network design in mind, specific work elements with respect to the study objectives are described in following sections.

Urban Hydrology Data Base

The first objective of the study is to establish a data base for typical urban drainage basins in the Truckee Meadows. That objective will be attained through the following data acquisitions and data management plan.

Meteorological data.--Because of their integral relationship with storm-water quality and quantity, precipitation data are essential. Each gaged drainage basin will require one or more rain gages, depending on size of the drainage area and spatial variation in the precipitation patterns.

Pan evaporation data will be required to support precipitation-runoff modeling. Suitable data are not available, and standardized pan evaporation instrumentation will be established and maintained throughout the study.

Modeling of the snowmelt-runoff process, if necessary, also requires supporting meteorological data on air temperature, dew point temperature, solar radiation, and wind velocity. Adequate data are available.

Runoff data.--The method used to measure runoff will depend on the geometry of the conveyance at the measuring site. Generally, stage-versus-discharge ratings for culvert entrances, weirs, and natural controls will be used for open channels. Constrictions will be used in sewer pipes. Flow measurements will be calibrated by combinations of theoretical ratings and field measurements.

Water-quality data.--In general, water-quality samples taken by automated pump samplers will be synchronized with precipitation and runoff data collection. Where possible, depth integrated samples will be taken as required to calibrate the point samples taken by the automated sampler. During the first months of the study, however, the automated sampling equipment will not be available, and all samples will be collected by manual techniques.

The water-quality determinations that might be applicable to the study probably exceed 100 constituents and properties. Practical constraints imposed by the sample size, analytical cost, collection system materials, and sample preservation requirements reduce the potential list to approximately 30 characteristics (table 11). This list is based on five categories of water-quality problems: suspended sediment, inorganic chemical constituents, organic chemical constituents, bacteria, and esthetics.

Atmospheric fallout.--Atmospheric fallout data are needed at one of the data collection sites to account for the atmospheric sources of pollutants measured in the runoff. Wetfall and dryfall samples of atmospheric fallout will be collected and analyzed after each storm for the water-quality constituents shown in table 11 (except suspended sediment). These samples will be collected by a mechanism that opens the wetfall collector when precipitation begins and simultaneously closes the dryfall collector. The mechanism then reverses when precipitation ceases.

TABLE 11.- Water-quality determinations to be made on samples of urban runoff[1]

Sediment	**Organic indicators**
Suspended sediment concentration	Dissolved organic carbon (DOC)
Particle-size analyses for selected samples	Suspended organic carbon (SOC)
	Chemical oxygen demand (COD)
	Ultimate biochemical oxygen demand (BOD)
Inorganic indicators	
Specific conductance[2]	**Priority pollutants** such as
pH[2]	pesticides, PCB's, oil, and grease[3]
Temperature[2]	
Dissolved oxygen[2]	**Bacteriological indicators**
Dissolved solids	Fecal coliform bacteria
Dissolved $NO_2 + NO_3$ - N	
Dissolved NH_3 - N	**Esthetic indicators**
Total Kjeldahl - N	Color
Total phosphorus	
Total lead	
Major cations and anions[3]	
Multiple-element scans for trace metals[3]	

[1]All samples to be discharge-integrated to the extent possible (Guy, 1969; Guy and Norman, 1970; and Porterfield, 1972). Laboratory determinations to use standard procedures detailed by Skougstad and others (1979) and Goerlitz and Brown (1972).

[2]Field determinations, using standard meters and electrodes.

[3]For selected samples.

Basin characteristics.--Previous studies in other parts of the Nation indicate that storm loading of selected water-quality constituents can be related statistically to watershed characteristics which describe the generalized physiography, land use, and climate. Data on these characteristics will be compiled for each drainage basin and storm sampled during the study. Recommended physiographic and land-use characteristics are given in table 12. Some of these characteristics will be updated during the study to document changes.

Climatological or hydrologic factors that affect stormwater loading include precipitation depth, precipitation intensity, runoff, and antecedent conditions. Data on these characteristics will be computed during the study. Table 13 is a recommended list of climatic characteristics, many of which have been found to be significant in previous statistical analyses or model applications.

Environmental practices.--Data describing environmental practices for each drainage basin will be collected to suggest cause-and-effect relationships between management techniques and water-quality processes. Because such data are difficult to collect for large areas, a spatial sampling procedure will be used. A generalized list of environmental-practice data recommended for each drainage basin is given in table 14.

TABLE 12. - Physiographic and land-use characteristics to be determined for the urban-runoff study

1. Total drainage area, in square miles.
2. Contributing drainage area, in square miles (total area less areas draining into impoundments for which no outlet exists).
3. Impervious area, in percentage of drainage area.
4. Effective impervious area, in percentage of drainage area. Includes only impervious surfaces connected directly to a sewer pipe or principal channel.
5. Average basin slope, in feet per mile, determined from an average of terrain slopes at 25 or more equally spaced points using best available topographic map.
6. Main channel slope, in feet per mile, measured at points 10 and 85 percent of the distance from the gaging station to the divide.
7. Permeability of the A horizon of the soil profile, in inches per hour.
8. Available water capacity as an average of the A, B, C soil horizons, in inches of water per inch of soil.
9. Soil-water pH of the A horizon.
10. Population density, in persons per square mile.
11. Street density, in miles per square mile.
12. Land use of the basins as a percentage of drainage area including:
    a. Rural and pasture
    b. Agricultural
    c. Single-family residential
    d. Multiple-family residential
    e. Commercial
    f. Industrial
    g. Under construction (bare surface)

TABLE 13. - Climatic characteristics to be determined for the urban-runoff study

1. Total rainfall average for the basin, in inches.
2. Maximum 5-minute rainfall rate, in inches per hour.
3. Maximum 15-minute rainfall rate, in inches per hour.
4. Maximum 1-hour rainfall rate, in inches.
5. Number of dry days prior to storm, counting backwards to day with greater than 0.2 inch.
6. Number of hours antecedent to storm in which 0.5 inch of rain fell.
7. Depth of rainfall accumulated during previous day, in inches.
8. Depth of rainfall accumulated during previous 3 days, in inches.
9. Depth of rainfall accumulated during previous 7 days, in inches.
10. Total runoff, in inches, over the basin.
11. Peak discharge, in cubic feet per second.
12. Base flow prior to storm, in cubic feet per second.
13. Duration of storm used to calculate load, in minutes.

TABLE 14. - Environmental-practices inventory for the urban-runoff study

1. Methods and frequency of street cleaning.
2. Amounts and frequency of chemical fertilizer application, determined in equivalent pounds per acre of nitrogen and phosphorus.
3. Sewer flushing and catch-basin cleaning.
4. Agricultural activities and practices.
5. Construction, excavating, and landscaping activities.
6. Average daily vehicle traffic.
7. Refuse collection practices.
8. Street salting during icy conditions.
9. Detention storage.

Magnitude and Frequency of Loadings

The second objective of the study is to estimate the magnitude and frequency of stormwater loadings of critical constituents contributed from each sampled basin. This objective will be attained through modeling techniques.

The principal use of models will be to simulate the precipitation, runoff, and water-quality characteristics in the Truckee Meadows. Simulations will be used to evaluate water quantity or quality conditions over a period of several years under stable conditions. The data collected during the study will not cover a sufficient time span for direct analysis of the frequency of loadings of a specified magnitude. A model, however, can be used to synthesize a long-term record (using transferred meteorologic data) which can be analyzed. In this case, the field data are used to adjust model parameters and test the model predictions.

The hydrology of urban drainage basins and the inherent water problems vary greatly from city to city. Consequently, models with differing complexity and capability are needed to approach urban water problems. Existing models are available from the U.S. Army Corps of Engineers, Geological Survey, and Environmental Protection Agency. One of these models will be adapted to this study.

The type of modeling approach will be selected early in the planning phase of the study because this selection will, in part, dictate the types and intensity of data needed. Additionally, model calibration will begin early in the data-collection phase of the study to determine if the data being collected are adequate. This approach to project planning will maximize benefits of data collection by allowing lead time to adjust deficiencies in the study plan.

Estimating Loading from Ungaged Drainage Basins

The third objective of the study is to develop methods of estimating stormwater loadings from ungaged drainage basins in the Truckee Meadows. Multiple-regression relations could be used for this purpose; however, modeling techniques often offer the advantage of greater flexibility.

Statistical techniques can provide a means for gaining understanding of urban stormwater processes as well as for estimating the effect of water management or land use on certain water-quality characteristics. Multiple-regression procedures have been used in other studies to relate storm-pollutant loads to storm-precipitation characteristics. These procedures will be applied to this study by using available computer programs. Statistical summaries and results will be published with annual data reports and final study reports.

The application of modeling techniques will require that relations be developed between model parameter values and easily measurable characteristics of the ungaged drainage basin such as physiographic characteristics, land-use characteristics (table 12), and environmental practices (table 13). The models that are candidates for use on the study employ a fixed set of mathematical expressions, which are adapted to a specific drainage basin by selecting the proper set of numerical values for certain critical parameters within the mathematical expressions. While some of these values are easily estimated from topographic maps or aerial photographs, others must be transferred from gaged drainage basins. The development from gaged drainage basins of relations between parameter values and drainage-basin characteristics offers a mechanism for transferring information from gaged to ungaged basins.

Once the model parameter values have been estimated for a given condition of urbanization, a synthetic runoff and water-quality record can be generated for the period of available climatic record. In addition, parameter values can be adjusted for the effects of continuing urbanization, and synthetic runoff and water-quality records can be produced for various degrees of urbanization and for various management alternatives. These records can then be analyzed statistically for average and extreme loadings.

Evaluation of Management Alternatives

The fourth objective of the study is to test the effectiveness of stormwater management alternatives. The principal alternatives to be considered are streetsweeping and sediment detention basins.

The effectiveness of these alternatives will be evaluated by collecting comparative data. To evaluate streetsweeping, one possible approach is to instrument paired drainage basins. Streetsweeping would be implemented on one basin; the other basin would remain unswept. Data from the paired drainage basins would be compared to evaluate the difference in pollutant loadings from the two basins. Another approach is to compare the effects of streetsweeping and not streetsweeping on the same drainage basin. This approach would require that data be collected for the condition of no sweeping for a period of time. Thereafter sweeping would be introduced, and additional data would be collected.

The selection of the actual approaches to be used for this phase of the study will depend on the availability of a nearly identical pair of drainage basins, the management alternatives considered most important, and the instrumentation needed to meet other objectives of the study. The approach selected should be designed to complement other data-collection objectives.

To evaluate the effectiveness of sediment detention basins in reducing pollutant loadings from a drainage basin, instruments would be installed to monitor the inflow and outflow from the detention basin. A comparison of these data will indicate the effectiveness of the detention basin in trapping pollutants.

SUPPLEMENT C--PROJECT PROPOSAL FOR THE EVALUATION OF EFFECTS OF POLLUTANT LOADINGS ON LAHONTAN RESERVOIR, NEVADA

Problem

Lahontan Reservoir is situated in west-central Nevada approximately 50 mi southeast of Reno (fig. 1). The impoundment is part of the Newlands Reclamation Project, one of the first irrigation projects selected for construction following passage of the Reclamation Act of 1902. The Project diverts and stores water from the Carson and Truckee River basins to irrigate agricultural lands near Fallon.

Both the Carson and Truckee Rivers receive point and nonpoint wastewater discharges from urban areas and nonpoint discharges from agricultural areas. These wastewater loadings contribute to water-quality degradation in Lahontan Reservoir. As a result, hypolimnetic oxygen depletions sometimes occur in the late summer months, becoming progressively severe until about August when oxygen concentrations have dropped below 1 mg/L. Additionally, in late summer phytoplankton growth becomes extensive in many years, becoming a nuisance to recreational users of the reservoir.

The effect of wastewater loadings on Lahontan Reservoir is a critical aspect of present areawide wastewater management planning in both the Carson and Truckee River basins. An understanding of the effects is important for at least two reasons. First, the reservoir is probably one of the ecologically more sensitive components of the Truckee-Carson River system. Second, the reservoir is one point where the results of separate management decisions made in the two river basins come together.

Approach

Regional Wastewater Loadings

Scope of work.--Both the Carson and Truckee Rivers contribute wastewater loadings to Lahontan Reservoir. Loadings from the Truckee River, however, would be adequately characterized by the study described in Supplement A if data from that study were available to this study. As of January 1980, the Truckee River part of the program proposed in Supplement A has not been implemented. However, a cooperative program to evaluate water-quality loadings at Carson River stations was begun in November 1979 between the U.S. Geological Survey and the Nevada Division of Environmental Protection.

Data collection.--Criteria for selection and location of sampling sites are discussed in Supplement A (Sites 11-16, table 9, fig. 9). Sampling sites will be located at existing stream-gaging stations to estimate inputs and outputs of contaminants from three subunits of the Carson River basin: Carson Valley, Eagle Valley, and Dayton-Churchill Valley.

For the Eagle Valley subunit, one site will be sampled. (Inputs are the loadings from the Carson Valley subunit.) Measurement on the Carson River at Deer Run Road near Carson City will reflect the aggregate of urban and agricultural nonpoint discharges and point discharges. As for the Carson Valley subunit, data to be collected on point discharges will be used to disaggregate point and nonpoint discharges.

Measurements on the Carson River near Fort Churchill will reflect the aggregate of nonpoint discharges from the Dayton-Churchill Valley subunit and all loadings from the Carson River into Lahontan Reservoir. To balance the budgets of sediment and other water-quality constituent loadings, measurements will also be made on the Carson River below Lahontan Reservoir.

Interpretation of results.--The basic products of the water-quality data collection program will be the development of curves that relate stream constituents and sediment particle size to discharge, the computation of stream-constituent loads to and from selected river reaches and from Lahontan Reservoir, the estimation of yields to relate river quality to land-use practices, and the tabulation of base line water-quality data.

Mathematical model.--To evaluate the effects of wastewater loadings on water quality, a mathematical model of Lahontan Reservoir will be developed. The limnological characteristics to be modeled will probably include:

1. Hydrodynamics,
2. Water temperature,
3. Concentration of dissolved oxygen,
4. Concentration of the major nitrogen species (nitrates, nitrite, and ammonia) and total phosphorus,
5. Sediment transport, and
6. Phytoplankton activity.

The success of a water-quality model is ultimately measured by its degree of acceptance and use by its intended recipients. In this regard, a balance must be met between simplicity for ease of use and understanding and the complexity and sophistication required to achieve the desired predictive accuracy. The study will attempt to use the simplest models that can be successfully calibrated and verified against observed conditions. Additionally, rather than develop new models for the study, existing models will be examined for applicability to Lahontan Reservoir and modifications made as required.

Reconnaissance data collection.--Basic limnological data have been collected by the Nevada Department of Fish and Game. These data indicate that thermal stratification begins in early summer with the mesolimnion forming at depths between 20 and 30 ft. By August, this layer drops to near 45 ft, and toward the end of September overturn and mixing have occurred.

While the available data for Lahontan Reservoir indicate that stratification does occur, the data are not adequate to evaluate the extent of transverse mixing. The degree of transverse mixing, however, will determine in part the type of data analysis to be used. If the reservoir is well mixed in the transverse direction, a two-dimensional mathematical model probably can be used. If the reservoir is not mixed in the transverse direction it may be necessary to use a three-dimensional model.

To resolve uncertainty as to the degree of transverse mixing, a reconnaissance water-quality survey of the lake will be undertaken at the beginning of the study. The survey will consist of data collection from multiple depths at about 40 stations. At each station, depth profiles of temperature, dissolved oxygen, pH, and specific conductance will be obtained from in situ measurements. On the basis of these profiles, samples will be collected at three locations in the water column. The samples will be analyzed for the following water-quality characteristics:

Temperature[1]	Nitrogen species
Dissolved oxygen[1]	Phosphorus species
pH[1]	Ultimate biochemical oxygen demand
Specific conductance[1]	

[1]In situ profiles.

Intensive data collection.--While the reconnaissance water-quality survey will be used to determine the complexity of the mathematical model to be used, an intensive data-collection and -analysis program is planned to calibrate and verify the selected models. The actual data-collection program cannot be designed until the form and data requirements of the model are established. Nevertheless, water-quality determinations for samples taken at multiple depths will probably include the following:

Sediment
- Suspended-sediment concentration
- Particle-size analyses for selected samples

Inorganic indicators
- Specific conductance
- pH
- Temperature
- Dissolved oxygen
- Dissolved solids
- Nitrogen species
- Phosphorus species
- Major cations and anions

Organic indicators
- Dissolved organic carbon
- Suspended organic carbon
- Ultimate biochemical oxygen demand

Biological indicators
- Bacteria
- Algal growth potential
- Phytoplankton
- Chlorophyll
- Primary productivity
- Zooplankton species enumeration

Physical indicators
- Turbidity
- Light availability

In addition to these water-quality characteristics, data will be collected on hydrodynamic characteristics such as water velocity, reservoir stage, wind velocity, and pan evaporation.

Interpretation of results.--The model will be used as a tool to predict concentrations of dissolved oxygen and nutrients, water temperatures, and phytoplankton activity in Lahontan Reservoir for various wastewater loadings to the reservoir. These predictions, the model, and the collected field data should aid in evaluating alternative management proposals and water-quality standards.

Reports

The results of the study will be described in two reports. A draft of the first report, which will evaluate regional pollutant loadings to Lahontan Reservoir, will be completed about March 1981. A draft of the second report, which will describe the development of water-quality models for Lahontan Reservoir, will be completed about October 1981.

Division of Work

The proposed work will be shared by the U.S. Geological Survey, Desert Research Institute, and Nevada Division of Environmental Protection. Work done by the Geological Survey will include the reconnaissance survey of Lahontan Reservoir, evaluation of regional pollutant loadings, and minor participation in the development of water-quality models for Lahontan Reservoir. The Desert Research Institute will assume the major responsibility for development of models for Lahontan Reservoir. The major activity of the Nevada Division of Environmental Protection will be to develop the data base necessary to calibrate and verify future water-quality models for the Carson River.

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