WATER RESOURCES MANAGEMENT PLAN

OCTOBER
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GRAND CANYON
NATIONAL PARK
ARIZONA

GRAND CANYON NATIONAL PARK

Water Resources Management Plan

Recommended: _____ 7/9/84
Superintendent, Grand Canyon National Park — Date

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Summary

Water Resources Management Plan
Grand Canyon National Park
1984

This is the first Water Resource Management Plan written for Grand Canyon National Park. It was developed to provide direction to this aspect of resources management in the park. The need for a park specific water resources management plan was presented by the Director of the National Park Service in October, 1979, and further emphasized by the Western Regional Director. Formal plan development began at Grand Canyon in January 1983.

The plan was developed to facilitate proper management of Grand Canyon's water resources. Two major concerns dominate our management efforts; (1) maintenance of natural aquatic and riparian ecosystems, and (2) protection of visitor health and safety. The following objectives are presented for the management of water resources in the park.

1. Manage the water resources of Grand Canyon National Park in accordance with legislative mandates.
2. Maintain existing natural riparian and aqautic ecosystems.
3. Minimize hazards to life and property presented by flooding.
4. Avoid or mitigate human induced contamination of water resources.
5. Identify water quality conditions that are potentially hazardous to wildlife and humans.
6. Minimize the adverse effects of water withdrawals for domestic water supplies.
7. Maintain the existing ecological and recreational values of the Colorado River.

Existing and potential problems are evaluated, and proposed solutions are developed using these objectives.

Water is an extremely valuable resource in the vicinity of Grand Canyon. Generally sparse rainfall quickly evaporates or sinks into the porous bedrock to feed numerous springs within the canyon. These springs and the creeks they support are centers of activity for people and wildlife. As such, these aquatic and riparian resources are often impacted by human activities and can present hazards such as flashflooding, waterborne pathogens, and chemical hazards. All park developments on the canyon rims rely on water pumped from Roaring Springs within the canyon. Lack of available water has stymied development on the plateaus surrounding the park. There are enormous economic incentives for land owners to obtain water from the park's pipeline system or by tapping the aquifers that feed canyon springs.

A substantial portion of this plan is devoted to a compilation and presentation of existing information. This was necessary before problems could be identified and solutions proposed. The next several paragraphs summarize the state of the park's knowledge in each subject area.

Water Quality. Past research in the area of microbiological water quality has provided a good understanding for most of the Colorado River and to a lesser extent for tributary creeks. In a very simplified form it can be stated that no Grand Canyon waters can be safely used for drinking without disinfection. Clear waters can be made potable with simple treatment methods, but turbid waters require specialized treatment. When they are flowing clear, the Colorado River and most tributaries are usually safe for full-body contact recreation. Indicator bacteria concentrations occasionally exceed levels considered safe for full-body contact recreation in heavily used tributaries, even when they are clear. All turbid canyon waters frequently exceed standards for full-body contact recreation. Project statements dealing with microbiological water quality propose actions to mitigate existing hazards, study special problem areas, expand existing baseline inventories, and develop a model of Colorado River water quality.

Chemical water quality of Grand Canyon is less understood. This is mostly due to the number of water sources (68 are identified in this plan) and their remoteness. Only 14 canyon water sources have been analyzed sufficiently to assess their suitability for consumption. Twenty-two other sources have never been analyzed. Fifteen chemical constituents have been found to exceed levels considered safe for consumption or con-tact in 24 canyon water sources. Most of these are common constituents that pose only a threat of a laxative action and a bad taste when consumed. A few large springs contain excess phosphate that could promote algal growth. Other constituents found in excess in some sources are aluminum, arsenic, boron, and slelenium. A very limited inventory of radionuclides has found no hazardous conditions, however, past and present mining activities in the park vicinity and high radionuclides measured in Little Colorado River upstream of the park cause continued concern. Project statements dealing with chemical water quality propose actions to expand the existing inventory, study radionuclide problems, and mitigate existing hazards.

Sewage Treatment Facilities and Backcountry Waste Disposal. The park has a variety of sewage treatment facilities, one of which poses a significant problem. A leach field system at Indian Gardens failed progressively through the 1970's. It was partly replaced in 1978 with a chemical toilet system where wastes are regularly helicoptered out of the canyon. Ranger residences are still using the old system that is probably contaminating Garden Creek. A new system is being planned for Indian Gardens in an effort separate from this plan. Disposal of human waste in the backcountry is accomplished with pit toilets where they are appropriate and with individual disposal in more remote areas. River trips are required to carry out all of their solid wastes. Project statements are included here that propose increasing hiker awareness of water quality problems and intensive studies of bacterial water quality in problem areas.

Water Use Inside and Outside the Park. Water supplies have always been a major problem for developments inside and near the park. There is no surface water on the plateaus surrounding the canyon, and the canyon effectively drains ground water aquifers. At various times water has been obtained from shallow wells, small springs, hauled in by train, and pumped from springs in Grand Canyon. Currently developed areas on both rims receive water piped from Roaring Springs. Water was first piped from Roaring Springs to North Rim in 1928 and to South Rim in 1970. In 1978 Public Law 95-586 was passed allowing the sale of water to Tusayan when

"such sale is not detrimental to the protection of the resources of Grand Canyon National Park or its visitors." A recent study found that these withdrawals from Roaring Springs could be impacting the flow, velocity, temperatures, and fauna of Bright Angel Creek. Project statements propose further study of these impacts and improved water conservation.

Water Quantity. With the exception of the Colorado River and four of its tributaries, there has been no systematic effort to accurately measure stream or springflow in Grand Canyon. Some scattered instantaneous flow measurements have been made by several researchers, but for the most part our knowledge of stream flows is based on gross estimates and intuition. A water resources inventory conducted by the park in 1979 provided some qualitative flow information for the east-central portion of the park. Twenty-one perennial creeks and 36 perennial springs were identified. A project statement proposes an expanded water resources inventory with accurate flow measurements of major sources.

Water Rights. Most of the lands in Grand Canyon National Park were reserved from the public domain or are transferred from other federal agencies and are subject to the Federal Reserved Water Rights Doctrine. Therefore, in general, the waters within Grand Canyon National Park (except Colorado River) are claimed in their entirity by the federal government for uses in concurrence with the enabling legislation of the park and the National Park Service. Water rights of lands acquired from state or private ownership are acquired in accordance with state law. There are 16 water rights claims with the park, two of which belong to the federal government. The remainder were filed by ranchers and other individuals, mostly in western Grand Canyon. The park has not as yet had to quantify or adjudicate water rights claims. Depending on the interpretation of recent court decisions the park may soon have to begin the adjudication process. A major portion of the project statement proposing an expanded water resource inventory also proposes collecting and organizing the information necessary to proceed with the adjudication process.

Flood Hazards. Several factors combine to enhance the flood hazards in Grand Canyon. The area is occasionally subject to unpredictable severe storms. Steep channels transport runoff and rock and soil debris rapidly. Almost all of the desirable camping areas in the canyon are located immediately adjacent to drainages, some in narrow box canyons with little opportunity for escape. All of the heavily used developed campgrounds in the cross canyon corridor are subject to periodic flooding, particularly Indian Gardens. Surveys of the 100 and 500 year floods are available for Phantom Ranch and of the 100 year flood at Indian Gardens. Any analysis of the extent of inundation of Indian Gardens must be considered an approximation because the channel geometry can change several feet with even minor floods. Two project statements are presented that propose a variety of actions to mitigate flood hazards.

Biotic Communities. Some biotic communities of Grand Canyon and particularly Colorado River are among the most studied and best understood aquatic resources. Many studies have been initiated to examine biotic communities that were or are threatened. There have also been some baseline inventories. Actions proposed in this plan include studies of more special problem areas.

Management Program

Seventeen project statements are included that propose actions to deal with problems and gaps in the park's information base. They are listed in priority order along with proposed scheduling and funding requests on the Water Resources Programming Sheet at the beginning of Chapter IV. A brief synopsis of each of the project statements is included below. They are presented in the same priority order as on the programming sheet.

N-67 Implement Water Resources Plan

Personnel with expertise in hydrology, water quality, water rights, and park operations will be required to implement many of the projects identified in the Water Resources Management Plan. A permanent position devoted to water resources and an accompanying increase in base funding will allow work on water resource issues to continue in a consistent and orderly manner. This will result in more effective implementation of proposed projects and improved response to new issues and continuity in future water resource planning.

N-59 Water Resources Inventory Including Water Rights

The existing water resource inventory for Grand Canyon will be expanded to include more remote areas of the park. Additional information will be collected on already inventoried water sources and all information will be organized in a form that will be readily useful when the park files for water rights.

N-52 Field Test Drinking Water Treatment Methodologies

Sediment laden waters of Grand Canyon present special problems for backcountry and river users. Bacterial concentrations are much greater in turbid waters, and sediment particles harbor bacteria and neutralize disinfectants. A practical water treatment method that is effective in turbid waters will greatly reduce the health hazards presented by these waters.

N-53 Flood Hazard Analysis of South Rim Village, Indian Gardens and Cottonwood Campground

Several developed areas in Grand Canyon are located very near streams or drainages subject to periodic flooding. The extent of flood hazard needs to be determined so that threats to life and property can be mitigated. The need for structural improvements, relocation of facilities, and evacuation plans will be based on reliable estimates of flood potential.

N-70 Water Conservation

The transcanyon pipeline system is a tenuous and expensive water delivery system. Water demand exceeds supply during the peak use season and frequent breakdowns complicate the supply problem. To help mitigate water shortages and the need to increase withdrawals from Roaring Springs, the park will make every effort to conserve water. Water conserving fixtures will be required in all new buildings constructed in the park and older structures will be retrofitted wherever possible.

N-72 Flood Hazard Mitigation

Topography and the proximity of Inner Canyon developments and activities to drainages combine to enhance flood hazards in Grand Canyon. Past floods have resulted in property damage and loss of life. At Indian Gardens, the most flood prone Inner Canyon development, the overnight camping area will be relocated to a less hazardous area. Evacuation plans will be prepared for Indian Gardens, Phantom Ranch, and Cottonwood Campgrounds. All interpretive media will be reviewed to insure that backcountry users receive adequate warning and have been advised of proper evasive actions.

N-66 Radionuclide Assessment of the Colorado River and Its Tributaries

Uranium mining activities in the Colorado River watershed and several tributary watersheds cause concern that some of these waters may be contaminated. Although past analysis of radionuclide concentrations have found only background emissions, they have not addressed the parameters for which the State of Arizona has established standards. To assess the park's compliance with state and federal standards and risks present, more analysis is needed.

N-56 Chemical Water Quality Inventory and Monitoring

Backcountry users in Grand Canyon obtain drinking water from and swim or wade in numerous Inner Canyon water sources. Chemical analysis of some sources identify potential health threats from drinking or contacting these waters. Only about one-half of the water sources in Grand Canyon have been analyzed sufficiently to assess their relative safety or hazard. A chemical water quality inventory will be a long-term project, annually sampling highest priority sources.

N-74 Hydrogeology of Kaibab Plateau

Past attempts to study the hydrogeology of Kaibab Plateau have had to rely on meager data collected over several years with inconsistent methods. Because of its hydrologic isolation Kaibab Plateau offers a unique opportunity to study ground water systems, water budgets, and influence of aquifer geology on water chemistry and subsequently riparian vegetation. A coordinated and consistent study of all major springs draining Kaibab Plateau, its structural geology, and the isolated riparian communities is needed to fully understand the ground water systems draining this feature. With this understanding, the park will be better able to assess the impacts of water withdrawals and watershed treatments on the surface of the plateau.

N-69 Increase Hiker Awareness of Water Quality Problems

Many hikers and river runners are unaware of microbial and chemical hazards present in Grand Canyon waters. Both man-caused and naturally occurring hazards exist. Through the use of informative phamphlets, interpretive displays at trailheads and in backcountry reservations office, and signing in some high hazards areas, backcountry users will be made aware of problems and actions they can take to avoid or mitigate them.

N-57 Lower Canyon Water Quality Monitoring From Diamond Creek to Lake Mead

Use of remote portions of the Colorado River from Diamond Creek to Lake Mead is increasing dramatically. Boating upriver from Lake Mead is increasingly popular and difficult to regulate. Although the park has good baseline water quality studies for most of the river, no information is available for the lower canyon. Bacterial water quality regime of this portion of the canyon may differ considerably from the remainder due to the varied use and the lake environment.

N-71 Fish Tissue Analysis

Colorado River in Grand Canyon is considered a major trophy trout fishery. The safety of these fish for consumption is in question because past analysis of Colorado River water has occasionally shown levels of some heavy metals are accumulating to unsafe levels. Fish tissue analysis will also be useful in examining the impact of radionuclides on humpback chubs inhabiting the Little Colorado River. Uranium mining and milling activities upstream of the park are known to have contaminated Little Colorado River. Tissue analysis of bottom feeding species will help assess the impacts of this contamination.

N-73 Impacts of Water Withdrawals on Temperature, Flow, and Fauna of Bright Angel Creek

Water withdrawn from Roaring Springs provides the domestic supply for all major developments within the park and demand for this water is increasing. A recently completed study of the impacts of this withdrawal identified the loss of riparian vegetation near Roaring Springs, a reduction in stream width, depth, and velocity, and an increase in water temperature and specific conductivity as major impacts. This study was hampered by a lack of accurate flow measurements, an inability to identify sub-adult aquatic insects to species, and a lack of continuous temperature. A study is needed that includes regular and accurate streamflow measurements, collection of adult aquatic insects and their identification to species, and continuous water temperature measurements.

N-4 Intensive Microbial Analysis of Selected Tributary Creeks

Past microbial analysis of backcountry water sources has been sufficient to confirm that no natural water sources in Grand Canyon are potable and that most are seriously contaminated when they carry large volumes of sediment. The next step is to sample selected waters intensively to identify diurnal and seasonal fluctuations and assess the influences of recreational activities, effluent discharges, sediment loading, wildlife contributions, and variations in stream flow. This will involve placing a person and self-contained laboratory at selected streams for extended periods.

N-25 Stock Tank Inventory

It has been estimated that over 40 earthen stock tanks have been constructed within the present boundary of Grand Canyon National Park to provide water for livestock and wildlife. Livestock grazing will soon be

eliminated from the park. Water available in stock tanks attracts trespass grazing and possibly encourages higher than natural wildlife populations. The number, location, size, and condition of these stock tanks need to be determined so that impacts of their removal can be quantified or so that water rights to the tanks may be obtained.

N-51 Colorado River Water Quality Modeling

Past examinations have determined the bacterial water quality regime of the Colorado River in Grand Canyon and identified major contributors of contamination. A model can be developed which will predict indicator bacteria concentrations throughout Grand Canyon with water analyses of a few easily accessible points along the Colorado and tributaries.

N-65 Fecal Streptococcus Species Identification of Garden and Bright Angel Creeks

Major trails along Bright Angel and Garden Creeks not only carry hikers but also mules. Mule feces are very abundant on the trails and are suspected of contaminating nearby creeks. Fecal streptococcus species identification will allow the park to determine if contamination originates from equines, humans or native wildlife.

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I. Introduction

A. Purpose of Plan

Grand Canyon National Park staff prepared this Water Resources Management Plan in response to instructions from the Director, National Park Service (NPS), in a memorandum dated October 16, 1979. Further impetus and valuable support was provided by the Director of the Western Region and his staff. Interest in managing the Nation's water resources is widespread and increasing because of competition for available water supplies and federal and state requirements for improvement of water quality. Also, perpetuation of many park ecosystems depends upon continuing supplies of high quality waters from both internal and external sources. These considerations make it apparent that NPS must have sound strategies for protection of park waters. Water resources management plans will facilitate NPS management of park waters and NPS cooperation with others in water resources management planning.

Water resources in Grand Canyon are a major concern for two reasons; (1) maintenance of aquatic and riparian ecosystems and (2) public health and safety. Riparian and aquatic ecosystems are rare in the arid southwest. These productive ecosystems have been systematically eliminated by groundwater overdraft, overgrazing, streambed channelization, elimination of fire in most ecosystems, and possible climatic changes. Free flowing waters in Grand Canyon National Park provide riparian and aquatic habitats, but there are several potential threats to these resources. Management practices on adjacent lands may affect groundwater recharge. Riparian zones are often impacted because they are favorite campsites for backcountry and river users. Fluctuations within the controlled flow regime of the Colorado River erodes pre-Glen Canyon Dam sediment deposits, thereby eliminating some riparian vegetation. Contaminants that could be introduced into the groundwater table by mining activities on the surrounding plateaus can alter the chemical water quality of inner canyon springs and streams.

This plan identifies management objectives for water resources in the park and describes past, current, and proposed management actions and research. Issues are identified and discussed regarding water quality and quantity, biotic dependency, water sales, recreational uses, flood plains, stock tanks, and influences of Glen Canyon Dam. A course of action is presented for protection, conservation, use, and management of park water resources.

Appendix A contains the development/study package proposals (10-238's). A glossary defining technical terms used in this plan is included in Appendix B.

B. Relation to Legislation and Other Park Plans

The 1916 National Park Service Organic Act directs NPS to regulate park use and promote enjoyment of park lands in a manner consistent with conserving park scenery and protecting natural and historical resources. Thus management of Grand Canyon must care for park resources in the short- and long-term, including water resources for protection of the natural system as well as for the public.

The Grand Canyon National Park Enlargement Act, January 3, 1975 (Public Law 93-620) provided for "...the further protection of the Grand Canyon in keeping with its true significance..." and established the current park boundary. This law incorporated Marble Canyon National Monument, Grand Canyon National Monument, portions of Lake Mead National Recreation Area and Kaibab National Forest, as well as some Bureau of Land Management lands and other lands into today's enlarged 1,226,656-acre national park. Consequently, additional water sources became part of the park.

Public Law 95-586 (November 3, 1978) allows the Secretary of Interior to sell water to a non-profit entity in Tusayan, Arizona. However, sale is based on proof there will be no detrimental effects on park resources or visitors.

Other legislation and executive orders that influence water resources management are listed below:

National Environmental Policy Act (1969) - Any major federal action must go through public review on the NEPA process. Concerning water resources this pertains to changes or increases in water use and treatment, i.e. constructing sewage treatment plant, pipeline, residences, visitor facilities, etc.

Safe Water Drinking Act (1974) - This applies to domestic drinking water. It requires testing for quality and necessary treatment.

Arizona State Water Quality Regulations (1978) - These are state regulations to enforce the federal requirements of the Safe Drinking Water Act. They are standards for water quality and use designations.

Clean Water Act (1977) - An act to provide for pollution control activities in the federal government and its grant programs, research and related programs. It also includes standards and enforcement.

Arizona State Water Law - Grand Canyon will abide by water laws as interpreted by Arizona. The state is also the administering agency for water rights.

Endangered Species Act (1973) - This law requires all federal agencies to consult with the Secretary of the Interior on all activities that potentially impact endangered flora and fauna. It also requires agencies to protect endangered species and their critical habitat.

Executive Order 11987 (1977) - States that "executive agencies shall, to the extent permitted by law, restrict the introduction of exotic species into the natural ecosystems on lands and waters which they own, lease, or hold for purposes of administration; and, shall encourage the States, local governments, and private citizens to prevent the introduction of exotic species into natural ecosystems of the United States."

Executive Order 11988 (1977) - This seeks to minimize impact on human life and reduce property loss by planning to avoid building in flood plains or when possible, remove people and structures. It recognizes restoring and preserving the natural and beneficial values of flood plains, and provides for public review of projects affecting flood plains.

Executive Order 11990 (1977) - This orders federal agencies to avoid impact from destroying or modifying wetlands. It supports building developments outside of wetlands and recognizes the beneficial values of this ecosystem type.

Actions in this Water Resources Management Plan are consistent with other Grand Canyon plans. These include the Natural and Cultural Resources Management Plan, Colorado River Management Plan, Feral Burro Management Plan, Backcountry Management Plan, and various development plans for water pipelines, buildings, and facilities.

C. Management Objectives

National Park Service Management Policies (revised 1981) forms the framework for dealing with water resources. The document states that park waters are a primary resource and should be conserved to allow for increased visitation without the need for additional water development. Therefore, the park should make only those water developments that are absolutely necessary for the visiting public and park operations. Withdrawal is permitted so long as it is necessary for use and management of the park and does not significantly alter natural processes and ecosystems. Continual vigilance will be maintained by observing and monitoring upstream diversions and ground water withdrawals for effects on occurrence, quantity, and quality of water necessary for ecosystem preservation.

Domestic water supplies shall be adequately treated so the return to water courses meets or exceeds applicable state and federal water quality standards. No new water systems or extensions of existing systems can be constructed until it is determined that the existing system cannot meet anticipated needs.

Water necessary for development, use, and management of a park will be obtained and used in accordance with the "reserved right" principle on lands withdrawn or reserved from the public domain for authorized purposes without ever having been in territorial or State ownership. The right to use of water to accomplish authorized purposes is also reserved.

In addition, the 1976 Grand Canyon National Park Master Plan identifies protection and maintenance of natural conditions as a management goal. It specifies the importance of the Colorado River and tributaries as an integral part of the park to support native ecosystems as well as provide potable water and water-oriented recreation to visitors and residents. The park is instructed to use reclaimed

water to supplement fresh water supplies and protect the river, its tributaries, and environs from human overuse.

The following objectives have been developed for managing water resources at Grand Canyon:

1. Manage the water resources of Grand Canyon National Park in accordance with legislative mandates.
2. Maintain existing natural riparian and aquatic ecosystems.
3. Minimize hazards to life and property presented by flooding.
4. Avoid or mitigate human induced contamination of water resources.
5. Identify water quality conditions that are potentially hazardous to wildlife and humans.
6. Minimize the adverse effects of water withdrawals for domestic water supplies.
7. Maintain the existing ecological and recreational values of the Colorado River.

II. Description of Environment and Water Uses

A. Geographic Description

Grand Canyon of the Colorado River is a large erosional feature in the 130,000 square mile Colorado Plateau in northwest Arizona. Grand Canyon National Park begins at the confluence of the Paria and Colorado Rivers at river mile 0.7 as measured from Lees Ferry (14 miles downstream of Glen Canyon Dam), Arizona, and ends at Grand Wash Cliffs at river mile 277 (figure 1, map). Area of the park is 1,226,656 acres. At the upper boundary of the park where the Grand Canyon begins the mean river elevation is 3,110 feet. Downstream, the canyon depth increases as the river flows in the Marble Platform. Near its confluence with the Little Colorado River (river mile 61.5) the Colorado begins passing through uplifted plateaus, the Kaibab to the north and the Coconino to the south. At river mile 71 the canyon depth is greater than 5,000 feet from both rims. Between river mile 71 and the western end of the uplifted Kaibab Plateau near river mile 136 the canyon is between 4,500 and 6,000 feet deep. Grand Canyon continues westward at depths of 4,000-5,000 feet for 140 river miles, then ends abruptly at the Grand Wash Cliffs. Lake Mead, which has a spillway elevation of 1,221.4 feet, backs water into the Grand Canyon as far as river mile 235, although more typically the lake begins a few miles downstream.

B. Climate

Due to extreme topographic variation there are many local climates in the Grand Canyon region. Variables which effect local climate include elevation, exposure to sunlight, local modification of upper level winds by landforms, and wind direction. Climatic conditions are cool and moist enough to support spruce-fir forests and alpine meadows on the Kaibab Plateau, while arid conditions typical of the Mohave desert prevail along the Colorado River in the western portion of the park. Throughout the region there are two pronounced rainy

seasons, one in the summer and one in winter. Average monthly precipitation for nine Grand Canyon locations is presented in Table 1. Winter precipitation is usually caused by cyclonic storms which produce widespread snow or rain lasting one or more days. In contrast, summer thunderstorms occur when warm, moist air surges into the area from the south and southeast around the western edge of the subtropical (Bermuda) high. Summer storms produce localized high intensity rainfall of short duration, typically lasting about ½ hour. The highest frequency of summer storm activity is in mid-afternoon, but especially moist surges can produce a series of heavy showers at any time of day.

Precipitation amounts in Grand Canyon National Park are a function of both elevation and geographic location. The importance of elevation is illustrated by comparing average annual precipitation of South Rim, Phantom Ranch, and North Rim, three locations at different elevations roughly lying on a straight line 13 miles long. For the period 1951-1980 the South Rim at an elevation of 6,970 feet averaged 14.6 inches, while Phantom Ranch at 2,570 feet averaged only 8.7 inches and North Rim at 8,400 feet averaged 25.5 inches. The importance of geographic location is illustrated by comparing average annual precipitation at South Rim and Desert View. For the period 1961-1982 South Rim averaged 15.5 inches while 18 miles east on the same plateau, Desert View averaged only 13.0 inches.

Practically all of the winter precipitation on the north and south rims occurs as snow. Figure 2 shows a plot of average snowpack characteristics at measuring sites on the north and south rims. On the Coconino Plateau, snow usually melts shortly after it falls, while on Kaibab Plateau much of the snow accumulates until the spring season when melting snow and rains recharge the groundwater supply and generate high stream flows.

Figure 3 shows estimates for potential evapotranspiration (PET) in northwest Arizona superimposed on a map showing average annual precipitation. According to National Oceanic and Atmospheric Administration (NOAA) data, June is the month with the highest PET.

C. Exceptional Storms and Floods

Significant floods have occurred on many occasions in Grand Canyon, as evidenced by debris accumulations at mouths of tributary streams of the Colorado River. In Grand Canyon, floods are caused by either excessive amounts of rainfall or by high rates of snowmelt. On rare occasions heavy rain falling on a snowpack can generate severe floods.

1. Tributary Watersheds

Floods initiated by heavy rainfall can occur during any season in Grand Canyon. Flood characteristics are determined by time and spatial distribution, intensity, and duration of rainfall. In floods caused by summer rains, elapsed time between first flow and flood peak is very short, and severe flash floods may approach a location as a high wall of water. In a large watershed, a summer thunderstorm

Table 1. Average monthly precipitation at Grand Canyon area locations.

	Elevation (ft)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
South Rim[1]	6785	1.49	1.26	1.61	0.92	0.62	0.58	1.49	1.96	1.07	1.20	1.01	1.45	14.64
Desert View[2]	7400	1.16	1.08	1.54	0.75	0.71	0.28	1.29	1.53	1.04	1.43	0.97	1.54	13.32
Phantom Ranch[1]	2570	0.85	0.65	0.92	0.46	0.36	0.35	0.82	1.20	0.76	0.82	0.74	0.78	8.69
North Rim[1]	8400	4.43	2.82	3.69	1.57	1.00	0.68	1.95	2.37	1.33	1.61	1.48	2.55	25.47
Mt. Trumball[3]	5600	0.78	0.62	0.81	0.56	0.52	0.48	1.72	1.89	0.98	0.74	0.72	0.83	10.63
Lees Ferry[1]	3210	0.43	0.34	0.51	0.38	0.33	0.23	0.83	0.86	0.50	0.60	0.53	0.46	5.99
Supai[4]	3205	0.65	0.69	0.85	0.38	0.42	0.28	1.10	1.41	0.63	0.64	0.77	0.67	8.48
Pierce Ferry[5]	3860	0.90	1.00	1.37	0.79	0.53	0.35	0.88	1.52	0.78	0.61	1.06	0.95	10.73
Tuweep[1]	4775	1.23	0.99	1.26	0.67	0.56	0.47	1.39	1.71	0.85	0.86	0.87	1.24	12.08

1 Period of Record 1951-1980
2 Period of Record 1960-1982
3 Period of Record 1948-1977, station now closed
4 Period of Record 1956-1982
5 Period of Record 1963-1982

Notes: Station title of north rim is Bright Angel RS. There are many gaps in the record for the north rim. Station title at south rim is Grand Canyon NP 2. Complete title for Pierce Ferry 17 SSW.

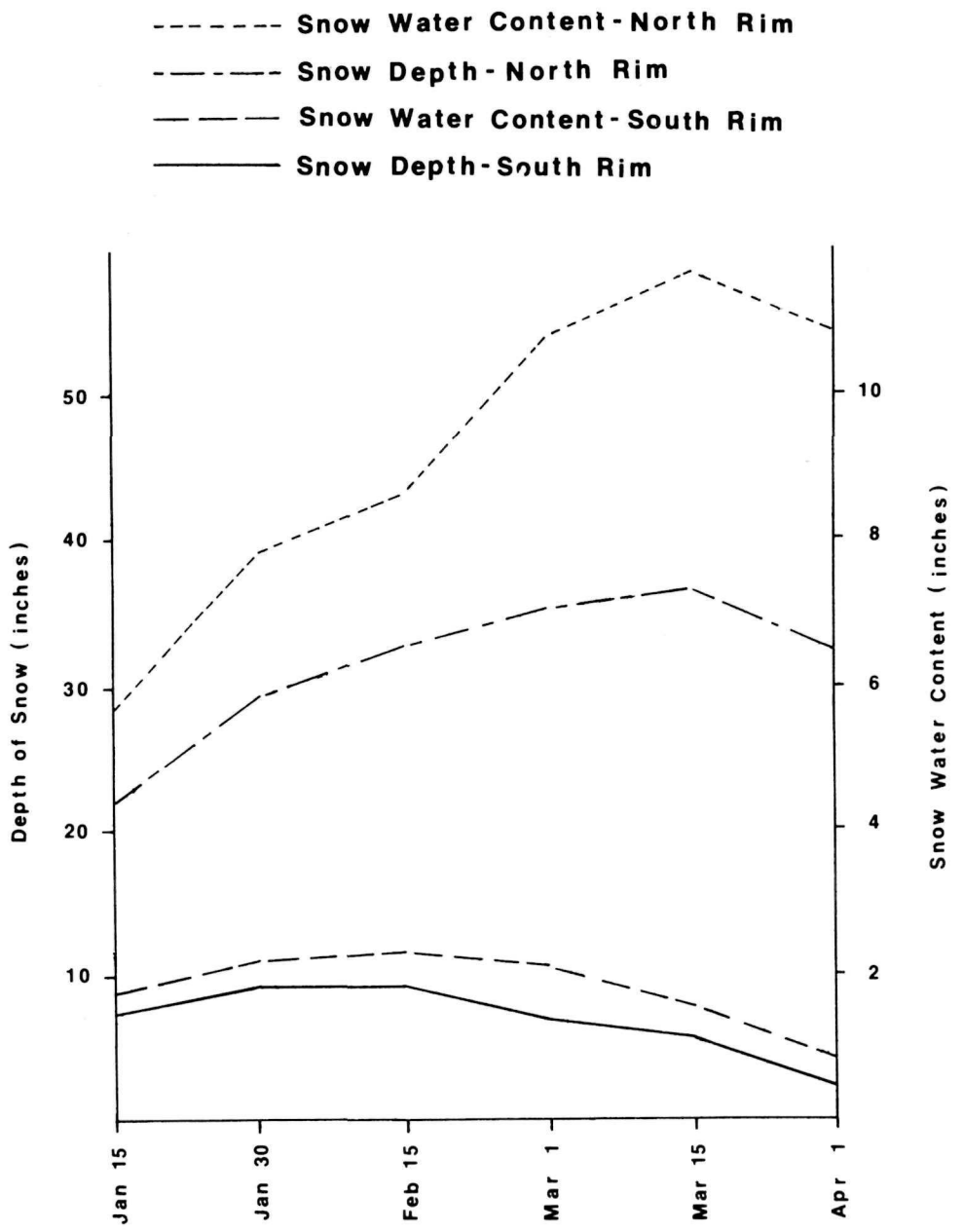


Figure 2. Comparison of mean snowpack characteristics for the North and South Rims of Grand Canyon. South Rim snowpack was measured at Grand Canyon snowcourse #11P1, T30N., R4E., Sec. 21, in the Hance Creek watershed. North Rim snowpack was measured at Bright Angel snowcourse #12N1, T33N., R3E., Sec. 34 in the Bright Angel Creek watershed.

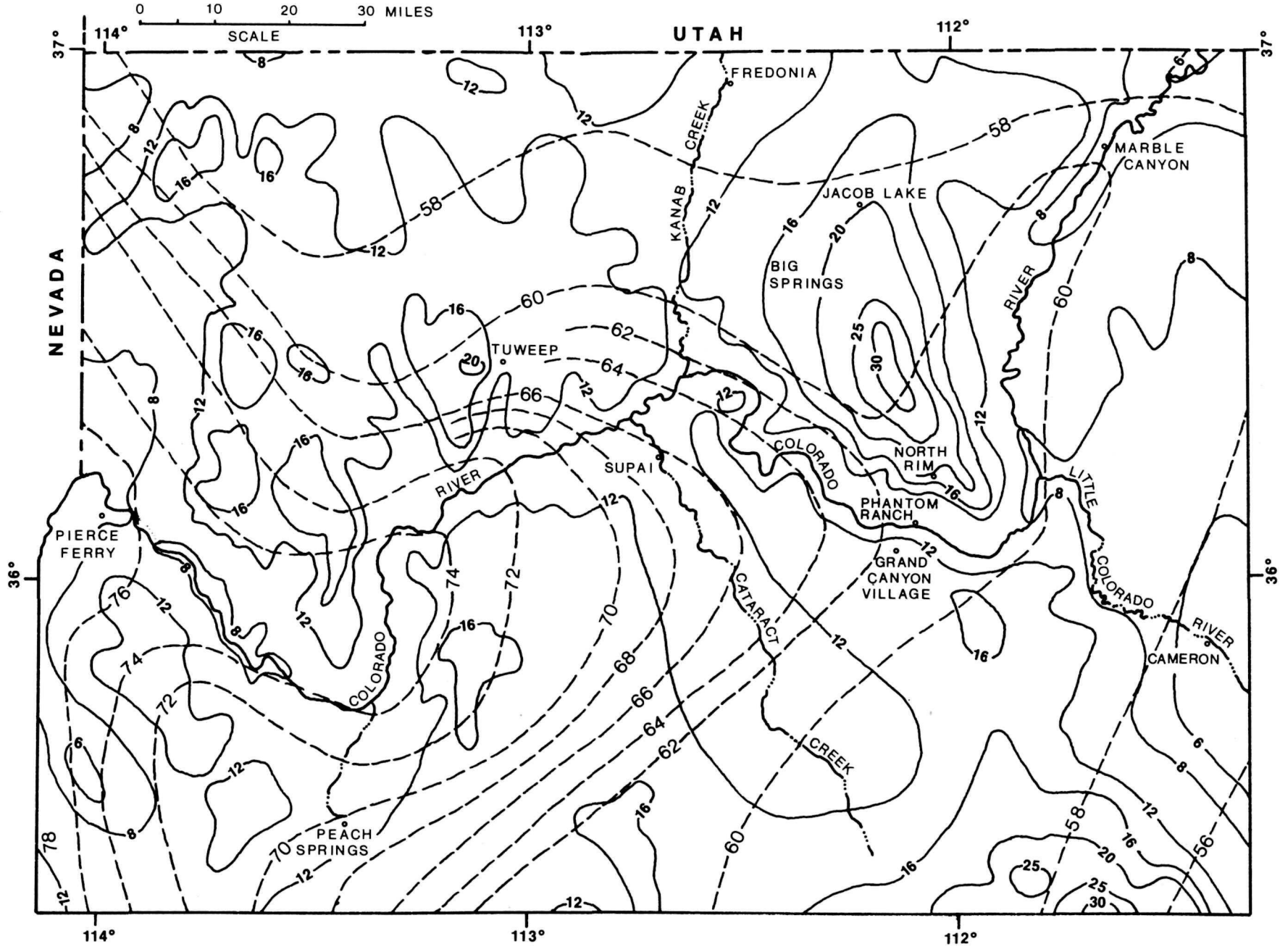


Figure 3. Average precipitation (solid lines) and potential evapotranspiration (broken lines) in the vicinity of Grand Canyon from Huntoon 1983.

may produce a severe flood in a small portion, but when the flood arrives at distant lower reaches its severity may be greatly reduced. Large scale cyclonic disturbances can bring widespread, moderate intensity rainfall with occasional heavy bursts that may last a day or longer. This can happen in later summer and fall when moisture from decaying tropical storms is fed into Arizona or in winter and early spring when very deep cyclones concentrate moisture over the state from as far south as the equator. Floods caused by these storms usually have rise times of several hours and flows may remain at or near the peak flow rate for several hours or even a day or more in exceptional cases.

A comparison of characteristics of the floods of December 6, 1966, and August 19, 1936, at Bright Angel Creek gaging station illustrates differences between summer and winter floods. The peak discharge of 4,000 cubic feet per second (cfs) of the 1966 flood was less than the 4400 cfs peak discharge of the 1936 flood. However, the 1966 flood had more impact on the stream environment because high flows persisted for a longer time and the total volume of water that flowed past the station during the 1966 flood was several times larger than that during the 1936 flood. Mean flow for August 19, 1936, was only 200 cfs whereas mean flow for December 6, 1966, was estimated to be 2,500 cfs.

Generally, in small watersheds of Grand Canyon (less than 10 sq. mi. area) flash floods caused by intense localized thunderstorms are much greater in magnitude than floods caused by widespread, moderate intensity storms typical of winter months. Large watersheds of Grand Canyon (10-100 sq. mi. or more) are susceptible to floods caused by all types of storms.

Flash floods are a potential danger to people in all Grand Canyon watersheds; however, terrain configuration may increase danger in certain locations. For example, orographic uplift plays a very important role in storm intensification in Grand Canyon, especially on plateaus north of Colorado River. The Kaibab Plateau is the best example of this. Summer thunderstorms form first over this plateau, occur more often, cover larger areas and drop slightly greater amounts of precipitation on the average than those over the canyon or Coconino Plateau. However, they have not been shown to be significantly greater in intensity. Winter storms passing over Kaibab Plateau are intensified by orographic uplift and appear to start earlier and linger longer there than they do in adjacent areas. The storm of December 1966 was a good example of winter storm intensification by Kaibab Plateau. In the Grand Canyon area, average precipitation for all months is greatest on Kaibab Plateau. Watershed orientation to direction of storm movement is a another important terrain effect that influences flash flood potential. Generally, if an intense storm moves across a watershed in a downstream direction, the flood peak will be higher than if the same storm moved across the watershed in an upstream direction. Given the fact that summer thunderstorms move into Grand Canyon from a southerly direction, flash floods in watersheds south of the Colorado River are enhanced by this effect.

Snowmelt floods occur after winters of heavy snowfall on Kaibab Plateau. These floods take several weeks to reach their peak, and much longer to recede. In many years, the highest flow rate in streams such as Bright Angel Creek occurs during spring because of snowmelt. Peak flow rates during snowmelt floods usually occur during the first heat wave of the spring season.

Debris flows can inundate a much larger cross-sectional area of a canyon and have much greater impact on the stream environment than flash floods. A debris flow is a slurry of water, mud, rocks, and vegetation pieces moving down a channel. Debris flows can transport much larger rocks than flash floods because their high proportion of soil particles increases the density of the entire flow enough that large rocks can be held in suspension. The storm of December 1966 produced sustained high flow rates in Crystal Creek, but near the end of the storm a sizeable debris flow was generated in the watershed which traveled all the way to the Colorado River. Rocks deposited in the Colorado River by this debris flow, some as large as 30 feet in diameter, transformed Crystal Rapid overnight into a major rapid. All of the well known rapids on the Colorado River have been created by debris flows.

Heavy rain storms often trigger rock falls in Grand Canyon. Rock falls are more common in the canyon than either debris flows or floods.

2. Colorado River

The flood regime on Colorado River in Grand Canyon has been greatly altered by construction of Glen Canyon Dam in the early 1960's. Before the dam was constructed, spring melt of deep Rocky Mountain snowpacks generated high amounts of runoff in the Colorado River. The greatest observed flood on the Colorado occurred in July 1884. It had an estimated peak discharge of 300,000 cfs. Several smaller floods on the order of 100,000 cfs occurred between 1884 and 1963.

Since completion of Glen Canyon Dam, only one notable flood has occurred in Grand Canyon, that of June/July 1983. Peak flows of this flood were measured at 92,000 cfs at the gaging station near Phantom Ranch. The lack of floods greater than 100,000 cfs since 1963 can be attributed more to the lack of high inflows into Lake Powell comparable to those of 1884 rather than to the existance of Glen Canyon Dam.

A substantial flood on Little Colorado River, which enters the Colorado below Glen Canyon Dam, also has potential to cause a dangerous flood on Colorado River. Since completion of the dam in 1963, the highest flow rate measured at Cameron gaging station was 17,800 cfs on December 23, 1978. However, on September 19-20, 1923, heavy rains in northeast Arizona and southern Utah triggered by an influx of tropical moisture caused a flood on the Little Colorado estimated to have had a peak discharge of 120,000 cfs. At the gaging station on Colorado River near Phantom Ranch, discharge jumped from 9,400 cfs on September 17 to 112,000 cfs at 6:00 p.m. September 19. Based on mean

discharge calculations for stations at Lees Ferry (which is 61.5 miles upstream from the Colorado/Little Colorado confluence) and Phantom Ranch, at least 85% of the peak discharge of 112,000 cfs measured at Phantom Ranch was accounted for by flow from the Little Colorado.

D. Regional Hydrology

The most noticeable hydrologic characteristic of the plateaus surrounding Grand Canyon is the lack of perennial streams. This is due to rapid infiltration of rain and melted snow and the fact that PET greatly exceeds precipitation. Water that does reach groundwater systems makes its way to numerous seeps and springs located throughout the canyon and its tributaries. Although average annual PET exceeds average annual precipitation, groundwater systems are still recharged from the surface on days of high rainfall or snowmelt.

The fraction of precipitation reaching groundwater systems of the Grand Canyon area is difficult to compute because in many places the boundary of their recharge area is uncertain. Huntoon (1974, 1982) has computed the areas drained by some groundwater systems. His figures indicate that the fraction of precipitation reaching the groundwater systems ranges from a low of about 1 percent for the Hualapai Plateau system (area = 600 square miles, total spring discharge = 4 cfs, average annual precipitation = 9 to 13 inches/ year) to about 20 percent for the Upper Bright Angel system (area = 53 square miles, total spring discharge = 24 cfs, average annual precipitation = 28 inches/year).

In the Grand Canyon area, groundwater moves down hydraulic gradients primarily along interconnected rock fractures. Often this movement is along fractures opposite the direction of rock layer dip. Major fractures occurring along faults govern locations of the larger springs. Most often, large springs issue from Muav Limestone or underlying Bright Angel Shale. Bright Angel Shale, both in a fractured or unfractured form, is a barrier to virtually all downward groundwater movement from overlying rocks. For a more detailed discussion on the influence of structural geology on groundwater movement, see Section II-E.

The length of time that water remains in a groundwater system, known as residence time, depends on properties such as recharge rate, surface recharge area, hydraulic gradient, and ability of rock to transmit water. For some systems, such as Blue Springs and Cataract, properties are such that their spring flow is not readily affected by seasonal or even yearly variations in precipitation. In contrast, flow from other springs with well-formed networks of underground passageways, such as Tapeats or Vasey's, may increase rapidly in response to precipitation or rapid snowmelt (Huntoon 1974, 1977).

The annual flow regime of most springs is highly dependent on type and amount of precipitation occurring over their recharge area. If precipitation over a watershed occurs as snow, peak flow rate in springs that drain the area will be delayed until the snowpack melts

and the meltwater passes through the groundwater system. Figure 4 illustrates this by showing a graph of the average precipitation record for Bright Angel Ranger Station (North Rim) above a graph of average discharge at the mouth of Bright Angel Creek. Discharge of Bright Angel Creek is essentially the sum of discharges from several springs that drain the Kaibab Plateau. Although substantial rainfall occurs during summer months, only a few heavier, more widespread storms cause an increase in discharge from springs.

Discharge of streams and springs draining Kaibab Plateau are highly interrelated. Figure 5 illustrates the strong relationships between Roaring Springs and Bright Angel Creek discharge, Bright Angel and Tapeats Creek discharge, and Thunder River and Tapeats Creek discharge.

E. Regional Geology

Grand Canyon lies in the physiographic region known as the Colorado Plateau or Plateau Province. The region is characterized by a thick sequence of flat to gently dipping sedimentary rocks that erode into majestic plateaus and mesas separated by deep canyons. Grand Canyon is the deepest and most extensive canyon found in the plateau country. Rock layers, or strata, exposed in the canyon represent all eras of geologic time.

Stratigraphy of the region is characterized by flat to very gently dipping Paleozoic (570-225 million years before present) sedimentary rocks that together range between 3500 and 4500 feet in thickness. These sedimentary rocks overlie highly deformed Precambrian (older than 570 million years bp) sedimentary, metamorphic, and igneous rocks. According to Huntoon (1974) it is hydrologically convenient to subdivide the Paleozoic rocks into four groups: (1) an upper sequence of permeable carbonates (rocks composed of carbonate minerals, especially limestone and dolomite) and clastic rocks (rocks formed from mineral particles that were mechanically transported), (2) an upper group of clastic rocks with small hydraulic conductivities, (3) a lower group of carbonates with structurally (i.e. fault) controlled zones of large hydraulic conductivity (i.e. caves), and (4) a bottom group of virtually impermeable clastics (see figure 6).

Stratigraphic units included in group 1 are Kaibab Limestone, Toroweap Formation, and Coconino Sandstone. Kaibab Limestone is primarily a magnesian carbonate with little tendency to karstify (form caverns or sinkholes). Toroweap Formation is composed of gypsum redbeds and limestones. The gypsum members are highly susceptible to solution and contain numerous sinkholes; however, the unit is not strong enough to structurally support large cavern systems. Coconino Sandstone is an eolian (wind deposited) sandstone of generally small hydraulic conductivity. In areas such as the Kaibab Plateau, Coconino Sandstone is highly fractured, permitting rapid downward movement of water. In unfractured areas Coconino Sandstone still permits slow downward percolation of water.

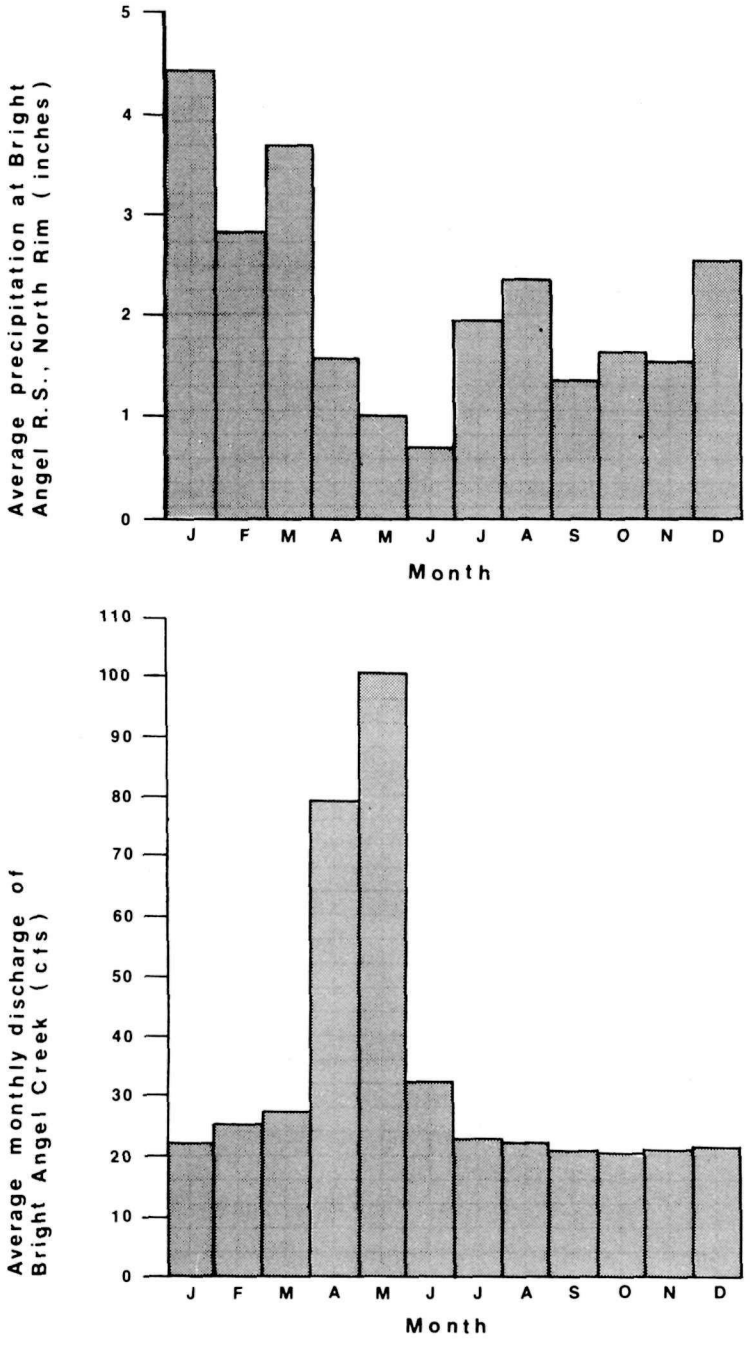


Figure 4. Mean monthly precipitation at North Rim and mean discharge of Bright Angel Creek. From Huntoon (1974).

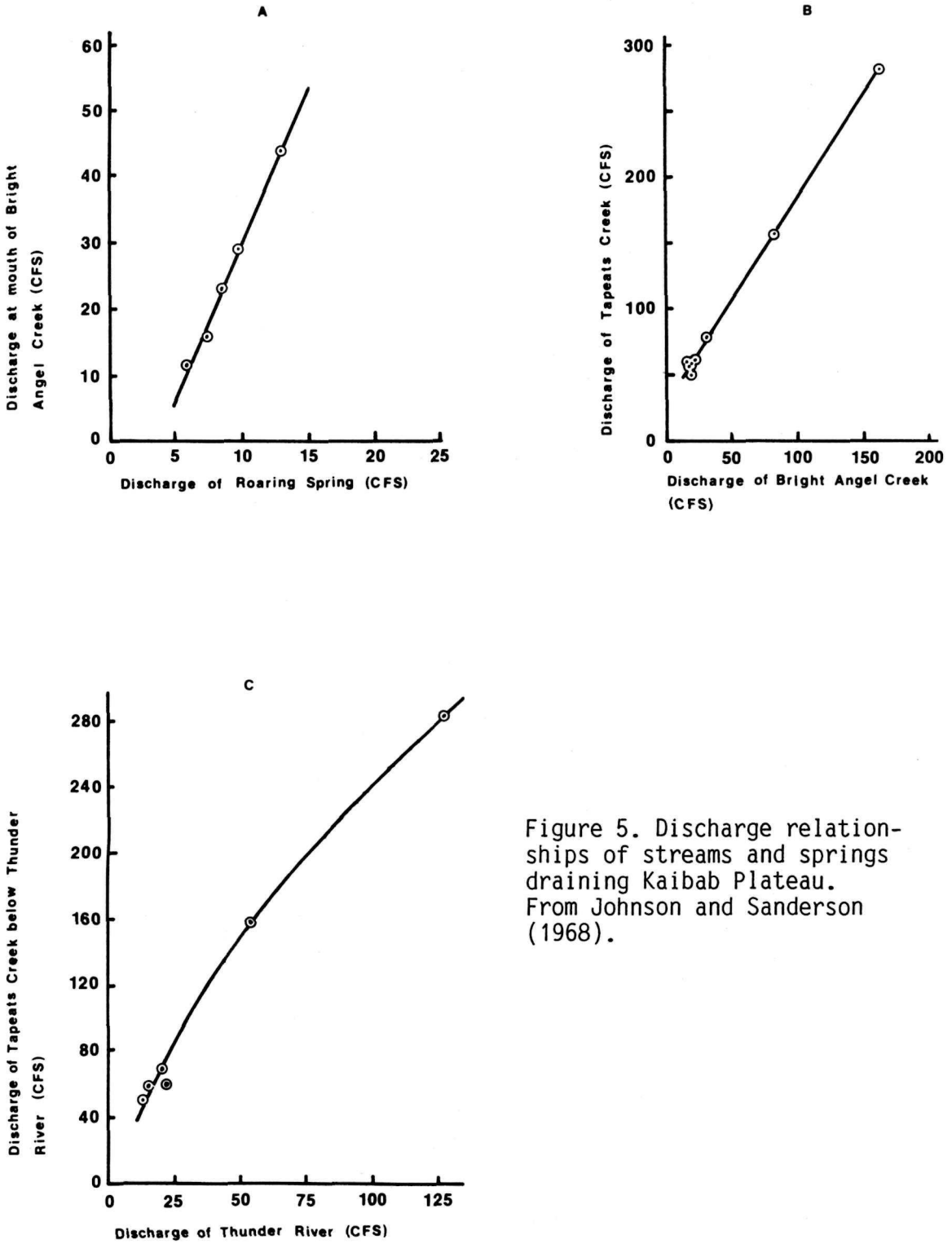


Figure 5. Discharge relationships of streams and springs draining Kaibab Plateau. From Johnson and Sanderson (1968).

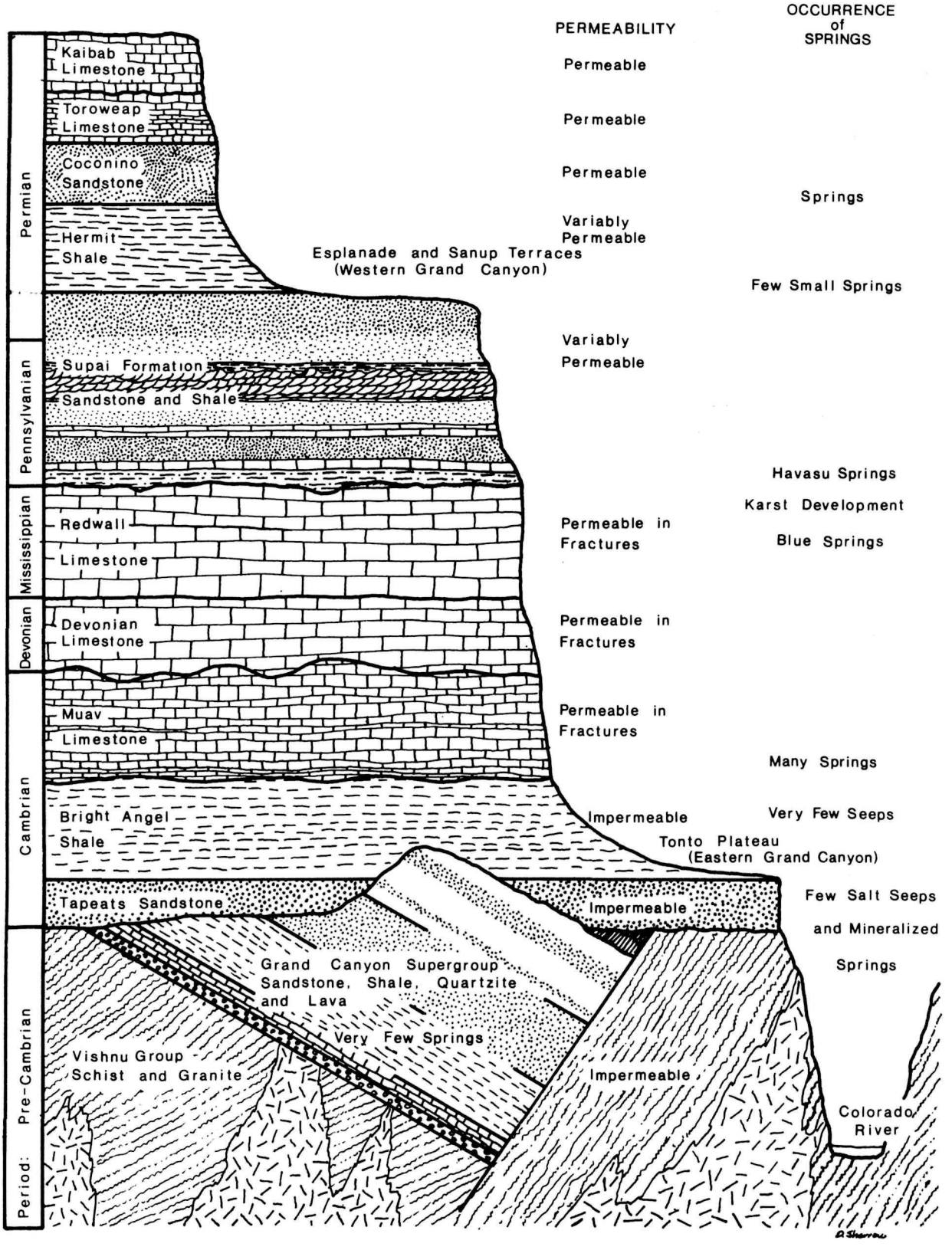


Figure 6. Typical cross section of rock strata in Grand Canyon showing relative permeability and occurance of springs.

Stratigraphic units included in group 2 are Hermit Shale and Supai Group. Hermit Shale is variably composed of red sandy shale and fine-grained sandstone. Where Hermit Shale contains large amounts of siltstone and claystone downward percolation of water is retarded and water accumulates on top of the shale in the bottom of Coconino Sandstone. Small springs or seeps may result in the canyon walls. Where Hermit Shale is mostly siltstone and sandstone it permits the downward percolation of water, although movement may be slow. Most groundwater movement through Hermit Shale occurs in fracture zones.

The Supai Group is comprised of several alternating layers of shale, siltstone, mudstone, fine-grained sandstone, dolomite, and minor beds of limestone. Water flow through the Supai is restricted to fractured areas, which are relatively common.

Stratigraphic units included in group 3 are Redwall Limestone, Temple Butte Limestone, and Muav Limestone. Redwall Limestone is the great cliff former in Grand Canyon. All three formations are composed primarily of limestone and dolomite which are impermeable unless fractured. Fracture zones have large hydraulic conductivities that become more permeable because of cavern development in zones of groundwater circulation.

Stratigraphic units included in group 4 are Bright Angel Shale and Tapeats Sandstone. These rocks have negligible hydraulic conductivities. Fracture zones in the Bright Angel Shale are usually sealed because micaceous shales that comprise the rock pulverize into an impermeable gouge that effectively seals fault zones. Consequently, Bright Angel Shale is a physical barrier to virtually all downward groundwater movement from overlying rocks in both fractured and unfractured states. The ease with which large caverns develop in fractured zones of the Muav limestone coupled with the tendency of the underlying Bright Angel Shale to serve as a barrier to downward groundwater movement causes most of the large springs in the Grand Canyon to issue from the Muav Limestone. Tapeats Sandstone is a well cemented sandstone that forms a sheer cliff. In areas such as Hermit and Monument Creeks, where some groundwater passes through Bright Angel Shale, there may be some small springs or seeps in the Tapeats Sandstone.

Several rock layers classified as the Grand Canyon Supergroup occur locally between Tapeats Sandstone and underlying precambrian shists. This group consists of several tilted strata of shale, mudstone, sandstone, limestone, basalt, and quartzite which would be about 10,000 feet thick if they were horizontal and intact. These rocks are exposed only in scattered locations in eastern and central Grand Canyon due to extensive erosion and faulting which occurred prior to deposition of Tapeats Sandstone. They are hydrogeologically unimportant because of their limited distribution and the fact that downward percolation of groundwater is usually stopped by overlying Bright Angel Shale. The few small springs which do arise from this stratiographic series are highly mineralized. In watersheds where the Grand Canyon Supergroup is found, these highly erodeable strata provide large amounts of debris which are carried to the Colorado River during flood events.

The precambrian shists and granites that underlie the Paleozoic sedimentary rocks form the spectacular inner gorge of the Colorado River between river miles 63 and 139 and again between miles 217 and 255. These rocks are also of little importance hydrogeologically because they lie below the Bright Angel Shale. The few small springs and seeps which issue from these rocks are highly mineralized.

F. Colorado River and Its Recreational Uses

Above the upper boundary of Grand Canyon National Park, the Colorado River drains an area of 110,390 square miles. Between the upper and lower boundaries of the park, the river travels 277 miles and drains an area of about 41,070 square miles of which only 1,904 square miles or 4.6 percent are within the national park boundary.

Before the completion of Glen Canyon Dam in 1963, the Colorado River was subject to natural seasonal and yearly variations in flow rate. At the United States Geological Survey (USGS) gaging station near Phantom Ranch, the lowest recorded flow of 700 cfs occurred in 1924 and the highest recorded flow of 127,000 cfs occurred in 1927. Floodmarks left by the flood of July 1884 indicated a flow rate estimated at 300,000 cfs.

Before 1963, the river carried a high suspended sediment load giving the water a muddy brown color. Sand beaches along the river were in a constant state of change. Beaches removed during floods were restored with new sand as floods receded. River temperature fluctuated widely, varying from near freezing during cold winters to 80°F or more in warmer summers.

Since 1963, Glen Canyon Dam has regulated the flow of the Colorado River. It was designed primarily as a water storage facility and was given electrical power generation capability to pay for construction costs. During normal operation times, all water released from the dam is used to generate power. Because penstocks feeding the powerhouse remove water from about 200 feet below the surface of Lake Powell, releases into the Colorado River below the dam are cold (45-50°F) and are largely free of suspended sediments. In the summer, the river warms only a few degrees between Glen Canyon Dam and Lake Mead. Water temperatures near the surface of Lake Mead in Grand Canyon are significantly warmer and exceed 70°F in the summer.

Except in rare years when high spring season runoff forces spilling of excess water, releases from the dam correspond to demand for electrical power in the southwest United States. Generally, releases from the dam are highest during the winter and summer months. Releases also vary widely on a daily basis. The Bureau of Reclamation (BR), which operates Glen Canyon Dam, has agreed to release certain minimum flows to facilitate river rafting through Grand Canyon. Except in times of drought, the BR has agreed to release a minimum of 3,000 cfs for the first 8 hours of the day, followed by a minimum of 8,000 cfs for the remainder of the day during the peak river running season from Easter to Labor Day. Peak releases during this period typically occur in August, when Glen Canyon Dam releases

are as high as 25,000 to 30,000 cfs during the daytime. During the remainder of the year, the dam is required to release a minimum of 1,000 cfs. Typically, the dam releases water at a much higher rate in winter to generate power for heating.

The Colorado River through the Grand Canyon is the longest stretch of recreational whitewater in North America. River running is the dominant recreational use of the Colorado in the national park. River trips increased dramatically in number through the 1960's and 1970's, until the NPS began regulating use levels in 1973. Currently, the total permitted commercial and noncommercial use levels are 150,076 user days in the summer season (May 1 through September 30) and 19,874 user days in the winter season (October 1 to April 30). Lees Ferry (river mile 0) is the launching point for almost all river trips through Grand Canyon.

The impact of river runners extends beyond the river corridor because people hike to attractions in tributary watersheds and sometimes camp overnight. Backcountry permits are required, but illegal camping does occur, especially in the rarely patrolled western Grand Canyon. Backpackers from the canyon rims also use some river beaches that are accessible by trail. River runners usually avoid those beaches that receive heavy use by backpackers.

G. Tributary Watersheds and Their Recreational Uses

Popular watersheds in Grand Canyon National Park are not limited to those with large surface drainage areas. Some smaller watersheds are popular because they contain frequently used trails, campsites, or swimming holes, and their springs may serve as water sources. Many watersheds have lush riparian communities along main channels that support a variety of plant and animal species. Others contain large springs which produce flows disproportionate to their surface watershed area.

Tributary watersheds of the Colorado River show the strong influence of geologic structure along the entire length of Grand Canyon. In the portions of the canyon between the Kaibab and Coconino Plateaus, the general dip of the sedimentary rocks is to the south-southwest. As a result, watersheds north of the Colorado in this portion are longer and much larger in area than those south of the river. Several watersheds north of the river in this portion drain the surface of the Kaibab plateau, whereas the Coconino Plateau is almost entirely drained by the one stream to the south, Cataract Creek. Below about river mile 140, watersheds are roughly equivalent in area both north and south of the Colorado. Throughout the Grand Canyon, structural controls such as faults and monoclines influence the location and drainage pattern of most watersheds.

Generally, backcountry users perceive tributary streams to be superior to the Colorado River as water sources for drinking and cooking. Actually, in places where both river and tributary water is available, water from the Colorado is usually of higher water quality. However, most trails are located away from the river, therefore backcountry users must rely on water from springs and tributary streams. In addition, tributary streams are the only possible safe locations for swimming because of the cold turbulent flow of the Colorado.

The following is a discussion of important watersheds in Grand Canyon National Park. The Grand Canyon National Park Backcountry Management Plan divided the park into travel zones, which are used here for grouping watersheds. A travel zone may cover only a portion of a watershed, cover roughly the same area as a watershed, or may consist of several watersheds. A large watershed may be divided into several travel zones. Although watersheds may cover large areas, use by hikers or river runners is usually concentrated near a water source. Watersheds are described in order of the location of their confluence with the Colorado River as it is traversed in a downstream direction from river mile 0 at Lees Ferry. River mileages are taken from the Grand Canyon River Guide by Belknap (1969). Some springs discussed are not located in recognizable surface watersheds, but are fed by subsurface networks that may extend underneath several nearby surface watersheds.

Paria River Watershed: river mile 0.7
Surface drainage area: 1,411 sq. mi.
Headwaters of the Paria River are in southern Utah, and the entire watershed is outside the park. A USGS stream gaging station has been located 1.1 miles upstream from the confluence with the Colorado River since October 1923. Average discharge for the 58 years of available record is 30.0 cfs. The Paria is a major contributor of sediment to the Colorado River, especially when flooding.

South Canyon Travel Zone
Vasey's Paradise: river mile 31.8
Estimated subsurface drainage area: 46.0 sq. mi. (from Huntoon, 1983).
Vasey's Paradise is a scenic spring which issues from caves in the Redwall Limestone cliff then cascades down a 125 foot slope to the Colorado River. The average discharge of the spring is estimated to be 4 cfs (Huntoon, 1974). The spring is known to respond rapidly to precipitation events on the surrounding plateau. Vasey's is a popular stopping point for river runners. Water from the spring has good chemical quality and provides moisture for a variety of water loving plants including golden columbine, lobelia, poison ivy, and crimson monkey flower.

Nankoweap Travel Zone
Nankoweap Creek Watershed: river mile 52.3
Surface drainage area: 32.7 sq. mi.
Nankoweap Creek is an intermittent stream draining a portion of the Eastern Kaibab Plateau. Discharge measurements made near the mouth

by various researchers vary from 0.0 to 3.1 cfs. This creek is a popular stopping point for river runners because of its many archeological ruins, some of which are visible from the river.

Palisades Travel Zone
Little Colorado River Watershed: river mile 61.5
Surface drainage area: 26,977 sq. mi.
The Little Colorado drains much of northeast Arizona and its headwaters are in western New Mexico. Only the last 2.8 miles of the river is within the national park. No gaging station exists near the confluence with the Colorado River, but a USGS station 45 miles upstream near Cameron has been operating since June 1947. The average discharge for the 35 years of available record is 235 cfs and the record discharge is 24,000 cfs. An estimated flow of 120,000 cfs occurred in September 1923 before the gaging station was built. From 3.5 to 21 miles above the confluence are the Blue Springs, which have a highly constant combined discharge of 211 cfs (Loughlin, 1983). Therefore, the average discharge at the confluence with the Colorado can be estimated to be 450 cfs by combining the average flow at Cameron with the average flow from Blue Springs.

The Little Colorado has deposited a large delta at its mouth creating a boulder-laden beach that is frequently used as a stopping point for river runners. It is the largest contributor of suspended sediment to Colorado River in Grand Canyon. The confluence is interesting to view because the two rivers often have different sediment loads, creating the impression that two rivers are flowing side by side for a long distance downstream before mixing completely. Because Little Colorado River provides an extremely important reproductive habitat for the endangered humpback chub, the park does not permit fishing and bathing with soap or shampoo. Camping between river miles 60.5 and 65 on the south side of the Colorado is also not permitted. The confluence area can be reached by backpackers using Beamer Trail, which connects with Tanner Trail 8 miles downstream. This large watershed contains numerous uranium mines and mills, some of which are known to discharge water contaminated with radioneuclides into Little Colorado River or its tributaries.

Chuar Travel Zone
Carbon Canyon Watershed: river mile 64.6
Lava Canyon (Chuar Valley) Watershed: river mile 65.5
Surface drainage area: 4.4 and 21.0 sq. mi., respectively
A large beach at the mouth of Carbon Canyon is often used for camping by river runners. In 1982 it ranked 9th in overnight use by river trips. The stream in the canyon is intermittent. Many scenic lava outcrops can be found a short distance up the canyon.

Lava Canyon also has several scenic lava outcrops. A small shaft once mined for copper is often explored near the canyon mouth. Lava Creek is dry for short periods of the year.

Tanner Travel Zone
Tanner Canyon Watershed: river mile 68.5
Surface drainage area: 7.4 sq. mi.
Few river runners use the beaches at Tanner Canyon for camping,

but the lower part of the watershed, especially the beach area, is popular with backpackers. This is the most eastern watershed with trail access from the developed areas of the South Rim. Tanner Canyon watershed ranked 7th in overnight use by backpackers in 1982. The upper reaches of the watershed contain the Desert View development.

Unkar Travel Zone
Unkar Creek Watershed: river mile 72.5
Surface drainage area: 14.3 sq. mi.
The river beaches near the Unkar Creek mouth are very popular overnight stopping points for river runners. Grouping the upper and lower Unkar beaches together, they constitute the most popular river campsites in the Grand Canyon. The extensive Unkar Delta contains the largest known prehistoric settlement along the river in the canyon.

Red Canyon Travel Zone
Red Canyon Watershed: river mile 76.5
Surface drainage area: 4.1 sq. mi.
The beach at Red Canyon is used heavily by backpackers on the Hance Trail, but sparingly by river runners. In general, due to the steepness of the Inner Gorge between Unkar and Monument Creek (river mile 93.3), good camping beaches are rare along this reach. The Tonto Trail begins at the mouth of Red Canyon and heads west for 77 miles traveling along the Tonto Plateau through several other south rim watersheds. Red Canyon watershed ranked 8th during 1982 in overnight use by backpackers.

Hance Creek Travel Zone
Mineral Creek Watershed: river mile 77.7
Hance Creek Watershed: river mile 78.5
Surface drainage area: 1.4 and 9.1 sq. mi., respectively
Hance travel zone ranked 9th during 1982 in overnight use by backpackers. No beach exists at the canyon mouth for use by river runners for overnight camping. Grandview Spring discharges from Muav Limestone at the east side of Hance Canyon and feeds a small perennial stream used by hikers on the Tonto Trail. A short trail links the Tonto Trail to the Grandview Trail on Horseshoe Mesa. Mineral Creek watershed receives very little overnight use by backpackers and no overnight use by river runners.

Cottonwood Creek Travel Zone
Cottonwood Creek Watershed: river mile 80.6
Surface drainage area: 3.9 sq. mi.
Cottonwood Creek is a small watershed on the south side of the Colorado River crossed by the Tonto Trail. Several small unnamed springs supply a perennial flow to the creek for about ¼ mile which is used as a water source by hikers. The watershed also contains a short trail linking the Grandview and Tonto trails. Horseshoe Mesa, which is grouped into a separate zone, lies between Hance Creek and Cottonwood Creek watersheds. Horseshoe Mesa zone ranked 11th and Cottonwood Creek watershed ranked 12th during 1982 in overnight use by backpackers.

Grapevine Travel Zone
Grapevine Creek Watershed: river mile 81.8
Boulder Creek Watershed: river mile 82.8
Surface drainage areas: 11.5 and 2.0 sq. mi., respectively
Although Grapevine Creek is large for a south rim watershed in eastern Grand Canyon, the Grapevine travel zone receives the second lowest amount of overnight use along the Tonto Trail between Red and Boucher Canyons. Grapevine Creek has perennial flow. The beach near the canyon mouth receives moderate overnight use by river runners. Boulder Creek watershed receives very little overnight use by backpackers and no overnight use by river runners.

Cremation Travel Zone
Lonetree Canyon Watershed: river mile 83.9
Cremation Creek Watershed: river mile 85.8
Surface drainage area: 1.0 and 4.6 sq. mi., respectively
Cremation travel zone received the least amount of overnight use in 1982 by backpackers for all zones along the Tonto Trail between Red and Boucher Canyons. Lonetree Spring supplies a small flow to Lonetree Creek for most of the year except during late summer and fall. Cremation Creek is even less reliable. There is no overnight use by river runners at the mouths of either Cremation Creek or Lonetree Canyon.

The Kaibab Trail switchbacks down from Yaki Point through the upper western portion of the Cremation Creek watershed and crosses the Colorado River opposite Phantom Ranch. The trail receives heavy use from backpackers, day hikers, and mule riders. No overnight use is permitted along the Kaibab Trail in Cremation Creek watershed.

Cheyava, Clear Creek, and Walhalla Plateau Travel Zones
Clear Creek Watershed: river mile 84.0
Surface drainage area: 35.7 sq. mi.
Although large in surface area, Clear Creek watershed contains smaller springs than those found in other watersheds of comparable size north of the Colorado River. This is because the subsurface drainage system feeding springs in Clear Creek watershed is smaller than those of nearby watersheds. In 1982, the Clear Creek watershed received the second highest overnight use by backpackers on the north side of the Colorado and the fourth highest in the entire park. Clear Creek trail extends east from Phantom Ranch to a well used camping area along Clear Creek about 4 miles upstream from the confluence with the Colorado River. Several small springs contribute a small but reliable flow to Clear Creek. Cheyava Falls, a popular attraction for hikers, can be reached by hiking about 3 miles up Clear Creek from the end of the trail. Cheyava Falls begins as a spring in the Redwall Limestone and plunges down several cascades to the valley below. The falls support a lush community of riparian plants at the top of each cascade and below the falls.

Corridor, Phantom Creek, Manzanita, Transept, Uncle Jim Point, Greenland Spring, Outlet, The Basin, Robbers Roost, Thompson Canyon, Widforss, and Walhalla Plateau Travel Zones
Bright Angel Creek Watershed: river mile 87.6
Surface drainage area: 101 sq. mi.
This is the most heavily visited watershed north of the Colorado River. The watershed ranked first in 1982 in overnight use by backpackers in the park. The concessioner operated Phantom Ranch, a popular tourist attraction, is located at the mouth of Bright Angel Creek. The Kaibab Trail follows Bright Angel Creek upstream from Phantom Ranch for 8.5 miles then veers northwest up Roaring Springs Canyon to the top of the Kaibab Plateau near the North Rim developed area. Concessioner operated mule trips from the North Rim use the Kaibab Trail. Most mule trips travel only about 2 miles down Roaring Springs Canyon to the top of Redwall Limestone, but some travel to Phantom Ranch. Backpackers are permitted to camp in only two locations, one near Phantom Ranch at the Bright Angel Campground and the other 6.7 miles upstream at Cottonwood Campground. Bright Angel Creek has a growing reputation as a trophy trout stream, and it is not uncommon to find 20 to 30 anglers in the Bright Angel campground during the spawning period of November to January. Additionally, all visitor developments on the North Rim are within the higher reaches of the Bright Angel Creek watershed.

Three springs, Emmett, Angel, and Roaring, supply most of the flow to Bright Angel Creek and account for about 20 percent of the measurable discharge leaving the Kaibab Plateau. As with other large springs draining the plateau, these respond quite rapidly to high runoff events on the plateau surface. Emmett Spring discharges about 0.5 cfs from a small cave in the upper Muav Limestone on the westernmost branch of Bright Angel Fault. Angel Spring discharges about 13 cfs from dozens of solution tubes at the top of the Muav Limestone on the east side of Bright Angel Canyon. Roaring Springs discharges from several caves near the base of the Muav Limestone into Roaring Springs Creek a few hundred feet above the confluence with Bright Angel Creek.

A portion of the flow from Roaring Springs is diverted to the Roaring Springs pumping station. At the station, some of the diverted water is pumped to developments on the North Rim (from about May to October), and the remaining water travels to Indian Gardens pumping station via the transcanyon pipeline for use at South Rim developments.

Long-term measurements of Roaring Springs discharge have not been made. However, Huntoon (1969) measured it on several occasions and found it varied between 7 and 26 cfs and averaged 9.6 cfs.

Corridor Travel Zone
Pipe/Garden Creek Watershed: river mile 89.0
Surface drainage area: 6.6 sq. mi.
Pipe/Garden Creek watershed is the most heavily used of all watersheds south of the Colorado River. In terms of overnight use in the park, it ranked 2nd in 1982. Pipe Creek, which is located northeast

of Grand Canyon Village, and Garden Creek, which is located north of the village, merge 0.5 mile above the Colorado River. Bright Angel Trail begins at the top of the Garden Creek subwatershed and switchbacks 4.5 miles to Indian Gardens Campground (elevation 3,800 feet), which is the only camping location in the watershed. From Indian Gardens the trail follows Garden Creek to the confluence with Pipe Creek and then to the Colorado River. At the river, the trail follows the south bank upstream to two bridges which cross to the delta of Bright Angel Creek.

Depending on season, water in the transcanyon pipeline reaches Indian Gardens from Roaring Springs under gravity feed at the rate of 660-740 gpm. From Indian Gardens, one of two pumps delivers 400-420 gpm to South Rim storage tanks at an elevation of 7,043 feet. Presently the remaining 240-340 gpm is discharged into Garden Creek where it joins the natural flow of the creek. Two springs, one above the campground and one below, supply a natural flow of about 300 gpm to Garden Creek. In Pipe Creek subwatershed, Pipe and Burro Springs discharge about 1 gpm each.

Bright Angel Trail is heavily used by pack mule trips between the South Rim and Phantom Ranch (table 2). Beach camping by river runners is not permitted from ¼ mile above Kaibab bridge to ¼ mile downstream from Pipe Creek.

Monument Travel Zone
Horn Creek Watershed: river mile 90.2
Salt Creek Watershed: river mile 92.6
Cedar Spring Watershed: river mile 93.3
Monument Creek Watershed: river mile 93.3
Surface drainage areas: 1.7, 1.2, 0.35, and 3.5 sq. mi., respectively.
Monument travel zone is a heavily used area that can be reached only via the Tonto Trail. The Monument travel zone is part of a very popular trail loop used by backpackers involving a descent of the Hermit Trail, an eastward traverse of the zone, and an ascent of the Bright Angel Trail. Individually, Horn Creek, Salt Creek, Cedar Springs, and Monument Creek watersheds ranked 19th, 21st, 28th, and 5th, respectively, in overnight use during 1982. Monument Creek has a reliable perennial flow, but Horn Creek, Salt Creek, and Cedar Spring are usually unusable salty trickles or dry streambeds from late summer to fall. The beach above Granite Rapids at the mouth of Monument Creek is very popular with both backpackers and river runners.

Hermit, Long Jim, and Pasture Wash Travel Zones
Hermit Creek Watershed: river mile 94.9
Surface drainage area: 12.6 sq. mi.
Hermit Creek watershed has the second highest overnight use of all watersheds and zones south of the Colorado River. Hermits Rest, located at the top of the watershed, is the farthest point west that can be reached by paved road from Grand Canyon Village. The Hermit Trail begins at Hermits Rest and switchbacks into the watershed until

Table 2. Number of mule trips by both NPS and concessionaire in 1982

	Bright Angel Trail			South Kaibab Trail		
	up	down	total	up	down	total
January	213	252	465	250	211	461
February	156	250	406	294	201	495
March	344	548	892	576	348	954
April	742	1128	1870	765	382	1147
May	1018	1445	2463	816	398	1214
June	926	1361	2287	860	416	1276
July	899	1409	2308	968	462	1430
August	927	1389	2316	930	468	1398
September	845	1320	2165	956	484	1440
October	852	1282	2134	932	504	1436
November	351	617	968	735	454	1189
December	220	392	612	430	262	692
Year Total	7493	11393	18886	8512	4590	13132

it reaches the Tonto Trail. Santa Maria Spring perennially discharges about 1 gpm from the Esplanade Sandstone member of the Supai Group about 2 miles below the trailhead. Dripping Springs, located in the west fork of Hermit Creek, discharges from the Coconino Sandstone - Hermit Shale contact at a rate of about 1 gpm. Hermit Springs is a series of springs above Hermit campground discharging a total of about 210 gpm from the Muav Limestone (Metzger, 1961). Two pools in Hermit Creek below the campground are popular swimming holes for hikers during the warmer months. The beach at the mouth of Hermit Creek receives very little use by river runners, but is nearly as popular as Hermit Camp with hikers.

Boucher Travel Zone
Travertine Canyon Watershed: river mile 95.4
Boucher Creek Watershed: river mile 96.5
Surface drainage areas: 1.4 and 6.5 sq. mi., respectively
Boucher travel zone received the 4th highest overnight use of all watersheds or zones south of the Colorado River. All overnight camping in this zone occurs in Boucher Creek watershed. Boucher Creek has a steady perennial flow while Travertine Canyon is dry for much of the year. The small beaches at the mouths of Boucher Creek and Travertine Canyon receive light use by river runners.

Trinity, Point Sublime, and Robbers Roost Travel Zones
Crystal Creek Watershed: river mile 98.2
Surface drainage area: 42.8 sq. mi.
Crystal Creek is another large watershed north of the Colorado River with comparatively small springs. As with the Clear Creek watershed, much of the groundwater recharged from the Kaibab Plateau is diverted to other watersheds by the subsurface drainage system. The upper portion of the watershed is drained by two streams, Dragon and Crystal Creeks, which join about 4 miles above the Colorado River. The 4 mile reach of Crystal Creek below the Crystal/Dragon Creek confluence has a reliable perennial flow.

Dragon Spring discharges from the Bright Angel Shale 2.7 miles upstream from the Dragon/Crystal Creek confluence. Huntoon (1974) estimated its discharge to be 1.4 cfs (630 gpm). Crystal Spring discharges from Tapeats Sandstone 1.3 miles upstream from the confluence. Huntoon estimated its discharge to be 0.2 cfs (90 gpm). Both Dragon and Crystal Springs are of hydrogeologic interest because they discharge from formations below the Muav Limestone.

The river beach at the mouth of Crystal Creek receives moderate overnight use by river runners. The beach is used by river runners for brief stops to view Crystal Rapids, one of the most challenging in the entire Grand Canyon. The Crystal Creek watershed, part of the Trinity travel zone, receives little overnight use by backpackers.

North Bass, Scorpion Ridge, and Swamp Ridge Travel Zones
Shinumo Creek Watershed: river mile 108.5
Surface drainage area: 85.4 sq. mi.
Shinumo Creek watershed is another large watershed north of the Colorado River with comparatively small springs. Shinumo Creek has several large tributaries, many of which have courses that are

fault-controlled. Several small springs give Shinumo Creek a reliable perennial flow, which supports a lush riparian community in the lower portion of the creek. Shinumo Spring, the largest spring in the watershed, discharges from the base of Muav Limestone. Huntoon (1974) estimated its discharge to be 1.9 cfs (850 gpm).

North Bass Trail, which descends into the watershed from the North Rim, was one of the major cross canyon routes until about 1920. It is now largely overgrown and receives only occasional use by inner canyon hikers. The beach at the mouth of Shinumo Creek is small and receives little overnight use. However, river runners often stop there to visit a large swimming pool on the creek a hundred yards upstream from the mouth. Several species of native fish have also been collected in the lower 100 yards of Shinumo creek and probably breed there. North Bass river camp, located 0.5 mile upstream on the Colorado River from Shinumo Creek, ranked 5th overnight use during 1982 by river runners, but lies just outside the area drained by Shinumo Creek. River runners often take a short hike up the lower part of the North Bass Trail to visit historic sites along Shinumo Creek.

Garnet and Pasture Wash Travel Zones
Royal Arch Creek Watershed: river mile 116.4
Surface drainage area: 12.0 sq. mi.
Royal Arch Creek watershed is a small, scenic watershed on the south side of the Grand Canyon that contains a series of waterfalls and pools known as Elves Chasm. About 0.5 mile upstream from the mouth is a beautiful natural bridge that can only be reached by an arduous off-trail hike. The park does not permit overnight camping within 1 mile of the mouth of Royal Arch Creek, but river runners frequently stop at Elves Chasm to swim in pools below waterfalls. The Garnet travel zone, which contains Royal Arch Creek watershed, receives very little use by backpackers due to inaccessability.

Blacktail Travel Zone
Blacktail Canyon Watershed: river mile 120.0
Stone Creek Watershed: river mile 132.0
Surface drainage area: 9.3 and 2.6 sq. mi., respectively
Blacktail Canyon is a very narrow scenic canyon on the north side of the Colorado River that is a popular stopping point for river runners. The beach at the canyon mouth receives heavy overnight use. The stream in Blacktail Canyon, 120 mile creek, is perennial but reduces to a trickle during the summer.

Stone Creek watershed is a very small watershed on the north side of the Colorado River that is also a popular stopping point for river runners. The beach at the mouth receives heavy overnight use. Although small in size, the watershed contains several springs issuing from the Muav Limestone that contribute to a reliable perennial flow in Stone Creek.

Tapeats, Tapeats Amphitheatre, and Blacktail Travel Zones
Tapeats Creek Watershed: river mile 133.7
Surface drainage area: 82.7 sq. mi.
Tapeats Creek drains a very large watershed north of the Colorado River. According to figures from Huntoon (1974), about 60 percent of the total measurable discharge leaving the Kaibab Plateau is accounted for from springs in the Tapeats Creek watershed. However, the area on the surface of the Kaibab Plateau drained by Tapeats Creek is much less than 60 percent of the total area of the plateau. This illustrates that the subsurface drainage system feeding the springs extends well beyond the boundary of the surface watershed.

Tapeats Spring, the largest spring in the park, discharges from a large fault controlled cave in the Muav Limestone about 1 mile north of Tapeats Creek. The stream fed by Tapeats Spring joins Tapeats Creek about 3 miles upstream from the Colorado River. Huntoon (1974) estimated discharge of Tapeats Spring to be 48 cfs. Thunder Spring discharges from two closely spaced joint controlled passages in the Muav Limestone and plunges over a vertical cliff into Thunder River. Thunder River drops 1500 feet in a distance of 0.5 mile and joins Tapeats Creek 1.7 miles above the Colorado River. Huntoon estimated the discharge of Thunder Spring to be 21 cfs.

Tapeats Creek watershed ranked 10th in 1982 in overnight use by backpackers. The beach at the mouth receives moderate overnight use by river runners, but trips often stop for a few hours to hike in about 3 miles to view Thunder Falls.

Deer Creek, Esplanade, and Surprise Valley Travel Zone
Deer Creek Watershed: river mile 136.5
Surface drainage area: 16.7 sq. mi.
Deer Creek watershed, which is adjacent to Tapeats Creek watershed, is believed to be connected to the same underground system that feeds Tapeats and Thunder Springs. Deer Spring perennially discharges about 5 cfs into a Deer Creek tributary about 1 mile above the Colorado River. Vaughn Spring, located about 2.8 miles upstream from the Colorado, is part of the same underground system as Deer Spring, but ceases to flow during dry periods.

Deer Creek watershed ranked 13th in 1982 in overnight use by backpackers. The beach on the opposite (south) side from the mouth had the 4th highest overnight use by river runners in 1982. Overnight camping is not permitted by the park within 0.5 mile of the mouth of Deer Creek on the north side of the Colorado River. Deer Creek empties into the Colorado River by plunging over 100-foot-high Deer Creek Falls. The falls are a very popular swimming location for backpackers and river runners.

Kanab Creek Travel Zone
Kanab Creek Watershed: river mile 143.5
Surface drainage area: 2000 sq. mi.
The vast majority of this large watershed on the north side of the Colorado River is outside Grand Canyon National Park. Only the lowest 12.7 miles of Kanab Creek are within the park. The upper portion of the watershed is in southern Utah. Kanab Creek watershed yields the smallest quantity of water per unit surface area in the

Grand Canyon region. No gaging station exists at the mouth of Kanab Creek, but the USGS operated one at Fredonia, Arizona, between 1963 and 1980 (watershed area above Fredonia is 1085 sq. mi.). Average discharge at Fredonia for this period was 6.8 cfs. The creek is usually dry there during summer and early fall except on days of heavy thundershowers. Flow is more reliable during the winter and spring months. Close to the mouth, several small springs maintain a small perennial flow, estimated to be 4 cfs during the summer months. Kanab Creek is rarely used by backpackers or river runners.

Apache Travel Zone
Cataract (Havasu) Creek Watershed: river mile 156.8
Surface drainage area: 3070 sq. mi.
Cataract Creek watershed is a very large watershed south of the Colorado River which is mostly outside Grand Canyon National Park. The Havasupai Indian Reservation covers much of the lower portion of the watershed, and only the last 3.1 miles of the main stream below Beaver Falls are within the park. The boundary of Cataract Creek watershed extends eastward to near Grandview Point (above Horseshoe Mesa), southward to Bill Williams Mountain, and westward almost to the Aubrey Cliffs. Generally, the northern boundary of the watershed closely follows the south rim of the Grand Canyon and is within the park boundary. The small total discharge of springs on the south side of the Colorado River between Desert View and Havasu Creek indicates that most of the area south of the canyon is a recharge area for springs in the Cataract system.

The largest spring in the watershed is Havasu Springs, located on the main drainage 9 miles upstream from the Colorado River and 1 mile upstream from the town of Supai. The main drainage is referred to as Cataract Creek above Havasu Springs and Havasu Creek below the springs. Year-round temperature of the springs is about 70° F and discharge is fairly uniform at about 63 cfs (Johnson and Sanderson, 1968). Below Havasu Springs are several beautiful waterfalls including Supai, Navajo, Havasu, and Mooney Falls. Travertine dams holding back large pools of water have been built up below each falls from the spontaneous precipitation of calcium carbonate in the agitated water. All of these pools are popular swimming locations.

Overnight camping is not permitted by the National Park Service along the Colorado River from the mouth of Havasu Creek to a point 0.5 mile downstream and along the 3.1 mile section of Havasu Creek within the park. However, almost all river runners stop during the day at Havasu Creek to swim in the lower reaches of the stream in one of dozens of pools. Some hike in far enough to camp overnight at Havasu Campground inside the Reservation. The campground is very heavily used, being filled to capacity with over 200 people every night during warmer months.

National Canyon Watershed: river mile 166.0
Surface drainage area: 187 sq. mi.
National Canyon watershed is a large watershed on the south side of the Colorado River that has a highly reliable perennial flow in its lower reaches. The lower part of the canyon near the Colorado is a scenic narrow gorge with several small waterfalls. The beach at the

mouth of National Canyon ranked first in overnight use by river runners at a single campsite because it is the first large camp encountered after visiting Havasu Creek. National Canyon is entirely inside the Hualapai Indian Reservation.

The Dome and Tuckup Point Travel Zones
Fern Glen Canyon Watershed: river mile 168.0
Surface drainage area: 15.3 sq. mi.
Fern Glen Canyon watershed is a relatively small watershed on the north side of the Colorado River. It has a very narrow canyon with walls several hundred feet high but only a few tens of feet apart. Several small springs maintain a perennial flow in the canyon. The beach at the mouth ranked 7th in overnight use by river runners in 1982.

Warm Springs (Lava Falls Springs): river mile 179.3
Subsurface drainage area: unknown
Warm Springs are a series of springs discharging from the Rampart Cave member of Muav Limestone on the south side of the Colorado River at Lava Falls Rapid. Temperature of the spring water is about 78° F and total discharge of the springs is about 10 cfs. Although Warm Springs is a major series of springs, few people notice it because of the excitement of running Lava Falls.

The Dome Travel Zone
Whitmore Canyon Watershed: river mile 188.0
Surface drainage area: 104 sq. mi.
Whitmore Canyon watershed contains spectacular volcanic flows in its lower reaches. It is filled to the level of the Esplanade Sandstone with lava and interbedded alluvium. The filled valley now has a broad flat floor which slopes gently towards the canyon, but ends abrubtly in a near-vertical cliff above the Colorado River where the wash suddenly steepens and drops 800 feet in less than a mile. The park boundary follows the top of these cliffs in the Whitmore Canyon area, therefore very little of the watershed is within the park. The beach at the mouth of Whitmore Wash receives heavy overnight use by river runners.

Parashant Travel Zone
Parashant Canyon Watershed: river mile 198.5
Surface drainage area: 375 sq. mi.
Parashant Canyon watershed is an outstanding example of the role of faults in regulating drainage pattern. It actually consists of two large subwatersheds, Andrus Canyon and Parashant Canyon, which join 5.6 miles upstream from the Colorado and flow through a spectacular, steep-sided gorge to the mouth. Several small springs flow perennially into main drainages but their water is quickly absorbed into the channel alluvium. The beach at the mouth receives light overnight use by river runners.

Pumpkin Spring: river mile 212.1
Pumpkin Spring is a highly mineralized spring of low flow just above the south banks of the Colorado River. Because of its low discharge rate (a few gpm), it has negligible effect on the river water quality and is mainly of scientific interest. Orange tinted travertine deposits from spontaneous percipitation of calcium carbonate and other minerals have surrounded the spring. This gives it the appearance of a bowl-shaped swimming pool or giant pumpkin. The temperature of the spring is about 86° F.

Diamond Creek Watershed: river mile 225.4
Surface drainage area: 284 sq. mi.
Diamond Creek watershed is a large watershed on the south side of the Colorado River that is entirely inside the Hualapai Indian Reservation. Diamond Creek is the usual takeout point for river trips, as it is the first point below Lee's Ferry where a road reaches the river. Some river trips continue to Pierce Ferry 55 miles downstream. The watershed is also a starting point for river trips operated by the Hualapai Tribe. Diamond Creek is the farthest point upstream from Lake Mead that can be reached by upriver trips originating in the lake. The flow in Diamond Creek is perennial but small, estimated to be from 0.5 to 1 cfs.

Travertine Canyon Watershed: river mile 229.1
Surface drainage area: 5.8 sq. mi.
Travertine Canyon watershed is entirely inside the Hualupai Reservation. No river camp is available near its mouth, but it is often visited because of its unusually tortuous vertical walls.

Travertine Falls Watershed: river mile 230.5
Surface drainage area: 0.59 sq. mi.
Travertine Falls watershed is entirely inside the Hualapai Reservation. River trips often stop here to visit the falls just 300 feet from the river. Beautiful travertine drip castles have built up under the falls.

Bridge Canyon Watershed: river mile 235.0
Surface drainage area: 8.5 sq. mi.
Bridge Canyon watershed is entirely inside the Hualapai Reservation. It can be reached fairly easily by boats traveling up Lake Mead. The beach at the mouth is underwater at times when Lake Mead is high, but receives moderate overnight use by river runners when it is exposed.

Separation Travel Zone
Separation Canyon Watersheds (north and south): river mile 239.5
Surface drainage areas: 48.2 and 3.8 sq. mi., respectively
The Separation Canyon watersheds offer the most obvious illustrations of the importance of geologic structures in determining watershed location and shape in Grand Canyon. The straight, deep watersheds north and south of the river are aligned along Separation Fault. North Separation Canyon is where three members of the Powell party left the first downriver trip through the Grand Canyon. River trips often stop here to view a plaque commemorating this event, and the beach receives moderate overnight use. The flow in both canyons is intermittent.

Spencer Canyon Watershed: river mile 246.0
Surface drainage area: 276 sq. mi.
Spencer Canyon watershed is entirely inside the Hualapai Reservation. The flow in its lower reaches is perennial. Spencer Canyon receives heavy use by boaters traveling up Lake Mead and by downriver trips.

Surprise Travel Zone
Surprise Canyon Watershed: river mile 248.4
Surface drainage area: 156 sq. mi.
Surprise Canyon is a large watershed on the north side of the Colorado River. It receives very heavy use by boats traveling up Lake Mead. Surprise Spring, located 2.4 miles up the canyon, maintains a perennial flow to the Colorado River. Several other springs, including Cottonwood Spring, discharge perenially further upstream in the watershed.

Quartermaster Canyon Watershed: river mile 260.2
Surface drainage area: 34.6 sq. mi.
Quartermaster Canyon watershed is entirely inside the Hualapai Reservation. Quartermaster Spring flows perenially over a scenic waterfall ¼ mile upstream from the mouth that is plainly visible from Lake Mead. The watershed receives heavy use by boaters traveling up Lake Mead.

Grand Wash Cliffs Travel Zone
Cave Canyon Watershed: river mile 274.3
Surface drainage area: 48.2 sq. mi.
Cave Canyon watershed is a small watershed on the south side of Lake Mead, part of which is within the national park boundary. Columbine Falls, which is supplied by a small spring just upstream from the falls, plunges almost directly into a small cove that is very popular with lake boaters.

H. Vegetation

Most major biotic communities of Arizona are represented in Grand Canyon National Park either as entire species assemblages or simply as individual characteristic species. The major communities represented are listed below.

1. Rocky Mountain Forest

Rocky Mountain forest communities occur on the high plateaus surrounding Grand Canyon. Spruce-fir vegetation is found in the coolest, wettest locations in the park on the Kaibab Plateau above 8,700 feet. Some species include blue spruce, Engelman spruce, subalpine fir, white fir, ponderosa pine, and Douglas-fir. A lower elevation association of white fir, ponderosa pine, quaking aspen, and Douglas-fir occurs on the Kaibab Plateau between 8,250 feet and 8,700 feet. Ponderosa pine forests are extensive on the Kaibab Plateau between 6,500 feet and 8,500 feet. On the south rim, ponderosa pine occurs in favorable locations such as dry water courses, and Douglas-fir occurs occasionally just below the edge of the rim on sheltered northern exposures. Isolated stands of ponderosa pine also occur on the highest portions of the Shivwits Plateau and the Pine Mountains.

Pinyon-juniper vegetation occurs between 4,000 feet and 7,500 feet on both sides of the canyon. Pinyon-juniper vegetation is dominant on plateaus bordering the south rim of the canyon and on lower plateaus bordering the north rim of the canyon.

2. Desert Scrub

Grand Canyon is situated in a region of transition between three of the four major desert regions of North America. Great Basin desert scrub communities are found in the cooler, higher parts of the canyon where hard freezes often occur. This vegetation type is represented by such plants as a big sagebrush, rabbitbrush, Mormon tea, and a variety of perennial grasses such as blue grama, Indian ricegrass, and needle-grasses. The Mohave desert scrub and Sonoran desert scrub are found intermixed in the warmer inner canyon. Mohave desert scrub is represented by such species as turpentine broom, bladder sage, rabbitbrush, and blackbrush. Sonoran desert scrub is represented by such species as brittle bush, catclaw acacia, ocotillo, and creosote bush.

3. Riparian Woodland and Scrub

Riparian woodland is found primarily along perennial streams and springs. Riparian vegetation around small springs often extract and transpire the entire spring discharge. Characteristic species are Fremont cottonwood, willow, baccharis exotic species such as tamarix, camelthorn, and numerous smaller plants. Reliable water sources coupled with lush, diverse vegetation of riparian woodlands also support dozens of species of birds, mammals, reptiles, and amphibians. The water sources are also used by animals foraging in a much larger surrounding area. Some of the large springs such as Roaring Springs and Thunder River support flora which are unusually diverse and contain relatively uncommon species such as scarlet sumac, water birch, red-osier dogwood, knowlton hop-horn bean, and Martin ceanothus.

Riparian scrub usually occurs along ephemeral water courses in narrow canyons which are periodically scoured by floods. These canyons may have intermittent water sources hidden below the surface of their sandy streambeds.

Riparian vegetation along Colorado River has changed dramatically since completion of Glen Canyon Dam in 1963, and succession changes continue to occur. Periodic pre-dam floods in Grand Canyon removed plants growing in the floodplain below the high water line. A band of riparian scrub vegetation was established on the high water line. This band of vegetation was represented by honey mesquite, catclaw acacia, California redbud, coyote willow, and rarely cottonwood. With control of flows by Glen Canyon Dam several species rapidly colonized the relatively stable sediments below the old high water line which were left behind by earlier floods. Exotic species such as tamarix and camelthorn were successful post dam colonizers as were such native species as coyote willow and baccharis. The originally dominant tamarix is apparently no longer increasing and coyote willow is gaining dominance. There are 807 plant species representing 92

families found in the new riparian zone and in remnant areas of the old riparian zone. Of these, 210 species are introduced. High flows in the Colorado River during the summer of 1983 may have temporarily removed some of this riparian zone vegetation.

I. Wildlife

1. Mammals

On the plateaus bordering the canyon, 11 species of mammals are found exclusively to the north of the canyon, 14 are found to the south, and 12 are found on both north and south rims, but are divided into subspecies (Hoffmeister, 1971). Rodents are most numerous, commonly represented by rock squirrel, cliff chipmunk, and pocket mice. Common large mammals on both rims include coyotes, mule deer, gray fox, and bobcat. Mountain lions are common on the North Rim but rare on the South Rim.

Approximately 25 species of terrestrial mammals and 7 species of bats are known to occur within the desert scrub community. Again the most common mammal group is the rodents, with 16 speices inhabiting the desert scrub community of the Tonto Plateau. Such large mammals as coyote, fox, mountain lion, and mule deer are present but are very reclusive.

The spring-fed tributaries of the Colorado River are an essential water source for many mammals. Species that have been observed in the riparian zone include racoon, river otter (rare), beaver, spotted skunk, mule deer, several species of rodents, and several species of bats. Cougar and bobcat are rare visitors to the riparian zone.

2. Birds

There are 284 species of birds known to use the Grand Canyon area (Brown et. al., 1978). Few tributary riparian zones in the canyon have been surveyed for bird species, but a minimum of 106 species are known to occur within the habitat from Roaring Springs to Indian Gardens. Of the 106 species in this area, 50 are transients, passing through the area primarily during spring and fall migration; 29 are permanent residents; 26 are summer residents, returning only during spring and summer to breed; and one is an accidental occurrence far from its normal range (Carothers et al, 1983).

3. Reptiles and Amphibians

There have been 40 species of reptiles and 7 species of amphibians found in the Grand Canyon area. Of these, 4 species of amphibians and 14 species of reptiles live in and near the tributary riparian zone. The amphibian species are highly dependent on both riparian vegetation for habitat and water for reproduction. The Grand Canyon ground snake is probably restricted to the riparian zone. A complete discussion of reptiles and amphibians of the area can be found in Miller (1982).

4. Fish

At least seven fish species are native to the waters of Grand Canyon. All of these have been severely impacted by ecosystem changes caused by Glen Canyon Dam. Warm turbid Colorado River waters with annual floods have been replaced by clear cold flows which fluctuate daily. Most severely impacted were the four species that inhabited the mainstream Colorado almost exclusively. The humpback chub and bony-tailed chub are now confined to Little Colorado River and are both listed as endangered by the U.S. Fish and Wildlife Service. Records state one humpback chub was netted by Suttkus at. al., (1976) in Shinumo Creek, therefore, a slight chance exists that the species could inhabit other creeks. Two other species, Colorado River squawfish and razorback sucker, were not able to inhabit tributary creeks following completion of Glen Canyon Dam and are now considered extinct in Grand Canyon. Three native species, flannelmouth sucker, bluehead sucker, and speckled dace, remain common in tributary creeks. These three species once had a much larger distribution but are not currently considered threatened or endangered.

At least 21 introduced species of fish exist in Grand Canyon. Several species of trout were stocked in creeks in the park between 1920 and 1960. Trout stocking continues at Lees Ferry just upstream of the park boundary. With construction of Glen Canyon Dam and the subsequent altered riverine environment these trout prospered. Colorado River and its tributaries in Grand Canyon are considered among North Americas finest trout fisheries. Rainbow trout are now the most common.

Several other fish species introduced into Lake Mead and Lake Powell have migrated into the park. Minkley and Blinn (1976) and Clemmer and Suttkus (1981) have studied fish in the park. They have found the following exotic species in the headwaters of Lake Mead, Colorado River, and tributary creeks.

Roundtail chub (Gila robusta)
Fathead minnow (Pimphales promelas)
Plains or Rio Grande Killifish (Fundulus zebrinus)
Rainbow trout (Salmo gairdneri)
Cutthroat trout (Salmo clarki Lewisi)
Carp (Cyprinus carpio)
Channel catfish (Ictalurus punctatus)
Black bullhead (Ictalurus melas)
Threadfin shad (Dorosoma petenense)
Coho salmon (Oncorhynchus Kisutch)
Redside dace (Richardsonius balteatus)
Green sunfish (Lepomis cyanellus)
Golden shiner (Notemigonus crysolencas)
Red shiner (Notropis lutrensis)
Redside shiner (Richardsonius balteatus)
Mosquitofish (Gambusia affinis)
Bluegill (Lepomis macrochirus)
Striped bass (Morone saxatilis)
Largemouth bass (Micropterus salmonoides)
Brook Trout (Salvelinus fontinalis)
Brown Trout (Salmo trutta fario)

J. Mining in Grand Canyon Area

1. Historic Mining Activities

Many prospectors roamed the Northern Arizona region in the late 1860's through middle 1900's. During the height of this era, 85 to 100 claims were located in what was later to become Grand Canyon National Park and Lake Mead National Recreation Area. Grand Canyon National Park was closed to mining and mineral exploration on January 26, 1931, (46 Stat. 1043) except for claims patented prior to that date. Since then, successful efforts have been made by the NPS to acquire legal mine claims within the park.

Although mining claims were distributed widely throughout Grand Canyon, mines were generally constructed in 3 types of geological structures. Most commonly they occur in breccia pipes, which are cylindrical or conical collapse features in sedimentary rocks and are occasionally mineralized. Asbestos mines are located in contacts between Bass Limestone of the Grand Canyon Supergroup and intruded diabase sills. A few mines are located in slightly minerlized pockets in Vishnu Shist.

Mining in Grand Canyon was usually unprofitable because of the small extent of ore bodies, lack of water, and great expense in bringing ore to the canyon rims. Many mine ruins can be visited in the canyon today.

Bridal Veil Mines, located in the walls of Havasu Canyon, operated from about 1873 to 1905. Moderate amounts of high grade lead-silver ore and vanadium were removed from the mine.

The Ridenour Mine is located in a breccia pipe in the Esplanade Sandstone on the south rim west of Prospect Valley. The mine was worked primarily for copper from about 1880 until World War I.

The Copper Mountain Lode Mine is located in a breccia pipe in the Esplanade Sandstone above the confluence of Andrus and Parashant Canyons. The mine was actively worked for copper beginning sometime after 1875, and intermittently since then.

John Hance's Asbestos Mine operated in Asbestos Canyon from about 1883 to 1895. Asbestos fibers can still be found in the mine and much of the mining equipment is still there. Hance built the old and new Hance trails to serve his mine.

The Grandview Mine, located where the Grandview - Phantom monocline intersects Horseshoe Mesa, was operated by various owners from 1890 to 1916. The mine was worked primarily for very high grade copper ore. The mine would have kept operating under its last owner, William Randolph Hearst, had not the Grand Canyon been declared a national park in 1919.

The Tanner Mine, located near the mouth of Palisades Creek (river mile 65.5), was operated from 1880 to 1907. The mine was worked primarily for copper and silver. Seth B. Tanner improved an old Indian trail, now called the Tanner Trail, to serve his mine.

The Bass Mines, located in Copper Canyon and Hakatai Canyon, operated from about 1890 to 1933. The Copper Canyon mine yielded primarily copper and silver ores. The mine in Hakatai Canyon yielded asbestos fibers.

The Orphan Mine, located in a breccia pipe near Maricopa Point in the Horn Creek watershed, was mined for copper for a short period after 1893. The mine was reactivated in 1951 when the lode was found to be rich in uranium. Mining ceased at the Orphan Mine in 1969, and title to the mine property will pass to the federal government in 1987.

The Boucher Mine, located in the Boucher Creek watershed, was a small copper mine operated for a short time after 1891.

The Hack Mine, located in Hack Canyon of the Kanab Creek watershed, was first mined for copper in 1944. Later, it was discovered that the green copper mineral prominent in the mine was actually torbernite (copper uranyl phosphate). It was the first established commercial uranium producer in the Arizona strip (north of Grand Canyon) area.

2. Present Mining Activities

The establishment of Grand Canyon National Monument in 1908 ended all prospecting and mining on all lands within the monument which were not already covered by patented claims or valid existing rights. The monument became a national park in 1919, and as surrounding areas were declared national monuments, the same regulations applied to these lands. Since 1908, the NPS has made efforts to acquire valid existing rights within the park boundaries.

Presently, the only valid mining claim inside the national park boundary is at the Orphan Mine. The claim, which is currently owned by Republic Mining Enterprises, Inc., will expire August 8, 1987, and ownership of the claim will pass to the NPS. Given the depressed nature of the uranium market, it is highly unlikely that any more ore will be removed from the mine prior to that time.

Thousands of mining claims have been staked outside the park boundary in tributary watersheds to the north of the Colorado River. Exxon Company and Energy Fuels Nuclear, Inc. have done exploratory drilling in Parashant Canyon watershed, but no mining has taken place there. In Kanab Creek watersheds Energy Fuels Nuclear, Inc. is presently mining uranium ore from the Hack Mine, which is being stockpiled near the mine. The company is presently undergoing test drilling at two other sites, Pigeon and Kanab North. The Pigeon site is in cliffs north of Snake Gulch about 8.4 miles above Kanab Creek. The Kanab North site is located atop the western cliffs of Kanab Creek about 4 miles above the Kanab Creek/Snake Gulch confluence. Energy Fuels Nuclear, Inc. is presently considering at least three other sites in Kanab Creek watershed for test drilling.

Numerous uranium mines exist in the Little Colorado River watershed. The nearest ones to Grand Canyon are located in breccia pipes near Cameron, Arizona. Several uranium processing mills in that area are currently inactive due to the depressed uranium market and the low grade of remaining uranium ores.

K. Grazing in Grand Canyon Area

Grazing occurs on many state, national forest, Indian reservation, BLM, and private lands surrounding the park. Five permittees have legal grazing allotments in western Grand Canyon, which are on land added to the park in 1974. These allotments will expire on January 2, 1985, as mandated in the Grand Canyon National Park Enlargement Act (PL 93-620). Grazing occurs on the Sanup Plateau, which includes portions of most watersheds north of the Colorado River between Parashant Canyon and Grand Wash Cliffs, as well as in Columbine watershed south of the Colorado River.

Several stock water tanks were constructed by ranchers to support livestock and provide water for wildlife. At least 13 exist in the park. Of these, two have been issued certified water rights and applications have been filed for five others. Most of these tanks are in western Grand Canyon and little is known of their ability to hold water. Those that do hold water probably support unnaturally high wildlife populations and attract trespass cattle in areas where grazing is not permitted.

Trespass grazing occurs in several portions of the park. Only a small portion of the park boundary is fenced and the fences that do exist are frequently in a state of disrepair. Trespass grazing is known to occur regularly along the eastern park boundary between Desert View and the Little Colorado River gorge and on the Kanab Plateau in the vicinity of Tuckup Canyon.

III. Background Information and Past Management Actions

A. Water Quality

Water quality is a prime consideration in management of natural waters of Grand Canyon National Park. Water quality is the aggregate of physical, chemical, and biological constituents which characerize a water resource. Constituents, often referred to as parameters, which comprise water quality include: dissolved chemical constituents such as calcium and sodium; physical properties such as temperature, flow, and sediment load; and biological constituents such as bacteria. The nature of each parameter is a function of inputs from the atmosphere, land surface and biota, and groundwater system. Once discharge occurs from a spring, water quality is modified by natural chemical and biological processes and by human activity. Water quality management in Grand Canyon has two aspects: 1) control human and domestic stock impacts on water quality, and 2) warn people about naturally occurring water quality situations that may be hazardous to human health.

The park will attempt to meet State of Arizona water quality requirements whenever possible, so long as this does not conflict with maintenance of natural ecosystems. Such conflicts exist where naturally occurring levels of fecal bacteria and chemical constituents exceed state standards. Most often these standards are exceeded when backcountry waters are used as a source for drinking water or for full-body contact recreation. Some canyon waters far exceed state standards for both warm and cold water fisheries yet are suitable habitat for several native fish species. In these cases the park will attempt to minimize health hazards through education of backcountry users but no attempt will be made to modify the natural water quality. The park will comply with state requirements for sewage effluent discharge and the park's domestic water supply.

Water quality has a profound influence on the suitability of a water resource for various uses, and often it is desirable to manage water quality so that certain uses may safely occur. Arizona Department of Health Services and the NPS have cooperatively designated protected uses for Colorado River and several tributaries in Grand Canyon National Park (see table 3). Legal power of these designations is contained in Sections R9-21-102, Parts C and D of the State of Arizona Official Compilation of Administrative Rules and Regulations excerpted as follows:

> C. No further degradation shall be allowed in high quality waters which constitute an outstanding public resource and in designated waters of exceptional recreational or ecological significance. Streams and lakes which are to receive this protection shall be designated by the Council.
>
> D. No further degradation shall be allowed in any stream or lake which would destroy the critical habitat for a threatened or endangered species which is historically associated with such waters. Streams and lakes, which are to receive this protection, shall be designated by the Council.

Explanation of state protected use catagories is in Section R9-21-207 of the State of Arizona Official Compilation of Administrative Rules and Regulations:

> A. "Domestic water source" is the use of a surface water for potable water source. Treatment by coagulation, sedimentation, filtration disinfection, and other treatments may be required to yield a finished water suitable for human consumption. Domestic water source includes the use of a treated surface water for manufacturing, processing, or canning of foods and beverages for human consumption, and manufacturing or processing certain related products such as ice, or vegetable and animal fats or oils.

B. "Full body contact recreation" is the use of surface water for an activity which normally causes the human body to come into direct contact with the raw water to the point of complete body submergence. Full body contact includes swimming, water skiing, skin diving, and other similar activities, during which the water may be ingested accidentally and certain sensitive body organs, such as the eyes, ears, nose, etc., may be exposed to the water. Although the water may be ingested accidentally, it is not intended to be used as a potable water supply unless acceptable treatment is applied.

C. "Partial body contact recreation" is the use of a surface water for an activity which may cause the human body to come in direct contact with the water, but normally not to the point of complete submergence. Partial body contact includes fishing, hunting, trapping, boating, wading, and other similar activities, during which it is very unlikely that this water will be ingested, nor will critical organs such as eyes, ears and nose normally be exposed to the water.

D. "Aquatic and wildlife" is the use of a surface water for the growth and propagation of fish, waterfowl, fur-bearers, other aquatic life, semiaquatic life and wildlife. This water may be used for a cold water fishery, warm water fishery, wildlife habitat and other similar uses.

E. "Agricultural irrigation" is the use of a surface water for irrigation farming. Agricultural irrigation does not include the use of a surface water for washing and cooling raw farm products and washing milk handling equipment and cooling dairy products.

Table 3 lists designated protected uses for streams in Grand Canyon National Park. Some streams have uses not indicated in the table. For example, portions of Deer Creek are used for swimming, a full body contact activity, while the stream is designated only for partial body contact recreation. Allowable limits for several chemical and bacterial parameters for waters with designated protected uses are presented in table 4 excerpted from Arizona Water Quality Standards for Surface Waters (R9-21-209).

The state of knowledge and past management actions regarding park water quality can best be discussed in two parts, chemical water quality and microbial water quality.

1. Chemical Water Quality

Chemical water quality is the assemblage of dissolved constituents which characterize a water resource. Several factors combine to determine the chemical quality of springs, creeks, and the Colorado River in Grand Canyon. The amount of precipitation determines the amount of water available for overland flow and infiltration into the groundwater system. Precipitation quality determines the initial chemical quality of infiltrating water. Once in the ground water

Table 3. State of Arizona designated protected uses for Colorado River and Tributaries in Grand Canyon National Park. (Source: State of Arizona Official Compilation of Administrative Rules and Regulations Sec. R9-21-208.)

River mile	Stream	Full body contact[1]	Partial body contact	Aquatic wildlife	Domestic water source	Agricultural irrigation	Agricultural livestock watering
	Colorado River	X		cold[2] & warm[3]	X	X	X
0.7	Paria River		X	X	X		
32.0	Vasey's Paradise	X		X	X		
52.7	Nankoweap Creek		X	X	X		
81.5	Grapevine Creek		X	X	X		
87.9	Phantom Creek		X	cold			
87.9	Bright Angel Creek	X		cold	X		
88.9	Garden Creek		X	X	X		
90.2	Horn Creek			X			
93.5	Monument Creek		X	X	X		
94.8	Hermit Creek	X		X	X		
96.5	Boucher Creek		X	X	X		
108.5	Shinumo Creek		X	X	X		
116.5	Royal Arch Creek	X		X	X		
133.4	Tapeats Creek		X	cold	X		
136.2	Deer Creek		X	cold	X		
143.4	Kanab Creek		X	warm			X
156.8	Havasu Creek	X		X			X
225.4	Diamond Creek		X	cold			

Notes:
1 When full body contact is a designated protected use, it is implied that partial body contact is also a protected use.
2 "Cold" indicates cold water fishery: water having an environment suitable for the propagation and habitation of salmonids (trout).
3 "Warm" indicates warm water fishery: waters having an environment suitable for the propagation and habitation of species of fresh water fishes other than salmonids.

TABLE 4. SUMMARY OF ARIZONA WATER QUALITY CRITERIA FOR DESIGNATED USES

Standard	Full Body Contact	Partial Body Contact	Domestic & Industrial Water Supply	Cold Water Fishery	Warm Water Fishery	Agri-culture & Industry	Aquatic Life & Wildlife
FECAL COLIFORMS (colony forming units/100 ml)							
Geometric Mean	200	1000	1000	1000	1000	1000	1000
90% value (for 5 samples over 30 days)	400	2000	2000	2000	2000	2000	2000
pH							
Range	6.5-8.6	6.5-8.6	None[2]	6.5-8.6	6.5-8.6	None	6.5-8.6
Maximum change	± 0.5	± 0.5	None	± 0.5	± 0.5	None	± 0.5
TURBIDITY (JTU)[1]							
Streams	Lowest practicable value		None	10	50	None	Lowest practicable value
Lakes	Lowest practicable value		None	10	25	None	Lowest practicable value
DISSOLVED OXYGEN (mg/l)[1]							
Minimum	None	None	None	6.0	6.0	None	None
TEMPERATURE (^{o}F)[1]							
Maximum change	5^{o}	5^{o}	None	2^{o}	5^{o}	None	No temperature Interference
Maximum	93^{o}	93^{o}	None	55^{o}(winter) 70^{o}(summer)	93^{o}	None	No temperature Interference
TOXICS (mg/l)							
Arsenic	0.050	0.050	0.050	0.050	0.050	None	0.050
Barium	1.000	1.000	1.000	0.500	0.500	None	0.500
Boron	None	None	None	None	None	1.000	None
Cadmium	0.010	0.010	0.010	0.010	0.010	None	0.010
Chromium (hexavalent)	0.050	0.050	0.050	0.050	0.050	None	0.050
Copper	1.000	1.000	1.000	0.050	0.050	None	0.050
Cyanide	0.200	0.200	0.200	0.100	0.100	None	0.100
Mercury	0.005	0.005	0.005	0.005	0.005	None	0.005
Lead	0.050	0.050	0.050	0.050	0.050	None	0.050
Phenol	0.001	0.001	0.001	0.001	0.001	None	0.001
Selenium	0.010	0.010	0.010	0.010	0.010	None	0.010
Silver	0.050	0.050	0.050	0.050	0.050	None	0.050
Zinc	5.000	5.000	5.000	0.500	0.500	None	0.500
RADIOACTIVITY (pCi/ml)[3]							
Combined Radium 226 and 228	None	None	5[4]	None	None	None	None
Gross alpha particle activity	None	None	15[4]	None	None	None	None
Tritium	None	None	20,000[4]	None	None	None	None
Strontium 90	None	None	8[4]	None	None	None	None

[1]Discharge related parameters. This means that a discharge cannot cause changes in the receiving waters in excess of these standards

[2]"None" means no standard.

[3]The Monitoring Section of the Bureau of Water Quality Control references the list of acceptable concentrations of individual radioactive materials used by the Arizona Atomic Energy Commission to license radioactive discharges (Arizona State Administrative Rules and Regulations R12-1-407 Appendix A) as standards for radioactivity in all surface water regardless of designated uses.

[4]R9-8-221(E). These numbers refer to drinking water as delivered to the consumer.

system geological characteristics of the aquifer determine residence time and flow paths, which in turn affect the amount and type of minerals dissolved. Local alterations in water quality occur after discharge from a spring are a result of biotic activity, gas exchange, precipitation of dissolved solids, and human inputs or withdrawals.

At least 19 researchers have examined chemical water quality in Grand Canyon. These include NPS and USGS monitoring as well as independent research. No single effort has been comprehensive; in fact of 69 water sources identified by the park as important, 23 have never been sampled. Most investigations have been narrowly focused on limited areas, a few springs of interest or only major tributaries. Considered in total, however, these investigations present a good picture of chemical characteristics of Grand Canyon waters. Additionally, work by Huntoon (1977 and 1983), Laughlin (1983), and Foust et. al. (1978 and 1980) provides considerable insight into regional hydrology and identifiable factors influencing water quality and quantity. Their work enables classification of Grand Canyon waters into discrete groups with similar characteristics and origins.

With the exception of the Colorado River all streams in Grand Canyon arise from springs except during times of high snowmelt or rainfall runoff. Before reaching these springs water from rain or snowmelt on the surrounding plateaus must percolate 2,300 to 6,000 feet through numerous rocks strata. Structural and hydrogeologic characteristics of each strata are discussed in Section II-E. These characteristics have profound effects on chemical water quality.

Strata Influence on Springs. Characteristics of springs discharging from each strata are discussed below to the extent that current knowledge and data analysis allow. For this discussion springs are grouped by the strata from which they discharge because springs from each strata share many characteristics. The majority of them discharge from the lower carbonate strata (Redwall, Devonian, and Muav Limestones). These carbonate springs are the most studied in the canyon, and yet much more needs to be learned of their chemical quality and aquifers before they can be fully characterized. Few other springs have been analyzed, so this discussion of their characteristics includes considerable inference.

a. Springs in Lower Carbonate Strata

The largest springs in the park are dolomitic springs draining Kaibab Plateau which issue from lower carbonate strata. These springs, which are generally found in large watersheds north of the Colorado River, fall in the short residence time high volume category. Major dolomitic springs are Tapeats, Thunder, Deer, Vaughn, Roaring, Angel, and Vasey's Springs, and those feeding Shinumo and Clear Creeks. These springs have concentrations of total dissolved solids (TDS) ranging from 150 to 250 milligrams per liter (mg/l). Permeability of overlying rock strata drained by these springs has been enhanced by faulting and solution channels to such an extent that increased flow and sediment discharge can occur within 12 hours of a heavy storm event. This has been observed at both Vasey's and Roaring Springs. The chemical quality of waters from these large dolomitic springs has

been found to be consistently good with standards exceeded in only two areas. Phosphate concentrations in excess of the EPA nutrient standard for this portion of the Colorado River have been found in Bright Angel Creek, Tapeats Creek, Shinumo Creek, and Deer Creek. The EPA standard of .04 mg/l total phosphate is intended to prevent excessive plant growth. Humans have consumed waters with phosphate concentrations over 100 times higher with no ill effects (Mckee and Wolf, 1963). Phosphate concentrations in these creeks are assumed to be of natural origin because concentrations are similar among several similar but separate ground water systems, and activities which normally introduce phosphates such as agriculture, boiler discharge, and domestic sewage, do not occur in the area except at Bright Angel Canyon, where a small amount of treated effluent from north rim developments is discharged. The only other chemical quality problem found in the large dolomitic springs is aluminum concentrations in Shinumo Creek which are sufficient to cause eye irritation in swimmers.

Havasu Springs and Blue Springs are both excellent examples of long residence time springs. The fifty or so springs, including Blue Spring, which make up the base flow of the Little Colorado River, discharge a constant 211 cfs and have concentrations of dissolved solids of 2,270 to 4,177 mg/l (Loughlin 1983). All springs in Little Colorado River Gorge discharge sodium chloride waters, though absolute composition varies from spring to spring. A similar situation occurs in Havasu Canyon where several springs discharge an almost constant 60 cfs. These are calcium carbonate waters with a concentration of total dissolved solids of approximately 500 mg/l. This concentration decreases significantly downstream as calcium carbonate precipitates to form the spectacular travertine formations in Havasu Canyon.

Most smaller springs which discharge from lower carbonate strata have characteristics between the extremes presented by the large North Rim springs and Blue or Havasu Springs. Many south rim springs fall into this category including Hermit, Indian Gardens, Pipe, Burro, Grapevine, Cottonwood, and Hance. Small north rim springs from lower carbonate strata probably are also in this category, but few of these have been analyzed individually and many creeks also have inputs from small but highly mineralized seeps in lower rock strata. Like large North Rim springs, these are all dolomitic springs with a similar composition dominated by calcium, magnesium and bicarbonate. The difference is that these smaller springs have a higher concentration of these ions. Total dissolved solids in waters from this diverse group of springs varies from 250-1000 mg/l. Foust et. al. (1978) attributes this to lower flows and therefore less dilution than large north rim springs. Flow from these springs also fluctuates seasonally, though not so dramatically as flow from large north rim springs, indicating a relatively short residence time and/or small aquifer. Of these waters only two exceed U.S. Public Health Service (USPHS) recommendations for drinking water in any of the tested parameters. Surprise Spring and Spring Canyon Spring both discharge below Shivwits Plateau in western Grand Canyon and have high sulfate contents. This is attributed to low flow rates which allow little dilution of dissolved solids and, at least in Suprise Canyon, to evapotranspiration from the gravelly stream bed before water surfaces.

An interesting group of springs discharge from lower carbonate strata in the Kanab Creek area. The groundwater system draining Kanab Plateau supports only a few small springs in Kanab Canyon with a combined discharge of about 4 cfs. These springs discharge highly mineralized calcium sulfate waters. The few analyses of Kanab Creek waters have found total dissolved solids concentrations varying from 1,007 to 1,160 mg/l. Sulfate and calcium concentrations were also consistently high with values of from 570 to 680 mg/l and 176 to 228 mg/l, respectively. In addition, magnesium and manganese concentrations exceed USPHS drinking water recommendations. These waters may have a laxative effect and bad taste due to these mineral concentrations.

Several canyons near Kanab Creek probably have similar water quality. Small flows in Matkatamiba, Olo, Sinyala, National, Mohawk, and Fern Glen Canyons arise from the same lower carbonate rock strata as Kanab Creek springs. One analysis of waters from Matkatamiba by Johnson (1978) is very similar to Kanab Creek waters, and limited analysis of Fern Glen, National, and Mohawk Creeks by Brickler and Tunnicliff (1980a) have found similar concentrations of total dissolved solids and alkalinity. Further sampling is necessary to fully characterize these waters. These appear to be long residence time springs due to a lack of joints or solution cavities to transmit water quickly through the carbonate strata.

Several small springs in western Grand Canyon discharge from groundwater systems draining the Hualapai Plateau. Huntoon (1977) found that most discharge calcium - magnesium - bicarbonate waters similar to those in the remainder of Grand Canyon. Flow from these springs tends to be much smaller than from springs in eastern Grand Canyon because of less precipitation and greater evapotranspiration on the western plateaus. But the most interesting difference is the relatively low concentrations of sulfate in waters from Hualapai Plateau. Huntoon (1977) attributes this to the absence of the gypsum rich Kaibab and Toroweap formations in that area. These formations have eroded from Hualapai Plateau, leaving the land surface at the level of the Supai Group or Redwall Limestone. Concentrations of several major ions exceed USPHS recommendations for drinking waters in at least three of these springs. Travertine Falls (river mile 230.5) has high levels of total dissolved solids, calcium, bicarbonate, sodium, and chloride. Two Hundred Five Mile Creek has been found to have high levels of total dissolved solids, chloride, and sulfate. Huntoon suspects these concentrations are elevated, at least in part, by evapotranspiration from the alluvial stream bed before flow reaches the surface. An analysis of Warm Springs found high concentrations of total dissolved solids, bicarbonate, calcium and sodium. Huntoon (1977) attributes the higher levels of dissolved solids in springs from Hualapai and Shivwits Plateaus to a longer residence time because rock strata are not as fractured as those draining Kaibab Plateau. These unfractured rocks transmit water much more slowly. It is expected that most other water sources in western Grand Canyon are similar in chemical content, and limited analysis by Huntoon supports this. The only health hazards presented by drinking these waters is that they may have a laxative effect on some individuals.

b. Springs in Coconino Sandstone

Coconino Sandstone is a major regional aquifer south and east of Grand Canyon. In the vicinity of Grand Canyon, however, the hydraulic gradient and permeability of underlying strata allow water to percolate to the lower carbonate strata. Only scattered springs and seeps occur in Coconino Sandstone in Grand Canyon. Most commonly these springs are indicated only by increased vegetation densities below the Coconino Sandstone/ Hermit Shale contact. Dripping Springs, in Hermit Creek watershed, is one of the most productive and frequently visited of the Coconino springs. Other relatively large springs of this type are Fossil Spring in Fossil Canyon watershed and Great Thumb Spring in 140 Mile Canyon watershed. Only Dripping Springs has been analyzed for basic constituents, showing dolomitic waters low in dissolved solids concentrations much like the high volume north rim springs, with only slightly elevated sulfate and sodium concentrations. Because of this and its proximity to Hermit and Boucher Trails, Dripping Springs is a very attractive drinking water source for hikers. Fossil and Great Thumb Springs probably have similar qualities but receive little use by hikers because they are in extremely remote and little used areas of the park. They are, however, the only reliable water sources in that vicinity of Grand Canyon.

c. Springs in Supai Group

Small seeps and springs in Supai Group are numerous, particularly on the Esplanade Terrace in western Grand Canyon and Sanup Plateau. They are always small and water from these springs evaporates long before reaching Colorado River and in most cases even before reaching a tributary drainage. Flows often cease during dry seasons. Of these springs only Santa Maria Spring along Hermit Trail has been analyzed. That analysis found waters similar to nearby Dripping Springs with minor increases in dissolved sodium, bicarbonate, sulfate, and chloride. Because of spatial variation in characteristics of Supai Group, Santa Maria Spring may not be typical of springs on the Esplanade or Sanup Plateau, particularly after evaporation concentrates dissolved minerals.

d. Springs in Tapeats Sandstone

Springs in Tapeats Sandstone can best be described as salty. Though concentrations of dissolved solids varies considerably among the springs, sodium and chloride are always major constituents. This group includes such unpalatable waters as Pumpkin Spring, Sipapu Spring, and numerous salt encrusted seeps along the Colorado River. Pumpkin Spring is a small spring discharging into a multicolored travertine bowl at the edge of Colorado River at mile 212. Total dissolved solids have been measured here at 8940 mg/l and sodium and chloride have been measured at 3200 mg/l and 4100 mg/l, respectively. Sipapu Spring, which is outside the park, discharges into a travertine dome along Little Colorado River about 4 miles from its confluence with Colorado River. It is part of the Blue Springs system but is treated separately due to its different composition and temperature.

Laughlin (1983) measured total dissolved solids of Sipapu Spring at 23,031 mg/l. It is the most sodium and sulfate rich source in the Blue Springs system. Monument Spring is a somewhat more palatable spring arising from Tapeats Sandstone. The small perennial creek supplied by this spring has sodium and chloride concentrations of 220 mg/l and 110 mg/l, respectively. These concentrations are still high enough to affect taste and act as a laxative.

e. Springs in Precambrian Strata

Some small springs also occur in precambrian schists and rarely some members of the Grand Canyon Super Group. Little is known of the chemical nature of these springs as few if any have been analyzed. Because the small amount of water discharged from these springs has had to percolate through 4000 or more feet of rock, it is expected to be highly mineralized. This is supported by encrustations of salts and other minerals at these seeps. A brightly colored seep from Vishnu Schist near the mouth of Crystal Creek is suspected as the source of high arsenic concentrations in that creek. Nankoweep Creek would be expected to contain waters similar to the large dolomitic north rim springs. However, analysis near its mouth have shown higher concentrations of total dissolved solids, sodium, and sulfate than expected. A small spring in the precambrian rocks about 2 miles above the mouth of Nankoweap Creek is the suspected source of these ions.

Health Risks Associated with Chemical Qualities of Grand Canyon Waters. Available chemical water quality information has been examined for chemical concentrations which may pose a health risk. A list of water sources in the park is presented in Table 5 along with suspected or documented water quality problems and an assessment of the status of documentation. Also presented is the relative amount of backcountry use and, considering these factors, the priority for future sampling. These priorities are for chemical samples only and priorities for bacterial sampling differ considerably. This list includes most water sources in the park which receive even modest visitation or are of scientific interest. It is neither complete nor final and will be updated as use patterns change and more water resource inventory data becomes available. For the purpose of this assessment, the chemical quality of a water source is considered to be sufficiently documented if it has been analyzed several times, preferably by different investigators, with good agreement among the analyses.

Possible water quality problems are identified using State of Arizona water quality criteria, EPA standards, and recommendations from the USPHS. For parameters where no maximum allowances exist, discussion in McKee and Wolf (1963) are used as reasonable indicators of concentrations which warrant concern. Chemical constituents found in excess in Grand Canyon waters are presented in Table 6 along with the limits used to identify problems, the agency mandating or recommending those limits, and a brief discussion of problems associated with excesses of each constituent. Fifteen constituents have been found in excess in 24 canyon water sources. Most of these are major constituents found in all natural waters and are often used to characterize those waters.

Table 5. Chemical water quality of Grand Canyon water sources, status of documentation, and potential problems.

Source	River mile	Documentation [1]	Suspected or documented problems [2]	Back-country use [3]	Priority for future sampling [4]
Paria River	0.8	S	None	3	D
Cave Springs	25.2	N	ID	1	C
Vasey's Spring	32.0	S	Phosphate	5	C
Fence Springs	29-35	N	ID	1	C
Buck Farm Creek	41.0	N	ID	3	B
Saddle Creek	47.1	N	ID	3	B
Nankoweap Creek	52.2	I	Phosphate	2	B
Little Colorado R	61.5	S	Dissolved solids, sodium, chloride, calcium, magnesium, manganese, bicarbonate	5	D
Chuar Creek	65.5	N	ID	2	B
Unkar Creek	72.4	N	ID	1	C
Red Canyon Creek	76.5	I	None	4	B
Asbestos Creek	78.0	N	ID	1	D
Hance Creek	78.5	I	None	5	A
Miners Spring	78.5	I	ID	4	A
Cottonwood Creek	80.5	I	None	3	B
Grapevine Creek	81.5	I	None	2	C
Lonetree Creek	83.8	N	ID	2	B
Clear Creek	84.0	I	None	4	B
Bright Angel Creek	87.9	S	Phosphate	5	D
Transept Canyon C	87.9	I	None	2	B
Phantom Creek	87.9	I	None	2	B
Roaring Springs	87.9	S	None	1	D
Pipe Creek	88.9	S	None	5	C
Garden Creek	88.9	S	None	5	C
Burro Spring	88.9	I	None	3	B

Table 5 (cont.)

Source	River mile	Documentation [1]	Suspected or documented problems [2]	Back-country use [3]	Priority for future sampling [4]
Salt Spring	92.6	S	Magnesium, sodium, sulfates, dissolved solids	3	C
Cedar Springs	93.2	N	ID	3	A
Monument Creek	93.3	I	Sodium, chloride	4	A
Hermit Creek	94.8	S	None	5	C
Santa Maria Sp	94.8	N	ID	4	A
Dripping Spring	94.8	N	ID	4	A
Boucher Creek	96.5	I	None	3	B
Slate Creek	98.1	N	ID	2	B
Crystal Creek	98.1	I	Arsenic, phosphate, aluminum	1	A
Turquoise Creek	102.0	N	ID	1	C
Ruby Creek	104.5	N	ID	1	C
Serpentine Creek	106.0	N	ID	1	C
Shinumo Creek	108.5	I	Iron, aluminum, phosphate	3	A
Royal Arch Creek	116.5	I	Sulfate	5	A
Blacktail Creek	120.0	N	ID	2	C
Galloway Creek	131.9	N	ID	2	C
Stone Creek	132.0	N	ID	3	B
Tapeats Creek	133.4	I	Phosphate, aluminum	5	C
Thunder River	133.4	S	None	5	D
Deer Creek	136.2	I	Phosphate, aluminum	5	C
140 mile Creek	139.9	N	ID	1	C
Great Thumb Sp.	139.9	N	ID	1	C
Kanab Creek	143.4	S	Dissolved solids, sulfate, bicarbonate, calcium magnesium, manganeses, phosphate	2	D
Olo Creek	145.5	N	ID	2	B
Matkatamiba Creek	147.7	I	Sulfate, calcium, magnesium, dissolved solids bicarbonate	2	B
Slime Canyon Cr	155.5	N	ID	1	C
Havasu Creek	156.8	S	Aluminum, magnesium, bicarbonate, calcium	5	D

Table 5 (cont.)

Source	River mile	Documentation[1]	Suspected or documented problems[2]	Backcountry use[3]	Priority for future sampling[4]
National Creek	166.0	I	Dissolved solids, chloride	3	A
Fern Glen Creek	168.0	I	Dissolved solids, calcium	3	B
Mohawk Canyon	171.4	I	Dissolved solids	1	C
Warm Springs	179.2	I	Dissolved solids, magnesium, chloride, bicarb	2	C
205 mile Canyon	205.0	I	Dissolved solids, sulfate, chloride	1	C
Spring Canyon	206.7	I	Sulfate	1	C
Pumpkin Spring	212.1	S	Dissolved solids, calcium, magnesium, sodium bicarbonate, sulfate, chloride floride, boron	2	D
Three Springs	215.5	I	None	1	C
Diamond Creek	225.4	I	None	2	C
Travertine Sp.	230.5	I	Dissolved solids, sodium, chloride,	2	C
Spencer Canyon	246.0	I	bicarbonate	2	C
Surprise Sp.	246.0	I	Calcium, sulfate	2	C
Meriwhitica Sp.	246.0	I	None	2	C
Quartermaster Sp.	260.0	I	None	2	C
Columbine Sp.	274.3	I	None	2	C
			ID		
Colorado River		S	Dissolved solids, sodium, chloride	5	D

1 Documentation:
S=Sufficient
I=Insufficient
N=None

2 Nature of problem:
ID=Insufficient data
None=No problems identified

3 Backcountry use:
1=Little or none
2=Light
3=Moderate
4=Heavy
5=Very heavy

4 Priority for future sampling:
A=Top priority
B=High priority
C=Intermediate priority
D=Very low priority

Table 6. Chemical water quality parameters found in excess in some Grand Canyon waters and their human health implications. State of Arizona allowances are for non-community water systems, that is systems which serve individuals for short periods of time.

Substance	Maximum allowance mg/l	Agency which administers standard	Problems associated with excess
Aluminum	No standard		Concentrations of aluminum over 0.1 mg/l causes eye irritation in bathers.
Arsenic	0.1	St. of AZ.	Accumulates in the body. Acts as an enzyme inhibitor causing damage to liver, kidneys, and intestinal wall. May also be carcenogenic.
Bicarbonate	No standard		May affect taste. Recommendations for drinking water vary from 150 mg/l to 700 mg/l (McKee and Wolf 1963). 400 mg/l is selected as a reasonable value.
Boron	1.0	St. of AZ.	No human health standards established but is implicated in development of kidney and bladder stones. May contribute to laxative effects. World Health Organization (1958) recommends 200 mg/l as a standard for drinking water. Toxic to some plants.
Chloride	250	USPHS	Taste, laxative
Fluoride	6.0	St. of AZ.	Standard depends on temperature. Causes dental fluorosis (mottling of teeth) in excess.
Iron	0.3	USPHS	Color, taste.

Table 6. cont.

Substance	Maximum allowed mg/l	Agency which administers standard	Problems associated with excess
Magnesium	400	USPHS	Taste, laxative
Manganese	.05	USPHS	Color, Taste
Phosphate	.04	EPA	Allowance for Colorado River to prevent excessive algal growth. No ill effects with human consumption at 100 times this concentration.
Selenium	.02	St. of AZ.	Accumulates in body. Possibly carcenogenic. Taste degradation reported at concentrations above 500 mg/l (McKee and Wolf 1963).
Sulfate	250	USPHS	Taste, laxative
Total dissolved solids	500	USPHS	Taste, laxative

Major constituents found in excess in canyon waters are, bicarbonate, calcium, chloride, magnesium, sodium and sulfate. Total dissolved solids can also be included in this category as it is the sum of all dissolved minerals, predominantly major constituents. All of these consituents have similar negative effects when they are found in excess, including undesirable taste and laxative action. Many canyon waters are noticably unpalatable. The severity of any laxative action resulting from consumption of these waters is very dependent on a person's previous exposure. Many cases of travelers diarrhea are attributable to waters differing in dissolved solids concentrations from place to place.

The second most common problem is excess phosphate in waters from the large dolimitic springs draining Kaibab Plateau. These phosphate levels exceed EPA nutirent standards for this reach of Colorado River and could cause excessive plant growth downstream. This has not been a problem and Arizona Game and Fish Department has identified Lake Mead as phosphate deficient because most phosphate is bound in the bottom sediments (Brooks 1983). These phosphate levels pose no threat to human health and are considered to be a natural occurrence. They are, therefore, of little management concern.

Suspended Sediment. Concentrations of dissolved minerals are supplemented by minerals contained in suspended sediment. This is particularly apparent with relatively insoluble metals, where concentrations in suspended sediment are frequently ten times higher than dissolved concentrations. Concentrations of highly soluble minerals such as nitrate are not increased significantly in suspended sediments. As would be expected, the difference between dissolved concentrations and suspended concentrations is most pronounced in sediment laden rivers and probably occurs in Colorado River and all tributaries during floods. Concentrations of suspended barium, cadmium, chromium, lead, and arsenic have been measured in excess of state standards during periods of turbid flow.

These excesses are of only minor concern for health risks for two reasons. First, proper water treatment will remove almost all suspended sediment to facilitate disinfection. Secondly, these metals are found in high concentrations in sediments because they are relatively insoluble. This will severely limit the amount absorbed during digestion.

Radionuclides. Radionuclides are of concern in Grand Canyon National Park because of uranium mining activities in the park and vicinity and the potential for naturally high radionuclide activity. The Colorado Plateau was the center of uranium mining activity in North America during the 1950's and 1960's, and recent discoveries have rekindled interest despite a depressed uranium market. Before potential threats to Grand Canyon can be clearly discussed, it is important to understand something of the nature of radionuclides and how drinking water standards for them are developed.

Radionuclides are commonly treated as a chemical property of water because sampling and analysis techniques are similar to those used

for chemical parameters. In actuality, radionuclides are physical parameters of concern because of their radioactivity and not strictly because of their chemical activity. The chemical activity of a radionuclide can, however, aggravate its deleterious effects by influencing its rate of absorption and site of deposition within the body. For example, because it is readily absorbed and deposited almost permanently in bone, radium-226 is considered for more dangerous than cobalt-60, which is readily excreted by the body.

The effects of chronic exposure to radiation are used in developing standards for radionuclides in natural waters. Though acute exposure to high level radiation can cause serious illness and death, these levels of exposure are only encountered during industrial or medical accident or war. Several factors are considered in establishing water quality standards for an isotope including the specific activity (rate of decay) of the isotope, its half-life, and its absorbtion, deposition, and excretion by the body. Isotopes with long half-lives that are readily absorbed and deposited in sensitive organs and bone are considered most dangerous. Strontium, radium, and thorium fall into this category. Radium is the most common of these in natural waters as it is a naturally occuring product of the decay of uranium. Strontium and thorium are much less common in natural systems but are used and produced by fission reactors and therefore are potential pollutants. Radioactive calcium and phosphorus are also bone seekers that remain in the body for long periods, but they are not considered serious health problems because their radiological half-lives are short.

The State of Arizona has established drinking water standards for radionuclides that are applicable to all waters of Grand Canyon. These are shown below:

Parameter	Drinking water standard
Gross alpha emissions	15 pci/l
Combined Ra-226 and Ra-228	5 pci/l
Tritium	20,000 pci/l
Strontium-90	8 pci/l

The unit picocurie (pci) is a measure of specific activity. It is equivalent to the number of disintegrations per second given off by a gram of radium divided by one trillion (1,000,000,000,000).

These standards are established to limit the annual radiation dose to a person drinking two liters of water a day to four millirems per year. The use of gross alpha emissions in place of radium measurements is allowed if gross alpha emissions are less than five picocuries per liter. If standards for tritium and strontium are both met, and gross beta emissions are less than 50 picocuries per liter, compliance for all other beta emitters can be assumed. The World Health Organization drinking water standards recommend that if alpha emissions are less than one picocurie per liter and beta emissions are less than 10 picocuries per liter, the water can be considered safe for use without further investigation.

The vicinity of Grand Canyon is known to be rich in uranium ore. Many uranium mills and mines have historically operated in the Little Colorado River watershed east of Grand Canyon. One mine, the Orphan Lode, was intermittently operated for over half a century in the Horn Creek watershed just two miles east of Grand Canyon Village. Currently two active mines, Hack Canyon and Pidgeon, are operating in the Kanab Creek watershed north of the park. There is much more exploration in the Kanab Creek vicinity and south of the park on the Hualapai Reservation. All of these mines are removing small high grade ore deposits. The entire ore body in the Hack Canyon Mine is a cylindrical breccia pipe about 300 feet in diameter and 1,000 feet deep. The local nature of these ores allows most waters to be contained, minimizing potential contamination of water sources.

There are, however, incidences of contamination which have caused substantial concern in the park and throughout northeast Arizona. The largest of these occurred in 1979 in New Mexico along the Rio Puerco, a major tributary of Little Colorado River. A tailings dam at the Churchrock Mine failed, spilling 3,300 tons of solid mine waste and 300 acre feet of water into the Rio Puerco. This spill caused considerable concern for the health of humans and livestock that obtain drinking water from local aquifers adjacent to Rio Puerco and Little Colorado River. Both gross alpha and beta emissions were found to be well in excess of Arizona surface water quality standards at Chambers, Arizona, approximately 30 miles downstream of the spill. Residue from the spill apparently did not reach Grand Canyon, 350 miles downstream, or was substantially diluted. Six sediment samples collected from Little Colorado River in the park in June 1980 contained only background levels of thorium-230. Another sediment sample collected in 1981 and analyzed for four radionuclides also contained only background levels.

Concerns were again raised in 1983 when gross alpha and gross beta emissions regularly exceeded Arizona water quality standards at both Chambers and Cameron (60 miles upstream of Grand Canyon National Park). It was found that discharge from the Churchrock Mine regularly exceeded limits prescribed in its discharge permit. There are also several other potential sources of contamination much closer to Cameron and Grand Canyon. Runoff from several abandoned uranium quarries near Cameron are suspected to be the source of high levels of radionuclides measured there. Samples of the runoff from these quarries have recently been collected but the results of their analysis by Arizona Department of Health Services is not yet available.

Whether this contamination is reaching Little Colorado River inside Grand Canyon National Park has not been determined. No samples of water or sediment have been collected for radionuclide analysis since 1981, when Tunnicliff and Brickler (1981) found only background levels of radiation.

If radionuclide contamination is now reaching the park its greatest threat is to fish and wildlife species that inhabit Little Colorado River. Of particular concern is the endangered humpback chub which spawn at the confluence of Little Colorado and Colorado Rivers.

Below the confluence, dilution by the much larger Colorado River (about 100:1 at normal flows and 5:1 when Little Colorado is flooding) would negate all but the most severe contamination. The threat to hikers and boaters is also substantially reduced by their very brief exposure. Even commercial river boatmen who visit the Little Colorado River confluence several times a year, receive far less exposure than the theoretical person for which the standards are written who drinks two liters of water from a source in question every day for a lifetime.

Other potential radionuclide sources in the vicinity are not as threatening, at least at this time. Though Hack Canyon Mine has been operating for 40 years, mined first for copper then for uranium, there has been no need to discharge waste water and no abnormal radionuclide levels have been detected. Tunnicliff and Brickler (1981) actually found radionuclide levels in Kanab Creek to be lower than at twelve other sample locations in Grand Canyon. Considering the large amount of uranium exploration on-going in the vicinity of Grand Canyon, these activities should be monitored closely. Where water contamination is possible, water quality monitoring will play an integral role.

Baseline radionuclide data from the numerous water sources in Grand Canyon is very limited. Twenty-four sources have been analyzed for at least one radionuclide parameter. In all but two cases, analysis has included only dissolved uranium. Paria River has been analyzed for radium-226 in addition to uranium. More complete analysis of Colorado River water has included potassium-40, uranium, radium-226, gross alpha, gross beta, hydrogen-3, and tritium. No radioneuclide levels have been found approaching Arizona drinking water standards or U.S. Public Health Service drinking water recommendations.

This does not mean that all Grand Canyon waters can be considered safe for consumption with respect to radionuclides. A few analyses for dissolved uranium can hardly provide a complete representation of radionuclides in a water source. Short of extensive analyses for several radionuclide parameters, which are very costly, the best overall representation of radionuclide status is provided by gross alpha and gross beta emissions. These parameters can be compared against established standards to determine the need for more extensive analysis.

Sampling for radionuclides will be included in chemical water quality monitoring, because of similarities in collection and analysis procedures, and the identification of sampling needs. This is discussed in project statements.

Acid Precipitation. Acid precipitation is one of the most widespread pollution problems. It has been identified as the major cause of water quality degradation and declines in aquatic fauna in lakes and streams in the northeastern United States and Europe. Acidification of precipitation has been noted to a lesser extent in the western United States.

Acid precipitation is defined as any precipitation with a pH below 5.7. The normal pH of precipitation is slightly acidic due to the natural assimilation of carbon dioxide in atmospheric moisture. Atmospheric pollutants, primarily sulfer and nitrous oxides, combine with moisture to form weak acids and fall as acid precipitation.

One of the many impacts of acid precipitation is degradation of water quality. This is most commonly observed as reduced pH in lakes and streams. Waters in areas with shallow poorly buffered soils and crystalline bedrock are most susceptible to pH changes. Greater acidity reduces aquatic productivity and in extreme cases can become toxic to fish and aquatic invertebrates. Another problem associated with lowered pH is an increase in dissolved metals and radioneuclides. Many metals and radioneuclides become much more soluble as water becomes more acidic.

Precipitation has been sampled at Grand Canyon National Park since September 1981 as part of the National Atmospheric Deposition Program (NADP). Both wet and dry deposition are collected and analyzed for pH and several chemical constituents. Since this sampling began, precipitation at Grand Canyon has been slightly acidic with a mean pH of 5.56. The pH has been quite variable though with one sample pH as low as 3.94 and 18 per cent of samples below pH 5.0.

The impact of this precipitation on water quality in Grand Canyon is probably minimal. Rock strata in the vicinity consist mainly of limestones, shales, and sandstones, all of which are highly buffered. Creeks and rivers in Grand Canyon show remarkable consistency in pH. For example, the mean pH and 95 per cent confidence intervals for Bright Angel Creek, Paria River, and Colorado River at Lee's Ferry are 7.94 ± .06, 7.89 ± .02, and 7.71 ± .02, respectively. There is potential for acid precipitation to affect water quality in Grand Canyon is through influencing concentrations of heavy metals and radioneuclides. Though precipitation is quickly buffered to an alkaline pH, it is uncertain if substances dissolved at the surface while recent precipitation is still relatively acidic will remain in solution and eventually be discharged by springs within the canyon.

Continued monitoring of chemical water quality, including pH, metals and radioneuclides will supplement precipitation monitoring in identifying the extent of acid precipitation and its impacts. Precipitation sampling is discussed in the park's Natural and Cultural Resources Management Plan.

Future Chemical Analysis. The chemical water quality inventory needs to be expanded to include more water sources. A project statement presenting this need is included is Chapter IV of this plan. Parameters to be included in future analysis are listed in Table 7. This list includes all parameters which have been found in excess in canyon waters, several parameters that are generally used to characterize water quality, and toxic trace elements that occasionally become problems. Two general radioneuclides parameters are also included. More extensive radioneuclide analysis may be indicated in

Table 7. Parameters to analyze in the chemical inventory of Grand Canyon waters.

Physical Parameters:
- Temperature
- Flow
- Turbidity

Major Constituents:
- pH (field and lab)
- Alkalinity
- Hardness
- Specific conductance
- Chloride
- Sulfate
- Calcium
- Magnesium
- Potassium
- Sodium
- Bicarbonate
- Fluoride
- Silica

Nutrients
- Nitrate
- Phosphate

Trace Elements:
- Arsenic
- Boron
- Cadmium
- Copper
- Iron
- Lead
- Manganese
- Molybdemum
- Nickle
- Vanadium
- Zinc
- Aluminum
- Selenium
- Mercury

Radionuclides:
- Gross alpha
- Gross beta

the future, but these are too expensive for an initial inventory. This list will be modified as initial analysis improves background knowledge and available funds dictate.

2. Microbial Water Quality

Microbial organisms, particularly pathogenic organisms, are a major concern in drinking waters. Waterborn pathogens are one of the most common and unpredictable sources of water associated illness. The hazard presented by these organisms is difficult to assess because their population varies both in time and space. Pathogens can be introduced by either humans or wildlife. Introductions can occur at any time and are often transient in nature. This unpredictability is further compounded by the ability of microorganisms to remain viable in bottom sediments long after surface waters are flushed clean, only to be resuspended when the sediments are disturbed.

Waterborn pathogenic bacteria are relatively rare and difficult to detect. For this reason, indicator bacteria are used to represent the potential for contracting waterborn enteric diseases. The most commonly used indicator bacteria are total coliform (TC), fecal coliform (FC), and fecal streptococcus (FS). All are common organisms in the lower intestinal tract of warm-blooded animals and therefore indicate the presence of fecal contamination. They also have the desirable characteristics of being easily cultured and enumerated. They are present in feces in large numbers and therefore are detectable when their concentration is very low, and they die off at rates similar to pathogenic bacteria. Fecal coliforms and fecal streptoccus are generally associated only with feces. Total coliforms are a broader group of bacteria than fecal coliforms and are naturally found in soils and on plant and animal surfaces in addition to feces. These characteristics limit the usefulness of total coliforms to indicate contamination of strictly fecal origin, but make them a more sensitive indicator of very dilute contamination. Total coliforms are therefore used for drinking water standards, while fecal coliforms are used to establish less stringent primary and secondary contact standards.

In Grand Canyon visitors contact Colorado River and its tributary waters in several ways. The use of natural waters for drinking presents the greatest hazard to visitors from microbial contamination. During warm weather, hikers and boaters can consume over a gallon of water per day. The severe terrain of Grand Canyon usually precludes carrying sufficient water for extended trips; therefore, hikers must regularly collect natural waters for drinking.

Pathogenic organisms can be introduced to natural waters by infected humans or wildlife, some of who may be asymptomatic. Many people do not treat their drinking water because they wrongly believe that flowing water quickly purifies itself and/or that wilderness watersheds always yield pure water.

Bacterial quality standards are very strict for drinking water because any pathogenic organisms present are repeatedly introduced directly into the digestive tract. The State of Arizona allows an

arithmetic mean concentration of total coliform bacteria of only one per 100 milliliters (1/100 ml). Analysis by several investigators have demonstrated that Grand Canyon waters regularly exceed this standard.

Recreational activities such as wading, swimming, and rafting expose people to a lesser risk and have correspondingly lower standards. For full body contact activities like swimming and rafting, where ingestion of small amounts of water is likely, the maximum concentration for fecal coliform bacteria is a geometric mean of 200/100 ml over a 30 day period, or a single sample maximum of 800/100 ml. For partial contact activities such as fishing and wading, where ingestion of water is unlikely, the standards are a geometric mean concentration of fecal coliform bacteria of 1000/100 ml of samples taken over a 30 day period, or a single sample maximum of 4000/100 ml.

Dramatic increases in Grand Canyon backcountry use during the 1960's and 1970's caused concern among park managers over the quality of park waters. Visual evidence of improper disposal of human wastes became commonplace. Reports of illness among hikers also increased, and epidemic outbreaks of gastrointestinal disease occured among river users. Heavy use overtaxed sewage systems in inner canyon developed zones, creating hazardous conditions which caused closure of campgrounds and concession facilities by state and county health inspectors. These occurrences lead to a series of investigations into the bacterial quality of the Colorado River and its tributaries. Through these investigations a good understanding has been gained of the general bacterial quality of Grand Canyon waters and some factors which influence it.

Large increases in recreational use increased the hazards presented by natural waters in two ways. First, more people in the backcountry were exposed to any potential hazards. Second, the potential for an infected recreationist to introduce pathogenic microorganisms increased dramatically through both improper waste disposal and over loaded sewage systems.

Improper disposal of human feces on Colorado River beaches was identified as a problem as early as 1967. The need for disposal facilities was identified and 19 beach sites were selected for installation of pit toilets. These were never installed because they would have detracted from the wilderness characteristics of the river corridor. As an alternative, the park recommended that all river trips use portable toilets to contain wastes for daily burial in the beach sands. Though burial of portable toilet wastes had some undesirable aspects, it was far superior to random disposal and remained the mitigation method of choice for several years.

Bacterial analysis of the Colorado River and some tributaries in Grand Canyon first occurred in 1970 and 1971. Samples of Colorado River water were collected at Phantom Ranch and analyzed for total coliform concentrations. They ranged from zero per 100 ml to 50,000 or more per 100 ml. Everett (1971) also performed some bacterial analysis of Colorado River and tributary waters in 1971. He found

most samples had total coliform concentrations too high to be enumerated accurately, indicating concentrations greater than 7,200/100 ml. Heavy sediment from Paria River was thought to be responsible for the high concetrations and caused analysis problems.

The U.S. Public Health Service became concerned about feces disposal and the safety of drinking water in the canyon and made several recommendations in 1971. These included disinfection of all inner canyon waters before drinking and continued use of portable toilets by river trips. It was recommended that commercial boatmen receive training in the proper use of these toilets and that if necessary wastes be taken downstream for burial in another beach if suitable sites were not available on the camp beach. After examining backcountry areas, the USPHS also recommended installation of chemical toilets at Hermit Camp.

Water quality concerns became a focus of attention in 1972 when a Shigellosis epidemic occurred among passengers and boatmen on the Colorado River. The illness first appeared in June and over the following 6 weeks about half of all people on the river became infected. Symptoms were severe diarrhea often accompanied by vomiting, cramps, and fever. Some cases were so severe that helicopter evacuation was required. Many other passengers on slower oar powered craft were transferred to motor rafts for rapid transport out of the canyon.

Arizona Department of Health Services and the USPHS were called in to investigate the outbreak. Their study (Boyer and Merson 1972) included a survey of persons completing river trips at Temple Bar, collection of water quality samples, and a phone survey of all people on infected boats.

Boyer and Merson found that the epidemic was caused by Shigella sonnei and that 500-1000 passengers and boatmen had been infected during the 6-8 weeks in which it persisted. Ill boatmen were identified as the probable original source. Boatmen were usually the first on a trip to become infected and 91% of them became infected. No point source was identified. The epidemic followed a pattern typical of disease spread by person-to-person contact. Involvement in certain camp activities affected the chance of a person becoming infected. People who assisted with kitchen and dishwashing activities were most often infected. Though indicator bacteria were found in the Colorado River and several tributaries, water was thought to play little or no role in transmission of the disease. Boyer and Merson state that if waterborn transmission occurred, it most likely happened during waterplay in tributary pools. Six weeks after the epidemic, only sporadic cases of travelers diarrhea were found, but one asymptomatic boatman was found to be still carrying Shigella.

Although Boyer and Merson discounted water transmittal, passengers reported infected people repeatedly contaminating the river and beaches with feces and vomit. Contamination of water and beaches is very likely when river passengers are infected by gastrointestinal diseases.

Boyer and Merson recommended the following actions to reduce the possibility of recurring epidemics. Crew members who are ill should not be allowed to begin a trip. There was a need for improved kitchen sanitation and food handling practices. Thorough hand washing after toilet use and before food preparation should be required. They recommended that Colorado River water, when properly treated, be approved as a source of drinking water, by the Arizona Department of Health Services. Proper treatment was prescribed as eight drops of chlorine bleach per gallon, doubled for turbid water, to achieve a chlorine residule of 0.2 to 1.0 ppm. Subsequent studies (Tunnicliff and Brickler 1984) have shown a chlorine residual of 0.2 ppm to be insufficient to kill Giardia. The quality of tributary waters was relatively unknown and not recommended as a source of drinking water.

Another minor outbreak of Shigellosis occurred on the river in 1979. It was short in duration and involved only a few individuals. The diagnosis was confirmed by the USPHS Center for Disease Control.

Water samples were collected and analyzed in 1972 as part of the Shigellosis outbreak investigation by Slawson and Everett (report in 1973). They found variable bacteria concentrations in the river and tributaries. Fecal coliform concentrations in Colorado River consistently exceeded drinking water standards ranging from 10/100 ml to 60/100 ml. Waters were usually very sediment laden and allowed to settle before analysis. This probably reduced bacteria concentrations considerably in the analyzed water. Tributary samples were more variable with FC concentrations of 0/100 ml to 1600/100 ml, with the highest concentrations being from Kanab Creek (1600/100 ml) and Elves Chasm (200/100 ml). Though no Shigella organisms could be isolated, Slawson and Everett found Salmonella bacteria in waters from Elves Chasm, Kanab Creek, Havasu Creek, and Colorado River below Kanab Creek.

Impacts to the riverine ecosystem and hazards to the health of river recreationists demonstrated the need for a Colorado River Management Plan. In 1973 a multifaceted Colorado River Research Program was initiated to provide background information necessary to develop a plan. This program investigated diverse topics including baseline inventories of campsites and riparian and aquatic biota, sedimentology of the Colorado River, sociologic interactions on river trips, water quality, disposal of portable toilet wastes and noise pollution. The following are findings of those studies or portions of studies pertinent to microbial water quality.

Knudson et. al. (1976) investigated burial of portable toilet wastes on beaches. Despite the use of the disinfectant chemicals, fecal coliform bacteria were found in a majority of portable toilet dumps after eight months and in some after twelve months. Bacteria were found to migrate out of the dump pit into the surrounding sand, leading to the possibility of water contamination. Previously buried fecal material presented a hazard to boatmen and passengers when disposal locations were accidentaly re-excavated. Improperly disposed of feces, both from portable toilets and individual deposits, also posed substantial hazard.

Czarnecki et. al. (1976) occasionally found algal associations indicative of polluted waters in Paria River, Bright Angel Creek, Shinumo Creek, Havasu Creek, and Diamond Creek.

Phillips and Lynch (1976) observed that use of chemical toilets and burial of wastes greatly reduced indiscriminant fecal deposition. However, they found prolonged bacterial survival in moist beach sands. They expressed concern that bacteria could travel to the river through the porus substrate or be exposed when disposal pits were re-excavated. They were also concerned that chemicals used in portable toilets were polluting beaches.

Although Deacon and Baker (1976) found potential health hazards they concluded that sewage effluent from visitor use had minimal impact on Colorado River water quality. They found dissolved oxygen concentrations typical of natural unpolluted conditions.

Sommerfield et. al. (1976) found bacteria concentrations in Colorado River to be similar to most other natural waters with the highest concentrations attributable to high sediment loads.

Tierney completed a bacterial analysis of Hermit and Boucher Creeks in 1976 which was not part of the Colorado River Research Project. He found high concentrations of total coliforms, fecal streptococcus, and Psuedomonas aeruginosa in both creeks, but low fecal coliform concentrations in all samples. Low FC concentrations may have been the result of incubation problems. He also found that bacterial concentrations were proportional to use levels, both spatially and with respect to time.

As a result of the health hazards identified in association with human waste burial, the park began developing and testing methods of human waste carry out and encouraging commercial river outfitters to do the same. By the 1977 river season, at least one commercial company was successfully containerizing and carrying out all solid human wastes. Carry out became mandatory for all river users in 1978. It was also required that commercial boatmen inform passengers of proper use of toilet facilities and waste disposal procedures when a toilet was not available.

Several other operating regulations were initiated during this period to protect water quality and visitor safety. The use of soap for bathing in tributary creeks was prohibited. Most tributary creeks are much warmer than the Colorado River and therefore very attractive to bathers, but the small flow might be locally impacted by a large river party bathing with soap. Commerical river trips were required to provide purified drinking water. Improved food and water sanitation were instituted including frequent hand washing, sanitization of food preparation surfaces, maintenance of proper food temperatures, sanitary dishwashing, and the exclusion of persons with communicable diseases from kitchen duties.

In 1977 the Federal Water Pollution Control Act was amended by the Clean Water Act (PL 95-217). Section 208 of this act provided that

individual states identify water quality management areas, designate an administrating agency, and develop water quality regulations using guidelines developed by the federal government. As a result, state water quality regulations are administered in the Grand Canyon vicinity by the Northern Arizona Council of Governments (NACOG) which is a coalition of governing bodies from Apache, Navajo, Coconino, and Yavapai counties.

A Memorandum of Understanding (MOU) was signed in January 1977 between the Administrator of the U.S. Environmental Protection Agency and the Assistant Secretary for Fish and Wildlife and Parks of the U.S. Department of the Interior. This MOU stated that the National Park Service will encourage and assist in development of water quality management plans in their areas. The park worked with NACOG on the identification of designated uses for park waters, appropriate standards for these waters and problem areas that needed further attention.

Several problem areas were identified in 1977 including, inadequate sewage systems at Phantom Ranch and Indian Gardens, a lack of baseline chemical and bacterial water quality data for most canyon water sources, and the absence of a water resource management plan. In 1978 NACOG requested that the park develop a water resource management plan to ensure that state water quality standards were met. In response to these concerns the park took several actions. The sewage treatment system at Indian Gardens was modified in 1978 to minimize use of the malfunctioning leach field, a new sewage treatment plant for Phantom Ranch was completed in 1982, and the following bacterial water quality monitoring programs were instituted.

The first comprehensive examination of bacterial water quality in Grand Canyon was that of Brickler and Tunnicliff 1980a and 1980b), and Tunnicliff and Brickler 1981. They began four years of water quality research and monitoring in 1978. The emphasis of research in 1978 and 1979 was to establish baseline water quality conditions in the Colorado River and its tributaries in Grand Canyon. Subsequent projects included an examination of the role of sediment and bacteria inputs from tributary creeks, water treatment methodologies and their applicability to the Colorado River, and baseline radioneuclide activity. Development of a self-contained field laboratory made it possible for them to collect and analyze large numbers of samples using accepted procedures while traversing the canyon by raft.

Brickler and Tunnicliff found similar conditions in 1978 and 1979. In 424 samples collected from the Colorado River they reported a geometric mean FC concentration of 2.1/100 ml. In 1979, 73 samples were collected and a geometric mean FC concentration of 2.4/100 ml was found. Only twice in these 497 river samples did FC concentrations exceed 200/100 ml. Despite these low concentrations Colorado River did not meet standards for potable water and treatment was recommended. The FC/FS ratio indicated that fecal contamination was from a nonhuman source. They found very little variation in FC concentrations in the Colorado and no variation was attributable to the relative use levels of beaches or tributaries, position in the flow, or time of day. During this sampling period the river flowed muddy only on one occasion when both turbidity and FC concentrations increased.

Samples collected from 26 tributaries in 1978 and 10 tributaries in 1979 had slightly higher and more variable FC concentrations than the river. Mean FC concentrations were 3.6/100 ml for 204 samples and 8.0/100 ml for ten samples in 1978 and 1979 respectively. Although high concentrations were found, they were not consistently high in any tributaries. A nonhuman source of contamination was also indicated in the tributaries.

Fecal coliform concentrations in river and tributary bottom sediments were also examined by Brickler and Tunnicliff (1980a). The inclusion of bottom sediment analysis has several advantages over examing suface waters alone. Bacteria tend to concentrate in bottom sediments and can survive there for extended periods. They can then be resuspended by waterplay or other acitivities. A contamination episode may quickly flush through a creeks surface waters but be retained in the bottom sediments. In 1978, bottom sediment bacterial concentrations were found to be uniformly distributed along the Colorado River. Fecal coliform concentrations in river sediments increased through the river running season. Though surface microbial water quality was similar for all tributary watersheds, bottom sediment FC concentrations varied significantly from a log mean of 26/100 ml in Crystal Creek to 2130/100 ml in Hermit Creek. For all tributary creeks sampled in 1978, the log mean FC concentration in bottom sediments was 422/100 ml, over 10 times the concentration in surface waters.

Brickler and Tunnicliff (1980a) drew the following conclusions from their 1978 and 1979 analysis:

1. During clear flow, tributaries and the Colorado River are acceptable for full body contact recreation.
2. All surface waters require treatment before drinking.
3. Turbid storm runoff increases bacterial concentrations.
4. Sediments carry more bacteria and inhibit water treatment.
5. Surface water analysis alone does not fully characterize bacterial water quality, bottom sediment analysis is also necessary.
6. User awareness is the key to minimizing hazards.

Monitoring in 1980 by Brickler and Tunnicliff was expanded to include that portion of the Colorado River above Lees Ferry. The results were very similar to those obtained in 1978 and 1979 and further supported the aforementioned conclusions.

Very different conditions existed during monitoring in 1981 (Tunnicliff and Brickler 1981). In that year, the investigators had the opportunity to sample very turbid Colorado River and tributary waters for an extended period. Both Paria River and Little Colorado River were flooding, contributing waters with turbidities of 262,500 FTU (Formazin Turbidity Unit) and 5,500 FTU respectively to Colorado River. Fecal coliform concentrations in these two tributaries were correspondingly high, with 13,000/100 ml detected in Paria River and 5,500/100 ml in Little Colorado River. Such levels of contamination exceed full and partial body contact standards. Fine sediments

contributed by water from these two rivers remained suspended in Colorado River through the entire monitoring river trip. Bacterial concentrations in the Colorado River were distinctly higher than in previous years, rising to a log mean density of 66/100 ml for 37 samples. Seven of those samples exceeded 200/100 ml.

These results indicated that there are two distinct water quality regimes for waters in Grand Canyon; clear waters with low levels of contamination and turbid waters which are highly contaminated. The researchers cautioned however, that high levels of contamination can occur in clear waters due to local events.

Tunnicliff and Brickler (1981) concluded that bacterial quality of Colorado River water is a function of two factors. First is bacterial contamination from non-point sources, including storm runoff from tributaries. No point source of bacterial contamination was identified in the four years of sampling. Second is the persistance of bacteria in bottom sediments, allowing relatively bacteria free waters to become contaminated solely through disturbance of sediments, with no apparent inputs of bacteria.

In summarizing their four years of water quality research Tunnicliff and Brickler (1981) made the following statements:

1. No Grand Canyon waters are safe to drink without treatment.
2. When clear, the Colorado River is the best source of drinking water. Clear tributaries are an alternative when the Colorado is turbid, but not Paria River, Little Colorado River, Bright Angel Creek, Garden Creek, Hermit Creek, Elves Chasm, Havasu Creek or Diamond Creek. Human activities on these watersheds increase the chance of contamination.
3. Full body contact recreation is acceptable except in turbid waters.
4. Collect drinking water before disturbing bottom sediments such as by wading or swimming, or allow sediments to settle.
5. When possible, avoid drinking turbid waters.

Storm runoff, the major source of contamination, is beyond the scope of NPS control. Consequently, Tunnicliff and Brickler (1981) recommended the following mitigating measures.

1. Educate river and backcountry users about using canyon waters.
2. Research to refine methods of water treatment is needed.
3. Develop a bacterial quality model for Colorado River using inputs from Glen Canyon, Paria River, and Little Colorado River.

In 1982, Tunnicliff presented a literature review of methods of water treatment. Of the methods examined, he found the addition of chlorine or iodine most applicable to conditions in Grand Canyon. The amount of either chlorine or iodine needed for purification is a function of water turbidity, temperature, and pH. Sediment particles react with purifiers, reducing their effectiveness. Increased temperature increases disinfectant activity and reduces the amount needed. Increased pH reduces disinfectant activity, increasing the amount

necessary. The target organism also influences the effectiveness of disinfectants, viruses being the most resistant, protozoans intermediate, and bacteria the least resistant. Tunnicliff recommends treatment of clear river water with 8 drops of chlorine bleach per gallon (5.5 mg/l) and 10-12 drops per gallon (6.9 mg/l-8.6 mg/l) in cloudy water. Turbid water should be settled before treatment. He recommended a minimum of 30 minutes contact time before drinking, longer for cold water. Dishwater and cooking water which will not be boiled should also be treated.

The NPS also had a backcountry water quality monitoring program from 1979 to 1981. This was initiated in cooperation with NACOG's requests that the park monitor water quality in heavily used backcountry areas. Emphasis was placed on tributary creeks with samples collected at campgrounds and trail crossings. A total of 38 sources were sampled, 20 of these were sampled five or more times.

Bacterial concentrations were similar to those found by Brickler and Tunnicliff (1980a and 1980b) and Tunnicliff and Brickler (1981) in tributary creeks. The geometric mean FC concentration for 253 samples was 3.0/100 ml. Individual samples with high concentrations of FC were collected from Cremation Creek, too numerous to count (TNTC) and Boulder Creek 1390/100 ml. In both instances, very little water was present and collection of some sediments was unavoidable. Sources with the highest log mean FC concentrations were Serpentine Creek (11.9/100 ml), Grapevine Creek (10.1/100 ml), and Cottonwood Creek (9.5/100 ml). As with other bacterial water quality studies in Grand Canyon, no water sources were found to be suitable for drinking without treatment.

The FC/FS ratio can sometimes be used as an indicator of the source of bacterial contamination, human vs. animal. Caution should be exercised however, because use of the FC/FS ratio relies on several assumptions that are usually not met in wildland conditions. One sample from Crystal Creek had a FC/FS ratio greater than 4.0, indicating a human source of contamination. Four samples from Serpentine Creek, Monument Creek, Cottonwood Creek, and Red Canyon had FC/FS ratios between 1.0 and 4.0, which is suggestive of human contamination. For the remaining 248 samples the FC/FS ratio indicates a nonhuman source of contamination. The conclusion that contamination is predominantly from animals is further supported by the fact that seven of the ten sites with the highest FC concentrations were in watersheds with very little visitor use. Contamination from animals poses some of the same hazards as human contamination but is essentially impossible to eliminate. Mitigating bacterial problems through water treatment and avoidance of waters with a high potential for contamination presents the best possibility of avoiding water associated illness.

B. Sewage Treatment Facilities and Backcountry Waste Disposal

As visitation to Grand Canyon increased improvement in sewage disposal methods became necessary. Updating treatment facilities has historically been a high priority for the NPS. Following is a discussion on past management actions pertaining to sewage treatment facilities in developed areas. Actions on backcountry waste management will be discussed following an assessment of sewage treatment facilities.

1. South Rim Treatment Plant

South Rim Sewage treatment plant, located about 0.5 mile southwest of Grand Canyon Village, has operated in its present form since 1972. The previous facility had an activated sludge system with secondary treatment capability, but no solids handling capacity. The present plant is capable of treating up to 450,000 gallons of sewage per day (gpd), or a continuous flow of 310 gpm, and has two sludge digestors for handling solids. It treats an annual average of 350,000 gpd (240 gpm), but has had peak inflow rates exceeding its rated maximum inflow capacity of 555 gpm. Summer season flows have peaked at nearly 700 gpm for short periods and maintained flows of over 500 gpm for two to three hours. The south rim treatment plant is hydraulically overloaded from April to October. Most effluent is pumped into 3 of 4 lagoons (one lagoon is set aside for disposal of chemical toilet wastes) located on an unnamed tributary of Coconino Wash about 2.5 miles southwest of the treatment plan and 0.5 mile north of the park boundary. Extensive riparian vegetation has become established at and below the lagoons. Effluent flow is not metered and varies considerably. One measurement of flow crossing the park boundary was 37 gpm, which is much less than the inflow rate to the lagoons. Before effluent leaves the treatment plant, it is treated with chlorine to kill microrganisms. Treatment plant personnel have a goal of finding less than 200 fecal coliform per 100 milliliters in treated effluent using multiple tube analysis, which is performed once a month. Some effluent is tertiary treated (reclaimed) and used inside the park and in Tusayan. Locations inside the park where this reclaimed water is used are Victor and Coulter Halls restrooms, Bright Angel Lodge public restrooms, lawns around the rim lodges, and lawns at Grand Canyon School. Reclaimed water is also available for car washing at the school. In Tusayan reclaimed water is sold to Canyon Squire Inn, Red Feather Inn, and David Babbitt Industries.

Presently, water leaving the south rim lagoons does not meet NPDES (National Pollution Discharge Elimination System) standards for biochemical oxygen demand (BOD) and suspended solids (SS). The pH of lagoon water has been measured to be as high as 9.0, which is outside the required range of 6.5 to 8.0. All three water quality problems are attributable to the presence of algae in the lagoons. These problems should be corrected when the treatment plant is upgraded during the next three years.

2. North Rim Treatment Plant

North Rim Sewage treatment plant, located about 0.3 miles north of the ranger station, has operated in its present form since May 1977. Sewage was treated previously by a lagoon system, which became overtaxed in the 1970's. The present plant operates during the season when North Rim is open, which is usually May to October. During the remainder of the year only about five NPS maintenance workers are living on North Rim, and their sewage is discharged into a 30,000 gallon septic system with two sequental drain fields. In the spring this tank is aerated and its contents gradually released to the treatment plant. Estimated amount of sewage generated during the off season is 200 gpd (0.14 gpm).

North Rim treatment plant is capable of treating up to 150,000 gallons of sewage per day (110 gpm). It treats an average of 50,000 gpd (35 gpm) and has had inflows as high as 75,000 gpd (52 gpm). Past metering information is questionable and inflows are estimated to be 30% higher than metered. A new metering system installed early in 1984 has remedied this inaccuracy. The plant has an activated sludge system and a tertiary microfloc process. Effluent is filtered and chlorinated, and about 70% of the inflow discharged into Transcept Canyon. About 300,000 gallons of treated effluent is stored for use in fire fighting.

The primary environmental problem encountered by North Rim treatment plant operators arises from difficulty in start-up each May. Approximately one month is needed to achieve a stable population of bacteria living in the sludge digestors. There have also been problems meeting NPDES guidelines for turbidity (30 Nephelometric Turbidity Units).

3. Phantom Ranch Treatment Plant

Phantom Ranch treatment plant, located on the Bright Angel Creek delta, has operated in its present form since January 1982. The previous sewage disposal system consisted of a 10,000 gallon septic tank and two leach fields, one behind the Fred Harvey mule corral and one in the delta area. Chemical toilets were used in Bright Angel Campground, and liquid wastes were deposited in nearby pits. Solid wastes from these toilets were packed out by mule. The two leach fields become overloaded as new facilities were connected to them, and sewage began rising to the surface and flowing into the Colorado River. Using authority given under Article 3, Section R9-8-313, Paragraph A of the State of Arizona Official Compilation of Administrative Rules and regulations, Arizona Department of Health Services and Coconino County Department of Public Health condemned the leach fields. The condemnation had the effect of closing Phantom Ranch. The law reads as follows:

> "No sewage or industrial wastes shall be permitted to flow into any of the waters, or upon or under any of the lands of the state in any manner determined by the Department to be detrimental to the quality of the receiving body of water or the use of the receiving lands, or prejudicial to the health, safety, or

welfare of persons who may be affected by the resulting environmental conditions. Where characteristics of the waters or the receiving bodies indicate pollution to exist, treatment works as are determined to be necessary by the Department shall be installed and operated."

Construction of the present treatment plant began 8 months prior to closure by the two health departments, and approval for reopening of Phantom Ranch was issued on March 8, 1982, after completion of the plant.

All facilities in the Phantom Ranch area, including new flush toilets at Bright Angel Campground, are now connected to the treatment plant. It is capable of treating 12,000 gallons of sewage per day (8.3 gpm), but a normal summer load is between 6,000 and 8,000 gpd (4.2 and 5.6 gpm) with peak loads of 13,000 gpd (9 gpm). The plant uses the same tertiary treatment process as the north rim plant, and effluent is used to irrigate a large area of trees west of the plant. NPS has plans to irrigate a nursery near the plant to provide plants for revegetation projects. Some dried sludge from the treatment process is used as fertilizer, and the remainder is packed out by mule.

4. Indian Gardens System

The Indian Gardens system has operated in its present form since 1978. The previous system utilized a leach field on a hill of about 10% slope west of the campground. The leach field handled sewage from both the campground and NPS residences. Water from the leach field was shown to be contaminating Garden Creek, therefore Arizona Department of Health Services and the Coconino County Department of Public Health condemned the system in summer, 1978. On installation of a satisfactory alternate system in late summer 1978, the campground was allowed to reopen. Contamination of Garden Creek was reduced by installation of four chemical toilets and a lift station for filling 55 gallon drums with sewage. The 55 gallon drums are removed by helicopter on a weekly basis and their contents are dumped in a lagoon designated for chemcial toilet wastes at the South Rim Treatment Plants lagoons. The drums must be removed as often as three times weekly during periods of peak use. Facilities in NPS buildings are still connected to the old leach field system which continues to malfunction contaminating Garden Creek. NPS has proposed installation of a new sewage treatment system at Indian Gardens to replace the present carry-out system.

5. Cottonwood Campground System

Sewage at Cottonwood Campground is handled by a septic tank leach field system. This system appears to be operating well but the close proximity to Bright Angel Creek causes concern that contamination may be occurring. Limited bacterial analysis of waters below Cottonwood Campground have not detected serious contamination.

6. Hermits Rest System

Sewage disposal at Hermits Rest is handled in two ways. The concession and residences are connected to a small septic system, and public facilities are chemical toilets. Chemical toilet wastes are trucked to the same sewage lagoon used for Indian Gardens wastes. Before 1982, small amounts of waste water reached the surface of the leach field and flowed down a small tributary of Hermit Creek. The leach field was repaired by re-excavation and installation of new pipes, and no surface flow has been visible since that time.

7. Desert View System

Sewage disposal at Desert View is handled by two lagoons. One lagoon is about 45 years old and the second is 15 years old. During peak visition almost 20,000 gallons of sewage per day (14 gpm) are generated. The current problem facing this system is that the lagoons sometimes come close to overflowing because much of their storage capcity has been displaced by solids.

8. Backcountry Waste Disposal

Human waste disposal in locations away from rim developments, i.e., backcountry, presents special management problems. If toilets are lacking, waste will not be concentrated at point locations. If toilets are present, remoteness makes processing and removal of wastes difficult. Backcountry waste management is strongly tied to water resources management because improper methods of human waste disposal have a detrimental effect on water quality.

9. Waste Disposal in the Backcountry Subdistrict

Past management actions on backcountry waste disposal have been in two directions: 1) to educate visitors about proper waste disposal methods and 2) to install self contained toilet systems in areas of highest use. Backcountry Reservation Office gives each permittee a booklet entitled Walk Softly, Walk Safely when the wilderness permit is obtained. This booklet deals with many aspects of backcountry etiquette and includes a section on proper methods of human waste disposal. Another section advises that all water from backcountry water sources be purified "with iodine, bleach, or by boiling." Day hikers and non-permitted hikers do not receive this information.

Two types of waste disposal systems have been installed in highly used backcountry areas: pit toilets and Shasta dehydrating toilets. Shasta toilets have been installed at Hermit and Upper Tapeats Campgrounds. Pit toilets have been installed at Horseshoe Mesa and at Horn, Salt, Monument and Clear Creeks. When hikers pick up their permits at Backcountry Reservation Office they are given an informational sheet with an attached map showing, among other things, locations of backcountry toilets. Day hikers and non-permitted hikers do not receive this information.

10. Waste Disposal in the Corridor Subdistrict

Because large numbers of hikers are concentrated in a relatively small area, management of human wastes in the Corridor has been a persistant problem. Installation of Shasta dehydrating toilets at Roaring Springs, Tipoff and Cedar Ridge on North and South Kaibab Trails, in addition to facilities at Indian Gardens, Bright Angel, and Cottonwood Campgrounds have been the primary past management actions. When hikers pick up their permits at Backcountry Reservation office they are given an information sheet containing, among other things, the locations of toilets along corridor trails. Versions of this information are available in English, French, and German. As with non-corridor trails, day hikers do not receive this information unless they inquire at the Backcountry Reservations Office or Visitor Center. Improper illegal disposal of human wastes is a problem at many locations along corridor trails. Installation of a Shasta toilet at 1.5 mile resthouse on Bright Angel trail is planned in the near future.

11. Waste Disposal in the River Subdistrict

National Park Service began requiring all river trips to carry out all solid human wastes in 1978. Prior to initiation of the carry-out policy, river users buried human wastes in pits dug in beach sands. Improper burial and sheer volume of wastes created unsanitary conditions (Phillips and Lynch, 1977). Sanitary condition of Colorado River beaches has been greatly improved since the carry-out regulations went into effect, and potential for water quality degradation has been greatly reduced.

C. Water Use by Developments Inside and Outside Grand Canyon National Park

Historically, water supply problems have always existed in Grand Canyon National Park. Two factors that have contributed to these problems are 1) lack of reliable surface water sources on surrounding plateaus and 2) increasing demand for water as new facilities are constructed to serve canyon visitors. Water sources for developments, as well as associated water supply problems, have changed through the years as visitation increased. A brief history of Grand Canyon water supply systems is listed below:

1890 (approx)	Sanford H. Rowe dug well about 2 1/2 miles southwest of present Grand Canyon Village.
1896	Development of the Grand Canyon Village begins with construction of the first Bright Angel Hotel.
1901	First passenger train arrives at Grand Canyon Village. Water is hauled from Willaims in tank cars.
1928	Construction and operation occurs for first system to withdraw water from Bright Angel Creek to be pumped to the North Rim. System consists of a 10 to 12 foot high dam across Bright Angel Creek immediately below Roaring Springs Creek, a pipeline to powerhouse located at the site of present pumphouse, and a pipeline to North Rim.

1932 Construction and first operation occurs for system delivering water from Garden Spring to the South Rim. Almost all baseflow in Garden Creek ceases as a result of this diversion. Hauling water in from Williams by tank car ends.

1960 to 1967 Water from Garden Springs is insufficient to handle increased visitation. Hauling by tank car resumes intermittently during the period.

1965 to 1966 Construction of 12.5 mile long Transcanyon Pipeline by Elling Halvorson, Inc. and Lents, Inc. of Seattle, Washington occurs, but flood of December 3-7, 1966, destroys most of the work before completion.

1970 A new, more floodproof version of the Transcanyon Pipeline is completed, and diversion of portion of Roaring Springs flow begins. One of two identical pumps connected directly to the Transcanyon Pipeline begins pumping water from Indian Gardens to the South Rim via the 6 inch pipeline constructed in 1932. Maximum pumping rate using residual pressure from the Transcanyon Pipeline is 460 gpm. Excess water from the Transcanyon Pipeline begins to flow down Garden Creek, and the flow from Garden Spring is no longer diverted.

1973 High spring season snowmelt causes Roaring Springs to flow heavy with suspended sediment, which fouls internal parts of Indian Gardens pumps. Delivery system is changed, such that water from Transcanyon Pipeline emptys first into a small water reservoir to allow settling of sediments. From the reservoir, water is pumped to the South Rim at a lower maximum rate of 420 gpm because residual pressure can no longer be used.

1978 Public Law 95-586 is passed by Congress allowing sale of water to Tusayan when "such sale is not detrimental to the protection of the resources of Grand Canyon National Park or its visitors".

1980 Sale of water to Tusayan Water Development Association, Inc. (TWDA) first occurs in February.

1985 Pending availibility of funds, this is the projected year for installation of larger a pump at Indian Gardens and larger (8") pipe to South Rim. Pumping capacity will increase to 600-650 gpm.

The primary water supply issue facing Grand Canyon National Park is withdrawal of a portion of Roaring Springs flow for use by developments at South Rim, North Rim, and Phantom Ranch. Use of Bright Angel Creek as a water source is not a recent occurrence. Water has been withdrawn from the creek and pumped to developments on the North Rim since 1928. However, the pumping capacity was only about 90 gpm, and the pumphouse operated for only a portion of each day because the pumps needed constant maintenance.

The present water supply system came into operation in July of 1970. The main components of the system are: 1) a pipe which extends into one of several caves from which Roaring Springs discharges and diverts the water to the Roaring Springs pumphouse, 2) Roaring Springs pumphouse (elev. 5220) where a portion of the withdrawn water (roughly 80 gpm) is pumped to the North Rim (during May to October) and the remainder is routed into the Transcanyon Pipeline to Indian Gardens pumphouse (some pipeline water, about 10 gpm at most, is used in Phantom Ranch area), 3) Indian Gardens pumphouse where water is lifted from an elevation of 3771 feet to 7043 feet on the South Rim, and 4) a storage and distribution system on the South Rim. A diagram of the Roaring Springs pumphouse operation is shown in figure 7. Measurement of the average monthly withdrawal from Roaring Springs began in October of 1979 for the months in which the operator was present at the pumphouse (generally May to November). The average monthly withdrawal rate for 19 months of record through 1982 was 739 gpm with a high average monthly rate of 823 gpm (June, 1981) and a low of 709 gpm (June, 1982). Because water withdrawn from the spring first empties into an overflow box just below the caves, pressure head on the pipeline to the pumphouse is constant. Therefore, fluctuation in average monthly withdrawal records is probably due to faulty flow meters and mechanical breakdowns.

Withdrawal from Roaring Springs did not come to the forefront as an environmental issue until 1978, when Public Law 95-586 was passed by Congress in November. The following is the text of the law:

> "The Act of February 26, 1916, 40 Stat. 1117: (16 U.S.C. 222) is amended by adding the following sentence: Under such terms and conditions as he deems advisable and consistent with the requirements of Section 483a of Title 31 hereof, the Secretary is authorized, without derogation of any of the water rights of the United States and notwithstanding any provision of law to the contrary, to sell by contract water located within Grand Canyon National Park for the use of customers within Tusayan, Arizona, to a nonprofit entity authorized to receive and distribute water within Tusayan, Arizona, by the laws of the State of Arizona, upon his determination that such sale is not detrimental to the protection of the resources of Grand Canyon National Park or its visitors and that appropriate measures to provide for such protection, including a right of immediate termination, are included in the transaction."

Sale of water to the authorized nonprofit entity in Tusayan, known as the Tusayan Water Development Association (TWDA) began in February, 1980. Currently water is sold to Tusayan for the price of $3.60 per thousand gallons with the TWDA providing their own hauling services. Water is sold only during periods of low-visitation, usually November to April. TWDA purchases water from Bellemont, Arizona during the entire year, but the NPS furnishes 60 to 70 percent of TWDA's water needs during the time NPS water is available. Tusayan water consumption since 1980 is shown in table 8.

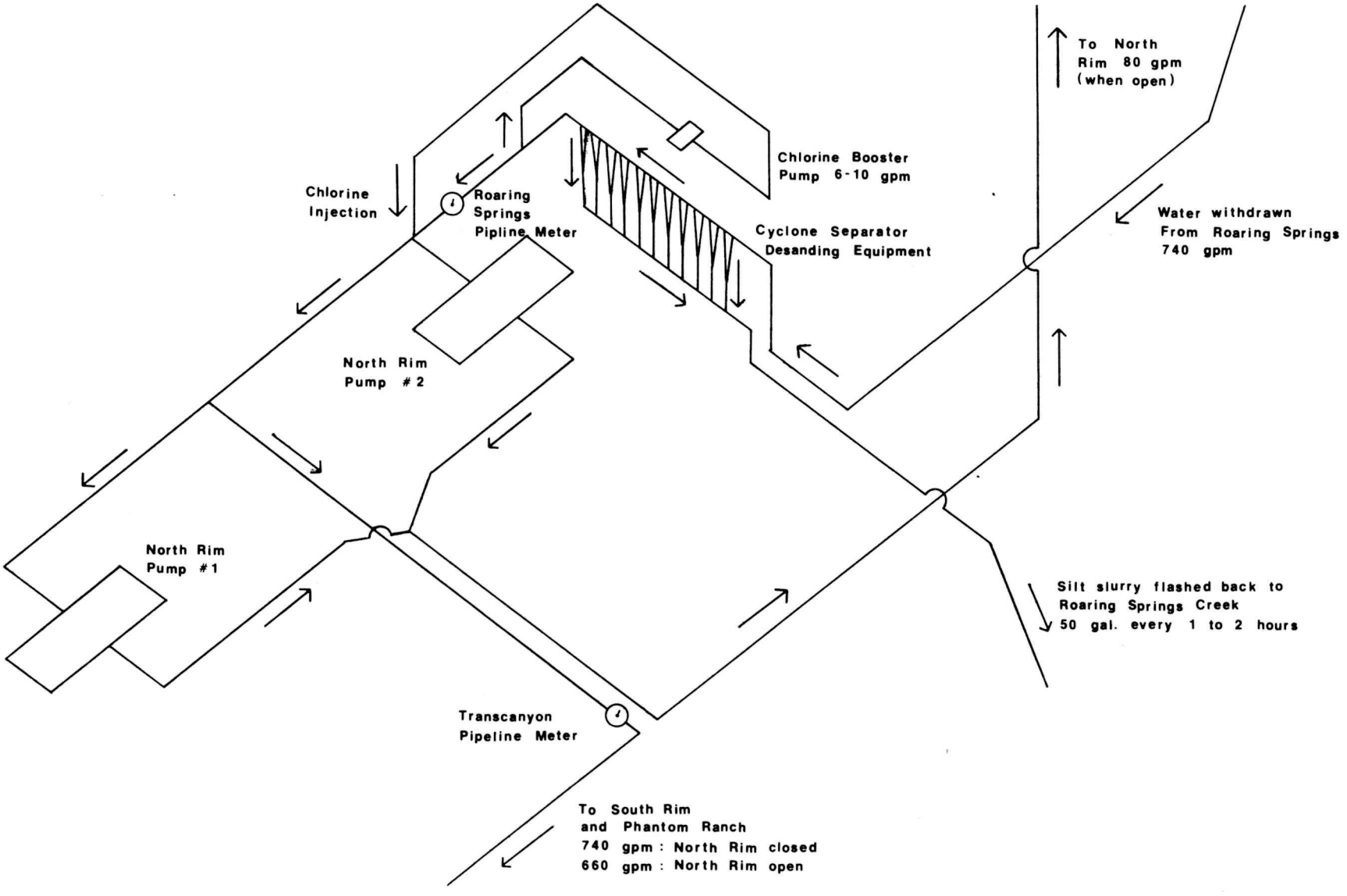


Figure 7. Schematic diagram of Roaring Springs pumphouse.

Table 8. Water use by Tusayan Water Development Association (TWDA). Figures for water purchased from Bellemont provided by TWDA.

Month	Water sold to TWDA by NPS* (gallons)	Water sold to TWDA by Bellemont (gallons)	Month	Water sold to TWDA by NPS * (gallons)	Water sold to TWDA by Bellemont (gallons)
	1980			1982	
Jan	0	1,145,300	Jan	1,594,200	32,600
Feb	0	955,500	Feb	1,640,900	30,700
Mar	1,276,500	666,000	Mar	1,556,600	266,400
Apr	1,246,100	1,870,500	Apr	1,171,100	1,107,400
May	2,631,000	213,600	May	1,035,400	1,378,000
Jun	713,700	3,053,500	Jun	0	4,092,500
Jul	0	4,029,500	Jul	0	4,246,600
Aug	0	4,526,400	Aug	0	3,766,900
Sep	0	3,820,800	Sep	200	2,500,500
Oct	0	2,611,900	Oct	0	2,781,400
Nov	0	2,682,400	Nov	1,336,200	781,800
Dec	0	1,145,400	Dec	760,000	**
Year	5,867,300	26,720,800	Year	9,094,600	(20,984,800)
	1981			1983	
Jan	2,225,600	124,400	Jan	0	2,725,600
Feb	1,864,000	93,700	Feb	1,897,000	1,444,300
Mar	937,300	1,870,400	Mar	1,371,600	2,186,500
Apr	0	2,417,800	Apr	2,770,700	638,700
May	0	3,296,800	May	571,600	**
Jun	0	3,296,600	Jun	0	**
Jul	0	3,959,600	Jul	0	**
Aug	0	3,668,500	Aug	0	**
Sep	0	3,376,900	Sep	0	**
Oct	0	2,751,800	Oct	0	**
Nov	0	2,235,600	Nov	1,255,800	**
Dec	1,251,200	542,200	Dec	1,950,000	**
Year	6,278,100	27,634,300	Year	9,816,700	(6,995,100)

* NPS billing occurs on 15th of each month. Therefore, the amount on the line for a given month spans the 15th of previous month to 15 of the given month.

** Information not available from TWDA.

In April, 1978, Denver Service Center released a special study entitled "Capacity Analysis/Water Management Alternatives" for the South Rim developed area. In this study, two options were suggested for enlarging the capacity of the Transcanyon Pipeline, which would necessitate increased withdrawal rates from Roaring Springs. They were to 1) replace the existing aluminum pipeline with a steel pipeline 2 inches larger in diameter, which would increase the withdrawal rate to an estimated 1200 gpm and 2) construct a second steel pipeline along side the existing pipeline that has the same capacity as the original, which would increase the withdrawal rate to an estimated 1400 gpm.

Because Roaring Springs supplies a substantial portion of the flow in Bright Angel Creek, a study was needed to quantify the potential effects on the environment of increasing the withdrawal rate from the springs. Passage of PL 95-586 allowing sale of water to Tusayan provided the needed impetus to intitate the study. In September of 1979 NPS contracted the Museum of Northern Arizona (MNA) to conduct a study entitled "A Study of Present and Future Impacts of Water Deletions and Additions on the Aquatic and Terrestrial Habitats of Roaring Springs, Bright Angel, Garden and Pipe Creeks, Grand Canyon National Park" (Usher et.al. 1984).

Usher et. al. examined potential impacts of two withdrawal rates higher than the present rate: 975 gpm and 1500 gpm. The 1500 gpm rate examined is near the 1400 gpm rate suggested as option 2 of the capacity analysis study. However, the MNA study did not examine potential impacts of withdrawing 1200 gpm, which was suggested as option 1 in the capacity analysis study. Four potential impacts to Bright Angel Creek as a result of increased water depletions at Roaring Springs were identified: 1) Water depletions at Roaring Springs could result in the loss of unique plant species in the immediate vicinity of Roaring Springs; however, the potential for impact to the remaining riparian communities along Roaring Springs and Bright Angel Creeks appears minimal, 2) A reduction in stream width, depth, and current velocity that could, in turn, change the temperature regime of the stream, 3) Chemically, a slight increase in specific conductivity is expected due to the concentration of natural compounds in a smaller volume of water, and 4) according to an instream flow habitat simulation model, the increased withdrawals examined will have little effect on the physical habitat available to trout and aquatic insects in Bright Angel Creek. This model did not assess the importance of water chemistry and temperature. Of these potential impacts, the alterations of flow and temperature regimes are probably the most severe.

This study of the impacts of water withdrawals was hampered by a lack of accurate flow measurements, the collection of only immature aquatic insects that could not be identified to species, and limited water temperature measurements. Another study addressing these deficiencies is needed to fully assess the impacts current and future withdrawals.

We wish to emphasize that the NPS has made no plans to increase the withdrawal rate from Roaring Springs. The next logical step for increasing the water delivery rate to the South Rim is to increase the pumping capacity at Indian Gardens. This would have no addi-

tional effect on the natural environment at Roaring Springs and Bright Angel Creek because the Transcanyon Pipeline presently delivers 240 to 340 gpm in excess of the Indian Garden pumping capacity. Use of the excess 240 to 340 gpm that is currently discharged into Garden Creek would affect the unnatural ecosystem that has adjusted to the presence of unnatural flow. Denver Service Center is currently writing an environmental assessment which will examine the impacts of upgrading Indian Gardens pumping capacity.

Pending availability of funds, in fiscal year 1985 one of the pumps will be replaced with a pump capable of lifting 600-650 gpm to the South Rim. The pipeline between Indian Gardens and the south rim will also be enlarged to handle this flow.

In the last three years of record (1980-1982) the pumps at Indian Gardens have operated near the limit of what can be realistically expected for the station (i.e. pumps operating 90% of the time). Table 9 shows a record of number of hours of operation and an estimate for the volume of water pumped to the South Rim for the period 1973-1982. It can be implied from the statistics that water consumption is leveling off in the South Rim Village, but could still increase in the coming years.

Table 9. Indian Gardens Pumping Record and South Rim Water Consumption.

Year	Hours of pumping	Pumping time, % of possible	Volume pumped to south rim assuming 420 gpm (mil-gal)	South rim water consumption (mil-gal)
1973	5,231	60	131.8	unknown
1974	5,593	64	140.9	138.4
1975	5,749	66	144.9	unknown
1976	6,522	74	164.4	unknown
1977	6,183	71	155.8	124.2
1978	6,336	72	159.7	126.8
1979	6,191	71	156.0	unknown
1980	7,678	87	193.5	unknown
1981	7,744	88	195.1	145.0*
1982	7,415	85	186.9	145.0*

*estimated

D. Water Quantity

Long term efforts to measure stream flow rates in the Grand Canyon area have been made in six locations by the USGS: Paria River near Colorado River, Colorado River near Lees Ferry, Little Colorado River near Cameron, Bright Angel Creek near Colorado River, Colorado River near Phantom Ranch, and Kanab Creek near Fredonia. Instantaneous flow rates have been measured by several researchers in springs and streams throughout Grand Canyon. Small springs were measured by finding the time needed to fill a small container such as a canteen.

Larger springs and streams were measured by estimating both the cross sectional area and velocity of the flow. Most commonly, stream velocity was estimated by finding the time needed for a floating object such as a wood chip to travel a known distance. A few tributaries have been measured using portable flumes or current meters.

Because long-term streamflow rates have not been recorded for most watersheds, water source reliability must be established by recording personal observations made by hikers and backpackers. The Backcountry Reservations Office has kept several years of records of such observations. Most visitors provided observations such as "good flow" or "trickle", but a few gave quantified estimates for flow rates. While some of these estimates of flow rate may have been made by qualified individuals, they cannot be considered reliable because of a lack of consistent measurement methods.

One study was conducted by NPS in 1979 to inventory water resources in Grand Canyon. The study entitled "An Inventory of Surface Water Resources in Grand Canyon National Park, Arizona" identified 21 perennial streams and 36 perennial springs or seeps. The study compiled data on location, history, quality and permanence of surface water resources and also developed a system to classify water sources. Water sources were located and marked on topographic quads, and descriptive data was organized into files.

E. Water Rights

National Park Service management policy calls for the preservation and protection of park water resources, related water rights, and water dependent environments. The policy for acquisition of water rights is presented in NPS Management Policy, Part IV, pages 15-17 (revised 1981). This section is a synopsis of water rights of Grand Canyon National Park. A brief history is included of major land status changes within the park and the resulting effect that has had on water rights. Also included are discussions of the Colorado River, acquired state water rights, Arizona watershed adjudications, and Arizona Groundwater Management Act.

The majority of lands within Grand Canyon National Park were reserved from public domain or transferred from other federal agencies, and thus are lands to which the Federal Reserved Water Right Doctrine applies. Therefore, in general, the waters within the boundaries of Grand Canyon National Park (other than the Colorado River) are claimed in their entirety by the federal government for uses in concurrence with the enabling legislation of Grand Canyon National Park and the NPS. On the other hand, water rights of lands which are acquired from state or private ownership are acquired in accordance with state law. This is discussed in more detail in the State Water Rights" section (2).

1. Land Status History

Boundaries of Grand Canyon National Park were developed as a result of a series of legislative actions.

On January 11, 1908, Theodore Roosevelt set aside land from the public domain for establishment of Grand Canyon National Monument (Proclamation 794). Eleven years later, on February 26, 1919, Grand Canyon was proclaimed a national park. The importance of this act was that it mandated that the park be administered according to the NPS Organic Act of 1916. This specified that the purpose of the NPS was to "conserve the scenary and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."

Additional lands were added to the park in 1927 by an act to revise the boundary of Grand Canyon National Park. This acquisition included several sections of Arizona State lands which were incorporated after a series of land exchanges.

On December 22, 1932, a new Grand Canyon National Monument was created to the west of Grand Canyon National Park to protect "that portion of the canyon which continues down the Colorado River below the Grand Canyon National Park containing much that is most significant and important in this scientific interest..." This monument also included state inholdings which were gradually acquired by land exchanges. However, about one-third of this new monument was returned to public domain in 1940.

In 1975, a major step was taken to consolidate the diverse federal reservations protecting the Canyon. The Grand Canyon Enlargement Act was passed which necessitated recognizing the unitary character of Grand Canyon from "north of the Paria River to the Grand Wash Cliffs, including tributary side canyons and surrounding plateaus." As a result of this Act, Grand Canyon National Monument and Marble Canyon National Monument were abolished and their lands incorporated into Grand Canyon National Park, whose expanded boundaries are essentially the same today.

Of the present 1,226,656 acres authorized within the boundary of Grand Canyon National Park, almost 89% was originally reserved from the public domain and/or transferred from other federal agencies. The remaining land was incorporated from the state from private ownership. About 2% of the land within boundaries of the park have not yet been acquired by NPS.

2. State Water Rights

Service claims are water rights owned by Grand Canyon National Park. Non-service claims are owned by other agencies or private entities. A project statement is included in this plan to inventory all water rights in the park. This has been partly completed.

3. Colorado River

The Colorado River through Grand Canyon is the longest stretch of recreational whitewater in the world. Since the building of Glen Canyon Dam in 1963, however, the flow of the Colorado River has been

controlled by the Bureau of Reclamation. Management objectives regarding the Colorado River resources within Grand Canyon are described in detail in the Colorado River Management Plan and Annual Operating Requirements, December 1981, and are not further discussed here.

The legislative history regarding the water of the Colorado River is a long one and includes a series of legislative acts: Colorado River Compact (45 Stat. 1057); Upper Colorado River Basin Compact (63 Stat. 31); Water Treaty of 1944 with the United Mexican States (Treaty Series 944, 59 Stat. 1219); decree entered by the Supreme Court of the United States in Arizona v. California et al (376 U.S. 340); Boulder Canyon Project Act Stat. 1057); Boulder Canyon Project Adjustment Act (54 Stat. 774, 43 U.S.C. 618a); Colorado River Storage Project Act (70 Stat. 105, 43 U.S. 620); the Colorado River Basin Project Act (82 Stat. 885; 43 U.S.C. 150).

In essence Grand Canyon National Park makes no claim for consumptive use of Colorado River waters other than for recreational purposes (as described in the Colorado River Management Plan). Admittedly, insignificant amounts of water from the Colorado River are used by visitors and concessioners (river runners) within Grand Canyon National Park.

4. Watershed Petition for Adjudications

Within the State of Arizona, five watersheds have been petitioned for adjudication. They are the Salt, San Pedro, Verde, Gila, and Little Colorado River Basins. Of these, only the Little Colorado watershed contains a portion of Grand Canyon National Park. October of 1981 field Solicitor's office in San Francisco received a copy of the summary issued by the Supreme Court of the State of Arizona in and for the County of Apache for adjudications of water rights in the Little Colorado River watershed. While they had not yet received a request from the Department of Justice to provide the requisite information, it was recommended that we begin to gather relevant data for the Statement of Claimant forms in the same manner and degree as had been done for the San Pedro and Salt River adjudications. However, before the data collection started, the Superior Court of Arizona of the State of Arizona issued a court order suspending all proceedings, including the filing requirements for the Little Colorado River. This suspension was to remain in effect until the U.S. Supreme Court resolved the jurisdictional issues which were raised in Navajo Nation v. United States (This suit is one of three companion cases regarding Indian sovereign immunity: Navajo Nation v. United States; San Carlos Apache Tribe v. Arizona; and Northern Cheyenne Tribe v. Adsit.). In July of 1983, U.S. Supreme Court reached a decision which determined that the State(s) could indeed adjudicate Indian water rights in State Court. This thus clears the way for the various water adjudications in Arizona which had been put in abeyance by the court order. Therefore, we anticipate that we will soon be receiving notice from the Department of Justice requesting us to begin data collection for the Statement of Claimant forms for the adjudication of the Little Colorado Watershed.

5. Arizona Groundwater Management Act of 1980

Provision ARS 45-593 of this Act required registration of all existing wells within Arizona by June 12, 1982. Since no wells exist from which to draw groundwater, with Grand Canyon National Park, the National Park Service, Western Region, did not submit any well registration forms for the park.

F. Flood Hazards

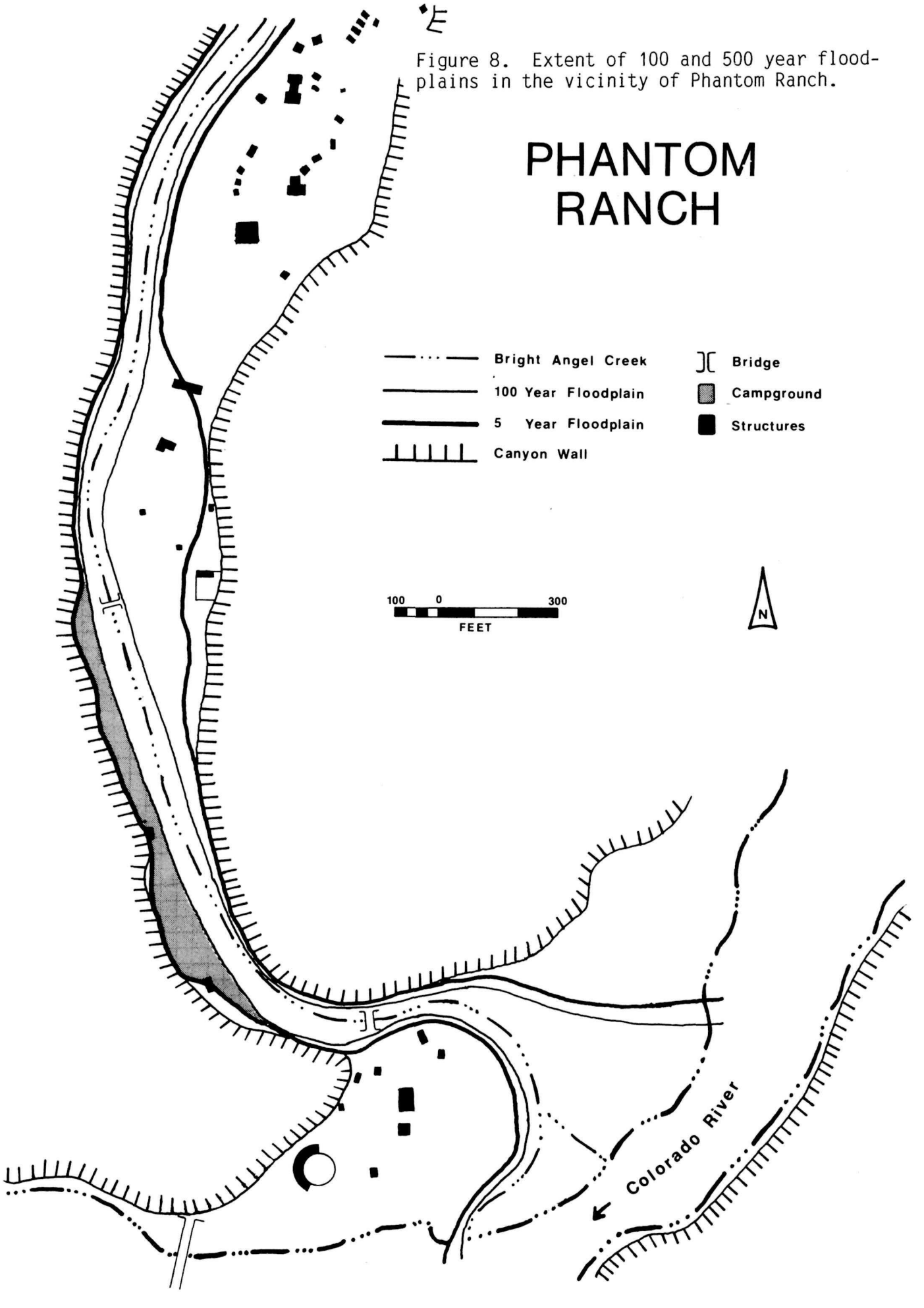
Because of the wilderness character of hundreds of tributary watersheds in the Grand Canyon backcountry, floodplains have been delineated only in developed areas of Phantom Ranch and Indian Gardens. During 1979, floodplain studies were conducted on these two locations by the Army Corps of Engineers and the NPS Denver Service Center (DSC) to assess flood danger to corridor visitors and employees. At Phantom Ranch (see figure 8) a 100-year flood in Bright Angel Creek would be confined within the channel where the banks are protected by gabions. Gabions on the east side of the creek begin above Phantom Ranch and extend downstream to the lower bridge. Shorter gabions on the west side protect Bright Angel Campground. It was calculated that a 500-year flood would not reach tourist facilities at Phantom Ranch, but the guides quarters, ranger station, and campground comfort station would be affected. Of these buildings, the guide's quarters would be most affected, being subjected to flood waters approximately two feet deep. The 500-year flood would probably wash out the lower bridge across Bright Angel Creek. However, if the bridge was not washed out water would be deflected across the delta into a natural distributary channel towards the location of the present sewage treatment plant, which was in the planning stage at the time of the study. If this occurred, the lower portion of the bi-level plant would be subjected to sheetflow less than 1 foot in depth. The treatment plant was protected with trenching to channel away such a flow.

In Indian Gardens Campground, engineers found the 100-year flood would potentially cover the campground with an average depth of less than 1 foot of water. Debris and sediment clogging the two channels on either side of the campground would bring average water depths to about one foot. The 500-year floodplain was not estimated at Indian Gardens, but given the narrow dimensions of the canyon there, the entire campground likely would be inundated by several feet of water.

In many watersheds, potential for debris flows is a more serious threat than flooding. Debris flows are especially dangerous because no method exists to estimate their magnitude or predict their occurrence. Fortunately, debris flows generally announce their approach with a loud rumble often comparable to that of a freight train and usually travel slow enough to allow time for escape.

In discussing floodplain delineation, several important factors should be emphasized which affect reliability of these estimates. First, it should be realized that a flow rate for a given return period is only an estimated value and is derived using either statistical procedures involving past streamflow records or hydrologic

Figure 8. Extent of 100 and 500 year floodplains in the vicinity of Phantom Ranch.



models requiring an input of estimated flood initiating rainfall. Second, once the estimated discharge rate for a flow of given return period is derived for a desired location on a stream channel, the height to which this flow rate would cause water to rise on the stream banks must be estimated using hydraulic methods. Third, because streamflow records have been kept for a much shorter time than the return periods of interest (i.e. 100 and 500 years), the statistical estimate for the 500 year flood, for example, will change as the length of stream flow record increases. Therefore, when estimates are made on water elevation in a flood of given return period, errors of several feet can exist.

In the Corridor, rangers have a procedure to warn visitors at Indian Gardens, Cottonwood, Bright Angel, and Phantom of impending flash floods. If unusually intense rains occur on the rims, rangers are notified by phone or radio at each location that would be affected and evacuation procedures begin. Often, as in the case of the 1980 Indian Gardens flood, the ranger at the endangered campground will commence evacuation even before he or she is notified, if it appears flooding is imminent. The park has proposed installation of an electronic flood warning system for Indian Gardens and development of formal evacuation plans for all developed areas within the canyon.

G. Biotic Communities

Past management actions regarding biotic communities and their relationship to water resources can be grouped in two general catagories which are 1) actions relating to human induced impacts such as existence of feral burros, livestock, and stock tanks and 2) research actions relating to natural stream and riparian communities such as field surveys and observational studies. Actions in the first category are usually performed by NPS personnel while actions in the second category generally involve outside researchers assisted by NPS personnel.

1. Feral Burros

Feral burros were having an adverse impact on Grand Canyon, aquatic environments. Burro feces were frequently observed floating in streams, and burros were constantly disturbing stream bottom sediments with their hoofs. They may also have been competing with native animals for forage in the riparian zone. The 1980 Feral Burro Management and Ecosystem Restoration Plan and Final Environmental Statement called for total removal of burros. Removal was accomplished between August 1980 and September 1982.

2. Livestock

Livestock grazing has impacted biotic communities in some areas. Significant damage to riparian environments near springs on Sanup Plateau and on Havasupai Traditional Use Lands (TUL) has been observed. The U.S. Forest Service Carrying Capacity Study of 1982 found that the TUL was not capable of supporting grazing livestock,

and NPS has requested that all unclaimed horses be removed from the land by the Havasupai Tribe. Damage to riparian environments on the Kanab and Sanup Plateaus has been caused by trespass and permitted cattle grazing. Grazing allotments on lands inside the park boundary will expire in 1985, and NPS is evaluating several options to mitigate grazing impacts including fence construction and removal of stock tanks.

NPS has contracted USFS to conduct a study on grazing impacts on the Sanup Plateau, which will be completed in 1984.

3. Stock Tanks

An artificial riparian environment is now established around several stock tanks inside the park boundary. These water sources have caused the areas surrounding them to be heavily impacted. In the past NPS has allowed these tanks to gradually fill up with silt until they are no longer capable of storing water.

4. Past Research

The majority of past research on water related biotic communities has been related to Colorado River. A few researchers have focused on tributary riparian communities. In 1973, NPS embarked upon the multiphase Colorado River Research Program designed to secure information on the river environment and associated human impacts. The following is a brief description of eight studies in the program relating to biotic communities along Colorado River and some tributaries.

Suttkus, R.D. et. al (1976) surveyed fishes, mammals, and herptofauna of the Colorado River and adjacent riparian areas of the Grand Canyon National Park. Sampling was done for plants, fish, mammals, reptiles, and amphibians at several locations along Colorado River and in Lake Mead. Samples were collected during 14 river trips from 1970 to 1976. Some collecting was also done in lower reaches of a few tributary watersheds.

Czarnecki, et. al. (1976) conducted periphytic microflora analysis of the Colorado River and major tributaries in Grand Canyon on and vicinity. This analysis was conducted seasonally at sites near the confluence of 12 major tributaries and the Colorado River in Grand Canyon National Park and vicinity. Twenty-one additional locations along the 225 miles stretch of the Colorado River (Lees Ferry to Diamond Creek) were also examined. Samples were collected during three river trips in spring, summer, and fall 1975.

Carothers, S.W. (1976) conducted an ecological survey of the riparian zone of the Colorado River between Lees Ferry and the Grand Wash Cliffs. Purposes of this study were: to describe vegetational changes as a result of the controlled water releases from Glen Canyon Dam; to prepare a vegetation map from river level up to the 500 foot contour level; to describe population densities, home ranges, and demography of important vertebrates, to inventory insects of the riparian zone; to desribe the distribution and impact caused by feral burros; and to describe interrelationships of humans with the biota.

Sommerfield (1976) surveyed bacteria, phytoplankton, and trace chemistry of the lower Colorado River and tributaries in Grand Canyon National Park. Purposes of this study were: first, to assess both the day-to-day and site-to-site variation in bacteria counts in Colorado River and major tributaries; second, to find the quantity and species of phytoplankton living in Colorado River and major tributaries; and third, to monitor concentrations of 15 trace elements in Colorado River and major tributaries.

Minckley and Blinn (1976) examined the summer distribution and reproductive status of fish of the Colorado River in Grand Canyon National Park and vicinity. The purpose of the study was to determine summer distribution and general reproductive status of fish, particularly native species. Abundance of native and exotic fish both in total numbers and in localities was also assessed.

Deacon and Baker (1976) made an aquatic investigation on the Colorado River from Separation Canyon to the Grand Wash Cliffs. The purpose of the study was to examine limnological effects of the Colorado River in relation to Lake Mead and to supplement other research on Colorado River. Fish were collected from various locations, and sampling was done for water temperature, turbidity, dissolved oxygen, nutrients, bacteria, and phytoplankton.

Phillips, et. al. (1979) researched values of the aquatic and riparian vegetation of springs in Grand Canyon. This study included a study of riparian vegetation communities at Roaring Springs, Clear Creek Spring, Thunder River, Deer Spring, and Dutton Springs.

5. Other Research on Water Related Biotic Communities

Several other books and research papers have been written either partially or entirely on topics related to Grand Canyon. Four papers listed below contain extensive bibliographies on past research. Two of these include annotations. Together they are a complete collection of research titles on water related biotic communities.

An Annotated Bibliography of Limnologically Related Research on the Colorado River and Its Major Tributaries in the Region of Marble and Grand Canyons, Colorado River Research Program Technical Report No. 9, Dennis M. Kubly, 1975.

Synthesis and Management Implications of the Colorado River Research Program, Colorado River Research Program Technical Report No. 17, R. Roy Johnson, 1977.

An Annotated Bibliography of Research Related to Roaring Springs, Bright Angel, Garden and Pipe Creeks in Grand Canyon National Park, Rebecca Nelson, 1979. Available in Grand Canyon National Park, Resource Management Division files.

Bibliography from An Inventory of Surface Water Resources in Grand Canyon National Park, Arizona, Bryan T. Brown and M. Susan Moran, 1979.

IV. Management Program

The water resources management program is presented here as seventeen project statements. Each discusses an issue or problem and purposes an action or actions to deal with it. This is not a static list of projects. Its content and priorities will be updated as needed. The water resources projects programming sheet is presented first to provide an overview of project priorities and funding requests. This is followed by the project statements, also in priority order. A development/ study package proposal, form 10-238, is included in Appendix A for each project for which funding is requested.

A. Water Resources Projects Programming Sheet

The water resources project programming sheet includes each proposed project in priority order, the overall project priority from the Natural and Cultural Resources Management Plan, the type of action, funding requests for the five-year period FY 85 to FY 89, prospective funding sources, and package numbers corresponding to 10-238's. Some minor descrepancies exist between this programming sheet and the priorities presented in the 1984 Natural and Cultural Resource Management Plan. This is because new projects have been added and priorities updated.

Water Resources Projects Programming Sheet
(Costs in $1,000)

RMP No.	Project Title	WRMP Pri.	RMP* Pri.	Action** Type	FY 85 Base	FY 85 New	FY 86 Base	FY 86 New	FY 87 Base	FY 87 New	FY 88 Base	FY 88 New	FY 89 Base	FY 89 New	Fund*** Source	Pkg. No.
N-67	Implement Water Resources Plan	1	7UF	Mit.		22.0		23.0		24.0		24.0		24.0	1	452
N-59	Water Resources Inventory Including Water Rights	2	10UF	Res.	2.0	15.0	2.0	4.0	2.0	4.0	2.0	4.0	2.0	4.0	2	448
N-52	Field Test Drinking Water Treatment Methodologies	3	11UF	Res.		20.0		8.0							2,3	449
N-53	Flood Hazard Analysis of Grand Canyon Village, Indian Gardens, and Cottonwood Campground	4	23 F	Mit.	3.0		3.0								2,5	452
N-70	Water Conservation	5	16UF	Mit.	3.0	3.0	3.0	3.0	3.0	3.0	2.0		2.0		2,4,5,6	
N-72	Flood Hazard Mitigation	6	20UF	Mit.	4.0	4.0	4.0	4.0	4.0	4.0					2,4,5,	452
N-66	Radionuclide Assessment of Colorado River and Tributaries	7	22UF	Mon.				4.0		4.0		4.0			2,3	471
N-56	Chemical Water Quality Inventory and Monitoring	8	26UF	Mon.				7.0		7.0		7.0		6.0	2,3	474
N-74	Hydrogeology of Kaibab Plateau	9	28UF	Res.				25.0		25.0					2,3	482
N-69	Increase Hiker Awareness of Water Quality Problems	10	30UF	Mit.					3.0	3.0	3.0		2.0		2,5	452
N-57	Lower Canyon Water Quality Monitoring, Diamond Creek to Lake Mead	11	33UF	Res.						25.0		20.0			2,3,5	477

RMP No.	Project Title	WRMP Pri.	RMP Pri.*	Action** Type	FY 85 Base	FY 85 New	FY 86 Base	FY 86 New	FY 87 Base	FY 87 New	FY 88 Base	FY 88 New	FY 89 Base	FY 89 New	Fund*** Source	Pkg. No.
N-71	Fish Tissue Analysis	12	37UF	Res.						6.0		6.0			2,3	478
N-73	Impacts of Water Withdrawals on Temperature, Flow and Fauna of Bright Angel Creek	13	38UF	Res.								14.0			2,3	481
N-4	Intensive Microbial Analysis of Selected Tributary Creeks	14	40UF	Mon.								18.0		18.0	2,3	479
N-25	Stock Tank Inventory	15	41UF	Mit.							3.0	2.0	3.0	2.0	1,2	452
N-51	Colorado River Water Quality Modeling	16	42UF	Res.								34.0		34.0	2,3	480
N-65	Fecal Streptococcus	17	43UF	Res.									4.0	4.0	2,3	475

* F=Funded, UF=Unfunded
** Action Type: Res.=Research, Mon.=Monitoring, Mit.=Mitigation
*** Funding Source: 1=Park base, 2=Servicewide water resources program base, 3=Research, 4=Repair and rehabilitation, 5=Health and safety, 6=Cyclic maintenance

B. Natural Resource Project Statements

Each of the following 17 project statements discusses on issue or problem then presents proposed actions to deal with it. They are placed in priority order as presented on the programming sheet. Project statements and their priorities will be updated annually or more often if warranted. There is a development/study package proposal (form 10-238) in Appendix A for each unfunded project.

NATURAL RESOURCES PROJECT STATEMENT

1. GRCA-N-67 Water Resources Planning, Monitoring, and Mitigation

2. Statement of Issue or Problem

Water resources in Grand Canyon are a major concern for two reasons: (1) maintenance of acquatic and riparian ecosystems and (2) public health and safety. The park was established in order to preserve and protect natural resources, which includes the water resources.

Free flowing water in Grand Canyon National Park provide riparian and acquatic habitats, but there are several potential threats to these resources. Management practices on adjacent lands may affect groundwater recharge. Riparian zones are often impacted because they are favorite campsites for backcountry and river users. Fluctuations within the controlled flow regime of the Colorado River erodes predam sediment deposits, thereby eliminating some riparian vegetation. Contaminants that could be introduced into the groundwater table by mining activities up river and on the rims can alter the chemical water quality of inner canyon springs and streams. Bacterial contamination also occurs as a result of human and animal activity.

Other concerns exist. Most campsites are located in floodplains so human safety is a problem when runoff occurs. There has not been a complete inventory of park water resources nor a compilation of water rights. Criteria should be documented for sale of water to Tusayan. Stock tanks should be inventoried and water conservation measures implemented.

Resources Management staff will finalize the Water Resources Management Plan in spring 1984, which reports past research and activities and discusses current issues. Information was completed for water quality (chemical and baterial), water resources inventory, water rights, flood hazards and mitigation, sewage treatment, water pipeline system, human waste disposal in the backcountry, biotic communities, water sales, and conservation.

Past work in water resouces by park staff has been sporadic and inconsistent because there has not been a professional hydrologist on staff to provide input and water resources has received only part time attention of the limited number of resources personnel. In 1980 a seasonal worker was hired who had formal education and work experience as a hydrologist. Only in the last two years has at least half his time been spent in water resources. Consequently, work has been done on specific projects, and issues and needs have been identified. The Water Resources Management Plan results from the recent effort to manage water related problems in the park.

The plan defines a course of action for protection, conservation, use, and management of park water resources. Fifteen projects have been identified primarily dealing with public health and safety, environmental concern regarding water quality (chemical and bacterial), and floodplain analysis. Finishing the water resources inventory and analyzing water rights is another top priority project. Additional projects include inventorying stock tanks, establishing written criteria for water sales, and implementing water conservation means.

The park is now ready to implement projects identified in the Water Resources Management Plan with support of funding and personnel. This project statement is a request for a permanent position and increase to base funding.

3. Alternative Actions and Their Probable Impacts

a. Acquire a Permanent Position for Water Resources Management. By having a fully funded permanent position added to the division, work will continue in a consistent and orderly manner to recognize issues and mitigate them when possible.

Impacts. With this position, the park would begin working on some projects that can be handled by an experienced staff hydrologist with helpers. Projects thus identified are:

N-53 Flood hazard analysis of Grand Canyon Village, Indian Gardens, and Cottonwood Campground
N-65 Fecal streptococcus speciation of Garden and Bright Angel Creeks
N-25 Stock Tank inventory
N-69 Increase hiker awareness of water quality problems
N-70 Water conservation
N-72 Flood hazard mitigation

This person would continue gathering information on water resources and rights plus provide professional input to contracted projects and independent research. In addition, she/he would also assist as needed to perform assorted duties that include NEPA compliance, water supply data, clean water requirement, and liaison with other agencies regarding water issues and human waste disposal.

b. No Action. Continue the present management action of using staff which is not specifically trained on a part time basis and with intermittent funding.

Impacts. The program will continue very much as it is now. Water resources projects will be done in the park when there is expertise, personnel, time, and funding available. Consequently, work on the listed projects will be sporadic.

4. Recommended Course of Action

Alternative a. is recommended to acquire a permanent position to handle water resources management.

NATURAL RESOURCES PROJECT STATEMENT

1. GRCA-N-59 Water Resources Inventory Including Water Rights

2. Statement of Issue or Problem

Grand Canyon's water resources inventory is incomplete. An inventory begun in 1979 concentrated on availability of drinking water for back-country users. This resulted in a collection of substantial qualitative information about the location of water resources frequently by hikers and river runners. But little is known of water resources outside the most visited areas of the park. The 1979 NPS water resources inventory concentrated on central Grand Canyon, roughly from Nankoweap Canyon to Havasu Canyon. Twenty-one perennial streams and 36 perennial springs were inventoried. Researchers have provided some information on more remote areas of the park. Huntoon (1983) and Foust (1983) identified more than forty other springs or seeps, mostly in western Grand Canyon. Obvious information gaps occur for the Esplanade and Sanup terraces in the western canyon and in Marble Canyon.

Accurate flow measurements are almost nonexistent. Most water resource inventory information contains only descriptive flow data like "good flow", "trickle", or "perennial." Long term efforts to measure streamflow have been made at only six locations by the U.S. Geological Survey. Researchers have also contributed a few accurate flow measurements. But even with these most stream flows can only be grossly estimated.

The water rights information base for Grand Canyon is also incomplete. In addition to two certified water rights held by NPS, certified water rights have been issued to individuals or other government agencies for at least nine other water sources in the park. Applications for water rights have been filed on at least 16 other sources. Almost all of these are located in western Grand Canyon where an inventory is lacking.

If recent court decisions in Colorado which required NPS to adjudicate water rights are applied in Arizona, a rigorous water resources inventory will be necessary to quantify flows. Without an intial inventory it will be impossible to initiate a inventory in an efficient and timely manner.

3. Alternative Actions and Their Probable Impacts

a. Complete the Water Resources Inventory. The water resources inventory for the park begun in 1979 will be completed by expanding the area of study into the western and Marble Canyon portions of the park. As in the initial inventory, water resources will be investigated through a literature search followed by on-site examination. Sources of initial information include research publications, maps, aerial photographs, hiker reports, ranger trip reports, and interviews. After probable water sources are identified, as many as possible will be visited and evaluated for flow, size, reliability, palatibility, associated flora and fauna, source lithology, exact location, and use by man, wildlife, and domestic livestock. Information on the water rights status of each water source will be collected from park files, state records, and other agencies. Sources with alien water rights or applications will be inspected to determine exact location and to verify diversion and use.

The discharge of major streams and springs will be accurately measured. This will be accomplished using a portable flume or pigmy or Price flow meters. To assess seasonal variations, discharge will be measured several times during periods of high and low flows. Some streams have stable regular reaches which can easily be graded so that subsequent flow measurements can be made simply by measuring stream stage as determined from the Colorado River. River and backcountry rangers trained in the use of sampling equipment can make measurements throughout the year. Ideally collection of flow information will become a routine monitoring activity.

Priorities for sampling will depend on existing data, accessibility, volume and variability of flow, status of water rights adjudication, and extent of the ground water drainage area outside the park where it is subject to withdrawals. Accurate flow data will be collected whenever bacterial and chemical water quality samples are collected. Researchers examining water resource related issues will be encouraged to include accurate flow measurements in their data collection.

Impacts. The park will know its water resources and will be better prepared to file for water rights if that becomes necessary. The park will be able to knowledgably respond to inquiries from state, Western Region, and Washington Offices. More accurate information will be available to visitors traveling to remote areas of the park. Quantitative flow measurements will allow the park to better assess impacts to aquatic resources.

b. No Action. The park will organize information which is currently on hand or obtainable without extraordinary effort.

Impacts. The park will be slow to implement a rigorous water inventory should one become necessary in order to file for water rights. Responses to information requests will be limited by the incomplete information on hand. Without baseline flow information baseline future impacts will be difficult to assess.

4. Recommended Course of Action

Implement Alternative a. to inventory water resources including water rights.

NATURAL RESOURCES PROJECT STATEMENT

1. GRCA-N-52 Field Test Drinking Water Treatment Methodologies

2. Statement of Issue or Problem

Waters of Grand Canyon are frequently heavily laden with sediment. This creates special problems for hikers and river runners who must treat this water for drinking. All canyon waters require treatment before they can be safely consumed. Standard water treatment methods have been found to be effective in disinfecting Grand Canyon waters that are not sediment laden. Fine organic and inorganic sediment particles react readily with chemical disinfectants to quickly neturalize their microbiocidal action. In field conditions it is difficult if not impossible to estimate the additional disinfectant necessary to satisfy the additional demand of suspended sediment. When flooding tributaries introduce sediment into Colorado River, clear water is often unavailable for extended periods. Hikers and river runners are then forced to attempt treatment of turbid water with uncertain results.

A literature search of water treatment methodologies and laboratory development of a prototype treatment system has been completed (Tunnicliff and Brickler 1981). However, most studies dealt with clear or only slightly turbid water and their results are not directly applicable to Grand Canyon.

Several methods of water treatment were identified which potentially can be adapted to Grand Canyon conditions. Field and laboratory testing will be necessary to ensure the effectiveness and practicality of each method. These should be evaluated by the following criteria: (1) an ability to supply the daily water needs of large river parties and/or individual backpackers, (2) procedures and equipment that are practical for white water and backcountry transport and schedules, (3) use of readily available equipment and disinfectants at reasonable costs, and (4) achievement of complete inactivation of enteric organisms in Colorado River water regardless of initial suspended sediment load.

3. Alternative Actions and Their Probable Impacts

a. Test Water Treatment Methodologies in the Laboratory and In Field Conditions. Sediment laden waters from Colorado River and tributary streams will be used for testing water treatment methods.

Impacts. Backcountry and river users will have a reliable method to treat water. This can result in fewer cases of enteric illness in Grand Canyon if visitors use the appropriate methodology. Having a clearly reliable method of water treatment should increase compliance with treatment recommendations. Many cases of improper water treatment are the result of confusion about which treatment is best. With the existing lack of knowledge the park can do little to correct this confusion.

b. No action. No further evaluation will be made.

Impacts. Hikers and river runners will continue inadequate water treatment and continue to contract enteric diseases. Compliance with existing treatment recommendations will continue to decline because of confusion over methodologies.

4. Recommended Course of Action

Alternative a. is recommended to test water treatment methodologies in the laboratory and in field conditions.

NATURAL RESOURCES PROJECT STATEMENT

1. GRCA-N-53 Flood Hazard Analysis of Grand Canyon Village, Indian Gardens, and Cottonwood Campground

2. Statement of Issue or Problem

Topographic, climatologic, and human use characteristics combine in Grand Canyon to enhance flood hazards. Steep canyons with plentiful slickrock promote rapid runoff of heavy precipitation. Stream channels cutting through alternating layers of hard and soft rock create numerous narrow, vertical walled box canyons. Air circulation over the extreme topography enhances both regional cyclonic storms and local thunderstorms. Most prolonged human use in the canyon occurs in the immediate vicinity of tributary creeks contributing to potential property damage, injury, or death.

Evidence of past flooding abounds in Grand Canyon. Large debris fans occur at the mouths of most tributary canyons. These fans, which create the rapids for which Colorado River is renowned, often contain boulders and driftwood from rock layers and forests many miles away and several thousand feet above the river. Many dry canyon bottoms have been scoured clean by rushing water and debris or are choked with rubble.

Indian Gardens has experienced repeated flooding of the campground area. Rapid onset floods have swept through the area causing property damage, requiring evasive action, and resulting in two fatalities. Recently flooding has occurred on the average of once every two years. In most cases impending floods were predicted by observation of heavy rains, and evacuation of the campground was sufficient to prevent injury or loss of life. When there were fatilities, flooding occurred at night and no evacuation warning was given. Measures have been taken since to ensure rangers are aware of heavy precipitation and impending floods.

Cottonwood campground and Roaring Springs residence and pumphouse are located along Bright Angel Creek. No floodplain studies have been completed for these areas. Cottonwood Campground was inundated by the 1966 flood and remains threatened. Easy escape routes are available from the camping area to high ground, but the ranger station is not staffed during winter months so campers must make their own decision to flee. The residence and pumphouse at Roaring Springs are situated well above the creek bed and do not appear threatened.

Local areas in Grand Canyon Village are subject to periodic flooding. The village is drained by Bright Angel wash which flows southward eventually draining into Havasu (Cataract) Canyon. Only about 900 acres of watershed lie above the village but this is sufficient to produce flows exceeding the capacity of drainage culverts. These culverts divert the flow under a historic stone structure now housing the Public Garage and General Offices for Grand Canyon National Park Lodges. When the capacity of the culverts is exceeded and water flows through this building up to three feet deep. Such floods have occurred several times in recent years.

No hydrologic analysis has been completed for this watershed. Runoff has probably been enhanced greatly by extensive areas of asphalt, roofs and compacted soils on the watershed. Any future developments will further increase runoff aggrevating the problems. In addition to increased flood flows, enhanced runoffs accelerates erosion and creates sediment transport problems. Downstream from the Garage/General Offices, flooding has caused minor damage to roadways and railroad bridges.

3. Alternative Actions and Their Probable Impacts.

a. Complete a Flood Flow Analysis of Indian Gardens, Cottonwood Campground, and Grand Canyon Village. One hundred year floodplains will be identified for each of these locations. This will involve an analysis of watershed and rainfall characteristics by the emperical method and measurement of channel characteristics to estimate the magnitude of previous floods. The proposed new camping area (see N-74) at Indian Gardens will be given special attention to insure that it is not also flood prone. The focal point of the load analysis in Grand Canyon Village will be an assessment of the adequacy of culverts that carry water beneath the General offices building. Results of this analysis will be used to determine the need to replace or modify the culverts. Results of flood hazard analysis at Cottonwood Campground will be used in determining the extent and type of mitigation needed.

Impacts. Accurate knowledge of flood hazards in each of these areas will promote more effective protection of life and property. If the proposed new camping area at Indian Gardens is outside the floodplain, development of this previously undisturbed site will be encouraged.

b. No Action. Use of these areas will continue without accurate knowledge of their flood hazards.

Impacts. Property damage and potential loss of life will continue. Unnecessary or inappropriate actions may be taken. This includes installation of over or under sized culverts in Grand Cnayon Village and movement of Indian Gardens camping area into a previously undisturbed area that may be just as flood prone as the existing site.

4. Recommended Course of Action.

Complete the flood hazard analysis of these areas using park Resources Management and Maintenance staff.

NATURAL RESOURCES PROJECT STATEMENT

1. GRCA-N-70 Water Conservation

2. Statement of Issue or Problem

Grand Canyon National Park is an arid environment where water is a precious resource. Its importance is recognized by the fact that water is pumped in a transcanyon pipeline system to support developments at North Rim, South Rim, and Desert View.

Portions of this pipe are over 50 years old and breakdowns occur frequently. When pumping is interrupted, residents and guests are asked to ration water and sales to Tusayan are suspended. Even when the system operates well, consumption during the peak use season exceeds supply.

Consequently, the park is concerned about water conservation in conjunction with improvements in the present water distribution system. Most of the housing and guest accomodations within the park were built before water conserving fixtures were available. Park and concession maintenance divisions are making improvements to reduce water consumption by toilets, faucets, and showers by replacing faulty parts with flow restricting devices. In addition, new facilities are constructed with flow restricting devices.

3. Alternative Actions and Their Probable Impacts

a. Water Conserving Fixtures in All New Buildings in the Park and Where Practical Retro-fit Existing Structures. Water consumption by existing toilets should be reduced to a maximum of 5 gallons per flush by installation of toilet dams or other appropriate flow restriction devices. All new toilets installed in the park should be the new water conserving models which have a maximum water consumption of 3.5 gallons per flush. All showers should be fitted with water conserving shower heads such that their flow rate is no more than 3 gallons per minute under standard system pressures from 40 to 80 pounds per square inch (psi). All sink faucets should be fitted with aerator devices such that their flow rate is no more than 2 gpm under standard system pressures. In addition, all new water using appliances purchased such as washing machines and dishwashers should use the latest available technology for water conservations. Many conservation devices will return the initial costs very quickly through savings in pumping and sewage treatment costs.

Tusayan Water Development Assocation will be encouraged to have a water conservation program for replacement fixtures and new development. The Association would likely find a decrease of consumption and more awareness of conservation by users.

Impacts. A considerable reduction in water consumption per household would be realized, which could reduce future demands to withdraw more water from Roaring Springs. The park will be able to operate longer on storage during pipeline breaks or other shutdowns. Flow into the sewage treatment plant will be reduced.

Though water conservation in Tusayan will result in reduced consumption in the area, it is doubtful this will reduce demand for water from the park. Tusayan's alternative water sources are much more expensive than park water.

b. No Action. Require no water conserving measures.

Impacts. Use of water conservation devices will remain inconsistent. High consumption fixtures will continue to put an unnecessary drain on the park's water supply system and Roaring Springs and will continue to hydraulically overload treatment facilities on the South Rim and at Phantom Ranch.

4. Recommended Course of Action.

Alternative a. should be instituted to adjust to water conserving measures.

NATURAL RESOURCES PROJECT STATEMENT

1. GRCA-N-72 Flood Hazard Mitigation

2. Statement of Issue or Problem

Topography and human use patterns combine to enhance flood hazards. Steep canyon walls and slickrock promote rapid runoff. Narrow vertical walled box canyons are common. Air circulation over the extreme topography enhances both regional cyclonic and local thunder storms. Most human use in the canyon occurs in the immediate vicinity of Colorado River and tributary creeks. All these factors contribute to potential injury, death or property damage.

Flood characteristics and the history of flooding are discussed in the Water Resources Plan under unusual storm events. Several problem areas are identified. These include established camping areas in drainages such as Indian Gardens, Phantom Ranch, and Cottonwood Campground which are very popular camping sites. In backcountry areas, most campsites are in side canyons by water courses. River runners have two potential flood hazards. Most campable beaches are at the mouth of tributary creeks which can have flash floods. In addition, high flow releases from the dam can affect camping beaches.

Park staff warn visitors about potential flood hazards. Hikers are contacted by personnel at the visitor information desk and Backcountry Reservation Office, with a pamphlet, and through signs in the backcountry. River runners receive information about flood hazards through interpretive displays at Lee's Ferry. The park has a plan for emergency warning and evacuation for high water flows from Glen Canyon Dam or a dam failure.

When heavy rainfall occurs in Grand Canyon Village area, the dispatcher calls the Indian Gardens ranger to warn of potential flooding. Park staff will also try to warn backcountry and river users of extreme flood hazards by messages via helicopters.

Media and personal contact are used to warn park visitors about flood hazards. It is not known how aware visitors are of flood hazards or how seriously they take the warnings. Park staff have responded routinely to flooding at campgrounds, particularly Indian Gardens, and to high water flow from Glen Canyon Dam. These efforts have prevented injury. More consideration needs to be given evacuation plans, and extending warnings about flood hazard situations to visitors.

3. Alternative Actions and Their Probable Impacts

a. Decrease Potential of Flood Hazards. This alternative entails a couple of activities. First is to assess relocating Indian Gardens Campground which has flooded frequently in past years. Loss of life due to flooding makes relocation a top priority. Prior to relocation we would prepare an environmental assessment, analyze flood hazard of proposed sites, establish shade trees, compile campground design, and install water and toilet facilities.

In addition to relocation, the park could augment the flood warning system for Indian Gardens. Currently, park staff recognize flood potential when heavy rainfall occurs in the watershed. Sometimes staff on the rim will alert Indian Gardens rangers to the potential. One consideration is installing an electronic flood warning system on water courses above Indian Gardens. Two telemeterized rain intensity gauges, which are solar powered, would sense rainfall intensity. Based on a predetermined critical intensity, the gauges would broadcast a warning signal to Indian Gardens and dispatch on the rim. This sytem would cost about $20,000 and would be superior to stream gauging.

The third activity is developing evacuation plans for Indian Gardens, Phantom Ranch, and Cottonwood Campground. The Corridor Subdistrict Ranger would prepare these plans which would include criteria for evacuation or closure, warning system, and routes of escape.

The final activity suggested in this alternative is to review all caution and interpretive media to make sure adequate warning and advice is given. This would entail reviewing signs, displays, and pamphlets.

Impacts. The overall impact of doing all four activities to mitigate flood hazards would be increased warning and protection for visitors and staff in flood prone areas. Consequently the threat of injury or death will decrease. If a new campground is established at Indian Gardens, an area of about an acre will be disturbed with construction of facilities and individual sites.

b. No Action. This alternative means not making any changes to existing situations.

Impacts. While the park does notify visitors and staff of flooding potential there is more that can be done to protect people. The worst situations are designated campgrounds in major side canyons that are popular sites, especially in the Corridor.

4. Recommended Course of Action

Alternative a. is recommended to do the listed activities to mitigate flood hazards. Specifically this entails relocating Indian Gardens Campground with the option of a mechanical warning system, developing evacuation plans, and upgrading caution and interpretive media about flooding.

NATURAL RESOURCES PROJECT STATEMENT

1. GRCA-N-66 Radionuclide Assessment of Colorado River and Tributaries

2. Statement of Issue or Problem

Radioneuclides are of concern in Grand Canyon National Park because of uranium mining activities in the park vicinity and the potential for naturally high radionuclide activity. The Colorado Plateau was the center of uranium mining activity in North America during the 1950's and 1960's and recent discoveries have rekindled interest despite a depressed uranium market.

Many uranium mills and mines have historically operated in the Little Colorado River watershed east of Grand Canyon. One mine, the Orphan Lode, was intermittently operated for over half a century in the Horn Creek watershed just two miles northwest of Grand Canyon Village. Currently two active mines, Hack Canyon and Pidgeon, are operating in the Kanab Creek watershed north of the park. There is much more exploration in the Kanab Creek vicinity and south of the park on the Hualapai Reservation.

In 1979 a tailings dam at the Churchrock Mine failed spilling 3,300 tons of solid mine waste and 300 acre feet of water into the Rio Puerco. This spill caused considerable concern for the health of humans and livestock that obtain drinking water from local aquifers adjacent to Rio Puerco and Little Colorado River. Both gross alpha and beta emissions were found to be well in excess of Arizona surface water quality standards at Chambers, Arizona, approximately 30 miles downstream of the spill. Residue from the spill apparently did not reach Grand Canyon, 350 miles downstream, or was substantially diluted. Six sediment samples collected from Little Colorado River in the park in June 1980 contained only background levels of thorium-250. Another sediment sample collected in 1981 and analyzed for four radionuclides also showed only background levels.

Concerns were again raised in 1983 when gross alpha and gross beta emissions regularly exceeded Arizona water quality standards at both Chambers and Cameron (60 miles upstream of Grand Canyon National Park). It was found that discharge from the Churchrock Mine regularly exceeded limits prescribed in its discharge permit. There are also several other potential sources of contamination much closer to Cameron and Grand Canyon. Runoff from several abandoned uranium quarries near Cameron are suspected to be the source of high levels of radionuclides measured there. Samples of the runoff from these quarries have recently been collected but the results of their analysis by Arizona Department of Health Services are not yet available.

Whether this contamination is reaching Little Colorado River inside Grand Canyon National Park has not been deterined. No samples of water or sediment have been collected for radionuclide analysis since 1981, when Tunnicliff and Brickler found only background levels of radiation.

If radionuclide contamination is now reaching the park its greatest threat is to fish and wildlife species that inhabit Little Colorado River. Of particular concern is the endangered humpback chub which is known to spawn at the confluence of Little Colorado and Colorado Rivers. The threat to hikers and boaters is reduced because of their brief exposure.

Baseline radionuclide data from the numerous water sources in Grand Canyon is very limited. Twenty-four sources have been analyzed for at least least one radionuclide parameter. In all but two cases, analysis has included only dissolved uranium. Paria River has been analyzed for radium-226 in addition to uranium. More complete analysis of Colorado River has included potassium-40, uranium, radium-226, gross alpha, gross beta, hydrogen-3, and tritium. No radionuclide levels have been found approaching Arizona drinking water standards or exceeding U.S. Public Health Service drinking water recommendations.

This does not mean that all Grand Canyon waters can be considered safe for consumption with respect to radionuclides. An analysis for dissolved uranium can hardly provide a complete representation of radionuclides in a water source. Short of extensive analyses for several radionuclide parameters, which are very costly, the best overall representation of radionuclide status is provided by gross alpha and gross beta emissions. These parameters can be compared against established standards to determine the need for more extensive analysis.

3. Alternative Actions and Their Probable Impacts

a. Begin a Program of Radionuclide Monitoring. Samples will be collected from all sources with a high potential for contamination. Analysis will be performed for a wide spectrum of radionuclide parameters.

Impacts. Hazards and contamination most certainly will be identified. If high levels of radionuclides exist, mitigation could be initiated soon.

b. No Action. Do not sample for radionuclides.

Impacts. Potential hazards and contamination will go undetected. Fish and wildlife species may receive unhealthful radiation doses.

4. Recommended Course of Action.

Alternative a. is recommended. Radionuclide analysis could be included in project for chemical water quality inventory and monitoring. Gross alpha and gross beta emissions will be measured whenever chemical analyses are performed. Levels of these parameters will indicate the need for more extensive analysis.

NATURAL RESOURCES PROJECT STATEMENT

1. GRCA-N-56 Chemical Water Quality Inventory and Monitoring

2. Statement of Issue or Problem

The goal of chemical water quality analysis of Grand Canyon water sources is to document the baseline water quality of all commonly used water sources so that threats to human health can be identified and mitigated, and natural systems can be maintained. Additional understanding of the hydrogeologic and biotic systems affecting chemical water quality gained through an analysis program will be useful in development of future monitoring, mitigation of water associated problems, and identification of sensitive resources.

Chemical water quality is a concern in Grand Canyon for three primary reasons. First is the protection of public health. Most palatable waters in Grand Canyon and some which are only marginally palatable are sources of drinking water for backcountry users. Many are also used for swimming, wading, and other forms of contact recreation.

Naturally occurring chemical concentrations will be maintained even if they exceed federal and state water quality standards and pose a threat to health. These hazards would be mitigated through informing the public.

High concentrations of naturally occurring dissolved minerals typical of some Grand Canyon waters can cause a variety of health problems in humans. These vary from minor inconveniences, such as bad taste caused by iron or sulfate irons, or a laxative action caused by the combined presence of several common ions, to more severe toxic reactions caused by high concentrations of arsenic or aluminum.

Secondly, maintenance of natural ecosystems is a major water resources management concern in the park. Deviations from the naturally occurring water quality regime will negatively affect aquatic and riparian processes. Fortunately most small watersheds in Grand Canyon are contained within the park and are relatively unaltered. However, large watersheds extending out of the park are subject to a variety of uses. Creeks from these large watersheds should be monitored periodically to identify possible changes. This will require reliable baseline data and a monitoring design which is sufficiently intensive to assess future conditions. Streams included in this category are Havasu Creek, Kanab Creek, Paria River, and Little Colorado River.

The third reason is acquiring basic knowledge in chemical water quality. The geologic and topographic nature of the Grand Canyon vicinity offers a unique opportunity to study many aspects of ground water circulation. Aquifiers are isolated by topography, structure, and impermeable rock strata which allow study of water budgets, structural control of ground water flow, and ground water residence time and its effects on water quality. Much of the baseline chemical water quality data gathered to date has much been provided by researchers exploring these areas. An understanding of the hydrogeology of the area also provides a valuable insight into water quality regimes and is invaluable in prescribing management actions and developing priorities. Because an improved volume of

basis knowledge in this area is desirable, research efforts should be provided with logistical, informational, and monitory support whenever possible.

The Water Resources Management Plan identifies 68 water sources for sampling. Only 14 sources have been analyzed sufficiently to characterize baseline chemical quality. Data is insufficient to charterize 32 of the water sources and the remaining 22 sources have yet to be analyzed. Of the sources that have been at least minimally analyzed, over 50 percent have been found to exceed state drinking water standards or United States Public Health Service recommendations for at least one parameter. Fifteen parameters have been found in excess in the sources that have been analyzed.

3. Alternative Actions and Their Probable Impacts

a. Complete Baseline Inventory of Chemical Water Quality and Continue Monitoring. Sampling priorities are identified in the plan. These could be revised as more information becomes available.

Physical parameters to be analyzed included are temperature, flow, and turbidity. Analyis for fifteen common constituents will allow characterization of the basic chemical nature of the water source. Major nutrients determine in part the productivity of a water resource and frequently are affected by activities on a watershed. Many trace elements are toxic even at low concentrations and can also be a useful characteristic for describing a water resource. Analysis for gross alpha and beta particle activity will provide a general assessment of levels of radioactivity. Should either of these parameters approach State of Arizona drinking water standards, further analysis for selected isotopes will be undertaken.

When waters are found to be unhealthful, potentially affected individuals will be notified. They will be advised of the source location, nature of the hazard and its ramifications, and alternative water sources.

A monitoring program of chemical water quality should be initiated once baseline information becomes fairly complete. Water quality problems identified in the baseline inventory will be a prime consideration in the establishment of monitoring priorities. Activities occurring on the watershed or groundwater drainage area indicate the potential for changes in ground water quality and should also be considered, as should the type and amount of use associated with the water resource. Habitat for threatened and endangered species will be a high priority for monitoring. The results of baseline analysis and a more extensive literature review will be used in the identification of parameters to be monitored. These will include parameters most likely to change over time, those which are identified as problems or are likely to become problems, those which have special value for characterizing ground water circulation, and parameters which are inexpensive to analyze.

Impacts. Hazardous water will be identified. Understanding of ground water circulation in Grand Canyon vicinity will be improved. Continued monitoring should identify changes chemical water quality which may impact aquatic and riparian ecosystems on the visiting public.

b. No Action. Do not complete inventory or monitor.

Impacts. Hazardous waters may not be identified. The park will have to rely on outside researchers for water quality data. These researchers will probably have different priorities for sample sites and parameters. Changes in chemical quality will not be identified until subsequent ecosystem changes become obvious. Even then, without baseline data the cause of such changes will be difficult to identify.

4. Recommended Course of Action

Alternative a. is recommended. The baseline inventory of chemical water quality should proceed and be followed by a monitoring program. This will be a long term program with some of the highest priority sources being samples each year. The number of samples collected annually will be dependent on available funding and the cost of analysis which varies with the number and type of parameters examined.

NATURAL RESOURCES PROJECT STATEMENT

1. GRCN-N-74 Hydrogeology of the Kaibab Plateau and Its Relationship to Spring Flow, Water Chemistry and Plant Communities

2. Statement of Issue or Problem

A coordinated and consistant study of all major springs draining Kaibab Plateau, its structural geology, and isolated riparian communities is needed to fully understand the ground water systems draining this feature. Past attempts to compare chemical and hydrolic characteristics of springs draining Kaibab Plateau have relied on disjointed data collected over several years and, therefore, not internally consistent (Huntoon 1974). The relative amount of data collected has also been inconsistant; some springs with several analyses and flow measurements, while others have few or none. With the exception of one study comparing the plant communities at Roaring Springs with those of three other springs (Phillips et. al., 1980), little has been done to examine these isolated and diverse habitats. What has been accomplished has usually been incidental to studies with other focuses.

Kaibab Plateau provides an opportunity to study groundwater systems, water budgets, and the influence of aquifer geology on water chemistry and subsequently riparian vegetation that is probably unique in North America. Its ground water systems are isolated. Rain water and snowmelt quickly percolates into the porous rock layers atop the plateau, but downward percolation is blocked by the impervious Bright Angel shale 2500 feet below the surface. Various geologic structures then confine ground water so that it drains into Grand Canyon through twenty large springs. Nearly all water that infiltrates the surface of Kaibab Plateau can be accounted for as spring flow or evapotranspiration. Additionally, the structural geology of Grand Canyon is much studied and well understood. Plant communities associated with these springs are ideal for studing the effects of water quality and quantity because they are isolated by the extreme aridity of the surrounding land and are virtually undisturbed.

A comprehensive knowledge of hydrologeology of Kanab Plateau will have several benefits for land use planners. The park and Kaibab National Forest manage nearly all of the Kaibab Plateau. All major springs, except Big Springs, discharge into Grand Canyon. Several land use practices can have a profound affect on the quality and quantity of water discharged from these springs. The Forest Service is involved in a comprehensive land management planning effort relys heavily on changes in water yield and quality as criteria for evaluating alternative treatments. The park is also concerned that land treatments on the National Forest not adversely impact springs in Grand Canyon. Results from this study will give both agencies relyable data to use in evaluating alternative land treatments. The basic knowledge of water budgets, groundwater circulation and the influence of water quality on riparian plant communities learned from this study will be applicable to many karstic groundwater systems in the west.

3. Alternative Actions and Their Probable Impacts

a. Study the Hydrogeology of the Kaibab Plateau and Its Relationship to Spring Flow, Water Chemistry, and Plant Communities. Twenty-one springs will be sampled at least twice over a two-year period. Spring discharge will be measured and water samples collected and analyzed for all major constituents and selected trace elements. The vegetation at each site will be studied to determine species distribution and abundance as well as the relationship of water quality and quantity to these plant communities. Special attention will be given to rare or unusual plant species. Specific groundwater basins on the Kaibab Plateau will be determined for each spring.

Impacts. With improved knowledge of the relationship between riparian vegetation and spring flow and quality the park will be better able to assess the impacts of water withdrawals for domestic use on the canyon rims and watershed treatments on the Kaibab Plateau. Flow and water quality information will supplement the parks water resources inventory (see Project Statements N-59 and N-56). Other land uses on surrounding areas will be better evaluated. The distribution and habitat requirements of several riparian plant species thought to be rare will be better documented. Several plant species previously undescribed in Grand Canyon could be documented.

b. No Action. The park and National Forest will rely on existing information.

Impacts. Land use practices may be unknowingly undertaken that have a profound influence on groundwater flow and quality. The park may make incorrect assumptions regarding future withdrawals of water from Roaring Springs. The parks information base for spring flow, water quality and riparian vegetation for these springs will remain incomplete.

4. Recommended Course of Action

Implement Alternative a., and initiate a multifacetted study of the hydrogeology of Kaibab Plateau.

NATURAL RESOURCES PROJECT STATEMENT

1. GRCA-N-69 Increase Hiker Awareness of Water Quality Problems

2. Statement of Issue or Problem

Many backcountry and river users are ignorant of microbial activity in natural waters and the potential health hazards present. They wrongly assume natural waters in a wilderness setting to be free of microbial contamination and safe for drinking, swimming or wading. Analysis of waters in Grand Canyon and many other wildland areas clearly show that this is not true. All water sources in the canyon have been shown to be subject to fecal contamination.

Hikers in Grand Canyon can be divided into three groups based on their activities and the information they receive. Wilderness hikers use the most remote portions of Grand Canyon. Few of these areas have toilet facilities and individuals are responsible for their own waste disposal. When these hikers receive permits at the Backcountry Reservations Office (BRO) they receive a copy of Walk Softly, Walk Safely, a pamphlet promoting minimum impact hiking. This pamphlet includes a section detailing a sound method of human waste disposal and care of water resources. Hikers in the more developed cross canyon corridor, where toilet facilities are available, receive Hiking the Bright Angel and Kaibab Trails. This is a smaller pamphlet that mentions toilet locations but does not include encouragement to use these facilities nor caution against drinking untreated stream water.

Day hikers are the most uninformed of all backcountry users and have the greatest potential for improper disposal of human wastes and contacts with contaminated waters. The only practical way to inform these hikers is with trail and toilet signing. They should be informed of the location of toilet facilities and that they are expected to use them.

Many improper waste disposal problems can be avoided by informing hikers of toilet locations so that they can plan accordingly. They should be informed that all natural waters are probably contaminated and should be treated before drinking. This is of particular importance at Cottonwood Campground where no ranger is on duty and the potable water system is shut off during winter months. Campers then are forced to collect water from Bright Angel Creek. Illnesses have occurred among campers drinking untreated Bright Angel Creek water.

To minimize hiker impacts on water quality and to mitigate existing water quality hazards several actions need to be undertaken. Most of these involve a minor enhancement of existing information sources.

3. Alternative Actions and Their Probable Impacts

a. Increase Hiker Awareness of Water Quality Problems. Several actions will be taken to better inform the differing types of backcountry users of water quality hazards, ways to avoid them, and proper methods of human waste disposal. In each case the vehicle to provide this information already exists and it will be a relatively simple task to implement these actions.

Discussions of water hazards and drinking water treatment in the pamphlet given to wilderness hikers will be expanded to include giardiasis, specific water treatment recommendations, and water contamination from animals. The results of proposed research into methods of drinking water treatment will be necessary to make these recommendations (see project statement N-52).

For corridor hikers the pamphlet Hiking the Bright Angel and Kaibab Trails will be revised soon to accommodate changes in the backcountry reservations system. This revision will also include a caution presenting potential water quality hazards, clearly mentioning the location of toilet facilities and drinking water sources and encouraging their use.

New information signs have been installed at most trailheads. They provide fairly complete information on campsite locations, trails, sources of water, hazards, permits, and water treatment precautions. This type of sign will be installed at the remaining trailheads including corridor trails. Multilingual signing will help foreign visitors understand sanitation procedures. Signs cautioning hikers at Cottonwood Campground to treat Bright Angel Creek water will be installed, at least when the water system is shut off.

Informative displays in the Backcountry Reservation Office will be used to inform wilderness hikers of water sources that may be unsafe to drink due to chemical concentrations. The health implications of drinking or contacting these waters will be presented along with alternative water sources.

Impacts. Incidents of improper human waste disposal due to ignorance will be decreased, as will the resulting water contamination. Hikers will be more aware of the need to treat their drinking water. This should result in a reduction in the occurrence of enteric disease in the backcountry. Increased awareness will also help hikers avoid enteric diseases outside the park.

b. No action. Existing information sources will be maintained.

Impacts. Levels of improper waste disposal will remain near current levels varying somewhat with use. Through ignorance many hikers will contract enteric diseases from drinking untreated water.

4. Recommended Course of Action.

Alternative a. is recommended to increase hiker awareness of water quality problems.

NATURAL RESOURCES PROJECT STATEMENT

1. GRCA-N-57 Lower Canyon Water Quality Monitoring Diamond Creek to Lake Mead

2. Statement of Issue or Problem

Baseline bacterial and chemical water quality information has not been collected for the portion of Colorado River between Diamond Creek and Grand Wash Cliffs (52 river miles). Increasingly heavy unregulated use and a lake environment suggest that water quality here may differ substantially from that of the remainder of the river corridor.

Recreational use of lower Grand Canyon has increased greatly in recent years and is expected to increase even more in the near future. Commercial river trips which used to take out at Diamond Creek now continue on to Pierce Ferry on Lake Mead because of the Hualapai Tribe's take-out fees at Diamond Creek. These trips spend one or two more days travelling on the river. The Hualapai Tribe now also offers three day trips on this portion of the Colorado. Increasingly numerous pleasure boats travel up from Lake Mead into Lower Grand Canyon visiting several attraction sites and camping on beaches. Most craft can travel upstream as far as Separation Canyon (river mile 239) before encountering strong currents and rapids. Jet boats and some motorized inflatables can continue upstream for 14 more miles to Diamond Creek.

3. Alternative Actions and Their Probable Impacts

a. Perform Baseline Water Quality Analysis of Lower Colorado River in Grand Canyon. This analysis will emphasize bacterial quality of surface waters and bottom sediments. Chemical analysis of Colorado River and tributary streams will be included.

Impacts. Park management will be made aware of any differences in water quality in the Lower Colorado and other portions of the park. Threats to visitor health will be more accurately assessed. Baseline data will allow future water quality degredation, caused by expected large increases in use, to be identified.

b. No Action. Assume water quality information collected in other areas of the park is applicable here.

Impacts. This assumption may be faulty and significant health threats may go undetected. It will be impossible to detect future degredation without baseline data.

4. Recommended Course of Action.

Alternative a. is recommended to perform baseline water quality analysis. Procedures of water quality analysis on this river segment should be similar to analysis successfully completed in the remainder of the river corridor. Slight modifications may be necessary to accomodate differing use patterns and the lake environment. Indicator bacteria populations in surface waters and bottom sediments should be examined as well as selected

physical and chemical parameters. A chemical water quality inventory of backcountry water resources can easily be combined with this research. This will involve collection of accurate flow measurements and stabilized water samples for later analysis. This inventory of bacterial water quality in lower Grand Canyon can be accomplished as an independent project or as a simple extension of research and monitoring efforts which would normally terminate at Diamond Creek. Monitoring should be repeated at five year intervals until use patterns stabilize and the dynamics of bacterial concentrations in this area are understood.

NATURAL RESOURCES PROJECT STATEMENT

1. GRCA-N-71 Fish Tissue Analysis

2. Statement of Issue or Problem

Fish tissue analysis will be valuable in examining two water quality concerns in Grand Canyon; radionuclide contamination of Little Colorado River and the safety of sportfish for consumption. Several incidents of radionuclide contamination of Little Colorado River have been documented upstream of Grand Canyon. But the very limited sediment analyses conducted in the park have indicated only background levels if radionuclides. No radionuclide sampling has been done at Little Colorado River since 1981. Arizona Game and Fish Department has expressed concern for the endangered humpback chub, which are only known to breed at the confluence of Little Colorado and Colorado Rivers. They recommended collection of several carp, suckers, and catfish to be examined for tumors and analyzed for radionuclides and heavy metals. These species are bottom feeders and as such would be exposed to toxic substances contained in sediments. They are also high in the food chain and subject to biological concentration of some substances.

Colorado River through Grand Canyon and several of its tributaries are renowned trophy trout fisheries. Anglers catch thousands of pounds of rainbow, brown, and brook trout annually. Though mean heavy metals concentrations in Colorado River meet Arizona drinking water standards, single samples have exceeded standards for cadmium, silver, and lead. It is unknown whether these metals are being concentrated through the trouts food chain making the fish unsafe for consumption. Collection of several fish from the river and tributaries and performing tissue analysis is the simplest way to asceratin their suitability for consumption.

3. Alternative Actions and Their Probable Impacts

a. Examine Fish Collected from Park Waters for Tumors and Analyze Tissue for Radioneuclides. Carp, suckers, and catfish will be collected from Little Colorado River. Their tissue analysis will also include heavy metals. Trout tissues will be analyzed for heavy metals, radionuclides and selected organic contaminates. Trout will be taken from Colorado River and some tributaries.

Impacts. The extent to which chronic radionuclide contamination of Little Colorado River has accumulated in fish living there will be determined. This information will guide the park's efforts to have sources of radionuclide contamination identified and corrected.

The suitability of trout from these waters for consumption will be ascertained. If problems are identified measures can be taken to correct them or advise fishermen against consuming these fish.

b. No Action. Do not sample fish tissue.

Impacts. A situation detrimental to the only remaining population of humpback chub below Lake Powell will remain undetected. Fishermen will continue to catch and consume fish which may be unhealthful.

4. Recommended Course of Action.

Alternative a. is recommended to collect fish tissue for analysis.

NATURAL RESOURCES PROJECT STATEMENT

1. GPCA-N-73 Impacts of Water Withdrawals on Streamflow, Water Temperature, and Fauna of Bright Angel Creek

2. Statement of Issue or Problem

Water withdrawn from Roaring Springs provides the domestic supply for all major developments within the park and demand for this water is increasing. Concern that these withdrawals were impacting the flora and fauna of Roaring Springs and Bright Angel Creeks lead to a recently completed study (Usher et. al., 1984). Several impacts of water withdrawal were identified including the potential loss of unique plant species in the immediate vicinity of Roaring Springs, a reduction in stream width, depth, and velocity which could, in turn, alter the creek's temperature regime, and a slight increase in specific conductivity. Of these, the alteration of the water temperature regime is the most severe potential impact. Aquatic plants and to a greater extent aquatic macroinvertebrates (predominately insects) can be profoundly affected by changes in water temperature. Impacts to these organisms at the base of the food chain could affect virtually all aquatic organisms.

The impacts identified by Usher et. al. could have been stated more positively had this study not been handicapped by several factors. First, neither Roaring Springs, Roaring Springs Creek, or Bright Angel Creek are gauged. The relative amount of water currently withdrawn and the examination of increased withdrawals were based on estimations, a very few stream flow measurements, and some questionable assumptions. Before the impacts of water withdrawals can be adequately assessed, these streams must be accurately gauged and long-term records kept. Secondly, only immature aquatic insects were collected. These can only be identified to genus, thus limiting their usefulness as indicators of impacts. Adult insects need to be collected using light traps and identified to species to take full advantage of these valuable indicators. And thirdly, water temperature measurements were taken only when researchers were in the field. Because water temperature is probably the parameter most sensitive to water withdrawals future studies should monitor it continuously.

The aquatic fauna, flow, and temperature regimes are even less understood in other Grand Canyon creeks. Few adult insects have ever been collected and identified to species. The unique nature of many canyon water sources and their isolation suggests unique aquatic invertebrate populations and previously unreported species. Collection of accurate baseline flow data would be complimentary to the expanded water resources inventory presented in project statement N-59.

Water consumption on both canyon rims often exceeds the parks pumping capabilities. Water stored during the winter and used to make up pumping deficiencies during the peak use season. Pump and pipeline improvements are currently being planned or are under construction to increase pumping capacity. As yet, none of these improvements will result in increased withdrawals from Roaring Springs and discharge into Garden Creek. But, it is only a matter of time before increased demand leads to proposals to withdraw more water from the canyon.

3. Alternative Actions and Their Probable Impacts

a. Study the Impacts of Water Withdrawals on Flow Volume, Water Temperature, and Aquatic Invertebrates. Permanent staff gauges will be installed on Roaring Springs and Bright Angel Creeks. These will be calibrated and read routinely. Submersible recording thermographs will be installed at a minimum of four locations along the creeks. These will be maintained to record water temperature for at least one year. Adult aquatic insects will be captured using light traps and identified to species. Subadults will also be collected and compared with adults to identify subadults to species. Population densities will be determined by quantitative sampling of aquatic macroinvertebrates with artificial substrates. The relationship of temperature to flow can be verified when withdrawals through the transcanyon pipeline are suspended. This can be expected to occur several times annually when the pipeline is shut down for repairs.

At least one other tributary creek similar to Bright Angel Creek will be gauged, instrumented, and sampled although at a lesser intensity. This will provide a control and expand our basic knowledge of streamflow and temperature characteristics and aquatic macroinvertebrate populations.

Impacts. The park will have a much better understanding of the impacts of current water withdrawals and will be able to predict the impacts of future withdrawals with greater certainty. The flow and temperature regimes and aquatic macroinvertebrate fauna of each studied creek will be much better understood.

b. No Action. Further studies of water withdrawal impacts will not be undertaken.

Impacts. The park will have to rely on the existing study and intuition as a basis for making decisions regarding future withdrawals from Roaring Springs. The existing study does not contain adequate quantified data to withstand scrutiny from those wishing to increase withdrawals from Roaring Springs.

4. Recommended Course of Action

Implement Alternative a. to further study the impacts of water withdrawals from Roaring Springs.

NATURAL RESOURCES PROJECT STATEMENT

1. GRCA-N-4 Intensive Microbial Analysis of Selected Tributary Creeks

2. Statement of Issue or Problem

Bacterial analysis of most tributary water sources in Grand Canyon has consisted of a very few samples collected at irregular and widely spaced intervals. While this sampling pattern has provided conclusive evidence that all canyon waters are subject to fecal contamination, it provides little insight into the extent of contamination and variation with respect to time, location, human activities, and natural events. Collection of more samples in this haphazard manner will provide little more information than is already known.

Future bacterial analysis of tributary creeks in Grand Canyon's backcountry needs to be done in a more intensive manner. Depending on local conditions, intensive sampling will include several samples a day, collected at several locations along the water source and different seasons through the year. This will allow a more complete characterization of individual water sources and natural and human induced factors affecting them. A sampling schedule will be designed which will examine bacterial concentrations and their diurnal and seasonal fluctuations and changes attributable to hiker and livestock activities, runoff events, and stream flow. Most hiker activity is not distributed uniformly along tributary creeks. Simultaneous sampling of several locations along each study creek will allow an assessment of the impacts of this activity.

3. Alternative Actions and Their Probable Impacts

a. Intensively Analyze the Microbial Water Quality of Selected Tributaries. Numerous samples will be collected of surface waters and bottom sediments, and analyzed for fecal bacteria. The sampling schedule will allow statistical identification of variations in bacterial concentrations and the parameters which influence those variations.

This intensive sampling program should not be initiated with the intent of examining every backcountry water source. Instead representative waters should be selected with an intent to characterize the bacterial water quality regime of various types of canyon waters and quantify the impacts of natural and human influences. This information will be valuable in mitigating existing contamination and modifying human or livestock acitivities to reduce levels of contamination.

Representative creeks will be selected by examining the following criteria:

1. Characteristics of the surface watershed and groundwater basin
2. Chemical water quality
3. Amount and variability of flow
4. Geologic strata from which source springs arise
5. Human activities on the watershed

The remoteness of backcountry areas and cost of helicopter transportation necessitate stationing a laboratory and personnel in the field for several days of sampling. This will require a specialized field laboratory capable of reliably operating for several days without resupply. Procedural constraints require some analysis to be performed in the field, i.e. bacterial, flow and unstable chemicals, while some samples may be collected and preserved for later analysis of more stable parameters. All analysis will be performed in accordance with accepted laboratory procedures.

Impacts. The microbial water quality regime of tributary creeks will be much more clearly understood. This understanding will allow park management to take actions to reduce contamination or alter use patterns so contaminated water is avoided.

b. Continue to Monitor Creeks on an Intermittent Schedule. Single samples will be collected from several tributary creeks as funds are available. The emphasis will be to sample as many heavily used creeks as possible.

Impacts. A considerable expense will result in little more information. Resources committed to this type of sampling effort will not be available for more valuable projects. Changes in bacterial quality may be detected.

c. No Action. No bacterial quality analysis is undertaken. The park will rely on existing information.

Impacts. Most management based on existing information will be appropriate. Changes in bacterial water quality will be undetected. Some actions may be taken based on faulty assumptions of the source as well as extent and dynamics of bacterial contamination.

4. Recommended Course of Action

Alternative a. is recommended to intensively analyze the microbial water quality of selected tributary creeks.

NATURAL RESOURCES PROJECT STATEMENT

1. GRCA-N-25 Stock Tank Inventory

2. Statement of Issue or Problem

Several areas of the park are or were legally grazed. Though livestock have been removed from most of the park and the remainder of permits are legislated to be terminated in 1985, numerous earthen stock tanks and spring developments remain. All have not been inventoried but some are known to hold water and attract trespass grazing. This is particularly prevalent on the Kanab Plateau which remains unfenced. Old stock tanks and trespass grazing are also common along the South Rim and Pasture Wash. Boundaries are fenced in these areas but the fence is often in a state of disrepair. The Sanup Plateau and hook areas of the park are currently being grazed under permits extended to the end of 1984 by the Grand Canyon National Park Enlargement Act. Several functional stock tanks support grazing in these areas and will continue to attract trespass grazing after permits terminate as both areas are completely unfenced.

These stock tanks attract not only trespass livestock but also native wildlife. Tanks which hold water are often the only water sources for several miles and probably support unnaturally large wildlife populations. Wildlife may overuse an area because of overpopulation or because they remain in the vicinity of a stock tank long after they would normally have moved on in search of water. Both situations are undesirable.

The existence of stock tanks has been essentially ignored in the past. Little is known of the number, location or condition of stock tanks in the park. Without more knowledge of the extent of wildlife dependence on these water sources, the best methods and timing of removal cannot be determined. Some stock tanks or springs may have certified alien water rights acquired by ranchers when the area was legally grazed.

3. Alternative Actions and Their Probable Impacts

a. Develop a Plan to Eliminate Stock Tank Impacts. All stock tanks in the park will be inventoried. This will be accomplished using aerial photographs, topographic maps, and allotment maps. Each tank will be visited and assessed for its ability to hold water, attract trespass livestock, and support wildlife species. Alternative actions include allowing tanks to gradually fill with sediment or breaching earthen dams. If dams are breached this should be done during a season when it will have minimal impacts on wildlife. If tanks are allowed to fill slowly, boundary fencing in that area will become a higher priority because the filling process will require many years. Removal of stock tanks may require preparation of an environmental assessment. The Arizona Game and Fish Department and wildlife biologists with Kaibab National Forest and the Arizona Strip District of the BLM can provide assistance in assessing the reliance of wildlife on stock tanks.

Impacts. Removal of stock tanks might lower wildlife populations to more natural levels and lessen trespass grazing. Animals dependent on existing

stock tanks will suffer from lack of water but proper timing tank removal will minimize this impact. Dependent livestock and wildlife will be forced to seek water elsewhere possibly increasing their impacts outside the park at least temporarily. Vegetation and soils in the vicinity of functional stock tanks will recover to a more natural state.

b. No Action. Do not inventory or remove tanks.

Impacts. Trespass grazing and increased wildlife populations will continue on park lands. Most stock tanks will eventually fill with sediment or breach during floods, but this can take many decades.

c. Allow Tanks To Gradually Fill with Sediment and Fence Boundaries near Them. All stock tanks in the park will be inventoried. Boundaries near tanks capable of holding water will be fenced. Fencing will be of a design that allows passage by wildlife while excluding livestock.

Impacts. Trespass grazing will continue to occur until fences are constructed and maintained. Unnatural wildlife populations will continue until tanks fill. Once fences are in place the impacts of trespass grazing will diminish.

4. Recommended Course of Action.

Alternative a. is recommended. Before substantial resources are committed to a program of stock tank removal or fencing, the scope of the problem should be identified and all of the alternatives explored. Once this is done the solution will probably involve some combination of breaching, fencing, and no action. Boundary fencing is expensive and often passed over in lieu of higher priorities, making alternative c. practically a no action alternative, at least in the short term.

NATURAL RESOURCES PROJECT STATEMENT

1. GRCA-N-51 Colorado River Water Quality Modeling

2. Statement of Issue or Problem

Monitoring Colorado River bacterial quality now requires the use of specialized river rafts and a self contained water laboratory, which the park does not possess. Another method is helicopter transport of samples, which is prohibitively expensive considering the number of samples necessary for statistically viable results. Development of a model which would allow bacterial water quality of Colorado River to be predicted by analyzing very few easily accessible locations would result in a considerable savings of time and expense.

Research by Tunnicliff and Brickler suggests that bacterial water quality of Colorado River is primarily a function of inputs from Glen Canyon supplemented by flooding tributaries, primarily Paria River and Little Colorado River. Both these tributaries drain large watersheds outside the park containing highly erodable soils. They are subject to frequent flooding contributing large amounts of sediment and associated bacteria to the Colorado. Numerous smaller tributaries also occasionally flood but these are relatively rare and short term events. A model characterizing Colorado River water quality can be developed by examining these inputs intensively. Such a model will allow the bacterial quality of remote portions of Colorado River to be quickly and economically predicted by collecting samples at easily accessible locations at Paria River, Little Colorado River, and Lee's Ferry. When conditions indicate a high probability of contamination special warnings will be given to river runners and backpackers. Potentially, this model could predict that hazardous conditions are so likely whenever tributary creeks are flooding that warnings should be issued even if Paria and Little Colorado rivers are not sampled.

3. Alternative Actions and Their Probable Impacts.

a. Develop a Model for Predicting Bacterial Quality of the Colorado River. This model will be developed using inputs from the mainstream Colorado and significant tributaries.

Impacts. Bacterial conditions along remote portions of Colorado River will be assessable without expensive river trips or helicopter sampling. The greater understanding provided by this study will allow the park to more accurately inform river users of water quality conditions.

b. Continue to monitor Colorado River Water Quality with Laboratory Rafts. Equipment and methods used for previous monitoring will be repeated.

Impacts. In the long term monitoring costs will be much greater. Accuracy of raft trip monitoring is probably greater than that obtained with a model.

C. No Action. No bacterial water quality monitoring of Colorado River.

Impacts. Water quality degredation of the Colorado River will go undetected. Factors affecting Colorado River water quality will not be fully understood. The park will have to assume that existing knowledge remains valid.

4. Recommended Course of Action.

Alternative a. is recommended to develop a model for predicting bacterial quality of the Colrado River. The model should be checked every 7-10 years.

NATURAL RESOURCES PROJECT STATEMENT

1. GRCA-N-65 Fecal Streptococcus Species Identification in Garden and Bright Angel Creeks

2. Statement of Issue or Problem

There is concern that mule feces are contaminating streams adjacent to some inner canyon trails. Bright Angel and Garden Creeks are the most heavily used inner canyon watersheds. Day hikers, overnight campers, and mules all use the trails, campgrounds and other facilities in this cross-canyon corridor. Mule feces and urine are common on Bright Angel and North and South Kaibab trails. These wastes are aesthetically disturbing and present a potential health hazard. Trails, corrals, and hitching areas are very near streams and drainages where surface runoff can easily carry feces into the creeks. Bacterial analysis of Bright Angel and Garden Creeks have regularly shown the presence of fecal contamination. Fecal coliform/fecal streptococcus (FC/FS) ratios from past analysis of these waters have indicated a non-human source of contamination. In most other canyon waters where domestic livestock do not occur, similar FC/FS ratios would strongly incidate wildlife as the major source of contamination. Without speciation of streptococcus bacteria it is not possible to differentiate contamination from livestock and wildlife.

Species Identification of FS bacteria will allow more definitive identification of the source of fecal contamination in Bright Angel and Garden Creeks. Each group of warm blooded animals maintains a characteristic species of streptococcus bacteria in its digestive tract. Through a series of laboratory procedures these species can be differentiated.

If mules are clearly shown to be contaminating these heavily used creeks, special mitigating measures will be considered. Options include moving corrals and hitching areas, constructing diversions so that runoff from corrals is directed away from creeks, warning visitors and restricting their use of these creeks, and restricting or eliminating mule use on these trails. Some of these actions may require NEPA compliance.

3. Alternative Actions and Their Probable Impacts

a. Determine the Fecal Streptococcus Species Present in Garden and Bright Angel Creeks. Two samples will be collected from at least two sites on each creek. Samples will be collected three times through a year with at least one sample during the heavy use season, one sample during light use, and one sample during or after storm runoff.

Impacts. The park will be able to determine the relative extent of mule, human, and wildlife contamination of these waters. The extent of contamination attributable to mules will indicate whether mitigating action is needed.

b. No action. Do not identify fecal streptococcus species.

Impacts. Fecal contamination will not be determined. The need for mitigating measures will not be fully determined. Actions may be taken which are not needed, and needed actions may be neglected.

4. Recommended Course of Action.

Alternative a. is recommended to determine fecal streptococcus species present in Garden and Bright Angel Creeks.

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APPENDIX A

Development/Study Package Proposals (10-238's)

FORM 10-238
(REV. 1-76)

UNITED STATES DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE

DEVELOPMENT/STUDY PACKAGE PROPOSAL

PACKAGE NO. 452
REVISION NO.

ORG NO	PARK (OR OTHER ORIGINATOR)	DEVELOPED AREA (NAME)	D A CODE	REGION
8210	Grand Canyon	Park General	PG	Western

STATE	STATE CODE	COUNTY(S)	CONGRESSIONAL DISTRICT
Arizona	04	Coconino-Mohave	03

PACKAGE TITLE: IMPLEMENT PARK WATER RESOURCES PLAN

STUDY PACKAGE [ ]
NEW CONSTRUCTION B [ ]
REHABILITATION A [ ]
NEW PACKAGE [ ]
REVISION [ ]

CRITERIA (INSERT X's)	PARK PRIORITY	DATE	REG'N PRIORITY	DATE

PROGRAM THRUST, STATUS AND OTHER INFORMATION

WILL ADDITIONAL OPERATING FUNDS AND POSITIONS BE NEEDED UPON COMPLETION OF THIS PACKAGE?
(IF YES EXPLAIN NEEDS IN SECTION XI OUTLINE OF PLANNING AND MANAGEMENT REQUIREMENTS)
YES [ ]
NO [ ]

FULL PACKAGE DESCRIPTION **Grand Canyon is completing a Water Resources Management Plan that identifies 16 projects necessary to meet Grand Canyon resources preservation and legislative mandates. One GS-7 Park Technician will complete park projects and provide professional input on contract projects. Immediate projects identified in the Water Resources Management Plan are (1) conduct flood hazard analysis at 3 locations, (2) provide information to increase hiker awareness of water quality problems and flood hazards, (3) conduct testing for fecal streptococcus speciation, (4) inventory/quantify park water rights, (5) complete water quality overview, (6) devise a water conservation plan which includes metering and flow controls, and (7) develop a decision criteria for water sales.**

PACKAGE JUSTIFICATION CONSEQUENCES **Water resources in GRCA are a major concern for two reasons: (1) maintenance of aquatic and riparian ecosystems and (2) public health and safety. The park was established to preserve and protect natural resources including water resources. Water resources of GRCA are threatened by management practices on adjacent lands including: mining, grazing, agriculture, and flood control. In addition, compliance with state water quality laws, the Clean Water Act, Safe Drinking Water Act and Executive Order 11988 on floodplain development are required in all park activities. This position would be responsible for carrying out all water resources projects and ensuring compliance with applicable laws and policy.**

PLANNING AND MANAGEMENT REQUIREMENTS *(Follow instructions and outline provided in Program Formulation Guideline)*

-SEE ATTACHED-

ORIGINATOR (Sign, Type and Title)	DATE	CONCURRENCE (Signature of next superior of originator)	DATE
Steve Hodapp Chf Resources Mgt	3/15/84	Richard Clarke	3/15/84

APPROVAL (Signature of Regional Director or Equivalent Official)

PLANNING AND MANAGEMENT REQUIREMENTS: Package No. 452

Available Information: All park records and reports have been analyzed during development of the Water Resources Management Plan. Analysis indicate only 50% of park water sources have been inventoried, only 20% of the commonly used sources have been analyzed, only one of four required flood hazard studies have been completed and review of water conservation measures has been minimal.

Project Type: Monitoring 80

Mandated Projects: Project is mandated by Clean Water Act, Arizona Water Quality Act, Safe Drinking Water Act, Executive Order 11988 on Floodplain Management, Public Law, 95-586, and NPS policy.

Park Resources: Water is a critical resource to visitors, wildlife, and riparian and aquatic vegetation in the arid canyon environment.

Immediacy: Action is necessary to protect park water sources from ongoing threats and to resolve immediate visitor health and safety concerns.

Magnitude: Sixteen separate projects are identified in the park's Water Resources Plan. Time required to complete the individual projects varies from several months to several years.

Health/Safety: There are several projects which will contribute to visitor health and safety including: flood hazard identification, studies of backcountry water treatment methods, studies of water quality, and radioneuclide surveys.

Scope of Contribution: The benefits from this project will be directly towards park visitors and park water resources and associated aquatic ecosystems.

Data Collection: The primary purpose of this project is the collection, organization, and analysis of baseline data.

Cost:

FY1	$22,000
FY2	$23,000
FY3	$24,000

Funding/Staffing Commitments: Existing funding and program emphasis is sporadic and receives only part-time attention from largely untrained staff.

Other Funding Sources: n/a

Benefits of Immediate Funding: Funding for this project will promote visitor health/safety and protect park water rights.

FORM 10-238
(REV. 1-76)

UNITED STATES DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE

DEVELOPMENT/STUDY PACKAGE PROPOSAL

PACKAGE NO. 448
REVISION NO.

ORG NO	PARK (OR OTHER ORIGINATOR)	DEVELOPED AREA (NAME)	D A CODE	REGION
8210	Grand Canyon	Inner Canyon	IC	Western

STATE	STATE CODE	COUNTY(S)	CONGRESSIONAL DISTRICT
Arizona	04	Coconino-Mohave	03

PACKAGE TITLE: N-59 WATER RES. INVENTORY INCLUDING WATER RIGHTS

STUDY PACKAGE [ ]
NEW CONSTRUCTION B [ ]
REHABILITATION A [ ]
NEW PACKAGE [ ]
REVISION [ ]

CRITERIA (INSERT X s)	PARK PRIORITY	DATE	REG'N PRIORITY	DATE

PROGRAM THRUST, STATUS AND OTHER INFORMATION

WILL ADDITIONAL OPERATING FUNDS AND POSITIONS BE NEEDED UPON COMPLETION OF THIS PACKAGE?
(IF YES EXPLAIN NEEDS IN SECTION XI OUTLINE OF PLANNING AND MANAGEMENT REQUIREMENTS) YES [ ] NO [ ]

FULL PACKAGE DESCRIPTION: FY1: The park's water resource inventory will be completed. It was begun in 1979 and needs to be expanded to include western Grand Canyon and Marble Canyon. The inventory will be made throug a literature search followed by onsite examination. Water sources will be evaluated for flow, size, palatability, reliability, associated flora and fauna, source lithology, exact location and use. All information pertinent to water rights status of each source will be assembled and organized. Sources with alien water rights will be inspected to determine exact location and to verify diversion and use. Water sources will be prioritized for obtaining water rights if that becomes necessary. Quantitative flow measurements will be made whenever possible. Graded sections will be established on most perennial streams so flow can be quickly and accurately determined by visual observation.
FY2: Flow measurements and other data collection will continue.
FY3: Same as FY86.

PACKAGE JUSTIFICATION/CONSEQUENCES: The park's water resource inventory and water rights information files are incomplete. This lack of information will make it very difficult to participate in water rights adjudications. Accurate stream and spring flow measurements are almost nonexistant. Approximately 50% of the park remains to be inventoried.

This inventory will provide an information base from which water rights applications and associated studies can proceed. This inventory will be useful in designing other projects such as chemical water quality inventory and monitoring, and in providing information to visitors to western Grand Canyon.

PLANNING AND MANAGEMENT REQUIREMENTS *(Follow instructions and outline provided in Program Formulation Guideline)*

-SEE ATTACHED-

Steve Hodapp Chf Resources Mgt	3/15/84	[signature]	3/15/84
APPROVAL (Signature of Regional Director or Designated Official)			DATE

PLANNING AND MANAGEMENT REQUIREMENTS: Package No. 448

Available Information: Only about 50% of the park has been inventoried. Management decisions in the remainder of the park must be based on incomplete and often inaccurate information gathered from a number of unconsolidated sources.

Project Type: Monitoring 80

Mandated Projects: This project is not currently mandated. Water rights inventory will become a mandated project if Colorado court decisions are applied in Arizona.

Park Resources: Water is a critical resource to visitors, wildlife, and riparian and aquatic vegetation in the arid canyon environment. Water is so scarce immediately outside Grand Canyon that the town of Tusayan must truck water most of the year 60 miles round trip at a cost of $25.00 per 1000 gallons.

Immediacy: Court decisions forcing National Park Service participation in water rights adjudication may be applied in Arizona within the next two to three years. Before that occurs, the park should complete this baseline inventory and information organization.

Magnitude: Approximately 50% of the park remains to be inventoried. This area accounts for less than 15% of the total spring flow in the park but 70% of the existing water rights claims.

Health/Safety: Knowledge of water sources will contribute to the safety of hikers/river runners in these areas.

Scope of Contribution: The benefits from this project will be primarily confined to the water resources and associated ecosystems of Grand Canyon and management of water resources.

Data Collection: The primary purpose of this project is the collection, organization, and analysis of baseline data.

Cost:

FY1	15,000
FY2	4,000
FY3	4,000

Funding/Staffing Commitments: No park base funding exists. Resources Management staff would supervise a seasonal to do field work. Money requested would support seasonal, equipment, and travel.

Other Funding Sources: n/a

Benefits of Immediate Funding: With this inventory completed and water rights information collected and organized, water rights filing and associated studies can be accomplished most efficiently. If this study is not completed before water rights filings are initiated, expensive studies to quantify instream flow requirements will be initiated without complete knowledge of the location, extent or legal status of much of the park's water resources.

FORM 10-238
(REV. 1-76)

UNITED STATES DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE

DEVELOPMENT/STUDY PACKAGE PROPOSAL

PACKAGE NO. 449
REVISION NO.

ORG NO.	PARK (OR OTHER ORIGINATOR)	DEVELOPED AREA (NAME)	D A CODE	REGION
8210	Grand Canyon	Inner Canyon	IC	Western

STATE	STATE CODE	COUNTY(s)	CONGRESSIONAL DISTRICT(S)
Arizona	04	Coconino -Mohave	03

PACKAGE TITLE: GRCA-N-52 FIELD TEST DRINKING WATER TREAT METH

STUDY PACKAGE ( )
NEW CONSTRUCTION B ( )
REHABILITATION A ( )
NEW PACKAGE X
REVISION ( )

CRITERIA (INSERT X's)	PARK PRIORITY	DATE	REGION PRIORITY	DATE

PROGRAM THRUST, STATUS AND OTHER INFORMATION

WILL ADDITIONAL OPERATING FUNDS AND POSITIONS BE NEEDED UPON COMPLETION OF THIS PACKAGE?
(IF YES EXPLAIN NEEDS IN SECTION XI OUTLINE OF PLANNING AND MANAGEMENT REQUIREMENTS) YES ( ) NO ( )

FULL PACKAGE DESCRIPTION

FY1: Water treatment methods with potential applications in Grand Canyon have been identified and tested in the laboratory. Methods most applicable to park waters now need to be field tested. Sediment laden and clear waters from Colorado River and its tributaries will be treated in the field. Some water will have to be innoculated with cultured bacteria concentrations to adequately test methodologies. Each treatment method will be evaluated by the following criteria: (1) ability to supply the daily water needs of large river parties and/or individual backpackers, (2) procedures and equipment that are practical for white water and backcountry transport and schedules, (3) use of readily available equipment and disinfectants at reasonable costs, and (4) achievement of complete inactivation of enteric organisms in park waters regardless of initial sediment load.

FY2: Data analysis and report preparation

PACKAGE JUSTIFICATION/CONSEQUENCES

Drinking water disinfection methods commonly used for wildland waters are rendered ineffective in Grand Canyon because of extremely high sediment loads. Suspended sediment harbors high concentrations of bacteria and inactivates most disinfectants. Hikers and river runners are forced to attempt treatment of sediment laden waters for extended periods with uncertain results.

This project will result in identification of a specific method or methods to consistently and reliably treat sediment laden waters to make them potable. This will result in a reduction of the occurrence of enteric diseases among hikers and river runners.

PLANNING AND MANAGEMENT REQUIREMENTS *(Follow instructions and outline provided in Program Formulation Guideline)*

-SEE ATTACHED-

ORIGINATOR (Signature and Title)	DATE	CONCURRENCE (Signature of Superintendent or Equivalent Official)	DATE
Steve Hodapp Chf Resources Mgt	3/15/84		3/15/84

APPROVAL (Signature of Regional Director or Equivalent Official) DATE

Available Information: A literature search of water treatment methods appliable to wildland waters has been completed. Literature on methods to deal with sediment laden waters is scarce. None of the methods identified are directly applicable to canyon waters without further testing.

Project type: 78 Research

Mandated Projects: There are no specific mandates to engage in research into water treatment methods.

Park Resources: Annually approximately 40,000 hikers and 16,000 river runners collect drinking water in the park. Many river runners and some hikers must rely on water they have treated for 7 to 15 days.

Immediacy: Continued use of ineffective water treatment methods will result in a higher then necessary incidence of enteric disease among backcountry users. No park resources will be irreparably damaged without this action.

Magnitude: Several cases of enteric disease occur annually in Grand Canyon though exact data is not available. These range from severe cases requiring helicopter evacuation to many minor cases which are unreported. Potential exists for epidemics of enteric disease, like the shigella outbreaks of 1972 and 1979. This potential is greatly enhanced during periods of turbid flow.

Health Safety: A major objective of this project is to reduce the incidents of enteric disease among canyon visitors.

Scope of Contribution: Results of this project will be directly applicable to parks where visitors rely on water sources which are occasionally sediment laden. Because heavily sediment laden waters are a worst case situation, the treatment methods identified should be effective in all backcountry waters.

Data Collection: No baseline or monitoring data will be collected as a direct result of this project. Water quality monitoring of Colorado River or selected tributaries can be combined with this project for a small increase in cost (approximately $5,000).

Cost:

FY1	20,000
FY2	8,000

Funding/staffing Commitments: Resources Management Division personnel will be required to develop the scope of work and review progress. They will also be involved in field data collection

Other Funding Sources: n/a

Benefits of Immediate Funding: Researchers have recently completed the literature search and some preliminary laboratory tests of some treatment methods. Immediate funding will make use of this information and research personnel before they become completely commited to other projects or institutions.

FORM 10-2-84
(REV. 1-76)

PAGE ____ OF ____
FOR THIS PACKAGE

UNITED STATES DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE

DEVELOPMENT/STUDY PACKAGE PROPOSAL

PACKAGE NO. 471
REVISION NO.

ORG. NO	PARK (OR OTHER ORIGINATOR)	DEVELOPED AREA (NAME)	D.A. CODE	REGION
8210	Grand Canyon	Inner Canyon	IC	WE

STATE	STATE CODE	COUNTY(S)	CONGRESSIONAL DISTRICT(S)
Arizona	04	Coconino-Mohave	03

PACKAGE TITLE: RADIONEUCLIDE ASSESSMENT OF COLORADO RVR. & TRIB.

STUDY PACKAGE [ ]
NEW CONSTRUCTION B [ ]
REHABILITATION A [ ]

NEW PACKAGE [ ]
REVISION [ ]

CRITERIA (INSERT X'S)	PARK PRIORITY	DATE	REG'N PRIORITY	DATE

PROGRAM THRUST, STATUS AND OTHER INFORMATION

WILL ADDITIONAL OPERATING FUNDS AND POSITIONS BE NEEDED UPON COMPLETION OF THIS PACKAGE? YES [ ] NO [ ]
(IF YES, EXPLAIN NEEDS IN SECTION XI OUTLINE OF PLANNING AND MANAGEMENT REQUIREMENTS)

FULL PACKAGE DESCRIPTION

FY1: Radioneuclids analysis will be included in chemical water quality inventory and monitoring. In addition, special radioneuclide sampling will be undertaken when specific threats are identified. Gross alpha and gross beta emissions will be measured for each sample. If these levels indicate the need for more extensive analysis, specific radioneuclides will be examined. Little Colorado River will be given priority attention due to current concern for mine waste contamination upstream. Samples will be collected from surface waters sediments and fish tissues and analyzed for radioneuclide levels.

PACKAGE JUSTIFICATION/CONSEQUENCES

There are numerous active and abandoned uranium mines on watersheds draining into Grand Canyon. There is concern for contamination from these mines and mills and for naturally high levels of radioneuclides. Several incidents of contaminated mine discharge and a large tailings spill have occurred in recent years in the Little Colorado River watershed. Radioneuclide levels have recently been measured in excess of state standards in water discharging from abandoned mines 70 miles upstream from the park. A mine further upstream regularly discharges water with radioneuclide levels in excess of its NPDES permit. This potential contamination is a major concern in Little Colorado River because it is the only known breeding habitat for the endangered humpback chub in the Lower Colorado River Basin. This project will assess the immediate threat to the humpback chub in the Little Colorado River. It will also provide systematic information about potential human health hazards presented by Little Colorado River or other waters in the park.

PLANNING AND MANAGEMENT REQUIREMENTS *(Follow instructions and outline provided in Program Formulation Guideline)*

-SEE ATTACHED-

ORIGINATOR (Signature and Title)	DATE	CONCURRENCE (Signature of Superintendent or Equivalent Official)	DATE
Steve Hedges Chf Res/Mgt/Plan	12/21/84	[signature]	12/21/84

APPROVAL (Signature of Regional Director or Equivalent Official) DATE

Planning and Management Requirements: Package N. 471

Available Information: Radioneuclide analysis has been very limited in the park to date. These limited analyses have shown only background levels of radiation. Several recent samples of Little Colorado River near Cameron, Arizona by Arizona Department of Health Services have contained radioneuclides in excess of state drinking water standards.

Project Type: 80 monitoring

Mandated Projects: Specific mandates do not exist but the Endangered Species Act requires the park to protect endangered species and their critical habitat.

Park Resources: Water resources in Grand Canyon are extremely valuable to the hikers, boaters and wildlife which obtain drinking water from them. Little Colorado River is the only known breeding habitat for the endangered humpback chub below Glen Canyon Dam.

Immediacy: Contamination of Little Colorado River is currently receiving attention from the State of Arizona and NPS areas upstream. If contamination is reaching humpback chub habitat, it could be reducing chub vigor and productivity and increasing the incidents of tumors. Delays in detection of radioneuclide problems will increase visitor contact with contaiminated waters.

Magnitude: Though past analyses have documented no radioneuclide problems, they have been so limited in scope that it is not possible to assess the magnitude of the problem without baseline information.

Health/Safety: Undetected areas of radioneuclide contamination pose a threat to human health and safety.

Scope of Contribution: Beyond the benefits directly to the park, documentation of contamination of Little Colorado River, or lack of contamination, will assist the State of Arizona in assessing the extent of contamination.

Data Collection: This project expands baseline radioneuclide data for the park.

Cost:

FY1	$4,000
FY2	$2,000
FY3	$2,000

Funding/Staffing Commitments: No park or regional base funding now exists for this work. The park will commit technical expertise and liaison with laboratories and state agencies. Funding is requested for sample transportation and analysis.

Other Funding Sources: Should the problem at Little Colorado River become more urgent the State of Arizona may be willing to fund some water analysis.

Benefits of Immediate Funding: Information collected in Grand Canyon will be valuable and timely for other agencies investigating contamination of Little Colorado River. Collection of fish tissues, and water and sediment samples can be coordinated with Arizona Fish and Game Department humpback chub monitoring in summer of 1984.

FORM 10-929
(REV. 1-76)

PAGE ____ OF ____
FOR THIS PACKAGE

UNITED STATES DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE

DEVELOPMENT/STUDY PACKAGE PROPOSAL

PACKAGE NO. 474
REVISION NO.

ORG. NO.	PARK (OR OTHER ORIGINATOR)	DEVELOPED AREA (NAME)	D.A. CODE	REGION
8210	Grand Canyon	Inner Canyon	IC	WE

STATE	STATE CODE	COUNTY(S)	CONGRESSIONAL DISTRICT(S)
Arizona	04	Coconino-Mohave	03

PACKAGE TITLE: CHEMICAL WATER QUALITY N-56

STUDY PACKAGE [ ]
NEW CONSTRUCTION B [ ]
REHABILITATION A [ ]

NEW PACKAGE [ ]
REVISION [ ]

CRITERIA (INSERT X'S)	PARK PRIORITY	DATE	REG'N PRIORITY	DATE

PROGRAM THRUST, STATES AND OTHER INFORMATION

WILL ADDITIONAL OPERATING FUNDS AND POSITIONS BE NEEDED UPON COMPLETION OF THIS PACKAGE?
(IF YES, EXPLAIN NEEDS IN SECTION XI OUTLINE OF PLANNING AND MANAGEMENT REQUIREMENTS) YES [ ] NO [ ]

FULL PACKAGE DESCRIPTION FY1: Water sources will be sampled and analyzed for major constituents, nutriants, and trace elements. Highest priority for sampling will be given to heavily used sources for which no baseline analysis exists or where limited analysis indicates the water ma be unsafe for consumption. Sampling priorities will be reassessed annually. Once baseline data is gathered for most frequently used water sources a monitoring program will be institute and continued indefinitely. Sample site selection, sample collection, field measurements, and data storage and analysis will be completed by park personnel. Sample analysis will be performed by an independent laboratory. FY2: Same as FY1, continue to inventory and monitor emical water quality. FY3: Same as FY1, continue to inventory and monitor chemical water quality.

PACKAGE JUSTIFICATION/CONSEQUENCES

Of the 68 most used water sources in the park, data is insufficient to characterize the chemic quality of 32 and no data is available for 22 more. Of the sources which have been sampled, 24 (52%) have been found to contain constituents in excess of what is considered safe for drinking by the State of Arizona or U.S. Public Health Service. The park's policy is to mitigate these potential health hazards through informed avoidance. To adequately inform bakccountry users of these potential threats, the park must have a more complete chemical wate quality inventory. Continued monitoring will strengthen the information base and allow for future identification of changes in chemical quality.

PLANNING AND MANAGEMENT REQUIREMENTS *(Follow instructions and outline provided in Program Formulation Guideline)*

-SEE ATTACHED-

ORIGINATOR (Signature and Title)	DATE	CONCURRENCE (Signature of Superintendent or Equivalent Official)	DATE
Stephen Hodapp Chief Res Mgt/Plan	12/21/84	[signature]	12/21/84

APPROVAL (Signature of Regional Director or Equivalent Official) DATE

Available Information: Baseline chemical water qulaity information is adequate for only 14 of the park's 68 most used water sources. Long-term water quality monitoring has been conducted by USGS of 3 of these water sources. A small amount of data is available for another 32 sources, but this is insufficient to reliably characterize their chemical quality.

Project Type: 80 monitoring

Mandated Projects: No specific mandates exist requiring completion of this project.

Park Resources: HIkers and boaters spend about 180,000 user nights a year in Grand Canyon. All of those outside the cross canyon corridor must collect water for drinking. Rivers and creeks in the park are centers for biologic activity.

Immediacy: Hikers and boaters will continue to be unknowingly exposed to unhealthful levels of several chemical constituents.

Magnitude: Fifty-two percent of the sources sampled thus far have been found to contain at least one constituent in excess of what is considered safe for drinking. Considering their source geology and discharge, problem concentrations can be expected to be found more frequently in the more remote waters.

Health/Safety: Proecting the health of backcountry users is the major reason for proceeding with this project. Most of the constituents found excess in park waters can be expected to cause diarrehea and import a fowl taste to the water, but some constituents, such as arsenic, aluminum, and selenium pose more serious health threats.

Scope of Contribution: The value of this project is, for the most part, limited to Grand Canyon.

Data Collection: This project will expand the park's baseline water quality information.

Cost:

FY1	$5,000
FY2	$5,000
FY3	$5,000

Funding Staffing Commitments: No park or regional base funding now exists for this work. Park will contribute existing equipment, technical expertise, and personnel for sampling and data storage and analysis. Some sampling equipment will have to be purchased and maintained. Most funding will be commited to sample collection and analysis.

Other funding sources: No other funding sources are expected for this project.

Benefits of immediate funding: The park will be able to make use of expertise which now exists within the park.

FORM 10-238
(REV. 1-76)

UNITED STATES DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE

144

DEVELOPMENT/STUDY PACKAGE PROPOSAL

PACKAGE NO. 482
REVISION NO.

ORG. NO	PARK (OR OTHER ORIGINATOR)	DEVELOPED AREA (NAME)	D.A. CODE	REGION
8210	Grand Canyon	Inner Canyon-North Rim	IC-NR	WE

STATE	STATE CODE	COUNTY(S)	CONGRESSIONAL DISTRICT(S)
Arizona	04	Coconino	03

PACKAGE TITLE: HYDROGEOLOGY OF KAIBAB PLATEAU N-74

STUDY PACKAGE [ ]
NEW CONSTRUCTION B [ ]
REHABILITATION A [ ]

NEW PACKAGE [ ]
REVISION [ ]

CRITERIA (INSERT X's)

PARK PRIORITY	DATE	REG'N PRIORITY	DATE

PROGRAM THRUST, STATUS AND OTHER INFORMATION

WILL ADDITIONAL OPERATING FUNDS AND POSITIONS BE NEEDED UPON COMPLETION OF THIS PACKAGE?
(IF 'YES' EXPLAIN NEEDS IN SECTION XI OUTLINE OF PLANNING AND MANAGEMENT REQUIREMENTS)
YES [ ]
NO [ ]

FULL PACKAGE DESCRIPTION

FY1. Large springs draining Kaibab Plateau will be examined to determine their groundwater drainage areas, chemical composition, flow and associated riparian vegetation. Twenty-one springs will be sampled at least twice over a two-year period. Spring discharge will be measured and water samples collected and analyzed for all major constituents and selected trace elements. The vegetation at each site will be studied to determine species distribution and abundance as well as the influence of water quality and quantity on these plant communities. Special attention will be given to rare or unusual plant species.

FY2. Continue sampling as in FY1 and prepare report.

PACKAGE JUSTIFICATION/CONSEQUENCES

A coordinated and consistent study of all major springs draining the Kaibab Plateau, its structural geology, and isolated riparian plant communities is needed to fully understand the groundwater systems draining this feature. Because of its hydrologic isolation and near complete draining of groundwater into Grand Canyon, Kaibab Plateau presents an ideal opportunity to study groundwater circulation. Past efforts to examine chemical and hydrolic characteristics of these springs have had to rely on disjointed data collected over several years. Many of these springs have never had accurate flow measurements or chemical analysis. Plant communities associated with these springs are even less studied. The surface of Kaibab Plateau is managed by the Park and Kaibab National Forest. Their management activities can affect both the quantity and quality of spring flow. Results of this study will allow both agencies to better evaluate land use alternatives. It will also improve the park's ability to evaluate proposals for increased water withdrawals from Roaring Springs.

PLANNING AND MANAGEMENT REQUIREMENTS *(Follow instructions and outline provided in Program Formulation Guideline)*

SEE ATTACHED

ORIGINATOR (Signature and Title)	DATE	CONCURRENCE (Signature of Superintendent or Equivalent Official)	DATE
Stephen Hodapp Chief Res Mgt/Plan	12/21/84		12/21/84

APPROVAL (Signature of Regional Director or Equivalent Official) DATE

PLANNING AND MANAGEMENT REQUIREMENTS: Package No. 482

Available Information: Past work by Huntoon (1968, 1970, 1974, 1977) made some preliminary delineations of groundwater basins draining Kaibab Plateau. Water quality measurements of these springs have been scattered over the last twenty years. Of the 21 major springs draining Kaibab Plateau, 12 have never been specifically analyzed. The numerous analyses of Bright Angel Creek by USGS are not directly useful to this study because at the sample site the creek is a composite of at least five springs. Some qualitative information is available on the vegetation at four of these springs. Accurate flow measurements are not available for any of these springs.

Project Type: 78 Research

Mandated: No specific mandates exist for this project.

Park Resources: These springs feed nine major tributary creeks to the Colorado River in Grand Canyon. Each spring and creek supports a riparian zone rich in flora and fauna and the center of human activity. All of the water for developments in the park is obtained from Roaring Springs which drains the Kaibab Plateau.

Immediacy: Kaibab National Forest is currently developing a management plan to be carried out over the next 50 years. The understanding provided by this study would allow both the Park Service and the Forest Service to better evaluate land management alternatives.

Magnitude: Riparian ecosystems are the most diverse and productive in Grand Canyon. They are also centers of human activity within the Canyon.

Health/Safety: This project will in all probability not affect visitor health and safety.

Scope of Contribution: The basic knowledge of water budgets, groundwater circulations, and the relationship of water quality to riparian vegetation gained through this project will be applicable to Karstic groundwater systems throughout the west.

Data Collection: Data collected as part of this project will greatly expand the limited spring flow and water quality information base.

Cost: FY1 $25,000
FY2 $25,000

Funding/Staffing Commitments: No park base or regional funding exists for this project.

Other Funding Sources: Researchers are requesting support and funding from U.S. Forest Service, National Science Foundation and other sources.

Benefits of Immediate Funding: Land Management Planning is ongoing at the USFS. For the results of this project to be fully useful in the planning process, it should be initiated soon. Rapid completion of this project will also provide timely information to the park to use in evaluating water withdrawals from Roaring Springs.

FORM 10-238
(REV. 1-76)

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FOR THIS PACKAGE

UNITED STATES DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE

DEVELOPMENT/STUDY PACKAGE PROPOSAL

PACKAGE NO. 477
REVISION NO.

ORG. NO.	PARK (OR OTHER ORIGINATOR)	DEVELOPED AREA (NAME)	D.A. CODE	REGION
8210	Grand Canyon	Inner Canyon	IC	WE

STATE	STATE CODE	COUNTY(S)	CONGRESSIONAL DISTRICT(S)
Arizona	04	Coconino-Mohave	03

PACKAGE TITLE: N-57 LOWER CANYON WATER QUALITY MONITORING

STUDY PACKAGE [ ]
NEW CONSTRUCTION B [ ]
REHABILITATION A [ ]

NEW PACKAGE [ ]
REVISION [ ]

CRITERIA (INSERT X's)	PARK PRIORITY	DATE	REG'N PRIORITY	DATE

PROGRAM THRUST, STATUS AND OTHER INFORMATION

WILL ADDITIONAL OPERATING FUNDS AND POSITIONS BE NEEDED UPON COMPLETION OF THIS PACKAGE?
(IF YES EXPLAIN NEEDS IN SECTION XI OUTLINE OF PLANNING AND MANAGEMENT REQUIREMENTS)
YES [ ]
NO [ ]

FULL PACKAGE DESCRIPTION FY1: Bacterial and chemical water quality analysis will be done for the lower canyon from Diamond Creek to Lake Mead. While some work has been done above Diamond Creek, the Colorado River and tributaries below have not been sampled. Bacterial analysis will be emphasized. Physical and selected chemical parameters will also be examined. Visito use by river runners and boaters is seasonally heavy and increasing annually. Based on up-river testing, a health threat to the public does exist. Lower canyon analysis would provide baseline data, allow us to assess water quality hazards, and warn the public about health threats. FY2: Sampling would continue for 2 years to gather baseline data then at 5-year intervals to monitor changes.

PACKAGE JUSTIFICATION/CONSEQUENCES
Recreational use of lower Grand Canyon has increased with power boaters coming upstream from Lake Mead. In addition, more river runners are extending their trips to take out at Lake Mead facilities. No analysis has been completed for this portion of the Colorado River corric and the bacterial regime could differ from upstream areas because of the lake environment and upriver recreation. Based on data from upriver areas in the park, concentrations of indicator bacteria regularly exceed standards for drinking water and locally and/or seasonally exceed full body contact standards. It is reasonable to believe some parameters are exceeded likewis in the lower canyon. An analysis would show which parameters are exceeded when and where.

PLANNING AND MANAGEMENT REQUIREMENTS *(Follow instructions and outline provided in Program Formulation Guideline)*

-SEE ATTACHED -

ORIGINATOR (Signature and Title)	DATE	CONCURRENCE (Signature of Superintendent or Equivalent Official)	DATE
Stephen Hodapp Chf Res Mgt/Plan	12/21/84		12/24/84

APPROVAL (Signature of Regional Director or Equivalent Official)

N-57 Lower Canyon Water Quality

Planning and Management Requirements: Package No. 477

Available Information: No water quality analysis information is available for lower canyon. Samplling designs and methodologies used successfully up river will be applicable to this reach.

Project Type: 78 Research

Mandated: There is no specific mandate for this project.

Park Resources: Canyon waters are critical for recreationists; therefore, water quality must be assessed to safeguard public health.

Immediacy: People are continually exposed to using water with questionable quality, particularly during periods of heavy use or turbid flows in the lower canyon. Park staff will not be able to warn visitors of specific threats until analyses are completed.

Magnitude: Several cases of enteric diseases occur annually in Grand Canyon ranging from severe cases to mild ones. The potential of water quality related illnesses increase during periods of turbid flow.

Health/Safety: A major objective of this project is to reduce water quality related illnesses. By learning the potential dangers through chemical and bacterial analysis, park staff can alert recreationists.

Scope of Contribution: Results of this project are primarily applicable to Grand Canyon, but Lake Mead NRA would benefit from knowing water quality entering the recreation area.

Data Collection: This project expands baseline water quality information and provides data to monitor changes. It also extends current water quality information by adding data from another park area.

Cost: FY1 $25,000
FY2 $20,000

Funding/Staffing Commitment: No park or regional base funding exists for this project. The park can provide information from water quality monitoring in other areas of the park.

Other Funding Sources: No other funding sources are expected for this project.

Benefits of Immediate Funding: The park would be able to accurately warn recreationists about water quality hazards.

FORM 10-238
(REV. 1-76)

PAGE ____ OF ____
FOR THIS PACKAGE

UNITED STATES DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE

DEVELOPMENT/STUDY PACKAGE PROPOSAL

PACKAGE NO. 478
REVISION NO.

ORG NO	PARK (OR OTHER ORIGINATOR)	DEVELOPED AREA (NAME)	D A CODE	REGION
8210	Grand Canyon	Inner Canyon	IC	WE

STATE	STATE CODE	COUNTY(S)	CONGRESSIONAL DISTRICT(S)
Arizona	04	Coconino-Mohave	03

PACKAGE TITLE: N-71 FISH TISSUE ANALYSIS

STUDY PACKAGE ☐
NEW CONSTRUCTION B ☐
REHABILITATION A ☐

NEW PACKAGE ☐
REVISION ☐

CRITERIA (INSERT X s)	PARK PRIORITY	DATE	REG'N PRIORITY	DATE

PROGRAM THRUST, STATUS AND OTHER INFORMATION

WILL ADDITIONAL OPERATING FUNDS AND POSITIONS BE NEEDED UPON COMPLETION OF THIS PACKAGE?
(IF YES, EXPLAIN NEEDS IN SECTION XI OUTLINE OF PLANNING AND MANAGEMENT REQUIREMENTS)
YES ☐
NO ☐

FULL PACKAGE DESCRIPTION

FY1: Fish tissue samples would be analyzed for radioneuclides, heavy metals, and tumors. Sampling would provide information about contaminates and thus an indication of safety for sport fish consumers. Carp, suckers, and catfish are primary sampling candidates because they are bottom feeders exposed to toxic substance in sediment as well as river water. Sampling done at the confluence of Little Colorado River and Colorado River would give an indication of contamination from upstream sources and possible effects on endangered humpback chubs. Radioneuclide contamination of Little Colorado River has become a concern recently due to uranium mining wastes along the river. Other sampling would be done to analyze samples from trout since trout fishing is popular in Grand Canyon. Levels of silver, lead, and cadmium are of particular interest. FY2: Sampling will continue. The extent will be determined by examining the results of FY1 sampling and other information on potential contamination. FY3: If warrented, sampling will continue, probably at reduced levels.

PACKAGE JUSTIFICATION/CONSEQUENCES

The Colorado River system is exposed to toxic substances primarily from land uses in the water shed, i.e., mining, industry, pesticide application, etc. In addition, there are natural levels of heavy metals and other potential contaminants which are inherent in the system. Concern for public safety warrent sampling when contamination is suspected. Colorado River and its major tributaries in Grand Canyon are renounced trophy trout fisheries and fishing pressure is increasing. By sampling fish tissue from trout, cat fish, carp, and suckers, park staff can assess (1) presence of malignant tumors, 2) levels of accumulated contaminates in sport fish, and 3) levels of accumulated contaminates in bottom feeders which are more exposed to toxins. Contiminant levels in bottom feeders will be used to assess threats to endangered humpback chubs.

PLANNING AND MANAGEMENT REQUIREMENTS *(Follow instructions and outline provided in Program Formulation Guideline)*

- SEE ATTACHED -

ORGINATOR (Signature and Title)	DATE	CONCURRENCE (Signature of Superintendent or Equivalent Official.)	DATE
Steve Hodapp Chf Res Mgt/Plan	12/21/84	[signature]	12/21/84
APPROVAL (Signature of Regional Director or Equivalent Official)			DATE

N-71 Fish Tissue Analysis

Planning and Management Requirements : Package No. 478

Available Information: In 1980 and 1981, a total of 14 samples were taken of river sediment which showed background levels of radioneuclides. No sampling of fish tissue has been done to assess accumulation of contaminates in body tissues. Limited sampling has been done of river water to compare with Arizona drinking water standards. Results show mean concentrations meet standards but single samples exceed standards for cadmium, lead, and silver.

Project Type: 78 research

Mandated: No specific mandates exist requiring completion of this project.

Park Resources: The humpback chub, an endangered fish, and other aquatic organisms are exposed to waterborne contaminates. People who eat fish caught in the park are exposed to accumulated contaminates. Contamination of the Colorado River system does occur from upstream sources and therefore, concern for the environment and public health is warranted.

Immediacy: People and aquatic related organisms are continually exposed to any contaminates carried in the river system. Sampling will provide a baseline to measure future changes and allow the park to take quick action to mitigate threats to human health and native aquatic species.

Magnitude: Considering the extent of toxins released upstream through mining, pesticide use, industry, and natural sources, contamination in park waters is expected, particularly in primary waterways such as Colorado River, Little Colorado River, and Paria River. Limited sampling has shown background levels exist and some incidents where contaminants exceed standards.

Health/Safety: Public health is threatened if people eat contaminated fish.

Scope of Contribution: The value of this project is primarily for public health awareness in Grand Canyon, but the results would contribute to knowledge of toxins in the environment that can be used locally or nationwide.

Data Collection: This project develops baseline information as well as extends limited previously collected data.

Cost:

FY1	$6,000
FY2	$5,000
FY3	$3,000

Funding/Staffing Commitments: No park base or regional funding exists for this project. Park staff could contribute field personnel.

Package No. 478

Other Funding Sources: No other funding sources are anticipated for this project.

Benefits of Immediate Funding: The park will be able to collect information in a timely manner that can be used to protect public health and to record baseline data.

FORM 10-238
(REV 1-76)

UNITED STATES DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE

DEVELOPMENT/STUDY PACKAGE PROPOSAL

PACKAGE NO. 481
REVISION NO.

ORG NO	PARK (OR OTHER ORIGINATOR)	DEVELOPED AREA (NAME)	D A CODE	REGION
8210	Grand Canyon	Inner Canyon	IC	WE

STATE	STATE CODE	COUNTY(S)	CONGRESSIONAL DISTRICT(S)
Arizona	04	Coconino	03

PACKAGE TITLE: IMPACTS OF WITHDRAWLS ON TEMP., FLOW & FAUNA N-73

STUDY PACKAGE [ ]
NEW CONSTRUCTION B [ ]
REHABILITATION A [ ]
NEW PACKAGE [ ]
REVISION [ ]

CRITERIA (INSERT X s)	PARK PRIORITY	DATE	REG'N PRIORITY	DATE

PROGRAM THRUST, STATUS AND OTHER INFORMATION

WILL ADDITIONAL OPERATING FUNDS AND POSITIONS BE NEEDED UPON COMPLETION OF THIS PACKAGE?
(IF YES EXPLAIN NEEDS IN SECTION XI OUTLINE OF PLANNING AND MANAGEMENT REQUIREMENTS)
YES [ ]
NO [ ]

FULL PACKAGE DESCRIPTION

FY1. Staff gauges will be installed on Roaring Springs and Bright Angel Creeks. These will be calibrated and read routinely to provide reliable stream flow data on which to base an assessment of the impacts of water withdrawal. Recording thermographs will be placed in at least four locations to monitor water temperature continuously for at least one year. Adult aquatic insects will be captured using light traps and identified to species. Subadults will also be sampled with artificial substrates. Subadults will be matched with adults for identification to species. Insects will be sampled during four one month periods selected to be representative of each season. Data will be examined to determine the impact of water withdrawals on stream temperature and subsequently aquatic insect populations. At least one other creek similar to Bright Angel Creek, but not subject to water withdrawals will be gauged, have thermographs installed, and be sampled for subadult and adult aquatic insects. This will provide a control and broaden our knowledge of aquatic insect populations in Grand Canyon.

FY2. Sampling will continue if needed and the report will be prepared.

PACKAGE JUSTIFICATION/CONSEQUENCES

All major developments within Grand Canyon National Park are dependent on water withdrawn from Roaring Springs. A recent study of the impacts of water withdrawals from Roaring Springs (Usher et.al., 1984) identified a reduction in stream velocity and width and subsequent increase in stream temperature as the greatest impacts. This study was hampered by a lack of accurate streamflow measurements, an inability to identify subadult aquatic insects to species, and a lack of continuous stream temperature measurements. Consequently, it will probably not stand up to scrutiny by those wishing to increase withdrawals from Roaring Springs to support further development in and near the park. The proposed study will focus on the most probable impacts and include sufficient documentation of flows, temperature and aquatic insect species and populations to support conclusions. With this information the park will be able to make knowledgeable decisions regarding future withdrawals and support those decisions.

PLANNING AND MANAGEMENT REQUIREMENTS *(Follow instructions and outline provided in Program Formulation Guideline)*

SEE ATTACHED

ORGINATOR (Signature and Title)	DATE	CONCURRENCE (Signature of Superintendent or Equivalent Official)	DATE
Steve Hodapp Chf Res Mgt/Plan	12/21/84		12/21/84

APPROVAL (Signature of Regional Director or Equivalent Official) DATE

Available Information: a recently completed study (Usher et.al., 1984) identified a reduction in stream width and velocity, and subsequent increases in water temperature as the most probable impacts of water withdrawals from Roaring Springs. A few stream-flow and temperature measurements were taken during this study. Extensive collections of subadult aquatic insects were made and identified to genus.

Project Type: 78 Research

Mandated: P.L. 95-586 authorized the Secretary of the Interior to sell water from Grand Canyon National Park to the town of Tusayan, outside the park, "upon his determination that such sale is not detrimental to the protection of the resources of Grand Canyon National Park or its visitors..." Although water sales began in February 1980, any detriment caused by such sales has yet to be determined. This study will provide the best documentation yet available of the impacts of water withdrawals for in-park use and sale to Tusayan.

Park Resources: Roaring Springs supports a large area of riparian vegetation at its mouth, including several species found no where else in Grand Canyon. Roaring Springs and Bright Angel Creek flow through the cross canyon corridor, the most heavily visited inner canyon area. At least three native fish inhabit Bright Angel Creek.

Immediacy: The park should have the information from this study prior to finalizing plans to replace the transcanyon pipeline. The pipeline is nearing its designed life span and its aluminum pipe is subject to numerous leaks and expensive repairs. When plans are made to replace this pipe, the park will certainly be under pressure to expand its capacity.

Magnitude: Roaring Springs and Bright Angel Creek are the only water sources subject to withdrawal in Grand Canyon; they are also the most visited. What is learned of the aquatic invertebrates, flow and temperature regimes should be at least partly applicable to the other large North Rim springs.

Health/Safety: This project will not effect visitor health or safety.

Scope of Contribution: This study of aquatic insects will fill a void in the knowledge of aquatic insects in the southwest.

Data Collection: This project initiates the collection of long-term flow data and extends the knowledge of aquatic insect species and populations.

Cost: FY1 $10,000
FY2 $ 2,000 (if needed)

Funding/Staffing Commitments: No park base or regional funding exists for this project. Whether NPS or privately funded, the park will provide assistance in installing and reading stream gauges, and in maintaining thermographs. The park will also provide logistical support and inner canyon housing for researchers.

Other Funding Sources: A researcher has submitted proposals to Grand Canyon Natural History Association and other organizations for partial funding of this project.

Benefits of Immediate Funding: The park will have the largest data base and a complete report when it comes time to evaluate proposals to expand the transcanyon pipeline.

FORM 10-238
REV. 1-70

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UNITED STATES DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE

DEVELOPMENT/STUDY PACKAGE PROPOSAL

PACKAGE NO. 479
REVISION NO.

ORG. NO.	PARK (OR OTHER ORIGINATOR)	DEVELOPED AREA (NAME)	D.A. CODE	REGION
8210	Grand Canyon	Inner Canyon	IC	WE

STATE	STATE CODE	COUNTY(S)	CONGRESSIONAL DISTRICT(S)
Arizona	04	Coconino-Mohave	03

PACKAGE TITLE: N-4 INTENSIVE MICROBIAL ANAL. OF SELECTED TRIB.

STUDY PACKAGE [ ]
NEW CONSTRUCTION B [ ]
REHABILITATION A [ ]
NEW PACKAGE [ ]
REVISION [ ]

CRITERIA (INSERT X's)	PARK PRIORITY	DATE	REG'N PRIORITY	DATE

PROGRAM IMPACT, STATUS AND OTHER INFORMATION

WILL ADDITIONAL OPERATING FUNDS AND POSITIONS BE NEEDED UPON COMPLETION OF THIS PACKAGE?
(IF YES, EXPLAIN NEEDS IN SECTION XI OUTLINE OF PLANNING AND MANAGEMENT REQUIREMENTS)
YES [ ]
NO [ ]

FULL PACKAGE DESCRIPTION

Y1: An intensive sampling and analysis design will be used to monitor selected tributary creeks. Samples will be collected from surface waters and bottom sediments and analyzed for fecal bacteria. The sampling schedule will examine bacterial concentrations and their diurnal and seasonal fluctuations and changes attributable to hiker activities, livestock, runoff events, and stream flow. Simultaneous sampling of several locations along each study creek will allow an assessment of the impacts of hiker activity. A self-contained field laboratory will be transported by helicopter to the sample creek for sampling periods of up to 2 weeks. These sampling periods will be repeated up to 5 times a year to assess seasonal variations. Physical and chemical parameters will also be examined.

Y2: Sampling will continue as above at other sites.

Y3: Sampling will continue as above at other sites.

PACKAGE JUSTIFICATION/CONSEQUENCES

Past sampling of tributary creeks has consisted of a few samples collected at irregular intervals. While this sampling has provided conclusive evidence that all canyon waters are subject to fecal contamination, it has provided little in-sight into the extent of contamination and variations with respect to time, location, human activities, and natural events.

An intensive sampling schedule will provide a complete understanding of the water quality regime of these creeks. This understanding will allow the park to take actions to reduce contaminations or alter use patterns so contaminated water is avoided.

PLANNING AND MANAGEMENT REQUIREMENTS *(Follow instructions and outline provided in Program Formulation Guideline)*

- SEE ATTACHED -

ORIGINATOR (Signature and Title)	DATE	CONCURRENCE (Signature of Superintendent or Equivalent Official)	DATE
Stephen Hodapp Chief Res Mgt/Plan	12/21/84	Richard H. Marks	12/24/84

APPROVAL (Signature of Regional Director or Equivalent Official) DATE

Planning and Management Requirements: Package No. 479

N-4 Intensive Microbial Analysis of Selected Tributaries

Available Information: There is sufficient data to identify a fecal contamination problem but data provides limited insight into the extent and variability of the contamination.

Project Type: 80 monitoring

Mandated: No specific mandates exist requiring completion of this project.

Park Resources: Almost all inner canyon recreation is closely associated with rivers and creeks. Visitors collect drinking water, swim, wade and fish in these waters and occasionally contaminate them.

Immediacy: Fecal contamination of these creeks is a health threat that should not be allowed to continue.

Magnitude: Waters receiving heavy use will be the highest priority for this sampling. No canyon waters, except the Colorado River, have received this type of intensive sampling.

Health/Safety: Concern for visitor health is the prime reason for this project. With the insight provided by this project it should be feasible to correct or avoid some fecal contamination.

Scope of Contribution: The understanding of bacterial water quality provided by this study will be applicable to many wildland waters. Quantified data will be most applicable to the waters sampled and very similar sources, but the relationships between water quality and natural and human activities will be more broadly useful.

Data Collection: This project will build on the limited baseline data available providing a very complete and accurate baseline.

Cost:

FY1	$18,000
FY2	$18,000
FY3	$18,000

Funding/Staffing Commitments: No park or regional base funding exists for this project. The park does not have field laboratory facilities necessary for this project, so researchers from a university or other agency will have to be contracted to do the work. The park can contribute baseline bacterial and chemical data, technical expertise, knowledge of the resource, climatic data, and backcountry use data.

Other Funding Sources: No other funding sources are anticipated for this project.

Benefits of Immediate Funding: Actions to mitigate contamination can be taken as soon as possible.

FORM 10-2-80
(REV. 1-79)

PAGE ___ OF ___
FOR THIS PACKAGE

UNITED STATES DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE

DEVELOPMENT/STUDY PACKAGE PROPOSAL

PACKAGE NO. 480
REVISION NO.

ORG NO	PARK (OR OTHER ORIGINATOR)	DEVELOPED AREA (NAME)	D A CODE	REGION
8210	Grand Canyon	Inner Canyon	IC	WE

STATE	STATE CODE	COUNTY(s)	CONGRESSIONAL DISTRICT(S)
Arizona	04	Coconino-Mohave	03

PACKAGE TITLE: N-51 COLORADO RIVER WATE / R QUALITY MODELING

STUDY PACKAGE ☐
NEW CONSTRUCTION B ☐
REHABILITATION A ☐

NEW PACKAGE ☐
REVISION ☐

CRITERIA (INSERT X's)	PARK PRIORITY	DATE	REG'N PRIORITY	DATE

PROGRAM THRUST, STATUS AND OTHER INFORMATION

WILL ADDITIONAL OPERATING FUNDS AND POSITIONS BE NEEDED UPON COMPLETION OF THIS PACKAGE?
(IF YES, EXPLAIN NEEDS IN SECTION XI OUTLINE OF PLANNING AND MANAGEMENT REQUIREMENTS)
YES ☐
NO ☐

FULL PACKAGE DESCRIPTION

FY1: The first year would entail intensive sampling for indicator bacteria for fecal contamir tion. Measurements would be taken at Paria River, Little Colorado River Lees Ferry, and Brigl Angel and then at points downstream in the Colorado River. Samples would be taken during selected times of the year ranging from clean to sediment-laden river flow in order to record various levels of bacteria. Essentially this will provide a profile of contamination. From this model the park will predict cotntamination levels using upstream inputs and would be able to caution visitors and staff accordingly.

FY2: Laboratory and data analyses and report preparation will be completed.

PACKAGE JUSTIFICATION CONSEQUENCES

Bacterial water quality of the Colorado River is primarily a function of inflows from Glen Canyon Dam supplemented by flooding tributaries, especially Little Colorado River and Paria River. This model will allow the bacterial quality of Colorado River to be predicted by analyzing a few easily accessible points, thus avoiding costly monitoring through the entire canyon. Identification of potentially hazardous conditions will be much more timely. Also, developing a model would be less expensive than annual monitoring.

PLANNING AND MANAGEMENT REQUIREMENTS *(Follow instructions and outline provided in Program Formulation Guideline)*

ORGINATOR (Signature and Title)	DATE	CONCURRENCE (Signature of Superintendent or Equivalent Official)	DATE
Stephen Hodapp Chf ResMgt/Plnn	12/21/84		12/24/84
APPROVAL (Signature of Regional Director or Equivalent Official)			DATE

N-51 Colorado River Water Quality Modeling

Planning and Management Requirements: Package No. 480

Available Information: Baseline water quality information is available for the Colorado River and to a lesser extent tributary creeks. A more rigorous sampling schedule and extensive data analysis is necessary to develop a model.

Project Type: 78 research

Mandated: No specific mandate exists for this project.

Park Resources: Canyon waters are critical for recreationists. Therefore, water quality must be assessed to safeguard public health.

Immediacy: People will be continually exposed to using water with questionable levels of bacterial contamination, particularly locally and/or seasonally. Park staff would not be able to warn visitors about specific conditions under which contamination occurs until this modelling is completed.

Magnitude: Several cases of enteric diseases occur annually in Grand Canyon ranging from severe to mild cases. The potential of water quality related illnesses increase during periods of turbid flow.

Health/Safety: A major objective of this project is to reduce water quality related illnesses by warning people when bacterial contamination is worse. By developing a model, park staff can provide warning to river and backcountry users.

Scope of Contribution: Results of this study are primarily applicable to Grand Canyon, but Lake Mead NRA would benefit from knowing water quality entering the recreation area.

Data Collection: This project increases knowledge of bacterial contamination and provides a model to predict hazardous conditions for public health.

Cost: FY1 $34,000
FY2 $34,000

Funding/Staffing Commitments: No park or regional base funding exists for this project. The park can provide information from past studies and technical expertise.

Other Funding Sources: No other funding sources are anticipated for this project.

Benefits of Immediate Funding: Immediate funding will make best use of available technology, skilled personnel and baseline data.

FORM 10-238
(REV. 1-70)

PAGE ____ OF ____
FOR THIS PACKAGE

UNITED STATES DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE

DEVELOPMENT/STUDY PACKAGE PROPOSAL

PACKAGE NO. 475
REVISION NO.

ORG NO	PARK (OR OTHER ORIGINATOR)	DEVELOPED AREA (NAME)	D A CODE	REGION
8210	Grand Canyon	Inner Canyon	IC	WE

STATE	STATE CODE	COUNTY(S)	CONGRESSIONAL DISTRICT(S)
Arizona	04	Coconino-Mohave	03

PACKAGE TITLE: N-65 FECAL STREP. SPECIATION OF GARDEN AND BA CR.

STUDY PACKAGE ☐
NEW CONSTRUCTION B ☐
REHABILITATION A ☐

NEW PACKAGE ☐
REVISION ☐

CRITERIA (INSERT X'S)	PARK PRIORITY	DATE	REG'N PRIORITY	DATE

PROGRAM THRUST, STATUS AND OTHER INFORMATION

WILL ADDITIONAL OPERATING FUNDS AND POSITIONS BE NEEDED UPON COMPLETION OF THIS PACKAGE?
(IF YES, EXPLAIN NEEDS IN SECTION XI OUTLINE OF PLANNING AND MANAGEMENT REQUIREMENTS)
YES ☐
NO ☐

FULL PACKAGE DESCRIPTION

Water samples will be collected from Bright Angel and Garden Creeks during varying flow conditions and seasons. These samples will be analyzed to determine fecal streptococcus species. The relative concentrations of streptococcus species will be used as an indicator of the origi of fecal contamination. Streptococcus bacteria originating from equines, humans, and wildlif can be differentiated by this analysis.

PACKAGE JUSTIFICATION/CONSEQUENCES

There are several possible sources for bacterial contamination of Bright Angel and Garden Creeks. Trail mules use the Bright Angel and North Kaibab trails which are adjacent to these creeks. Mule feces are common along the trails and in corrals near these creeks. Human fecal contamination is probably also occurring through improper waste disposal by visitors and malfunctioning sewage systems. Wildlife are another potential source. Past bacterial analyses of these creeks has consistently shown the presence of fecal contamination.

Fecal streptococcus speciation will allow the most probable source or sources of contamination to be determined. With evidence of the source the park will be better able to initiate measures to correct the problem.

PLANNING AND MANAGEMENT REQUIREMENTS *(Follow instructions and outline provided in Program Formulation Guideline)*

- SEE ATTACHED -

ORGINATOR (Signature and Title)	DATE	CONCURRENCE (Signature of Superintendent or Equivalent Official)	DATE
Stephen Hodapp Chf Rs Mgt/Plan	12/21/84	Richard H. Clarke	12/24/84

APPROVAL (Signature of Regional Director or Equivalent Official) DATE

Planning and Management Requirements: Package No. 475

N-65 Fecal Streptococcus Species Identification

Available Information: Numerous analysis of these creeks have shown regular fecal contamination. There has been no previous streptococeus speciation analysis.

Project Type: 78 research

Mandated: No specific mandates exist requiring completion of this project.

Park Resources: Both creeks are within the cross canyon corridor, the most heavily visited inner canyon area. Visitors often wade, bathe, and collect drinking water from these creeks.

Immediacy: Fecal contamination of these creeks presents a threat to human health that should not be allowed to continue.

Magnitude: Mule use in the canyon is restricted to these two watersheds. This area is visited by approximately 200,000 hikers and mule riders annually, many of whom enjoy contact recreation in the creeks.

Health/Safety: Fecal contamination of these creeks presents a threat to human health. A clearer determination of the origin of this contamination will help the park focus efforts to correct it.

Scope of Contribution: The results of this project will be valuable in other parks and natural areas experiencing livestock and human use. Fecal streptococcus speciation is a useful, but little used tool. Its successful application in Grand Canyon might encourage more use of this procedure.

Data Collection: This project will enhance baseline data previously collected.

Cost: FY1 $8,000

Funding/Staffing Commitments: No park base or regional funding exists for this project. The park will contribute field and lab personnel, technical expertise and laboratory facilities.

Other Funding Sources: No other funding sources are anticipated for this project.

Benefits of Immediate Funding: Action can be taken to eliminate contamination as soon as results are available. If information is available when the camping area at Indian Gardens is modified, these changes can include measures to mitigate contamination.

APPENDIX B

Glossary

Acid precipitation - precipitation with a pH below 5.7.

ADHS - Arizona Department of Health Services.

Aquifier - water bearing stratum of porous rock.

Arithmetic mean - a value representing a group of members calculated by dividing the sum of n numbers by n

Asymptomatic - a condition where an individual is infected with a disease and is capable of infecting others but has no symptoms of the illness.

BLM - Bureau of Land Management, U.S. Department of Interior.

Buffered - able to resist change. Used here to indicate a resistance to changes in pH.

Breccia pipe - collapse features which are generally cylinderial or conical in shape and found in Redwall limestone, Supai group and Hermit Shale. In Grand Canyon breccia pipes are 100-300 feet in diameter and are occasionally mineralized with Copper or Uranium.

CFS - cubic feet per second. A measure of flow approximately equal to 448 gallons per minute

Confluence - the point where two or more rivers join.

Corridor - cross canyon corridor, including the heavily used Bright Angel, North Kaibab and South Kaibab trails and campgrounds at Cottonwood, Phantom Ranch, and Indian Gardens.

Curie - a unit used to represent the level of radioactive emissions. It was originally intended to represent the rate of disinigration of one gram of radium, but is now defined as 3.70×10^{10} disintigrations per second.

Debris flow - a flood event where water flow is supplemented by a large volume of rock and soil. Debris flows have the consistency of wet concrete and are capable of transporting enormous boulders.

Delta - an alluvial deposit at the confluence of a river with a larger river, lake or ocean. In Grand Canyon delta refers to alluvial fans deposited by tributary creeks at their confluence with the Colorado River.

Dip - the inclination of rock strata.

Dissolved Solids - particles so small that they cannot be separated from the fluid by filtration.

Ephemeral stream or spring - a water source which flows only in direct response to precipitation.

FC - fecal coliform bacteria (see indicator bacteria).

FC/FS - fecal coliform/fecal streptococcus ratio. This ratio is used to indicate the origin of bacterial contamination. A ratio of less than one strongly indicates a non-human source of contamination. A ratio of greater than four strongly indicates a human source, while inter mediate values are less conclusive. Application of this method includes several assumptions which may not be met in wildland waters.

Flashflood - a flood which occurs with such rapidly that people in the flood plain do not have time to escape.

Floodplain - the land area inundated by a flooding river or creek. Flood plains are often referred to by their return period as in a 100 year flood. In Grand Canyon calculations of flood magnitude and flood plain inundation are subject to large errors because of inadequate records on which to base calculations, and radical changes in stream channel geometry due to sediment movements and debris flows.

Flume - a flow measurement device through the entire stream flow is channeled through a standardized structure and volume of flow calculated by measuring depth.

FS - fecal streptococcus bacteria (see indicator bacteria).

Gabions - wire baskets which are filled with rock and are assembled into erosion control structures. They can be used to make check dams, barriers, and rock mats to prevent bank erosion resembling rip-rap.

Graded reach of a stream - a portion of a stream that is sufficiently uniform so that once it is calabrated, flow rates can be determined simply by measuring depth of flow.

Groundwater system - the collection of aquifers and solution channels which conduct water to a spring.

Hydrogeology - the study of the hydrologic properties of the geologic profile.

Hydraulic gradiant - the change in hydraulic head between two points. Water will move from a position of higher energy to that of lower energy. In Grand Canyon that movement can be either along or across the dip of rock strata.

Indicator bacteria - bacterial groups which can be easily isolated to indicate fecal contamination. Total coliform, fecal coliform and fecal streptococcus bacteria are most commonly used as indicator bacteria. They inhabit the intestinal tract of warm blooded animals, are easily enumerated with few exceptions are not pathogenic and die off at rates similar to pathogenic organisms. Fecal coliform bacteria are used to establish state and federal standards.

Intermittent stream or spring - a water source that flows following wet weather but regularly dries up during dry seasons.

Log mean, geometric mean - a statistical representation of a group of numbers calculated by taking the n^{th} root of the product of numbers. It is most often used to describe numbers which occur in a logrhytmic manner, such as bacterial concentrations, and gives more weight to lower numbers than does an arithmetic mean.

mg/l - milligrams per liter. A measure of concentration approximately equivalent to parts per million.

NACOG - Northern Arizona Council of Governments.

NPS - National Park Service, U.S. Department of Interior.

Perennial stream or spring - a water source that flows year round, even during periods of drought.

Picocurie - 10^{-12} curies or .037 disintegrations per second.

Radioneuclides - elements that emit radiation

Suspended sediment - particles that are small enough to be suspended by turbulents and large enough to be removed by filtration.

WATER RESOURCES OF GRAND CANYON NATIONAL PARK

SCALE 1:250,000

5 0 5 10 15 20 STATUTE MILES

5 0 5 10 15 20 25 30 KILOMETERS

WATER RESOURCE FEATURES

- Colorado River
- Stone Tributary Streams
- Kanab Major Ephemeral Channels
- Green Springs
- Willow Small Lakes, Ponds and Stock Tanks
- Sewage Lagoons
- Water Sources with Certified Water Rights Issued to N. P. S.
- Water Sources with Certified Water Rights Issued to Others
- Water Sources for which Claims have been Filed and No Certificate Issued (No N.P.S. Filings)

POLITICAL FEATURES

- Grand Canyon National Park Boundary
- Other Boundaries
- 64 Surfaced Roads
- Unsurfaced Roads
- SUPAI Towns

PHYSICAL FEATURES

- Canyon Rim
- SANUP PLATEAU Notable Surface Features

LAKE MEAD NATIONAL RECREATION AREA

GRAND WASH CLIFFS

SHIVWITS PLATEAU

LAKE MEAD NRA

SANUP PLATEAU

LOWER GRANITE GORGE

HUALAPAI INDIAN RESERVATION

HURRICANE CLIFFS

TO FREDONIA

KANAB PLATEAU

UINKARET MOUNTAINS

TOROWEAP VALLEY

TOROWEAP RANGER STATION

AUBREY CLIFFS

COLORADO RIVER

HAVASUPAI INDIAN RESERVATION

COCONINO PLATEAU

KAIBAB NATIONAL FOREST

KAIBAB PLATEAU

TO JACOB LAKE

MIDDLE GRANITE GORGE

UPPER GRANITE GORGE

MARBLE PLATFORM

NAVAJO INDIAN RESERVATION

GRAND CANYON VILLAGE

NORTH RIM

DESERT VIEW

TUSAYAN

TO FLAGSTAFF AND WILLIAMS

TO CAMERON