Grand Canyon National Park
Water Supply
Appraisal Study

Coconino, Mohave, and
Yavapai Counties, Arizona

Prepared for

National Park Service
Grand Canyon National Park
Grand Canyon, Arizona

Prepared by

Bureau of Reclamation
Phoenix Area Office, Phoenix, Arizona
Technical Service Center, Denver, Colorado

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Executive Summary

Study Purpose

The Bureau of Reclamation (Reclamation) conducted this appraisal study to develop potentially viable options (alternatives) that would provide a treated water supply to the North and South Rims of Grand Canyon National Park (Park) through the year 2050. The alternatives could be further investigated at a feasibility level of study, with the intent of developing a preferred plan.

Study Need

Estimated water use at the Park in 1999 was 194.1 million gallons, or 596 acre-feet (af) a year. Based on National Park Service (NPS) projections, increased visitor growth would about double this water use by the year 2050 to 1,255 af per year.

Currently, the 12.5-mile-long transcanyon pipeline (TCP) delivers water from Roaring Springs (located about 3,000 feet below the North Rim) to the North Rim by pumping and by gravity flow to Indian Garden, located about 3,000 feet below the South Rim. Water is then pumped from Indian Garden to water storage tanks on the South Rim before it is delivered to developed areas along the South Rim. The South Rim receives about 90 percent of the Park's 5 million annual visitors.

The TCP frequently experiences two types of failures: (1) failures at bends in the pipeline and (2) failures due to washouts during high flow events. The reach of the TCP most sensitive and vulnerable to washouts is located in the "Box" area, a long narrow section of Bright Angel Canyon upstream of Phantom Ranch. About 10 to 12 minor failures occur throughout the TCP each year, mostly in the Box area, and mostly during the spring. Each failure costs about $15,000 and requires 1-4 days to repair. A catastrophic event occurs every 5 to 8 years that temporarily stops the flow of water to Park facilities on the South Rim.

These frequent failures of the TCP make it imperative for the Park to acquire a reliable, long-term water supply to meet existing and future visitor needs.

Study Constraints

The viability of any of the proposed alternatives is contingent on the many constraints that would apply to any opportunity to meet the study need. The Park would need to consider statutory and institutional constraints on any ground-disturbing activities that could affect the natural resources within the study area, including: South Rim seeps and springs; wetlands; caves; Wilderness areas; wildlife habitat and movement; species listed as threatened, endangered, or sensitive; historic buildings, districts, or landscapes; archeological sites; traditional cultural properties.

Alternatives

Reclamation evaluated 11 alternatives. Alternatives 1 through 8 were evaluated at an appraisal-level of detail. Alternatives 9 through 11 were evaluated in concept only, and costs were not estimated.

1. No Action
2. Repair or Replace Portions of the TCP
3. Replace the TCP from Roaring Springs to the Colorado River
4. Construct an Infiltration Gallery and Pumping Plant on Bright Angel Creek to Supply the South Rim and Phantom Ranch
5. Drill a Well from the North Rim to Roaring Springs

6. Use the Colorado River to Supply the South Rim and Continue to Use Roaring Springs to Supply the North Rim
7. Construct a Wellfield Inside the Park
8. Construct a Wellfield Outside the Park
9. Obtain a Dependable Water Supply From Water Providers or Companies
10. Truck or Train Water Into Park
11. Develop Water Conservation Measures

Alternative 1, the No Action Alternative, serves as the basis for comparing the effects of the alternatives. Under alternative 1, the Park would maintain the TCP and continue to use Roaring Springs as the primary water source for the Park. Failing TCP sections would continue to be replaced, as needed.

Under alternative 2, reaches of the TCP on the north side of the Colorado River (in the Box area) would be replaced.

Under alternative 3, a new TCP would be constructed along the existing alignment from Roaring Springs to the Colorado River. Roaring Springs would continue as the primary water source for the North and South Rims.

Under alternative 4, an infiltration gallery would be constructed at Bright Angel Creek, and the water would be conveyed to a pumping plant near the existing sewage treatment plant. The existing TCP from Roaring Springs to Phantom Ranch would be abandoned, but the remainder of the TCP would still supply water to the South Rim. Roaring Springs would continue to supply the North Rim, and a small package water treatment plant would be constructed near the new pumping plant to supply water to Phantom Ranch.

Alternative 5 consists of two sub-alternatives: Well Field (alternative 5A) and Directional Drill Hole (alternative 5B). Under alternative 5A, a well from the North Rim would be constructed to tap the groundwater system feeding Roaring Springs. The existing pump station would no longer be used to pump water up to the North Rim. Roaring Springs would continue to supply Phantom Ranch and the South Rim via the TCP.

Under alternative 5B, a directional drill hole (but not a well) would replace the exposed TCP reach from the Roaring Springs pump station to the North Rim. Alternative 5B includes two options: one option would use the existing overland power line for power (5B1), while the second option would replace the existing overland power line with two power cables placed in the directional drill hole (5B2).

Under alternative 6, another water supply system, such as a pumping plant on the mainstem of the Colorado River, and a pipeline routed through Tanner Canyon (alternative 6A), Cardenas Creek (alternative 6B), or the Comanche site (alternative 6C) would deliver water to the South Rim. Roaring Springs would continue to supply the North Rim. Phantom Ranch would still use the existing TCP to deliver its water and would require a storage tank if TCP failures occur in the future.

Under alternative 7, water would be supplied to the South Rim by constructing a well field and associated conveyance system within the Park boundaries. Water piped from the well field could be stored and used directly (depending on its quality) or treated.

Under alternative 8, NPS would acquire land to the south of the Canyon and construct a well field and associated conveyance system to supply water to the South Rim. Water piped from the wellfield could be stored and used directly (depending on its quality) or treated.

Table 1 summarizes project costs for these eight alternatives.

Table 1—Project costs,
Grand Canyon Water Supply Study

Alternative No.	Construction Cost	Nonconstruction Cost	Total Project Cost	Annual Operation and Maintenance Cost
1	$1,350,000	$351,000	$1,701,001	$189,220
2	$21,000,000	$5,460,000	$26,460,000	$142,944
3	$24,000,000	$6,240,000	$30,240,000	$142,944
4	$14,000,000	$3,640,000	$17,640,000	$1,057,451
5A	$10,500,000	$2,730,000	$13,230,000	$112,467
5B1	$5,200,000	$1,352,000	$6,552,000	$112,467
5B2	$9,400,000	$2,444,000	$11,844,000	$112,467
6A	$23,000,000	$5,980,000	$28,980,000	$1,028,768
6B	$39,000,000	$10,140,000	$49,140,000	$1,002,926
6C	$33,000,000	$8,580,000	$41,580,000	$1,002,926
7	$38,000,000	$9,880,000	$47,880,000	$345,363
8	$50,000,000	$13,000,000	$63,000,000	$537,570

Reclamation evaluated alternatives 9, 10, and 11 in concept only.

Under alternative 9, Roaring Springs would continue as the water source for the North Rim, and water companies or larger communities (Flagstaff, Williams, etc.) located within 100 miles of the Park would supply water to the South Rim. Water would have to be transported to the South Rim by pipeline, truck, or rail.

Under alternative 10, Roaring Springs would continue as the water source for the North Rim, and water would be transported by rail or truck to the South Rim.

Under alternative 11, the Park would implement water conservation measures and maximize reuse of treated effluent for irrigation and the potable water supply at the Park.

Table 2 ranks the 11 alternatives according to eight factors for alternatives that would affect the South Rim and according to six factors for alternatives that would affect the

North Rim only. Each factor was weighted according to its relative importance. Reclamation evaluated each alternative on the basis of how well it met the criteria. As shown in the table, alternative 4, with a score of 195 out of a maximum of 225, had the highest ranking.

Table 3 summarizes the effects of the alternatives on various resources within the study area, including water, wilderness and wildlife, geology, air quality, geology, economics, social environment/environmental justice, cultural resources, Indian trust assets, aesthetics, noise, and transportation.

Consultation and Coordination

Before any of the alternatives could be implemented, the Park would likely be required to conduct consultation under the Endangered Species Act, the Fish and Wildlife Coordination Act, and the Federal Clean Water Act. The Park would also consult with the State Historic Preservation Officer and affected tribes to determine cultural resource survey needs, effects, and mitigation in accordance with Section 106 of National Historic Preservation Act.

Conclusions and Recommendations

In conclusion, alternatives 1 through 5 appear to be viable alternatives, but a number of environmental issues for each would need to be resolved. Alternative 6 would have a significant effect on a designated Wilderness area. Alternatives 7 and 8 could significantly affect springs and seeps both inside and outside the Park.

Based on the potentially viable alternatives identified in this appraisal study, it is recommended to proceed to feasibility study. The focus of the feasibility study would be to investigate the potentially viable alternatives in detail and to develop a preferred plan that would meet the water supply needs of the Grand Canyon National Park through the year 2050. National Environmental Policy Act compliance would be completed in conjunction with the feasibility study.

Table 2.—Ranking of alternatives that affect the South Rim, Grand Canyon National Park Water Supply Study

Factor	Weight	% Weight	Alterna-tive 1	Alterna-tive 2	Alterna-tive 3	Alterna-tive 4	Alterna-tive 6A	Alterna-tive 6B	Alterna-tive 6C	Alterna-tive 7	Alterna-tive 8	Alterna-tive 9	Alterna-ative 10	Alterna tive 11
Restore flow to Bright Angel Creek	3	6.7%	NO 0	NO 0	NO 0	YES 5	YES 5	YES 5	YES 5	YES 5	YES 5	YES 5	YES 5	YES 5
Reduce or eliminate flow augmentation of Garden Creek	3	6.7%	NO 0	NO 0	NO 0	MAYBE 2	YES 5	YES 5	YES 5	YES 5	YES 5	YES 5	YES 5	YES 5
Protect prehistoric and historical cultural resources	6	13.3%	YES 5	YES 5	YES 5	YES 5	NO 0	NO 0	NO 0	YES 4	YES 4	YES 5	YES 5	YES 5
Deliver water to Tusayan	2	4.5%	NO 0	NO 0	NO 0	MAYBE 2	MAYBE 2	MAYBE 2	MAYBE 2	MAYBE 2	MAYBE 2	MAYBE 2	MAYBE 2	MAYBE 2
Keep development in TCP corridor and out of proposed wilderness areas	6	13.3%	YES 5	YES 5	YES 5	YES 5	NO 0	NO 0	NO 0	YES 5	YES 5	YES 5	YES 5	YES 5
Protect South Rim aquifer, seeps, and springs	5	11.1%	YES 5	YES 5	YES 5	YES 5	YES 5	YES 5	YES 5	NO 0	MAYBE 3	YES 5	YES 5	YES 5
Capital cost	15	33.3%	$1,701,000 5	$26,460,000 3	$30,240,000 3	$17,640,000 4	$28,980,000 3	$49,140,000 1	$41,580,000 2	$47,880,000 1	$63,000,000 1	$0 1	$0 1	$0 5
Maintenance	5	11.1%	HIGH 1	Moderate 3	LOW 5	LOW 5	LOW 5	LOW 5	LOW 5	LOW 5	LOW 5	LOW 5	LOW 5	LOW 5
Totals (maximum = 225)	45	100.0 %	165	145	155	195	129	99	114	128	143	159	159	159

Table 2.—Ranking criterial for alternatives that affect the North Rim,
Grand Canyon National Park Water Supply Study

Factor	Weight	% Weight	Alternative 5A	Alternative 5B1	Alternative 5B2
Capital cost	10	34.4%	$10,500,000 1	$5,200,000 5	$9,400,000 2
Maintenance	7	24.1%	LOW 5	MODERATE 3	LOW 4
Aesthetics	5	17.2%	No Pumping Plant or Pipeline 5	No Pipeline 2	No Power Lines or Pipeline 4
Complexity of system operation	2	7.0%	SIMPLE 5	MODERATE 3	MODERATE 3
Water source reliability	3	10.3%	MODERATE 3	HIGH 5	HIGH 5
Construction difficulty	2	7.0%	HIGH 3	MODERATE 5	HIGH 3
Totals (maximum = 145)	29	100.0%	95	112	95

Table 3.—Potential effects of alternatives on resources, Grand Canyon National Park Water Supply Study

Alternative	Water Resources	Wilderness and wildlife (See table 3A)	Geology	Air Quality	Recreation	Economics	Social Environment/ Environmental Justice	Cultural Resources	ITAs	Aesthetics	Noise	Transpor-tation
No Action Alternative (Alternative 1)	No effect.		No effect.	Federal and State standards would not be exceeded.	Potential significant effect on recreation because water availability constraints would limit recreation activities.	No significant effect.	No effect.	No effect.	No effect.	Minor effect.	No significant effect.	Minor effect.
Repair or Replace Certain Portions of the TCP (Alternative 2)	No effect on water quantity or quality.		No effect.	Air quality would degraded during construction.	Substantial effect because of major construction activity.	No significant effect.	No effect.	Consultation with the SHPO and affected Tribes would occur early in the planning process to determine survey needs, effects, and mitigation in accordance with Section 106 of NHPA.	No effect.	Slightly greater effects than alternative 1.	Possible significant effect.	Moderate effect.
Replace the TCP from Roaring Springs to the Colorado River (Alternative 3)	No effect on water quantity or quality.		No effect.	Air quality would degraded during construction.	Substantial effect because of major construction activity.	Minor beneficial effect.	No effect.	Same as alternative 2.	No effect.	Greatest effect.	Possible significant effect.	Moderate effect.
Construct an Infiltration Gallery and Pumping Plant on Bright Angel Creek to Supply the South Rim and Phantom Ranch (Alternative 4)	Would eliminate current excess unused flows (overflow) at Garden Creek		No effect.	Air quality would degraded during construction.	Minimal effect.	Minor beneficial effect.	No effect.	Same as alternative 2.	No effect.	Long-term beneficial effect.	Significant effect.	Moderate effect.
Drill a Well from the North Rim to Roaring Springs (Alternative 5)	No effect on water quantity or quality.		No effect.	Federal and State standards would not be exceeded.	Minimal effect.	No significant effect.	No effect.	Same as alternative 2.	No effect.	Minor effect.	No significant effect.	Moderate effect.
Use the Colorado River to Supply the South Rim and Continue to Use Roaring Springs to Supply the North Rim (Alternative 6)	No effect on water quantity. Water treatment would be required.		No effect.	Air quality would degraded during construction.	Minimal effect.	Minor beneficial effect.	No effect.	Same as alternative 2.	No effect.	Greatest effect.	Significant effect.	Greatest effect.

Table 3.—Potential effects of alternatives on resources, Grand Canyon National Park Water Supply Study (continued)

Alternative	Water Resources	Biological Resources (See table 3A)	Geology	Air Quality	Recreation	Economics	Social Environment/ Environmental Justice	Cultural Resources	ITAs	Aesthetics	Noise	Transpor-tation
Construct a Wellfield Inside the Park (Alternative 7)	Would affect water quality and quantity at the Park. Could significantly affect springs and seeps inside and outside Park.		No effect.	Air quality would degraded during construction.	Minimal effect.	Minor beneficial effect.	No effect.	Same as alternative 2.	No effect.	Minor effect.	Would generate noise inside Park.	Moderate-to-significant effects.
Construct a Wellfield Outside the Park (Alternative 8)	Same as alternative 8.		No effect.	Air quality would degraded during construction.	Minimal effect.	Minor beneficial effect.	No effect.	Same as alternative 2.	No effect.	Minor effect.	Would generate noise inside and outside Park.	Moderate-to-significant effects.
Obtain a Dependable Water Supply from Water Providers or Companies (Alternative 9)	No effect on water quantity or quality.		No effect.	Federal and State standards would not be exceeded	Minimal effect.	No effect.	No effect.	Same as alternative 2.	No effect.	No effect.	Minimal effect.	No significant effect
Truck or Train Water into Park (Alternative 10)	No effect on water quantity or quality.		No effect.	Federal and State standards would not be exceeded	No effect.	No effect.	No effect.	Same as alternative 2.	No effect.	No effect.	Minimal effect.	No significant effect.
Develop Water Conservation Measures (Alternative 11)	No effect on water quantity or quality.		No effect.	Federal and State standards would not be exceeded.	No effect.	No effect.	No effect.	Same as alternative 2.	No effect.	No effect.	Minimal effect.	

Table 3A.—Potential effects of alternatives on wilderness and wildlife,
Grand Canyon National Park Water Supply Study

Alter-native No.	Wilder-ness	Section 7	Critical habitat	MSO surveys	SWF surveys	T&E Fish	T&E Plant surveys	Springs and seeps	Sensitive species	Historic buildings, districts, landscapes	Archeo-logical sites	Traditional Cultural Properties	Caves	Wet-lands	Habitat loss
1		/													
2		/		/		/									
3		X		X		X	X								
4		X	X		/	X									X
5		X	X	/	/	X			/						X
6	X	X	X	X	X	X	X		X						X
7	/	/		X				X	/						
8		/		/				X	/						
9															
10															
11															

/ = possible   X = likely
Sensitive species = desert bighorn sheep, peregrin falcon, bats, goshawk, etc.
MSO = Mexican spotted owl
SWF = Southwestern willow flycatcher
TE - Threatened or endangered species

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CHAPTER 1

Introduction

1.1 Study Purpose, Scope, and Objectives

The Bureau of Reclamation (Reclamation) conducted this appraisal study to develop potentially viable options (alternatives) that would provide a treated water supply to the North and South Rims of Grand Canyon National Park (Park) through the year 2050. The alternatives could be further investigated at a feasibility level of study, with the intent of developing a preferred plan.

An appraisal study is a brief, preliminary investigation to determine the desirability of proceeding to a feasibility study. An appraisal study primarily uses existing data and information to identify plans to meet current and projected needs and problems of the planning area. An appraisal study identifies at least one potential solution that requires Federal involvement or identifies an array of options that have been screened and evaluated to substantiate potential Federal involvement.

A feasibility study is a detailed investigation, specifically authorized by law, to determine the desirability of seeking congressional authority for implementation. A feasibility study requires acquisition of primary data and the participation of public agencies and entities and the general public to develop a preferred plan from a range of alternatives. A feasibility study is usually integrated with compliance under the National Environmental Policy Act (NEPA), Fish and Wildlife Coordination Act, Endangered Species Act, National Historic Preservation Act, and other related environmental and cultural resources laws.

1.2 Study Authority

The Economy Act of 1932 gives Reclamation authority to provide services. The National Park Service's (NPS) authority to manage natural resources in Grand Canyon National Park comes from general authorities in the Organic Act of 1916 (Public Law [P.L.] 64-235), Grand Canyon National Park Establishment Act of 1919 (40 Statute 1175), Grand Canyon National Park General Management Plan (1995), and NPS Management Policies (2001).

The National Park Service Organic Act of 1916, P.L. 64-235, directs the National Park Service to:

> *Conserve the scenery 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.*

Grand Canyon National Park was established on February 26, 1919, as a public park for the "benefit and enjoyment of the people" (Grand Canyon National Park Establishment Act, 40 Statute 1175). Grand Canyon National General Management Plan, Park (August 1995) recognizes that the Grand Canyon (Canyon) is a place of national and global significance and states that the Park is to be managed to:

> *Preserve and protect its natural and cultural resources and ecological processes, as well as its scenic, aesthetic, and scientific values. And to provide opportunities for visitors to experience and understand the environmental interrelationships, resources, and values of the Grand Canyon without impairing the resources.*

NPS Management Policies (2001) address aquatic resource policy:

> *The Service will perpetuate surface waters and groundwaters as integral components of park aquatic and terrestrial ecosystems. . .. The Service will. . .[t]ake all necessary actions to maintain or restore the quality of*

surface waters and ground waters within the parks consistent with the Clean Water Act [33 United States Code (USC) 1251 et seq.] and other applicable federal, state, and local laws and regulations.

1.3 Study Area

The study area is generally within the Park, although some alternatives contain components that may lie outside the Park boundaries. See figure 1-1. The Park is within the Colorado Plateau in northwestern Arizona and encompasses 1,218,376 acres. It is bounded on the north by the Kaibab National Forest and the Arizona Strip District of the Bureau of Land Management (BLM), on the east by the Navajo Reservation, on the south by the Kaibab National Forest and Hualapai and Havasupai Reservations, and on the west by the upper reaches of Lake Mead National Recreation Area.

1.4 Public Involvement and Scoping

General public involvement activities were not conducted at this level of planning, but will be conducted during the feasibility study.

1.5 Previous Studies of the Study Area

Previous studies in the study area include the following:

- Final Environmental Impact Statement for Tusayan Growth, Kaibab National Forest

Other water and related resources activities include:

- North Central Arizona Regional Water Study
- Western Navajo pipleline
- Coal Slurry/Mohave Pipeline lease renewal
- Coconino hydrological research
- Glen Canyon Environmental Study and Grand Canyon Research and Monitoring

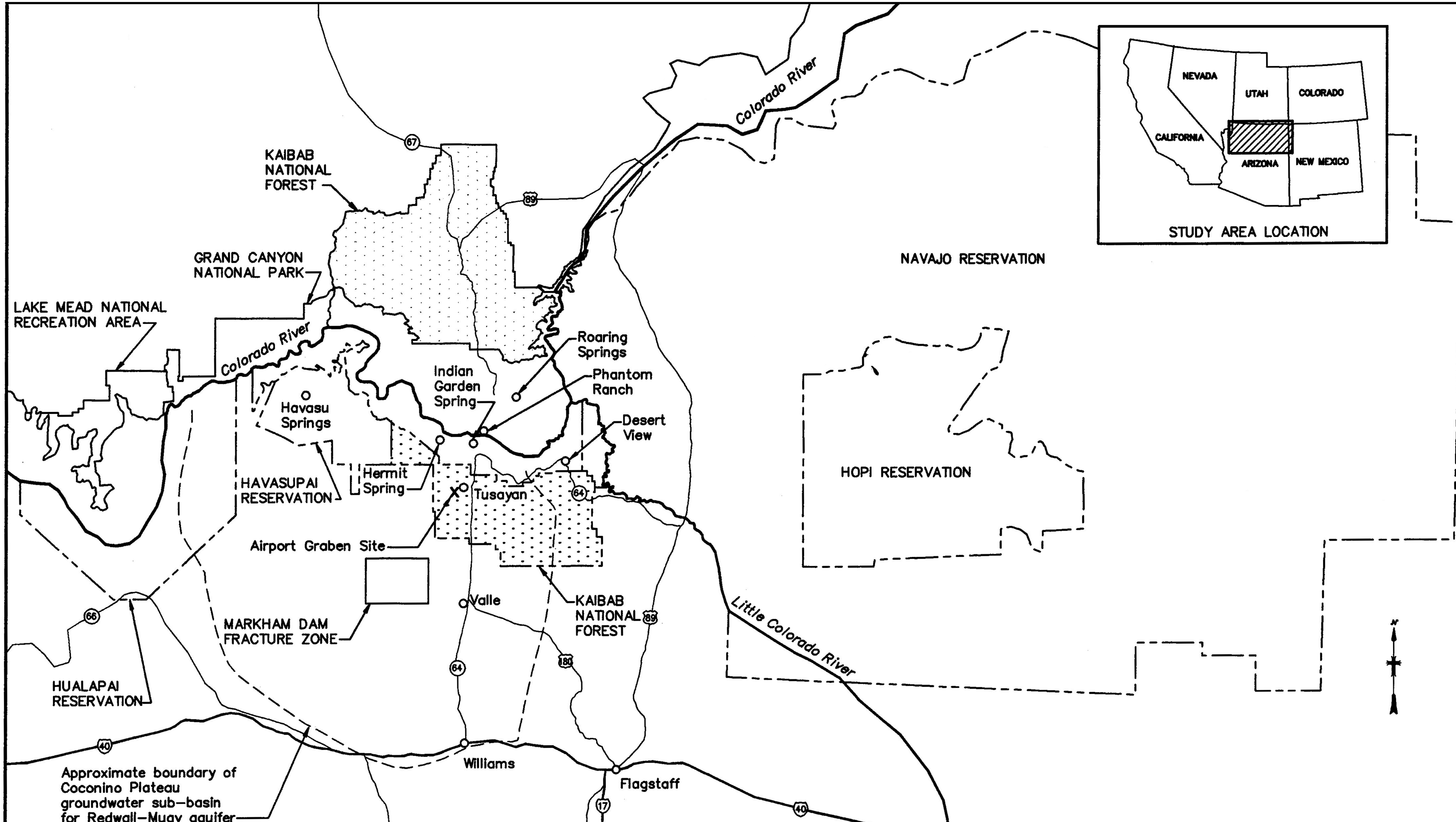

Figure 1-1.- General location map.

CHAPTER 2

Need for Action

This chapter describes the Park's need for a reliable water supply through the year 2050.

Estimated water use at the Park in 1999 was 194.1 million gallons, or 596 acre-feet (af) a year. Based on NPS projections, increased visitor growth would about double this water use by the year 2050 to 1,255 af per year (NPS, 2000).

Currently, the 12.5-mile-long transcanyon pipeline (TCP) delivers water by gravity flow from Roaring Springs, located approximately 3,000 feet below the North Rim in Bright Angel Canyon, to Indian Garden. Indian Garden, a NPS camping area with a pump station, is located along the Bright Angel Trail on the south side of the Colorado River, about 3,000 feet below the South Rim. Water is then pumped from the Indian Garden pump station through a directional bore hole to water storage tanks on the South Rim before it is delivered to developed areas along the South Rim. Nearly 90 percent of the Park's 5 million annual visitors enter at the South Rim; the remaining visitors enter at the North Rim.

The TCP frequently experiences two types of failures: (1) failures at bends in the pipeline and (2) failures due to washouts during high flow events. The reach of the TCP most sensitive and vulnerable to washouts is located in the "Box" area, a long narrow section of Bright Angel Canyon upstream of Phantom Ranch. Here, the TCP is buried beneath the trail carved out of the cliff wall. (Phantom Ranch is a camping area located on the north side of the Colorado River, near the confluence of Bright Angel Creek and the mainstem Colorado River.)

About 10 to 12 minor failures occur throughout the TCP each year, mostly in the Box area during the spring. Each failure costs about $15,000 and requires 1-4 days to repair. A catastrophic event occurs every 5 to 8 years that temporarily stops the flow of water to Park facilities on the South Rim. Washouts require more than $100,000 to repair. A maintenance plan is being developed now that will probably add about $250,000 to the cost for a full maintenance program, including the replacement of air valves.

These frequent failures of the TCP make it imperative for the Park to acquire a reliable, long-term water supply to meet existing and future visitor needs.

This study examines several alternatives intended to meet these needs, including use of groundwater. Many studies have been commissioned, some controversial, to evaluate the effects of continued development and existing use of groundwater on seeps and springs. The Havasupai Tribe has confidential studies that suggest the continued pumping of the regional aquifer has affected, and will continue to affect, base flow of the Havasupai Spring. Studies are underway (2001 Grand Canyon Park and Arizona Water Protection Fund) to determine the effects on springs in the south wall of the Grand Canyon. Early indications are that groundwater use will adversely affect the seeps and springs emanating from the regional aquifer.

CHAPTER 3

Constraints

This chapter discusses the physical, statutory, social, institutional, and environmental constraints that could limit the capability of the resources to provide a treated water supply to the North and South Rims of the Park through the year 2050.

The viability of any of the alternatives described in chapter 4 is contingent on the many constraints that would apply to any opportunity to meet the study need. NPS would need to consider statutory and institutional constraints on any ground-disturbing activities that could affect the natural resources within the study area, including the following:

- **South Rim seeps and springs.** Participants in the North Central Arizona Water Supply Study, including NPS, have expressed concerns that continued development of groundwater will have long-term adverse effects on seeps and springs in the region.
- **Wetlands.**
- **Caves.**
- **Wilderness area.** In 1993, the NPS called for the immediate designation of 1,109,257 acres and the potential designation of 29,820 acres as Wilderness, for a total of 1,139,077 acres. While not designated, Park policy states that all categories of Wilderness (e.g., potential, proposed study) will be considered and managed as though they were designated Wilderness until legislative action occurs.
- **Wildlife habitat and movement**.
- **Eight species listed as threatened or endangered**.
- **Species listed as sensitive** (including desert bighorn sheep, peregrine falcon, bats, goshawk)

- **Historic buildings, districts, landscapes; archeological sites; traditional cultural properties**. In assessing the potential effects of the alternatives on cultural resources, NPS would coordinate with the nine tribal governments that have cultural and historical affiliations with the Grand Canyon. Each of these tribes maintains a government-to-government relationship with the Park.

CHAPTER 4

Alternatives

This chapter describes alternatives that could provide a treated water supply to the North and South Rims of the Park through the year 2050. Section 4.1 provides background information for the alternatives; section 4.2 describes alternative formulation and engineering methods of analysis. Section 4.3 describes alternatives 1 through 8—the construction alternatives—in detail and alternatives 9, 10, and 11 in concept only. Section 4.4 summarizes cost estimates for alternatives 1 through 8. Table 4-12 (at the end of the chapter) compares the effects of the alternatives on resources in the study area. Appendix 1 includes cost estimate worksheets for alternatives 1 through 8; appendix 2 contains the field report and cathodic protection requirements; and appendix 3 contains the hydraulic design notes.

4.1 Background

This section describes the study area setting, geology, and the Park's existing water supply system.

4.1.1 Setting

The study area is Grand Canyon National Park, located in northern Arizona. See figure 4-1, location map. The Grand Canyon divides the Park into the North Rim and South Rim areas. The South Rim has two entrances: the south entrance at the unincorporated community of Tusayan and the east entrance at Desert View. Other communities in the area include Valle, Williams, and Flagstaff. Phantom Ranch, located in the inner Grand Canyon, is a camping area that includes a NPS housing area and wastewater treatment plant.

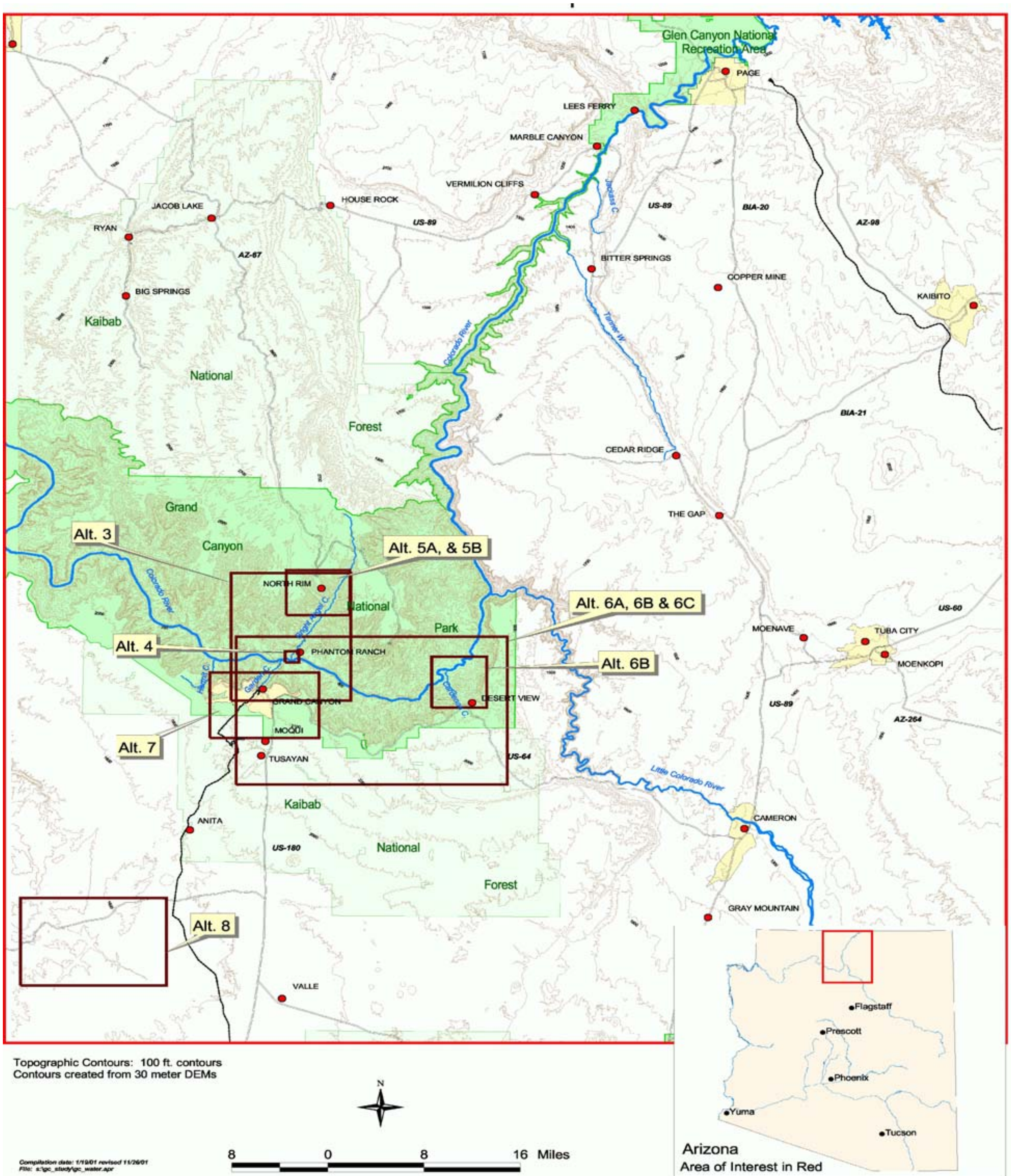

Figure 4-1.—Location of alternatives.

The two primary highways to the South Rim are U.S. 180 and State Route 64. U.S. Highway 180 connects Flagstaff to Valle, where it joins State Route 64 heading north from Williams. From Valle to Tusayan, the highway is jointly named U.S. Highway 180/State Route 64. Access to the North Rim is via State Route 67. See figure 1-1.

4.1.2 Geology

The Grand Canyon lies within the physiographic region known as the Colorado Plateau or Plateau Province. The Canyon's South Rim is considered a part of the Coconino Plateau, and the North Rim is a part of the Kaibab Plateau.

The Canyon consists of 11 Paleozoic Era-aged layers that from top to bottom (youngest to oldest) include the following: Kaibab Formation, Toroweap Formation, Coconino Sandstone, Hermit Shale, Supai Group, Surprise Canyon Formation, Redwall Limestone, Temple Butte Formation, Muav Limestone, Bright Angel Shale, and Tapeats Sandstone. Below the Tapeats Sandstone, Precambrian Era rocks are represented by two groups—one group composed of crystalline metamorphics (such as the Vishnu Schist) and the other of mostly unmetamorphosed sedimentary rocks.

4.1.2.1 Redwall-Muav Aquifer.—The primary water-bearing unit of the Coconino Plateau is the Redwall-Muav aquifer, found in the Redwall, Temple Butte, and Muav Limestones about 3,000 feet below the ground surface. The Redwall-Muav Limestone, which overlies the Bright Angel Shale and underlies the Supai Group, ranges from about 500 to 750 feet thick. The top of the Redwall-Muav Limestone formation is at a lower elevation than the water table, except as it approaches the South Rim, where only the lower half or so of the Redwall-Muav aquifer is saturated.

The Redwall-Muav aquifer is the only regional Coconino Plateau aquifer capable of yielding useable quantities of good quality water to wells. Most water supply wells in the Coconino Plateau tap this aquifer. Deep wells in Williams and Tusayan, for example, are completed in the Redwall-Muav aquifer. The largest South Rim springs, Havasu, Hermit, and Indian Garden Springs, (figure 1-1) also derive their flow from this aquifer. Springs along the lower South Rim support diverse flora and fauna and some known sensitive species.

4.1.2.1.1 Groundwater Recharge and Discharge.—Most of the recharge to the Redwall-Muav aquifer in the Coconino Plateau is via faults that propagate from the ground surface down through the strata. Spring discharge points on the South Rim of the Grand Canyon tend to be found where faults intersect the rim, indicating that the faults act as conduits. For example, the Havasu downwarp leads directly to Havasu Spring, the Hermit Fault leads to Hermit Spring and its associated springs, and the Bright Angel Fault leads to Indian Garden Spring.

Some investigators (Montgomery and Associates, 1996) report that about 98 percent of the reported discharge occurs at Havasu, Hermit, and Indian Garden Springs. The greatest discharge from the aquifer in the Coconino Plateau is thought to be 29,000 gallons per minute (gpm) at Havasu Spring. Groundwater discharge at Hermit Spring and Indian Garden Spring occurs along faults and related fracture systems. The base rate of discharge at each of these springs is 300 gpm.

Sections 4.3.7 and 4.3.8 discuss whether and to what extent new wellfields could affect South Rim springs and seeps.

4.1.2.1.2 Other Seeps and Springs.—A number of other seeps and small springs issue from the Redwall-Muav aquifer within the Grand Canyon. The seasonal nature and unsteady base flow of many of these seeps and small springs—compared to the steady flow of Havasu, Hermit, and Indian Garden Springs—suggest that discharge from these seeps and small springs may result mainly or solely from local near-rim recharge.

Perched water[1] is known to occur at the base of the Coconino Sandstone and throughout the Supai Group in the Coconino Plateau region. From these units, perched water is the source of small springs and seeps which discharge from the south Canyon walls. These small water-bearing zones respond to seasonal droughts and probably would not yield

[1]Groundwater that occurs in a saturated zone that is higher than the general body of groundwater (in this case, the regional Redwall-Mauv aquifer) and separated from it by an unsaturated zone.

enough good quality water from wells drilled in any site near the South Rim. Drilling many moderately deep wells is not worthy of consideration as a reliable supply of water.

4.1.2.2 Depth to Water.—Some of the alternatives under consideration consider drilling wells, both inside and outside the Park. To fully penetrate the Redwall-Muav aquifer near the Canyon, wells inside the Park would need to be about 3,000 to 3,400 feet deep because the water table surface drops in elevation from about Tusayan north as the South Rim is approached. Wells outside the Park would need to be about 2,500 feet deep.

Table 4-1 shows that the depth to water in seven existing wells, which fully penetrate the Redwall-Muav aquifer, ranges from about 2,350 to 2,600 feet below ground surface (bgs). Land surface elevations vary from about 6000 feet above mean sea level (amsl) at Valle, about 5500 in the Markham Dam Fracture Zone (MDFZ) area, to 6500 feet amsl at Tusayan and 7000 feet amsl at the South Rim. Montgomery (1996) used static water level readings from these wells to calibrate its steady-state groundwater model.

Table 4-1.—Characteristics of existing wells in the Coconino Plateau that penetrate the Redwall-Muav aquifer

Cadastral location	Located by	Reported yield (gpm), casing diameter (inches)	Water level elevation (feet amsl)	Depth to water (feet bgs)
(A-25-2) 27 aba	Quivero	28, 7	3327, poor quality	2838
(A-26-2) 01 cdd	Valle	41, 8	3550	2500
(A-26-2) 11 ddc	Valle	89, 8	3450	2550
(A-29-3) 20 bcd	Canyon Mine	5, 5½	3971	2534
(A-30-2) 24 bac	Tusayan	65, 8	4200	2400
(A-30-2) 24 caa	Tusayan	80, (as built), 8	4155	2420
(B-32-4) 24 cd	Supai	50, 5½	3310	2370

Note: Modified from table 3 in Tusayan Growth Environmental Impact Statement appendix (USDA, 1999).

Although one or several wells possibly could supply the entire amount of water that the Park needs in the future (for example, if the well screen were to tap a good water-bearing, cave feature), as many as 15 new wells, each 3,000 to 3,400 feet deep, may be required to produce the needed amount. This premise is based on data from deep wells completed in the Redwall-Muav aquifer and assumes that sustained yields of 50 gpm are available from any given new well, while assuming minimal drawdown interference in a wellfield setting.

4.1.2.3 Groundwater Conditions for the North Rim.—As discussed previously, Roaring Springs, located about 3,000 feet below the North Rim, is the primary source of water for both rims. Roaring Springs is a perennial spring that emanates from a solution opening (cave in the hillside) in the Muav Limestone at about elevation 5270. See figure 4-2. The spring occurs above the apex of the intersection of the Roaring Springs and Bright Angel faults (the two canyons are the eroded expressions of these faults). The Roaring Springs cave discharges an average of 3,500 gpm of water but can discharge up to 20,000 gpm during flood events. (However, Huntoon (2000) reports the normal discharge as 9 cubic feet per second (cfs) or 4,039 gpm, or 6,516 af per year.)

4.1.3 Transcanyon Pipeline

Indian Garden Spring, located 3,000 feet below the South Rim, was the original water source for the Canyon's South Rim. However, because this spring could not meet visitor growth needs in the 1960s, the NPS in 1970 completed a 12.5 mile-long transcanyon pipeline from Roaring Springs to the North Rim (figure 4-3).

The TCP delivers water from Roaring Springs to the North Rim by pumping (Roaring Springs pump station) and by gravity flow to Indian Garden, below the South Rim. Water is then pumped from the Indian Garden pump station through a directional bore hole to water storage tanks on the South Rim before it is delivered to developed areas along the South Rim. (A small amount of the flow between Roaring Springs and Indian Garden is siphoned off the TCP to supply Cottonwood and Phantom Ranch.

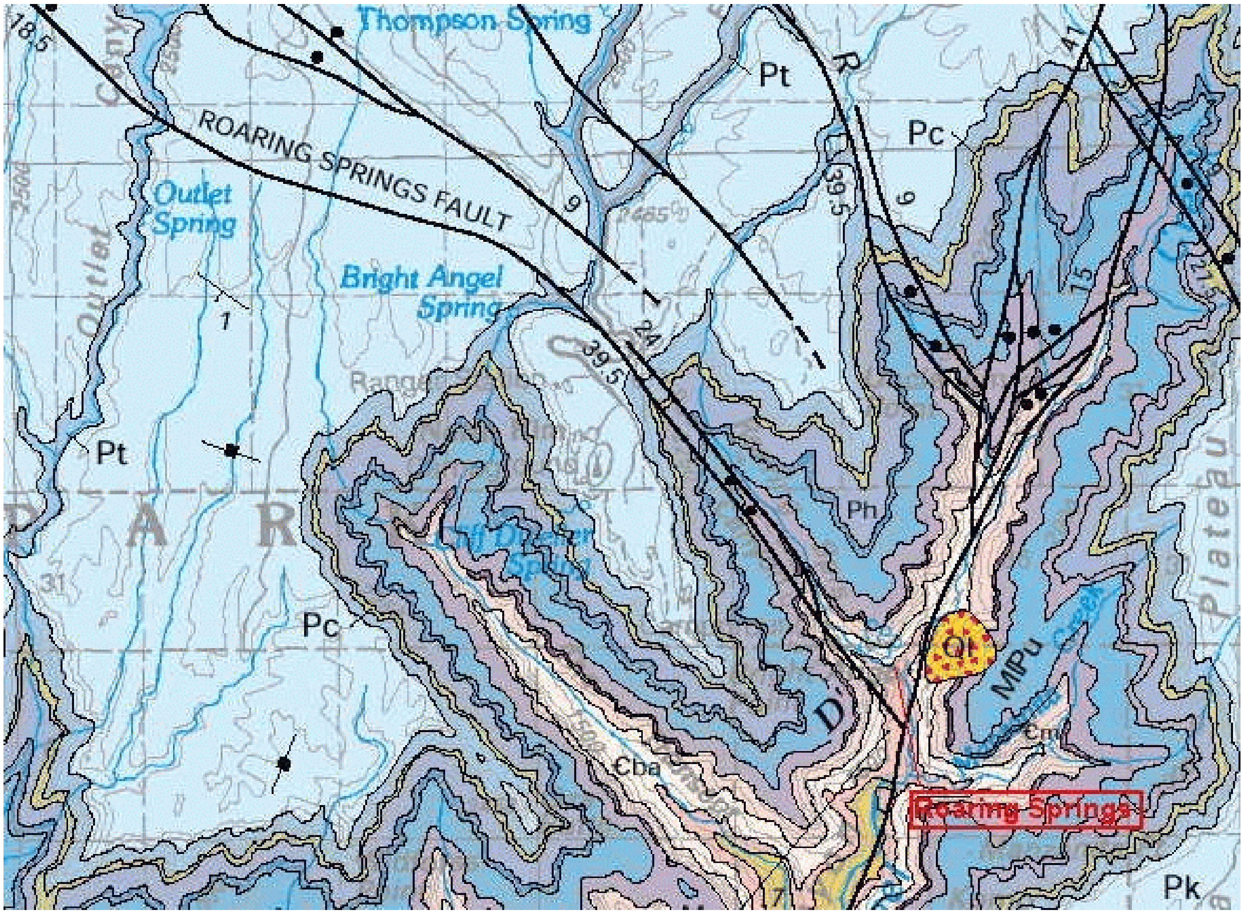

Figure 4-2.–Geologic map of North Rim and Roaring Springs (after Billingsly, 2000).

Cottonwood is a primitive camp area located 2 miles north of Phantom Ranch along the TCP alignment towards the Roaring Spring pump station.)

The TCP delivers 117 gpm to the North Rim when the pump is operating. The TCP delivers 650 to 700 gpm continually (24 hours per day, 7 days a week) between Roaring Springs and Indian Garden, or approximately 360 million gallons per year. The Indian Garden pump station can deliver a minimum flow of 530 gpm and a maximum flow of 640 gpm. The pump runs about 70 percent of the time (off-peak hours) and pumps approximately 200 million gallons to the South Rim annually. The remaining 160 million gallons is diverted to a riparian area (Garden Creek) at Indian Garden when the pump is not operating.

Figure 4-3.—Alternative 1.

The water storage tanks on the South Rim have a capacity of 13 million gallons, a 2-week water supply for the South Rim. The bottom 6 million gallons is held in reserve for fire protection, and the top 7 million gallons is used for the potable water supply. The water is treated (chlorinated) at the springs, North Rim, and South Rim storage tanks. Turbidity and mineral matter are also extracted from the water at the springs, pump sites, and storage tanks, but removal of these particulates is not a major problem.

4.2 Alternative Formulation and Engineering Methods of Analysis

Reclamation held a 2-day brainstorming session with NPS on July 19-21, 2000, at the Park to develop or consider alternatives that would provide a water supply to the Park.

Reclamation evaluated 11 alternatives. Alternatives 1 through 8 were evaluated at an appraisal-level of detail. Alternatives 9 through 11 are discussed in concept only, and costs were not estimated. (See chapter 1 for a definition of appraisal study.)

1. No Action
2. Repair or Replace Portions of the TCP
3. Replace the TCP from Roaring Springs to the Colorado River
4. Construct an Infiltration Gallery and Pumping Plant on Bright Angel Creek to Supply the South Rim and Phantom Ranch
5. Drill a Well from the North Rim to Roaring Springs
6. Use the Colorado River to Supply the South Rim and Continue to Use Roaring Springs to Supply the North Rim
7. Construct a Wellfield Inside the Park
8. Construct a Wellfield Outside the Park
9. Obtain a Dependable Water Supply from Water Providers or Companies
10. Truck or Train Water into Park
11. Develop Water Conservation Measures

To develop the alternatives, Reclamation first examined the following:

- Flow demand (for all alternatives)
- Hydraulics (for all alternatives except 9, 10, and 11)
- Diverting Colorado River water (alternative 6)
- Directional drilling (alternatives 5A, 5B, 6B, and 6C)

4.2.1 Flow Demand

The Park's current water demand is 596 af a year (NPS, 2000). Reclamation used a peaking factor of 1.3 to derive the maximum day volume of 3.41 af. The peaking factor is based on information derived from *Water Delivery System Analysis, Appraisal Level Peer Review Study of the ADWR Phase 1, North Central Arizona Water Supply Study* (Reclamation, 2000a). Assuming pumping occurs 20 out of 24 hours on the maximum day, the required design flow is 1.72 cfs. Current maximum flow rate for the South Rim is 1.56 cfs. The remaining 0.16 cfs of the flow, or 10 percent, goes to the North Rim.

The Park's 2050 water demand was assumed to be 1,255 af a year (NPS, 2000). Using the same factors applied to the current demand, this demand equals a maximum day volume of 5.36 af and maximum flow rate of 2.70 cfs. The amount of flow required at the North Rim was increased from 10 percent to 20 percent of the total flow required in the Park. Therefore, for the South Rim, the maximum day volume is 4.29 af and the maximum flow rate is 2.16 cfs. For the North Rim, the maximum day volume is 1.07 af and the maximum flow rate is 0.54 cfs.

The flow demand of Phantom Ranch was based on information from John Beshears, Park Engineer (Beshears, 2001).

Average day = 10,000 gallons
Peak day = 14,000 gallons

4.2.2 Hydraulics

For alternatives 1, 2, 3, 4, 5, 6, and 8, Reclamation examined the existing TCP to determine the flow characteristics. Appendix 3 includes spreadsheets that show detailed hydraulic analyses. Park personnel provided data indicating that, in the past, the TCP supplied a maximum flow rate of 1.56 cfs to the South Rim. Reclamation determined losses using this flow rate and existing pipeline sizes. Reclamation used a "C" value of 143 as the frictional co-efficient to design a new, larger TCP (alternative 3) and the other pipeline alternatives (alternatives 2, 4, 5, and 6).

Reclamation derived all data for lengths and sizes of pipeline for the existing TCP from the Richard P. Arber Associates Inc. report, *Corrosion Assessment of Transcanyon Pipeline, Grand Canyon National Park* (Arber, 1993).

4.2.3 Colorado River Diversions

This section discusses diverting water from the Colorado River, which is a component of alternative 6.

4.2.3.1 Options for Diverting Colorado River Water.—Three possible options exist for diverting water out of the Colorado River to a pumping plant site: (1) infiltration gallery, (2) river intake, and (3) canal diversion.

4.2.3.1.1 Infiltration Gallery.—An infiltration gallery is essentially a horizontal well or subsurface drain that intercepts underflow in permeable materials or infiltration of surface water. Infiltration galleries are usually constructed to discharge water into a pump sump. The gallery can be placed below or adjacent to the river. The collector pipelines should always be packed with gravel. An infiltration gallery site requires permeable soils. Following are the advantages and disadvantages of an infiltration gallery.

Advantages

1. Intake facility would be buried.
2. No sediment disposal required.
3. Could be installed outside of the river bed.
4. Works with large river elevation fluctuations.

Disadvantages

1. Sands and gravels of sufficient stability to prevent movement of fines may be difficult to locate in the Canyon.
2. May have to construct a gallery with three times capacity to provide required reliability.

4.2.3.1.2 River Intake.—A river intake would consist of a pipeline that extends into the river and has a screening system at the end. The water would then be pumped into a settling basin or clarifier. The screens would be exposed to the elements in the river. Following are the advantages and disadvantages of a river intake.

Advantages

1. Can be installed in rocky areas.
2. Works with large fluctuations in river elevation.
3. Intake facility would be buried or below water line in river.
4. Less sediment to dispose of than with a canal diversion.

Disadvantages

1. Intake is exposed in the river.
2. Requires sediment trap.
3. Settling basin or clarifier is exposed.

4.2.3.1.3 Canal Diversion.—To divert water out of the Colorado River, a canal could be constructed that would divert water from the river into a settling basin, where the water would be pumped after the sediment has dropped out. This method normally requires a diversion dam in areas where the river fluctuates widely to provide a constant head into the canal diversion. Following are the advantages and disadvantages of a canal diversion.

Advantages

1. Simple system that provides reliable water delivery.

Disadvantages

1. Requires sediment disposal or sluicing back to the river.
2. Facilities are exposed.
3. Requires diversion dam.
4. Possibly high costs to removal of sediment may be high.

After evaluating these three options, Reclamation concluded that an infiltration gallery is the best option for use in the Canyon. All sites investigated for Colorado River diversions were evaluated based on an infiltration gallery design.

4.2.3.2 Treating Diverted Colorado River Water.—Under alternative 6, a peak day demand of 4.29 af or 1.4 million gallons per day (MGD) would be diverted from the mainstem of the Colorado River and treated to meet the requirements of the Surface Water Treatment Rule (SWTR) under the Safe Drinking Water Act (SDWA).

The appraisal level design for treating Colorado River water was based on unit capital and operation costs developed for the city of Espanola, New Mexico, in 2000 to evaluate using the Rio Grande River as an alternative water supply (Reclamation, 2000a).

Table 4-2 characterizes the water quality at two locations on the Colorado River: Lees Ferry and Glen Canyon Dam. With total dissolved solids (TDS) and sulfates below or at the secondary maximum contaminant levels of 500 parts per million (ppm) and 250 ppm respectively, water of this quality could be treated using either a ultrafiltration or a conventional system to meet the requirements of the SWTR. To reduce the effects of this turbid water on the treatment system, a streambed infiltration system would be used.

Table 4-2.—Colorado River water quality

Water quality parameter (mg/L)	Colorado River at Lees Ferry	Colorado River at Glen Canyon Dam	SMCL[1]
Average TDS concentration	489	512	500
Average sulfates concentration	205	228	250
Chlorides	41	45	250
Average total suspended solids - TDS	4.1	3.7	None
Maximum TDS	19	17	None
Average alkalinity	128	129	None

[1] Secondary maximum contaminant limits. These levels relate to aesthetic qualities only.
Source: 1990's U.S. Geological Survey data base.

The appraisal level design includes the cost and land requirements for two complete water treatment systems: hollow fiber ultrafiltration and conventional treatment. The estimated appraisal level capital cost of the state-of-the-art, hollow fiber ultrafiltration system with ultraviolet (UV) disinfection, clearwell, residual chlorination, controls, settling ponds, and building is $3.70 per gallon per day capacity, or $5,200,000. The estimated appraisal level annual operation and maintenance (O&M) cost is approximately $0.38 per million gallons per day capacity, or $532,000. Annual O&M costs include chemical usage, power, cost for operators, and annualized costs to replace membranes and pumps every 10 years. Costs to clean and dispose of material collected in the evaporation ponds are not included.

The estimated appraisal level capital cost of the conventional treatment system with UV disinfection, clearwell, residual chlorination, controls, evaporation ponds, sludge storage ponds, and building is $2.60 per gallon per day capacity, or $3,640,000. The estimated annual appraisal level O&M cost is $0.43 per million gallons per day capacity, or $602,000. Annual O&M costs include chemical usage, power, cost for operators, and annualized costs to replace pumps every 10 years. Costs to clean and dispose of material collected in the evaporation ponds and sludge storage ponds are not included.

In both systems, the wastewater generated during membrane cleaning, without citric acid, and sand filter backwash water would be routed to the settling ponds for settling and reuse.

Both systems would treat the water diverted from the Colorado River to a quality that meets current and future SWTR regulations. The main difference between the systems is that the conventional system would produce large amounts of chemical sludge that would need to be stored on site and eventually disposed of as waste. It would also require a larger "footprint."

Following are additional advantages and disadvantages of both systems.

Advantages of the Hollow Fiber Ultrafiltration System

1. Physically removes suspended solids greater than 0.1 microns in diameter, which includes Giardia (5-15 microns), Cryptosporidium (4-6 microns), large virus and large organic molecules, and requires no or minimal chemical addition for coagulation. The system has been demonstrated to remove up to 6 log reduction in Giardia/Cryptosporidium and 2 log reduction in viruses.
2. Is fully automated and easy to operate, and most of the wastewater can be recycled back into the treatment plant.
3. Annual O&M costs are lower than a conventional system because it uses fewer chemicals and requires no or little management of generated sludge.
4. Requires less land above the 100-year flood elevation.

Advantages of a Conventional Treatment System

1. Has lower capital costs and has been demonstrated to physically remove 2.5 logs (99.5%) of Giardia, 2.0 logs (99%) of Cryptosporidium and 2.0 logs (99%) of viruses.

Disadvantages of a Hollow Fiber Ultrafiltration System

1. Has a higher capital cost than a conventional treatment system.
2. Uses more water for continual cleaning or back washing than a conventional system and requires routine cleaning with citric acid. Although the citric acid is naturalized, it requires further treatment and disposal.
3. Hollow fiber modules typically need to be replaced every 10 years.

Disadvantages of a Conventional Treatment System

1. Requires highly skilled operators.
2. Requires the injection of a chemical coagulant.
3. Produces large quantities of sludge.

Table 4-3 provides an overview of the estimated land requirements and per gallon costs for each treatment system. Figures 4-4 and 4-5 show the approximate site layout for each system.

If alternative 6 were selected, additional data, including maps of the potential sites, would be needed to further refine surface water treatment costs and land requirements.

Bench scale testing and pilot testing of each treatment system would be required to verify the ability of each proposed treatment systems to meet the requirements of SWTR and to analyze the production of disinfection byproducts during the conveyance of treated water to various service points within the Grand Canyon.

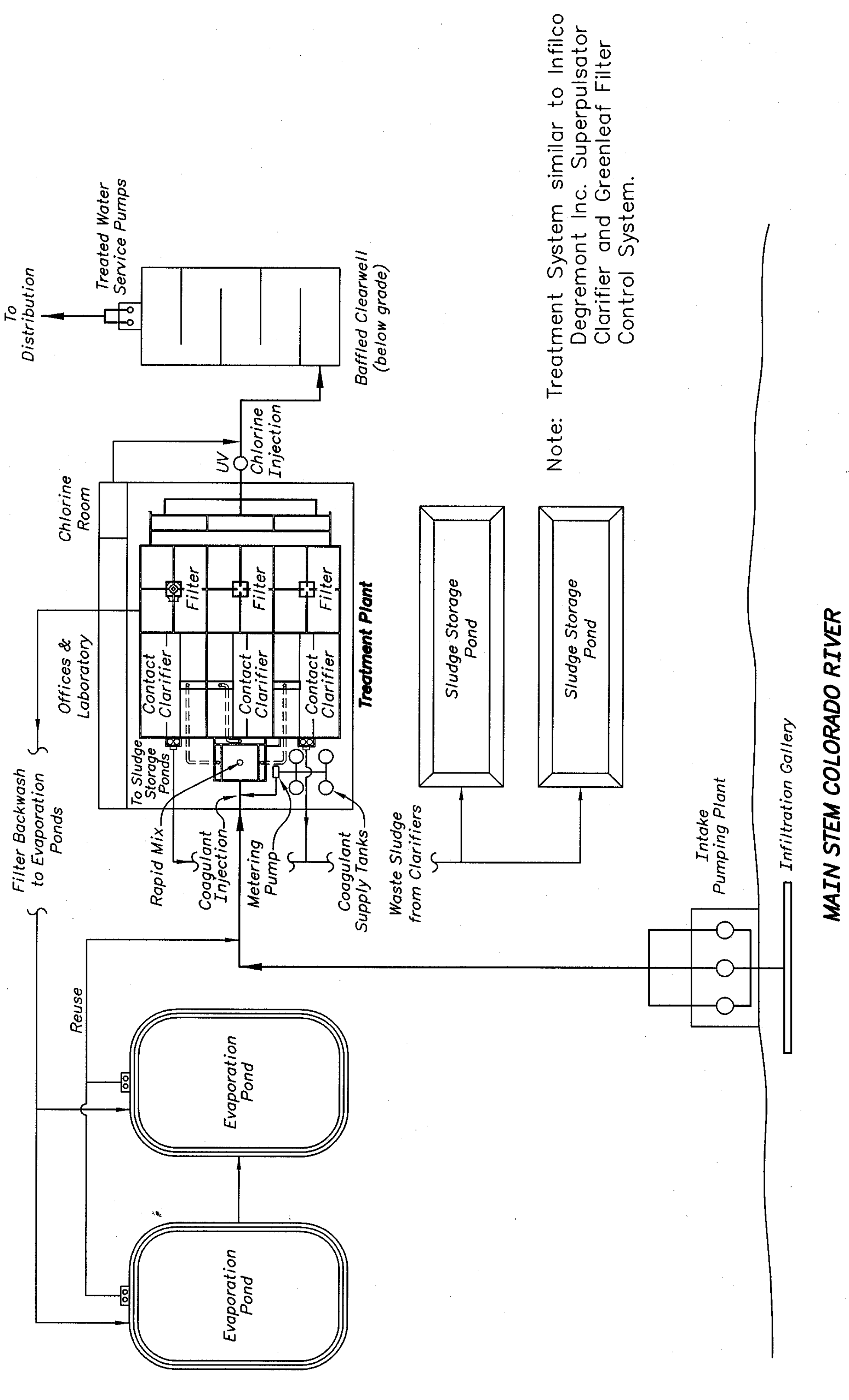

Figure 4-4.—Site layout – conventional treatment plant.

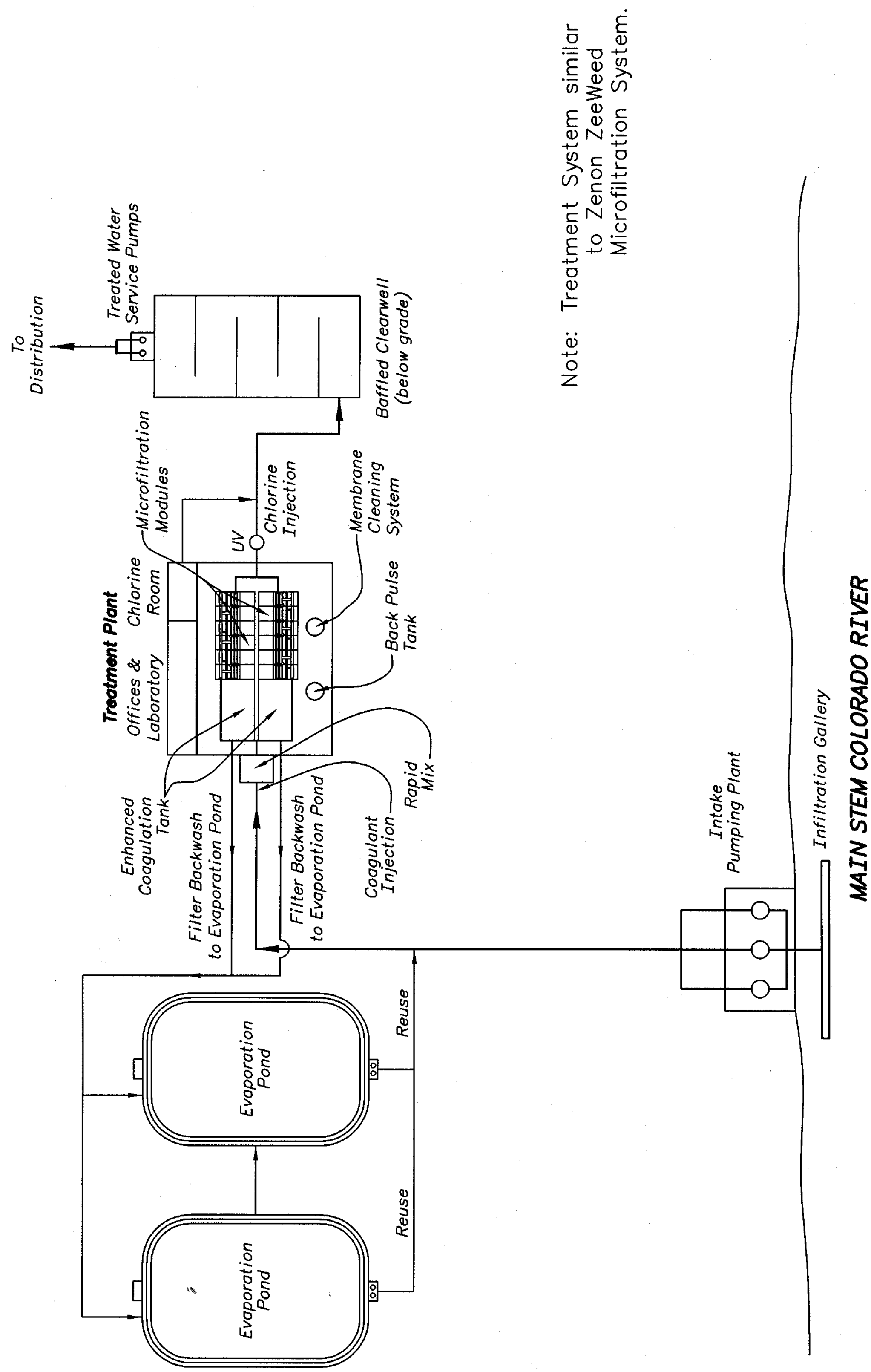

Figure 4-5.—Site layout – microfiltration treatment system.

Table 4-3.—Estimated land requirements for each treatment system (treatment rate of 1.4 MGD)

Feature	Conventional system (acres)	Ultrafiltration system (acres)
Treatment plant	0.11	0.1
Clearwell	0.03	0.03
Evaporation ponds	2.0	2.0
Sludge storage ponds	2.0	not required
Miscellaneous area for roadways, intake structure, etc.	0.5	0.5
Land requirement (acres) above 100-year flood elevation	4.64 say 5	2.63 say 3
Capital cost per gallon of water treated per day	$2.60	$3.70
Annual operations and maintenance costs per gallon of water treated water per day	$0.43	$0.38
Appraisal-level capital cost	$3,640,000	$5,200,000
Appraisal-level annual O&M cost	$602,000	$532,000

Source: Reclamation, 2000a.

4.2.4 Directional Drilling Technology

Reclamation examined directional drilling technology for alternatives 5A, 5B, 6B, and 6C. Current technology for drilling holes up to 12¾ inches in diameter suggests that it may be feasible to drill up to 12,000 feet using technology acquired from drilling oil wells.

However, based on the previous directional drilling at the Park, it seems likely that the hole may have to be drilled using air instead of a fluid because of leakage into the rock. Based on telephone conversations with Jerry Cerkovnik of Baker-Hughes, a horizontal directional drilling contractor, this would limit the practical length of air drilling to around 6,000 feet.

A directional drilled hole at the Park in the 1980s missed the final exit point by 200 feet, but technology advancements should significantly improve the accuracy. Baker-Hughes gave cost guidelines but stated that, without more information, uncertainties still exist.

The construction cost estimates assume 200 feet per day could be drilled and assume mobilization/demobilization costs of $100,000 and drilling costs of $30,000 per day. Final design would require the construction records for the hole drilled in the1980s and possibly some exploratory drilling on the North Rim.

4.3 Description of Alternatives

This section describes alternatives 1 through 8 in detail and provides a general description of alternatives 9, 10, and 11.

4.3.1 No Action Alternative (Alternative 1)

The No Action Alternative serves as the basis for comparing the effects of the alternatives. Under the No Action Alternative, NPS would maintain the TCP and continue to use Roaring Springs as the Park's main water source.

The existing TCP could not meet the flow requirements for the year 2050. The 6-inch sections of the pipeline would have to be replaced with 8-inch pipeline to meet this demand.

As discussed in chapter 2, the existing aluminum TCP experiences periodic failures that result in short-term outages that can lead to water restrictions in the Park. The failures are usually of two types: (1) failures at bends in the pipeline and (2) failures due to washouts during high flow events. The reach of the TCP most sensitive and vulnerable to washouts is located in the "Box" area, a long narrow section of Bright Angel Canyon upstream of Phantom Ranch.

About 10 to 12 minor failures occur in the TCP each year, mostly in the Box area during the spring. Each failure costs about $15,000 and requires 1-4 days to repair. A catastrophic event occurs every 5 to 8 years that temporarily stops the flow of water to Park facilities on the South Rim. Washouts require more than $100,000 to repair. A maintenance plan is being developed now that will probably add about $250,000 to the cost for a full maintenance program, including the replacement of air valves.

Under the No Action Alternative, pipeline sections that fail would continue to be replaced as needed.

Reclamation conducted a survey in the early 1990s to determine the past performance of buried water pipelines, which culminated in the report, *Historical Performance of Buried Water Pipelines*, dated September 1994. This report compiled the failure rates for 12 different pipeline types from Reclamation and American Water Works Association (AWWA) water users. Failure rates were calculated using a weighted average age of pipeline to account for older pipelines that were more likely to have experienced more failures. Age for a pipeline was weighted by the feet of pipeline for a given pipeline type. The number of failures was then divided by the weighted average age and length of pipeline to yield failures per mile-year, as shown in the following tabulation:

Pipeline type	Failure rate
Asbestos cement	2.63
Cast iron	5.97
Ductile iron	1.75
Embedded cylinder prestressed concrete	[1]4.9
Lined cylinder prestressed concrete	0.3
Non-cylinder prestressed concrete	[1]48
Polyethylene	15.8
Pretensioned concrete cylinder	0.84
Polyvinyl chloride	2.14
Reinforced concrete	5.3
Reinforced concrete cylinder	0.0
Reinforced plastic mortar	5.82
Steel	3.4
Combined average	4.40

[1] Rates were determined based on projected repairs for Reclamation siphons on the Central Arizona Project.

While the report did not address aluminum pipeline, Reclamation derived a general sense of its expected reliability. Assuming that the 30-year-old TCP has experienced 10 breaks a year for the last 10 years, its failure rate per mile-year is 30.9, or nearly 10 times the combined average for the different pipeline types shown in the tabulation. From this failure analysis, Reclamation concluded that the reach of the TCP on the north side of the Colorado River should be replaced.

Future pipeline breaks and washouts will keep the TCP from being a reliable water source; therefore, sufficient water storage for Phantom Ranch must be addressed. A small storage tank could be constructed to supply water during outages due to line breaks. The tank should be designed for a 5-day supply and should also provide adequate fire protection. The tank could be sized on the maximum day usage of 13,000 gallons, which equates to a 65,000-gallon tank. The tank would be approximately 22 feet high and 22 feet in diameter. Figure 4-6 shows the piping and pumping plant associated with the storage tank.

Reclamation did not complete surveys to determine if the TCP is actively corroding. Appendix 2 includes recommendations for future study of the cathodic protection system.

4.3.1.1 Estimated Costs.—Estimate sheet No. 1 in appendix 1 summarizes the estimated quantities and costs of alternative 1.

4.3.1.2 Conclusions.—Alternative 1 is the least expensive of all alternatives under consideration, but it does not solve the problem of TCP breaks and washouts. The addition of a storage tank at Phantom Ranch would provide some flexibility for future TCP outages. Additionally, alternative 1 is not viable because the 6-inch pipeline would not meet the future water needs, which require an 8-inch pipeline.

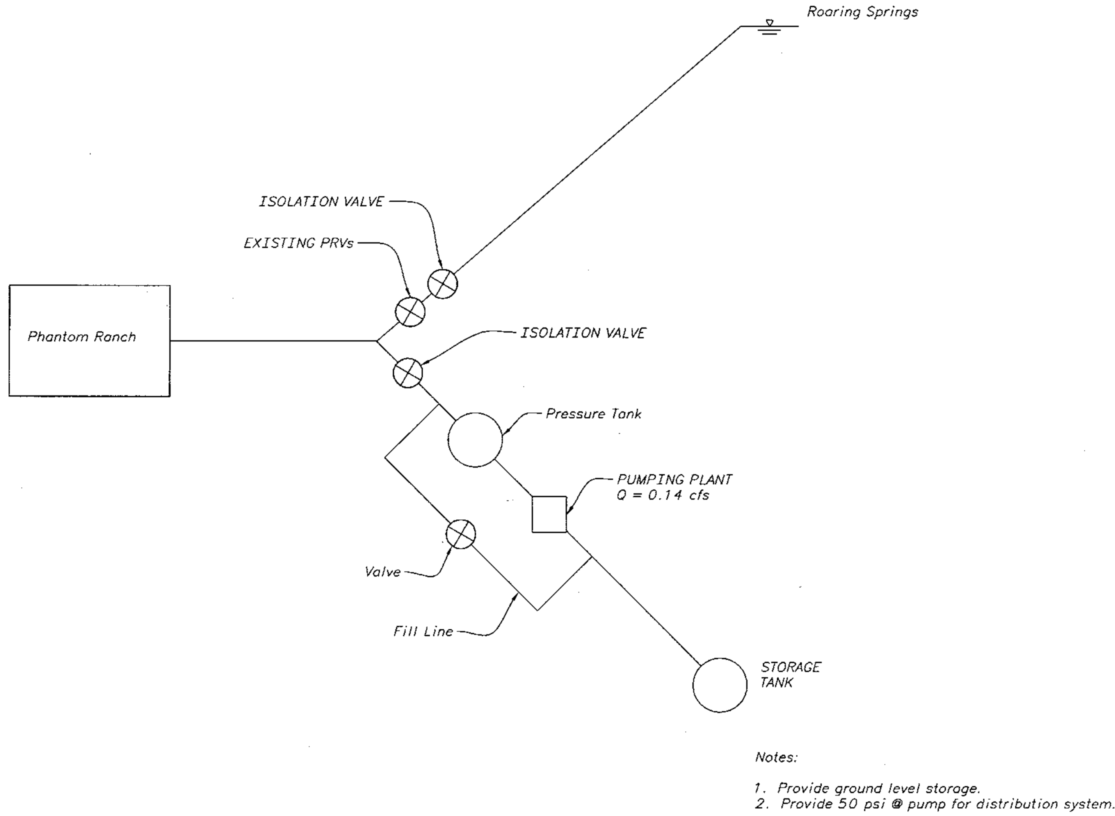

Figure 4-6.—Phantom Ranch schematic.

4.3.2 Repair or Replace Portions of the TCP (Alternative 2)

Under alternative 2, the reach of the TCP on the north side of the Colorado River (in the Box area) would be replaced. This reach can be further broken down into areas where problems actively occur.

A total of 36,000 feet of existing 6-inch pipeline would be replaced with an 8-inch pipeline to increase capacity. The objective would be to remove sections of the TCP in the Box area first (reach 1), where pipeline breaks are common. The Box area has approximately 10,000 feet of 6-inch pipeline that would need to be replaced with 8-inch pipeline to provide the required flow rate in 2050. At a replacement rate of 1,000 feet a year, a crew would need 10 years to replace this portion of the pipeline. The remainder of the 6-inch pipeline lies in a reach where washouts occur (reach 2). Assuming a 2,000-foot-per-year replacement, this portion could be completed in 13 years. This estimate assumes one crew would replace one section at a time. This alternative is shown in figure 4-7. Section 4.4.1.1 lists durations and construction times.

The TCP would be drained; original pipeline would be removed and replaced with new sections of pipeline, and then the TCP would be refilled. This work would require a 2-week (or more) shutdown and would have to be performed during times of low demand. It would also require an intensive field survey of the trail to determine as close as possible the horizontal and vertical alignment required for the pipeline. The contractor would then manufacture bends to fit the surveyed alignment, which should minimize the amount of field changes required. Excavation and removal of the previous pipeline would be relatively easy because minimal rock excavation would be required.

4.3.2.1 Pipelines.—To develop pipeline cost estimates, Reclamation divided the pipeline pressure classes into five zones: 1,000 feet, 2,000 feet, 3,000 feet, 4,000 feet, and 5,000 feet. Pipeline pressure class equals elevation of the design gradient (static plus 10 percent) minus the centerline elevation of the pipeline.

In-line sectionalizing valves (valves located in the line of the pipe) would be spaced every 3 miles along the pipeline alignment. They would be housed in a corrugated metal pipeline vault-type structure. Blowoff valves would be located at several low points along the alignment to allow a 3-mile reach to be drained and filled in 72 hours. They would be designed for buried service. Air valves would be located at all high points, at either side of the sectionalizing valves, and where required for filling and draining of the pipeline. They also would be designed for buried service.

4.3.2.2 Excavation and Backfill.—The cost estimate for excavation was based on 100-percent rock trenching and a minimum trail width of 3 feet. The trench excavation for a pipeline was based on a depth equal to the pipeline diameter plus 2 feet, vertical sidewalls, and a trench width of 2 feet. See drawing 4-1. A track-mounted vehicle, such as the Vermeer T455, may be required for rock excavation.