Hetch Hetchy Valley:
A Plan for Adaptive Restoration

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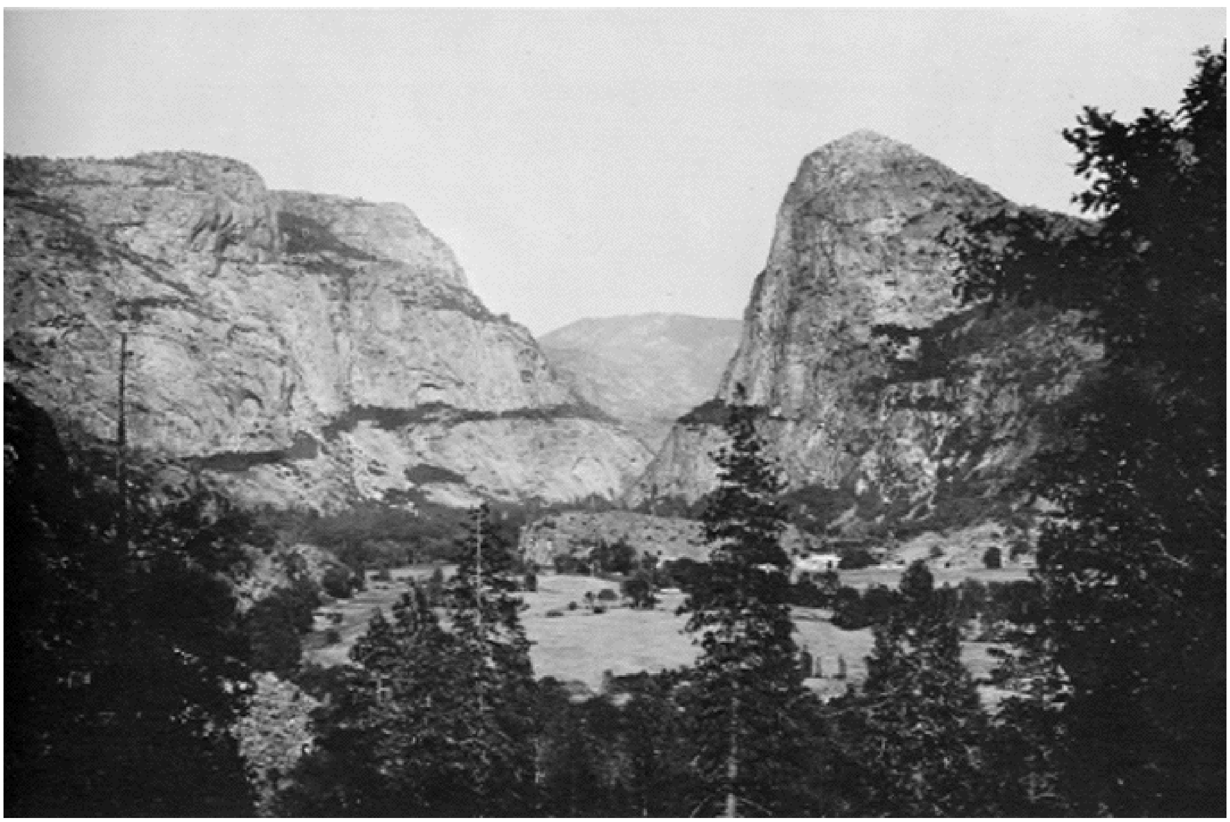

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1.0 INTRODUCTION

1.1 Project Overview

The O'Shaughnessy Dam in Yosemite National Park was completed in 1923 and maintains Hetch Hetchy Reservoir. The reservoir, with a surface area of over 18 kilometers^2, provides drinking and irrigation water as well as hydropower for the San Francisco Bay Area. Cities and farmers in the Bay Area are major stakeholders in maintenance of the dam. However, the reservoir also inundates an area once described by John Muir as "one of nature's rarest and most precious mountain temples." The natural beauty of the area, as well as its high-profile location in one of America's most visited National Parks (NPS 2004), has inspired calls for removal of the dam and restoration of the valley.

Recent investigations by Environmental Defense and the Sierra Club "Restore Hetch Hetchy Task Force" demonstrate the legal, economic and practical feasibility of removing O'Shaugnessey Dam and restoring Hetch Hetchy Valley. This plan addresses the ecological issues surrounding the restoration of Hetch Hetchy Valley, if Hetch Hetchy Reservoir and dam were to be decommissioned.

1.2 Restoration Goal and Strategy

A restoration plan for Hetch Hetchy Valley should consider the long-term goals and site use policy for the area. Restoration goals could emphasize:

- Maximizing biological diversity and habitat.
- Creating additional recreational space for Yosemite National Park visitors with varying levels of development.

- Improving large-scale restoration practice and theory.
- Implementing the most cost-effective restoration.

As the opportunity to restore Hetch Hetchy Valley is considered, these factors may require further consideration by stakeholders, and should be prioritized to develop restoration goals.

The goal of this restoration plan is based on location, resources, invasive plant species, and long-term management. The Hetch Hetchy site, high in its watershed and surrounded by congressionally designated wilderness areas, provides an opportunity to restore plant communities of maximum ecologic value. As a feature of Yosemite National Park, a restoration of Hetch Hetchy Valley could offer educational and research opportunities for visitors and NPS staff.

Resources required to restore Hetch Hetchy Valley also influenced goal development. Environmental Defense's economic feasibility analysis of removing O'Shaughnessy Dam removal and developing alternative water and power supply options to replace Hetch Hetchy Reservoir indicates the restoration will be a resource-intensive process. The quality of restoration in Hetch Hetchy Valley should reflect positively on the resources required to reestablish this historic landscape

Long term management and downstream effects of the restoration were the final considerations influencing development of the restoration goal. These factors address public perception of the restoration and resources required for the landscape reestablishment. The water quality of the Tuolumne River immediately downstream of Hetch Hetchy Valley should remain high, sediment loads should not dramatically increase, and the site should not be a major seed source of non-native invasive plants.

Based on these factors, the most appropriate restoration goal is to restore the plant and animal communities in Hetch Hetchy Valley to their pre-inundation state. To achieve this goal native plant species should be reintroduced and establishment of non-native species should be minimized. Numerous unknowns regarding site conditions will exist once the dam is removed, which may hinder the success of a conventional restoration plan.

To successfully restore Hetch Hetchy valley to its pre-inundation state, adaptive restoration is the best strategy. Adaptive restoration is "the design and implementation of a restoration project as a series of experiments, using knowledge from early experiments to revise subsequent experiments and improve subsequent restoration efforts"(Zedler and Callaway 2004). Because drawdown of the reservoir can be completed incrementally, an adaptive plan including a temporal series of studies is well suited for the site.

Adaptive restoration improves the likelihood of success by studying site conditions and responses on a small scale and then applying those results to the rest of the site, resulting in diverse plant communities. Adaptive restoration also provides opportunities for targeting restoration expenditures where they are needed most, creating more cost effective restorations with fewer long-term intensive management needs. Furthermore, an adaptive restoration at Hetch Hetchy Valley would be a model for future large-scale ecological restorations.

RESTORATION GOAL:

Adaptively restore Hetch Hetchy Valley so that it contains communities similar in composition and structure to communities

present before inundation. These communities include wetlands, grasslands, oak savanna, oak woods, and conifer forest.

2.0 BACKGROUND AND SITE CHARACTERISTICS

2.1 Site Location

Hetch Hetchy Valley is located within Yosemite National Park (Figure 2.1). The valley is 275 kilometers east of San Francisco and 1,160 meters above sea level (Rosekrans et al. 2004). Yosemite National Park (YNP) covers 303,238 hectares along the western slope of the Sierra Nevada mountains in eastern California. The park ranges in elevation from approximately 610 meters in the Merced River Canyon to the summit of Mount Dana at 3,979 meters (Botti 2001).

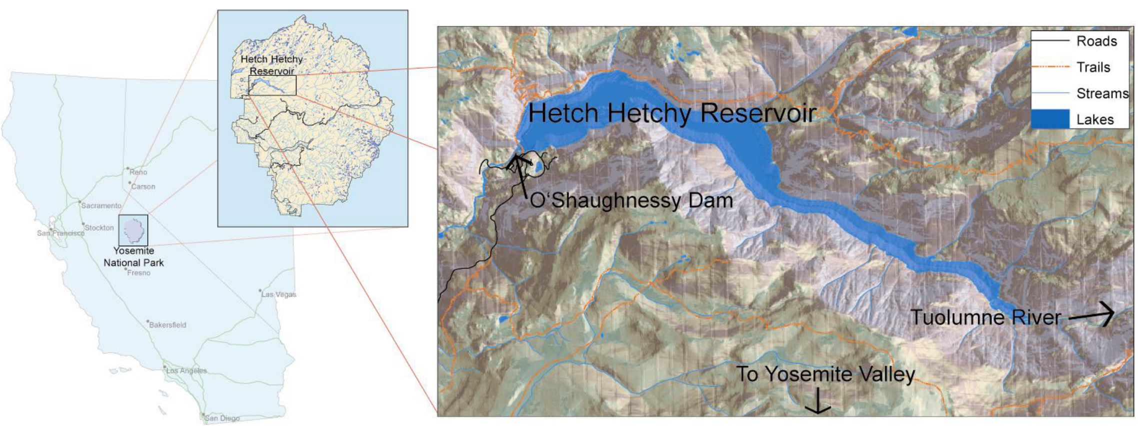

Figure 2.1: Location of Hetch Hetchy Valley

Vehicle access to Hetch Hetchy Valley is restricted to the O'Shaugnessy Dam area. East of the dam there are only hiking trails. The main trail in the area follows 4.3 kilometers of the north shore of the reservoir, beginning at the dam and ending at the base of Wapama Falls (NPS 2004).

2.2 Site History

The Ahwahneechee Indians were the first to discover and live in what is now Yosemite National Park; they named Hetch Hetchy after a native grass that grew in the valley. In the mid 1800s, the gold rush brought large numbers of settlers to California, and by 1850 California had gained statehood. In 1860, J.D. Whitney conducted a geological survey of the valley. In his description of the valley he stated:

> "Hetch Hetchy is divided into two parts by a spur of granite, which nearly closes it up in the center. The portion of the valley below this spur is a large open meadow, a mile in length and from an eighth to half a mile in width, with excellent grass, timbered along the edge. The meadow terminates below in an extremely narrow canon, through which the river has not sufficient room to flow at the time of the spring freshets, so that the valley is then inundated, giving rise to a fine lake. On the north side of the Hetch Hetchy is a perpendicular bluff, the edge of which is 1.800 feet above the valley, and having a remarkable resemblance to El Capitan. A little farther east is the Hetch Hetchy Fall, the counterpart to Yosemite" (Jones, 1964).

A small group of settlers recognized the unique geological formations and diverse plant communities in Yosemite Valley and lobbied Congress to protect the area. On June 30, 1864, President Lincoln signed the Yosemite Act, which preserved the valley for public and recreational use. Many conservationists, including John Muir, soon realized that much of the land surrounding the valley also should be protected. Another bill was introduced in 1890 to protect additional land surrounding Yosemite, including Hetch Hetchy Valley. This bill was passed by Congress and signed by President Harrison, creating Yosemite National Park.

Figure 2.2: Hetch Hetchy Valley before construction of O'Shaugnessy Dam (Photo credit: Sierra Club)

Soon after the creation of the Park, the City of San Francisco began petitioning the Federal government for permission to build a dam in Hetch Hetchy Valley. Many conservationists were outraged at the prospect of building a dam in a federally protected park; the plan would destroy Hetch Hetchy Valley. Hetch Hetchy Valley was considered by many to be the twin to Yosemite Valley and some, like M.C. Trumen, believed that "…Hetch Hetchy would command the admiration of all who visit it, and would probably stand as the grandest and most beautiful aggregation of rock and water in the world" (Jones 1964).

Despite the efforts of the Sierra Club and many other preservationists, Congress passed the Raker Act in 1913, which gave San Francisco permission to begin building a dam in Hetch Hetchy Valley. The O'Shaughnessy Dam was completed in 1923. Today, the reservoir in Hetch Hetchy Valley supplies about 85% of the public water to San Francisco and its suburbs in San Mateo, Alameda and Santa Clara counties (www.hetchhetchy.org 2004). There are three hydroelectric facilities associated with the dam, which provide an annual average of 1.7 billion kilowatt hours of power to the San Francisco Public Utilities Commission, with any excess sold to the Modesto and Turlock Irrigation Districts (sfwater.org 2004).

2.3 Site Conditions

2.3.1 Tuolumne River Watershed

The Tuolumne River begins in the peaks above Tuolumne Meadows and drains the majority of the park's northern area (1733 km^2). The river has two origins, Mount Dana and Mount Lyell, and continues through the Tuolumne Meadows and the Grand Canyon of the Tuolumne before entering the eastern shore of Hetch Hetchy Reservoir. After exiting O'Shaughnessy Dam, the water finally reaches the Yosemite National Park boundary about 9.7 kilometers downstream.

Figure 2.2: Tueeulala Falls is one of two spectacular waterfalls within the Hetch Hetchy valley (NPS 2004). Photo credit: Robert Parks.

2.3.2 Hydrology

Water plays a major role in the attraction of visitors to Yosemite National Park. With its towering waterfalls and roaring rapids, the unique hydrology of the park contributes greatly to its character. The Hetch Hetchy area has two major waterfalls, Wapama Falls and Tueeulala Falls. Not only does the water in the park have excellent aesthetic qualities, but the water is in pristine condition in most areas of minimal visitor use (NPS 2004).

2.3.3 Soils and Topography

Three major glaciations helped form the topography in the Yosemite region. These glaciers produced the thin soils found throughout the high country, while the mountain and sub alpine meadow soils were formed mainly by glacier sediment (Botti 2001). Soils are also derived from underlying granite bedrock. Soil texture and density vary with topography, but in general the chemical composition of the soils in this region is uniform (Yosemite Valley Restoration Plan 1978). Soils above 1830 meters are covered by glacial moraine material, which includes a mixture of sand, glacial flour and variously sized rock. Areas near ponds and rivers have higher concentrations of organic material due to the presence of grasses and sedges, while soils dominated by conifers have higher organic content but lower pH levels. Soils found in the valley typically have deeper soil profiles than soils at higher elevations and range from a fine sandy loam to a silt loam (Yosemite Valley Restoration Plan 1978).

The soils of Yosemite Valley are similar to those occurring in Hetch Hetchy Valley. The Tuolumne River, which ran through Hetch Hetchy Valley prior to the construction of the dam, flooded annually and probably deposited sediment in the surrounding area. Thus, sandy loam soils probably exist in the valley. As distance from the river increases and the topography becomes increasingly sloped, soil depth should decrease and the rock content increase (Heady and Zinke 1978). Soil composition and topography are important to consider during the restoration of the Hetch Hetchy Valley because they influence the growth and establishment of plant communities, and also affect surface run-off and ground water accumulation.

2.3.4 Vegetation

There is some evidence that the vegetation of Hetch Hetchy Valley was similar to the plant community of Yosemite Valley, 32 kilometers to the south (Muir 1912). Both valleys lie at similar elevations and have comparable topography and hydrology (Muir 1912). Since completion of O'Shaugnessy Dam in 1923, similarities between the plant communities of Hetch Hetchy Valley and Yosemite Valley have likely decreased as native plant communities have undergone modifications due to increased development in Yosemite Valley and extensive competition from invasive plants. *Therefore, the extant plant communities of Yosemite Valley should not be used as a precise target for a restoration of Hetch Hetchy Valley, but as a general reference for restoration work.* To achieve the restoration goal of creating native plant communities similar to those found in the valley prior to inundation, analysis of pre-dam photographs and survey information from both Hetch Hetchy Valley and Yosemite Valleys is necessary to determine the flora of each valley prior to development of the Hetch Hetchy Reservoir.

Meadow communities once covered 302 hectares of Yosemite Valley but today only about 146 hectares remain (Yosemite National Park 2003). The remaining grasslands are degraded, and the composition of the original grassland community is unknown (Barbour et al. 1993). Settlement in the Yosemite Valley region brought an end to natural fire and annual burning by Native American Indians (Yosemite National Park 2003). In addition, settlers brought cattle and sheep into the area, which led to overgrazing and soil compaction. Cattle grazing not only reduced native perennial species, but also exposed bare soil to invasion by non-native and annual species (Barbour et al. 1993).

Two species of needle grass, *Stipa cernua* and *S. pulchra*, were thought to be the dominate grass species, while perennial flowers may have included baby blue-eyes (*Nemophila meniesii*), California fuchsia (*Epilobium canum ssp. latifolium*) and wild brodiaea (*Triteleis hyacinthine*), all currently found in the Hetch Hetchy Valley (Botti 2001). Today, introduced European grasses such as soft chess (*Bromus mollis*), wild oat (*Avena fatua*), and California bur-clover (*Medicago polymorpha*), dominate most grasslands in central California (Barbour 1993).

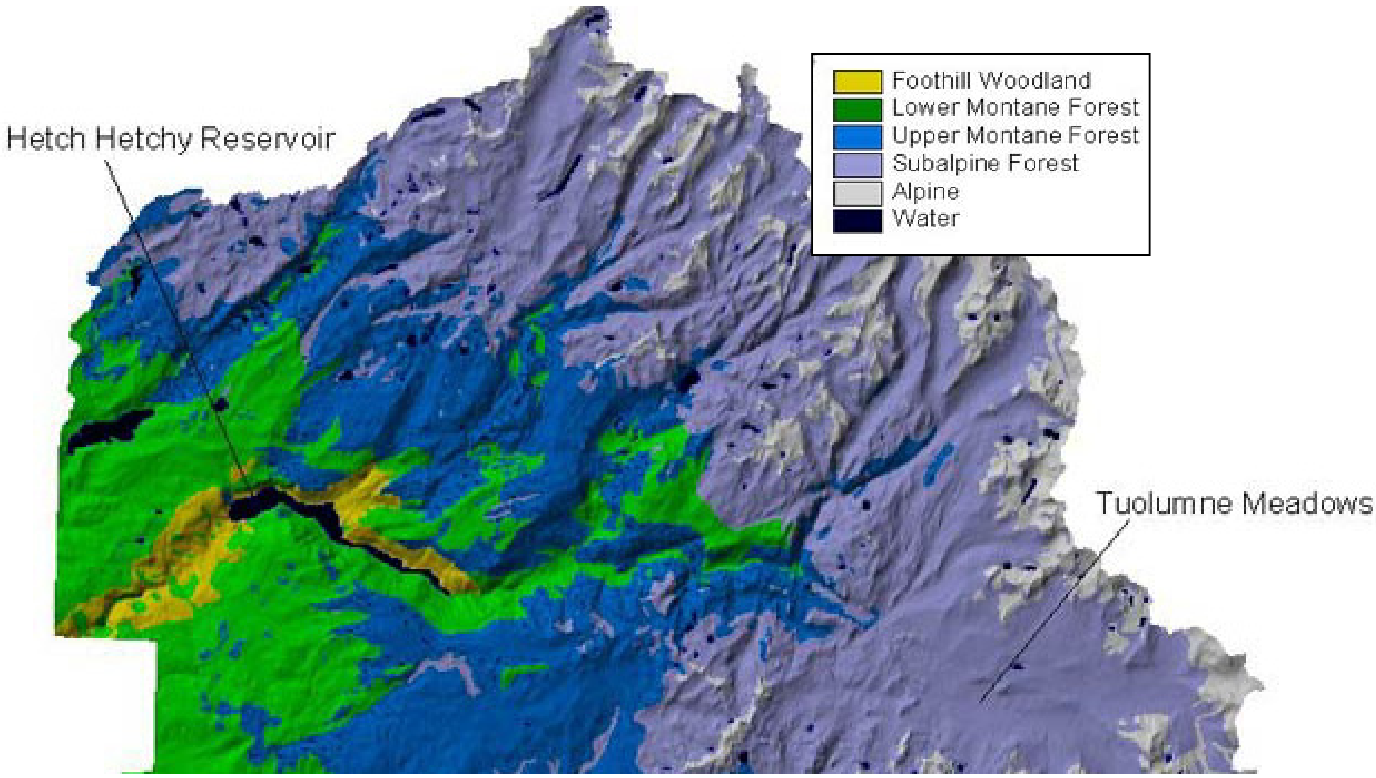

Figure 2.3: Plant communities of northern Yosemite National Park (NPS 2004).

Based on historic photographs and written accounts of Hetch Hetchy Valley prior to the construction of the dam, we have grouped likely communities that existed in the valley into the following categories:

- Wetland
- Grassland
- Oak savanna
- Oak woods
- Pine forest

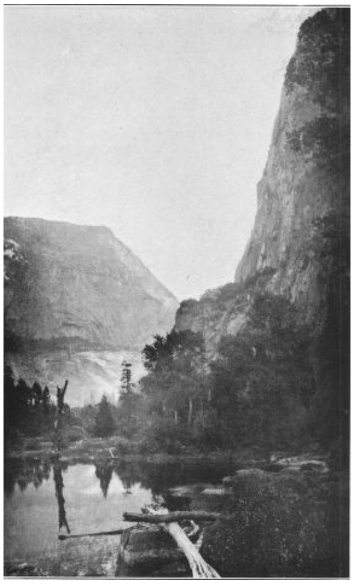

Figure 2.5: Hetch Hetchy wetland community.

Figure 2.6: Meadow/Grassland

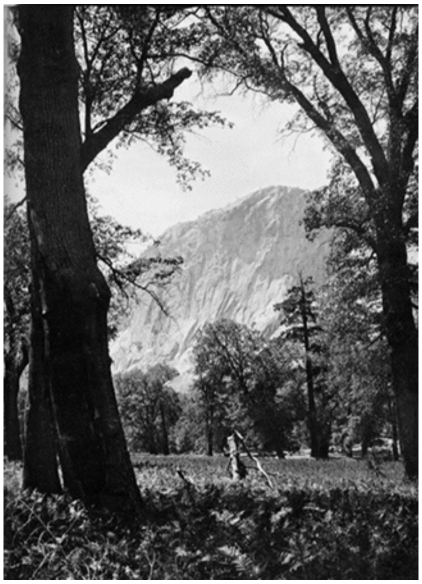

Figure 2.7: Oak Savanna

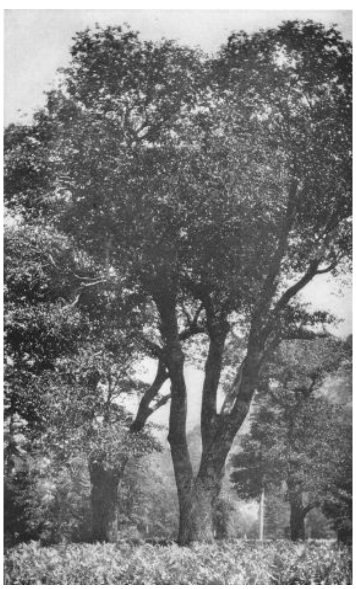

Figure 2.8: Oak Woods

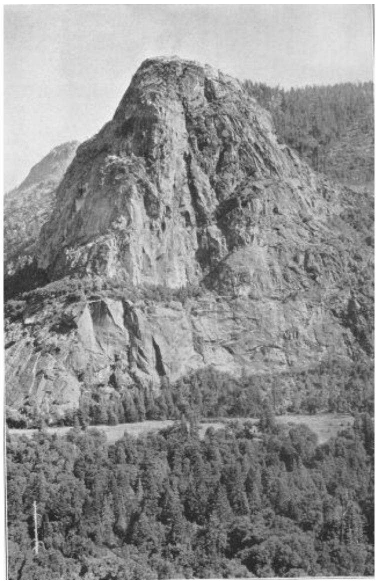

Figure 2.9: Pine Forest

With respect to these communities, John Muir wrote “after my first visit to it in the autumn of 1871, I have always called it the "Tuolumne Yosemite," for it is a wonderfully exact counterpart of the Merced Yosemite, not only in its sublime rocks and waterfalls but in the gardens, groves and meadows of its flowery park-like floor.”

In addition to information regarding historic vegetation communities in Hetch Hetchy Valley, it is also useful to consider the broader vegetation community types present in Yosemite National Park. Vegetation in Yosemite National Park varies with elevation, slope, soil conditions, and water availability throughout the site. Elevation in the inundated portion of Hetch Hetchy Valley ranges from 1220 meters to 1300 meters.. The general vegetation zones at these elevations are the Foothill Woodland Zone and Lower Montane Forest.

Foothill Woodland Zone

This zone begins at an elevation of 550 meters and just reaches the elevations of the Hetch Hetchy area. This area is generally hot and dry in the summer and there is very little snow in the winter. Plant species found in Yosemite that thrive in these conditions are chamise, ceanothus, manzanita, blue oak, interior live oak, and gray pine (NPS).

Lower Montane Forest

Beginning around 900 meters, the lower montane forest has a Mediterranean-type climate, with hot, dry summers and cool, moist winters. Trees such as California black oak, ponderosa pine, incense-cedar and white fir can be found in this zone as well as the park's giant sequoia groves.

3.0 OPPORTUNITIES AND CONSTRAINTS

The location of Hetch Hetchy Valley and other site conditions provide several opportunities and constraints for restoration. The San Francisco Public Utilities Commission is planning a $3.6 billion upgrade for its aging, seismically susceptible Hetch Hetchy water system; funds for dam removal and other necessary water diversion costs may come from this existing pool. While the dam is still in place, incremental drawdowns can present an opportunity for using adaptive restoration methods, by exposing smaller tracts of land that would be more manageable. Results from experiments conducted in these areas can then guide later restoration decisions.

Additionally, the location of Hetch Hetchy valley within the park affords the valley a measure of protection from development, now and after the restoration is completed. As part of a national park, the restoration should have access to park labor, research and educational resources. Park visitors will be exposed to the restoration process, potentially increasing support for the project. The removal of Hetch Hetchy dam and subsequent restoration of the valley can serve as a model for future large-scale restoration projects.

However, high visibility can be a constraint on restoration efforts: public perceptions and expectations will come into play, especially if initial work includes visually unattractive stages. Since Hetch Hetchy Valley is surrounded by Congressionally-designated wilderness area, NPS guidelines may restrict the methods used for restoration including; fire, mechanical equipment and herbicides. Herbicides are a tool commonly used in ecological restoration, but may present health concerns when used in proximity to reservoir water. Although the valley is within a national park, invasive plant species are already a concern in Yosemite (Appendix A: Invasive Plants of Yosemite National Park). Invasive plant seeds from Yosemite Valley and other park areas could be easily transported to the restoration site.

The site presents other difficulties. Because the valley is in the Sierras, much of the soil is rocky and highly erodible. Poor soil conditions may make establishment of native plant communities difficult, though poor soil conditions may also limit invasion by invasive species. Seed banks that existed in the valley prior to inundation may have been eliminated, making natural regeneration less likely.

Opportunity	Constraint
$3.6 billion SFPUC upgrade of water system	Funding has not been earmarked for restoration of the valley
Reservoir level may be controlled; flooding of valley can prevent invasion of non-native plants	Few viable seeds of native species may exist in seed bank
Location within national park may protect restoration site from negative development impacts (stormwater runoff, soil compaction, etc.)	Limited vehicle access to restoration site
High public visibility	Restoration efforts will need to include visitor services
Poor soil conditions may limit establishment of invasive non-native plants	Poor soil conditions may limit establishment of native plants
Park visitors could help with restoration work and research	Invasive plants could be transported into the restoration site

Table 3.1: Opportunities and constraints to be considered

The challenges to meeting restoration goals are discussed further in Section 6.0, Key Questions for Restoration Planning.

4.0 REFERENCE SITES

Yosemite Valley

Due to the similar topography and geology of Yosemite Valley and Hetch Hetchy Valley, the former can serve as a reference site for the restoration. However, the Yosemite Valley plant community has changed since the 1920's, and no longer accurately represents the plant community that existed prior to the inundation of Hetch Hetchy Valley. For this reason, historical data from both sites, including descriptions and photos, will be used to determine community types present before the dam was built. Current data from Yosemite Valley can also be useful; the vegetation can be surveyed to develop predictions of which invasive plant species could be a concern during restoration and subsequent monitoring. Additionally, plans and monitoring data from recent restoration projects in Yosemite Valley can provide information about desired plant composition and response to seeding and planting efforts.

Case Studies

In addition to evaluating the vegetation communities of Hetch Hetchy Valley and Yosemite Valley prior to the 1920's, it is helpful to consider what can be learned from restorations at other dam removal sites. Although several of the projects described below are much smaller in scale than the restoration of Hetch Hetchy Valley , they provide valuable examples of factors to consider in restoration.

Sturgeon River Dam, Sturgeon River, MI:

Deconstruction began on this 15-meter (45-foot) hydropower dam in summer 2003 by the hydropower owner, We Energies (American Rivers 2004). We Energies is also implementing a multi-year restoration project to restore the ecosystems of the river to their original state. The restoration plan is currently underway, and the first of three proposed drawdowns has occurred.

Figure 4.1: Sturgeon River Dam after phase one of deconstruction (Micigan 2004).

Incremental drawdowns offer control of the amount of land to be restored, and allow natural sediment stabilization and re-vegetation to begin (We 2004). After complete removal of the dam, more than 16.2 ha (40 acres) of land previously submerged will regenerate to pre-dam conditions of seasonally flooded wetlands and deciduous floodplain forest (We 2004). For more information on the Sturgeon River Dam project contact Sharon Hanshue, Michigan Department of Natural Resources, (517) 335-4058, hanshus1@michigan.gov.

Crocker Creek Dam, Crocker Creek, CA:

This 9-meter by 240-meter concrete flashboard dam, removed in summer/fall 2002, was originally built in 1904 for recreational use, but had been abandoned for many years (American Rivers 2004). After removal, the Sonoma County Water Agency (SCWA) came up with a restoration project with three goals, the last one being “prevent further bank erosion/re-establish riparian vegetation (SCWA 2004). They chose to do surveys of riparian habitats both upstream and downstream of the project site in order to choose which native vegetation to use in their restoration efforts. This project parallels the Hetch Hetchy project in that the stabilization of soil/erosion control and the regeneration of riparian vegetation are objectives of both. With the steep slopes of Hetch Hetchy Valley it will be important, as it was in the Crocker Creek project, to protect those slopes from losing what little soil they may have. For more info on the Crocker Creek Dam project contact Ron Benkert, Sonoma County Water Agency, (707) 547-1905, rcb@scwa.ca.gov.

Dam and Lock, Kissimmee River, FL:

In 1992 the Water Resources Development Act was passed by Congress and authorized the Kissimmee River Restoration Project. The removal of dam S65B, which occurred in June 2000 (American Rivers 2004), will require the restoration of a 69.2-mile river channel and 10926 hectares of wetlands (SRWMD 2004). Restoration efforts by the South Florida Water Management District (SRWMD) restoration team have resulted in some positive changes. With the absence of the dam, the river can now

Figure 4.2:Kissimmee River prior to the destruction of dam S65B (South 2004).

flow within its natural floodplain, and the improved hydrology can be seen with the formation of sandbars and sandy river floors. Emergent and shoreline vegetation is starting to reappear as well as waterfowl species (SRWMD 2004). With its similar scale and impact to the surrounding environment, the lessons learned from this restoration project may help guide restoration decisions at Hetch Hetchy Valley. For more information on the Kissimmee River restoration project contact Lou Toth, South Florida Water Management District, (561) 682-6615.

http://www.sfwmd.gov/org/erd/krr/index.html

5.0 THE CASE FOR ADAPTIVE RESTORATION

The following issues and questions lead us to determine that an active, adaptive strategy is the most appropriate approach to restoring Hetch Hetchy valley and meeting the restoration goal:

The need for experimentation & adaptive management:

- Size of restoration is large (~ 810 hectares)
- Many unknowns about site conditions
- Opportunity to control the water level
- Active restoration will be expensive.
- Adaptive management will help develop most effective restoration strategy and provide opportunities for targeted restoration expenditures where needed most.
- Adaptive management has already been successfully employed for restoration plans in Yosemite

Adaptive restoration studies could address key questions:

- Planting needs
- Invasive species
- Drawdown planning
- Long-term management
- Validity of NPS assumptions (in 1988 study report)

Benefits of adaptive restoration and "Phased Drawdown" approach:

- An opportunity to learn from previous years' work at the site and continually improve restoration techniques and management.
- Reduced costs for the restoration due to improved techniques and appropriately targeted expenditures.
- Less abrupt changes in the environment for the existing wildlife using the area.
- Reduced burden on park restoration staff due to a smaller area to restore annually.

6.0 KEY QUESTIONS FOR RESTORATION PLANNING

Although a great deal has been learned about effective restoration practices in the last 50 years, each restoration site is unique and poses challenges specific to its site characteristics and unknowns. Adaptive restoration provides an opportunity to study site conditions and site responses to restoration activities first at a small scale, and then to apply what is learned on a larger scale and improve subsequent restoration efforts. In order to develop strategies for adaptive restoration activities that are most likely to meet the restoration goals for Hetch Hetchy Valley, we evaluated what site characteristics and unknowns should be studied at the site.

We grouped key questions for restoration planning into the following categories, which are described in further detail below:

- Planting needs
- Invasive species
- Drawdown planning
- Long-term management

In the 1988 report on Hetch Hetchy restoration alternatives, the National Park Service made a number of assumptions regarding restoration scenarios. It is worthwhile to further evaluate the validity of some of these assumptions. The assumptions we recommend studying further are discussed in the relevant sections below.

Planting needs

The 1988 NPS report on alternatives for restoring Hetch Hetchy Valley includes an assumption that the Park would not attempt to restore all plant taxa that originally inhabited Hetch Hetchy Valley. The report states that "it is highly likely that all taxa originally inhabiting Hetch Hetchy still occur in close proximity to the valley and would reestablish themselves once habitat became available" (NPS 1988). The validity of this assumption is worth considering further.

The 1988 NPS report on alternatives for restoring Hetch Hetchy Valley also states that "it is very possible that granivorous birds and small mammals may recolonize the valley so rapidly and in such great numbers that seeds of herbaceous plants needed for vegetative recovery may be consumed at too high a rate to permit development of acceptable densities of important plants. In such a situation protective measures, such as avian exclosures or animal removal, may be necessary at selected sites and on a temporary basis" (NPS 1988). This assumption is also deserving of further study.

The 1988 NPS report also includes information on the soil conditions at the site, stating that "a half-mile long swath of materials excavated from the dam site was laid across the lower meadow, and much of this rock and debris may remain on what was rich meadow alluvium along the river banks. A rock crusher plant was built on the north side of the valley to provide material for the concrete work on the dam. A railroad skirted the north side of the immense rock and debris pile to service a gravel pit near the base of Wapama Falls and a sand pit on the valley floor near the confluence of Rancheria Creek. The banks of the sand excavation pit appear in photographs to be about 15-30 feet high for a considerable distance along the Tuolumne River. Restoration of natural contours and soil types would be required under any restoration alternative for aesthetic reasons and to allow natural plant communities the chance to become reestablished" (NPS 1988).

Figure 5.1: This sand and gravel operation in Hetch Hetchy Valley provided material for construction of O'Shaugnessy dam. (Photo credit Tuolumne County)

Soil conditions at the site should be further evaluated in order to increase understanding of the level of resources that will be required to address the historic site modifications.

The NPS report also states that "there is an unnatural, light-colored watermark ("bathtub ring") about two hundred feet in width which surrounds the reservoir and is highly visible to the visiting public. It is the result of impounded water killing the native rock lichen colonies which cover the granite walls. Natural restoration of such colonies would take between eighty and one hundred and twenty years. No practical way to hasten recovery is known" (NPS 1988).

A preliminary digital elevation model of the valley topography indicates that over 825 hectares (2,040 acres) of land will be exposed after Hetch Hetchy Reservoir is drained. In order to adaptively restore Hetch Hetchy Valley so that it contains communities similar in composition and structure to communities present before inundation, it will likely be necessary to plant native vegetation in the exposed area to establish wetlands, grasslands, oak savanna, oak woods, and conifer forests. Planting and managing this large restoration area will require extensive resources. In order to target resources where they are needed most, the following questions should be considered:

- What plant species need to be planted and what species will come back on their own?
- Will tree tubes and bird exclusion netting be necessary for seedling survival?
- Are soil conditions appropriate for supporting native plants?
- Is there a feasible method for hastening lichen recovery?
- What planting density is necessary for survival of desired species?
- What planting arrangement and method is most cost effective and successful? Which plant species need to be planted with seedlings and which species can be planted with seed? Could higher diversity seed or seedling mixes be planted in small "nodes of diversity" surrounded by less diverse mixes in an effort to minimize planting costs?
- Are successive plantings over time in the same area desired to achieve age-varied stands of trees?
- How will transitional conditions during drawdown (i.e. higher than normal water table at reservoir edge) affect plantings? Should there be a buffer zone in a newly

uncovered area next to the reservoir edge that is not planted until the following year when the reservoir edge is farther away? Should this buffer zone be managed to control weeds until planted?

- How will invasive competition and native reestablishment vary in different environmental settings?
- Can tree stumps exposed during later drawdown stages be utilized as "nurse logs" to support seedlings?

Invasive species

The 1988 NPS report on alternatives for restoring Hetch Hetchy Valley includes an assumption that the Park would acquiesce to the invasion of many common non-native plant taxa into Hetch Hetchy Valley. The report states that "about 140 non-native plant species occur in Yosemite National Park. About 40 widespread non-native grasses occur in Yosemite Valley and throughout the lower elevations in the park. It would be virtually impossible to prevent the rapid invasion of most of these taxa into Hetch Hetchy since many are characteristic pioneers of disturbed areas and already occur in close proximity to the reservoir. Massive herbicide spraying might hold these taxa in check initially, but such treatment would have to be continued indefinitely to be even partially effective long-term" (NPS 1988).

These assumptions regarding invasive plant species are worthy of further consideration. As discussed earlier in Section 1.2, the quality of restoration in Hetch Hetchy Valley should reflect positively on the resources required to remove O'Shaughnessy Dam and develop alternative water and power supply options in order to reestablish this historic landscape. If Hetch Hetchy Valley were to become overgrown with exotic, invasive plant species that provide poor habitat for park wildlife, prevent native plants from establishing, and fail to represent the former splendor of the valley, the resources required for dam removal may be considered to have been inappropriately allocated. In order to adaptively restore Hetch Hetchy Valley so that it contains communities similar in composition and structure to communities present before inundation, it will likely be necessary to actively control and remove invasive plant species. To target resources where they are needed most, the following questions should be considered:

- What non-native invasive plants are present in the vicinity of the site?
- How likely are non-native invasive plants to aggressively establish in former reservoir area if the restoration is not planted or seeded (i.e., a no-action scenario)?
- How likely are invasive plants to out-compete planted native plants and naturally reestablishing native plants, preventing their establishment?
- What weed control strategies will be most effective at reducing invasive plant cover?
- How will potential large-scale invasions of non-native plants be managed?
- Will herbicides be used to manage invasive plants?

Drawdown planning

Over 825 hectares (2,040 acres) of land will be exposed after Hetch Hetchy Reservoir is drained. This is a large area of land to expose all at once and the size could pose significant restoration challenges, such as locating adequate seed sources for native plants with local ecotypes. The drawdown of the reservoir could potentially be completed in increments, creating an opportunity for an adaptive restoration plan that includes a series of studies that could be completed over time in different locations as they become exposed. The following questions should be considered in evaluating this opportunity:

- What is the desired amount of land to be exposed each year for restoration?
- At what reservoir water elevations can power continue to be generated at the site and water removed for drinking water?
- Is SFPUC or the organization managing the dam and reservoir during the restoration process willing to adjust the drawdown schedule based on experimental results?

Long-term management

There are numerous questions related to long-term management of the restoration site to consider. A few questions we have identified include:

- What will be the role of the National Park Service in the restoration of Hetch Hetchy Valley? What will be the role of other government, non-profit, and educational institutions such as universities and environmental organizations?
- How will human impact on the restoration of Hetch Hetchy Valley be managed?
- What level of development and public access in the restored area will be allowed during the active restoration phases? What level of development and public access will provide the NPS with the opportunity to meet visitor interests without damaging the restoration?

- What level of development and access will be allowed once the restored areas are reestablished as functioning, mature communities?
- How long will it take for native communities to reestablish as functioning, mature communities?
- How will restored communities in streambank and floodplain areas need to be managed to address potential changes in stream and floodplain geomorphology and function over time?
- How will fire be managed, will it be suppressed or will managed burns be conducted?
- How will undesirable restoration outcomes be managed and mitigated?

Conclusion

The key questions identified in this section guided our consideration of alternative restoration plans (Section 7.0), the development of our recommended approach (Section 8.0), and our recommendations for long-term management (Section 9.0).

7.0 ALTERNATIVE RESTORATION PLANS

A number of alternative restoration plans were considered by our class before settling on the proposed plan for a phased drawdown and adaptive restoration. First, we examined the option of a full drawdown of the reservoir. While the phased drawdown may be logistically challenging for SFPUC or the organization responsible for the dam during the restoration process, it is the best approach for restoration. A complete drawdown would expose a large tract of land, susceptible to invasion by non-native plant species and erosion. The labor and other resources needed to restore such a large area at one time could be prohibitive. With a full drawdown, there would be one chance to “get it right,” precluding the opportunity to determine the most suitable and cost-effective restoration method for the site. A phased drawdown would allow for experimentation, the results of which could be used to guide the restoration process.

Our class also looked at the possibility of a no-action alternative, as discussed in the 1998 NPS report. However, because of the presence of invasive plant species in Yosemite, it is unlikely that the Hetch Hetchy Valley would be populated with the appropriate native species without an active restoration plan. Invasive plants are often extremely good competitors in disturbed restoration sites; and may constrain the restoration process (Zedler 2000). A no-action approach might not achieve the goal of predominant establishment of native plant species. For this reason, we also rejected a partial-site restoration plan, where only some sites would be actively restored, while others were allowed to self-generate, and opted to use at least minimal restoration practices over the whole exposed area.

Another option was to use a rigid plan, rather than an adaptive management plan. Again, with a rigid plan, we would not have the chance to find the most appropriate solutions for this particular site. Even with multiple reference sites and other studies of dam removal, the factors that are involved at each site cannot be replicated, and therefore, neither can the restoration plans. Experimentation allows us to use the Hetch Hetchy restoration as a learning tool, as well as to find the best strategy.

Even within the adaptive management/experimentation model, there are factors to consider. Mesocosm studies, which can be performed on-site or off-site by re-creating site conditions in containers and experimenting with planting methods, soil amendments, water availability and other relevant variables, are a potentially useful tool in adaptive restoration studies. However, these studies can be labor-intensive due to the artificially-maintained conditions. The lack of roads and utilities in Hetch Hetchy Valley could create challenging conditions for performing mesocosm studies on-site, due to the need to carry equipment to the site by boat and the need for daily research staff involvement. Off-site experiments, although valuable in some cases, were rejected by the class because soil, hydrology and other natural conditions unique to the formerly inundated condition at the site would be difficult to re-create off-site.

Based on this analysis of alternative restoration strategies, we concluded that the restoration strategy that would be most likely to help achieve the restoration goal would include the following components:

- **Phased drawdown**
- **Active, adaptive restoration of the entire site**
- **On-site experimentation**

8.0 RECOMMENDED APPROACH

8.1 Overview of Approach

We recommend a phased approach to designing, implementing, and evaluating restoration plans for Hetch Hetchy Valley. Using the concept of adaptive restoration to guide this process, results from studies conducted in each phase of the restoration will be applied to future phases. We propose the following phases:

- Phase 1: Studies prior to drawdown.
- Phase 2: Initial drawdown studies.
- Phase 3: Application of results from Phases 1 & 2 to consecutively larger areas of the site.
- Phase 4: Long-term monitoring and adaptive management of the site.

The studies in these phases could be performed by a coordinated group of investigators from government, academic and non-profit institutions such as the national laboratories, the University of California, the University of Wisconsin, Environmental Defense, and the Sierra Club. The National Park Service (NPS) could serve as the program manager for planning adaptive restoration studies and coordinating the efforts of investigators. There is precedence for NPS serving such a role in the Everglades National Park, where NPS designed a program for restoration research (Zedler 2004).

8.2 Phased Drawdown Analysis

The approach we recommend for restoration of Hetch Hetchy Valley is based on a phased drawdown of the reservoir. We propose conducting a non-uniform drawdown that exposes similar land surfaces (in terms of slope, soil characteristics, and water availability) of appropriate size for each of the recommended studies. To evaluate the potential land surface that would likely be available during drawdowns of various sizes, we developed a digital elevation model of the land surface that is currently inundated based on data provided by Environmental Defense and a 1902 historic topographic survey of the valley.

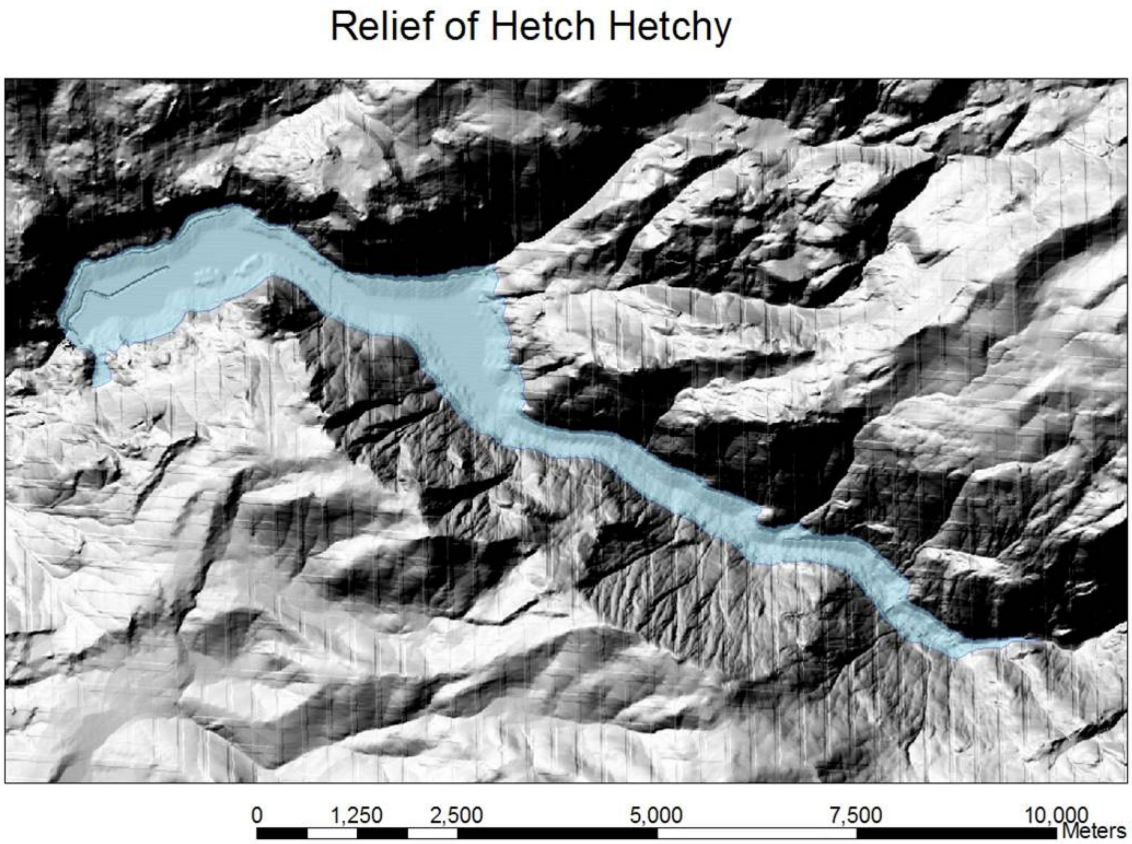

Figure 8.1: Preliminary digital elevation model of Hetch Hetchy Valley.

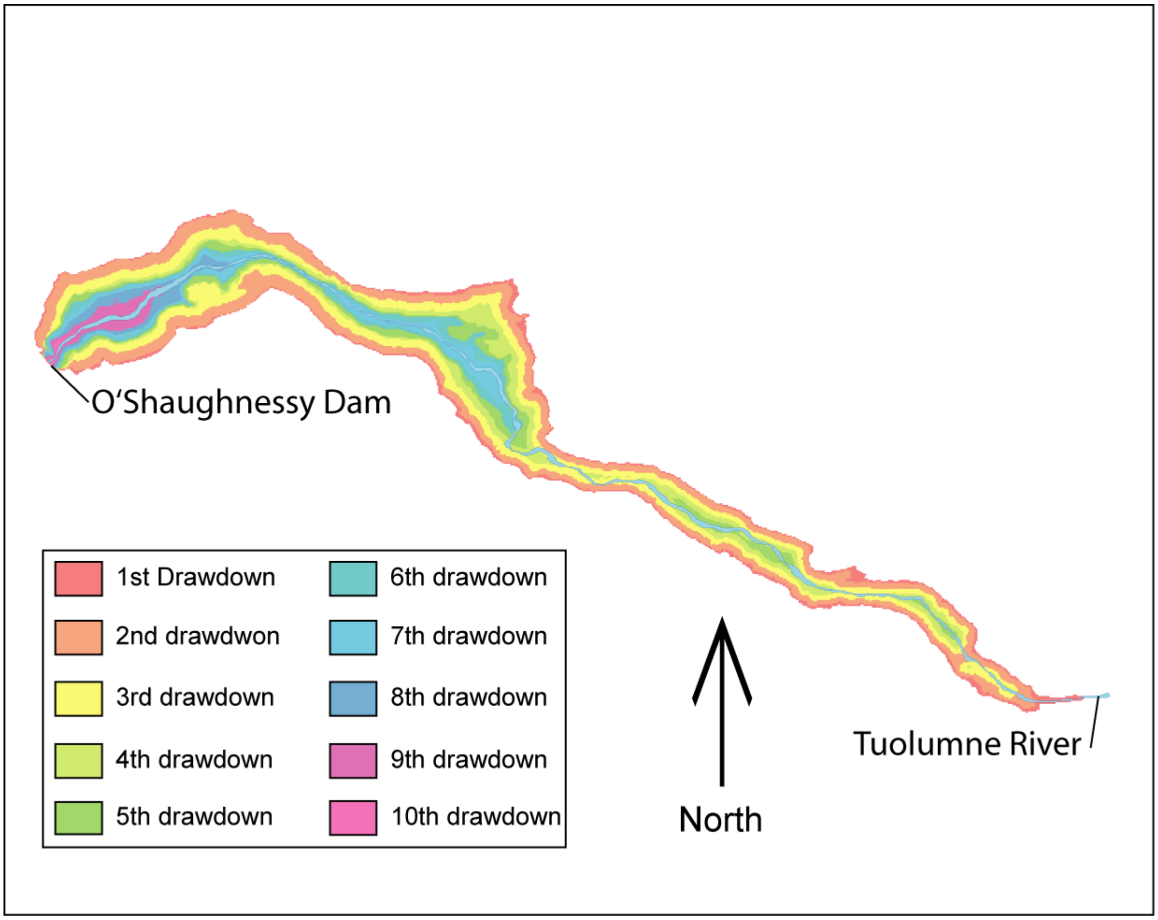

Figure 8.2: Areas of Hetch Hetchy Valley to be exposed by drawdowns based on preliminary digital elevation model.

The results of a potential phased drawdown approach based on this preliminary model are shown below in Tables 8.1 and 8.2. The initial drawdown of 15 meters was selected because it would likely expose areas with similar slope and moisture availability characteristics, and to some extent similar soil characteristics (recognizing that some areas will be shear granite faces that will not support vegetation and some will contain a more rocky/soil substrate that could support vegetation). In the following three drawdowns, we selected drawdown amounts of 9, 6, and 15 meters for this simulation, exposing small transitional slope areas that could be used for planting studies to mimic valley floor conditions and larger areas of the steep side slopes where the results of studies performed in the area exposed by the first drawdown could be applied. Later drawdowns range from six to nine meters in order to expose a variety of slope conditions for application of the results of the initial studies.

The digital elevation model we developed and the results (Tables 8.1, 8.2) are first approximations of the conditions in Hetch Hetchy Valley and should be reevaluated with greater precision prior to undertaking restoration of the valley.

Table 8.1: Estimated area and slope of land exposed during phased reservoir drawdown according to preliminary model.

Draw down	Draw down amount (meters)	0-3%	3-8%	8-25%	25-100%	100% + (45 degrees+)	Un-known	Total
		Area (in hectares) exposed						
1	15	0	0	1	15	49	4	69
2	9	10	1	11	29	39	0	91
3	6	1	3	40	102	7	0	153
4	15	1	2	25	165	3	0	196
5	9	7	9	18	66	1	0	101
6	9	10	3	59	0	0	0	72
7*	9	17	17	18	0	0	0*	52
8*	6	14	14	14	0	0	0*	42
9*	6	13	13	0	0	0	0*	27
10*	6	11	11	0	0	0	0*	22

Table 8.2: Percentage of land exposed in slope ranges during initial reservoir drawdown

Draw down	0-8%	8-25%	25-100%	100% + (45 degrees)
1	0%	2%	21%	71%
2	13%	12%	32%	43%
3	3%	26%	67%	4%
4	2%	13%	84%	1%
5	16%	18%	65%	1%
6	18%	82%	0%	0%
7*	66%	34%	0%	0%
8*	66%	34%	0%	0%
9*	100%	0%	0%	0%
10*	100%	0%	0%	0%

**Note: The preliminary digital elevation model that these tables are based on does not provide detailed data regarding the slopes of land surfaces in the base of the valley. Distribution of area in the slope ranges shown for drawdowns 7-8 is estimated to be 33% of the total land surface in each of the three lower slope ranges (0-3%, 3-8%, 8-25%) and for drawdowns 9-10 the area is estimated to be 50% of the total land surface in each of the two lower slope ranges (0-3% and 3-8%), since these areas are in the base of the valley.*

8.3 Phase 1: Studies Prior to Drawdown

It will likely take many years before a decision is reached to remove O'Shaughnessy Dam. During this time, much can be studied to determine the restoration needs for Hetch Hetchy Valley and increase the probability of attaining restoration goals. We propose the following studies be undertaken prior to drawdown of Hetch Hetchy Reservoir and the restoration of Hetch Hetchy Valley.

A. Vegetation Survey

We recommend surveying the existing vegetation surrounding Hetch Hetchy Reservoir to establish a knowledge base regarding the presence and abundance of native and invasive plants adjacent to the restoration area. This information will be helpful for evaluating what species thrive on the side slope areas and can be used to develop optimal seed mixes for restoration of the side slopes. This information will also be helpful for assessing potential invasions that may occur in the restoration area and for planning proactive management strategies to reduce the establishment of invasive plants.

B. Seed Trap Study

Performing a seed trap study may provide data regarding the specific native and non-native seeds that are being dispersed near and within Hetch Hetchy Valley. Existing data regarding the relative competitiveness of the species with seed found at the site could be used to evaluate the validity of the NPS assumptions regarding the invasion of non-native species and the natural regeneration of native species in a restored Hetch Hetchy Valley ecosystem.

We recommend that seed traps be placed in numerous locations around the edge of the reservoir as well as in the reservoir above the water level. The placement of multiple traps throughout the site would provide better data collection opportunities.

Figure 8.3: Seed trap

C. Germination & Soil Studies

We recommend studying the available seed bank and soil conditions in the reservoir sediments. Along with the data from the seed trap study, the data from a germination study could be used to begin evaluating the validity of the NPS assumptions regarding the likelihood of invasion of non-native plants and the natural regeneration of native species.

It is likely that soil characteristics in the valley have been altered during the extended period of inundation by Hetch Hetchy Reservoir. Topsoil may have eroded off the steep side slopes of the valley during successive filling and drawdown periods in the reservoir, and this eroded sediment may have accumulated on the valley floor. Sediments may also have accumulated behind the dam, although based on observations made during periods of very low reservoir water levels it appears that these deposits are not substantial due to the conditions of the upstream watershed. In addition, inundation may have altered the nutrient availability in the soil, and the water pressure from the reservoir may have resulted in soil compaction in the valley.

In their 1988 study of restoration alternatives for Hetch Hetchy valley, the NPS made the following statement regarding soil conditions:

> A half-mile long swath of materials excavated from the dam site was laid across the lower meadow, and much of this rock and debris may remain on what was rich meadow alluvium along the river banks. A rock crusher plant was built on the north side of the valley to provide material for the concrete work on the dam. A railroad skirted the north side of the immense rock and debris pile to service a gravel pit near the base of Wapama Falls and a sand pit on the valley floor near the confluence of Rancheria Creek. The banks of the sand excavation pit appear in photographs to be about 15-30 feet high for a considerable distance along the Tuolumne River. Restoration of natural contours and soil types would be required under any restoration alternative for aesthetic reasons and to allow natural plant communities the chance to become reestablished.

All of these factors could potentially impact the establishment of native and invasive plants in the valley. Data from a soil study could be used to evaluate the soil structure, soil depth, nutrient availability, and compaction levels in the sediment that will be exposed when the reservoir is drained. This information on the soil characteristics at the site could be used to assess the need for soil preparation prior to planting activities.

We recommend that soil samples be taken from the reservoir bottom at multiple locations to capture the full range of conditions (shallow and deep water, flat and steep topography). Germination and soil studies should then be performed in a lab to evaluate the available seed bank and soil conditions at the site.

D. Lichen Recruitment Study

There is an unnatural, light-colored watermark ("bathtub ring") about 61 meters in width which surrounds the reservoir and is highly visible. It is the result of impounded water killing the native rock lichen colonies and plants which cover the granite walls.

Figure 8.4: Periods of low water in Hetch Hetchy Reservoir reveal a light-colored "bathtub ring" devoid of lichens and plants.

The NPS stated in its 1988 report on alternatives for restoration of Hetch Hetchy that "no practical way to hasten recovery" of native rock lichen colonies on the granite walls is known. They estimate that natural restoration of such colonies would take between 80 and 120 years. As lichens are considered "pioneer species" crucial to the development of soil that can host other species (Chen 2000), it is important to explore potential methods for hastening lichen recruitment on the rock surfaces of Hetch Hetchy Valley. We propose a study to explore potential methods for hastening lichen recruitment between rock surfaces in Phase 1. The results of this study can then be applied during Phase 2 in the hydroseeding study.

We recommend incorporating the following components into the Lichen Recruitment Study:

- Conduct a survey of existing lichen and bryophyte communities within the valley, gathering cover and species richness data.
- Determine which species could colonize rock surfaces exposed by the restoration drawdown.
- Collect (by scraping or cutting) lichen and bryophyte biomass from existing communities. Biomass will be used to propagate new communities during the restoration drawdown.
- Determine if and what binding agents could be used to secure lichen and bryophyte biomass to rock surfaces

8.4 Phase 2: Early Drawdown Studies

8.4.1 Hydroseeding Planting Study

Questions Addressed:

- Do rocky side slope areas need to be planted to reduce soil erosion, help promote new soil formation, and prevent the establishment of invasive plants?

- If so, what planting methods will be feasible and successful, and what species should be planted?

Hypotheses:

- Rocky side slope areas need to be planted to reduce soil erosion, help promote new soil formation, and prevent the establishment of invasive plants.
- Hydroseeding is a feasible and successful planting method for rocky side slopes.
- A mixture of native grasses, shrubs, and trees planted where appropriate growing conditions exist will reduce establishment of invasive plants and improve native plant cover.

Discussion:

Topographic maps and photographs of the exposed reservoir sediments during periods of low storage indicate that much of the side slope area that will be first exposed during reservoir drawdown is steep and rocky with poor soil conditions (Figure 13). It is likely that during successive filling and drawdown cycles in the reservoir, the thin layer of topsoil previously present on these slopes was washed down to lower elevations in the valley. The harsh conditions on the side slopes may result in slow establishment of plants, or may favor certain aggressive invasive plants over native plants. Without vegetative cover, these slopes may be prone to erosion and new soil formation may be slow to occur.

Figure 4: Poor soil conditions on steep side slopes (Photo credit: Sierra Club/Galen Rowell)

We recommend performing an experiment during the first few years of reservoir drawdown to evaluate the necessity of planting the side slope area and a potential method for performing the planting. Due to the harsh soil conditions, steep slopes, and large area that will be exposed, we recommend studying the feasibility of hydroseeding using native seed mixes. Hydroseeding is a common practice in areas where there is a need to quickly establish vegetation on large areas of steep slopes, such as cut banks associated with road construction projects.

Hydroseeding is performed by spraying a mixture of seed, nutrients, water, and a binding agent onto exposed land. It is usually performed using large trucks equipped with a slurry holding tank, spray hoses and pressurized nozzles capable of spraying up to 300 meters. With the lack of roads around Hetch Hetchy Reservoir, it will likely be necessary to perform the hydroseeding from the water or from the air for large scale application, although smaller areas could potentially be treated on a trial basis by staff on foot with backpack sprayers. If hydroseeding is to be performed from the water, a hydroseeding truck could be loaded onto a barge or a boat could be modified to perform hydroseeding. Aerial dispersal of hydroseed mixtures could also be used; existing fire suppression aircraft within the park could be converted for this purpose.

Figure 8.6: A hydroseed mixture can be applied using existing fire-suppression aircraft.

Experimental Approach (Hydroseeding Study)

Overview

As with all adaptive restoration plans, our experimental approach for the hydroseeding study builds on the results of previous work in the study. We recommend taking the following steps:

1. Develop expected optimal seed mix based on results of Vegetation Survey, Germination Study, and Seed Trap Study. This mixture should include species that are highly resilient and capable of growing in poor conditions.
2. Drawdown reservoir a small amount (1-3 meters) or utilize a year of slightly lower water storage levels to perform small, hand-treated hydroseeding trials.
3. Map areas suited for vegetation growth and areas suited for lichen recruitment based on slopes and soil/substrate characteristics.
4. Use staff on foot with backpack sprayers to treat small exposed areas with hydroseed mixture. Hydroseed 50 percent of the exposed land surface that offers suitable conditions for growing vegetation with plant seed mix. Leave 50 percent of exposed land surface with suitable conditions for growing vegetation bare as a control area. Conduct lichen hydroseeding study simultaneously (Phase 2, Experiment B).
5. Establish at least five evaluation plots in the vegetation treatment area (hydroseeded) and five in the vegetation control area (non-hydroseeded).
6. After the first growing season, evaluate the following response variables in the vegetation treatment and control areas.
    - Erosion rates.
    - Percent cover of vegetation.
    - Number of non-native invasive species.
    - Cover of non-native invasive species.
    - Number of native species.
7. Utilize Rapid Assessment scoring criteria to generalize study results (Table 3).

8. Based on results of hand-treated hydroseeding trials, adjust hydroseed mixture, application rates, or other techniques as necessary and expand hydroseeding study to a larger area.
9. Drawdown reservoir 15 meters from highest possible water elevation.
10. Map areas suited for vegetation growth and areas suited for lichen recruitment based on slopes and soil/substrate characteristics.
11. Hydroseed 50 percent of the exposed land surface that offers suitable conditions for growing vegetation with plant seed mix. Leave 50 percent of exposed land surface with suitable conditions for growing vegetation bare as a control area. Conduct lichen hydroseeding study simultaneously (Phase 2, Experiment B).
12. Establish at least five evaluation plots in the vegetation treatment area (hydroseeded) and five in the vegetation control area (non-hydroseeded).
13. After the first growing season, evaluate the following response variables in the vegetation treatment and control areas.
    - Erosion rates.
    - Percent cover of vegetation.
    - Number of non-native invasive species.
    - Cover of non-native invasive species.
    - Number of native species.
14. Utilize Rapid Assessment scoring criteria to generalize study results (Table 3).
15. Utilize Decision Tree 1 to determine application of results and further studies needed.

Treatments

In the first year of the hydroseeding study, we recommend applying a single slurry mixture to the treatment areas. The mixture would be selected by consulting with hydroseeding experts to determine the seed mix and proportion of slurry components that is most likely to be successful in establishing at the site. This mixture should be developed based on the desired diversity for the site and the results of the On-Site Vegetation Survey (indicating which species thrive in the existing conditions), the Seed Trap Study, and the Germination Study (indicating which species may potentially self-establish without extensive seeding). This mixture should include some species that are highly resilient and capable of growing in poor conditions.

If the hydroseeded treatment areas in the hand-treated trials are evaluated as in good condition after the first growing season, we recommend applying the initial hydroseed mixture to a larger area of the site. If hydroseeded treatment areas in the hand-treated trials are evaluated as in fair or poor condition after the first growing season, we recommend experimenting with multiple slurry mixtures to determine the optimal mixture for the site conditions. Variables for the slurry mixtures that could be adjusted include the density of seeding, the diversity of seeds used, and the proportion of slurry components (nutrients, seed, binding agents, and water).

Size of Experimental Plots

In the hand-treated trials, we recommend exposing a small area and hydroseeding approximately 50 percent of the exposed land surface that offers suitable growing conditions for grasses, shrubs, or trees. During the larger application of hydroseeding treatments in the first year of reservoir drawdown, we also recommend hydroseeding approximately 50 percent of the exposed land surface that offers suitable growing conditions for grasses, shrubs, or trees. We are recommending using 50 percent of the exposed area for the hydroseeding treatments because of the potential for erosion from the steep side slopes and establishment of invasive plants if native plants are not actively planted. The area available to perform the hydroseeding study is dependent upon the initial water level drop and the exposed land surface that offers suitable growing conditions for vegetation. As discussed in Section 8.2, approximations of the area exposed as the reservoir level drops and the slopes of those areas are based on a model of the submerged topography in Hetch Hetchy valley.

Our topographic model shows that an initial water level drop of 15 meters is expected to expose approximately 69 hectares of land (Table 8.1). Of this exposed area, 2 percent is estimated to have slopes between 8 and 25 percent, 21 percent is estimated to have slopes between 25 and 100 percent, and 71 percent is estimated to have slopes greater than 100 percent (45 degrees).

With the information available, it is not known how much land exposed during the initial drawdown phases will be suitable for growing vegetation. Initial reservoir drawdown will expose some areas that are solid rock slabs or granite faces (Figure 8.7).

Figure 8.7: A period of low reservoir level reveals solid rock faces that will be exposed during initial reservoir drawdown.

We expect that suitable growing conditions for vegetation will be found on areas that are not solid rock slabs or faces lacking any growing medium. Rock formations may create solid rock slabs or other conditions unsuitable to growing vegetation at any slope, however these conditions are more likely to exist as slopes get steeper. Areas on the side slopes that do not contain suitable conditions for growing vegetation likely contain conditions more appropriate for establishing lichens. Lichen establishment is discussed in Phase 2, Experiment B.

Evaluation

We recommend establishing at least five evaluation plots in the control area (non-hydroseeded) and at least five in the treatment area. These plots should represent the variety of site conditions in the treatment and control areas (light conditions, slope, etc).

After the first growing season, we recommend performing quantitative and qualitative analysis of the evaluation plots. To assess erosion, we recommend measuring erosion rates and visually evaluating the areas to assess erosion. To measure erosion rates, establish check dams at the base of the evaluation plots that will capture eroded sediments. We also recommend vegetation sampling (using a quadrat or transect technique) and performing quantitative analysis of the following response variables in the hydroseeded and non-hydroseeded areas:

- Percent cover of vegetation.
- Number of non-native invasive species.
- Cover of non-native invasive species.
- Number of native species.
- Total species.
- Species habit/qualitative assessment

Thresholds should be established for each of these response variables to guide experimental review and application of results. We propose the following preliminary thresholds, but recommend further review and potential adjustment of these thresholds if deemed appropriate by experts in native vegetation in the Sierra Nevada. Each threshold has been assigned a point value to assist in the analysis and application of the results.

Table 8.1: Proposed preliminary thresholds for evaluating response variables in hydroseeding study.

Response Variables	**“Good” = 3 Points**	**“Fair” = 2 Points**	**“Poor” = 1 Point**
1. Erosion	Mild to no erosion observed	Moderate erosion observed	Extensive erosion observed
2. Percent cover of vegetation.	>80 % cover	40-80% cover	<40% cover
3. Number of non-native invasive species.	Low: <5 species observed	Moderate: 5 to 20 species observed	High: >20 species observed
4. Cover of non-native invasive species.	Low: <10%	Moderate: 10-50%	High: >50%
5. Number of native species.	High: >30	Moderate: 10-30	Low: <10
6. Overall qualitative assessment	Abundant desirable native species, invasives not aggressively establishing, expected future performance of site is good.	Less abundant desirable native species, invasives somewhat aggressively establishing, some concerns about future performance of site.	Desirable native species not present, invasives aggressively establishing, expected future performance of site is poor.

If all six response variables are assumed to have equal weight in evaluating the experimental results, the range of potential ratings for a given evaluation plot ranges from 6 (all “poor” ratings) to 18 (all “good” ratings). Although it is important to consider how the local site conditions at each plot may have affected the response variables, in order to simplify the analysis we recommend summing the results for each individual plot (resulting in five ratings, each ranging from 6 to 18), then averaging the results for the five evaluation plots to assess the overall results in the control and treatment areas.

The following ranges could be used to review and apply the results of the hydroseeding study:

- Poor: 6.0 to 9.9
- Fair: 10.0 to 13.9
- Good: 14.0 to 18.0

For example, if Plot 1 has a rating of 6.0, Plot 2 has a rating of 10.0, Plot 3 has a rating of 9.0, and Plots 4 and 5 have ratings of 8.0; the average rating for the five plots would be 8.2 and thus the overall rating for this treatment would be "poor."

Experimental Review and Application of Results

We recommend using a decision tree to apply the results of the vegetation hydroseeding study (Figure 8.8). Under any outcome, we recommend conducting a second year of monitoring of the larger hydroseeded treatment and control areas to account for annual climate variation and other factors in analyzing the study results. Once the second year of monitoring is complete, we recommend one of the following methods of applying the results of the study:

- Apply the activity that provided the desired results (e.g., consistently "good" ratings of evaluation plots).
- Continue the study by experimenting with different hydroseeding mixes if hydroseeding provides fair but not good results.
- Modify the study by experimenting with alternative planting methods for the side slopes if neither hydroseeding nor the control areas provide the desired results.

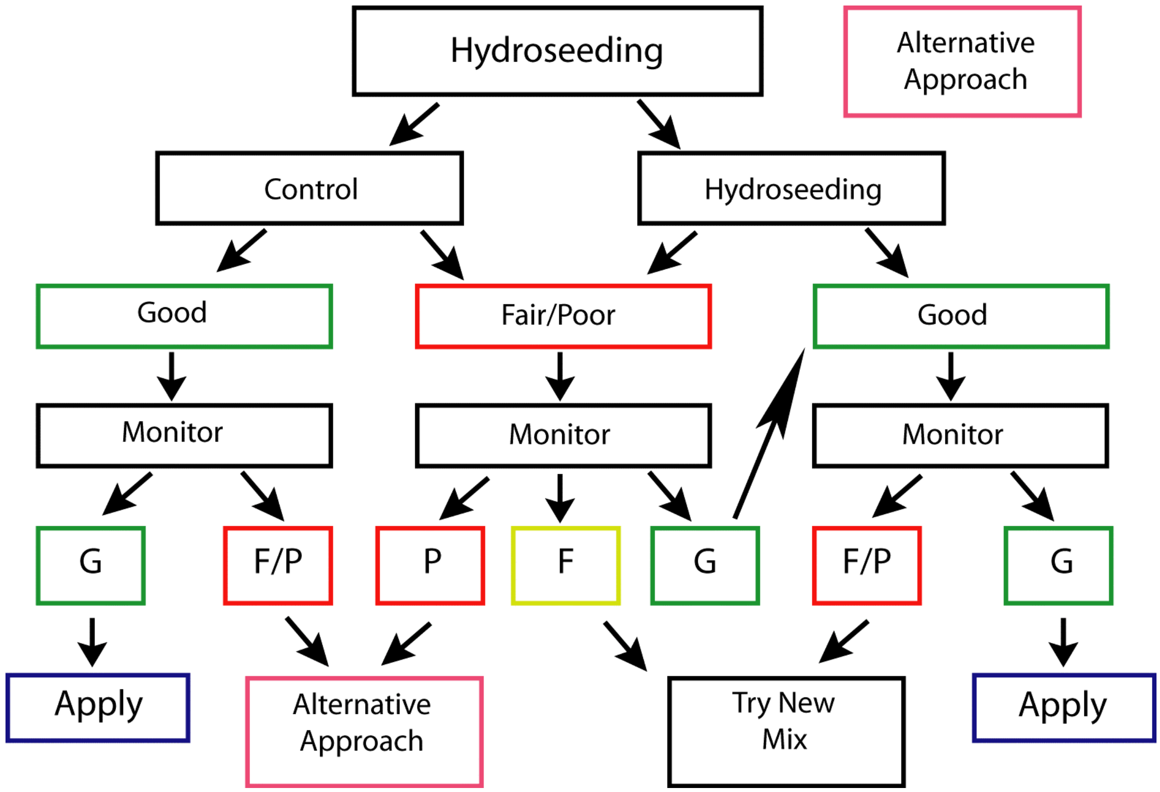

Figure 8.8: Hydroseeding decision tree

During the larger hydroseeding treatment phase, if the control areas are found to be in good condition for two consecutive years of monitoring, then it is possible that the rocky side slope areas do not need to be actively planted to reduce erosion and promote the establishment of native plants instead of invasive plants (Figure 8.8). This result could provide a rationale for a less expensive restoration strategy on the rocky side slope areas. Monitoring should continue to further evaluate the results of the control, which could be applied to larger areas of rocky side slopes as reservoir drawdowns continue.

If the hydroseeded treatment areas are evaluated as in good condition for two consecutive years of monitoring and the control areas are not evaluated as in good condition, we recommend applying the treatment to a larger area of the site. Small areas should be left as controls to continue monitoring over time, but most of the control area should be hydroseeded using the successful mixture. As future drawdowns expose additional rocky, steep side slope areas, the successful hydroseeding mixture should be further applied to those areas.

If the larger hydroseeded treatment areas are initially evaluated as in good condition but after a second year of monitoring degrade to fair or poor condition, or if the larger hydroseeded treatment areas are initially evaluated as fair or poor condition and after a second year of monitoring are evaluated in fair condition, we recommend further experimenting with multiple slurry mixtures to determine the optimal mixture for the site conditions. This experimentation could occur on areas used as control areas.

However, if the larger hydroseeded areas exhibit poor conditions for two years of monitoring, we recommend considering alternative planting and slope stabilization methods for the steep side slopes. These methods may include adding soil amendments, planting live seedlings, using erosion control matting or straw check dams, and other techniques.

8.4.2 Lichen Hydroseeding Study

Questions Addressed:

- Is there a feasible method for hastening lichen recovery on the rock faces in Hetch Hetchy Valley?
- When and where will lichens respond best to efforts to hasten recovery?

Hypotheses:

- Hydroseeding a lichen mixture onto rock faces will hasten lichen recovery in Hetch Hetchy Valley.

Discussion

As mentioned earlier, the NPS stated in its 1988 report on alternatives for restoration of Hetch Hetchy that “no practical way to hasten recovery” of native rock lichen colonies on the granite walls is known. They estimate that natural restoration of such colonies would take between 80 and 120 years. In Phase 1, we recommended a pre-drawdown study to explore potential methods for hastening lichen recruitment between rock surfaces. Based on personal communication with Professor Susan Will-Wolf, a UW-Madison ecologist who specializes in lichens, it is likely that hydroseeding a lichen mixture onto rock faces could hasten lichen recruitment. If this is found to be possible during the pre-drawdown study, we recommend performing a lichen hydroseeding study concurrently with the vegetation hydroseeding study.

Lichens are perhaps one of the most visible living communities within Yosemite National Park. The dark surfaces of the impressive domes of Yosemite National Park are not shadows, but crustose (growing within the rock) species of lichens (Armstrong 2004).

Lichens, a symbiotic relationship between an alga and a fungus, are very sensitive to changes in air quality, moisture and temperature. We see evidence of this sensitivity in Hetch Hetchy Valley today in the "bathtub ring" of lichen-free rock that surrounds the water impounded by O'Shaugnessy dam. Although lichens are able to establish on the rocky, exposed walls of Hetch Hetchy Valley, they cannot survive inundation as the reservoir fills, and they do not reestablish when the water level drops.

As water levels are lowered during the restoration process, microclimates will change and extant lichen communities will be impacted by changes in moisture availability and temperature. Lichens, which on average grow only a few millimeters per year, will not be able to keep up with the drop in water level and subsequent change in microclimate. *We propose a lichen "seeding" experiment*, whereby material from existing lichen communities growing near the edge of the reservoir could be used to establish new lichen communities as the water levels are lowered during the restoration drawdowns.

Experimental Approach

Overview

As with all adaptive restoration plans, our experimental approach for the lichen hydroseeding study builds on the results of previous work in the study. We recommend developing a decision tree, similar to the one described for the hydroseeding planting study, to apply the results of the lichen hydroseeding study.

We recommend taking the following steps in this study:

1. Based on the results of the Phase 1 pre-drawdown Lichen Recruitment Study, identify when lichens will respond best to hydroseeding and identify key habitats most likely to support introduced lichen colonies.
2. Develop optimal lichen and bryophyte recruitment mix based on results of the Lichen Recruitment Study. Mix lichen and bryophyte fragments with a binding agent into a solution that could be applied to rock surfaces.
3. Drawdown reservoir a small amount (1-3 meters) or utilize a year of slightly lower water storage levels to perform small, hand-treated hydroseeding trials.
4. Concurrent with the hydroseeding planting study, map areas suited for lichen recruitment based on slopes and soil/substrate characteristics.
5. Treat small exposed areas with lichen hydroseed mixture. Hydroseed 50 percent of the exposed land surface that does not offer suitable conditions for vegetation growth with lichen mix. Leave 50 percent of exposed land surface without suitable conditions for vegetation growth bare as a control area. Conduct plant hydroseeding study simultaneously.
6. Establish at least five evaluation plots in the lichen treatment area (hydroseeded) and five in the lichen control area (non-hydroseeded).
7. After the first growing season, evaluate treated and untreated areas for change in lichen and bryophyte cover and species richness.

8. Based on results of small-scale lichen hydroseeding trials, adjust time of application, hydroseed mixture, application rates, or other techniques as necessary and expand hydroseeding study to a larger area.
9. Drawdown reservoir 15 meters from highest possible water elevation.
10. Concurrent with the hydroseeding planting study, map areas suited for lichen recruitment and growth based on slopes and soil/substrate characteristics.
11. Hydroseed 50 percent of the exposed land surface that does not offer suitable conditions for vegetation growth with lichen mix. Leave 50 percent of exposed land surface without suitable conditions for vegetation growth bare as a control area.
12. Establish at least five evaluation plots in the lichen treatment area (hydroseeded) and five in the lichen control area (non-hydroseeded).
13. After the first growing season, evaluate treated and untreated areas for change in lichen and bryophyte cover and species richness.
14. Utilize a Decision Tree to determine application of results and further studies needed.

8.4.3 Planting Study

<u>Questions Addressed:</u>

- Will invasive plant species dominate if the exposed valley and transitional areas between the valley and steep side slopes are not planted with native species?
- What native plant species need to be planted to achieve the desired diversity levels and communities representative of pre-inundation conditions? What native species will regenerate on their own and do not need to be planted?

- What are the optimal seed or seedling mixes for planting in the valley and transitional areas? (Optimal mixes will result in the highest native diversity, lowest invasive cover, and lowest implementation and management cost.)
- What is the optimal method of weed control in the valley and transitional areas? (The optimal weed control strategy will be most effective at reducing invasive cover, have the least negative effect on native species, and the lowest implementation and management cost.)

Hypotheses:

- Invasive plant species will dominate if the exposed valley and transitional areas are not planted with native species.
- A high diversity mix of seeds and/or seedlings will provide optimal results.

Discussion

At least 129 non-native plant species exist in Yosemite National Park (NPS 2004). Many of these are Mediterranean annuals common throughout California below 1830 meter elevation. At least 39 widespread non-native grasses occur in Yosemite Valley and throughout the lower elevations in the park. The NPS assumed in its 1988 report on restoration alternatives for Hetch Hetchy valley that "it would be virtually impossible to prevent the rapid invasion of most of these taxa into Hetch Hetchy since many are characteristic pioneers of disturbed areas and already occur in close proximity to the reservoir. Massive herbicide spraying might hold these taxa in check initially, but such treatment would have to be continued indefinitely to be even partially effective long-term."

In order to evaluate this assumption, we propose developing a planting study at the site. If a planting study cannot be conducted at the site as proposed, research could also be performed off site to investigate planting needs. In this case, a mesocosm study could be conducted in experimental planting containers that attempt to mimic site conditions.

Experimental Approach

Overview

We recommend creating two experimental planting areas during the second proposed drawdown (9-meter drawdown following initial 15-meter drawdown). These planting areas should represent conditions similar to those that will be found in the valley areas adjacent to the Tuolumne River, as well as the transitional areas between the valley and the steep side slopes. We expect that the valley area will have moist soils and flat topography (0-3% slopes), and the transitional area will have moderately dry soils and gradual slopes (3-8%).

Based on the preliminary digital elevation model for the valley, we have identified an area where these experimental planting areas could be established (Figure 8.9, 8.10).

The plants grown in the initial planting study can be used for seed collection to seed other areas of the restoration as the reservoir drawdown continues. This will produce cost savings for the overall restoration project.

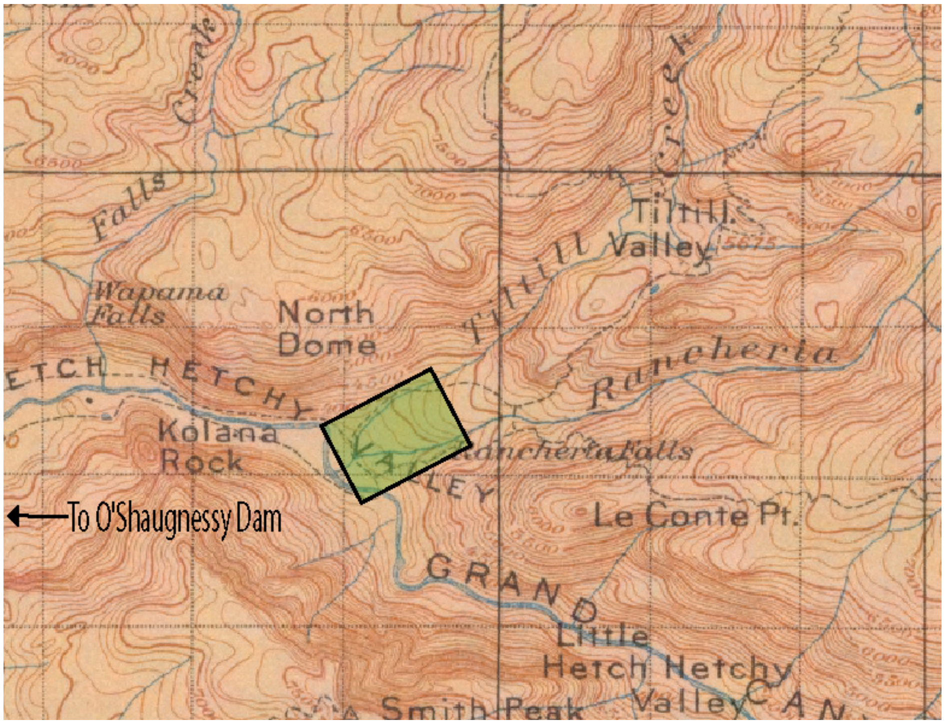

Figure 8.9: The shaded area within the box identifies potential location of planting study plots.

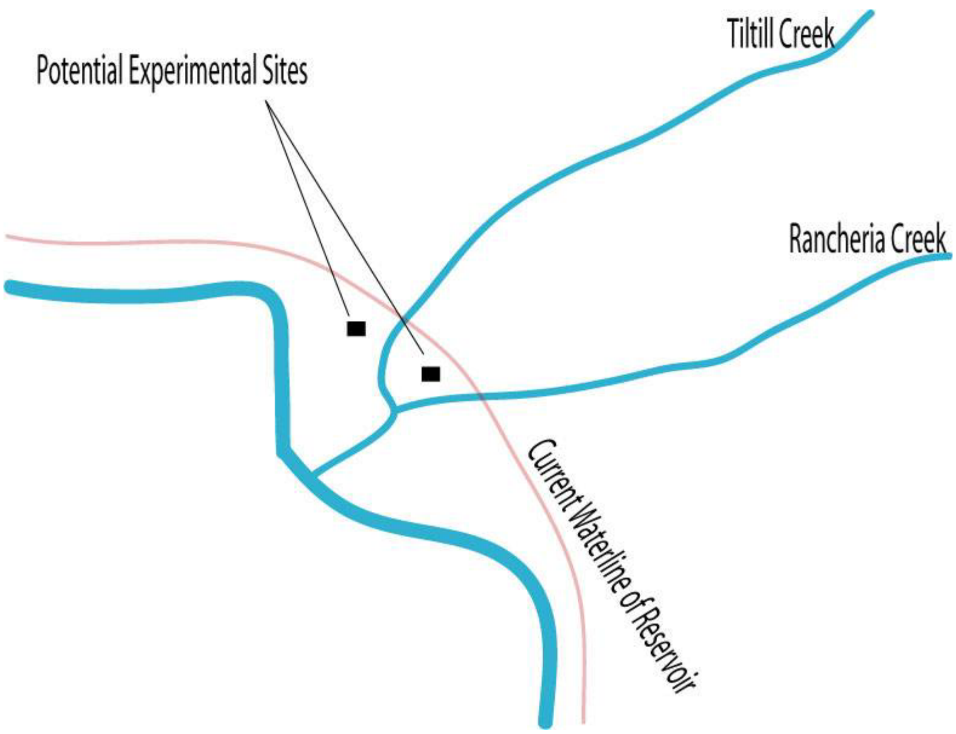

Figure 8.10: Conceptual drawing of planting study plot locations

Treatments

During the planting study, we recommend experimenting with different native seed and seedling mixes in conjunction with studying effective weed control methods. We recommend working with native plant specialists with knowledge of the local site conditions to develop seed and seedling mixes and weed control methods that are best suited to each site type (e.g. dry vs. wet). We recommend studying highly diverse native mixes composed of the following species:

- Graminoid & forb (seed)
- Graminoid & forb (seedling)
- Graminoid (seed) & forb (seedling)
- Graminoid, forb & tree (seedling)
- No planting (control)

The purpose of studying these planting mixes is to determine what native plant species will establish on their own and what species need to be planted to create diverse plant communities representative of those present at the site prior to inundation. In addition, this planting study will help determine which planting methods are necessary for native species survival and establishment. Planting seeds will be less expensive than planting seedlings, so the necessity of planting seedlings should be evaluated.

In addition to studying the types of plant species and planting methods that will be most effective at restoring native plant communities, it will also be important to study how to effectively control invasive, weedy and non-native plant species. We recommend selecting a single weed control technique to study first at each planting site, evaluating the effectiveness of this technique at controlling weeds while allowing native plants to thrive, and then experimenting with other weed control techniques if the first technique selected is not effective. Potential weed control techniques include:

- Herbicide
- Manual removal (by hand or with heavy equipment)
- Landscape fabric
- Mulch (with low-nutrient material such as straw)
- No weed suppression (control)

Further details regarding the implementation of the planting study are provided in the *Planting Study Implementation* portion of this section, below.

Size of Experimental Plots

We recommend implementing the planting study by creating five replicated plots of each treatment type. If the five seed/seedling mixes described above are planted and evaluated with and without weed control, the resulting experimental area will include twenty five replicated plots with weed control, and twenty five replicated plots without weed control. The plots should be distributed randomly (Figure 8.11).

1	3	2	5	4
2	4	3	1	5
5	2	4	1	3
3	4	5	2	1
1	3	4	5	2
2	1	4	5	3
2	3	1	4	5
1	3	4	2	5
5	4	3	1	2
4	5	3	2	1

Weed Control

No Weed Control

Figure 8.11 Planting study plot arrangement

In order to evaluate tree and shrub growth, these plots should be large enough to support several tree species. We recommend a plot size of 14-meters by 14-meters. We recommend planting the full plot area but only sampling within a 10-meter by 10-meter area within the plot to leave a 2 meter unsampled buffer around the plot (Figure 8.12).

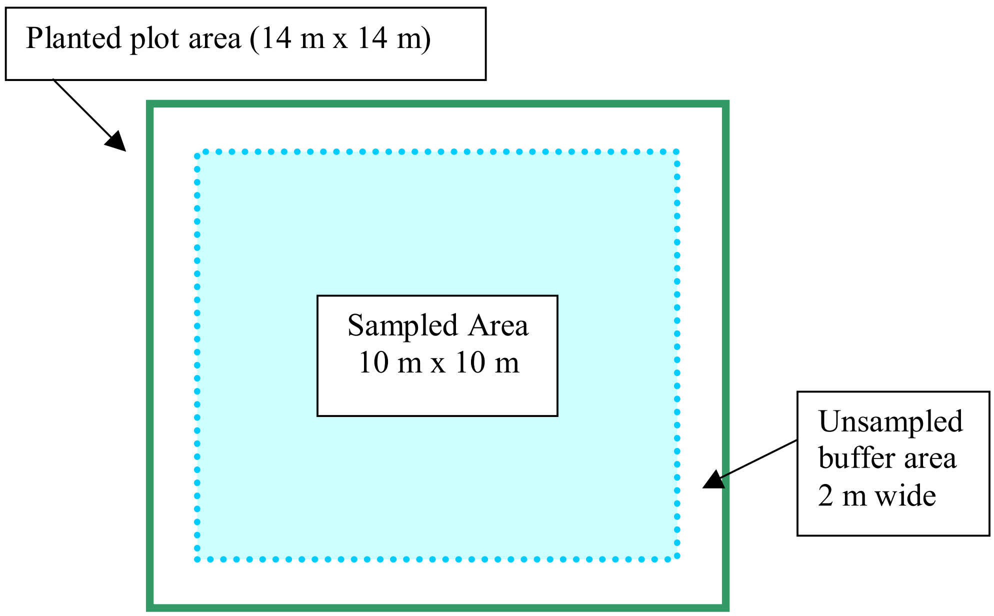

Figure 8.12: Experimental plot size for planting study

In order to plant fifty 14-meter by 14-meter plots in each of the two planting study area (valley and transitional), the total area needed for the planting study will be 1.94 hectares. This will include 0.97 hectares in an area with 0 to 3 percent slopes and 0.97 hectares in an area with 3 to 8 percent slopes. According to the preliminary digital elevation model discussed in Section 8.2, there will be 11 hectares of 0 to 3 percent slope land exposed and 1.0 hectares of 3 to 8 percent slope land exposed during the second proposed drawdown, so there should be adequate land area to perform the recommended experiments.

Evaluation

After the first growing season, we recommend performing quantitative and qualitative analysis of the experimental plots. We recommend sampling (using a quadrat or transect technique) and performing quantitative analysis of the following vegetation response variables:

- Percent cover of vegetation.
- Number of non-native invasive species.
- Cover of non-native invasive species.
- Number of native species.
- Number of rare/sensitive natives
- Which species occur.
- Description of conditions in which each species occurs.

Thresholds should be established for each of these response variables to guide experimental review and application of results. We propose the following preliminary thresholds, but recommend further review and potential adjustment of these thresholds if deemed appropriate by experts in native vegetation in the Sierra Nevada region. Each threshold has been assigned a point value to assist in the analysis and application of the results.

Table 8.2: Proposed preliminary thresholds for evaluating response variables in planting study.

Response Variables	**"Good" = 3 Points**	**"Fair" = 2 Points**	**"Poor" = 1 Point**
1. Percent cover of vegetation.	>80 % cover	50-80% cover	<50% cover
2. Number of invasive species	Low: <5 species observed	Moderate: 5 to 20 species observed	High: >20 species observed
3. Percent cover of invasive species	Low: <10%	Moderate: 10-50%	High: >50%
4. Number of natives	High: >30	Moderate: 10-30	Low: <10
5. Number of rare/sensitive	High: >5	Moderate: 3-5	Low: <3

natives			
6. Overall qualitative assessment	Abundant desirable native species, invasives not aggressively establishing, expected future performance of site is good.	Less abundant desirable native species, invasives somewhat aggressively establishing, some concerns about future performance of site.	Desirable native species not present, invasives aggressively establishing, expected future performance of site is poor.

If all six response variables are assumed to have equal weight in evaluating the experimental results, the range of potential ratings for a given evaluation plot ranges from 6 (all "poor" ratings) to 18 (all "good" ratings). Although it is important to consider how the local site conditions at each plot may have affected the response variables, in order to simplify the analysis we recommend summing the results for each individual plot (resulting in five ratings, each ranging from 6 to 18), then averaging the results for the five evaluation plots to assess the overall results in the control and treatment areas.

The following ranges could be used to review and apply the results of the hydroseeding study:

- Poor: 6.0 to 9.9
- Fair: 10.0 to 13.9
- Good: 14.0 to 18.0

For example, if Plot 1 has a rating of 6.0, Plot 2 has a rating of 10.0, Plot 3 has a rating of 9.0, and Plots 4 and 5 have ratings of 8.0; the average rating for the five plots would be 8.2 and thus the overall rating for this treatment would be "poor."

Experimental Review and Application of Results

We recommend using a decision tree in a similar manner as described for the hydroseeding study, to apply the results of the planting study (Figure 8.13). We recommend one of the following methods of applying the results of the study:

- Apply the activity that provided the desired results (e.g., consistently "good" ratings of evaluation plots).
- Continue the study by experimenting with different planting mixes and/or weed control methods if treatments provides fair but not good results.
- Modify the study by experimenting with alternative planting methods if neither the planting nor the control areas provide the desired results.

Further Planting Studies

In addition to the questions discussed above that are used for formulate the initial planting study, there are numerous other questions that could be explored during expanded planting studies conducted during later drawdown periods. These questions include:

- Will tree tubes and bird exclusion netting be necessary for seedling survival?
- Are successive plantings over time in the same area desired to achieve age-varied stands of trees?
- How will transitional conditions during drawdown (i.e. higher than normal water table at reservoir edge) affect plantings? Should there be a buffer zone in a newly uncovered area next to the reservoir edge that is not planted until the following year when the reservoir edge is farther away? Should this buffer zone be managed to control weeds until planted?
- How will invasive competition and native reestablishment vary in different environmental settings?
- What planting density is necessary for survival of desired species?

- What planting arrangement is most cost effective and successful? Could higher diversity seed or seedling mixes be planted in small "nodes of diversity" surrounded by less diverse mixes in an effort to minimize planting costs?
- Can tree stumps exposed during later drawdown stages be utilized as "nurse logs" to support seedlings?

Planting Study Implementation

<u>Seeds:</u>

Site preparation ("site prep") activities should include collecting and growing seedlings for the planting experiment. Seeds and seedlings with local genotypes should be collected from Yosemite Valley or remnant plant communities close to Hetch Hetchy. Seeds of herbaceous perennials and annuals should be collected and kept in cold storage for no more than one year prior to seeding because seeds stored for more than one growing season will have reduced rates of germination. Stratification of seeds is also recommended before seeding to improve germination rates. To ensure adequate seeds and seedlings are available for the seeding experiment and future restoration work in the valley, we recommend establishing an on site nursery. A nursery would ensure use of local genotypes, avoid supply shortages, and allow for the propagation of rare or endangered species found in the valley that would otherwise be unavailable or expensive to buy commercially.

<u>Soil pH and Nutrient levels:</u>

Pre-drawdown experiments included soil analysis; however, once water is drained from the experimentation site, soil samples should again be collected. Soil samples will determine soil pH, nutrient levels, and compaction levels. Soil pH in most natural forest and grassland communities is neutral to acidic (Curtis 1959). Soil samples indicating acid soils (< 6) can be amended with ground limestone to raise pH levels, while powdered sulfur incorporated into soils will reduce pH levels in alkaline soils (Saucer 1998).

Soil samples also can provide information on soil composition and nutrient levels. Low soil nutrient levels can be improved by adding or naturally allowing leaf litter and fallen logs to accumulate on the site (Saucer 1998). If soil nutrient levels are not improved by natural accumulation of decomposing plant material, wood mulch and vegetative debris can be added to the soil, but the source of the additional mulch and debris should be local. Soil microbial communities and fungi also benefit from the accumulation of leaf and wood litter, but their populations can be enhanced artificially by inoculating the soil with small amounts of soil from nearby analogous sites or spreading woodchips containing local mycorrhizae populations over the study site (Saucer 1998).

Soil Compaction:

Pre-drawdown studies may reveal that portions of the Hetch Hetchy valley have compacted soil, which should be improved before seeding. Soil compaction reduces root growth, aeration and water infiltration— all factors important to the successful establishment of a plant community (Saucer 1998). Several methods can be used to reduce compacted soil including: hand excavating, vertical staking and subsoiling, which is a method that uses a vibratory mole plow to loosen compacted soil. Hand raking targets specific areas of compaction, but is not an effective method in heavily compacted or large sites.

Vertical staking is an appropriate method to use where compaction is heavy and the threat of erosion exists. Vertical staking involves driving stakes made from branches vertically into the soil. Staking density and depth depends on the level of compaction. Generally, higher staking densities are used as levels of compaction increase. Stakes are left to naturally decompose in the soil, which further facilitates water and air movement through the soil and replenishes nutrients. Subsoiling is used where compaction is deep and native plant communities are highly degraded or absent. Subsoiling should be used in relatively flat areas where erosion is not a concern. Subsoiling may not be a feasible option in Hetch Hetchy Valley due to steep slopes and limited access to higher elevations.

Planting:

Once the seedbed is prepared, the study site may need to be tilled prior to planting. Tilling will incorporate any leaf litter or mulch added to the site and kill non-native plant material that has sprouted since the water drawdown. If large numbers of non-native plants have established, implementation of other weed control methods will be required prior to planting. Hand broadcasting seeds and planting seedling plugs are the recommended methods for planting the study site. Seeds should be mixed with a bulk material like sand or vermiculite to facilitate even distribution over the site.

In tallgrass restoration, seeding rates can range from 40-60 seeds per square foot. A seeding rate between 40-60 seeds per square foot translates roughly to 7 pounds per acre, if the seed is 95% pure (5% weed seed) (Packard 1997). Successful establishment of seed can be achieve using a rate of 30-40 seeds if the site is well prepared site and has good soil quality.

Seeds can be planted in the fall or spring. Fall plantings will give seeds an advantage in the spring by sprouting before weed seeds, potentially out competing invasive species. However, planting seeds in the fall will expose seeds to predation by birds and mammals. In addition, good seed to soil contact is needed to prevent desiccation and seed deflection by wind. A spring planting time will delay sprouting of native seed giving invasive species an advantage, but native seeds will not be as susceptible to predation or desiccation.

Mowing can be used as a method of controlling invasive species in study plots until natives establish. Spring seeding is recommended for this experiment.

Monitoring:

Once plant communities begin growing, monitoring will consist of quantitative quadrat sampling. Each study plot will be randomly sampled with a 0.5-meter x 0.5-meter quadrat in May and August until restoration goals are met. Ten samples will be collected from each study plot and the response variable measured will include the number of native and invasive species as well as percent cover of each species, as described above in the *Treatment* portion of the planting study description.

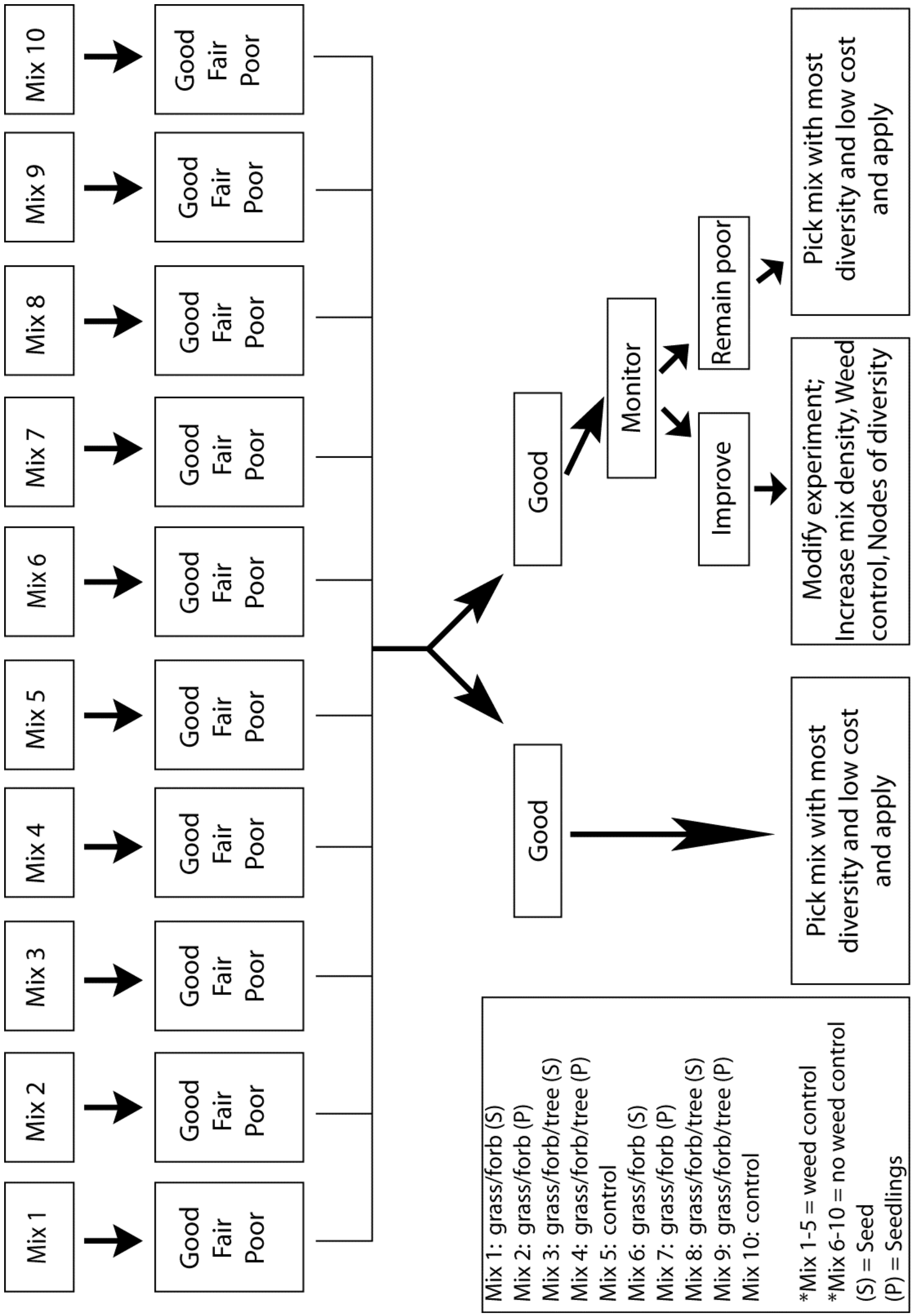

Figure 8.13: Decision tree for seed mixes.

9.0 RECOMMENDATIONS FOR LONG-TERM MANAGEMENT

The Role of the National Park Service

As the stewards of Yosemite National park, we assume that any restoration effort within the Hetch Hetchy Valley will be coordinated by the National Park Service (NPS). Since its official inception in 1916, the mission of the NPS has been to:

> … promote and regulate the use of the Federal areas known as national parks, monuments, and reservations hereinafter specified by such means and measures as conform to the fundamental purposes of the said parks, monuments, and reservations, which purpose is 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 (16 USC Chapter 1 §1).

Restoring Hetch Hetchy Valley will need to be accomplished over many decades, across generations. Given the profound responsibility of ensuring that the nation's national parks remain "unimpaired for future generations," the NPS has undertaken dozens of restoration efforts in many of its park units (McCaffrey 2003). Additionally, in order to achieve its mission of conserving the nation's natural and historic resources, the NPS has identified eight "Essential Universal Competencies" that all NPS employees are expected to attain. A universal competency that directly applies to the Hetch Hetchy restoration project is "Resource Stewardship":

> This competency requires an overall understanding of the spectrum of resources protected by the NPS; the range of NPS responsibilities in managing these resources; the individual's role in resource stewardship; the planning process and its purpose in the NPS; and working with partners outside the agency to promote resource stewardship (NPS 2004).

Currently, all NPS employees report to the Albright Training Center in Grand Canyon National Park, Arizona, for training in NPS Universal Competencies. As restoration efforts are becoming increasingly part of NPS operations throughout its park units, (NPS Natural Resource Management Reference Manual 2004), and the Hetch Hetchy restoration may be the largest restoration within a NPS site, requiring the time and energy of thousands of people, we recommend that participation in restoration activities at Hetch Hetchy valley be added to the existing NPS service-wide training program. Training at Hetch Hetchy would offer NPS employees hands-on experience in natural areas restoration and exposure to one of the most heavily visited parks in the country (Madej et al. 1994).

Management of Human Impact

By definition, in an "active restoration," human impact upon the landscape of Hetch Hetchy Valley is inevitable. We suggest that public access to the restoration area be limited to personnel actively engaged in the restoration process. We hope his will reduce the threat of alien plant invasions and allow the NPS to focus its limited resources on restoration efforts rather than visitor services. As the restoration progresses and plant communities mature, public visitation could be increased, offering opportunities for visitors to participate in the restoration effort.

Ecological Research

As Hetch Hetchy Valley exists within the relatively protected location of Yosemite National Park, it may be a desirable candidate for the National Science Foundation's "Long Term Ecological Research Area" program. Established in 1980, the Long Term Ecological Research (LTER) Network is a collaborative effort involving more than 1800 scientists and students investigating ecological processes over long temporal and broad spatial scales (US Ecological Research Network 2004). Participation within the LTER program would offer the Hetch Hetchy project a source of expertise and research funding for experimentation and monitoring components of the restoration effort. Currently, none of the 26 sites in the LTER network is located within the Sierra Nevada range.

Fire Management

Fire plays an integral role in the Yosemite National Park ecosystem (Wagtendonk 1985). The chaparral plant community now within Hetch Hetchy Valley is adapted to a regime of intense fires every 20 to 30 years (Parsons 1976). It is probable that fire maintained the oak savanna/grassland habitat depicted in pre-dam photos of HHV. Indeed, within Yosemite Valley, fire is thought to have maintained a plant community with more oak and meadow habitat than exists today (NPS ROD 2004).

Figure 9.1: Grassland and oak habitat of Hetch Hetchy Valley in 1911. (photo credit Library of Congress)

It will be necessary for the NPS to develop a fire management plan for Hetch Hetchy Valley based on both extant and pre-dam plant communities, as well as on restoration goals. Once plant communities are established in the restoration area, prescribed and wildland fire will likely be needed to maintain the fire-dependent ecosystems of the valley. Additionally, the use of fire should be explored for control of invasive, non-native plants. Any fire management plan should be periodically reviewed and updated as knowledge of local fire ecology and fire behavior increases though experimentation at the site.

Streambank and Floodplain Management

Despite the rapidly increasing number of dam removal projects in the United States, understanding of the hydrogeological implications of dam removal is quite limited (Doyle et al. 2003). As the restoration drawdowns of Hetch Hetchy reservoir progress, an increasing length of the Tuolumne River will be exposed. This phased exposure provides an opportunity to study how removal of the reservoir (and possibly O'Shaughnessy dam) could affect the geomorphology and hydrology of HHV. Once the reservoir is completely drained, this information could be used to predict the behavior of the river channel should O'Shaughnessy dam be removed.

In the short term, removal of the dam could have a negative impact on the restoration process. If a decision is made to completely remove the dam, plant communities established during the restoration process could be destroyed by headcutting within the river channel and changes in the size and shape of the river floodplain (Schumm et al. 1984). In the long term, assuming there is minimal human-caused disturbance within the watershed, the reach of the Tuolumne River within Hetch Hetchy Valley will return to equilibrium, where the amount of sediment entering the river is equal to the amount of sediment transported from the river.

Wildlife Management

The scope of this adaptive restoration plan has primarily included restoration of plant communities. As plant communities establish and diversify in size and structure, we predict that wildlife will move into the restoration site to utilize new food and shelter resources. The potential impact of herbivory on restoration planting will need to be balanced with wildlife management goals.

Managing Undesirable Restoration Outcomes

We recommend that the water control structures within O'Shaugnessy dam remain intact and maintained during the restoration process. This allows for both the phased drawdown approach and an "insurance policy" for undesirable restoration outcomes, such as unmanageable problems with invasive plants. If initial control strategies for invasive plants prove unsuccessful, temporarily refilling the reservoir could be used as a last-ditch option to restart the restoration process.

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APPENDICES

Appendix A: Invasive Species

Invasive species are a significant management problem in parks, reserves, and restoration projects. Control of invasive species in natural areas is important because exotic species can outcompete populations of native plants. Competition from non-native plants can change the composition and structure of native plant communities, which also impacts higher trophic levels. Many non-native plants were introduced into the Yosemite area by settlers in the 1850s. Recently, however, the spread of invasive species in Yosemite is the result of construction, lack of fire, and high human use in the park. Yosemite National Park has documented more than 130 non-native plant species within the park (Table 3;Yosemite Valley Restoration Plan 2000). Some of the more common exotic species found in Yosemite include: Bull Thistle (*Cirsium vulgare*), yellow star thistle (*Centaurea solstitialis*), Himalayan blackberry (*Rubus discolor*), and Periwinkle (*Vinca major*) (Yosemite Valley Restoration Plan 2000). Many of the species that are currently a problem in Yosemite are likely to establish in Hetch Hetchy Valley once dam removal begins. In fact, patterns of non-native plant invasion have been predicted for Yosemite National Park. Areas that occur at low to mid-elevations in flat area with other herbaceous species are likely to be invaded by non-native species. Hetch Hetchy Valley and the surrounding area has been identified as an area highly susceptible to invasion (Underwood, 2000). High intensity monitoring and management will be necessary to minimize the establishment and spread of invasive species in Hetch Hetchy Valley.

Table 4: Invasive plant species of Yosemite National Park

Genus	Species	Family	Common Name	Threat level assigned by NPS
Amaranthus	albus	Amaranthaceae	white pigweed	
Foeniculum	vulgare	Apiaceae	bitter fennel	Most invasive, Red alert
Torilis	arvensis	Apiaceae	field hedge-parsley	Lesser invasive
Anthriscus	caucalis	Apiaceae	bur-chervil	
Vinca	major	Apocynaceae	greater periwinkle	Lesser invasive
Hedera	helix	Araliaceae	English ivy	Lesser invasive, Most invasive
Hypochaeris	radicata	Asteraceae	rough cat's -ear	More information, Most invasive
Coreopsis	lanceolata	Asteraceae	garden coreopsis	
Scorzonera	hispanica	Asteraceae	Spanish salsify	
Chamomilla	suaveolens	Asteraceae	pineapple weed	
Filago	gallica	Asteraceae	narrow-leafed cudweed	
Centaurea	maculosa	Asteraceae	spotted knapweed	Red Alert, Red alert
Lactuca	serriola	Asteraceae	prickly lettuce	
Sonchus	oleraceus	Asteraceae	sow-thistle	
Sonchus	asper	Asteraceae	spiny sow-thistle	
Rudbeckia	hirta	Asteraceae	bristly coneflower	
Taraxacum	officinale	Asteraceae	dandelion	
Leucanthemum	maximum	Asteraceae	Shasta daisy	
Tragopogon	dubius	Asteraceae	yellow salsify	Most invasive
Centaurea	solstitialis	Asteraceae	yellow starthistle, St Barnaby's thistle	Most invasive, Most invasive

Genus	Species	Family	Common Name	Threat level assigned by NPS
Tanacetum	parthenium	Asteraceae	feverfew	Most invasive (T. vulgare)
Carduus	pycnocephalus	Asteraceae	Italian thistle	Lesser invasive, Lesser invasive
Cirsium	vulgare	Asteraceae	bull thistle	Lesser invasive, Lesser invasive
Anthemis	cotula	Asteraceae	stinking mayweed	
Centaurea	melitensis	Asteraceae	tocolote, Maltese starthistle	
Erigeron	strigosus	Asteraceae	tall fleabane	
Leucanthemum	vulgare	Asteraceae	ox-eye daisy	Lesser invasive, Most invasive
Centaurea	cyanus	Asteraceae	cornflower, batchelor button	
Hypochaeris	glabra	Asteraceae	smooth cat's-ear	
Raphanus	sativus	Brassicaceae	wild radish	
Barbarea	vulgaris	Brassicaceae	winter-cress, yellow rocket	
Sinapis	arvensis	Brassicaceae	charlock	
Sisymbrium	officinale	Brassicaceae	hedge mustard	
Raphanus	raphanistrum	Brassicaceae	wild radish	
Conringia	orientalis	Brassicaceae	hare's-ear mustard	
Lunaria	annua	Brassicaceae	honesty	
Capsella	bursa-pastoris	Brassicaceae	shepard's purse	
Hirschfeldia	incana	Brassicaceae	hoary mustard, Mediterranean mustard	More information
Sisymbrium	altissimum	Brassicaceae	tumble mustard	Most invasive
Brassica	nigra	Brassicaceae	black mustard	Lesser invasive
Cerastium	fontanum	Caryophyllaceae	common chickweed	
Lychnis	coronaria	Caryophyllaceae	rose campion	
Cerastium	glomeratum	Caryophyllaceae	mouse-ear chickweed	
Stellaria	media	Caryophyllaceae	chickweed	
Silene	latifolia	Caryophyllaceae		
Silene	gallica	Caryophyllaceae	small-flowered catchfly	
Herniaria	hirsuta	Caryophyllaceae	hairy rupture wort	
Dianthus	barbatus	Caryophyllaceae	sweet William	
Polycarpon	tetraphyllum	Caryophyllaceae	four-leaved allseed	
Spergularia	rubra	Caryophyllaceae	sand spurry	
Chenopodium	botrys	Chenopodiaceae	sticky goosefoot, Jerusalem oak	
Chenopodium	album	Chenopodiaceae	fat hen, white goosefoot	
Convolvulus	arvensis	Convolvulaceae	field bindweed	Not listed, Lesser invasive
Trifolium	repens	Fabaceae	white clover	
Trifolium	hirtum	Fabaceae	rose clover	
Trifolium	dubium	Fabaceae	shamrock, little hop clover	
Lathyrus	latifolius	Fabaceae	broad-leaved everlasting-pea	
Vicia	benghalensis	Fabaceae	purple vetch	
Medicago	lupulina	Fabaceae	black medic	
Trifolium	pratense	Fabaceae	red clover	
Melilotus	indica	Fabaceae	sour clover	
Medicago	polymorpha	Fabaceae	burclover	Not listed
Melilotus	officinalis	Fabaceae	yellow sweet clover	Not listed, Lesser invasive
Melilotus	alba	Fabaceae	white medic, white sweet clover	Lesser invasive

Genus	Species	Family	Common Name	Threat level assigned by NPS
Erodium	botrys	Geraniaceae	long-beaked filaree	
Geranium	robertianum	Geraniaceae	Robert's geranium	Red alert
Erodium	cicutarium	Geraniaceae	red-stemmed filaree	
Hypericum	perforatum	Hypericaceae	Klamath weed, St. Johnswort	Lesser invasive, Most invasive
Mentha	spicata	Lamiaceae	spearmint	
Marrubium	vulgare	Lamiaceae	horehound	Not listed
Alcea	rosea	Malvaceae	hollyhock	
Malva	nicaeensis	Malvaceae	French mallow	
Malva	parviflora	Malvaceae	Least mallow	
Oxalis	corniculata	Oxalidaceae	woodsorrel	
Plantago	lanceolata	Plantaginaceae	ribwort, buckhorn	
Plantago	major	Plantaginaceae	hoary plantain	
Avena	fatua	Poaceae	wild oats	Significant threat
Bromus	diandrus	Poaceae	ripgut brome	Significant threat
Agrostis	gigantea	Poaceae	giant bentgrass, redtop	Most invasive
Avena	barbata	Poaceae	slender wild oats	Significant threat
Bromus	tectorum	Poaceae	cheatgrass, downy brome	Most invasive, Most invasive
Lolium	perenne	Poaceae	perennial rye-grass	Lesser invasive
Poa	compressa	Poaceae	Canada blue grass	Lesser invasive
Holcus	lanatus	Poaceae	velvetgrass, London fog	Lesser invasive, Most invasive
Vulpia	myuros	Poaceae	rattail fescue	Lesser invasive
Phleum	pratense	Poaceae	timothy	Lesser invasive
Bromus	sterilis	Poaceae	sterile brome	Lesser invasive
Bromus	inermis	Poaceae	smooth brome	Most invasive
Poa	pratensis	Poaceae	Kentucky blue grass	Most invasive
Festuca	pratensis	Poaceae	meadow fescue	Lesser invasive
Dactylis	glomerata	Poaceae	orchard-grass	Lesser invasive
Festuca	arundinacea	Poaceae	tall fescue, reed fescue	Lesser invasive, Lesser invasive
Hordeum	murinum	Poaceae	foxtail	
Briza	maxima	Poaceae	quaking grass	
Panicum	miliaceum	Poaceae	broom-corn millet	
Briza	minor	Poaceae	little quaking grass	
Parapholis	incurva	Poaceae	sickle grass	
Hordeum	marinum	Poaceae	Mediterranean barley	
Bromus	hordeaceus	Poaceae	soft chess	
Poa	annua	Poaceae	annual blue grass	
Bromus	secalinus	Poaceae	rye brome	
Poa	bulbosa	Poaceae	bulbous blue grass	
Bromus	catharticus	Poaceae	rescue grass	
Lolium	temulentum	Poaceae	darnel	
Digitaria	sanguinalis	Poaceae	crabgrass	
Bromus	arenarius	Poaceae	Australian brome	
Cynodon	dactylon	Poaceae	bermuda grass	
Aira	caryophyllea	Poaceae	silver hairgrass	
Setaria	pumila	Poaceae		
Setaria	viridis	Poaceae	green bristlegrass	
Lolium	multiflorum	Poaceae	annual rye-grass, Italian rye-grass	Significant threat, Lesser invasive
Agrostis	viridis	Poaceae		
Triticum	aestivum	Poaceae	wheat	

Genus	Species	Family	Common Name	Threat level assigned by NPS
Cynosurus	echinatus	Poaceae	hedgehog dogtail-grass	
Rumex	crispus	Polygonaceae	curley dock	Lesser invasive
Polygonum	convolvulus	Polygonaceae	black bindweed	
Polygonum	arenastrum	Polygonaceae	common knot weed	
Rumex	acetosella	Polygonaceae	sheep's sorrel, garden sorrel	Most invasive
Anagallis	arvensis	Primulaceae	scarlet pimpernel	
Rubus	lacinatus	Rosaceae	evergreen blackberry	Lesser invasive
Rubus	discolor	Rosaceae	Himalayan blackberry	Most invasive, Most invasive
Galium	parisiense	Rubiaceae	wall bedstraw	
Digitalis	purpurea	Scrophulariaceae	purple foxglove	Not listed. Lesser invasive
Verbascum	thapsus	Scrophulariaceae	common mullein	Lesser invasive, Most invasive
Veronica	persica	Scrophulariaceae	field speedwell	
Veronica	arvensis	Scrophulariaceae	field speedwell	
Urtica	urens	Urticaceae	burning nettle	
Vitis	vinifera	Vitaceae	grape	
Tribulus	terrestris	Zygophyllaceae	caltrop	

Appendix B: Endangered, Threatened, and Rare species

Plants:

California has an unusually diverse flora that includes about 6,300 vascular plants (ferns gymnosperms and flowering plants) (Tibor 2001). In addition to California's flora being extremely diverse more than a third of the native species are endemic, meaning they are restricted to a particular habitat found only in the state of California. Yosemite National Park contains about 1,374 vascular plant species and 109 of these species are listed as federal species of concern or rare by the state of California (Yosemite National Park website 2004). Federal species of concern include: Three-bracted onion (*Allium tribracteatum*), Yosemite woolly sunflower (*Eriophyllum nubigenum*), Congdon's lomatium (*Lomatium congdonii*), Tiehm's rock-cress (*Arabis tiehmii*), Slender-stemmed monkey flower (*Mimulus filicaulis*), and Bolander's clover (*Trifolium bolanderi*). The state of California also has listed four rare species: Yosemite Onion (*Allium yosemitense*), Tompkin's sedge (*Carex tompkinsii*), Condgon's wooly sunflower (*Eriophyllum congdonii*), and Congdon's lewisia (*Lewisia congdonii*). In addition, Yosemite National Park has listed some plant species as rare, meaning they are not federally or state recognized as endangered or rare, but do have limited distributions in the park. Since Hetch Hetchy Valley is located within Yosemite National Park, endangered and rare plant species may occur in the restoration site. Restoration efforts should protect existing populations and promote the establishment of these plant species in the restoration site.

Federal Species of Concern:

Three-bracted onion (*Allium tribracteatum*)
Yosemite woolly sunflower (*Eriophyllym nubigenum*)
Congdon's lomatium (*Lomatium congdonii*)
Tiehm's rock-cress (*Arabis tiehmii*)
Slender-stemmed monkey flower (*Mimulus filicaulis*)
Bolander's clover (*Trifolium bolanderi*)

State Listed Rare Species:

Yosemite Onion (*Allium yosemitense*)
Tompkin's sedge (*Carex tomphkinsii*)
Condgon's wooly sunflower (*Eriophyllum congdonii*)
Congdon's lewisia (*Lewisia congdonii*)

Yosemite National Park Listed Rare:

Sugar stick (*Allotropa virgata*)
Snapdragon (*Antirrhinum leptaleum*)
Sweetwater Mountains milkvetch (*Astragalus kentrophyta var. danaus*)
Black and white sedge (*Carex albonigra*)
Capitate sedge (*Carex capitata*)
Congdon's sedge (*Carex congdonii*)
Indian paintbrush (*Castilleja foliolosa*)
Alpine cerastium (*Cerastium beeringianum*)
Small's southern clarkia (*Clarkia australis*)
Sierra claytonia (*Claytonia nevadensis*)
Child's blue-eyed Mary (*Collinsia childii*)
Collinsia (*Collinsia linearis*)
Draba (*Draba praelta*)
Round-leaved sundew (*Drosera rotundifolia*)
Stream orchid (*Epipactis gigantea*)
Desert fleabane (*Erigeron linearis*)
Rambling fleabane (*Erigeron vagus*)
Fawn-lily (*Erythronium purpurascens*)
Northern bedstraw (*Galium boreale ssp. septentrionale*)
Dane's gentian (*Gentianella tenella ssp. tenella*)
Goldenaster (*Heterotheca sessiliflora ssp. echioides*)
Yosemite ivesia (*Ivesia unguiculata*)
Common juniper (*Juniperus communis*)
Pitcher sage (*Lepechinia calycina*)
Sierra laurel (*Leucothoe davisiae)*
False pimpernel (*Lindernia dubia var. anagallidea*)
Congdon's monkeyflower (*Mimulus congdonii*)
Inconspicuous monkeyflower (*Mimulus inconspicuus*)
Palmer's monkeyflower (*Mimulus palmeri*)
Pansy monkeyflower (*Mimulus pulchellus*)
Dwarf sandwort (*Minuartia pusilla*)
Sierra sweet-bay (*Myrica hartwegii*)
Azure penstemon (*Penstemon azureus ssp. angustissimus*)
Phacelia (*Phacelia platyloba*)
Phacelia (*Phacelia tanacetifolia*)
Snow willow (*Salix reticulata*)
Wood saxifrage (*Saxifraga mertensiana*)
Bolander's skullcap (*Scutellaria bolanderi*)
Groundsel (*Senecio serra var. serra*)
Giant sequoia (*Sequoiadendron giganteum*)
Ladies' tresses (*Spiranthes porrifolia*)
Trillium (*Trillium angustipetalum*)
Hall's wyethia (*Wyethia elata*)

Animals:

Yosemite National Park is home to one federally endangered species: The Sierra Nevada bighorn Sheep (*Ovis canadensis sierrae*). In addition, there are three federally threatened species in Yosemite National Park: Bald Eagle (H*aliaeetus leucocephalus*), Valley Elderberry Longhorn Beetle (*Desmocerus californicus dimorphus*) and California Red-legged Frog *(Rana aurora draytonii*) (Yosemite Valley Restoration Plan 2000). Restoration efforts in Hetch Hetchy Valley should establish habitat required by these species. Reintroductions will be required if species that are not able to naturally recolonize the restored habitat.

Sierra Nevada bighorn Sheep:

In 1999, fewer than 200 bighorn sheep were left in the higher elevations of the Sierra Nevada, resulting in its addition to the endangered species list. Bighorn sheep population has been declining due to hunting, disease, and competition with domesticated sheep for foraging area (Yosemite Valley Restoration Plan 2000).

Bald Eagle:

The Bald Eagle was listed as a Federally Endangered species in1978. Populations of the Bald Eagle declined due to the effects of pesticide bioaccumulation in the food web, producing this egg shells and decreased hatchling survival. Since the banning of DDT, Bald Eagle populations have rebounded and in 1999 the species was reclassified as threatened (Yosemite Valley Restoration Plan 2000).

Valley Elderberry Longhorn Beetle:

The elderberry longhorn beetle was listed as threatened in 1980 die the destruction of riparian habitat. The host plant of the longhorn beetle is elderberry. Restoration efforts in Hetch Hetchy Valley should include the establishment of elderberry along the Tuolumne River, potentially creating more habitat for this species (Yosemite Valley Restoration Plan 2000).

California Red-legged Frog:

Populations of the California Red-legged frog have been declining in California, and the frog was listed as threatened in1996. The cause for the decline of this frog species is not known, but may be related to pesticides, habitat destruction or predation by exotic bullfrogs. (Yosemite Valley Restoration Plan 2000).

Federal Endangered Species

<u>Mammals</u>

Sierra Nevada bighorn sheep (*Ovis canadensis sierrae*)

Federal Threatened Species*:*

<u>Birds</u>

Bald eagle (*Haliaeetus leucocephalus*)

Reptiles and Amphibians
California red-legged frog (*Rana aurora draytonii*)

Fish
Delta smelt (*Hypomesus transpacificus*)
Paiute cutthroat trout (*Oncorhynchus clarki seleniris*)
Central Valley steelhead (*Oncorhynchus mykiss*)
Sacramento spittail (*Pogonichthys macrolepidotus*)

Invertebrates
Valley elderberry longhorn beetle (*Desmocerus californicus dimorphus*)

Federal Species of Concern

Birds

Harlequin duck (*Histrionicus histrionicus*)
Northern goshawk (*Accipiter gentilis*)
California spotted owl (*Strix occidentalis occidentalis*)
(Little) willow flycatcher (*Empidonax traillii brewsteri*)
Bell's sage sparrow (*Amphispiza belli belli*)

Fish

Longfin smelt (*Spirinchus thaleichys*)
Red Hills roach (*Lavinia symmetricus)*

Mammals

Mount Lyell shrew (*Sorex lyelli)*
Spotted bat (*Euderma maculatum*)
Small-footed myotis bat (*Myotis ciliolabrum*)
Long-eared myotis bat (*Myotis evotis*)
Fringed myotis bat (*Myotis thysanodes*)
Long-legged myotis bat (*Myotis volans*)
Yuma myotis bat (*Myotis yumanensis*)
Greater western mastiff bat (*Eumops perotis californicus)*
Sierra Nevada snowshoe hare (*Lepes americanus tahoensis*)
Sierra Nevada (Mono Basin) mountain beaver (*Aplodontia rufa californica*)
Sierra Nevada red fox (*Vulpes vulpes necator*)
California wolverine (*Gulo gulo luteus*)
American (pine) marten (*Martes americana*)
Pacific fisher (*Martes pennanti pacifica*)

Reptiles and Amphibians

Limestone salamander (*Hydromantes brunus*)
Mount Lyell salamander (*Hydromantes platycephalus*)
Yosemite toad (*Bufo canorus*)
Foothill yellow-legged frog (*Rana boylei*)
Mountain yellow-legged frog (*Rana muscosa*)
Northwestern pond turtle (*Clemmys marmorata marmorata*)
Southwestern pond turtle (*Clemmys marmorata pallida*)
Northern sagebrush lizard (*Sceloporus graciosus graciosus*)

Invertebrates

Merced Canyon (Yosemite) shoulderband snail (*Helminthoglypta allynsmithi*)
Keeled sideband snail (*Monadenia circumcarinata*)
Mariposa sideband snail (*Monadenia hillebrandi*) [Formerly known as Yosemite Mariposa sideband snail (*Monadenia hillebrandi yosemitensis*)]
Sierra pygmy grasshopper (*Tetrix sierrana*)
Wawona riffle beetle (*Atractelmis wawona*)
Bohart's blue butterfly (*Philotiella speciosa bohartorum*)

California State Endangered Species

Birds

Bald eagle *(Haliaeetus leucocephalus*)
American peregrine falcon *(Falco peregrinus anatum)*
Great gray owl *(Strix nebulosa)*
Willow flycatcher *(Empidonax traillii)*

California State Threatened Species

Mammals

Sierra Nevada red fox *(Vulpes vulpes necator)*
California wolverine *(Gulo gulo luteus)*