Habitat Restoration and Enhancement for the Cuyamaca Lake Downingia (*Downingia concolor* ssp. *brevior*) at Cuyamaca Rancho State Park

Prepared by:

Ellen T. Bauder, PhD
Department of Biology
San Diego State University
San Diego, CA 92182-4614

Assisted by:

David Bainbridge and Steven P. Netto
Department of Biology
San Diego State University
San Diego, CA 92182-4614

Prepared for:

California Department of Fish and Game
Natural Heritage Division
Endangered Plant Program
1416 Ninth Street
Sacramento, CA 95814-2090

Funded by:

Emergency Drought Relief Project
Contract # CA HER 022593

September 1994

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ACKNOWLEDGMENTS

This restoration and enhancement project was funded by the Emergency Drought Relief Project. I would like to thank Mr. Michael Golden and Ms Diane Steeck, Administrators of the Drought Relief Project for The Nature Conservancy, for their support, attention to detail and efficiency. Ms Steeck was exceptionally patient and helpful. Mr. Jim Dice, Regional Plant Ecologist for the Department of Fish and Game, provided effective local oversight. The idea for this project was developed under his guidance as plant ecologist for the California Department of Parks and Recreation. Mr. Bill Tippets and Mr. Jack Shu, also with Parks and Recreation at that time, provided important input in the development stage. When the actual restoration efforts began, new personnel were overseeing Cuyamaca Rancho State Park. I appreciate the assistance of Mr. Greg Picard, Park Superintendent, and Mr. Paul Jorgensen, Resource Ecologist. The Helix Water District and Lake Cuyamaca Recreation and Park District allowed us access to *Downingia* habitat on their land so that we could make seed collections and map the species. Seed collection was done with a California Department of Fish and Game permit and California Department of Parks and Recreation collecting permit. Ms Ronilee Clark aided in the preparation and filing of CEQA documentation, and Ms Alexa Luberski provided me with the historical information.

We are grateful, too, for the efficiency and generosity of our suppliers. Mr. Ray Falcon provided cleaned broom corn at no cost; Ms Sherryn Haynes sent us rice logs in record time; Rolanka International, likewise, met our tight deadlines and provided us with samples and outstanding service; and the employees of Hummertz International, Bailey's, and Sinclair Well Products and Services, provided product information and speedy shipping of bamboo, the hand trencher, and the hydrology monitoring supplies.

Ms Bree Buckner collected and organized the materials for the literature search. Her patience in dealing with the complexities of government documents, unpublished reports and interlibrary loan services is very much valued. Mr. David Bainbridge was responsible for the design of the erosion control structures as well as the use of tools he had on hand and information on hard-to-find materials. Mr. Steven Netto and Mr. Scott McMillan, both master's degree students at SDSU, supervised work crews, surveyed the Paso Picacho and Little Stonewall Creek watersheds and installed the erosion control structures. Mr. Netto deserves credit for his production of the computer maps of the Paso Picacho meadow and the drawings of the hydrology monitoring devices. He also designed the hydrology monitoring scheme and placed the monitoring well, piezometers and tensiometers. Mr. Larry Hendrickson mapped and monitored *Downingia* , made the seed collections and assisted with the reintroductions. With the assistance of Mr. Scott Delman, Ms Cathlyn Davis and Mr. Jim Stodola, Mr. McMillan installed fencing to reroute a horse trail from the Paso Picacho meadow edge. Mr. Fred Sullivan of the Greater Mountain Empire Resource Conservation District, with assistance from Mr. McMillan, helped analyze the erosion problems of the Little Stonewall Creek watershed. We thank also Mr. Fred Edwards, Ms Carla Toth and Ms Deborah Waldecker for their energetic and competent field work.

ABSTRACT

Downingia concolor ssp. *brevior* (Lake Cuyamaca downingia) is an endemic plant species restricted to temporary meadow wetlands in the watershed of the Cuyamaca Valley located in the mountains of eastern San Diego County. *Downingia*'s entire distribution is contained within a 16.7 km^2 (7.6 mi^2) area. This species is state Endangered and proposed for federal Endangered status. The primary objective of the project was to restore habitat for *Downingia* and to increase its potential to sustain populations through drought years.

Downingia is a small annual that grows and flowers in shallow, seasonally wet ponds, swales, drainages and meadows. The hydrology of its meadow habitat has been altered by historic land uses such as cattle and sheep grazing, mining, and water diversion or storage structures. Today, the primary impacts are from recreational activities such as a year-around artificial fishing lake, horse and hiking trails, trampling, and campsites, as well as cattle grazing.

An extensive literature search was conducted to better understand the historic land uses of the area, meadow hydrology and vegetation, and methods of stabilizing and improving eroded channels and restoring meadow hydrological regimes. Five types of erosion control structures, including a control "treatment", were installed in the Paso Picacho meadow area of Cuyamaca Rancho State Park. They were located primarily on two drainages: one artificially induced by a horse trail and the other eroded by water passing under a road culvert. Devices were also placed in the meadow to monitor its hydrology. A horse trail at the upper end of the meadow was rerouted, road fill was removed from a small drainage near the former Minshall home site, and *Downingia* seeds were introduced into four unoccupied sites where the habitat was deemed suitable. Recommendations are made for protection of and further improvements to the meadows in the Cuyamaca Rancho State Park.

EXECUTIVE SUMMARY

In California, montane meadows are limited in extent, but widely recognized for their resource values: food and water for domestic and wild animals, water storage, protection of watersheds from peaked flows and high sediment loads, unique plant communities, and aesthetic appeal. Southern California meadows occur in the Transverse Mountain Ranges as well as the Peninsular Ranges. The latter extend across San Diego from northwest to southeast and contain a modest number of relatively small, discrete meadows. These are found at an elevation of 1000 m or more and are set in a matrix of montane mixed coniferous forest. The meadow openings owe their character to their gentle slope and surface hydrology which differ from the surrounding area. As a result, the meadows contain a unique assemblage of herbaceous plant species that are dependent upon the moisture conditions, especially during the winter rainfall period. Notable among these plants is *Downingia concolor* ssp. *brevior* (Lake Cuyamaca downingia) which is an endemic temporary wetlands species found only in San Diego County in the Cuyamaca Valley and its watershed. It has state Endangered status and is proposed for federal Endangered species status.

A history of grazing, logging, mining, road building, damming and water diversions has severely altered the hydrology of the Cuyamaca Valley watershed and led to erosion, siltation, a lowered water table and out-of-season impoundments. Current uses, especially recreational activities, continue to impact the meadow habitat. Over the past 7 years, experimental research and field mapping of *Downingia* have indicated *Downingia* 's important relationship with the inundation regime and soil moisture levels. Inadequate moisture can prevent germination or lead to death prior to flowering and seed set. A period of drought years can exacerbate the effects of disturbed hydrology that already impact the plant.

The primary objective of this project was to restore habitat for this species and to increase its potential to sustain populations in drought years. The specific goals were twofold: to research intensively the causes, history and control of erosion in montane meadows and to implement restoration control measures in habitat of *Downingia* within Cuyamaca Rancho State Park (CRSP). An exhaustive literature search was completed on the causes of erosion, the nature of montane meadows and their relationship to slope and hydrology, and methods of montane meadow and riparian restoration.

The general conclusions derived from the literature search are that an episode of accelerated erosion occurred in California beginning in the latter half of the nineteenth century and that changes in land use practice—primarily grazing by domestic animals—were responsible. Other land use changes such as the concentration of water flow by culverts and lined channels, logging and mining contributed. A detailed statistical analysis of weather patterns does not support the hypothesis that climatic changes were the underlying cause, although periods of intense rainfall may have been the proximal cause in a number of cases. Loss of vegetative cover, and possibly changes in species composition of plant communities, has been an important factor leading to accelerated erosion. Erosion has led to even more vegetational changes because of soil removal, lowering of the surface water table and promotion of the establishment of exotic plant species. Changes in wildlife, including birds and fish, have been noted as well.

Beginning in the twentieth century, methods have been developed to retard or reverse the progress of erosion in the arid Southwest. Most of the research on restoration methods has been done by state and federal agencies. These studies indicate that successful erosion control efforts need to address the causes (especially current land use practices); generally require intervention in the form of erosion control structures (check dams, revetments, etc.); and that revegetation can be slow to proceed, especially in arid or high altitude ecosystems. Riparian systems revegetate rapidly, but stream channel morphology is restored very slowly, often taking decades or longer.

There are few studies of any type providing quantitative data on the effectiveness of restoration in montane meadows, especially on the alteration of meadow hydrology, upon which the unique vegetation depends. Little has been reported about the use of small-scale structures made of natural non-rock materials and installed by hand labor, nor have studies been designed to compare the effectiveness of various treatments. Even less is known of meadow hydrology. Consequently, we designed our restoration project to provide comparative information on a number of treatments and their effectiveness in improving meadow surface hydrology. We built five types of erosion control structures and randomly assigned them plus an untreated control treatment to two different drainage channels as well as scour holes in the main meadow at Paso Picacho, Cuyamaca Rancho State Park (CRSP). Data on channel morphology were taken to provide a baseline for judging the effect of the various structures. A water table monitoring well, nine piezometers and a tensiometer were installed in the same area as well. Seed introduction sites will be monitored to determine if Lake Cuyamaca downingia becomes established in self-sustaining populations.

CHAPTER 1. INTRODUCTION AND PROJECT OBJECTIVES

1.1. PROJECT OBJECTIVES

In California, montane meadows are limited in extent, but widely recognized for their resource values: food and water for domestic and wild animals, water storage, protection of watersheds from peaked flows and high sediment loads, unique plant communities, and aesthetic appeal (Ratliff 1982). The primary objective of this project was to restore habitat for *Downingia concolor* ssp. *brevior* (Lake Cuyamaca downingia), and to increase its potential to sustain populations in drought years. This plant is state Endangered and proposed for federal Endangered species status. It is endemic to the Cuyamaca Valley watershed in San Diego County and restricted entirely to that area. Recent experimental work and seven consecutive years of mapping indicated that the limited amount of suitable habitat for this plant might be expanded by restoration of eroded drainages and artificial channels (Bauder 1992b and unpublished data). A literature search was conducted to gather information on the erosion process in Western meadows and montane riparian habitat and to determine if any restoration projects had been attempted in areas similar to the Cuyamaca Valley watershed. Documents on historical land uses of the area were collected as well.

North of the Paso Picacho group campground in Cuyamaca Rancho State Park, a natural drainage, an eroded horse trail and the meadow into which they empty, were identified as suitable for restoration (See Figure 3). A trail edging the southern portion of the meadow was slated for rehabilitation. An additional drainage on the former Minshall property was selected for enhancement by removal of road fill. Finally, four areas of suitable—but currently unoccupied—habitat within the state park were identified for placement of *Downingia* seeds.

The restoration efforts are expected to retard or eliminate the active erosion process in the Paso Picacho meadow and channels, resulting in reduced siltation and scour and raising of the water table. They also were installed to allow comparison between five different erosion control treatments, and equivalent untreated areas as well. Introduction of seeds into suitable but currently unoccupied habitat, if successful establishment occurs, would have the immediate effect of increasing the number of *Downingia* occurrences on protected state park lands from seven (six of which are very small and nearly contiguous) to eleven. Monitoring of the meadow hydrology will assist in making future management decisions for this species.

Current land use practices were analyzed in order to make recommendations that might reduce or eliminate adverse impacts to *Downingia* or its habitat.

1.2. INTRODUCTION

1.2.1. The species: *Downingia concolor* ssp. *brevior*

Downingia (Campanulaceae) is a genus of semi-aquatic annuals distributed widely in western North America and southern South America. Species are restricted to ephemeral wetlands, and the patchiness of their distribution reflects the disjunct nature of suitable habitat. Plants of all 14 species (Weiler 1962) are small, glabrous, soft-stemmed annuals with minute seeds (< 1 mm long). Germination begins with the onset of winter rains. Plants grow in muddy soils or shallow waters during the winter and early spring. At the end of the rainy season, plants produce masses of showy blue flowers.

Two species of *Downingia* occur in San Diego County. *Downingia cuspidata* is found in vernal pools of indurated coastal marine terraces and occasionally in clay pan pools of the inland valleys (Bauder 1986). *Downingia concolor* ssp. *brevior* (Lake Cuyamaca downingia) is endemic to the watershed of the Cuyamaca Valley and is found only in areas that are seasonally inundated . The habitat is owned by private parties, the Helix Water District, and Cuyamaca Rancho State Park (CRSP). A portion of the Helix Water District property is leased by the Lake Cuyamaca Recreation and Park District. Most of the known occurrences of *Downingia concolor* ssp. *brevior* are on the property of the Helix Water District. The extremely limited distribution of this species, coupled with disturbance and development threats to the known habitat, are factors contributing to its classification by the State of California as Endangered and the proposal by the US Fish and Wildlife Service for federal Endangered status. Hereafter, reference to *Downingia* will mean *Downingia concolor* ssp. *brevior.*

1.2.2. Meadow Characteristics

Montane meadows are gently sloping or depressed high elevation areas with a shallow water table that support an herbaceous plant community. They are lower in elevation than subalpine or alpine meadows. In San Diego County, montane meadows are discontinuously distributed above 1000 m elevation on seasonally saturated soils within openings in montane coniferous forest. They are dominated by sedges (*Carex*), rushes (*Juncus*), grasses (*Poa, Elymus, Muhlenbergia*) and other perennial herbs (Thorne 1976, 1977; Beauchamp 1986; Holland 1986). The Cuyamaca Valley is noteworthy for its large number of plants that have limited distributions. Many of these plants are annuals. Allen and Curto (1987) list 45 taxa of plants that either occur only in the Cuyamaca Valley area or are found there as part of a limited, widely scattered distribution. Two of these plants are state Endangered (*Downingia concolor* ssp. *brevior*—Lake Cuyamaca downingia and *Limnanthes gracilis* ssp. *parishii*—Parish's meadowfoam), and one has rare status in California (*Delphinium hesperium* ssp. *cuyamacae*—Cuyamaca larkspur). In addition, *Downingia* is proposed for federal Endangered status and *Limnanthes* is proposed for federal Threatened status.

1.2.2.1. Hydrology and Vegetation

Hydrology is the primary factor determining the character of montane meadows because it is the variable controlling potential vegetation (Ratliff 1985). Referring to southeastern freshwater marshes, Gosselink and Turner (1978) wrote of a pulsed (i.e. seasonal) inundation regime that arrests wetland systems in immature stages. A pulsed hydrological regime is a salient feature of California's Mediterranean climate (Mooney and Parsons 1973).

In the mountains of northeastern California, Hormay (1943) found that the species composition of the vegetation was determined by the depth and duration of standing water. The stabilization of a particular vegetation type depended on the degree of yearly variation in moisture conditions. In areas where the vegetation was totally submerged for a long period, most of the plant species were killed. In other years, when standing water was absent, there were sparse stands of various rushes and sedges. Ratliff and Harding (1993), in a study of four Sierra Nevada meadow clovers, determined that all four species preferred moist or wet soils to dry soils, but they differed in their response to the degree of wetness. They concluded that when all other necessary growth requirements were met, soil water was the most important environmental factor determining the distribution of each species. On the basis of this, they predicted changes in the relative importance of each species under conditions of meadow erosion and drying. Klikoff (1965) found that productivity, species composition, and phenology of various Sierra Nevada meadows was determined primarily by their moisture regime.

Studies of other seasonal wetland or fluctuating aquatic systems support these observations. Vernal pool and associated grassland species respond to very small differences in depth and length of inundation (Lin 1970, Holland 1984, Bauder 1987, Zedler 1987). Invertebrates as well have a wide variety of adaptations to the variability of temporary waters (Williams 1987). On lake shores and in vernal pools, year-to-year variability in water levels is important in maintaining plant species diversity (Bauder 1987, Keddy 1986). In a monograph on prairie potholes sponsored by Ducks Unlimited's Institute for Wetland and Waterfowl Research, species composition was found to be directly related to the maximum depth and duration of standing water (Galatowitsch and van der Valk 1994). Work done in Missouri on seasonally flooded impoundments, indicated that vegetation differed as the result of different rates of water drop as well as the degree of soil drying that followed drawdown (Frederickson and Taylor 1982).

1.2.2.2. Factors Determining Meadow Hydrology

The hydrology of montane meadows is a function of topography, precipitation (amount and pattern) and soils (structure and texture) (Ratliff 1985).

1.2.2.2.1. *Topography*

Topographic positions of montane meadows have been categorized as basin, slope or stream (Benedict and Major 1982). Basins form above bedrock, either fresh or weathered, or from damming by a recessional or lateral moraine. Surficial outcrops are frequently associated with basin meadows formed over bedrock. Because glaciation did not extend to Southern California, meadows in the Peninsular Ranges are not caused by glacial moraines (Benedict and Major 1982).

On slopes, meadows may form where groundwater comes to the surface as seeps or springs. These have been called "hanging meadows" (Benedict and Major 1982). "Stringer meadows" develop along streams. They are usually narrow and occur in forested areas.

In the Sierra Nevada, geologic stability of meadows is directly related to meadow type, with those formed over bedrock basins more stable than ones formed by morainal dams (Benedict 1981).

1.2.2.2.2. *Precipitation*

The Mediterranean climate zone, of which cismontane and montane San Diego County are a part, is characterized by long dry summers and variable precipitation coming in a few, intense winter storms (Mooney and Parsons 1973, Walter 1979). At higher elevations, both the amount and pattern of precipitation change (Bowman 1973). San Diego's montane areas receive up to 114 cm per year (Palomar Mountain) and 65-90 cm in the Cuyamaca and Laguna Mountains, compared to about 24 cm at Lindbergh Field on the coast in San Diego (Bowman 1973). San Diego's desert and mountain areas are at the western reach of the summer convective storms that originate in the Gulf of Mexico and cross the southwestern deserts (Mac Mahon and Wagner 1985). At Cuyamaca these summer storms can bring up to 20 % of the yearly precipitation, but this is uncommon (author's analysis of US Weather Bureau data).

The intensity of storms affects their erosive potential as well as the character of runoff. Two types of storms have been described for the maritime West by the Runoff and Soil Loss Data Center at Purdue University (Goldman et al. 1986). Along the northern coast, the precipitation of a storm is well spread over a 24-hr period, with only a slight increase in percent of total storm at about 9 hours. In central and southern California, there is a sharp peak between 9 and 12 hours, with up to 45 percent of the storm total falling in this period.

1.2.2.2.3. *Soils*

Erodibility is a measure of the susceptibility of soil particles to be detached and transported. The primary factors affecting erodibility are texture, structure, organic matter and permeability (Goldman et al. 1986, Singer and Munns 1991). Silt-sized particles are most easily detached, sand particles are too big to be transported easily, and clays cohere to each other and function as larger particles (Singer and Munns 1991). Organic matter favors aggregation of particles, leading to a structured soil. If soil is well-structured and has medium texture, infiltration rates will be more rapid. This, in turn, reduces runoff.

If there is a slope, the velocity of the runoff will increase. Loss of vegetative cover will also lead to increased runoff velocity as well as greater exposure of the soil surface to raindrops and overland water flow. Therefore, erodible soils on a slope with little plant cover are most susceptible to water erosion.

1.2.2.3. Meadow Hydrology-Summary

Meadow hydrology has until recently been described in static terms, with meadows classified, for example, on openness or degree of drainage of the basin (Hormay 1943) or as wet, moist or dry (Klikoff 1965). A more dynamic view takes into account the timing and pattern of water movement (Ratliff 1985). This helps in understanding the species composition of the vegetation and the distributions of individual species. It also makes it possible to predict how the system would respond to perturbations and to estimate its potential for restoration or enhancement.

Ratliff (1985) took Gosselink and Turner's (1978) table of hydrodynamic characteristics for different marshes and adapted it to the Sierra Nevada (Table 1). He eliminated wetlands such as freshwater/tidal marshes and added others like hanging and xeric meadows. To account for the Mediterranean climate's strong seasonality of precipitation, he included as a variable the xero-pulse, or period of xeric conditions, in addition to the hydro-pulse, or time of water inputs. The resulting classification scheme uses five variables: input flow, internal flows, output flows, hydro-pulse and xero-pulse. Depending on the importance of each of these variables to the functioning of the meadow, six types of meadow hydrologic class are identified. Hydrostatic and capillary flows—both input and internal—are important features in meadows with raised-convex bogs. Raised bogs are absent from San Diego's mountains. The other hydrologic classes are probably all represented in San Diego County and in the Cuyamaca Valley area as well.

"Hanging meadows" are dependent on hydrostatic (fluid pressure) input flows and subsurface internal flows. Inputs occur seasonally, but outputs by evapotranspiration and downstream runoff rarely result in a xeric or dry period. Normal meadows obtain water from the water table, can be recharged by precipitation and flows from upslope and may dry at the surface during the summer—with some moisture still available at depth. Outputs are primarily by evapotranspiration and deep percolation. Xeric meadows are usually found on slopes or benches, are seasonally recharged by precipitation and are usually quite dry by late summer. Internal flows may be moving in surface sheets of variable depth. The generally shallow soils mean that deep percolation will not occur and most output becomes downstream runoff. Lotic sites are constantly watered by flows from upstream and depend on this input more than precipitation. Internally, water moves in surface sheets and outputs are primarily through downstream runoff. Percolation is usually very slow due to the saturated or slowly permeable underlying soils. Sunken-concave meadow sites have ponded water that is seasonally recharged

CLASSIFICTION VARIABLES	HYDROLOGIC CLASS*					
	Raised convex	Hanging	Normal	Lotic	Xeric	Sunken concave
Input flows						
Capillary	+		+			
Hydrostatic	+	+		-		
Precipitation	-	0	0	0	+	0
Upstream or upslope			0	+	0	+
Internal flows						
Capillary	+	0	0			
Subsurface	+	+	+	+	+	+
Surface sheet		0	-	+	+	0
Surface rill		-	0		0	
Output flows						
Evapotranspiration	+	+	+	+	+	+
Percolation	-		+		0	-
Downstream runoff		+	-	+	+	
Hydro-pulse						
Seasonal			+	+	+	+
Seasonal constant +	+		0			
Xero-pulse						
Seasonal			+		+	+
None	+	+		+		

*Key: + = major importance, 0 = moderate importance and - = minor importance.

Table 1. Hydrologic classification of meadow sites in the Sierra Nevada, California. Adapted from Ratliff (1985).

by flows from upstream. Because percolation losses are relatively minor due to impermeable substrates, evapotranspiration is the major mechanism of loss. In the Sierra Nevada, surface water is usually gone from these sites by late summer, and the soil may dry to considerable depth.

1.2.3. Cuyamaca Valley Meadows

1.2.3.1. Hydrology

Although the Cuyamaca Valley presents the appearance of a relatively uniform habitat, the distribution of individual plant species, especially those sensitive to the hydrologic regime, suggests otherwise. Mapping of three sensitive taxa (*Downingia concolor* ssp. *brevior*—Lake cuyamaca downingia; *Limnanthes gracilis* ssp. *parishii*—Parish's meadowfoam; and *Delphinium hesperium* ssp. *cuyamacae*—Cuyamaca larkspur) has indicated that each occupies a different position on the moisture gradient (Bauder 1992a,b and unpublished data). *Downingia* is found at the lowest points in the individual drainages or in the Cuyamaca watershed as a whole. It tolerates inundation and has a morphology and anatomy associated with wetland plants. *Limnanthes* is closely associated with *Downingia* but is generally found in moist areas that are never inundated, except with shallow surface flow. The *Delphinium* is not associated with ponds or drainage channels and is found in swales or on the benches at the edge of the main valley, above the high water line.

The basin of the Cuyamaca Valley watershed has features that correspond to Ratliff's "Sunken Concave" meadow. Within this meadow type, water collects in topographic depressions and remains ponded due to an impermeable layer. In the case of Cuyamaca Valley, this is probably bedrock overlain with clay soils. By summer, surface water in "Sunken Concave" meadows is gone and soils are dry. Outputs from the system are through evapotranspiration and overflow. This describes quite well the Laguna Que Se Seca , what we understand from the historical record was a large vernal pool or seasonal lake at the lowest elevation in the Cuyamaca Valley watershed (Elliott 1883, Woodward 1934, Wade 1937, Martin 1971, LeMenager 1992). This historic lake was an oval with an east/west axis. It was located to the north of the old Stonewall Mine which was on a peninsula, now separated from the current "island" (USGS map, 1903 edition surveyed 1891 and 1901-2; Wade 1937; USGS topographic map 1942 edition). Historic maps from 1874 and 1903 indicate that the lake was fed by two streams, one entering from the east and the other from the south (USGS map, 1903 edition surveyed 1891 and 1901-2; LeMenager 1992). The latter drainage was a combination of the Little Stonewall Creek and the unnamed creek draining the Paso Picacho meadow (USGS topographic map, 1903 edition).

Other areas that might fit into the "Sunken Concave" meadow class are the numerous tanks or ponds that have developed from scour holes in eroded drainages. These are common on the Little Stonewall Creek from the edge of the Helix Water District property east up into the park and along one of the Paso Picacho drainages. The scour basins are deep and retain water well into the summer. The loss of surface soil allows the water table to intercept the surface and produce small ponds.

The majority of the meadows appear to be "Normal" or "Xeric", depending on the slope. Numerous outcrops suggest that soils are shallow along the meadow edges as the slope increases, and an aerial photograph taken June 27, 1979 confirms by color differences in the vegetation the variation in soil moisture (Figure 1). Upland meadow edges appear tan, as do rock outcrops. Drainages are dark green and wetter meadow areas are lighter green.

1.2.3.2. *Downingia concolor* ssp. *brevior* Distribution and the Hydrologic Regime

Annual mapping of *Downingia* during the bloom period, coupled with a series of experiments on germination requirements and inundation tolerance, have indicated the effects of different hydrological regimes on *Downingia.* Laboratory and field research revealed that under controlled conditions *Downingia* tolerated moderate inundation periods (up to 2 months), but a long period of inundation subsequent to germination was lethal (Bauder 1992b). Cool temperatures, in addition to moisture, were required for germination (Bauder 1992b and unpublished data). Even slight depressions of the water potential in the germination trials, reduced germination percentages (Bauder 1992b). In addition, germination was reduced when seeds were kept in the dark. From these results, I would predict that *Downingia* would be absent from areas that remain inundated into the early summer or longer and that it would not germinate during the summer months or if the seeds are buried.

A 7-year mapping effort has yielded information on the close association of *Downingia* with the prevailing moisture conditions in any given year. In low rainfall years (1988/1989, 1989/1990—total precipitation <63.5 cm), *Downingia* flowered along the bottom of channels and was absent from most of the floor of Cuyamaca Valley (Bauder 1992b). In 1992/1993, a

wetter than average year (159.5 cm), it was found in narrow strips along the walls of steep-sided channels or "tanks", in flat, open grassy areas, and at the upper edges of the valley (Bauder unpublished data). When precipitation was closer to the long term mean of 95.1 cm (1987/88, 1990/91, 1992/93 and 1993/94), blooming *Downingia* plants were abundant, and they were widely distributed (Bauder 1992b and unpublished data). In three of these years, there were substantial numbers on the valley floor to the east of the dike. In all four of these "average" years, *Downingia* was common in the drainages that enter the valley directly as well as along the Little Stonewall Creek. These varying distributions indicate that *Downingia* does not become established except on flat surfaces or very gentle slopes with soils that are fully saturated or inundated for short periods. Likewise, it is clear that they do not survive to flowering stage in areas that remain under water for much of the growing season.

The most common associates of *Downingia* are *Navarretia intertexta* and *Plagiobothrys* cf. *acanthocarpus*. We found these species without *Downingia* , but rarely found *Downingia* without them.

1.2.3.3. Soils in Cuyamaca Meadows

The soils at the lower elevations in the Cuyamaca Valley are classified as Loamy Alluvial Land (Lu) by the USDA Soil Conservation Service (SCS)(Bowman 1973). This survey excluded lands within the Cuyamaca Rancho State Park. Borst (1984) surveyed the soils within the park. He tentatively identified James Canyon (JcA) soils on the south bank of Little Stonewall Creek and Shingletown soils in two small areas in the northern part of the park. Shingletown soils are on gentle slopes and are associated with James Canyon or Holland soils. The Shingletown soils had gilgai (Mima mound) microrelief. Although his survey was restricted to the park, Borst noted that Shingletown soils may be common in the Cuyamaca Valley. He noted that Bowman (1973) included both of these soil types within the Loamy Alluvial Land designation. Soils at slightly higher elevations on 5-30 percent slopes surrounding the drainage basin are Boomer stony loam (BrE), Holland stony fine sandy loam (HnE) and Crouch rocky coarse sandy loam (CuE) (Bowman 1973).

According to Bowman (1973), the Loamy Alluvial Land consists of very deep, dark brown to black silt and sandy loams with moderate permeability. The James Canyon soils are deep, poorly developed soils that developed on nearly level to strongly sloping alluvial fans and floodplains at elevations of 1400-1500 m (National Cooperative Soil Survey, pers. comm. from SCS in Escondido, CA). For these soils, the prevailing climate is cool, semiarid with 20-

40 cm precipitation per year. This soil series is poorly drained with slow or very slow runoff. The Shingletown Series of soils occurs in gently sloping to nearly level mountain valleys at 450-1700 m in an area with annual precipitation of 100+ cm, cool winters and warm dry summers (National Cooperative Soil Survey, pers. comm. from SCS in Escondido, CA). This soil series has slow permeability, is poorly drained and has slight erosion hazard.

Borst (1984) described the James Canyon loam he found at Cuyamaca as having a very dark, grayish brown micaceous loam in the A horizons. It was sticky and plastic with many fine pores. At the B horizon there was an irregular, abrupt boundary with lower soils being faintly mottled, non-sticky and slightly plastic. Below the well-defined C horizon, soils had faint mottles, were non-sticky and slightly plastic. This horizon, at 79-109 cm, represented the capillary fringe of the water table. The Shingletown soils he found in Cuyamaca had loamy A horizons with many fine pores. The B horizons shaded from yellowish brown to pale olive in deeper strata and were increasingly plastic and sticky with depth. Mottling became distinct. The boundary to the C horizon was abrupt. Below this boundary, the soil was micaceous clay loam with many large, prominent mottles on the peds; had an angular, blocky structure; and was hard, sticky and plastic. This horizon extended to 100+ cm.

CHAPTER 2. HABITAT DEGRADATION AND LOSS

2.1. EROSION AND ARROYO FORMATION IN THE WEST

Erosion is the detachment and transport of mineral grains through the action of mechanical or geologic elements (Emmett 1968). The primary agents of erosion are rain, ice, wind and gravity. Gravity is usually the agent in mass movements such as landslides or rock falls, but it may contribute to the erosional process (Gray and Leiser 1982). The variables that control erosion are climate; topography; soil attributes such as composition, structure and texture; and vegetative cover (Goldman et al. 1986, Gray and Leiser 1982). Normal erosion is the wearing away of land under natural environmental conditions, whereas accelerated erosion is brought about by man or climatic changes (Emmett 1968). Deposition of rock and soil material from a watershed into a lower elevation valley or meadow is part of a natural landform process (Schumm 1977). With time, the slope of the valley increases until, at some point, a threshold of stability is passed, and then the meadow or valley begins to erode (Ratliff 1985, Schumm 1977). Schumm (1977) calls this type of threshold an intrinsic threshold, and it is part of the process of normal erosion.

During the last century, many swales and undissected plains in the southwestern United States became rapidly and severely eroded (Bull 1964, Cooke and Reeves 1976, Heede 1976). Cooke and Reeves (1976) analyzed a number of eroded drainage systems in coastal southern California and southern Arizona. They used survey records, weather data, land use history and drawings of channel transections and longitudinal profiles. Their research indicated remarkable agreement on the general period in which arroyo formation was most active. The 1880's were especially important in most areas, with trenching accomplished in many localities during the period between 1865 and 1915. After 1915, the primary modifications have been widening of trenches, collapse of walls and slower changes in the levels of channel beds. Cooke and Reeves (1976) concluded that "The cutting of arroyos—spectacular and irrefutable—is thus seen as evidence of environmental change over a huge area and within a fairly well-defined period of time."

In some cases the beds of insignificant streams dropped 25-70 feet and gouged trenches several hundred feet wide (Bull 1964, Cooke and Reeves 1976). Gently sloping, grass-covered valleys became deeply incised channels, with the valley floors perched as desiccated alluvial benches or terraces that in turn were dissected by gullies and arroyos. Catastrophic changes occurred in some places such as the Imperial Valley, where 15,000 acres of land were converted to channels and 400-450 million yds^3 of material was removed during one year (1906) of especially heavy precipitation (Kennan 1917 cited in Cooke and Reeves 1976). The general effects of this widespread erosion on stream and meadow hydrology include loss of large portions of floodplains, increased sediment loads, more "peaked" discharges and reduced water storage (Kraebel and Pillsbury 1934, Cooke and Reeves 1976, Heede 1977a?). As water tables drop and water supplies become less reliable, changes take place in vegetation, with more xeric communities replacing the grassland and riparian species (Bryan 1928, Kraebel and Pillsbury 1934, Cottam and Stewart 1940, Lindquist and Bowie 1989).

Studies on alluvial deposits in drylands suggest that "...large infrequent storms can be erosionally significant, but only when a geomorphic threshold has been exceeded are [there] major, permanent changes...." (Schumm 1977). It seems unlikely that the crossing of intrinsic, geomorphic thresholds could account for the severe and widespread gully erosion that has been documented for the last half of the nineteenth century. Various causes of this accelerated erosion episode have been proposed, but changes in extrinsic variables such as land use and climate—separately or together—have received the most attention (Bull 1964, Denevan 1967, Cooke and Reeves 1976).

2.1.1. The Role of Weather Patterns and Climate Change

Cooke and Reeves (1976) provide a thorough statistical analysis of precipitation in California using weather data collected at 12 coastal and Central Valley stations extending from San Francisco and Sacramento in the north to San Diego in the south. They asked the fundamental question: "... has precipitation, or any specific attribute of it, changed in historical times in any ways that might have led to increased runoff and thus promoted entrenchment?"

After looking at data on amount, seasonal distribution, frequency and intensity of precipitation in records extending back as far as 1849, they concluded that neither cyclical nor secular changes in characteristics of precipitation in California have occurred during the period of active arroyo formation. Although there are periods of greater than average precipitation followed by dry periods, these fluctuations did not differ from those expected in a random series of observations (Cooke and Reeves 1976).

2.1.2. Changes in Land Use

Because trends in climatic change were not evident, Cooke and Reeves (1976) concluded that changes in land use, especially the introduction of domestic grazing animals and the cultivation of valley floors, were the underlying causes of regional alterations of soils and vegetation. Exceptionally intense storms have acted as triggers or proximal causes of the observed accelerated erosion. These widespread environmental changes included a transformation of the floristic composition of grasslands and the eradication of valley-floor vegetation, with the attendant exposure and disturbance of soils. Schumm reports that the relationship between erosion and vegetative cover is exponential (Schumm 1977). Above 70 percent cover little additional cover affects erosion and below 8 percent cover, vegetation is ineffective in controlling erosion. As cover drops from 50 to 20 percent, the estimated amount of erosion increases from 5,000 pounds per acre per storm to 25,000 pounds. Of secondary— but still major importance in causing accelerated erosion—were irrigation ditches, roads and railroads. "Beyond doubt, [these] drainage-concentration features provided the loci for the initiation of some arroyos."(Cooke and Reeves 1976). Structures that concentrate flow, such as the outlets of pipes and lined channels, are points of critical erosion potential (Goldman et al. 1986). Heede (1976), who has published extensively on gullying in Colorado and New Mexico, reaches the same conclusions regarding the importance of grazing in reducing vegetative cover and the lesser, but still significant, role played by roads and culverts. Trails may be the origin of gullies (Bainbridge 1974, Toy and Hadley 1987), and recreational use of montane meadows by campers, hikers, pack animals and fisherman has become an increasing concern, because of its damaging effects (DeBenedetti and Parsons 1979, Anonymous 1986) and long-lasting impacts (Rochefort and Gibbons 1992). A review of human trampling effects on grasslands in the United Kingdom, documents the vegetation and soil changes that occur in and around paths (Liddle 1975).

Within the last two centuries, land use practices in the West have changed both in type and intensity. The most widespread change came with the European settlers from Mexico, who introduced domestic livestock to provide hides and tallow for the missions of the Roman Catholic Church (Burcham 1956, 1957; Cooke and Reeves 1976). Estimates of the number of mission-owned cattle and sheep present in the period between 1770 and the 1840's vary widely and do not include feral or privately owned animals or mission horses and mules (Burcham 1957, Cooke and Reeves 1976). Even so, exports of hides indicate a cattle population of at least one-half million animals (Cooke and Reeves 1976). Discovery of gold in the 1840's and increased settlement by northern Europeans by way of the eastern United States, brought increased demand for beef cattle. It is estimated that the maximum cattle population in the state was attained in 1862, with the numbers of sheep peaking in 1876 (Cooke and Reeves 1976).

It is possible that sometime in the first half of the nineteenth century California had reached or exceeded the sustained livestock yield. This is suggested by the orders to slaughter wild horses in 1821 and again in 1828 because drought conditions reduced forage. The second drought was reported to have caused 40,000 mission cattle to starve (Burcham 1957). Other drought periods in the second half of the century had similar impacts, and probably led to the shift to greater numbers of sheep (Burcham 1956). Numbers of livestock appear to have peaked earlier in southern coastal California compared to the central or northern coasts, possibly because the drier areas reached carrying capacity earlier (Cooke and Reeves 1976). A recent extensive review of grazing impacts on natural ecosystems outlines the effect a century or more of grazing has had on ecosystem structure, functioning, and composition and provides citations to 160 studies and articles (Fleischner 1994). Fleischner provides an in-depth analysis of the impacts of grazing on riparian and adjacent meadow habitat because of the limited area and high resource value of these lands. Vankat and Major (1978) report on the effects of grazing on the montane meadows of Sequoia National Park. In 1885, a traveler to the Mount Whitney area (Magee, cited in Vankat and Major 1978) noted that " 'Each of these meadows is yearly cropped several times by various flocks of sheep, and the result is that, even where there was a genuine mountain meadow, there are now only shreds and patches. The sod and the verdure are gone—eaten and trodden out; the gravel is now in the ascendant.' "

2.2. HISTORIC LAND USE AT CUYAMACA

Native Americans had a rancheria near a spring on the southwest slope of North Peak to the west of the Laguna Que Se Seca, a seasonally dry lake or vernal pool. The hydrological regime was destroyed when the dam (1886) and subsequent dike system (1967) were built (Rensch 1950, Bloomquist 1966, Parkman 1981, Allen and Curto 1987). The Native Americans gathered acorns and pine nuts, hunted, and cultivated both wheat and corn (Rensch 1950, Bloomquist 1966). By the 1840's, sheep were herded through the area, according to Juan Maria Osuna, Jr who brought his flocks there several times (Rensch 1950). In 1854, much of the area became part of the 35,501-acre Cuyamaca Rancho granted to Agustin Olvera, whose wife was the niece of the Mexican governor (Brackett 1939). Other than an unsuccessful attempt at timber cutting, Olvera did nothing with his property, and he sold it to various owners in 1869 (Bloomquist 1966).

When gold was discovered in 1870, at what became the Stonewall Mine, a dispute arose over the boundaries of the Rancho (Brackett 1939, Bloomquist 1966, Martin 1971). Testimony given during the course of a law suit, provides a great deal of information regarding the use of the land in the Cuyamaca Valley during the second half of the nineteenth century (Bloomquist 1966). According to P. V. Smith, he had a camp for cattle purposes "... at a place about two miles southward from Laguna que se Seca (Cuyamaca Lake); this is at the head of one of the arms of Cuyamaca Valley. ... we took there to graze a quantity of cattle ... we kept them there until July last; then removed them northward, entirely out of Cuyamaca Valley...." (Bloomquist 1966). John Mulkins declared, "... Cuyamaca Valley must have been more than a league of good grazing land...." and tells of cattle grazing in the valley about 1864-65 (Bloomquist 1966). Others speak of cattle, horses and sheep, and Bloomquist (1966) concludes that "The meadowlands of the Cuyamacas became famous in southern California during the latter part of the nineteenth century, and in dry years cattle and sheep were driven from as far north as Los Angeles to feed on the tall grass. Cowboys on the long drives from Texas to California gold fields would sometimes pause to rest and fatten their stock in the lush highland valleys." In 1883, Elliott, speaking of the seasonal lake, says that "It lies in, and is but a small part of a beautiful grazing tract of land, known as Cuyamaca Valley, where thousands of cattle have been pastured, especially in summer...." (Elliott 1883, reprinted in 1965).

Over 20,000 acres of the original rancho became Cuyamaca Rancho State Park in 1933 (Wade 1937, Brackett 1939). Livestock grazing in the park was terminated in 1956 (Bloomquist 1966, Allen and Curto 1987) and in the lake bed in 1987 (Lake Cuyamaca Recreation and Park District, pers. comm.). However, cattle trails are still prominent on the valley floor where they act as drainage channels, and windrows of organic matter from cattle feces are deposited at high water lines (Pers. obs.). Grazing continues today on private property on the northwestern, north, eastern and southern edges of the main valley, and cattle occasionally intrude into the Helix Water District property. The lake bottom has been cultivated, with up to 400 acres planted to grain (1949 Helix Water District report cited in Allen and Curto 1987).

The advent of mining brought many other important changes in land use that affected runoff, soil stability, vegetative composition and cover and, hence, erosion. These included logging, collection of fuel wood for personal use and to power equipment, road construction and water collection and diversionary structures such as reservoirs, dikes and culverts (McAleer 1986). By 1891, the population was estimated at 500 people in Cuyamaca City (Stonewall

Mine), and the buildings were clustered on the peninsula and extended down the hillside on terraces toward the lake (Parkman 1981).

With the creation of the state park in 1933, and in 1967 the dike that formed the artificial fishing lake (Ball 1976, Allen and Curto 1987), recreation became a new sort of impact on the hydrology of the Cuyamaca watershed, with many of these activities contributing to erosion. Horse, hiking, and bike trails have created artificial channels that have changed the drainage patterns of the meadows. When parallel to the contour, they act as drainage channels; trails perpendicular to the gradient form interceptors, leaving the immediate down slope with diminished water input. Construction of campsites, roads and parking lots has reduced or eliminated plant cover in many areas, increased the rapidity of runoff and concentrated runoff in channels. Sediment deposition and scour holes are prominent features on the low elevation side of road culverts along SR 79, the Sunrise Highway (S-1), and the paved roads within the park to Stonewall mine and the Los Vaqueros group horse camp.

Various projects undertaken by the Civilian Conservation Corps in the 1930's had the potential for impacts on the watershed, but their reports, although extremely detailed in some respects, are too general in regard to locations to give more than an idea of their activities (Ballard 1934ab, 1935ab; Pirnie 1936). They cut trees for construction and to thin timber stands; graded and surfaced parking areas, constructed campground facilities as well as minor roads at the "Stonewall Picnic Area", "developed" springs, and installed a revetment and re-aligned the channel on the Sweetwater River (Ballard 1934 a and b, 1935 a and b; Pirnie 1936). Ballard speaks of floods in 1916 and 1927 that washed out "... acres of deep loam banks, leaving a channel which is constantly gnawing into the present banks." (Ballard 1935b). He lists the materials used to build the revetment, including 132 truck loads of brush (Ballard 1935b).

CHAPTER 3. HABITAT RESTORATION AND ENHANCEMENT

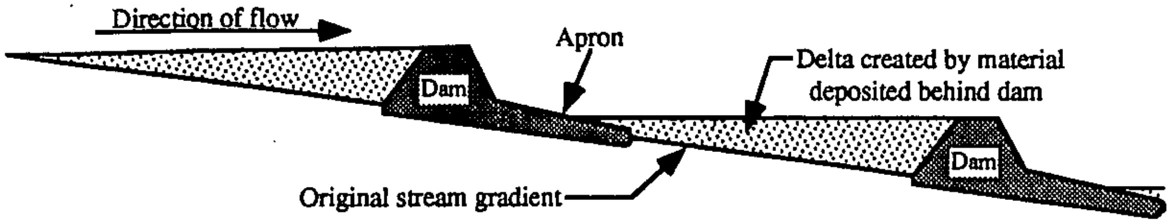
3.1. MEADOW AND RIPARIAN RESTORATION METHODS

3.1.1. Erosion Control Structures for Gullies

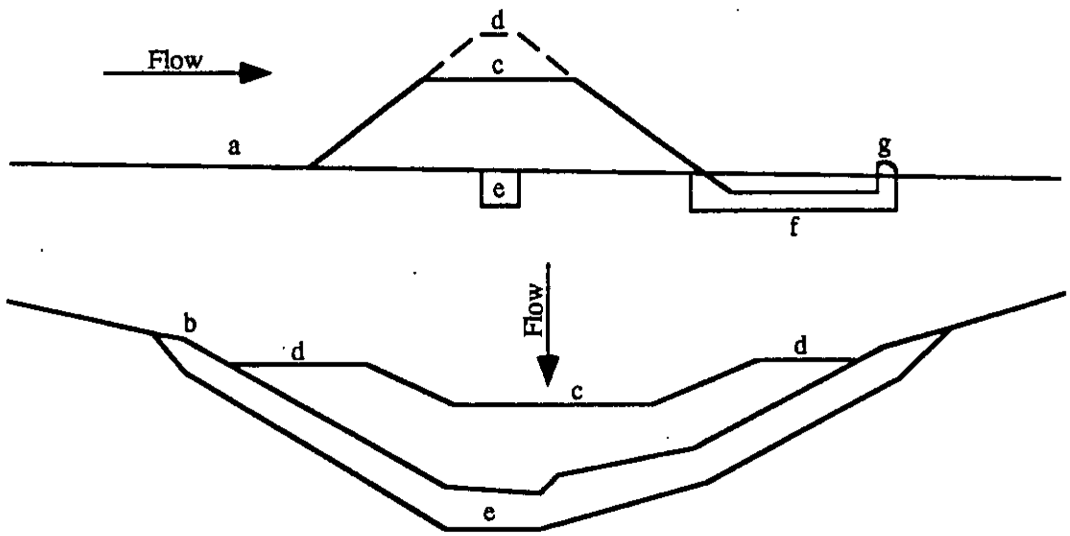
An understanding of the processes by which gullies form is important to the design of structures to stabilize the channels and/or trap sediments. Gullying results from the combined effects of downcutting and headcutting (Anderson et al. 1976, Heede 1976). Continuous gullies downcut along the entire waterway whereas discontinuous gullies may only have head cuts and active erosion at vulnerable "nick" points—places with locally steeper slopes (higher velocities) or more erosive soils. Head cuts commonly move upstream. Tons or thousands of tons of soil material may be mobilized and cannot realistically be replaced. In the small trail channel at Paso Picacho meadow (See Figure 3, A-A'), an estimated 1800 cubic feet (72 tons) have been removed (D. Bainbridge pers. comm.).

The three primary purposes of meadow erosion control are to check the progress of active gullying, refill deeper gullies with sediments, and restore the water table (Kraebel and Pillsbury 1934). These can be accomplished by a combination of actions: 1) modification of land use practices (grazing, recreational activities, logging, etc.); 2) building structures to cause gully filling; 3) control of gully heads and channels; and 4) planting to make control measures more effective and permanent (Kraebel and Pillsbury 1934, Anonymous 1986, GAO 1988).

Many stabilization methods have been explored to minimize erosion in gullies (Bennett 1939; Kraebel and Pillsbury 1934; Heede 1976, 1977 a and b; Gray and Leiser 1982). Kraebel and Pillsbury (1934) authored a handbook on control of erosion in inaccessible montane meadows using locally available materials. Typical check dams (rock, wire, or brush), fences, and rock-filled wire baskets (gabions) have been used to slow water flow and retain sediment (Kraebel and Pillsbury 1934; Heede 1976, 1977 a,b; Sheeter and Claire 1981; Wilken 1987; Key and Gish 1989; Lindquist and Bowie 1989; Meyer 1989). Sediment is deposited in dam catch basins in a wedge shape as seen in longitudinal section. Spacing of dams is dependent on the gradient, but it is frequently recommended that the crest of one dam be at the level of the apron of the one next above (Goldman et al. 1986, Kraebel and Pillsbury 1934)(Figure 2A). Wider spacing is acceptable, but the desirable goal is to have one-half of



A. Optimum dam spacing is such that the crest of one dam is at the same elevation as the apron of the dam upgradient from it (modified from Kraebel and Pillsbury, 1934).



B. Features: a) orginal gully bottom; b) original gully cross section; c) spillway; d) crest; e) excavation for key; f) excavation for apron; g) end sill (modified from Heede, 1976).

Figure 2. Erosion control structures A) spacing, B) features.

the gully area covered by the expected catch basins of the dams. Key locations for dams are at narrow places in the channel, immediately below the junction of two or more gullies, in channel areas with stable foundation material, or where gradients are gentle (Kraebel and Pillsbury 1934).

Work should proceed from the mouth of the gully upstream (Ratliff 1985). Porous structures are preferred because they develop much lower pressure on the banks and on the structure itself (Heede 1976, 1977b), as are more numerous, small dams (less than 3-4 feet in height). Small, porous dams are less expensive to build, and there is less danger that they will wash out (Kraebel and Pillsbury 1934, Heede 1976). Critical issues in the design of check dams are 1) "keying" the structure into the bank so that it does not get pushed over or flanked by subsequent bank erosion, 2) positioning a spillway that is lower than the sides of the structure, and 3) protecting the dam from undercutting by placing an apron below the spillway (Kraebel and Pillsbury 1934; Heede 1976, 1977; Gray and Leiser 1982)(Figure 2B).

Gully heads may be stabilized by constructing plugs or mattresses against the face of the cut to stop the waterfall or "plunge pool" that undermines the head, with a check dam immediately downstream. It may be necessary to modify the slope of the cut in situations where a mattress or plug cannot be constructed (Kraebel and Pillsbury 1934).

Reestablishing grasses, shrubs, and trees on the watershed slopes and gully bottoms can help reduce runoff, peak flow and erosion in the gully. Vegetation is preferred over mechanical controls as it is self-healing if correctly installed and protected, but mechanical controls must often be installed to break the erosion cycle and enable vegetation to establish. In montane California meadows, willow cuttings are an especially inexpensive, effective means of revegetation and rapid stabilization of soils (Kraebel and Pillsbury 1934; Ratliff 1985). Strips of sod may be used as well, if they are dug from areas not vulnerable to erosion and placed along contours (Kraebel and Pillsbury 1934, Ratliff 1985).

3.1.2. Ground Water Monitoring

Ground water monitoring contributes information necessary for a hydrogeologic investigation. Determination of recharge and discharge areas, ground water flow directions and variation of the soil moisture regime are obtained from knowledge of hydraulic potential distributions. More specifically related to meadow restoration are the effects of surface structures to ground water levels and effects of ground water fluctuations to plant communities. Accurate ground water monitoring is necessary to access these effects.

Piezometric head, sometimes referred to as hydraulic head or hydraulic potential, is defined as the sum of elevation head and pressure head. Elevation head, pressure head and velocity head are the three components of the Bernoulli energy equation (all with units of length), but typical ground water flow velocities are small enough so that velocity head is negligible in comparison to the other two heads. Elevation head at any point is simply the elevation of that point with respect to an arbitrary datum plane. This datum plane may be mean sea level, the elevation of underlying bedrock, or any convenient reference plane. Pressure head at that point is water pressure divided by the unit weight of water (Holtz and Kovacs 1981). In an unconfined aquifer, the piezometric surface is the water table and is generally defined as the interface between the saturated zone and the capillary fringe, or more precisely the surface where pressure head equals zero.

A piezometer is a type of monitoring well that is screened to allow water to enter it only at a specified depth (See Figures 10 and 11). Piezometers are constructed so that elevation head at the screened section is constant. Thus, water level measurements with time represent changes in pressure head. Hydraulic gradient is defined as change in hydraulic head over a unit distance. Ground water flows in the direction of decreasing head. When hydraulic head is the same everywhere in the aquifer, there is no ground water flow, and water level in a piezometer is the same as the water table elevation. If there is a hydraulic gradient, ground water is flowing, and water level in a piezometer is different from the water table elevation, with that difference being directly proportional to he magnitude of hydraulic gradient. A group of piezometers at the same location constructed to different depths (a piezometer nest)(See Figures 12 and 13) can be used to locate the water table. A vertical hydraulic gradient can be obtained from measurements of hydraulic head with depth, and the location of the water table can be extrapolated from that gradient.

A typical monitoring well is screened through its entire length in the saturated zone (See Figure 14). Water level in a monitoring well is the same as the water table elevation if there is no hydraulic gradient. With a hydraulic gradient, water level in a monitoring well will be the average hydraulic head throughout the screened interval. Temporal water level measurements represent changes in average hydraulic head.

Tensiometers are used to measure hydraulic head above the water table. Pressure head above the water table is negative, and is commonly referred to as soil suction (geologists) or soil water pressure potential (ecophysiologists). Tensiometers are inserted into the unsaturated zone . Elevation head at the tensiometer tip is constant. Soil suction (soil water potential) is measured with a vacuum gauge that is permanently attached to the tensiometer. Tensiometer nests can measure hydraulic gradient in a manner similar to piezometer nests.

Knowledge of hydraulic gradients through the unsaturated and saturated zone is necessary to characterize the hydrology of a meadow. Saturated zone gradients give the direction of ground water flow. Whether and to what extent an aquifer is being recharged, or discharged, can only be determined if direction of ground water flow throughout the aquifer is known (Ward 1967). Unsaturated zone gradients represent infiltration or evaporation of soil moisture and may have an effect on the establishment an health of plan communities. More specifically, they may have impacts on species like *Downingia* that have a narrow range of moisture requirements for germination, establishment and maturation.

3.1.3. Restoration Projects in Areas Similar to Cuyamaca

Numerous references have been found to assessments of Western montane meadow conditions and the impacts of various activities on meadow vegetation, soils and hydrology. Unfortunately, much of the information is not easily available because it is contained in theses, dissertations and unpublished reports (See literature cited in Benedict 1981, Ratliff 1985, Anonymous 1986). Even fewer studies on restoration projects have been located. Although riparian habitat is a small fraction of the land area in the West, its importance for water supplies, grazing, fish populations and wildlife have focussed attention on its restoration, and numerous reports are available on stream and creek bed restoration (Cope 1979; Heede 1977a; GAO report 1988; Gresswell, Barton and Kershner 1989; Key and Gish 1989; Meyer 1989). The most detailed report I found was that of Heede (1977a) who directed a watershed improvement project in Colorado on the western slope of the Rocky Mountains. This study included extensive pre-project data collection; the installation of 132 check dams and a permanent concrete dam at the mouth of the watershed; and a detailed analysis of the changes over a 12-year period in vegetation, soil erosion and hydrology—both in treated and untreated areas. Substantial improvements were documented, with an ephemeral stream becoming permanent and soil losses reduced by up to 78%. A project begun in 1985 on the Red Clover Creek on the eastern side of the northern Sierra Nevada, offers promise of important information on changes in meadow hydrology after installation of erosion control structures

(Lindquist and Bowie 1989). Four loose rock check dams were installed on the creek channel and a revetment of pine tree tops was built along 30 m of eroding bank. A revegetation plan with combinations of three treatment variables was implemented. Its design will allow comparison of four woody species, two plant forms (unrooted and rooted stakes) and two seasons of planting. Permanent transects have been established to monitor changes in streambed morphology, elevation and sediment entrapment. To determine the effect, if any, of the restoration measures on the shallow water table, 24 piezometers were installed on transects crossing the demonstration area and in downstream control areas. They extend from the stream bank to points 160 m into the floodplain. Preliminary data indicate that in control areas there is a steep groundwater gradient, with flow directed towards the stream (Lindquist and Bowie 1989). Near the catch basins behind the rock dams, the groundwater gradient is much less and flow tends to mound up around the ponds at certain times of the year. Preliminary data from another long-term study in two riparian systems in central Wyoming, indicates that an elevated water table above one check dam extended 22 m upstream (Kotansky et al. 1989).

The general conclusions derived from these projects are that a multi-faceted approach is necessary. Remedial actions usually begin with analysis of land use patterns and alterations in land use based on the type and degree of impacts. In some cases, exclosure of grazing animals may result in rapid and extensive revegetation in riparian habitats (Duff 1979, Platts and Wagstaff 1984, DeBano and Hansen 1989, Kondolf 1993), but changes in streambed morphology may take much longer (Kondolf 1993, Clifton 1989). Where recreational activities are the cause of adverse impacts, a combination of education and "exclosure" (by closing trails or campgrounds) may be important (Anonymous 1986, Rochefort and Gibbons 1992). In Sequoia National Park, many abandoned trails have revegetated, but the "treadways" remain intrenched (DeBenedetti and Parsons 1979). DeBenedetti and Parsons (1979) found that revegetation was more sparse and instability greater where trails passed through sandy soils. Intervention in the form of erosion control structures and seeding and/or planting, is often required, especially in arid or high elevation habitats where natural recovery rates are slow (Bainbridge and Virginia 1990, Rochefort and Gibbons 1992).

One study that is especially pertinent to the meadows in the Cuyamaca Valley area is that by Rochefort and Gibbons (1992). Although the habitat they worked with differs in important ways from Cuyamaca (higher elevation, in particular), the land use impacts of recreational activities are similar. The site is a subalpine meadow in Mount Rainier National Park. Damage scars caused over 30 years ago by horse trails are still 2-4 m wide and up to 0.6 m deep. Off-trail hiking remains a serious and intractable problem that leaves substantial areas denuded of vegetation. Bare ground sites vary from 0.5-1,740 m in length and 0.1-25.6 m in width. Soil subsidence due to erosion and compaction ranges from 0.01 m to 1.0 m. The Mount Rainier restoration program included an extensive inventory of types and extent of damage (Rochefort and Gibbons 1992). This inventory was entered into a computer, with computer software that allowed for prioritizing of potential restoration sites, calculation of supply needs for restoration, entering of monitoring data and generation of reports. Restoration methods employed were primarily erosion stabilization bars installed by hand labor and plantings grown in the park's own greenhouse. In many respects, the most important part of the restoration plan was the sociological study. Even when areas were restored, many people ignored signs and barriers erected to protect the areas and facilitate recovery. The purpose of the sociological studies was to better understand the "non-compliers" and to devise a strategy to gain their cooperation. Various types of signs and barriers were field tested, questionnaires were distributed to park visitors who were seen off-trail, and the presence of uniformed personnel was increased. Some sign designs appeared to be more effective than others, people responded better to unattractive polypropylene ropes than split rail fencing (the latter apparently was interpreted to be a landscaping feature not a barrier), and the threat of fines or the presence of uniformed personnel worked. Because the latter were seen as the least desirable management options, efforts to improve signage and barriers have been the main focus of protecting restored areas and preventing additional damage.

3.2. SELECTION OF RESTORATION SITES

Three meadow areas within the Cuyamaca Rancho State Park were examined for their restoration/enhancement potential for *Downingia concolor* ssp. *brevior*. These are the Little Stonewall Creek watershed, the southern edge of the main Cuyamaca Valley near the former location of the old Minshall house and the meadow north of the Paso Picacho group camp (Figure 3).

3.2.1. Little Stonewall Creek Watershed

The entire Little Stonewall Creek drainage was examined for sites that appeared suitable for placement of *Downingia* seeds and for installation of erosion control structures. Two areas were identified as being suitable for growth of *Downingia* where it may have occurred historically but is absent at this time (Figure 3). Both areas are gently sloping, retain shallow

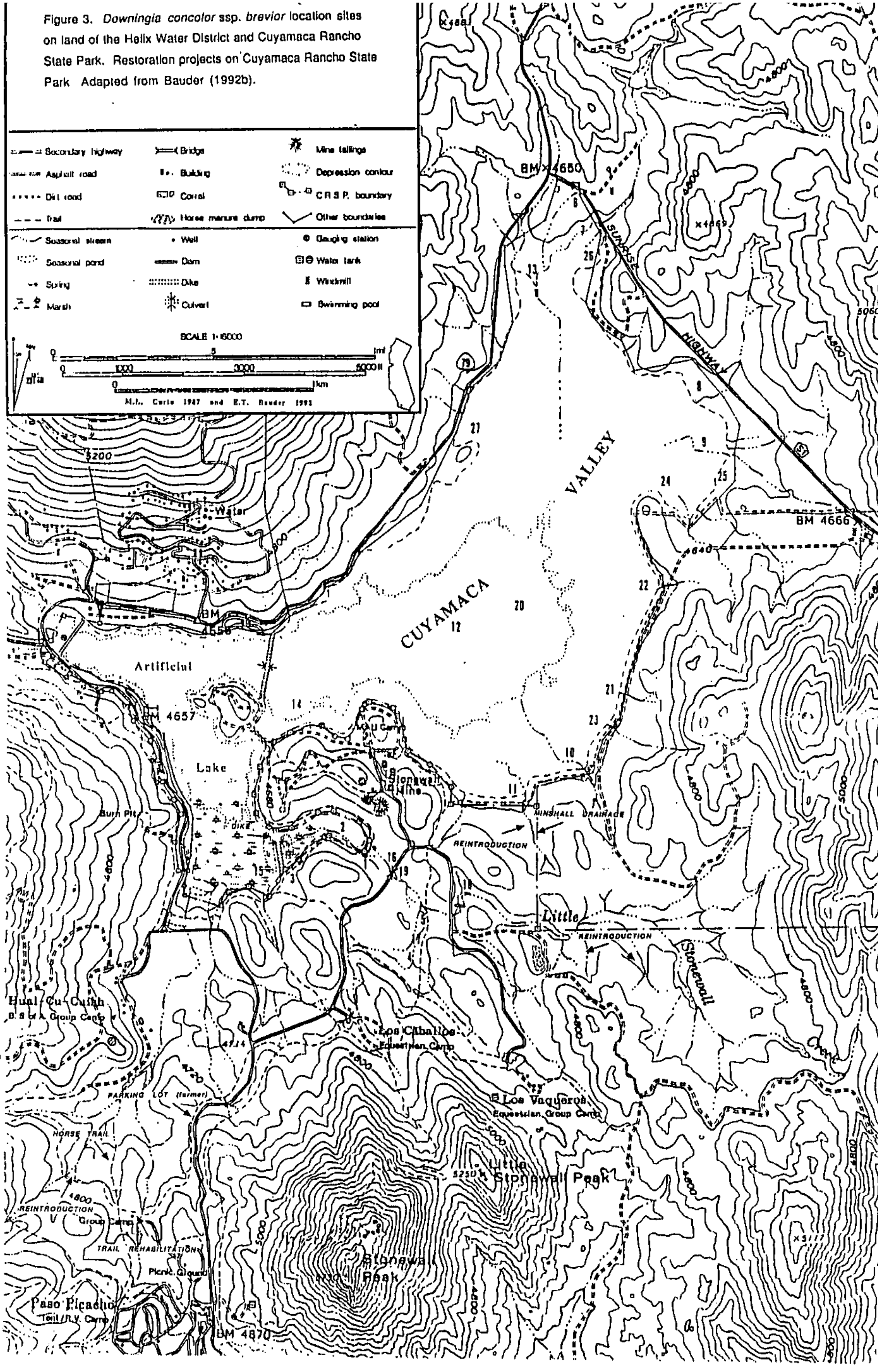


Figure 3. *Downingia concolor* ssp. *brevior* location sites on land of the Helix Water District and Cuyamaca Rancho State Park. Restoration projects on Cuyamaca Rancho State Park. Adapted from Bauder (1992b).

surface water during the rainy season and support the two most common associates of *Downingia* —*Plagiobothrys* cf. *acanthocarpus* and *Navarretia intertexta*. *Limnanthes gracilis* ssp. *parishii* (Parish's slender meadowfoam) occurs patchily at the edges of the open, wetter spots.

The Little Stonewall Creek watershed is about 965 acres (Bemis 1987) and exhibits evidence of both past and active erosion. The main channels are deep (up to 3-4.5 m), with nearly vertical sides and numerous "nick" points and scour holes. Bedrock is exposed in the upper main channel. Within the channel there are narrow terraces that suggest that the banks reached a stable condition several times in the past and then were cut down with new episodes of erosion. Schumm (1977) calls this a "complex" reaction. "When baselevel is lowered, erosion and channel adjustment occur near the mouth of the basin...the main channel probably will be adjusted to the change long before the information reaches upstream tributaries. However, when the tributaries are in turn rejuvenated, the increased sediment production is fed into a channel that has already adjusted to the baselevel change but not to increased sediment loads from upstream." (Schumm 1977). This can lead to a sequence of responses including reworking of sediments and terrace formation. Active headcutting is present in several locations, and there is evidence of bank sloughing as well. *Downingia* is found only in the flatter, undrained areas in the lower portions of the drainage (Sites # 4, 5 and 17, Figure 3 and Bauder 1992b); or very sparsely in channels and scour holes (Sites # 16 and 19, Figure 3 and Bauder 1992b).

The main drainage channel was surveyed by F. Sullivan and S. McMillan. Preliminary work indicated that substantial rock structures would be necessary because of the degree of erosion in the channel. Despite the obvious need for erosion control in this watershed, this proposed restoration effort was temporarily abandoned. Mr. Greg Picard, Superintendent of Cuyamaca Rancho State Park, expressed concerns for possible construction impacts to the surrounding meadow as well as the length of time that it would take to review the project for compliance with CEQA. Unfortunately, I was not able to secure the completed drawings from F. Sullivan of the Greater Mountain Empire Resource Conservation District.

When it became evident that we would not be able to construct the rock structures in the upper portion of the drainage, I investigated rerouting and restoration of a trail that currently is impacting *Downingia* and *Limnanthes* habitat near *Downingia* Sites #1-3 (Figure 3). Because this is part of a loop trail, if it were to be closed, it would be necessary to reroute the trail out of the park, onto Helix Water District property and back on to the park. To do so would have required costly repair of a breached dike (Figure 3). In addition, it would have been necessary to develop an agreement between the two landowners (Helix Water District and the California Department of Parks and Recreation) and Helix's lessee, the Lake Cuyamaca Recreation and Park District. A number of complex issues were involved, and it did not seem possible that they would be satisfactorily resolved within the time frame of this contract. Consequently, after several meetings on site with the concerned parties present, I (with the concurrence of Mr. James Dice of the California Department of Fish and Game), decided that this restoration project was desirable but undoable within the time available.

3.2.2. Minshall Drainage

Near the former location of the Minshall house, a small unnamed drainage that enters the southeastern corner of the Cuyamaca Valley was impeded by fill that formed a road to the residence. The fill causes a pond to form. The pond supports a dense growth of *Juncus xiphioides*. Neither *Downingia* nor *Limnanthes* is found in or around this pond. There is a small patch of *Downingia* where this drainage crosses the fence line onto Helix Water District property (Site # 11, Figure 3 and Bauder 1992) and in some years it is relatively abundant below this site as the drainage drops into the Cuyamaca Valley. *Downingia* is also found in the lower reaches of another small drainage slightly to the east (Site # 10, Figure 3 and Bauder 1992b). *Limnanthes* grows higher up in the "Minshall" drainage in more open areas, along with *Plagiobothrys* cf. *acanthocarpus* and *Navarretia intertexta*. By removal of the fill, the ponding would be eliminated and conditions would be less favorable for the rushes (*Juncus xiphioides*) and sedges (*Carex* spp.) and more suitable for *Downingia* and *Limnanthes*. Throughout the valley, both *Downingia* and *Limnanthes* appear to be absent or sparse where there is dense cover of perennials. This was judged to be an appropriate site for introduction of *Downingia* seed because it may have occurred there historically and the habitat indicators are currently present.

3.2.3. Paso Picacho Meadow

The meadow to the north of the Paso Picacho group camp drains slopes up to the south and southeast and at its southern, upper end is bisected by a forested ridge. At least three small drainages join with a creek at the northwest corner of the meadow. This creek subsequently flows through a narrows and empties into another meadow that is the upper end of the Cuyamaca Valley basin. In historical times this drainage joined with the Little Stonewall Creek just south of the Laguna Que Se Seca or vernal lake (USGS map, 1903 edition surveyed 1891 and 1901-2). Drainages that originate to the east of Highway 79 enter the Paso Picacho meadow via culverts (Figure 3). One of the natural drainages that is moderately eroded may be affected by the concentrated flow from a culvert. This drainage exhibits downcutting and has several very deep scour holes in association with mounds of sediments slightly downstream from each hole (B-B' in Figure 4; see Figure 5 also). The meadow is crisscrossed by horse and hiking trails, much in evidence in aerial photographs (Figure 1). Some of these trails have become discontinuous gullies with narrow box-shaped channels and numerous scour holes. They may be acting as interceptor drains which diminish the inputs to the meadow below them. It is clear that these are artificial drainages because of their shape, starting and ending points, and lack of conformance to contour lines. The trails are no longer intended for active use and the trail head parking area along the highway has been removed (Figure 3). Above the forest/meadow interface along the eastern and southern margins of the meadow, there is an active equestrian trail. As it passes the group camp, it becomes very rocky and is difficult to navigate. Consequently, riders seek an easier passage which can take them into the upper fringes of the meadow. Vegetative cover has been removed and new, artificial channels are beginning.

The Paso Picacho meadow was selected for installation of erosion control devices and hydrological monitoring instruments and for trail rehabilitation. Two drainages were chosen to be treated. One is an artificial drainage to the west of the forested ridge (peninsula). This drainage is labeled drainage " A-A' " (Figure 4). The second drainage is a natural drainage to the east of the ridge, and it was labeled " B-B' " (Figure 4). Scour holes not clearly attached to drainages were identified in the main meadow and proposed for individual treatment. This area also was chosen for the installation of a water table monitoring well, nests of piezometers and tensiometers. The problem area of the trail was delimited and slated for fencing, signage and rehabilitation.

In the western lobe of the upper meadow there is a large outcrop of granitic rock. During the rainy season, water ponds in and around this outcrop. *Limnanthes* is found primarily above the upper margins of the rocks, and *Navarretia intertexta* and *Plagiobothrys* cf. *acanthocarpus* are found in the areas of ponding. As with sites in the Minshall drainage and the Little Stonewall Creek watershed, this was chosen for the introduction of *Downingia* seed because *Downingia* may have occurred there historically, and the habitat indicators are currently present (Figure 3).

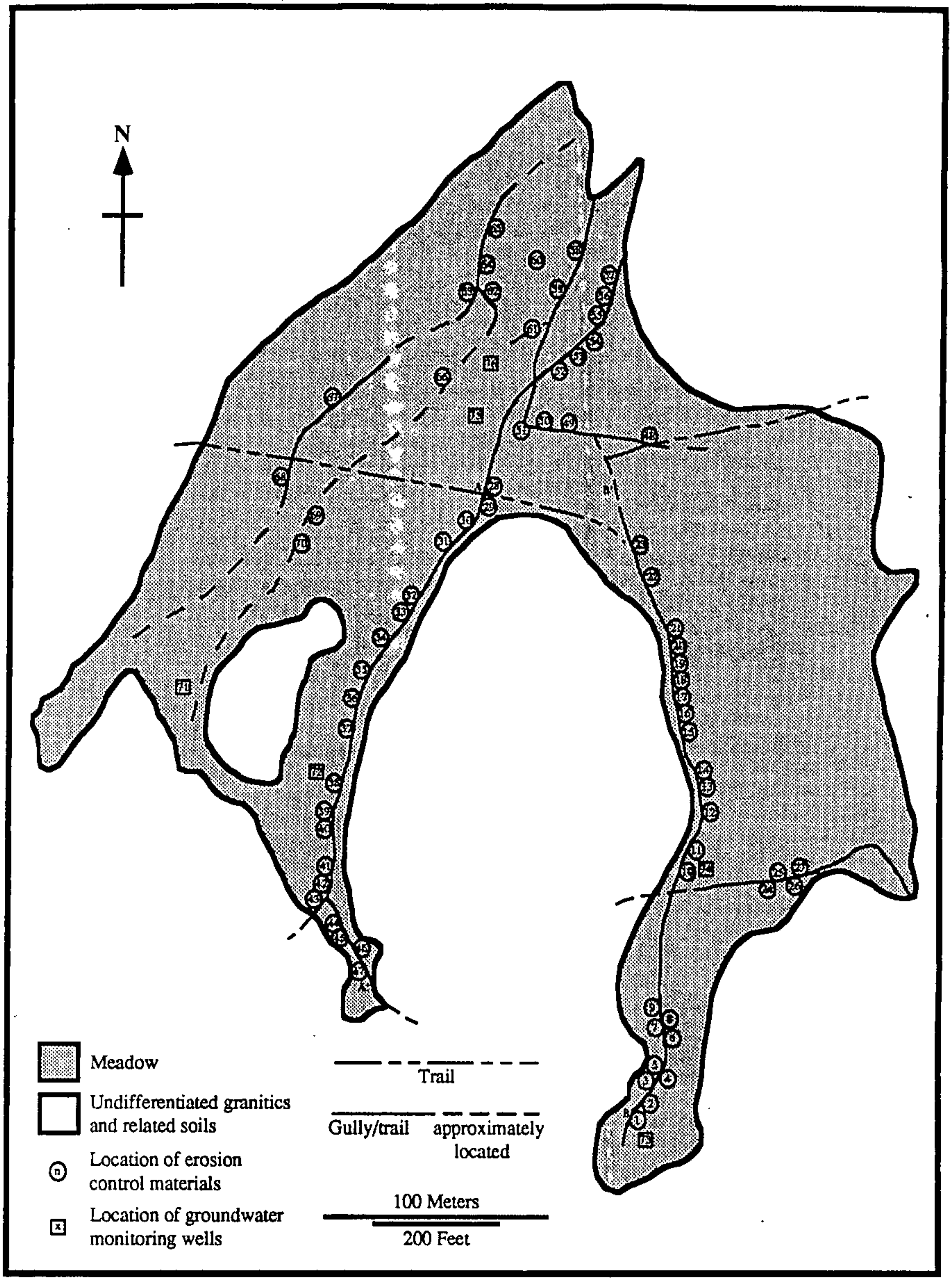


Figure 4. Map of meadow north of Paso Picacho Group Camp, Cuyamaca Rancho State Park.

CHAPTER 4. RESTORATION/ENHANCEMENT ACTIONS

All treatments were applied in late summer of 1994, with the exception of the seed introductions. Dates for these enhancements are noted as they are discussed.

4.1. PASO PICACHO MEADOW

4.1.1. Erosion Control-Design and Installation

The first step in planning the erosion control program was a survey of the two drainages. The purpose of the survey was to calculate the in-channel gradients, determine the width of the channels, locate and characterize "nicks" or head scarps and accompanying scour holes, and establish baseline data against which to judge the results. We used a surveyor's level and determined the relative elevation of each channel at 10 m intervals (Figure 5). From this we calculated the average gradient. Each 10-m point was marked with a rebar stake covered with a numbered safety cap (Table 2). At these numbered points, perpendicular sections were taken, using a sampling interval of 1 m and extending 5 m on each side of the channel bottom (Figures 6 and 7). These measurements reveal that the two channels differed in gradient, width, depth, and depth and number of scour holes (Table 2 and Figures 6 and 7). Areas without measurements had poison ivy or a dense stand of stinging nettles. The trail-induced channel (A-A') had a steep, even gradient and scour holes less than 0.5 m deep. The eastern drainage (B-B') was less steep, but descended at a less constant slope. It had two scour holes over 1 m deep, three between 0.66 m and 1 m, and three between 0.5 m and 0.66 m.

Erosion control structures were installed approximately 0.5 m below the "nick" points (scarp heads, head cuts) (Table 2). Five basic treatments were applied plus untreated areas for purposes of comparison ("control" treatment). Treatments were adjusted or altered for the unique attributes of each area, but were kept as uniform as possible. The treatments were randomly assigned to treatment points, and each channel was independently assigned treatments. The treatments were as follows: 1) bamboo retention dams with bamboo pickets and crossbars, 2) broom corn retention dams made with cleaned broom corn, 3) coir (coconut) fiber mesh dams, 4) rice straw logs, 5) brush dams reinforced with T-posts or bamboo and 6) controls or untreated points (Figures 8 and 9). Although the two drainages were numbered independently

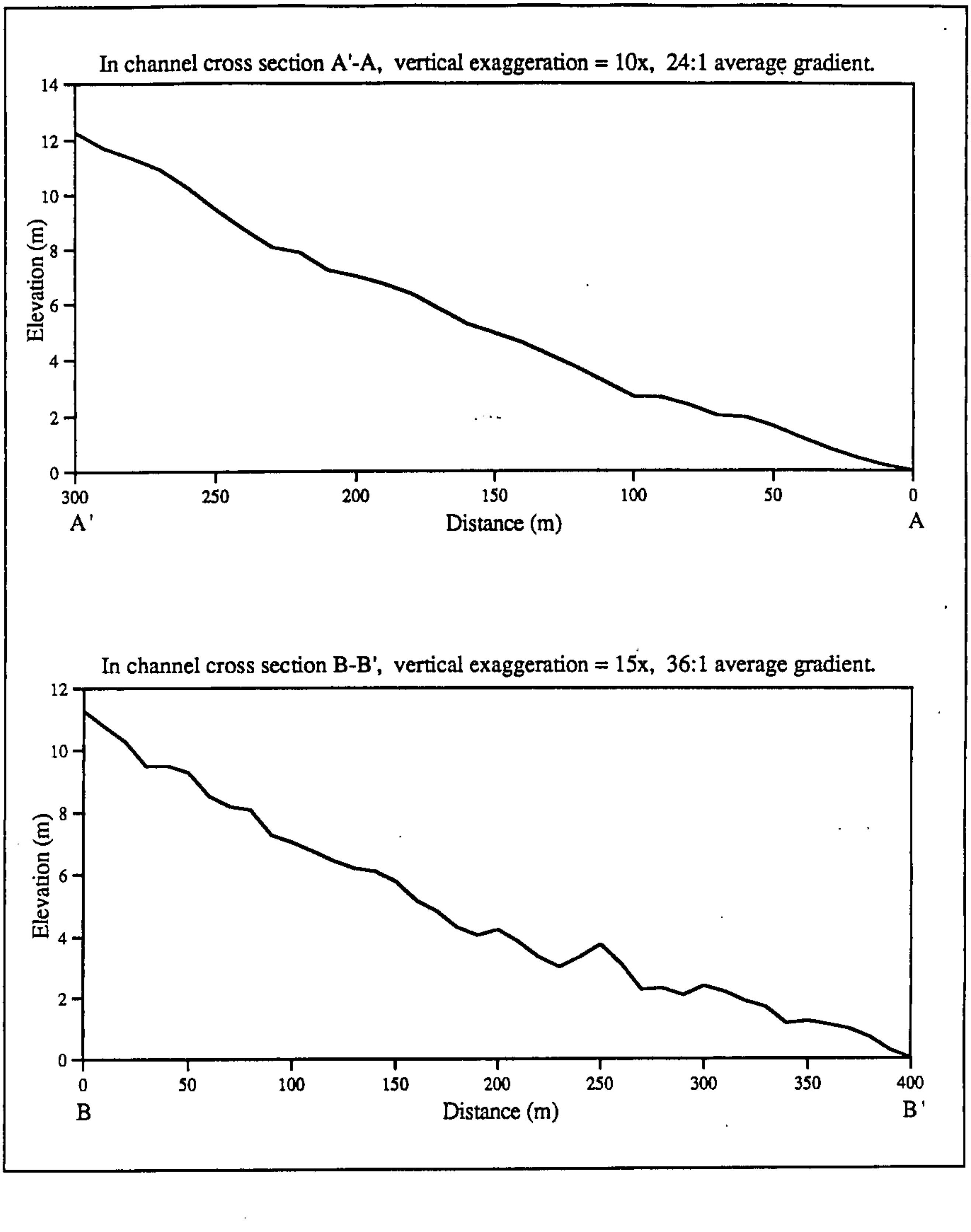


Figure 5. In channel cross sections in meadow north of Paso Picacho Group Camp, Cuyamaca Rancho State Park.

Map	Erosion Control							
Location	Treatment Placement			Channel Dimensions				
	Local.	Survey Pin (m)	Treatment	Depth (cm)	Width (cm)	50cm upst Depth (cm)	50cm downst Depth (cm)	Comments
1	B	0-0.87	Rice Straw	26.0	94.0	8.0	19.0	
2	B	10-0.83	Coir	29.0	64.5	23.0	14.0	
3	B	20-4.25	Rice Straw	33.0	50.0	28.0	28.0	
4	B	20+3.39	Coir	22.5	38.0	13.0	14.5	
5	B	30-3.15	Bamboo	60.0	111.0	55.0	37.0	
6	B	50-3.06	Brush	13.0	74.0	14.0	11.5	
7	B	50+4.97	Control	37.0	58.0	35.0	36.5	
8	B	60-2.78	Bamboo	37.0	54.0	45.5	26.0	
9	B	60+4.93	Rice Straw	12.0	93.0	13.0	15.0	
10	B	160-2.75	Brush	104.0	210.0	57.0	99.0	
11	B	170-3.35	Control	19.5	107.0	10.0	16.0	
12	B	190+0.81	Brush	32.0	102.0	26.0	23.0	
13	B	210-1.45	Rice Straw	15.0	360.0	19.0	18.0	
14	B	220-2.21	Rice Straw	14.0	196.0	13.0	13.0	Transect of 4 shallow (~8in) tensiometers
15	B	240+0.66	Coir	91.0	380.0	*91.5	*53	* Depths measured 2.0 m up/down stream
16	B	260-3.20	Bamboo	56.0	112.0	52.0	47.0	
17	B	260+4.00	Bamboo	42.0	191.0	44.5	46.5	
18	B	270-0.18	Brush	107.0	116.0	118.0	111.5	
19	B	280+1.53	Control	57.0	113.0	66.0	63.5	
20	B	290-1.87	Coir	74.0	102.0	70.0	71.0	
21	B	300+0.00	Rice Straw	48.0	530.0	*49.0	*39.0	* Depths measured 2.0 m up/down stream
22	B	340-1.73	Control	69.5	69.0	61.5	71.5	
23	B	360-0.70	Rice Straw	18.5	104.0	25.0	19.0	
24		50+2.00	Bamboo					
25		50-1.00	Coir					
26		30+4.00	Coir					
27		30+2.00	Rice Straw					
28	A	0-1.83	Control	18.0	97.0	23.0	14.0	
29	A	0+1.25	Coir	21.0	64.0	19.0	21.0	

Table 2. Map index with channel dimensions and placement of treatments.

Map Location	Erosion Control							
	Treatment Placement			Channel Dimensions				
	Local.	Survey Pin (m)	Treatment	Depth (cm)	Width (cm)	50cm upst Depth (cm)	50cm downst Depth (cm)	Comments
30	A	20-0.75	Broom Corn	22.0	122.0	26.0	20.0	
31	A	40-2.70	Rice Straw	22.0	46.0	22.0	23.0	
32	A	70+1.22	Broom Corn	44.0	45.0	33.0	40.0	
33	A	80+1.82	Control	32.0	92.0	35.0	33.0	
34	A	100-0.35	Bamboo	46.0	125.0	38.0	45.0	Rice Straw between locations 34 and 35
35	A	120-3.64	Coir	43.0	89.0	33.0	35.0	Rice Straw between locations 35 and 36
36	A	140-2.80	Rice Straw	26.0	90.0	26.0	27.0	
37	A	160-4.00	Bamboo	22.0	54.0	26.0	18.0	Rice Straw between locations 37 and 38
38	A	190-2.75	Broom Corn	33.0	66.0	43.0	30.0	
39	A	200+3.81	Rice Straw	23.0	56.0	21.0	18.0	
40	A	210+0.99	Coir	31.0	76.0	30.0	32.0	Rice Straw between locations 40 and 41
41	A	240-3.90	Bamboo	31.0	56.0	38.0	24.0	
42	A	240+2.42	Control	23.0	66.0	18.0	18.0	Rice Straw between locations 42 and 43
43	A	250+5.10	Coir	23.0	66.0	15.0	16.0	
44	A	270-2.63	Control	15.0	50.0	20.0	16.0	
45	A	280-2.74	Broom Corn	17.0	48.0	17.0	22.0	
46	A	290-2.58	Bamboo	18.0	37.0	16.0	22.0	
47	A	290+2.91	Rice Straw	18.0	56.0	18.0	12.0	
48	1		Coir					Broom Corn at head scarp
49	2		Broom Corn					Coir also stapled in at head scarp
50	3		Coir					
51	4		Coir Carpet					
52	5a		Broom Corn					
53	5b		Broom Corn					
54	5c		Broom Corn					
55	5d		Bamboo					
56	5e		Bamboo					
57	5f		Bamboo					
58	6		Coir					

Map Location	Erosion Control							
	Treatment Placement			Channel Dimensions				
	Local.	Survey Pin (m)	Treatment	Depth (cm)	Width (cm)	50cm upst Depth (cm)	50cm downst Depth (cm)	Comments
59	7		Coir Carpet					
60	8		Coir Carpet					
61	9		Coir Carpet					
62	10		Coir					
63	11		Coir					
64	12		Bamboo					
65	13		Bamboo					
66	14		Coir Carpet					
67	15		Coir					
68	16		Coir					
69	17		Bamboo					
70	18		Coir					

Map Location	Groundwater Monitoring							
	Wells			Tensiometers				
	Qty.	Well Type	Depths (ft)	Quantity	Depths (in)			
71	1	Piezometer	5.5	1	30.25			
72	1	Piezometer	6.5	None				
73	1	Piezometer	13	None				
74	3	Piezometer	13, 9.5, 7	2	6.0, 36.0			5ft. tensiometer @ power pole & pin 160
75	3	Piezometer	13.7, 10, 6.5	2	6.0, 36.0			
76	1	Monitoring Well	13.8	None				

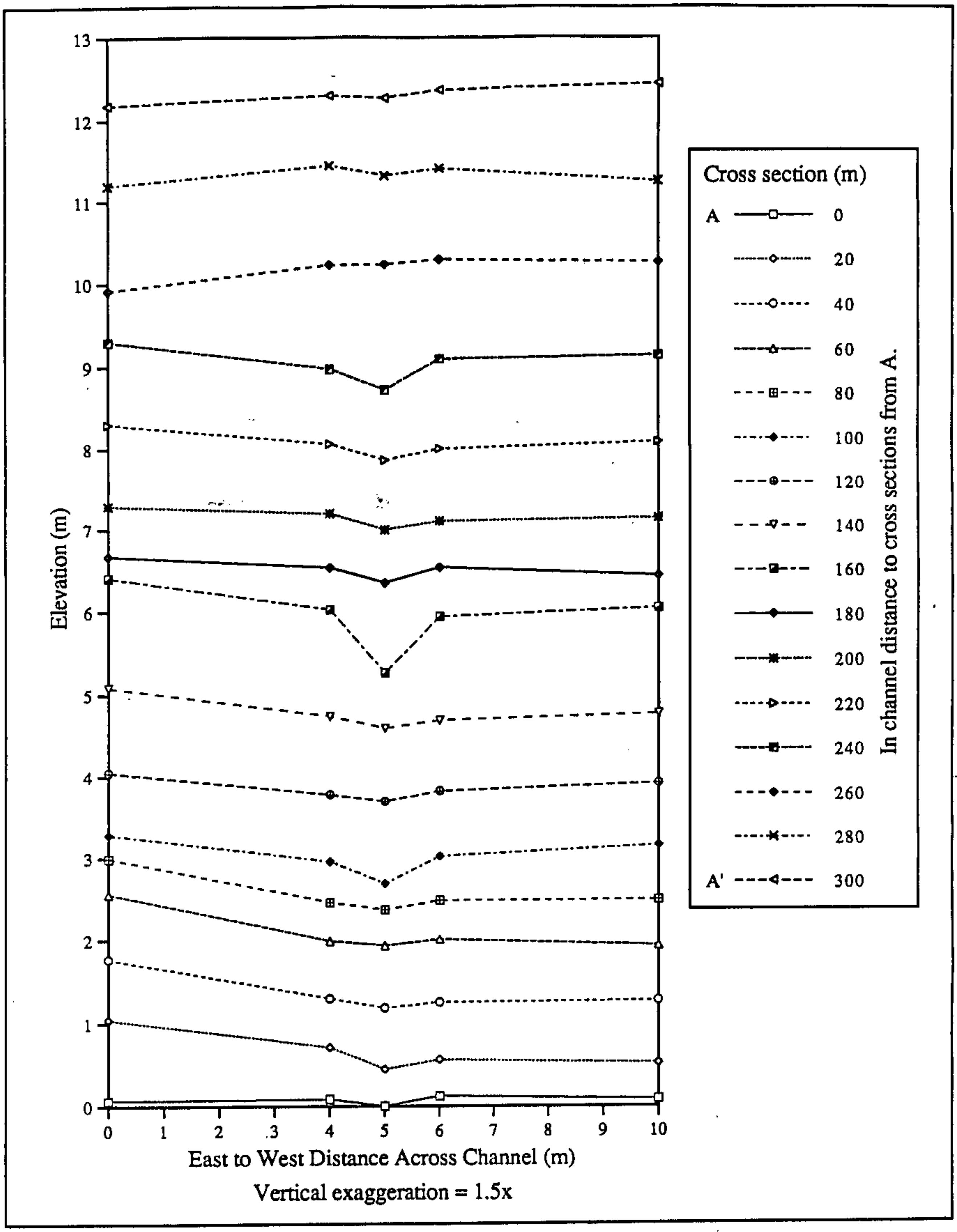


Figure 6. Perpendicular cross sections of channel A-A'.

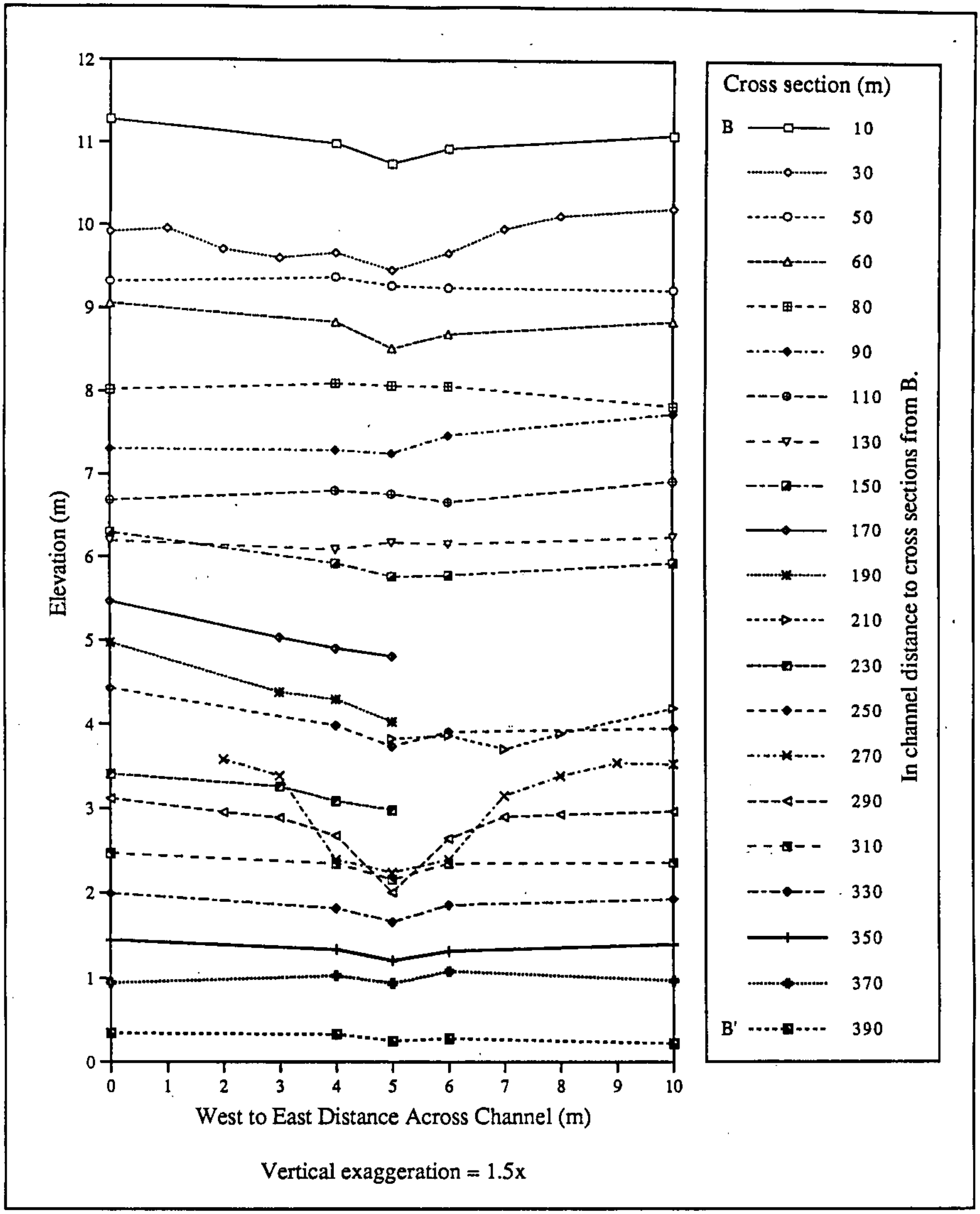
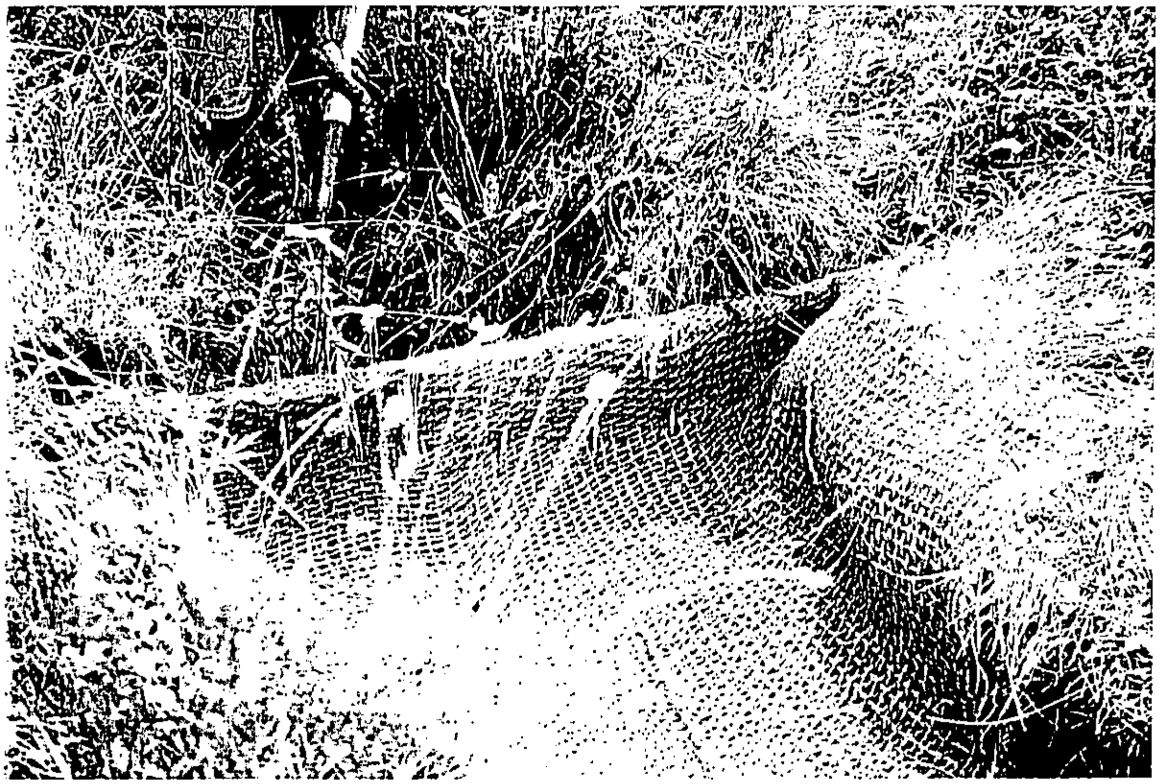
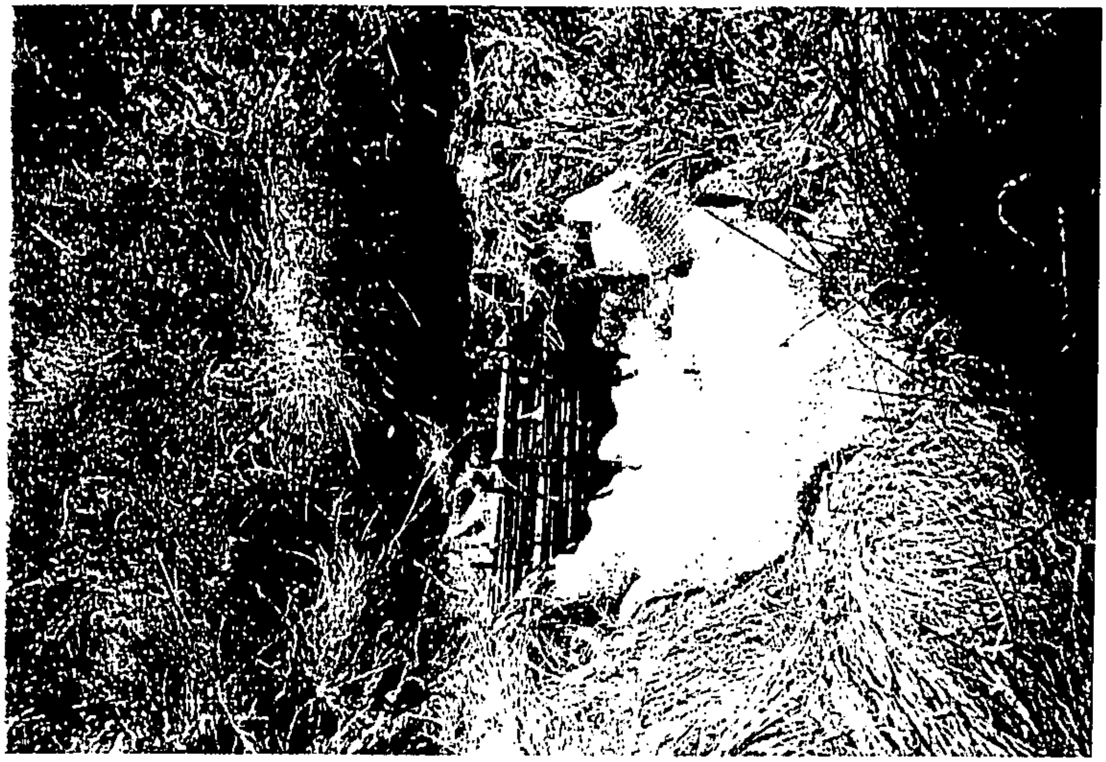


Figure 7. Perpendicular cross sections of channel B-B'.

Figure 8. Photos of treatments. Top) Coir fiber on a framework of bamboo. Bottom) Placement of rice straw logs. Photos by D. Bainbridge.

Figure 9. Photos of treatments. Left Top) Broom corn. Left Bottom) Brush "dam" with "T" post framework. Right) Bamboo "dam" with coir fabric apron. Photos by S. Netto.





as they were surveyed, a unique number was given to each treatment point in the meadow (Figure 4, Table 2). Each treatment was replicated at least four times.

The construction materials were cut and prepared as much as possible at San Diego State University, taken to a parking lot in the Paso Picacho Group Camp and then carried to the site. All dams were "keyed" 10-15 cm into the sides of the banks by using a chain saw with a trencher adaptor. Shallow trenches perpendicular to the channel were incised as well. Bamboo frames were made of 5/8 inch or 3/4 inch diameter bamboo stakes and woven with 3/8 inch or 5/8 inch bamboo stakes or covered with a piece of matchstick bamboo shade. Rice straw logs were 3 feet long and consisted of cleaned rice straw contained within a mesh cover. Logs were hydrated for 2 weeks prior to placement to test for seed contamination. They were embedded in the channel using one to three logs per treatment point, depending on the width of the channel. Logs were anchored with staples made of bent lengths of small diameter rebar. Broom corn was placed vertically in the channel. As with the rice logs, it was tested for seed contamination. Broom corn comes from *Sorghum vulgare* plants that are harvested while in bloom and placed in a revolving drum to remove seed (Kirby 1963). Whisks (branches and flower panicles) are cured in drying sheds. We pushed the stem end into the soil, leaving the divided inflorescence sticking up in the channel. Coir (coconut) fiber dams had a downstream apron that was stretched to protect the channel sides as well as the channel bottom. The coir was anchored either with staples or bamboo stakes. At two locations on the eastern drainage (Map location #'s 10 and 18, Figure 4), the scour basins were so wide and deep that metal T-posts were used to frame the brush dams. Additional brush was packed behind the retention structures.

In addition to the structures placed in the two channels, 23 scour holes in the open meadow were treated using bamboo, corn and coir (Map locations #48-70, Figure 4). Treatment locations were identified by hiking the meadow and marking sites on an acetate overlay on an aerial photograph. Treatments were not assigned by any method, but were applied according to the circumstances at each point.

4.1.2. Hydrology Monitoring Instruments

To monitor the hydrology of the meadow, a total of nine piezometers , one tensiometer, and one monitoring well were installed in the main meadow (Map locations #'s 71-76, Figure 4). To install the instruments, we hand augured a 3-inch diameter hole, 1 foot at a time. At each 1-foot interval, the auger was withdrawn and the soil classified and described. When the desired depth was reached, scrap pipe was inserted into the hole to keep it open. Then, the pre-assembled well was inserted. Sand was placed around the well or piezometer, then topped with a seal of bentonite clay pellets and finally a top seal of bentonite medium chip clay (Figures 10-14). Three piezometers were installed at the head of the meadow, two in the western lobe (Map locations #71 and 72, Figure 4) and one in the eastern lobe (Map location #73, Figure 4). One piezometer "nest" (i.e. cluster) was put mid-way down the eastern drainage (Map location #74, Figure 4), and the other (Map location #75, Figure 4) was placed close to the monitoring well (Map location # 76, Figure 4).

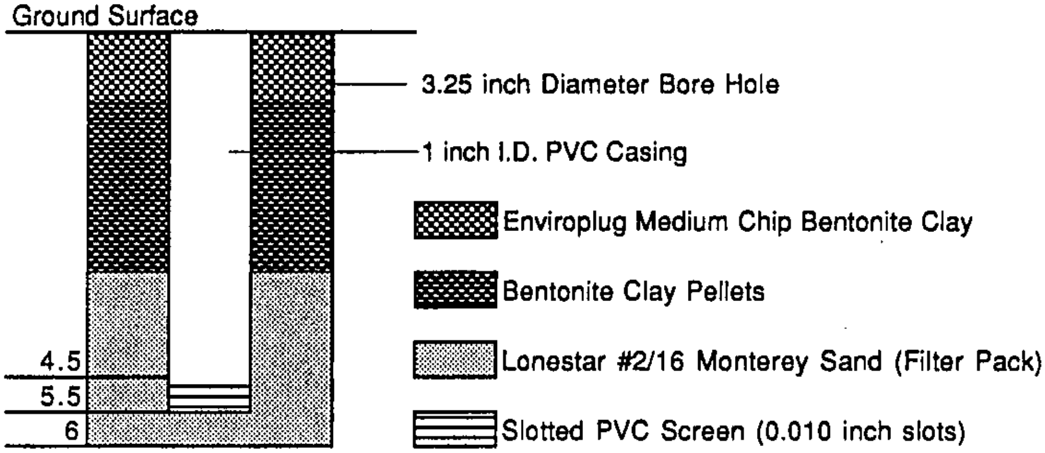
4.1.3. Seed Introduction

On March 14, 1994, seeds that had been collected from Sites # 1 and 2 (Figure 3) during the previous summer, were introduced to shallow topographic basins and swales in and around the rock outcrop of the western lobe of the meadow (white area between map locations #70, 71 and 72, Figure 4 and Figure 3). The amount of seed was unknown, but a limited number of plants were available in 1993. A maximum of 400 plants were harvested. The soils were moist at the time the seeds were scattered, and additional rainfall occurred after the introduction. In June of 1994, a careful survey was made of the area and a total of 925 flowering plants were found distributed among 5 patches. No plants were found in one area that had been seeded. This introduction site will be monitored again in the early summer of 1995 during the yearly mapping of *Downingia* . A report will be submitted as required by the California Department of Fish and Game collection permit.

4.1.4. Trail Rehabilitation

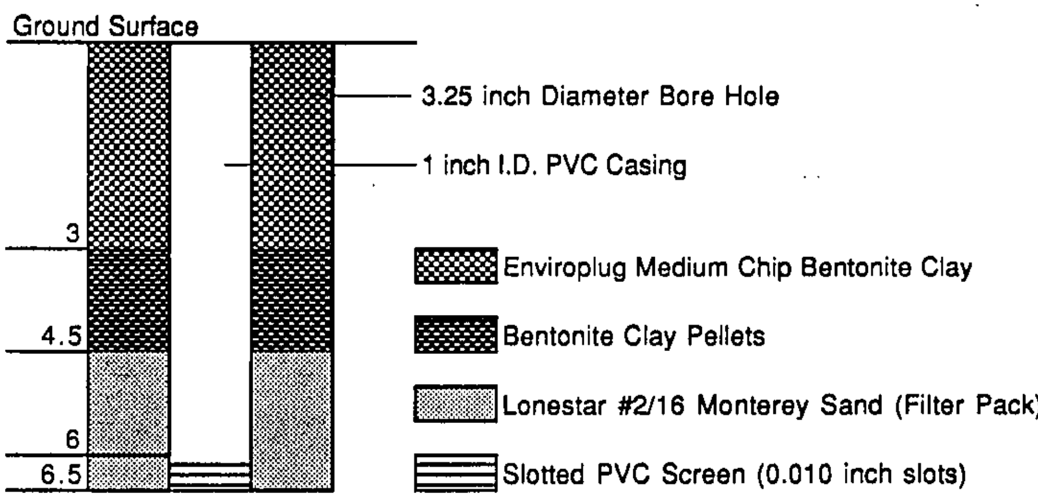
In August of 1994, we rehabilitated a trail that runs at the southern base of the ridge or peninsula, between A' and B on the map (Figures 3 and 4). Large rocks were removed to make passage of horses easier, natural rail fencing purchased by this project was installed to redirect the trail from an archaeological site, and signs were erected to clarify the new trail location for riders and hikers. We also removed tree branches in the newly designated portion of the trail and laid them on the ground to define the trail.

Cuyamaca Rancho State Park-Paso Picacho Group Camp
Map Location 71 (meadow north of group camp)
Piezometer Design



Depths shown are in feet below ground surface

Cuyamaca Rancho State Park-Paso Picacho Group Camp
Map Location 72 (meadow north of group camp)
Piezometer Design



Depths shown are in feet below ground surface

Figure 10. Piezometer design at map locations 71 and 72.

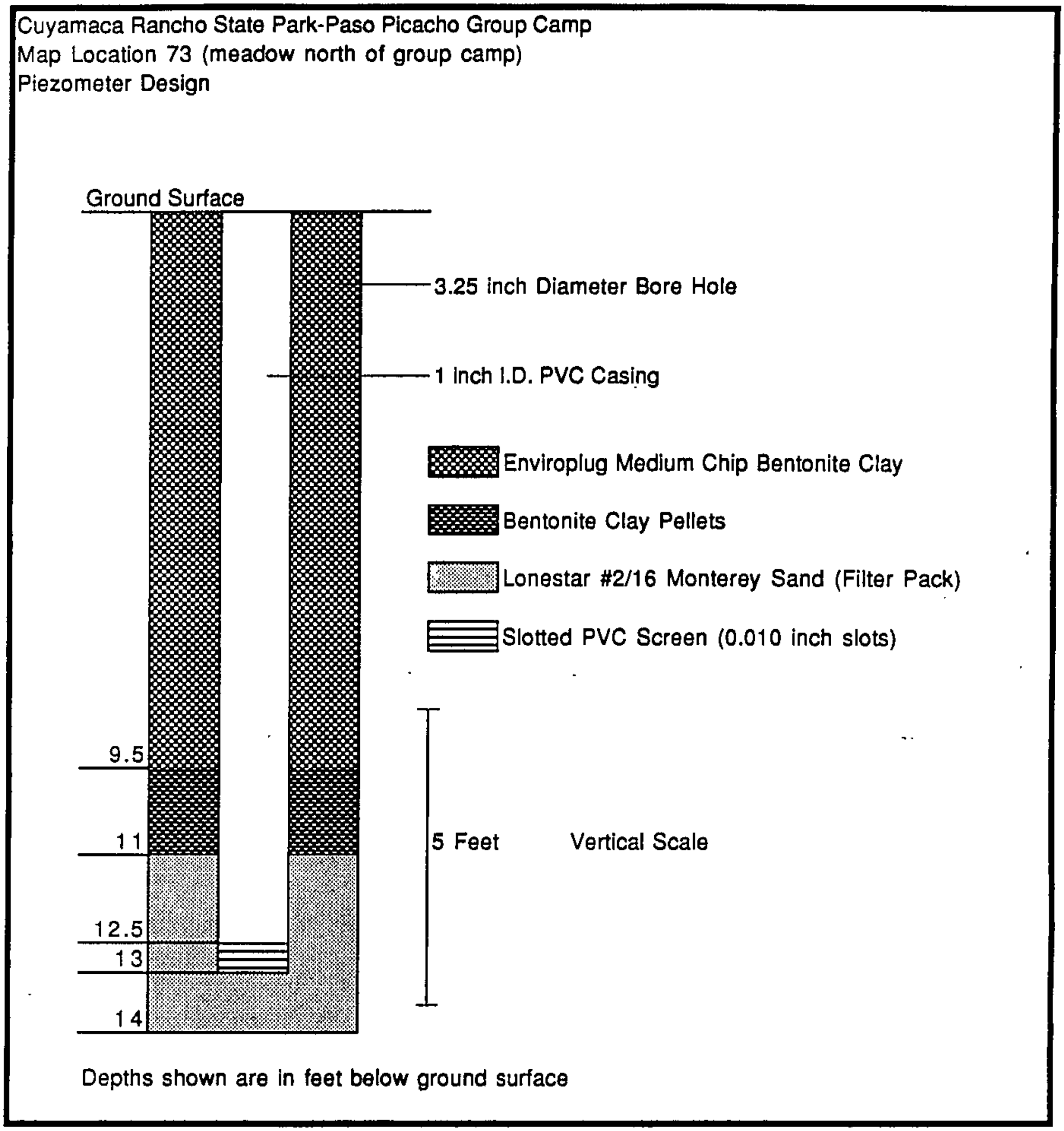


Figure 11. Piezometer design at map location 73.

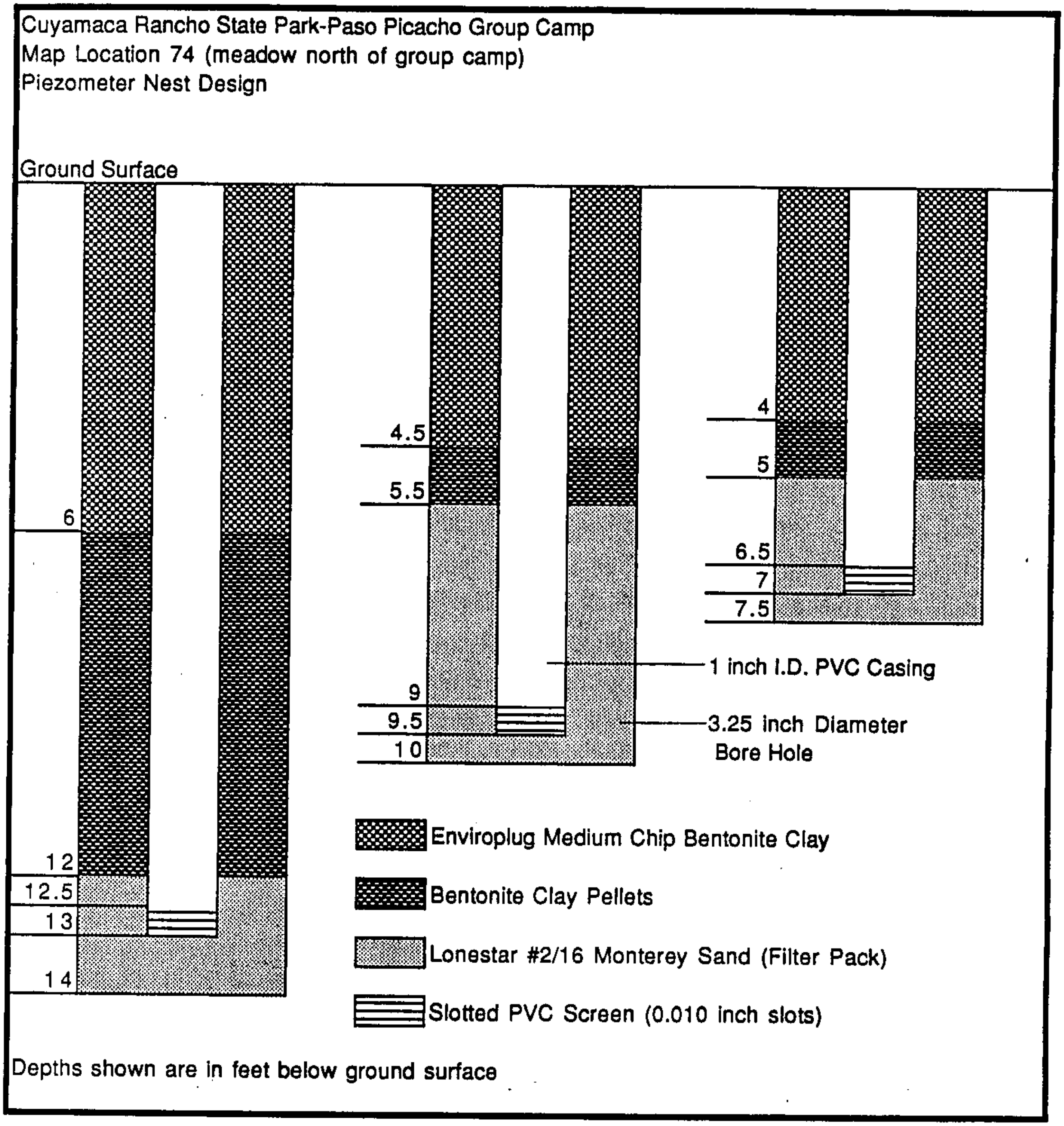


Figure 12. Piezometer nest design at map location 74.

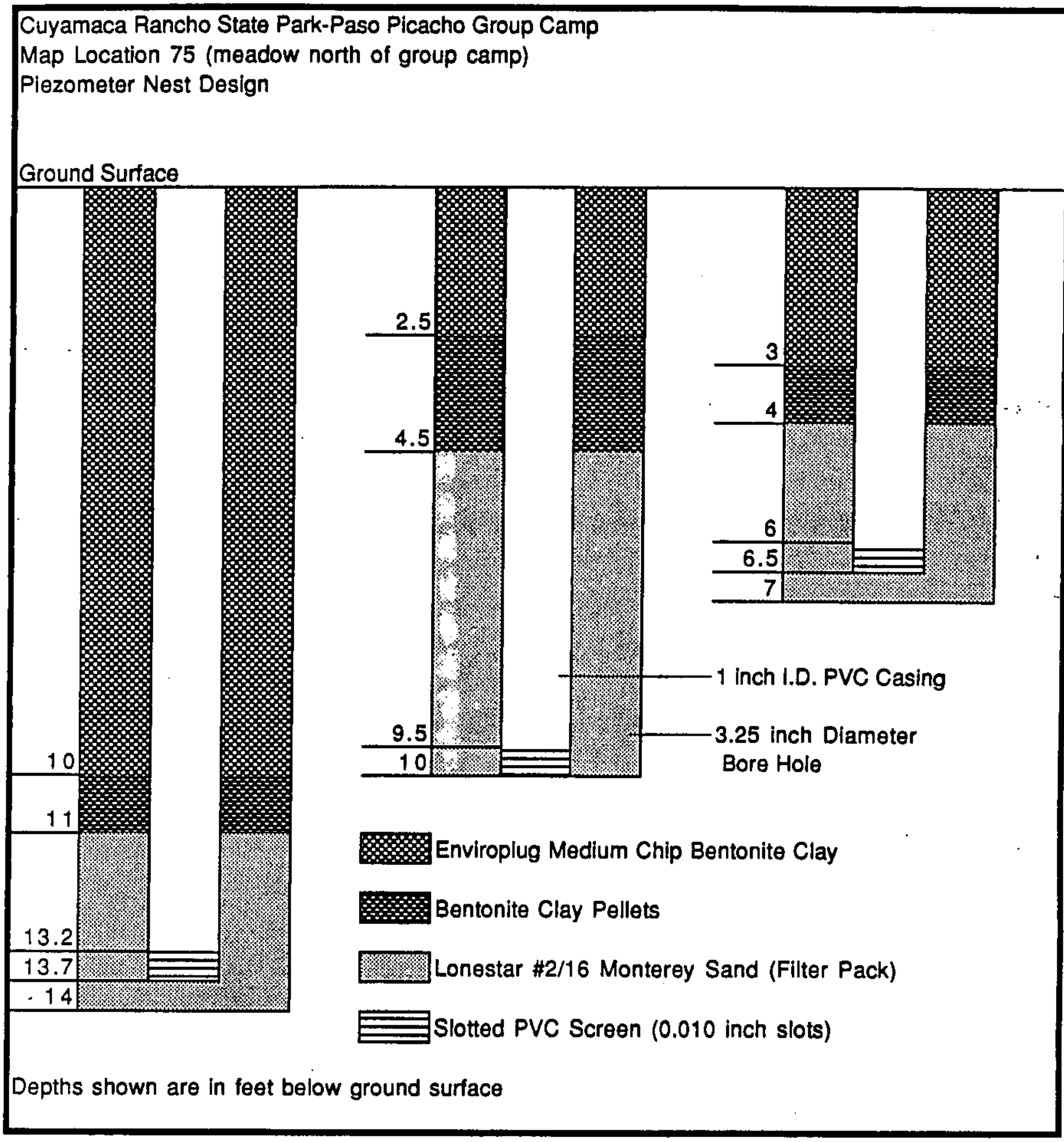


Figure 13. Piezometer nest design at map location 75.

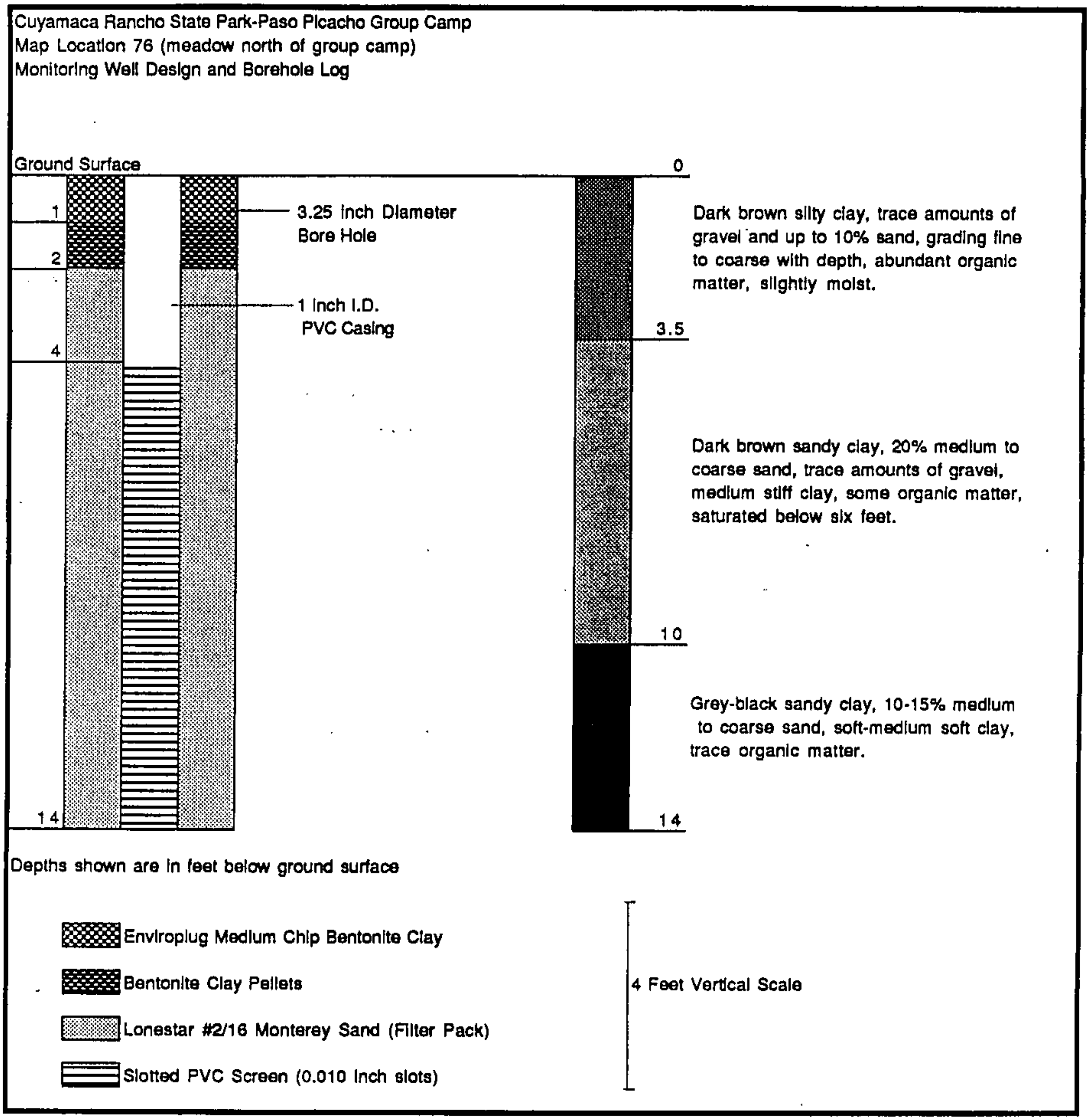


Figure 14. Well design and borehole log at map location 76.

4.2. MINSHALL DRAINAGE

The fill that provided a dirt road crossing of this un-named drainage was removed using hand tools (Figure 3). Excavated fill was placed in small, active lateral gullies; in low, cross ridges upstream in the channel; and in shallow layers above and below the excavation. We began digging in the center of the span and worked our way downward and outward. We estimated the original width and depth of the drainage by using vegetation, soil texture and elevation changes as indicators.

Seed for introduction was collected in the early summer of 1994 from *Downingia* Site #10 (Figure 3). Flowering plants were abundant at this site in 1994. Approximately 2000 plants were collected which represented only a small fraction of the plants at this site. Because the fruits had dehisced before the harvest, an even smaller fraction of the seed crop was harvested. For a variety of reasons, it is not possible to estimate with any accuracy the number of plants or number of seeds. The plants are small ($\leq$ 1 dm tall) and dense, and they cannot easily be picked individually. Because they vary greatly in size and fecundity, and shed many of their seeds before harvest, the number of seeds is likewise difficult to estimate. In addition, the seeds are minute, usually less than 1 mm in length. In any case, care was taken to remove a sufficiently small portion of the seed crop so that the local population would not be impacted.

Seeds will be introduced to the "Minshall" drainage in early 1995 after several substantial rainstorms. This will allow the loose soils in the drainage to settle and prevent the *Downingia* seeds from being washed away or buried. If seeds are washed downstream and not buried, they will join patches at Sites # 10 and 11, the site of their origin. The site will be monitored in the early summer of 1995 as part of our yearly mapping of *Downingia* .

4.3. LITTLE STONEWALL CREEK WATERSHED

The only restoration or enhancement undertaken in the creek watershed was the introduction of seed into two sites deemed suitable (Figure 3). Seed was collected from *Downingia* Sites #1 and 2 (Figure 3) in the early summer of 1994. Approximately 500 plants were collected. For the reasons outlined in Section 4.2, the number of seeds cannot be estimated accurately. Collection methods were similar to those outlined above. Likewise, the seed will be scattered in the late winter of 1994/1995 after several rainstorms have occurred to moisten the soil. The area will be monitored for flowering plants in the late spring/early summer of 1995.

Before check dams can be constructed in the channels of Little Stonewall Creek, the elevation survey will have to be completed. This survey would assist in determining the height, number and spacing of structures required, as outlined by Kraebel and Pillsbury (1934); Heede (1976, 1977 a and b); and Gray and Leiser (1982). The depth of the channel and the degree of soil loss, in some places to bedrock, means that intervention will be necessary, probably in the form of rock structures. Other portions of the upper drainage may be dealt with by placement of erosion "mattresses" and brush dams. Several willows are present in the upper portions of the main channel, and the planting of willow stakes in this area could be an effective supplemental measure to stabilize the banks and retain water in the upper meadow. Lower down in the channel, closer to the paved road to Stonewall Mine, smaller structures—similar to ones we installed in the B-B' drainage (Figure 4) or like those described in Kraebel and Pillsbury (1934)—would be appropriate.

CHAPTER 5. GENERAL RECOMMENDATIONS

At Cuyamaca Valley, meadow and riparian restoration projects will show minimal or ephemeral improvements unless the underlying causes are understood and addressed. In some cases this means researching and analyzing historic land uses such as grazing or logging, or identifying earlier land alterations that continue to have an effect, including roads, trails, campsites and culvert outfalls. Within Cuyamaca Rancho State Park, present adverse impacts are related primarily to recreational activities, and the work done in Mount Rainier National Park offers a model of an action plan to deal with these problems (Rochefort and Gibbons 1992).

I recommend that a multi-party plan be developed for the entire Cuyamaca Valley watershed that would contain the following elements: 1) an inventory of damage to meadow areas; 2) observations on human impacts to the habitat; 3) sociological studies to devise strategies to lessen on-going impacts and protect restored areas; 4) collection of data on important meadow variables with particular attention to soil erosion potential, hydrology, and presence of sensitive plant or animal species; 5) assessment of the restoration potential of the various types of disturbed habitat and prioritization of projects; 6) design and implementation of restoration projects; 7) implementation of management programs based on analysis of items 1-4; and 8) monitoring, analysis and publication of results. Few studies of any type provide quantitative data on the effectiveness of restoration in montane meadows or riparian habitat, especially in altering meadow hydrology, upon which the unique vegetation depends. Three species of special note occur in this habitat. Two of these plants are state Endangered (*Downingia concolor* ssp. *brevior*—Lake Cuyamaca downingia and *Limnanthes gràcilis* ssp. *parishii*—Parish's meadowfoam) and one has Rare status in California (*Delphinium hesperium* ssp. *cuyamacae*—Cuyamaca larkspur). Little is known about the use of small-scale structures made of natural non-rock materials and installed by hand labor or that were designed to compare various treatments. Development of effective, low-cost techniques that could be used more widely, would be a benefit not only for the park but other areas that contain this sensitive habitat as well.

LITERATURE CITED

Allen, L. and M.L. Curto. 1987. Cuyamaca State Park: rare plant habitat restoration, natural heritage stewardship project. California Department of Parks and Recreation, Southern Region, San Diego, CA.

Anderson, H.W., M.D. Hoover, and K.G. Reinhart. 1976. Forests and water: effect of forest management on floods, sedimentation, and water supply. Pacific Southwest Forest and Range Experiment Station, GTR PSW-18. Berkeley, CA.

Anonymous. 1986. Stock use and meadow management plan: Sequoia and Kings Canyon National Parks.

Aschmann, H. 1973. Distribution and peculiarity of mediterranean ecosystems. Pages 11-19 *in* F. diCastri, H. A. Mooney, editors. Mediterranean type ecosystems. Springer-Verlag, Berlin.

Bainbridge, D. A. 1974. Trail management. Bulletin of the Ecological Society of America 55:(3): 8-10

———— and R. A. Virginia. 1990. Restoration in the Sonoran Desert. Restoration and Management Notes 8(1): 3-14.

Ball, O. P. 1976. North shore improvement project: Initial environmental impact study. Orville P. Ball and Associates, El Cajon, CA.

Ballard, William H. 1934a. Narrative report to supplement statistical report for month of July, 1934. U. S. Department of the Interior, Washington, D.C.

————. 1934b. Narrative report to supplement statistical report of month of August, 1934. U. S. Department of the Interior, Washington, D.C.

————. 1935a. Narrative report to supplement statistical reports of December, 1934, and January, 1935. U. S. Department of the Interior, Washington, D.C.

————. 1935b. Narrative report and summary of project accomplishments, from October 1st, 1934, to March 31st, 1935, inclusive. U. S. Department of the Interior, Washington, D.C.

Bauder, E. T. 1986. San Diego vernal pools: Recent and projected losses; their condition; and threats to their existence, 1979-1990. California Department of Fish and Game, Sacramento, CA.

————. 1987. Species assortment along a small-scale gradient in San Diego vernal pools. Dissertation. University of California Davis and San Diego State University, Davis, CA.

————. 1992a. *Delphinium hesperium* spp. *cuyamacae*: Population dynamics and environmental factors. California Department of Parks and Recreation, San Diego, CA.

————. 1992b. Ecological monitoring of *Downingia concolor* ssp. *brevior* (Cuyamaca Lake downingia) and *Limnanthes gracilis* ssp. *parishii* (Paris's slender meadowfoam): Cuyamaca Rancho State Park and Cuyamaca Valley, San Diego County, California. California Department of Parks and Recreation and California Department of Fish and Game , San Diego, CA and Sacramento, CA.

Beauchamp, R. M. 1986. A flora of San Diego County, California. Sweetwater River Press, National City, CA.

Bemis, C. G. 1987. South Cuyamaca reservoir repair. Prepared by Woodward-Clyde, Consultants for Ducks Unlimited.

Benedict, N. B. 1981. The vegetation and ecology of subalpine meadows of the southern Sierra Nevada, California. Dissertation. University of California Davis, Davis, CA.

———— and J. Major. 1982. A physiographic classification of subalpine meadows of the Sierra Nevada, California. Madrono 29:1-12.

Bennett, H. H. 1939. Soil conservation. McGraw-Hill, New York.

Bloomquist, R. A. 1966. A history of Cuyamaca Rancho State Park, Part II. Unpublished typescript.

Borst, G. 1984. Soil survey of Cuyamaca State Park. Department of Agriculture, County of San Diego,CA.

Bowman, R. H. 1973. Soil survey of the San Diego area, California. Soil Conservation Service, U. S. Department of Agriculture, Washington, D. C.

Brackett, R. W. 1939. A history of the ranchos: The Spanish, Mexican, and American occupation of San Diego County and the story of the ownership of the land grants therein. Union Title Insurance and Trust Company, San Diego, CA.

Bryan, K. 1928. Change in plant associations by change in ground water level. Ecology 9:474-478.

Bull, W. B. 1964. History and causes of channel trenching in western Fresno County, California. American Journal of Science 262:249-258.

Burcham, L. T. 1956. Historical backgrounds of range land use in California. Journal of Range Management 9:81-86.

————. 1957. California range land. An historico-ecological study of the range resources of California. California Division of Forestry, Department of Natural Resources, Sacramento, CA.

Clifton, C. 1989. Effects of vegetation and land use on channel morphology. Pages 121-128 *in* R. E. Gresswell, B. A. Barton, J. L. Kershner, editors. Practical approaches to riparian resource management: an educational workshop. U. S. Bureau of Land Management, Billings, MT.

Cooke, R. U. and R. W. Reeves. 1976. Arroyos and environmental change in the American South-west. Clarendon Press, Oxford.

Cope, O. B., editor. 1979. Proceedings of the forum-grazing and riparian/stream ecosystems. Trout Unlimited,Inc.,

Cottam, W. P., and G. Stewart. 1940. Succession as a result of grazing and of meadow desiccation by erosion since settlement in 1862. Journal of Forestry 38:613-626.

Debano, L. F. and W. R. Hansen. 1989. Rehabilitating depleted riparian areas using channel structures. Pages 141-148 *in* R. E. Gresswell, B. A. Barton, J. L. Kershner, editors.Practical approaches to riparian resource management: an educational workshop. U. S.Bureau of Land Management, Billings, MT.

———— and L. J. Schmidt. 1989. Pages 45-52 *in* R. E. Gresswell, B. A. Barton, and J. L. Kershner, editors. Practical approaches to riparian resource management: an educational workshop. U. S. Bureau of Land Management, Billings, MT.

DeBenedetti, S. H. and D. J. Parsons. 1979. Mountain meadow management and research in Sequoia and Kings Canyon National Parks: A review and update. Pages 1305-1311 *in* R. Linn, editor. Proceedings first conference on scientific research in the national parks. United States

Denevan, W. M. 1967. Livestock numbers in nineteenth-century New Mexico, and the problem of gullying in the Southwest. Annals of the Association of American Geographers 57:691-703.

Duff, D. A. 1979. Riparian habitat recovery on Big Creek, Rich County, Utah—A summary of 8 years of study. Pages 91-92 *in* O. B. Cope, editor. Proceedings of the forum-grazing and riparian/stream ecosystems. Trout Unlimited,Inc.

Elliott, W. W. 1883 (reprinted in 1965). History of San Bernardino and San Diego Counties, California. Riverside Museum Press, Riverside, CA.

Emmet, W. P. 1968. Gully erosion. Pages 517-519 *in* R. W. Fairbridge, editor. The encyclopedia of geomorphology. Reinhold Book Corporation, New York.

Fleischner, T. L. 1994. Ecological costs of livestock grazing in western North America. Conservation Biology 8:629-644.

Fredrickson, L. H. and T. S. Taylor. 1982. Resource Publication 148. Fish and Wildlife Service, U. S. Department of the Interior, Washington, D. C.

Galatowitsch, S. M. and A. G. van der Valk. 1994. Restoring prairie wetlands: An ecological approach. Iowa State University Press, Ames, Iowa.

Gebhardt, K. A., C. Bohn, S. Jensen and W. S. Platts. 1989. Use of hydrology in riparian classification. Pages 53-59 *in* R. E. Gresswell, B. A. Barton, J. L. Kershner, editors. Practical approaches to riparian resource management: an educational workshop. U. S. Bureau of Land Management, Billings, MT.

General Accounting Office. 1988. Public rangelands: Some riparian areas restored but widespread improvement will be slow. Report to Congressional Requesters. United States General Accounting Office, RCED-88-105 Riparian Areas, Washington, D. C..

Goldman, S. J., K. Jackson and T. A. Bursztynsky. 1986. Erosion and sediment control handbook. McGraw-Hill Book Company, New York.

Gosselink, J. G. and R. E. Turner. 1978. The role of hydrology in freshwater wetland ecosystems. Pages 63-78 *in* R. E. Good, D. F. Whigham and R. L. Simpson, editors. Freshwater wetlands: Ecological processes and management potential. Academic Press, New York.

Gray, D. H. and A. T. Leiser. 1982. Biotechnical slope protection and erosion control. Van Nostrand Reinhold Company, New York.

Gresswell, R. E., B. A. Barton and J. L. Kershner, editors. 1989. Practical approaches to riparian resource management: an educational workshop. U. S. Bureau of Land Management, Billings, MT.

Heede, B. H. 1976. Gully development and control: The status of our knowledge. Rocky Mountain Forest and Range Experiment Station, Forest Service, United States Department of Agriculture. Research Paper RM-169.

———. 1977a. Case study of a watershed rehabilitation project: Alkalai Creek, Colorado. Rocky Mountain Forest and Range Experiment Station, Forest Service, United States Department of Agriculture USDA Forest Service Research Paper RM-189.

———. 1977b. Gully control structures and systems. Food and Agriculture Organization of the United Nations, Guidelines for Watershed Management. FAO Conservation Guide Number 1. Rome, Italy.

———— and J. G. Mufich. 1974. Field and computer procedures for gully control by check dams. Journal of Environmental Management 2:1-49.

————. 1973. Functional relationships and a computer program for structural gully control. Journal of Environmental Management 1:321-344.

Holland, R. F. 1984. Spatial and temporal variation in plant species diversity of vernal pools. Pages 198-209 *in* S. Jain and P. Moyle, editors. Vernal pools and intermittent streams. Institute of Ecology, University of California Davis, Davis, CA.

————. 1986. Preliminary descriptions of the terrestrial natural communities of California. Nongame-Heritage Program, Department of Fish and Game, State of California, Sacramento, CA.

———— and S. K. Jain. 1984. Spatial and temporal variation in plant species diversity of vernal pools. Pages 198-209 *in* S. Jain and P. Moyle, editors. Vernal pools and intermittent streams. Institute of Ecology, Davis, CA.

Holtz, R. D. and W. D. Kovacs. 1981. An introduction to geotechnical engineering. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Hormay, A. L. 1943. Observations on species composition in northeastern California meadows as influenced by moisture supply. Unpublished report to Pacific Southwest Forest and Range Experiment Station, Forest Service, United States Department of Agriculture.

Johnson, R. R. and D. A. Jones. 1977. Importance, preservation and management of riparian habitat: a symposium. Rocky Mountain Forest and Range Experiment Station, Forest Service, United States Department of Agriculture, GTR-RM-43, Fort Collins, CO..

———— and J. F. McCormick, technical coordinators. 1978. Strategies for protection and management of floodplain wetlands and other riparian ecosystems. Forest Service, United States Department of Agriculture, GTR-WO-12, Washington, D. C..

Keddy, P. A. 1986. Great Lakes vegetation dynamics: The role of fluctuating water levels and buried seeds. Journal of Great Lakes Research 12:25-36.

Key, J. W., and M. A. Gish. 1989. Clark Canyon (Mono County) riparian demonstration area. Pages 127-134 *in* Abell, D. L., technical coordinator. Proceedings of the California riparian systems conference: protection, management, and restoration for the 1990's. Pacific Southwest Forest and Range Experiment Station, Forest Service, USDA, Berkeley, CA.

Kirby, R. H. 1963. Vegetable fibres: Botany, cultivation, and utilization. Interscience Publishers, Inc., NY.

Klikoff, L. G. 1965. Microenvironmental influence on vegetational pattern near timberline in the central Sierra Nevada. Ecological Monographs 35:

Kondolf, G. M. 1993. Lag in stream channel adjustment to livestock exclosure, White Mountains, California. Restoration Ecology 1:226-230.

Kotansky, D. J., P. M. Brogan, W. H. Fitzgerald and L. J. Gerard. 1989. Monitoring techniques and management practices applied to two riparian areas in central Wyoming. Pages 166-167 *in* R. E. Gresswell, B. A. Barton, and J. L. Kershner, editors. Practical approaches to riparian resource management: an educational workshop. U. S. Bureau of Land Management, Billings, MT.

Kraebel, C. J. and A. F. Pillsbury. 1934. Handbook of erosion control in mountain meadows. California Forest and Range Experiment Station, Forest Service, USDA, Berkeley, CA.

LeMenager, C. R. 1992. Julian City and Cuyamaca country: A history and guide to the past and present. Eagle Peak Publishing Company, Ramona, CA.

Liddle, M. J. 1975. A selective review of the ecological effects of human trampling on natural ecosystems. Biological Conservation 7:17-36.

Lin, J. 1970. Floristics and plant succession in vernal pools. thesis. San Francisco State College, San Francisco, CA.

Lindquist, D. S. and L. Y. Bowie. 1989. Watershed restoration in the northern Sierra Nevada: A biotechnical approach. Pages 436-440 *in* Abell, D. L., technical coordinator.

Proceedings of the California riparian systems conference: protection, management, and restoration for the 1990's. Pacific Southwest Forest and Range Experiment Station, Forest Service, USDA, Berkeley, CA.

Linsley, R. K., Jr.; M. A. Kohler; J. L. H. Paulhus. 1975. Hydrology for engineers, second edition. McGraw-Hill Book Company, New York.

MacMahon, J. A. and W. F. Wagner. 1985. Pages 105-202 *in* M. Evenari, I. Noy-Meir, D. W. Goodall, editors. Hot deserts and arid shrublands. Elsevier, Amsterdam, New York.

Martin, R. C. 1971. Cuyamaca land grant trial. The Journal of San Diego History 17:3-13.

McAleer, H. J. 1986. Stonewall mine and Cuyamaca City: A historical and archeological investigation of Southern California's largest gold mine. California Department of Parks and Recreation, Sacramento, CA.

Meehan, W. R. and W. S. Platts. 1978. Livestock grazing and the aquatic environment. Journal of Soil and Water Conservation 33:274-278.

Meyer, M. E. 1989. A low cost brush deflection system for bank stabilization and revegetation. Pages 424-427 *in* Abell, D. L., technical coordinator. Proceedings of the California riparian systems conference: protection, management, and restoration for the 1990's. Pacific Southwest Forest and Range Experiment Station, Forest Service, USDA, Berkeley, CA.

Mooney, H. A. and D. J. Parsons. 1973. Structure and function of the California chaparral—an example from San Dimas. Pages 83-112 *in* F. diCastri and H. A. Mooney, editors. Mediterranean type ecosystems. Springer-Verlag, Berlin.

Parkman, E. B., editor. 1981. A cultural resources inventory and management plan for prescribed burning at Cuyamaca Rancho State Park, San Diego County, California.

Pirnie, P. C. 1936. Narrative supplementary report. U. S. Department of the Interior, Washington, D.C.

Platts, W. S. 1989. Compatibility of livestock grazing strategies with fisheries. Pages 103-110 R. *in* E. Gresswell, B. A. Barton and J. L. Kershner, editors. Practical approaches to riparian resource management: An educational workshop. U. S. Bureau of Land Management, Billings, MT.

———— and F. J. Wagstaff. 1984. Fencing to control livestock grazing on riparian habitats along streams: Is it a viable alternative? North American Journal of Fisheries Management 4:266-272.

Ratliff, R. D. 1982. A meadow site classification for the Sierra Nevada, California. United States Department of Agriculture Forest Service, Pacific Southwest Forest and Range Experiment Station General Technical Report PSW-60.

————. 1985. Meadows in the Sierra Nevada of California: State of knowledge. Pacific Southwest Forest and Range Experiment Station, Forest Service, USDA General Technical Report PSW-84.

———— and E. E. Harding. 1993. Soil acidity, temperature, and water relationships of four clovers in Sierra Nevada meadows. Pacific Southwest Research Station, Forest Service, USDA Research Note PSW-RN-413.

Rensch, H. E. 1950. The Indian place names of Rancho Cuyamaca. Unpublished typescript.

Rochefort, R. M. and S. T. Gibbons. 1992. Mending the meadow: High-altitude meadow restoration in Mount Rainier National Park. Restoration and Management Notes 10:120-126.

Schumm, S. A. 1977. The fluvial system. John Wiley and Sons, New York.

Sheeter, G. R. and E. W. Claire. 1981. Use of juniper trees to stabilize eroding streambanks on the South Fork John Day River. Technical Note OR-1. Bureau of Land Management, Portland, Oregon 4p.

Singer, M. J. and D. N. Munns. 1991. Soils: An introduction, second edition. Macmillan Publishing Company, New York.

Thorne, R. L. 1976. The vascular plant plant communities of California. Pages 1-30 *in* J. Latting, editor. Plant communities of Southern California. California Native Plant Society, Berkeley, CA.

———— 1977. Montane and subalpine forests of the Transverse and Peninsular Ranges. Pages 537-557 *in* M. G. Barbour and J. Major, editors. Terrestrial vegetation of California. Wiley Interscience, New York.

Toy, T. J. and R. F. Hadley. 1987. Geomorphology and reclamation of disturbed lands. Academic Press, Orlando, FL.

True, D. L. 1961. Archaeological survey of Cuyamaca Rancho State Park, San Diego County, California.

Vankat, J. L. and J. Major. 1978. Vegetation changes in Sequoia National Park, California. Journal of Biogeography 5:377-402.

Wade, K. C. 1937. Cuyamaca Rancho State Park: State Park No. 69. *in* V. A. Neasham, editor. California historical survey series: Historic landmarks, monuments, and state parks. Under the auspices of the Works Project Administration for Department of Natural Resources, Division of Parks, State of California, Berkeley.

Walter, H. 1979. Vegetation of the earth and ecological systems of the geo-biosphere. Springer-Verlag, New York.

Ward, R. C. 1967. Principles of hydrology. McGraw-Hill Publishing Company Limited, London.

————. 1975. Principles of hydrology, second edition. McGraw-Hill, London.

Weiler, J. H. 1962. A biosystematic study of the genus *Downingia*. Dissertation. University of California Berkeley, Berkeley, CA.

Williams, D. D. 1987. The ecology of temporary waters. Timber Press, Portland, OR.

Woodward, A. 1934. Notes on the Indians of San Diego County, from the manuscripts of Judge Benjamin Hayes. The Masterkey 8(5).

Zedler, P. H. 1987. The ecology of Southern California vernal pools: A community profile. Fish and Wildlife Service, United States Department of the Interior Biological Report 85 (7.11).