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ASSOCIATION OF MONTEREY BAY AREA GOVERNMENTS

PAJARO BASIN GROUNDWATER

MANAGEMENT STUDY

Prepared for:

ASSOCIATION OF MONTEREY
BAY AREA GOVERNMENTS

By

HEA, A Division of
J.H. Kleinfelder & Associates

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CHAPTER 1

INTRODUCTION

This report has been prepared by HEA, A Division of J. H. Kleinfelder & Associates under contract with the Association of Monterey Bay Area Governments (AMBAG). Funding for this investigation was provided by the U.S. Environmental Protection Agency under the provisions of Section 208 of Clean Water Act of 1977 as amended. AMBAG in its capacity as the lead agency in Santa Cruz and Monterey Counties has administered all of the 208 programs in this area.

Groundwater conditions in the Pajaro Valley have been investigated periodically since 1950. These studies have provided information on geologic and hydrologic conditions in the basin and have provided varying estimates of the safe yield of the basin. These estimates have in general increased with a progressively increasing rate of pumpage withdrawal from the aquifers. Incidence of seawater intrusion in the coastal areas of the valley has been reported in all of the previous investigations. The acreage of the coastal farm lands affected by seawater has increased appreciably as the result of the intensified pumping. A gradual, but small annual decline in the level of groundwater has also been documented in the interior portions of the valley.

Due to the above factors, local government agencies from both Santa Cruz and Monterey Counties and representatives of the Pajaro Valley residents have agreed on the need for evaluating groundwater management requirements in the valley. This study was the outgrowth of that agreement.

Project Objectives

The objectives of this study can be summarized as follows:

1. Review and summarize available information on geology, hydrology, and groundwater quantity and quality conditions in the Pajaro Valley.

2. Evaluate the need for additional water supplies in the Valley and identify potential sources of local and imported supplies as well as the procedures for distributing such supplies in the Valley.

3. Evaluate natural recharge conditions in the Valley and recommend procedures for protection and enhancement of natural recharge sources.

4. Evaluate institutional, financial, and economic aspects of water augmentation and natural recharge protection projects and programs in the valley.

5. Develop an overall plan for groundwater management in the Pajaro Valley discussing physical facility requirements, policy implications, institutional and financial arrangements, and legal issues involved in implementing the proposed plan.

Study Procedure

This study was undertaken by HEA staff over a 30-month period and included two major field investigation elements. The field investigation activities encompassed surface water hydrology work for evaluating the impact of development in sandy watersheds on peak storm runoff values in these basins. The second element of the field work involved hydrogeologic investigation of potential recharge spreading sites in San Andres dunes and in the lower Springfield area in Pajaro Valley. This element of the field work was carried out by Woodward-Clyde Consultants as a sub-contractor to HEA. Brown and Caldwell also participated in this study as the second sub-contractor to HEA and was responsible for developing cost estimates for alternative water supply and distribution systems discussed in this report.

Report Organization

This report is organized in eight chapters. Chapter 2 contains an overview of groundwater conditions and existing programs for groundwater monitoring, water quality protection, and other management related activities. Existing and projected water demands for municipal, industrial, and agricultural uses are reviewed and updated in Chapter 3. Alternative sources of water for augmentation of supplies in the valley from local and imported sources are discussed in Chapter 4. Chapter 5 covers the conceptual design of alternative water supply augmentation projects. Preliminary screening of the alternative projects is carried out in Chapter 6 and detailed capital, operation, and maintenance costs are developed for the viable alternatives. A brief discussion of institutional and financial aspects and environmental impacts of these alternatives are also presented in this chapter. Chapter 7 is devoted to a discussion of recharge conditions and groundwater recharge management options in the valley. Chapter 8 contains a detailed discussion of groundwater management options in the Pajaro Valley.

Acknowledgments

We would like to acknowledge the helpful advice and technical assistance received by HEA staff from a number of individuals and agencies in Santa Cruz and Monterey Counties and from state and federal agencies. The Technical Advisory Committee members have devoted a great number of hours in reviewing all of the reports prepared under this contract and have provided HEA staff with valuable advice in improving the clarity of our report.

We wish to acknowledge the specific assistance and advice received from the following individuals during the course of this project:

1. Mr. Charles Allen, board member, Central Coast Regional Water Quality Control Board (RWQCB)
2. Mr. Wendell Ayres, USGS
3. Mr. Charles Barr, Jr., TAC member
4. Ms. Julie Brandlin, Water Quality Program Manager, Association of Monterey Bay Area Governments (AMBAG)
5. Mr. Tom Burns, Santa Cruz County Planning Department
6. Mr. Terry Butler, Santa Cruz County Planning Department
7. Ms. Angela Charpentier, RWQCB
8. Mr. John Cooper, City of Watsonville Public Works Department
9. Mr. John Givlin, Santa Cruz County Public Works Department
10. Mr. George Goldman, University of California Cooperative Extension Service
11. Mr. Manuel Gularte, Monterey County Farm Bureau
12. Mr. Richard Hendry, Santa Cruz County Water Advisory Commission
13. Mr. Mike Johnson, U.S. Geological Survey
14. Mr. John Kirkish, Santa Cruz County Farm Bureau
15. Mr. David Koch, City of Watsonville Public Works Department
16. Mr. Vincent Piro, USGS
17. Mr. Steven Singer, Soil Conservation Service
18. Ms. Deena Stanley, AMBAG
19. Mr. Gene Taylor and Mr. Bruce Laclague, Monterey County Flood Control and Water Conservation District
20. Ms. Susan Perkins, Soil Conservation Service
21. Mr. Al Stroppini, U.S. Bureau of Reclamation
22. Mr. Bert Van Voris, RWQCB
23. Mr. Norman Welch and Mr. Charles McNeish, Cooperative Extension Service

We would like to make special acknowledgment of the detailed comments made on our various task and draft reports by Messrs. Gene Taylor, Tom Burns, Terry Butler and David Koch and Ms. Angela Charpentier. The supportive and friendly assistance of Ms. Julie Brandlin throughout the course of this study is also greatly appreciated.

Project Staff

This study was carried out under the general supervision of Dr. Houshang Esmaili. Mr. Barry Hecht of HEA staff played a major role in many phases of this project and was responsible for the performance of recharge analysis and deep aquifer evaluation work and assisted in the evaluation of local sources of water supply and in the development of the hydrologic budget for the basin. Mr. Nicholas Johnson participated in the analysis of local surface water sources. Former HEA staff members who participated in this project include Mr. Mark Woyshner who performed many of the field data gathering tasks and Mr. Mark Reid who took part in the analysis of alternative recharge sites. Ms. Deena Stanley of AMBAG staff, in conjunction with Santa Cruz County Cooperative Extension Service staff, evaluated the potential for water conservation in irrigated agriculture in the valley. She also provided input on the analysis of municipal and industrial water conservation. Ms. Stanley in conjunction with Mr. George Goldman of U.C. Cooperative Extension Service assisted HEA staff in evaluating the economic impact of the no-action (continuation of existing programs) groundwater management alternative.

Woodward-Clyde Consultant's performed the geotechnical analysis of the selected potential recharge sites under the supervision of Mr. David Kirshner. Brown and Caldwell assisted HEA in the analysis of the cost of alternative water supply and distribution projects under the supervision of Mr. Merle Hunter.

CHAPTER 2

AN OVERVIEW OF GROUNDWATER CONDITIONS AND EXISTING GROUNDWATER RELATED PROGRAMS

Introduction

The purpose of this chapter is to establish the context for the current groundwater management study. To this end, a brief review of available information on groundwater overdraft and quality changes is undertaken and areas of emphasis for this study are identified and elaborated. Throughout this chapter, extensive reference is made to previous reports published on the Pajaro Valley groundwater basin to avoid unnecessary repetition. Where possible, additional new information is presented to substantiate or modify the findings of previous studies.

Sources Of Groundwater Supply

Groundwater supplies well over 90 percent of the total water demand in the Pajaro Valley. The only major user of surface water is the City of Watsonville, which meets about 15 percent of its needs by diversions from Corralitos Creek. An increasing proportion of the agricultural, municipal, and industrial demands has been met by development of the groundwater resource. The usable groundwater reserves in the Pajaro Valley have gradually been expanded as production wells have been drilled deeper and further out in the peripheral areas of the valley. Production has also been increased by more intensive development of known aquifers.

Previous Studies

A number of groundwater investigations have been carried out in the Pajaro Valley in the past 30 years. A brief summary of these studies is presented below.

1. State Water Resources Control Board Bulletin No. 5 Santa Cruz - Monterey Counties Investigation, August, 1953. This study was the first comprehensive investigation of groundwater hydrology and water quality in the Pajaro Valley. Among the noteworthy findings of this project is the reference to the occurrence of seawater intrusion dating back to 1943.

Estimated safe yield and groundwater pumpage data are presented in this report. The safe groundwater yield of the basin was estimated at 21,000 ac-ft. An overdraft of about 3,600 to 3,700 ac-ft. was also estimated based on pumpage withdrawal levels for the 1946-49 period. The limit of safe groundwater yield is defined in this report as "that maximum rate of pumping extraction from the valley floor and upper pressure zones beyond which the hydraulic gradient in the confined aquifers would be depressed below mean sea level."

Groundwater pumping troughs with maximum depressions of 15 feet below mean sea level were reported in the coastal areas due to irrigation pumping withdrawals. These troughs completely disappeared with the end of pumping in the fall.

This report documents the occurrence of sea water intrusion in the confined aquifers near the coast as far as one mile inland from the shoreline of Monterey Bay. Chloride concentrations in the affected wells showed a significant increase during the irrigation season but went down each year following the cessation of pumping activities. It was estimated that 1,000 acres of agricultural land adjacent to Monterey Bay were affected by high concentration of chlorides in the underlying confined groundwater in the early 1950's.

Bulletin 5 also discusses a number of potential surface water supply projects within the Pajaro Valley and provides estimates of yield and costs for these projects. Reference will be made to appropriate sections of this report in the succeeding chapters of our report.

2. Department of Water Resources, Special Investigation, Pajaro River Basin, Memorandum Report, June 1968. This report contains a study of water quality, hydrologic, economic and geologic conditions in the Pajaro River Basin, including areas upstream of Chittenden.

A detailed discussion of groundwater occurrence and movement in the Pajaro Valley is included in the report and a recognition is made that the intermediate aquifer on the valley floor (150 to 300 feet depth) is probably recharged from the shallow zone through breaks in the confining clay layers and as a result of defective well casings.

This report recites the safe yield estimate developed in Bulletin No. 5 but indicates an increase in the level of pumpage to 44,000 ac-ft. in 1960 with a projected pumping demand of 47,000 ac-ft. for year 2020.

The areal extent of seawater intrusion is discussed in detail in this report. Occurrence of intrusion is documented in the valley floor region (1.5 miles inland), the San Andres Road area (one mile inland), and Springfield area (three miles inland). Nitrate contamination of groundwater in the Springfield area and in areas of semi-perched water in the shallow groundwater zone, between Watsonville and Monterey Bay, are also documented in this report.

3. Santa Cruz County Flood Control and Water Conservation District, 1968-2020 Master Plan Water Development, by Creegan & A'Angelo - McCandless Engineers, June 1968. This engineering report contains data on estimated water use for municipal, industrial, and agricultural requirements in the Pajaro Valley. Based on estimates of crop acreage and applied water demand data, as well as municipal and industrial water requirements, a total pumpage withdrawal of 77,000 ac-ft. was computed for 1966 conditions. This withdrawal rate was projected to increase to 81,500 ac-ft. by 2020.

4. U.S. Geological Survey. Several reports have been published by USGS on Pajaro Valley groundwater basin as follows:

a. Muir, K.S., 1972, Geology and Ground-Water of the Pajaro Valley Area, Santa Cruz and Monterey Counties, California Open-file report, 33p.

b. Muir, K.S., 1974, Seawater Intrusion, Ground-Water Pumpage, Ground-Water Yield, and Artificial Recharge of the Pajaro Valley Area, Santa Cruz and Monterey Counties, California, Water-Resources Investigation 9-74.

c. Muir, K.S., 1977, Initial Assessment of the Ground-Water Resources in the Monterey Bay Region, California, Water Resources Investigations 77-46.

d. Johnson, M.J., 1980, Groundwater in North Monterey County, California, Water Resource Investigations, Report 83-4023.

Of these four reports, the first one deals with geology and groundwater hydrology of the Valley. The second report provides quantitative estimates of groundwater pumpage and groundwater overdraft, seawater intrusion conditions and potential recharge augmentation sites. The third report deals with planning and management requirements for various groundwater basins in the Monterey Bay Region. The fourth report provides a detailed discussion of geology, hydrology, groundwater occurrence and movement, groundwater demand and yields in the North Monterey County area.

The estimates of total pumpage are shown by USGS to have ranged from 40,900 ac-ft in 1963, to 61,700 ac-ft in 1971. The safe yield of the Pajaro groundwater basin is estimated at 44,000 ac-ft/yr. The pumpage estimates were derived on the basis of average pumping lifts, annual records of electrical energy use and estimated unit energy use in various lift zones. Actual records of municipal and industrial pumpage were also used where available.

The report by Johnson states that present groundwater demands exceed long-term recharge throughout much of North Monterey County in shallow Quaternary deposits -- principally the upper part of the Aromas sand and the overlying alluvium. This report divides the North County area into sixteen subareas plus one additional subarea in San Benito County. A hydrologic budget is developed for each subarea by estimating pumpage, consumptive use, and recharge values. These data indicate an annual groundwater overdraft of 1,500 to 8,000 ac-ft. exists in the North Monterey County area. Data on the extent of seawater intrusion in this area is also presented in this report.

5. Saline Water Intrusion - Pajaro Valley, by Harvey Banks, Inc., May 1975. This report essentially summarizes the findings of the USGS reports prepared in 1972 and 1974 and does not provide any new information on saltwater intrusion conditions in the Pajaro Valley.

6. Pajaro Valley Groundwater Levels and Quality, Santa Cruz County Flood Control and Water Conservation District, by Steven H. Stiles, May 1977. This report provides an excellent summary of available groundwater monitoring data for the period through November 1976. These data are analyzed for groundwater level change in various aquifers. Recommendations are also made on possible solutions for the overdraft problem.

7. Groundwater Conditions in the Pajaro Valley, Brown and Caldwell, 1976. This report was prepared as an element of the City of Santa Cruz Wastewater Facilities Planning Study. Pumpage withdrawals were estimated on the basis of crop acreage and applied water demand data provided by the County Farm Advisor's Office. A total maximum pumpage of 68,000 ac-ft was estimated by this method for 1972-73 water year. The safe yield of the basin was estimated by plotting annual pumpage versus annual percipitation data with estimated overall annual change in groundwater level as a third parameter. An approximate line of zero water level fluctuation was fit to these data. Based on an analysis of these data, it was estimated that the safe yield of the basin may be in the range of 45,000 to 55,000 ac-ft per year.

8. Non-point Sources of Groundwater Pollution in Santa Cruz and Monterey Counties, H. Esmaili & Associates, Inc., 1978. This is a comprehensive report on groundwater quality and hydrology of the Pajaro Valley, and also discusses other groundwater basins in the two county areas. The report addresses pumping withdrawals, overdraft conditions, and water quality degradation caused by non-point source waste loadings from agricultural, industrial and municipal land use activities. Agricultural pumping withdrawals are calculated on the basis of crop acreage and estimated applied water demand values. This pumpage is estimated at 88,000 ac-ft per year which is significantly higher than the values presented in previous reports. The difference arises mainly from the much higher applied water demand values used in this report. However, regardless of the actual applied water demand, only the fraction consumed as ET, the portion running off to the ocean and some of the water recharging perched water bodies are an actual loss because the remainder percolated downward to the groundwater body. This factor as well as rainfall recharge through agricultural and native vegetation area, underlain by permeable formations, channel recharge from various streams and interbasin inflow is taken into account in developing a hydrologic balance for the basin. The result of these calculations show a net overdraft of about 19,500 ac-ft per year under 1976 land use conditions, based on applied water-demand estimates for crop irrigation practices which prevailed during the mid-1970's. This amount of overdraft is in general agreement with the values presented in Brown and Caldwell report and with the calculated year by year overdraft data using USGS safe yield of 44,000 ac-ft per year.

No attempt was made to develop a safe yield value for the basin in the HEA report.

9. Well Evaluation Report, Santa Cruz County - Pajaro Groundwater Protection Zone, Luhdorff & Scalmanini, Consulting Engineers, June 1983. This report was prepared under contract with Santa Cruz County

Environmental Health to evaluate 22 currently active-production wells in the Pajaro Groundwater Protection Zone. Among other objectives, the study was to recommend corrective actions for wells which may be serving as a conduit for movement of poor quality water from the alluvial aquifer to the Aromas aquifer or vice versa. The groundwater protection zone has been designated by Santa Cruz County as the area in which chloride concentration in well water is equal to or exceeds 100 mg/l. The present limits of the area in Santa Cruz County are the coast line, the Pajaro River, the northern boundary of Sections 23 and 24 (T12S, R1E) and a line connecting the midpoint of the northern and eastern boundaries of Section 24.

This report appears to question the conclusions reached in all previous investigations regarding the occurrence of seawater intrusion in the coastal portions of the Pajaro Valley aquifers. Due to this factor, the Technical Advisory Committee requested a more detailed review of this report. The results of this review are presented in Appendix A of this report.

10. Water resources data reports published periodically by both county flood control and water conservation districts. These reports provide information on historic and current groundwater level and quality for a network of wells which are monitored regularly by each district.

Generalized Description of the Groundwater System

The Pajaro Valley groundwater basin may be envisioned as a roughly rectangular unit lying between the Santa Cruz Mountains and Monterey Bay. The basin is sharply bounded on the northeast by San Andreas fault, and on the southwest by marine waters. Diffuse groundwater divides separate the Pajaro Valley from the Soquel-Aptos basin to the northwest, and the Prunedale and Moro Cojo sub-areas of the Salinas Valley basin to the southeast (Figures 1 and 2). Formation permeabilities and well yields generally decrease with depth; non-water bearing geologic units occur several thousand feet below the ground surface throughout most of the basin. Few water wells in the Pajaro Valley are deeper than 600 to 700 feet.

Groundwater Occurrence. Developable groundwater occurs within sands and gravels in the partially- to non-consolidated sediments throughout the valley. Five major water-bearing units are recognized (Table 1). Each aquifer contains coarser (usually alluvial, deltaic beach and dune deposits, and marine sands) and finer (generally marine, estuarine, lagoonal, and marsh deposits) facies. Yields and aquifer properties vary widely with the nature of material penetrated by any given well.

An interconnected main groundwater body is recognized in the Pajaro Valley, consisting of waters contained in the alluvium, terrace, and dunes deposits and the upper portion of the Aromas sands. Substantially lower water levels are reported for some wells perforated deeply in the Aromas aquifer and in the upper Purisima Formation, which are presently referred to as the "deep aquifer." A third zone of shallow, perched waters occurs in valley floor areas above the

U.S. GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
SANTA CRUZ COUNTY FLOOD CONTROL AND WATER CONSERVATION DISTRICT

Base from U.S. Geological Survey
7½ minute topographic series:
Prunedale, Moss Landing, Watsonville
West, 1954; Watsonville East, Loma
Prieta, Mt. Madonna, 1955

0 1 2 3 MILES

CONTOUR INTERVAL 20 AND 40 FEET

Geology by Clark (
modifications by

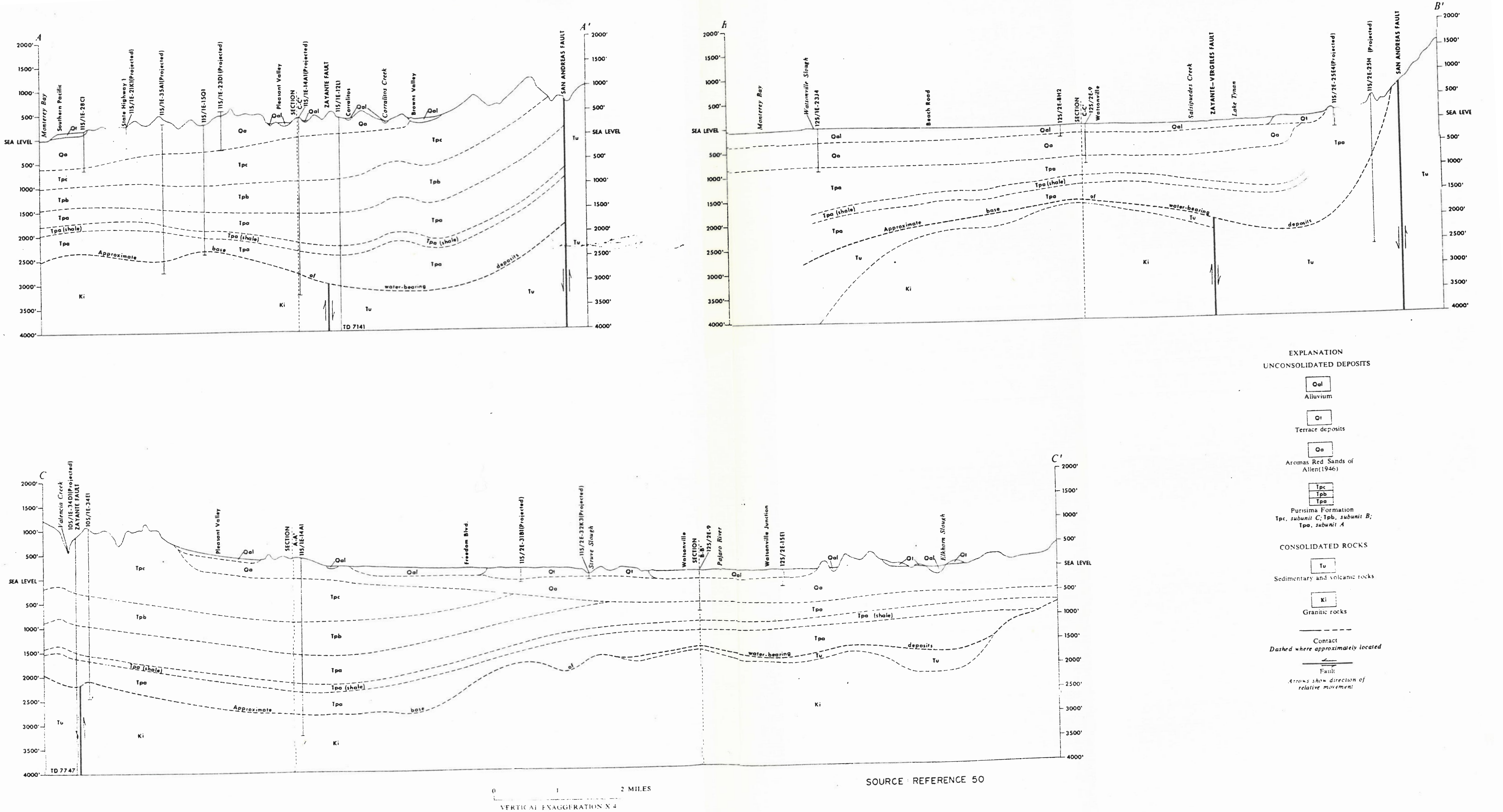

FIG. 2 GEOLOGIC SECTIONS OF THE PAJARO VALLEY AREA, SANTA CRUZ AND MONTEREY COUNTIES, CALIFORNIA

Table 1. Properties of Significant Water-Bearing Geologic Units of the Pajaro Valley

Formation Name	Geologic Age (epoch)	Representative Thickness (ft)	Location of Outcrop or Use	Description	Depositional Environments	Water-Bearing Properties	Water Quality Characteristics
Recent Dune Sands	Holocene	50-150	Between San Andreas Road and Monterey Bay; locally near Zmudowski Beach.	Well-sorted, fine-to-medium grain quartzose sands. Clays and silts virtually absent.	Beach and dune	Premier recharge area of ground-water basin; largely above water table, thus unsaturated.	Where developed, water of excellent quality, locally degraded with nitrates or intruding salt water.
Alluvium	Holocene	100-200	Pajaro River bottom-lands and floors of tributary valleys.	Gravels, sands, silts, and clays. Basal gravels grade upward into dense blue clays. Upper 20 to 40 ft. are Pajaro River flood plain deposits	Channel sediments; deltaic and estuarine and fresh water marsh deposits.	Basal gravels are most permeable unit in Pajaro Valley, with moderate to large yields; blue clays confine the gravels and are essentially non-water-bearing. Perched waters above clays.	East of Watsonville, TDS 550-1350 mg/l; elsewhere 150-750 mg/l, except where intruded by marine waters. Limited concentrations of nitrate, sulfate boron in some wells east of Watsonville.
Terrace Deposits	Pleistocene	100-200	Comprise most of the low hills and beach-lands of the Pajaro Valley.	Gravels, sands, silts and clays generally fining upward. Extensively cross-bedded and laterally variable.	Channel, lagoonal, beach and shallow marine sediments; also others.	Moderate yields obtainable, especially from lower half of formation. Usually connected with alluvial and Aromas aquifers.	Generally similar to adjacent alluvium; locally intruded near coast. Excessive manganese common.
Aromas Red Sands	Pleistocene	400-800	Outcrops over entire inner periphery of the valley; developed as an aquifer in outcrop areas and beneath alluvial and terrace deposits.	Red or brown quartzose sands and silts with clays and minor gravels. Local stringers of black sands.	Shallow marine, lagoonal, beach and dune channel, and deltaic deposits.	Moderate yields generally obtainable. Yields exceeding 1000 gpm reported from areas of predominantly dunal sands; yields below 10 gpm reported from fine-grained areas, such as Larkin Valley.	Usually excellent quality water, with TDS 150-450 mg/l, generally increasing with depth. Very low in sulfate and boron; iron and manganese usually low. Locally contaminated. Naturally occurring trace elements in sub- to marginally-toxic concentrations reported in isolated wells.
Purisima	Pliocene	1000-2000	Outcrops at outer periphery of the valley and occurs beneath younger deposits throughout the valley, minimally developed.	Partially-consolidated sands, silts and clays or shales of primary non-granitic origin.	Primarily marine environments.	Moderate to low permeabilities. Presently tapped by very few wells. Upper and middle members thought to be promising for moderate yields.	Usually good quality water, with TDS of 150-800 mg/l. Greater relative concentrations of sulfate than in Aromas waters. Low boron.

blue clays of the alluvial unit. The shallow zone is significant mainly as a potential source of saline and degraded flow into the heavily-used basal alluvial aquifer below. These relationships are shown schematically in Figure 3.

Groundwater Movement. In contrast to most coastal valleys in California, direct percolation of rainfall rather than infiltration through beds and banks of channels is the principal source of recharge to the main groundwater body. Many of the estimated 61 square miles of primary recharge area lie between Corralitos Creek and the coast (Figure 4). Recharge in this area is sufficient to maintain a low ridge in the water table approximately a mile inland from the beach, preventing salt water intrusion in most of the area north of Beach Road. Southeasterly flow toward Watsonville and the community of Pajaro provides the main source of agricultural waters in the lower Pajaro Valley, and is responsible for the generally good quality of water found between the city and coast. A smaller inflow of good-quality groundwater emanates from beneath the sand hills south of the Pajaro River bottomlands. Recharge from the river is the principal source of the poorer quality water in the alluvial aquifer east of Watsonville and Pajaro; under present conditions, recharge from the river does not appear to be a major source of groundwater in the immediate vicinity of Watsonville. Both rainfall and channel infiltration are important sources of recharge in the area north of Watsonville. Most of the area north of the city has experienced little or no decline in water levels or deterioration of water quality during the past 25 years.

Before overdraft conditions were established, groundwater throughout the basin flowed toward the Pajaro River bottomlands or Elkhorn Slough. The last reports of artesian conditions in the confined alluvial aquifer south and west of Watsonville were during the second decade of the century. Sea water intrusion was well-established in the upper aquifers by the early 1950's. The spatial extent of the area affected by intrusion has slowly and intermittently increased over the past three decades. The intensity of intrusion, interpreted from chloride concentrations, has progressively increased in some areas and aquifers, but not in others.

Figure 5 presents the standing water levels and chloride concentrations in the heavily-developed upper and intermediate water-bearing zones. Data are for late-fall of 1979, a year of about average rainfall, separated from the immediate effects of a severe drought by a year of high recharge (1978). We estimate that these conditions reflect the long-term average groundwater status during fall months in the coastal portion of the Pajaro Valley. The static water-level contours in Figure 5 highlight three areas of groundwater movement. Flow is radially inward toward a pumping depression near the center of the Springfield. High rates of recharge through the dunal sands in the San Andres area sustain a groundwater ridge, from which movement is to the east, south, and west. The ridge is a major source of water to the upper zones in the complex multi-aquifer system at the mouth of the Pajaro River, and also to the pumping depressions in the Watsonville area. In the Springfield area, radial flow toward a central pumping depression is supplied mainly from the southwest (rainfall

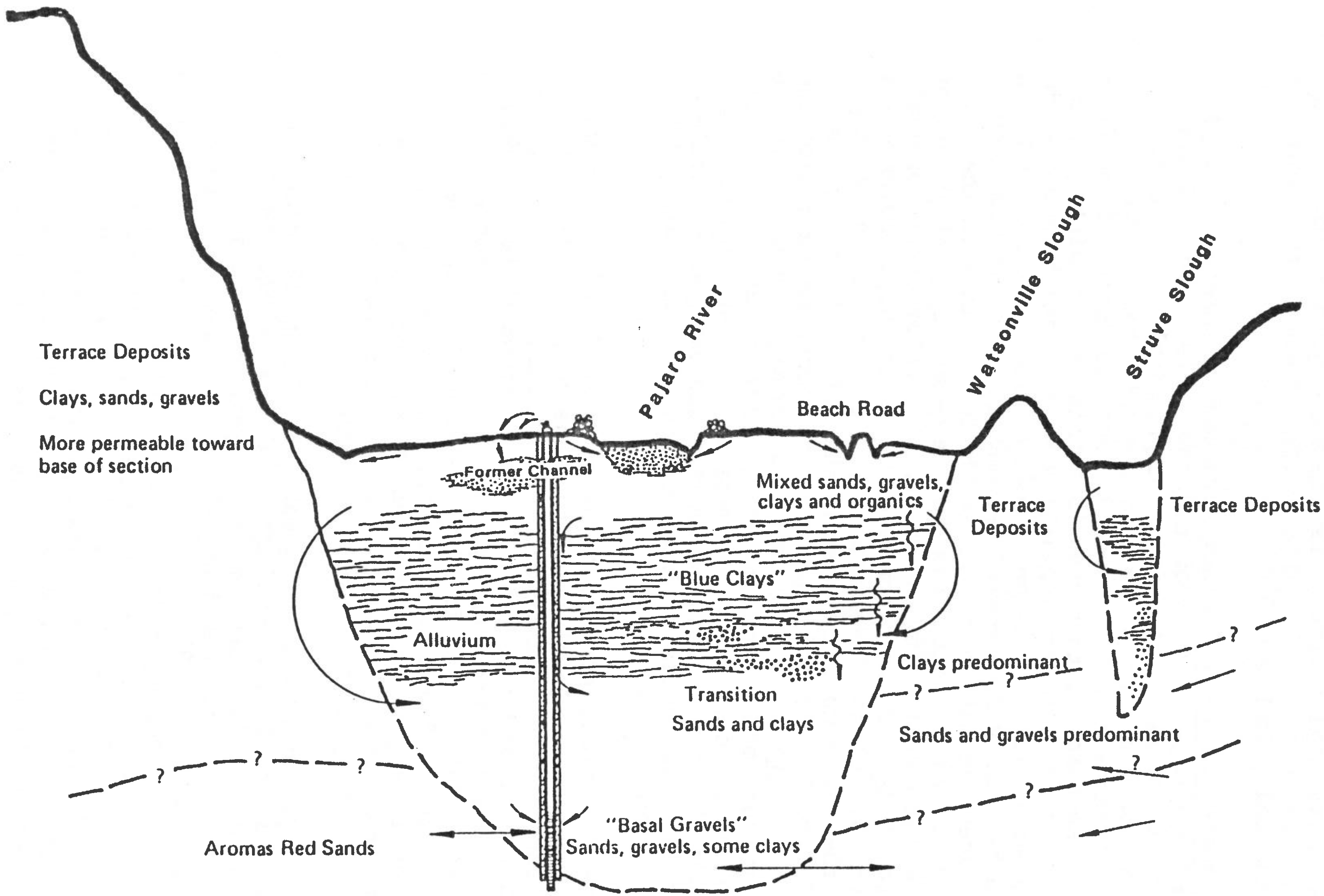

Figure 3. Section across the Pajaro Valley showing the relation of the semi-perched waters to the alluvial, Aromas, and terrace aquifers.

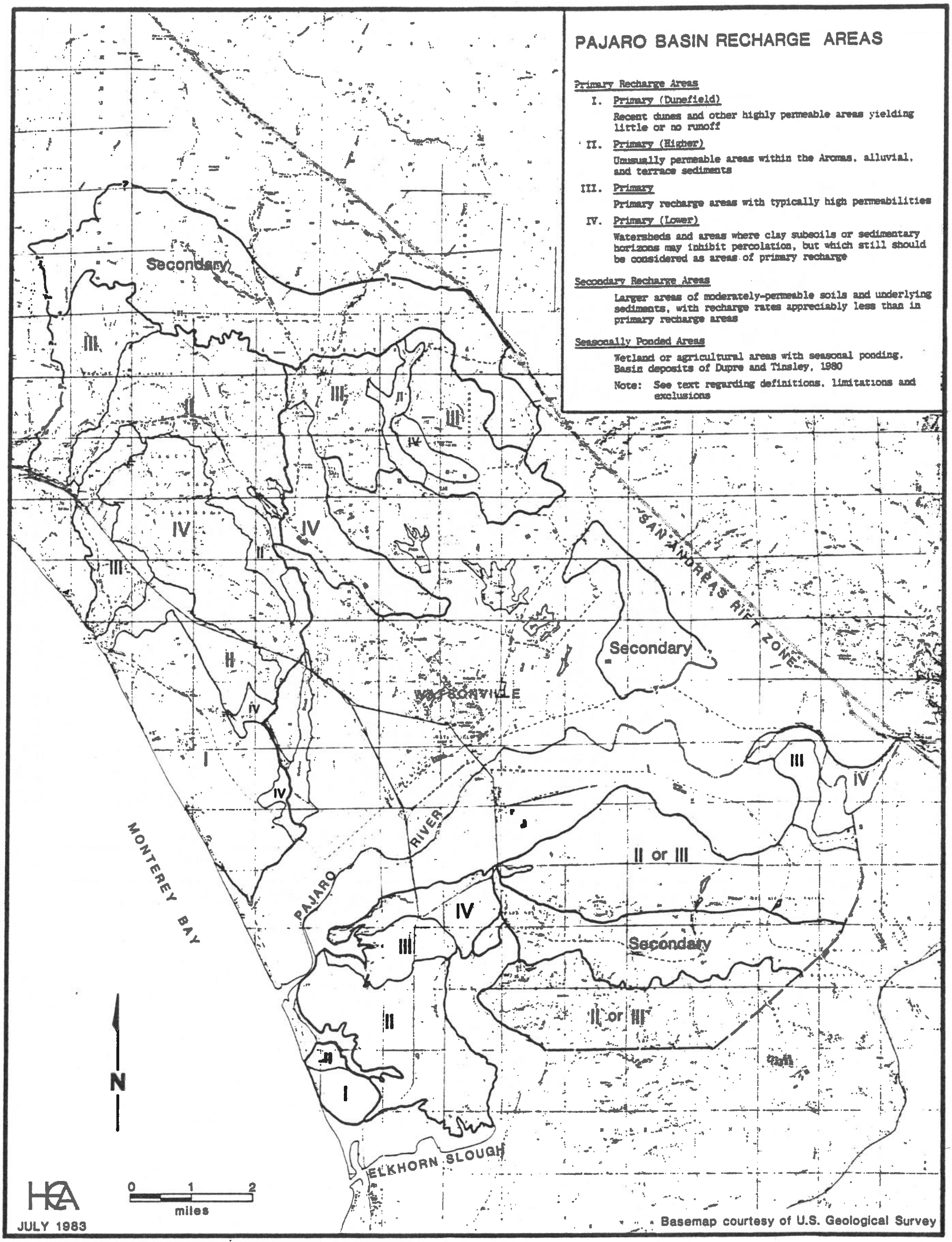

Figure 4. Pajaro Basin recharge map

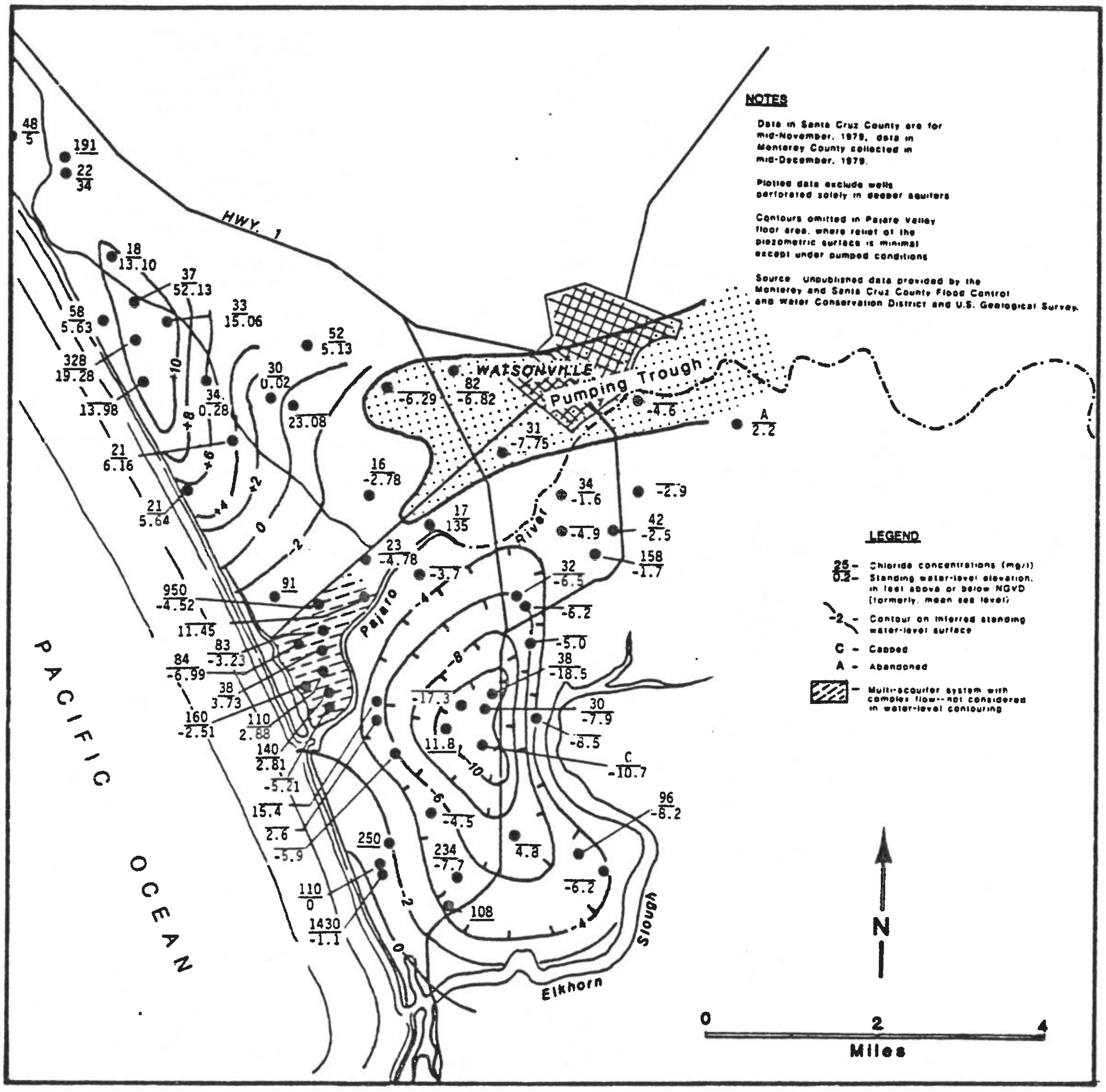

Figure 5. Standing water-level elevations and chloride concentrations, Western Pajaro Valley area, Nov. - Dec., 1979.

recharge through the sandy soils near the coast, plus a smaller increment of sea water), and from the alluvial and Aromas aquifers of the middle Pajaro Valley to the northeast. Net changes in static water levels between late-fall of 1976 (HEA, 1978) and late-fall of 1979 are not readily discernible. Long-term trends indicate little or no systmatic change in water levels within the San Andres area. The groundwater depression in the Springfield area appears to be very gradually intensifying in its northern and eastern portions.

Although data are more sparse elsewhere in the Pajaro groundwater basin, it is clear that static water levels during the late-autumn months are falling in two other areas. Apparent rates of decline in wells developed in the alluvial aquifer along Riverside and San Juan Roads (the "East" area) approach 1 foot per year over the past three decades. Apparent declines of perhaps 0.2 to 0.5 feet per year have been continued through this period in the terrace and Aromas sediments in the vicinity of the lakes northeast of Watsonville. This depression will be referred to as the "Salsipuedes pumping trough" in this report. In both the East and Salsipuedes areas, apparent rates of decline are somewhat greater than those for true static levels, as pumpage now continues into November and December in many wells. It is clear, however, that groundwater withdrawals exceed mean recharge in both areas, and that falling water levels contribute to increased operating costs.

Minimal information is available on movement between the groundwater bodies. Water levels in the shallow, perched body are about 10 feet higher than those in the main groundwater unit during the non-pumping periods of the year and about 20 to 25 feet higher during the irrigation season. Leakage through or around the confining blue clays probably occurs through sand lenses and well bores. Evidence that such flows do take place has been presented for the area near the coast (Muir, 1974) and for the Watsonville area (HEA, 1978a). Similarly, a small amount of salt water inflow from Elkhorn Slough is possibly occurring (Figure 5). Few direct indications of the hydraulic connection, if any, between the water-bearing units of the main and deep aquifers beneath the valley floor are known.

Mid-August 1982 water levels for the southern half of the Pajaro Valley are shown in Figure 6. The contours indicate a similar pattern of piezometric ridges and troughs as were observed during the drought conditions of August 1977 (Figure 3-9; HEA, 1978), although water levels are locally one to two feet higher in a much wetter year. District pumping troughs are shown in the complex, multi-aquifer system at the river mouth, beneath Springfield School, and in the Watsonville area. Natural recharge persist along San Andres and Giberson Road, despite heavy summer pumping in these areas. The figure indicates that measured water levels are below sea level in most of the southern half of the basin, an area which can roughly be demarcated by a line running from Sunset Beach to Freedom to Murphys Crossing to the head of Elkhorn Slough.

Water levels in the Pajaro Valley vary seasonally, and also from year to year. Elevations measured during August 1982 are commonly 8 to 12 feet lower than those during the previous or following winters,

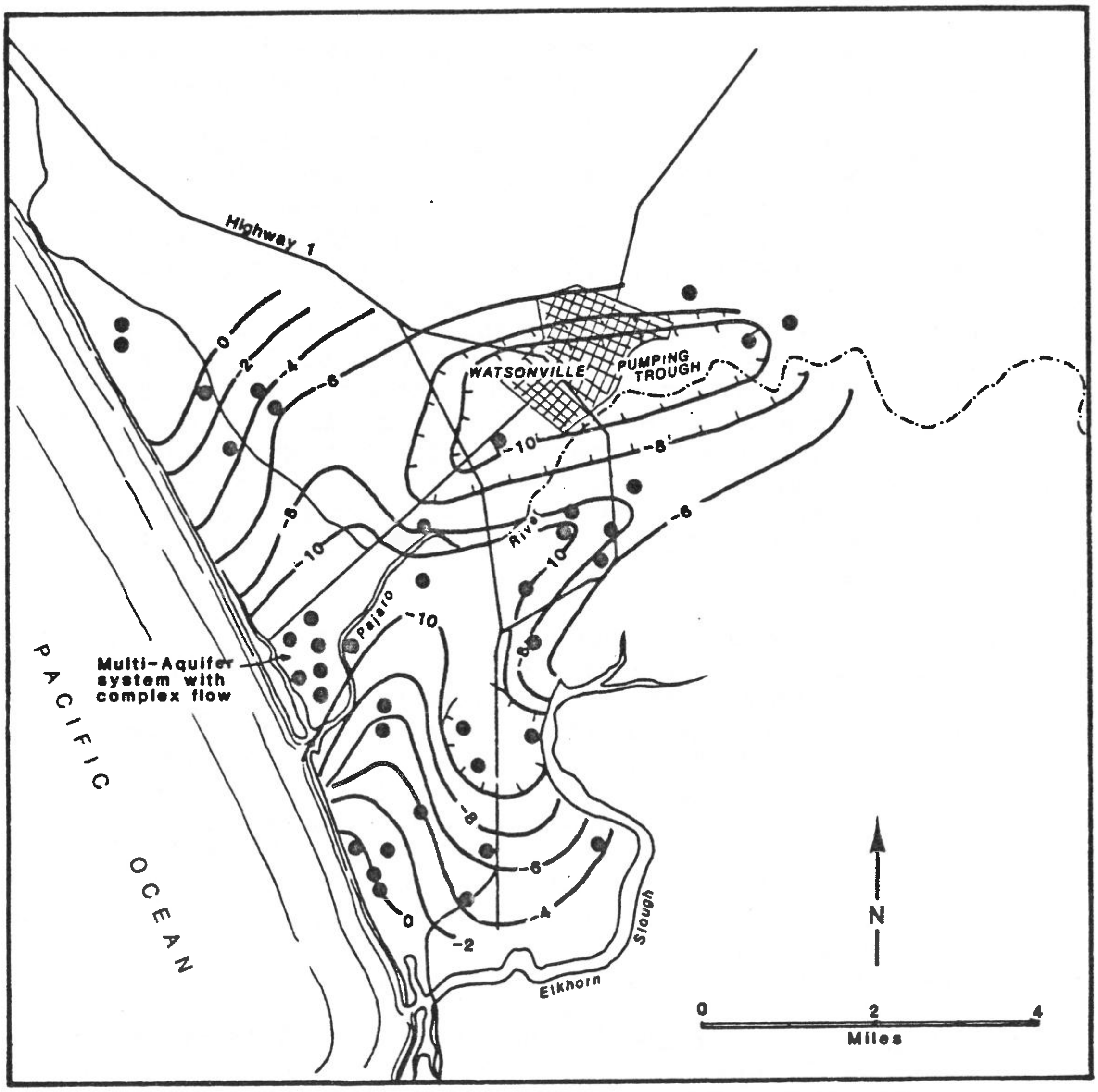

Figure 6. Static water levels in the Lower Pajaro and Springfield areas, August 1982. Contours are similar in form and average about one foot higher than the comparable map for August 1977, at the height of the drought. Data provided by Monterey and Santa Cruz Counties are identified as preliminary.

both of which had much-greater than average percipitation. Perhaps of greater management interest are water-level changes over a series of wet and dry years. Table 2 compares water levels in wells throughout the southern half of the basin over time. August 1974 followed the second wet winter in a row. The August 1977 measurements were made near the end of a severe two-year drought. August 1982 and August 1983 followed especially wet winters. The data suggest little long-term change in water levels in the Springfield area during this nine-year period, with a four-foot decline in the wells near Watsonville. In interpreting these values, it should be recognized that recharge during the winters of 1981-82 (with 39.4 inches of rainfall at Watsonville) and 1982-83 (about 46.1 inches of rainfall) was probably appreciably more than that during 1972-73 (30.2 inches of rainfall) and 1973-74 (32.9 inches of rainfall). Long term rainfall at Watsonville is about 21.7 inches per year.

Groundwater Quality

The quality of Pajaro Valley groundwater is influenced primarily by geologic conditions, and to a lesser extent by the basin-wide overdraft and limited contamination. The water of best chemical quality is generally found beneath and down-gradient of the major recharge areas (Figure 4). Poorer quality water is situated beneath areas recharged from the Pajaro River, and intruded by seawater. Excessive concentrations of dissolved solids or specific ionic constituents are reported beneath some areas of intensive agriculture, high septic tank density, and in the immediate vicinity of sanitary landfills. The water varies from moderately to extremely hard. Discolored or turbid water is often reported, especially in the northern part of the area, and usually appears to be associated with high concentrations of iron and manganese. Bacterial contamination is reported only very rarely in municipal wells in the Pajaro Valley. Groundwater quality in the Pajaro Valley is generally adequate for existing municipal and industrial uses.

Chloride concentrations exceeding the background levels are observed in wells near the coast. There are several conditions which impair water quality in the vicinity of Watsonville. These are discussed below. There are also some limited areas in which salt concentrations exceed recommended limits for municipal use.

Salinity. General water quality areas in the Pajaro Valley and typical salt content for each are shown in Figure 7. Groundwater salinity limiting municipal and industrial usage occurs in areas of seawater intrusion and also in the areas east of Watsonville. Marine waters affect City wells #13 and #16 in the Pajaro Dunes area. Intermittently, high salinities are reported seasonally along the coast as far north as Manresa Beach.

Chloride concentration in well water can be used as an indicator of seawater intrusion. Non-intruded groundwaters in the coastal areas of the Pajaro Valley have low chloride concentrations, generally below 40 ppm, and in all cases below 100 ppm (HEA, 1978). Near the coast, wells yielding water containing more than 100 ppm chloride should be

Table 2. Variations in August Water Levels Over a Wet-Dry-Wet Cycle[a]

	Static Water Level[b]			
Date of Measurement	Aug. 1974	Aug. 1977	Aug. 1982[c]	Aug. 1983[c]
Type of Year	2nd Wet Year	2nd Drought Year	1st Wet Year	2nd Wet Year
Mid-Valley Floor				
12S/2E-15E1	—	—	-6.9	-3.4
-16F1	-0.3	-10.1	-8.2	-3.8
-16J1	-0.5	-10.3	-8.6	-5.2
-16L1	—	-13.1	-12.0	-7.5
-16Q1	-0.7	-10.2	-7.8	-4.7
-19A2	—	-14.2	-14.1	-8.5
Net Change For Period		-9.7	+1.4	+4.1
Net Change, 1974-1982				-4.1
Upper Springfield				
12S/2E-20K1	-17.2[d]	-12.0	-9.9	-6.9
-29A1	—	-9.2	-7.5	-5.9
-29N1	—	-10.9	-11.0	-7.9
-29P1	—	-2.6	—	-2.6
-29R1	-6.9	-11.1	-10.6	-7.7
-30M2	-9.5	-8.5	-6.3	-5.8
-32C1	-8.0	-11.6	-10.3	-8.4
13S/2E-4F1	—	-12.3	-5.2	-5.3
Net Change For Period		-2.3	+2.1	4.8
Net Change, 1974-1983				+0.1
Lower Springfield				
12S/2E-31C2	+2.3	-11.0	-4.9	-3.1
-31K1	-2.2	-7.0	-4.1	-2.0
13S/1E-1A1	+0.8	0.0	-0.8	+2.1
13S/2E-5M1	-4.4		-6.2	-4.4
-6C1	-0.1		-0.1	+1.4
-6E1	+1.0	-3.0	-0.3	+1.2
-6E3	+1.2		-0.8	+0.9
Net Change For Period		-4.7	+2.7	+2.1
Net Change, 1974-1983				-0.5

[a]Source of data: Monterey County Flood Control and Water Conservation District

[b]Elevation (in feet) above (+) and below (-) sea level.

[c]MCFCWCD data labelled "Preliminary and Subject to Review"

[d]Validity of observation is questionable, and point is omitted from calculations.

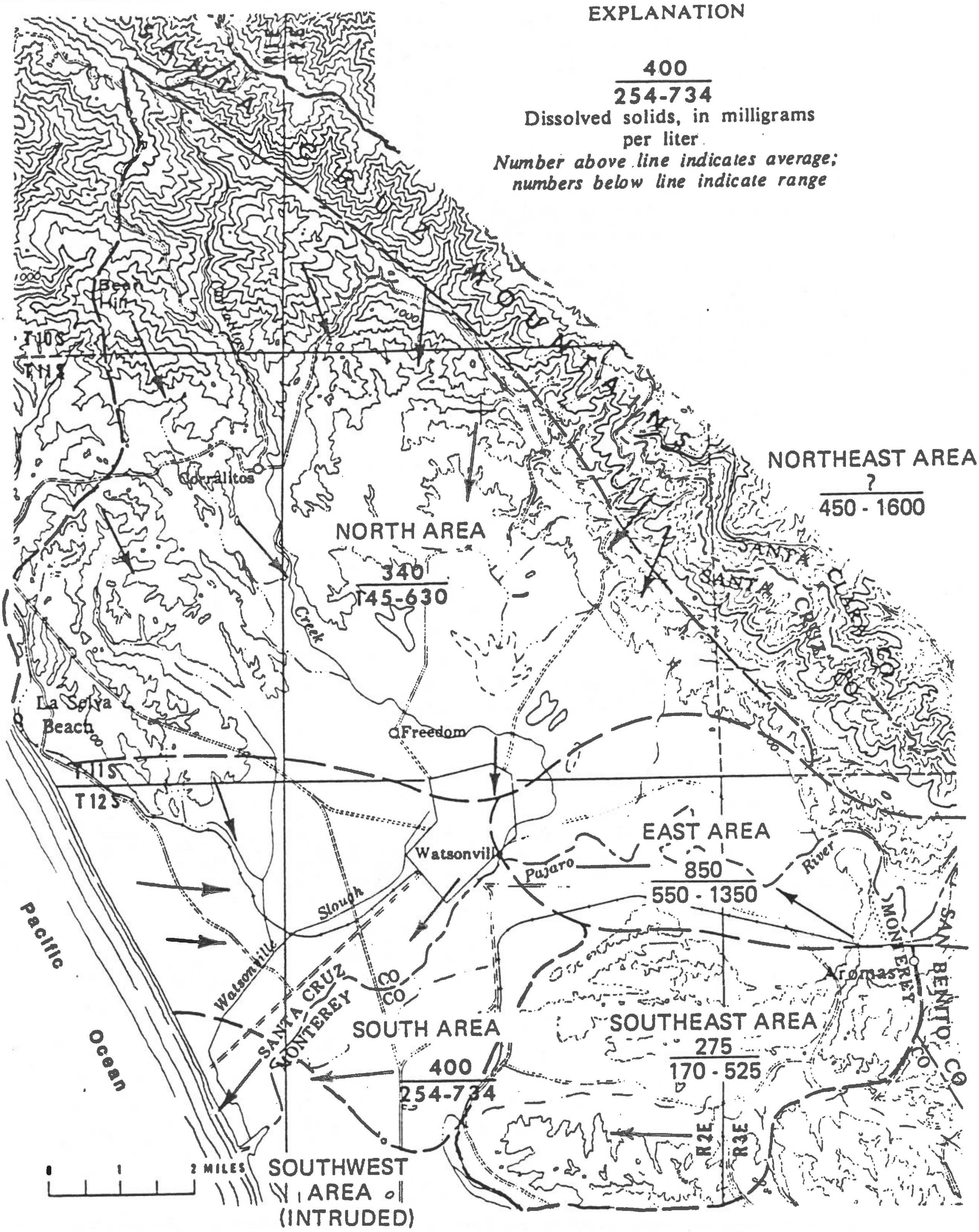

Figure 7. Groundwater quality areas in the Pajaro Valley.

Modified from Muir, 1974.

considered intruded. A map showing the approximate boundaries of the 100 mg/l isochlor in the coastal aquifers is shown in Figure 8. This boundary line encompasses an area of about five square miles in Santa Cruz and Monterey Counties.

The basal alluvial aquifer east of Watsonville yields water typically containing about 550 to 1350 mg/l of total dissolved solids. Chloride, sulfate, nitrate, calcium, and occasionally arsenic are also reported in concentrations exceeding recommended limits in some wells in the East Area. A transition zone of about a mile in width exists between the waters of satisfactory quality beneath Watsonville and the community of Pajaro and the clearly impaired waters of the East Area. Two pairs of analyses in Table 3 indicate the sharp gradient in water quality over a short distance. Wells 12S/2E-10D1 and 12S/2E-11E4 are one mile apart along San Juan Road; water quality in the first well is very similar to that of City wells #7, #10 and #15, while the latter analysis exhibits the characteristic composition of the East Area waters. At the northern edge of the East Area, the salinity of well 11S/2E-34K1 near the mouth of Drew Lake is almost half of that in well 12S/2E-3A2, located in the transition zone about half a mile away.

Semi-perched waters above the blue clays of the lower Pajaro Valley also have high salinities, perhaps in the range of 500-2500 mg/l or more. Relatively high sulfate, boron, nitrate, and chloride concentrations are typical of these waters. A very small volume of seepage into city wells #7, #10 and #15 is probably occurring at present. As water levels in the basal alluvial aquifer continue to fall, leakage of poorer quality semi-perched waters may be expected to increase slowly.

The greatest recent changes in salinity have been reported in the Elkhorn Road area, immediately south of Watsonville. Data for well 16Q1 (Figure 9) indicate an accelerating increase in chloride concentrations and specific conductance, at least through 1980 (the latest available data). Much more gradual increases in salinity have been observed in the East Area, near Murphys Crossing (Figure 9). Most of the small increases may be attributed to sulfate and nitrate, which are recharged into the local groundwater system by the Pajaro River. Future water-quality trends in this area will depend to a great extent upon the quality of water in the river.

Nitrates. Elevated concentrations of nitrates occur in Pajaro Valley groundwater recharged by agricultural leachate, septic tank effluent, percolation from the Pajaro River and other minor sources. Since virtually all nitrate in local groundwater derives from surface and is not a product of geologic weathering, the distribution of nitrates differs from those of other groundwater salts. Nitrate concentrations decrease with depth in the Pajaro Valley and adjacent groundwater basins (HEA, 1978a and b). High concentrations of nitrates generally do not occur beneath areas where thick clays prevent percolation from above. Clusters of wells with reported high nitrates occur in the sandier, peripheral areas of the groundwater basin, such as along Carlton Road, portions of the East Area not underlain by

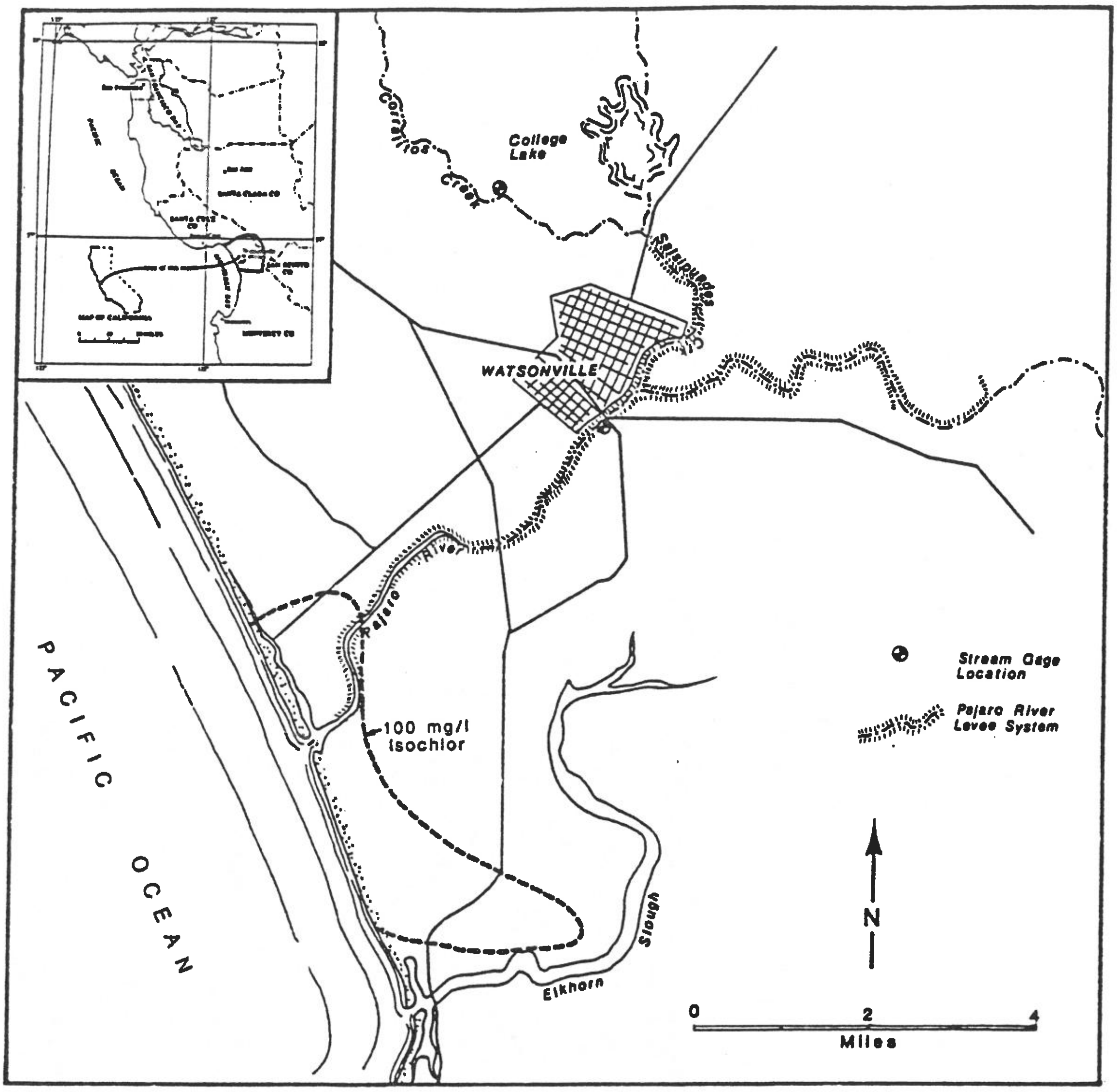

Figure 8. Approximate location of the 100 mg/l chloride front during Fall 1979. Multiple aquifers make location inexact near the mouth of the Pajaro River. Rainfall in 1978-79 was about average.

Table 3. Water Quality in Wells Near Watsonville

Well No.	Date	Aquifer	Ec µmhos/cm	pH Units	Ca	Mg	Na	K	CO_3+ HCO_3 [b]	SO_4	Cl	NO_3	Fe	Mn	TDS
City Well No. 7	1/3/78	Qal	550	7.8	55	23	37	2.4	256	33	44	2.3	<0.03	<0.01	385[e]
City Well No. 10	1/3/78	Qal	680	7.9	83	30	38	2.8	361	50	32	1.2	0.03	0.01	476[e]
City Well No. 15	1/3/78	Qal	700	8.0	86	32	37	2.9	378	56	36	0.64	0.02	0.04	490[e]
12S/2E-10D1	8/19/71	?	650	7.5	62	28	38	2.3	328	56	30	0.2	0.26	0.48	-
12S/2E-11E4	8/11/71	Qal	1340	7.8	110	79	76	2.1	546	190	79	0.0	0.14	0.27	-
12S/2E-3A2	10/13/76	Qal	855	7.5	95	45.8	52.3	2.23	356	120	48.6	7.38	0.15	0.42	593[r]
11S/2E-34K1	10/13/76	Qal,Qa	560	7.6	67.5	23.5	38.4	2.06	278	30	22.2	0.10	0.05	0.25	331[r]

[a] Constituents in milligrams per liter unless otherwise indicated.

[b] Often determined from alkalinity readings.

[e] Electrometric determination of total dissolved solids (TDS = 0.7xEC)

[r] Total dissolved determined by residue

Aquifer Notation

Qal Alluvial aquifer, including basal alluvium

Qa Aromas Red Sands

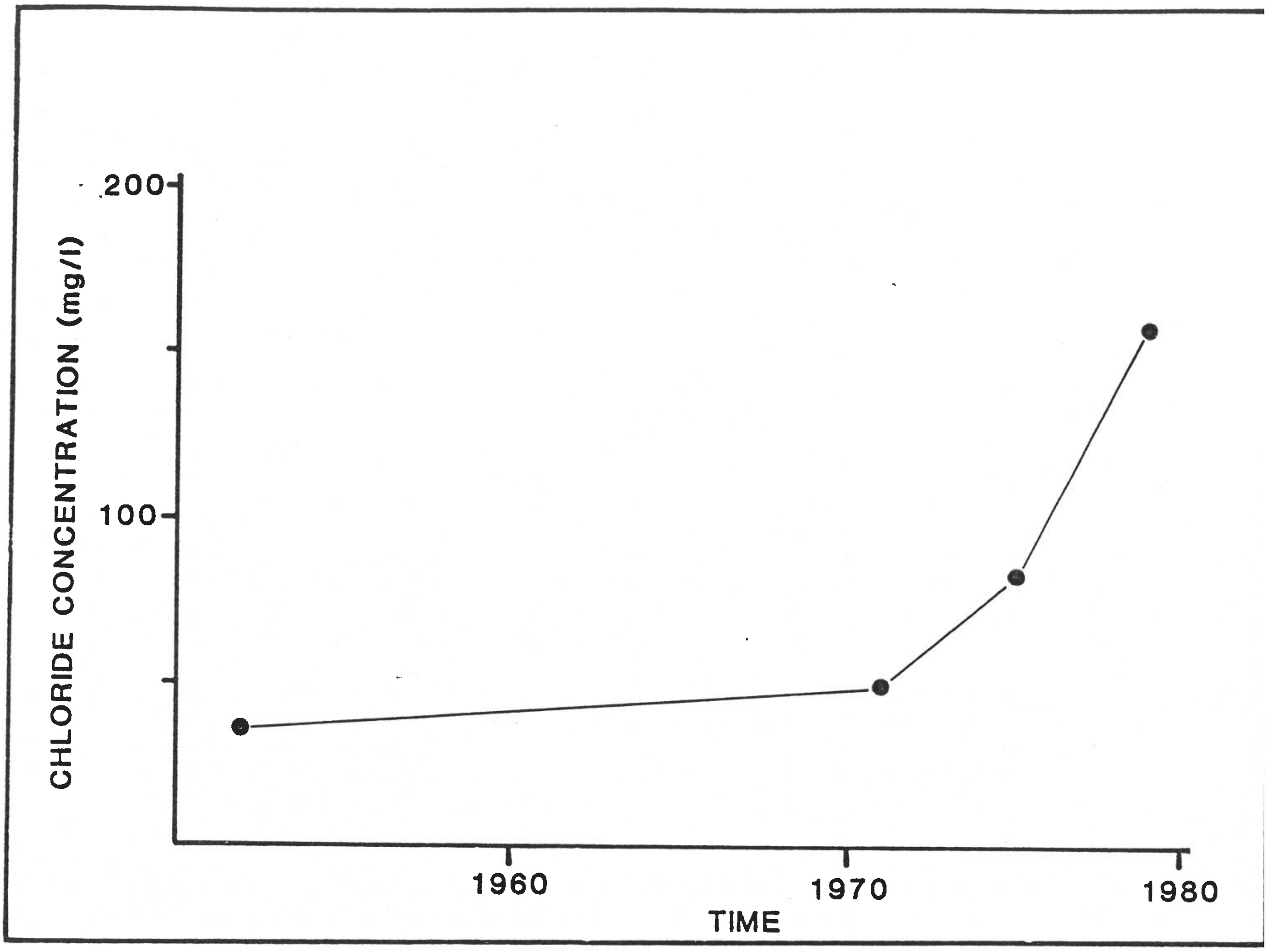

Figure 9. Changes in chloride concentration over time, well No. 12S/2E-16Q1 MDBM Elkhorn area, Pajaro Valley.

continuous clays, the Springfield district of northern Monterey County, and locally in the highly permeable coastal area along San Andres Road between La Selva Beach and Pajaro Dunes. Areas in which high nitrates are rarely reported in groundwater include the lower Pajaro Valley bottomlands and many areas underlain by finer-grained terrace deposits. Figure 10 indicates the envelopes of nitrate content in groundwaters in the Valley. The envelopes represent the highest likely concentration for an area. A review of recent data on nitrate levels in study wells of the two counties indicates little or no change over time. In all cases, nitrate concentrations remain within the limits described by the envelopes. Deep wells with adequate surface seals are likely to yield water with substantially lower concentrations.

Iron and Manganese. Although objectionable amounts of iron and manganese are widespread throughout the Pajaro Valley concentrations are generally lower than in other parts of the Monterey Bay area. Concentrations exceeding recommended drinking water levels are often encountered in wells north of the Zayante fault and east of Corralitos Creek. A second, smaller area of generally high concentrations occurs at river mouth, where most wells within 1-2 miles of the coast yield amounts exceeding recommended levels. Most other wells south of the Zayante-Vergeles fault usually contain lower concentrations which do not impair water quality, although localized and periodic exceptions are common. In general, the highest concentrations appear to coincide with portions of the aquifers in which reduced clays are common.

Heavy Metals. Concentrations of arsenic, cadmium, chromium, titanium and vanadium approaching or exceeding public health maxima have been reported in isolated wells in alluvial and Aromas aquifers. The distribution of all six constituents are considered to be controlled by geologic factors. The last five metals, plus possibly zinc and molybdenum, appear to be associated with distinct depositional facies within the Aromas Red Sands (HEA, 1978b). Elevated levels of dissolved arsenic are reported in a number of wells in the East Area and in two isolated wells near the coast, but all are below standards established for domestic, industrial or agricultural use.

Effects of Waste Disposal Sites. Two recent reports (HEA, 1977; Aston, 1976) indicate that the alluvial aquifer below the Buena Vista landfill along Gallighan Slough has been contaminated by leachate. Dispersal of the leachate toward the southeast, accompanied by dilution, is likely to occur at groundwater flow rates of several hundred feet per year. The extent of contamination, if any, in the Aromas aquifer remains to be defined. Continuing percolation from the City and County landfills in this area may be expected in the foreseeable future.

In summary, based on previous investigations, existing water quantity and quality related problems in the Pajaro Groundwater basin can be enumerated as follows:

1. A potential long-term groundwater overdraft with a possible range of 10,000 to 20,000 ac-ft per year.

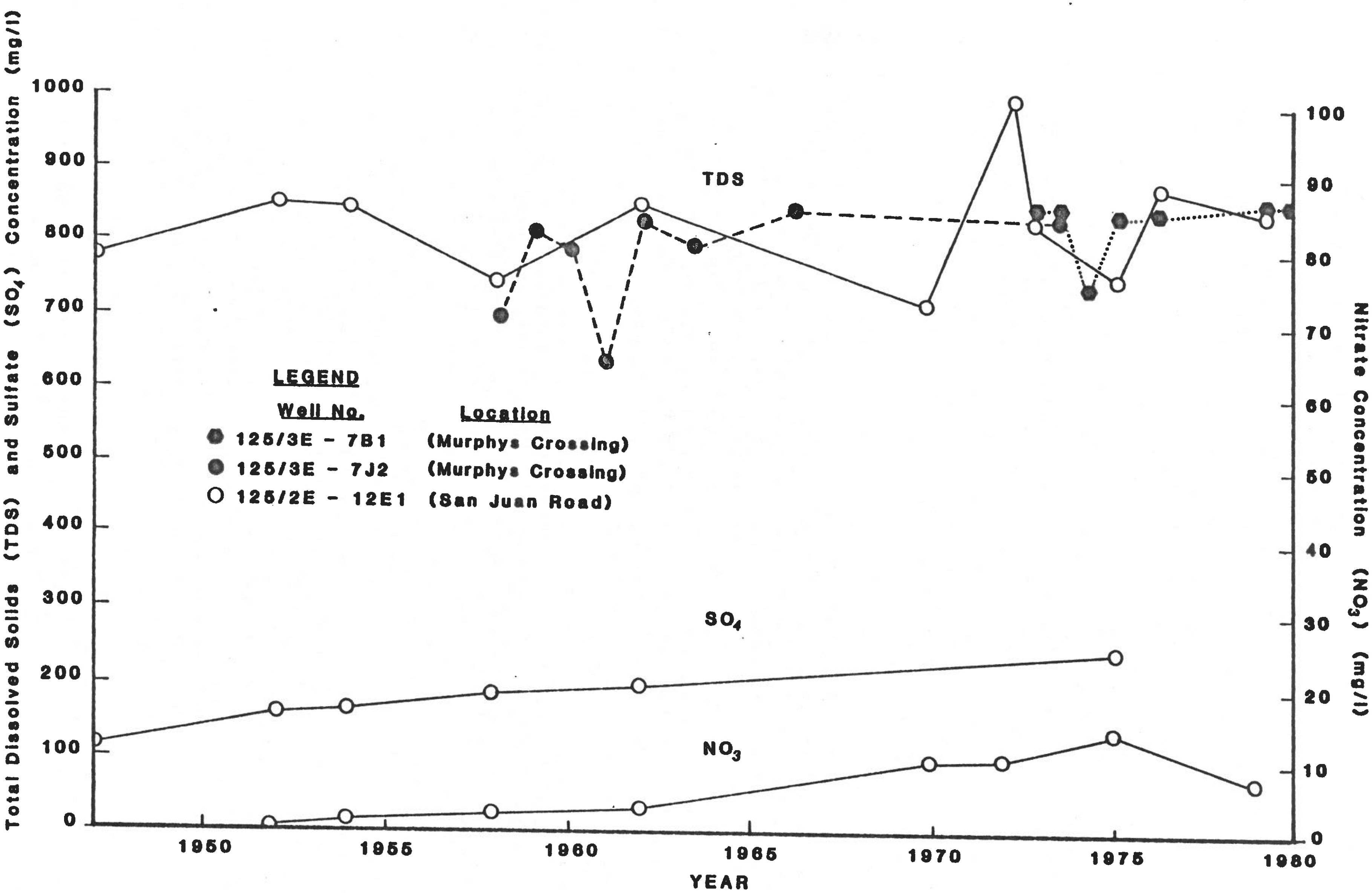

Figure 10. Changes in water quality with Time, Pajaro Forebay Area.

2. Seawater intrusion in the coastal portion of the basin extending up to three miles inland at some locations.

3. Other water quality related problems arising from the heavy use of fertilizers on cropped areas overlying sandy substrates, natural recharge of poor quality surface water from the Pajaro River, and potential groundwater degradation caused by two existing landfills.

Existing Groundwater Management Related Programs

With the exception of waste disposal operations which are subject to discharge permits issued by the Regional Water Quality Control Board - Central Coast Region and well construction and quality monitoring programs which are carried out by the County Environmental Health Departments, currently no other formal regulatory or enforcement programs exist for dealing with groundwater pollution related problems in the Pajaro Valley.

The environmental health departments in both Santa Cruz and Monterey Counties have permit issuing authority for all well drilling activities. These agencies also monitor water quality conditions in wells operated by small water purveyors. If the quality of water in these wells becomes inimical to the health of the people who consume such waters, the County health agencies can prohibit the use of the affected water supply wells. The State Department of Health Services exercises similar regulatory functions with respect to larger water purveying agencies. The county well ordinances incorporate the Department of Water Resources Well construction standards to protect the quality of groundwater aquifers.

Policy guidelines adopted by the Regional and State Coastal Commissions call for the protection of groundwater recharge areas and preservation of groundwater quality conditions within the coastal zone by prescribing specific land use policy guidelines. In Santa Cruz County, these guidelines indicate minimum parcel sizes for development over primary groundwater recharge areas (10 acres) and for other areas where on-site septic systems are used (1 acre). In Monterey County, the General Plan densities for the sand hill areas surrounding the Pajaro Basin normally call for minimum lot sizes of 2.5 acres. Retention and percolation of stormwater runoff from impermeable surfaces for all new developments in the primary recharge areas is also recommended. Groundwater quality protection provisions of these guidelines include a ban on the discharge of pollutants to the groundwater system from non-residential land use, the use of a shallow leaching system for septic tank effluent, identification and plugging of contaminated wells, monitoring of groundwater level and quality, and careful scrutiny of the quality of water produced by any new water supply well.

Adoption of specific land use policies addressing water supply, water quality, rainfall run off and soil erosion problems in North Monterey County area are currently under consideration in this county. A citizen's advisory committee recently submitted recommendations to the Board of Supervisors for land use policies that would protect natural vegetation, soil, and water resources of this area.

A number of agencies at the local, state, and federal levels have jurisdiction in groundwater resource-related issues. A list of these agencies with a brief description of their current programs or areas of responsibility is presented below:

1. Santa Cruz and Monterey County Flood Control and Water Conservation Districts. The major responsibility of these agencies is to control flood flows in natural streams and conserve the flood waters as needed. Both of these agencies have carried out groundwater level and quality monitoring programs in the past and have published reports containing such data from time-to-time. These districts can also undertake groundwater and water resources investigation projects. Flood Control Districts are governed by County Boards of Supervisors. These districts have no legislative mandate to enforce a groundwater management program; however, the operation and management of groundwater recharge projects falls under the category of water conservation activities and could be delegated to these districts. In this context, the counties could issue revenue bonds to raise needed capital funds for construction of such projects and could levy assessments on beneficiaries of such facilities to defray these costs and the required operation and maintenance costs subject to the approval of voters.

2. Santa Cruz and Monterey County Departments of Health. These agencies are mainly concerned with the monitoring of activities which may pose a risk to public health by affecting private or public water supplies. Both departments issue permits for installation of individual on-site wastewater disposal systems and review the suitability of proposed water supply sources for new developments. Neither department undertakes a routine monitoring program of water wells in the Pajaro Valley with the exception of monitoring of small water supply systems (two or more connections) for compliance with drinking water standards. Health departments also issue permits for drilling and abandonment of water-supply wells and inspect the construction of such wells.

3. City of Watsonville. The City monitors water levels and water quality conditions in its own water well system on a regular basis. At present, Watsonville is not engaged in any area-wide groundwater replenishment activities.

4. State Water Resources Control Board (SWRCB). The State Board has broad powers for regulating waste discharges into surface and ground water bodies under the Porter-Cologne Water Quality Control Act and based on powers delegated to the Board by the U.S. Environmental Protection Agency. The State Board is also empowered by the state legislature to take necessary actions to bring about adjudication of groundwater resources in any basin where the continued unregulated use of groundwater may lead to irreparable injury to the quality of such water. SWRCB also administers the Clean Water Grant Program in the State under delegated authority from U.S. Environmental Protection Agency.

5. Regional Water Quality Control Board, Central Coast Region. As indicated previously, RWQCB safeguards the quality of surface and groundwaters in the Pajaro Valley area by establishing treatment and disposal requirements for liquid and solid wastes generated by municipal and industrial activities. The Regional Board also monitors the performance of such waste disposal activities and can bring enforcement action against violators of the prescribed discharge requirements. The Regional Board is the local branch of the State Water Resources Control Board. The Water Quality Control Plan Report, Central Coastal Basin (Basin Plan) also provides an implementation plan for the control of non-point sources such as agricultural tailwater and individual sewage disposal systems. The Regional Board, however, has not yet adopted a formal procedure for control of non-point sources, especially with respect to agricultural activities.

6. State Department of Water Resources. DWR has conducted groundwater level and quality monitoring programs from time to time in the past. This agency is also the official repository for the drillers' logs for all wells drilled in the Valley. DWR is also required by the state legislature to respond to any requests of the State Water Resources Control Board for recommendations regarding the adjudication of groundwater resources of the state. After the filing of such recommendations the State Board may file an action with the superior court to restrict pumping, or to impose physical solutions, or both, to the extent necessary to prevent destruction of or irreparable injury to the quality of such water.

7. U.S. Geological Survey (USGS). The role of the USGS in the Pajaro Valley is presently limited to periodic monitoring of water levels and water quality conditions, analysis and interpretation of geologic and hydrologic information, and preparation of investigative reports on groundwater conditions in the basin. USGS also conducts routine monitoring of surface streams at selected locations in the Valley. Currently USGS is developing a digital model of the groundwater aquifers in the Pajaro Valley.

8. U.S. Environmental Protection Agency (EPA). EPA has broad powers for protecting the quality of integrity of water resources of the nation under the Clean Water Act, the Safe Drinking Water Act, and Resource Conservation and Recovery Act. In California, EPA has delegated most of its permit-issuing authority under National Pollutant Discharge Elimination System to the State Water Resources Control Board. However, EPA retains authority over hazardous waste disposal activities which may affect ground or surface water bodies and can also exert influence over land use activities in a groundwater basin by designating the basin as a sole-source aquifer.

9. Pajaro-North Monterey County Groundwater Study Management Committee. This committee was created by a formal resolution of the Santa Cruz County Board of Supervisors (Resolution 573-80) in 1980. Subsequently, Monterey County Board of Supervisors, Watsonville City Council and the Board of Directors of Aromas County Water District also adopted appropriate resolutions indicating their intent to participate in the committee and appointing a member to the committee. In

addition to the above agencies, the committee includes members from Santa Cruz County Agricultural Advisory Commission and a member from the public at large. AMBAG also serves as an ex officio member of this committee.

The mission of the committee as stated in the original resolution of the Santa Cruz County Board of Supervisors' is as follows:

1. Review hydrologic information pertaining to the Pajaro Valley.

2. Project water use needs in the Valley.

3. Determine the need for a groundwater management program, if any.

4. Formulate a groundwater management program, if necessary.

5. Recommend the type of management structure.

6. Identify the need for any action at the City, County, or State levels.

7. Recommend the need for performing any additional studies.

The committee was authorized to hold formal public hearings as needed during the course of its activities. The committee submitted an interim report to Santa Cruz County Board of Supervisors in July, 1981. In this report the committee recommended that a number of actions be undertaken as follows:

1. Encourage and support all current programs designed to increase the efficiency of water use, including irrigation use.

2. Encourage and support all current programs designed to increase public and consumer awareness of the need for water conservation.

3. Advise the City of Watsonville and the Counties of Monterey and Santa Cruz to encourage cost effective development regulations and land use controls which reduce domestic water consumption and protect and enhance recharge.

4. Institute a vigorous program to detect and seal abandoned wells, excepting those which are used as observation wells for study purposes.

5. Design and institute a system to detect and remedy water quality impairment caused by existing production wells.

6. Reinforce existing programs to insure proper well construction and destruction through the enforcement of existing ordinances and revised water well standards by the State

Department of Water Resources (Bulletin No. 74-81). Consider, with well drillers, the creation of special water resource protection zones incorporating specific well location and construction standards.

7. Establish a joint study with the Watsonville Water Department of the feasibility of increased diversion from Corralitos and Browns Creek for recharge to the underground aquifer and/or direct use by agriculture.

8. Investigate the possibility of similar diversions from other surface water streams and the Pajaro River.

9. Proceed with consideration of the Pescadero Creek Dam and reservoir and other potential water storage projects which would maintain summer stream flows for agricultural diversion and other compatible uses.

10. Undertake detailed area specific geologic investigations to identify areas suitable for artificial recharge.

11. Request the watershed manager to study and report on the recharge benefits of winter vegetation management in watershed and recharge areas including those lands involved in agriculture.

12. Establish a policy on contracting for San Felipe water.

In response to these recommendations, Santa Cruz County Board of Supervisors has adopted an ordinance establishing a Special Groundwater Protection Zone in the seawater intruded portion of the basin near the mouth of the Pajaro River. In this zone, the ordinance allows the Health Officer to take the following two actions:

a) If the Health Officer suspects that a well is allowing the exchange of water from a poor quality source to a good quality aquifer, he may require that the well be inspected by a qualified person, with the cost of the inspection to be borne by the owner of the well. If it is determined that a well is polluting or contaminating an aquifer, the Health Officer may abate the said well as a nuisance.

b) For a new well penetrating more than one aquifer within the said zone, electric logs (spontaneous potential and resistivity) must be run in the uncased bore-hole by the well driller or other qualified person. Based on the information obtained from these logs and the geologic log of the well, the well driller shall identify the strata containing poor quality water. The strata containing poor quality water shall be sealed off to prevent the entrance of the water into the well or its migration to other aquifers.

Action on other elements of the interim report recommendations is either under way or is currently under deliberation.

Many of the objectives and recommendations of the interim report have been incorporated in the scope of work for the current study. Final action on such elements has been postponed pending the completion of this study.

10. Association of Monterey Bay Area Governments (AMGAG). The major water and soil related activities of AMBAG in the Pajaro Valley encompass the administration of federally funded Section 208 projects dealing with groundwater management, habitat enhancement, erosion control, land use determinations and agricultural water use evaluation. The current groundwater management study is being carried out under the aegis of AMBAG.

Hydrologic Balance in the Pajaro Valley

Estimates of the hydrologic budget in the Pajaro Valley have been developed by different investigator in the past. These estimates have invariably indicated the existence of an overdraft condition in the basin, however, the reported volume of annual overdraft has varied widely over the years. These variations can be attributed to methods of evaluation, time of the estimate, and uncertainty over some of the parameters entering into a hydrologic budget.

Boundaries of the Budgeted System. The boundaries of the area for which the budget has been developed are shown on the recharge map Figure 4). This area encompasses 130.5 square miles. In three instances, some clarification is warranted. First, a small area in northwestern San Benito County is topographically within the basin and contributes groundwater to the valley-floor areas. The exact extent of this area -- perhaps 5 to 10 square miles -- is not known. The San Andreas Fault and the configuration of the top of the Purisima Formation direct water away from Pajaro Valley. The hydrogeologic relations in this area are quite complex. Groundwater movement across the Monterey-San Benito county line can, however, be estimated at about 400 acre feet per year based on known aquifer properties and groundwater gradients.

Second, the opposite situation prevails in the Aptos area because the boundary conditions cannot be clearly defined at the topographic divide. Water-level data defining hydrogeologic gradients across the topographic divide between the Aptos and Pajaro watersheds are erratic. A more reliable estimate of inflow through the Aromas aquifer can be made by quantifying inflow (recharge) and subtracting known outflows and other losses. The balance of these values potentially moves toward the Pajaro basin. This method of computation can also serve to highlight the effects of land and water use in the eastern Aptos area on the Pajaro basin.

Third, an area of about 10,500 acres between the San Andreas Fault and the Santa Cruz Mountains crest is not included in the budget area. Virtually all inflow from this steep area occurs as streamflow and infiltration through stream beds; as such, it is already incorporated in other specific budget elements. Existing evidence suggests that the San Andreas Fault serves as a major groundwater barrier (e.g., Muir, 1972). Even if this were not the case, the cemented siltstones and mudstones underlying this area contain minimal amounts of groundwater. Data developed for AMBAG's Pajaro Habitat Management Study indicate that areas north and east of the fault contribute only 5 to 10 percent as much summer baseflow in streams originating in the mountains as do equal areas underlain by Aromas or Purisima sediments to the south and west. We would expect groundwater contributions from the cemented rocks to be proportionately even lower due to the much smaller depth of the water-bearing zone. A maximum of several hundred acre feet per year could be contributed to the Pajaro Basin by areas north and east of the fault, if such flows could move past the fault barrier. This source is considered of negligible importance in the Pajaro Basin's water balance.

Hydrologic Budget. Revision of the hydrologic budget for the basin was not included in the scope of work for this study, however, due to the development of new data on crop water demands and because of the need for providing a frame for quantitative aspects of groundwater management in the valley, we felt that a re-evaluation of this topic was in order. Accordingly, a revised hydrologic budget for Pajaro Valley was developed and is presented in Table 4. The format of this budget has been changed in some areas from that presented in our 1978 report to eliminate some of the uncertainties associated with applied water demand of crops and recharge from cropped areas because the reported volume of this demand and the estimated recharge value has varied over a wide range in the past. Estimates of applied irrigation water depth for crops are still undergoing change due to changing irrigation technology. For these reasons, estimated annual evapotranspiration data was chosen for use in the hydrologic budget because these data are dependent only on crop and climatic factors and are independent of irrigation practices and the total depth of water applied to crops. A brief discussion on different components of the hydrologic budget is presented in the following paragraphs.

1. The estimated annual rainfall values for native vegetation and cropped areas were developed from isohyetal maps prepared by USGS for the period 1906-1956 which represented average long term conditions for these areas. This source was used because it is plotted at a high level of resolution, includes a representative 50 year period of record and covers the entire Pajaro basin.

2. Channel recharge values were estimated on the basis of gaging records and previous investigations as discussed in HEA, 1978 report and the 1979 Watsonville Water Supply and Distribution Master Plan.

3. Interbasin inflow values are also the same as discussed in the HEA 1978 report. The subsurface flow from the Aromas Formation is not identified because this formation in the Aptos area is included within the boundaries of the Pajaro Basin for hydrologic purposes.

Table 4. Revised Water Balance Calculations for the Pajaro Valley Groundwater Basin

Parameter	Acreage	Unit Rate (inches/year)	Volume (ac-ft/yr.)
Inflow			
Rainfall over primary recharge areas			
Native vegetation/open space	20,050	23.8	39,800
Cropped lands	15,000	22.1	27,600
Freshwater marshes and sloughs	250	21.0	400
Other uses[a]	2,600	25.5	5,500
Rainfall over other areas			
Native vegetation/open space	18,900	24.7	38,900
Cropped lands	20,500	21.9	37,400
Freshwater marshes and sloughs	1,160	21.0	2,000
Other uses[a]	2,700	21.7	4,900
Channel recharge			
Pajaro River			4,500
Santa Cruz Mountains streams			5,500
Los Carneros Creek			400
Interbasin inflow			
Aptos Area			
Purisima Aquifer Aromas Aquifer			9,100[b]
Aromas Area			400
Seawater Intrusion			200
Deep Percolation, Septic Tanks[c]			1,000
TOTAL INFLOW			177,600
Outflow			
Evapotranspiration			
Native vegetation/open space	38,900	20.0	64,900
Cropped areas	35,500	23.4	69,200
Freshwater marshes and sloughs	1,410	45.0	5,300
Other (mainly urban and industrial)			
Non-irrigated open space Impervious surfaces	3,200 1,600	20.0 0	5,300 0
Surface Runoff			
Non-agricultural uses			
Sandy soils Other soils	22,900 22,800	2.1 4.2	4,000 8,000
Cropped areas			
Sandy soils Other soils Tailwater runoff	15,000 20,500 35,500	2.1 4.2 0.25	2,600 7,200 700
Municipal and Industrial Pumpage			
City of Watsonville Industrial Pumpage Other domestic pumpage[e]			7,150 2,700 4,000
Seepage to Ocean			
Aromas and Terrace Aquifers Purisima Aquifer			1,200 1,500
Seepage from Perched water of Valley Floor			4,600[f]
TOTAL OUTFLOW			188,350
Estimated Annual Volume of Overdraft			11,000[g]

a Principally urban, industrial, quarry, and transportation.

b Incorporated in recharge values; see text.

c For 2800 units in Santa Cruz County portion of the basin, plus 750 units in Monterey County portion, plus 650 units in Freedom Boulevard/Day Valley areas which are not part of the basin, but are incorporated within the water budget boundaries.

d About half of the annual evapotranspiration demand in the freshwater marshes and sloughs is probably met by subsurface flow from the perched water table.

e Includes 200 ac-ft per year pumpage from Soquel Creek Water District wells, 240 ac-ft pumpage from Central Santa Cruz County Water District wells, 150 ac-ft per year pumpage for Aromas County Water District wells, and 1,500 ac-ft per year pumpage for domestic use in other parts of the valley not served by any of the existing water purveyors.

f Estimated on the basis of 6 cfs to the Pajaro River and its underflow, 0.5 cfs to Watsonville Slough and 0.1 cfs to Trafton Road ditch. An additional unknown volume may enter Elkhorn Slough from the Springfield area, and perhaps also from the valley floor through Elkhorn Gap.

g This is an approximation of the basin-wide overdraft based on existing knowledge and our best estimates of the many parameters entering the hydrologic budget. The actual basin-wide overdraft could potentially fall in the range of 6,000 to 18,000 ac-ft per year.

4. Total annual evapotranspiration value for cropped areas were derived on the basis of evapotranspiration demand for November-April and May-September periods as reported in State Water Resources Control Board's (SWRCB) Bulletin No. 5 (SWRCB, 1953), (Appendix I, Table 17). These values were modified on the basis of recent field measurements made by Santa Cruz County Agricultural Extension Service in 1983 which are summarized in Table 5.

5. Average evapotranspiration demand values for native vegetation areas were also derived from data reported in SWRCB's Bulletin No. 5. A wide range for the ET demand of native vegetation is indicated in this bulletin depending on the type of vegetation, depth to water table, annual precipitation level, etc. The bulletin states the following:

   "... it is estimated that the mean annual consumptive use by chapparral in the Pajaro watershed ranges from 18 inches to 24 inches while the use in the denser forest areas may be as much as 30 inches, depending upon the availability of groundwater to supply moisture to trees during the summer months" (page 185, Appendix I).

   Accordingly, we believe that the use of an average ET demand of 20 inches for native vegetation in the basin would be reasonable.

6. Estimates of surface runoff from sandy areas were developed based on the data and analyses in our 1978 study and in Chapter 7 of this report, plus the record developed for Monterey County Flood Control and Water Conservation District's Prunedale gage. Runoff from other lower areas of the basin were developed based on Monterey County's discharge record for Santa Rita Creek, a four square-mile lowland drainage near Salinas, where runoff averaged about 15 to 18 percent of the mean annual rainfall during a six-year period of record. Additionally, an analysis of the very limited discharge record for Los Carneros Creek (USGS, 1983) was used, and the streamflow history for Pescadero Creek was also considered.

   In the recent U.S. Geological Survey report for the north Monterey County area, a minimum runoff value of 6 and 12 percent of rainfall for sandy watersheds and for watershed composed primarily of less sandy materials, respectively, was estimated during a year with long term average annual precipitation. Data presented in Table 6 indicate that runoff for a year with average annual precipitation is not equivalent to long term average annual runoff for a given watershed. An empirical ratio of 0.65 can be derived between these values from data shown in this table. Accordingly, the percent runoff values developed by USGS have been modified by the application of this factor with a resulting estimated average annual runoff of 9 and 18 percent for sandy and non-sandy watersheds, respectively. Due to the

Table 5. Estimated Crop Consumptive Use (ET_c) and Average Irrigation Water Applied (AW) for Major Pajaro Valley Crops. From measurements taken during 1981 and 1982.

Crop	Estimated Total ET_c irrigation season*	Estimated Total AW (Average Grower)	Gross Irrigation Efficiency
Strawberries (drip-irrigated)	16"	24"	67%
Apples (mature orchard)	20"	10"	100% +
Lettuce	5"	9"	50-60% (Lettuce, Cauliflower, Celery)
Cauliflower (transplants)	7"	12"	
Celery (transplants)	11"	18"	
Artichokes	16"	15"	100% +
Brussels Sprouts	15"	14"	100% +
Raspberries	18"	20"	90%

*For perennial crops, the "irrigation season" is considered as that period between the last significant spring rain and the first significant fall rain. In 1981, this was the period of April 20 to October 26 and, in 1982, April 15 to September 22.

Source: Santa Cruz County Agricultural Extension Service

Table 6. Relation Between Mean Annual Runoff and Runoff During a Year of Mean Rainfall, Eastern Santa Cruz Mountains[a]

Steam/Station[b/]	Drainage Area (sq. mi.)	Period of Record	Runoff wy 1979 (ac.-ft.)	Mean Annual Runoff (ac.-ft.)	1979 Runoff / Mean Runoff
Pescadero Creek near Chittenden	10.2	10/70-9/81	1410	2200	0.64
Corralitos Creek at Freedom	27.8	10/56-Present	7640	10070	0.76
Aptos Creek near Aptos	10.2	10/73-Present	3390	5525[c/]	0.61
Uvas Creek above Uvas Reservoir	21.0	7/61-9/81	10000	18760[d/] or 16475	0.53[d/] 0.61
Bodfish Creek near Gilroy	7.4	10/59-Present	1550	2470	0.63
				Mean	0.649

a/ 1979 seasonal rainfall of 20.98 inches is 98 percent of long-term mean of about 21.4 inches at Watsonville Waterworks.

b/ Source of Data: U.S. Geological Survey

c/ Average for 1921-1981; extended record synthesized by HEA, 1983.

d/ For WY 1971 - WY 1981, equivalent to the period of record for Pescadero Creek. Higher runoff during 1960's following major watershed fire.

existence of surface irrigation methods in the valley, an estimated tailwater runoff loss of 700 ac-ft per year was also assumed in this analysis.

7. Deep percolation from natural precipitation and applied irrigation water in a 13,000 acre area underlain by a perched water table does not reach the productive aquifers in the valley and must be presumed to be lost by discharge into the Pajaro River and Watsonville slough and by direct subsurface seepage to local marshes and to Monterey Bay. This assumption is strongly supported by the existence of a persistent cone of depression in the confined water bodies under the perched water table because of a distinct difference in the ionic composition of poor quality water in the perched zone and waters of much higher quality in most wells pumping from the confined aquifers. A limited volume of the perched water body may, however, recharge the underlying aquifers through a gap in the confining clay formations near Watsonville. The maximum volume of water recharged into the perched water bodies but which does not contribute to the main water bearing formations is estimated as the difference between the sum of the average applied water for truck crops of 1.51 ac-ft per year (Table 4 of Chapter 3), and average annual precipitation of 1.68 ac-ft and the sum of average annual ET demand of 1.95 ac-ft and average annual precipitation and tailwater runoff of 0.37 ac-ft.

The annual volume of water percolating to the perched water table zone is estimated at about 11,300 ac-ft. In the hydrologic budget, this volume is distributed as follows: subsurface flow to freshwater marshes, 2,800 ac-ft and seepage to sloughs and Pajaro River, 4,600 ac-ft. The balance of 3,900 ac-ft is unaccounted for and depending on its fate, could either increase or decrease the actual overdraft by a corresponding amount. In the present budget, this volume is not counted as an outflow item. Accordingly, we have implicitly assumed that the annual volume of 3,900 ac-ft is available for use in the basin. We believe, however, that most of this volume may be lost through known or unidentified discharge routes.

Seepage from the perched water table to the developed aquifers is known to occur in significant quantities only in the "Watsonville Window" area, where the blue clays are interrupted (see Figure 3-13 of 1978 HEA report). We estimate that as much as 1,000 acre feet per year may percolate from the perched table into the underlying aquifers in this one area. This estimate is based on the relative concentration of salts in waters drawn from wells in this area and in the perched and alluvial gravel aquifers.

8. In the 1978 water budget, there was no provision for outflow from the deep aquifers. Geologic structure appeared to direct flow to the center of valley and we could find no evidence for bayward movement of flow in the deep aquifers.

The Salinas Valley model was adopted, in which the piezometric head in the deep aquifer exceeds that in the heavily-developed shallower zones. Under such conditions, potential for net movement from the deeper aquifers into the shallower aquifers exists. We felt at that time that such flow patterns were at least as likely as a shoreward net outflow.

Recent hydrologic and geologic work indicates that the deep aquifers may well discharge to the bay (e.g., USGS, 1980; Thorup, in prep). Additionally, wells developed in the Purisima sediments within the Pajaro basin have consistently recorded lower static water levels than nearby wells developed solely in the upper Aromas or alluvial aquifers. In the lower Pajaro Valley, the head in City's well #13 (developed in the lower Aromas and upper Purisima units) is consistently 5 to 15 feet lower than in other local wells developed in shallower zones.

Accordingly, conservative estimates of deep-zone outflow have been developed using available data. Unit hydraulic conductivities were estimated from data in recent studies, and from the work of Hickey (1968), data from the City's new airport test hole and formation tests conducted during oil exploration. Using these assumptions, net deep-zone outflow of between 500 and 2500 acre feet per year seems likely. These values would be approximately twice as great if transmissivity values developed by Luhdorff and Scalmanini (1982) are applied; this report, however, indicates that permeabilities diminish eastward toward the Pajaro Valley. An outflow value of 1,500 ac-ft. per year from the deep aquifers was used in the hydrologic budget.

Based on the information presented in Table 4, an estimated long-term basin-wide overdraft of 11,000 ac-ft appears to exist in the Pajaro Valley. This value has been derived on the basis of existing knowledge and our best estimates of the many parameters included in the hydrologic budget calculations. The actual basin-wide overdraft could potentially fall in the range of 6,000 to 18,000 ac-ft per year. A more precise estimate of the hydrologic budget for the basin can be made through the use of a calibrated digital model of the basin and by making field measurements of elements that have been estimated in the current budget. A more detailed discussion of these data needs are presented in the following chapters of this report.

Although the overdraft is caused by mining of water throughout the basin, the most acute manifestation of these conditions are observed near the coast where water levels have dropped to as much as 20 feet below sea level and where sea water intrusion has extended as far as three miles inland. A decline in the water levels has also been observed in other parts of the basin, however, the rate of decline in the inland areas has been very small and no significant economic impact has been created by the lowered water levels in these areas.

Areas of Emphasis of the Current Study

Existing groundwater resource related problems in the Pajaro Valley have been enumerated in the preceding section. The most acute problem requiring immediate attention is related to the existence of groundwater overdraft conditions. The most severe impact of the overdraft condition is experienced in the coastal area around the mouth of the Pajaro River where seawater intrusion has caused the abandonment of some wells and has degraded the quality of water pumped from other wells. Some of the current land use and waste disposal practices have also impaired the quality of the groundwater in local or sub-regional areas. The level and areal extent of all sources of groundwater pollution in the Pajaro Valley has been discussed in detail in the report published by HEA in 1978.

Abatement of water quality impairment caused by existing waste disposal practices is within the purview of the Regional Water Quality Control Board and State Water Resources Control Board. These agencies exercise regulatory control over such operations through permit issuing and enforcement mechanisms. Currently no regulatory and enforcement plans are in effect or are contemplated for controlling groundwater quality degradation caused by normal land use activities. The Basin Plan, however, prescribes procedures for control of non-point sources of pollution in the Central Coast area. Summary information on geographic distribution and severity of the problems discussed above is presented in Table 7.

Sandy hills forming the southern and northern boundaries of the Pajaro Valley are a major source of natural replenishment of alluvial, Aromas sands and possibly Purisima aquifers. Conversion of these recharge areas to residential, industrial or agricultural uses may result in an appreciable reduction in the rate of natural recharge to aquifers in the basin.

Based on the above discussion, the emphasis of this study will be on the analysis and evaluation of alternative structural and non-structural methods for protection and enhancement of natural recharge and for the development of new sources of groundwater replenishment or water supply in the Pajaro Valley. Institutional, financial and economic factors related to groundwater management will also be addressed within the context of the above objectives.

Table 7. Summary Information on Geographic Distribution and Severity of Groundwater Problems in the Pajaro Valley

Type of Problem	Affected Geographic Area and Subarea	Degree of Severity
Seawater Intrusion	1. Western and southern portions of Springfield area. 2. River-mouth area. 3. San Andres area, seasonally. 4. Elkhorn Road, possibly.	Severe in portions of the Springfield and river-mouth areas, to the point that many wells cannot be used. Intermittent and/or seasonal near coast in San Andres area. Potentially severe problem in Elkhorn Road area.
High dissolved-solids levels, not related to intrusion	1. East area. 2. San Andreas fault corridor.	Chronic levels of 700-1500 mg/l, primarily due to poor quality of recharging waters from Pajaro River. Connate brines emanate from early Tertiary sediments north and east of San Andreas fault.
High boron levels	1. East area. 2. Severely intruded portions of Springfield area.	Chronic levels of 0.5-0.8 mg/l in East area associated with recharge from Pajaro River. These levels may begin to affect sensitive crops.
High nitrate concentrations	1. Western and southern portions of Springfield area. 2. Other high-recharge areas where substantial loadings are applied.	Severe in Springfield area. Locally approaches or exceeds public health maxima.
Falling water levels	1. East area. 2. Salsipuedes area. 3. Valley floor area southwest of Watsonville. 4. Springfield area.	Rates as high as 1.5 ft/yr for portions of the East area. Rates of 0.1 to 0.5 ft/yr elsewhere.
Landfill Leachate Contamination	Known only for Buena Vista area; no investigation made at Lewis Rd. landfill.	Poorly known; monitoring program to be installed in near future.

CHAPTER 2 - REFERENCES

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CHAPTER 3

REVIEW AND UPDATE WATER DEMAND DATA

Introduction

Demand for water in the Pajaro Valley is generated by municipal, industrial, and agricultural land use activities. City of Watsonville supplies almost all of the municipal water requirements of the Valley as well as a significant portion of the industrial water demand. The city obtains over two-thirds of its current water need from the groundwater aquifers. A significant number of industrial users, such as food processing operations, rely on on-site water wells for all or a portion of their water supply requirements. Agricultural activities in the Valley are dependent entirely on groundwater for meeting the irrigation demand of various crops.

In this chapter, existing and projected annual water supply demand values for the three major land use activities in the valley are reviewed and updated based on the current available information. A brief discussion is also presented on water quality requirements and constraints for various uses.

Municipal Water Demands

Estimates of existing and projected future water demands for the Watsonville service area were developed on the basis of data supplied by the City of Watsonville and information contained in a Water Supply Master Plan report which was prepared for the city by Montgomery Engineers in 1979. Data supplied by the City Public Works Department indicate a total water production of 7,000 ac-ft. for the calendar year 1982. Of this total, approximately 1,075 ac-ft. was supplied from Corralitos Creek and the balance was pumped from groundwater aquifers. The average rate of diversion from Corralitos Creek by the City is about 1,000 ac-ft. per year.

In the Montgomery report, projected water demands for the City of Watsonville service area have been estimated at 11,960 and 14,120 ac-ft. in 1989 and 1999, respectively, with an ultimate demand of 19,500 ac-ft/yr. The future service area of the city at ultimate development is estimated at 11,950 acres which represents a 29 percent increase over the present service area (Montgomery Engineers, 1979). The city's water supply master plan indicates that all future demands will be met from groundwater supplies.

If the substantial projected increase in municipal water demand for the City of Watsonville were realized, it would generate additional net pumpage demands in the basin for the following reasons:

1. The average consumptive pumpage demand for crop irrigation in the Pajaro Valley is about 1.3 to 1.5 ac-ft. per acre. Municipal and industrial demands, however, exceed the above level by an appreciable margin as indicated in Table 1,

Table 1. Estimated Unit Water Demands for Various Land Use Types in the City of Watsonville Service Area[a]

Land Use	Water Duty (acre-ft/acre-yr)
Rural Residential	0.5
Low Density Residential	2.0
Medium Density Residential	2.3
High Density Residential	3.0
High Density Residential*	1.5
Commercial	1.5
Industrial	2.3
Agricultural/Open Space	0.5
Recreational	1.0

*Pajaro Dunes Service Zone

[a]Source: Montgomery Engineers, 1979

therefore, conversion of agricultural land to urban uses will result in greater pumpage withdrawal from the aquifers on a per acre basis.

2. When urban development occurs on non-agricultural lands, a new water supply demand is created in the basin.

3. All municipal pumpage in areas served by a sewer system is totally withdrawn from the basin because the generated wastewater is discharged to Monterey Bay.

4. Urban development in primary recharge areas may result in a net loss of rainfall recharge to the groundwater reservoir.

Future land use conversions for the City of Watsonville service area are presented in Table 2 for years 1990 and 2000. These data which were provided by the City staff indicate a level of growth far below that projected by Montgomery Engineers and are generally considered to be a more realistic estimate of future land use conditions within the sphere of influence of the City of Watsonville. Estimated increases in future water demand for Watsonville service area were calculated on the basis of unit demands shown in Table 1 and land use conversion values presented in Table 2. The results of these calculations show a net increase in annual water demand of 827 ac-ft by year 1990 and 1,142 ac-ft per year by year 2,000. In making these calculations, it was assumed that conversion of each acre of agricultural land to medium density residential use will result in a net increase in water demand of 0.8 ac-ft per year.

The County Planning Department anticipates very limited increases in domestic water supply demand in unincorporated areas of the Pajaro Valley. Therefore, it appears that projected municipal water supply demand in the valley will be significantly less than the values estimated by Montgomery Engineers and will be in the range of 8,000 to 9,000 ac-ft. per year by year 2000.

Aromas County Water District also pumps water from the ground for domestic and commercial water supply use. It is estimated that this district pumped a total volume of 146 ac-ft. from its two active wells (Riley Moore, 1982) in 1981. Central Santa Cruz County Water District (CSCCWD) pumps a portion of its supply from the Pajaro Valley groundwater basin. The level of total pumpage in 1981 for this district was 340 ac-ft. (George Silva, 1982). The active wells for Central Santa Cruz County Water District are located north of the of physiographic divide between the Pajaro Valley and Soquel-Aptos Area. However, the direction of groundwater flow from this portion of Soquel Aptos Area is toward the Pajaro Valley and pumpage withdrawals from this area affects subsurface flow into Pajaro Valley. Soquel Creek Water District operates two wells within the community of La Selva Beach. Both appear to draw water entirely from the Aromas Formation. For the purpose of this report, the Aromas Formation in the Aptos and LaSelva Beach areas has been included within the hydrologic boundaries of the Pajaro Basin and for this reason, the estimated annual pumpage with-

Table 2. Estimated Future Land Use Conversions and Additional Municipal Water Demand in Watsonville Sphere of Influence, Acres

	1990					2000					
Land Use Type	Agric. Land Acres	Non-Agric. Land Acres	Total Land Acres	Unit Water Demand ac-ft/yr.	Total Water Demand ac-ft/yr.	Agric. Land Acres	Non-Agric. Land Acres	Total Land Acres	Unit Water Demand ac-ft/yr.	Total Water Demand ac-ft/yr.	2000 Total Additional Water Demand ac-ft/yr.
Industrial	0	168	168	2.3	386	0	61	61	2.3	140	526
Residential[a]	46[b]	164	210	2.3	414	46[b]	56	102	2.3	166	580
Commercial	0	18	18	1.5	27	0	6	6	1.5	9	36.0
TOTAL	46	350	396	---	827	46	123	169	---	315	1,142

[a] Assumed to be of medium overall density.

[b] Conversion of agricultural land to medium density residential use will result in a net increase in water demand of 0.8 ac-ft. per acre per year.

Source: City of Watsonville Public Works Department drawal of 2,000 ac-ft from the two Soquel Creek Water District Wells has also been included as a part of the municipal water demand in the Pajaro Valley.

An estimated annual volume of 1,500 ac-ft is also pumped for domestic use in approximately 4,100 dwelling units in the valley that are not served by any of the existing water purveyors.

Industrial Water Demand

A number of food processing industries have independent water supply systems using privately owned on-site wells. The volume of water pumped by these industries was estimated on the basis of pumpage data supplied by The City of Watsonville (Table 3). The estimated annual water demand for these industries is 2,715 ac-ft per year. This demand is expected to remain at the current level in the future based on the assumption that all new industries would rely on the City system for their water supply needs.

Agricultural Water Use

Varying estimates of agricultural water use in the Pajaro Valley have been reported in previous investigations cited in Chapter 2 of this report. The reason for these variations has depended on a combination of factors such as the estimating method used, the unit applied water demand value assumed for various crops, or the estimated acreage of different crops. In the report prepared by HEA in 1978, data on the actual acreage of various crops were developed based on land use maps prepared by the Department of Water Resources from aerial photos taken in 1975 (Santa Cruz County) and 1976 (Monterey County). Unit applied water demand values were also estimated for these crops in consultation with Santa Cruz and Monterey County Agricultural Extension Service offices and by using estimated evapotranspiration data for general geographic locations in the state published by the Department of Water Resources (DWR).

For the purposes of this report, data developed in 1977 were revised in consultation with Santa Cruz County Agricultural Extension Service, Santa Cruz County Agricultural Commissioner's Office and Monterey County Planning Department. Individual crop acreages in the Monterey County Portion of the Pajaro Valley were estimated by subtracting the appropriate crop acreage for Santa Cruz County from the corresponding total acreage shown in HEA's 1978 report. The total acreage in each crop category in this area, however, was adjusted in accordance with land use maps provided by the Monterey County Planning Department.

Revised estimates of crop acreage and applied water demand values for the Pajaro Valley are shown in Table 4. These data show an estimated total applied water demand of 53,715 ac-ft per year for a combined crop acreage of 35,741 acres. Multiple cropping practices are reflected in the total crop acreage values presented in Table 4 for celery and lettuce. The applied water demand value shows a signi-

Table 3. Water Demand for Major Industries in Watsonville's Sphere of Influence

Industry	Annual Average Flow mgd	ac-ft
Coast Counties	0.07	78.2
Crosetti	0.10	110.2
Del Mar	0.17	190.0
Green Giant	0.85	945
New West Foods	0.02	24.5
Smucker	0.11	119.3
Speas	0.01	11.2
American Food Corporation	0.02	27.5
Watsonville Can	0.96	1,072.2
AMETEK	0.12	137.7
TOTAL Industry	2.31	2,715.0

[a] Source: City of Watsonville (1984).

Table 4. Estimated Crop Acreage and Applied Irrigation Water Demand in the Pajaro Valley

Land Use	Santa Cruz County[a] 1981	Monterey County[b] 1979	Total	Estimated Applied Water Demand: Unit[c] ac-ft/ac	Estimated Applied Water Demand: Total ac-ft	Estimated Annual Consumptive Use: Unit[c] ac-ft/ac	Estimated Annual Consumptive Use: Total[e] ac-ft
Truck Crops							
Artichokes	580	1,002	1,582	1.25	1,977.50	2.00	3,164.00
Beans (green)	900	-	900	0.5	450.00	1.50	1,350.00
Broccoli	90	954	1,044	1.5	1,566.00	1.70	1,775.00
Brussels sprouts	1,070	997	2,067	1.17	2,418.39	2.00	4,134.00
Cabbage	150	340	490	1.5	735.00	1.50	735.00
Cauliflower	920	-	920	1.0	920.00	1.70	1,564.00
Celery	390	420	810	1.5	1,215.00	1.70	1,377.00
Lettuce	4,465	1,909	16,238[d]	0.75	12,178.50	1.70	10,835.00[f]
Melons, squash, cucumbers	400	154	554	1.5	831.00	1.50	831.00
Onions, garlic	17	-	17	1.5	25.50	1.50	25.00
Peas	120	-	120	0.5	60.00	1.50	180.00
Tomatoes	100	146	246	2.0	492.00	1.80	443.00
Miscellaneous truck	1,600	1,870	3,470	1.0	3,470.00	1.50	5,205.00
Flowers/Nursery	800	400	1,200	3.5	4,200.00	1.25	1,500.00
Berry Crops							
Bushberries	350	383	733	1.67	1,099.50	2.17	1,590.00
Strawberries	1,200	2,940	4,140	2.5	10,350.00	1.75	7,245.00
Field Crops							
Beans, dry	0	-	0	-	0.00	0.00	0.00
Corn	50	-	50	2.0	100.00	2.00	100.00
Sugar beets	0	-	0	-	-		
Fruits and Nuts							
Apples (irrigated)	7,090	400	7,490	0.83	6,216.70	2.35	17,601.00
Apples (dryland)	450	-	450	0.0	0.00	2.35	1,057.00
Apricots	50	-	50	0.5	25.00	2.35	117.00
Miscellaneous tree	40	-	40	2.0	80.00	2.35	94.00
Pasture							
Alfalfa	5	-	5	3.0	15.00	3.15	15.00
Mixed pasture							
Native pasture (irrigated)	1,000	1,243	2,243	2.0	4,486.00	2.75	6,168.00
Native pasture (dryland)	32	-	32	0.0	0.00	2.75	88.00
Hay/grain (irrigated)	350	304	654	1.0	654.00	2.75	1,790.00
Hay-grain (dryland)	-	-	-	-	-		
Miscellaneous							
Avocado	60	-	60	2.5	150.00	2.35	141.00
TOTAL	22,279	13,462	35,471[g]		53,715.00		69,124.00

[a] Source: Santa Cruz County Agricultural Commissioner's Office and Santa Cruz County Cooperative Extension Service.

[b] Source: Monterey County Planning Department. Data modified by HEA based on 1976 DWR Land Use Information.

[c] Unit applied water demand values were obtained from Santa Cruz County Cooperative Extension Service.

[d] This value includes 90 percent of lettuce, cauliflower, broccoli, and celery acreage and 47 percent of miscellaneous vegetables acreage which is estimated to be double cropped to lettuce.

[e] Based on data published in State Water Resources Board - Bulletin 5 as revised per field data collected by Santa Cruz County Agricultural Extension Service. These values represent consumptive loss of water from land.

[f] This value represents consumptive loss per actual acre of cropped land. The effect of multiple cropping is reflected in the unit consumptive use factor.

[g] Exclusive of double cropped acreage.

ficant downward revision from the total irrigation pumpage value of 88,200 ac-ft per year used in HEA's 1978 report. This reduction is due in part to changing methods of cultivation and irrigation especially for berries, and in part, due to more refined applied water demand data developed by Santa Cruz County Agricultural Extension Service by actual field measurements during 1982 and 1983 crop growing seasons. The effect of this reduction on the hydrologic balance of the basin will not be as pronounced because some of the excess applied water returns to the aquifers in many parts of the basin. This question has been discussed in detail under the heading of groundwater problems in Chapter 2 of this report.

No major changes are anticipated in the total crop acreage in the Pajaro Valley in the foreseeable future, however, changes in the crop mix in the valley can be expected from time-to-time based on market conditions for agricultural commodities. In recent years, an appreciable increase in the acreage of strawberries and miscellaneous truck crops and a decrease in the acreage of orchards and field crops has occurred in the Pajaro Valley. Also, the total irrigated crop acreage has increased by approximately 1,000 acres from the acreage shown on 1975 and 1976 aerial photos. Santa Cruz County Extension Service staff believe that the trend toward increased strawberry acreage appears to have run its course due to market competition from other areas. Conversion of acreage from orchards to truck crops such as lettuce and cauliflower may continue at a very slow pace in the future. A maximum conversion of 1,000 acres could be anticipated by year 2,000 according to Extension Service staff. Such a conversion may result in an increase in the total agricultural water demand ranging from 0.25 to 1.75 ac-ft. per acre of the acreage involved depending on the type of crop replacing orchard crops. Assuming an average increase in applied water demand of one ac-ft. per acre, the potential maximum increase in irrigation water use could be as much as 1,000 ac-ft. per year for the conversion of 1,000 additional acres of apple orchards to truck crops.

Summary Of Water Demand Data

Existing and projected agricultural, municipal, and industrial water demand data are summarized in Table 5. These data indicate a total pumpage withdrawal of 66,700 ac-ft per year in the basin under current conditions. This pumpage is expected to increase to 68,850 ac-ft per year by the year 2000.

Table 5. Summary Data on Estimated Existing and Projected Annual Pumpage Demand in the Pajaro Valley

Type of Use	Annual Pumpage Demand, ac-ft		
	1983	1990	2000
Agricultural	54,000	54,500	55,000[a]
Municipal			
City of Watsonville	6,000[b]	6,800	7,150[b]
Other Communities[c]	4,000	4,000	4,000
Industrial[d]	2,700	2,700	2,700
TOTAL	66,700	68,000	68,850

[a] Assuming the conversion of 1,000 acres of apple orchards to truck crops based on personal communication with Mr. Norm Welch, Santa Cruz County Agricultural Extension Service.

[b] These values exclude 1,000 ac-ft per year of surface water use.

[c] Includes a demand of 150 ac-ft per year for Aromas County Water District and 350 ac-ft per year for Central Santa Cruz County Water District and 2,000 ac-ft per year for Soquel Creek Water District. and 1,500 ac-ft per year for domestic pumpage in other parts of the valley.

[d] This value does not include the demand for any new industries which may be developed within the Watsonville sphere of influence. All new industries are assumed to be served by the City supply system in the future.

WATER QUALITY REQUIREMENTS FOR VARIOUS BENEFICIAL USES

Introduction

Water quality standards for municipal drinking water supplies have been established by U.S. Environmental Protection Agency and by California State Department of Health Services (SDH). The SDH drinking water standards are summarized in Table 6.

Based on these data, it appears that probable water quality constraints for municipal uses may arise from high levels of nitrates, chlorides, total salts and/or sulfates in existing ground and surface water sources in the Pajaro Valley.

Industrial Water Quality Requirements

Food processing operations constitute the major industrial activity in the Pajaro Valley. The quality of raw water for use in the food canning industry is generally the same as that prescribed for public water supplies. However, quality requirements for water at the point of use are more stringent with respect to calcium hardness, nitrates, phenols, odor, and taste. Data on water quality requirements for industries are shown in Table 7. Groundwater quality in areas of concnetration of food processing plants meets the requiremens of this industry at the present time, however, migration of poorer quality water from the east area or intrusion of saline water from the coast could degrade the quality of water used by these industries. Such degradation could potentially occur if pumping withdrawlas are increased significantly from the alluvial and Aromas aquifers.

Agricultural Water Quality Requirements

Guidelines for interpretation of water quality for crop irrigation are presented in Table 8. In these guidelines, the suitability of irrigation water is discussed in terms of the level of problems which may be caused due to salinity, soil permeability, or specific ion toxicity effects by using water of a given quality for crop irrigation purposes. Potential agricultural constraints that may be encountered by additional local sources of supply in the Pajaro Valley may arise from high levels of dissolved salts, boron, sodium and/or chloride.

Table 6. California Department of Health Drinking Water Regulations

Primary Standards	Maximum Contaminant Level (mg/l - except as noted)
Inorganic Chemicals	
Arsenic	0.05
Barium	1.0
Cadmium	0.01
Chromium	0.05
Lead	0.05
Mercury	0.002
Nitrate	10 (NO_3-N)
Selenium	0.01
Silver	0.05
Fluoride	1.4-2.4
Organic Chemicals	
Endrin	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005
2,4 - D	0.1
2,4,5 - TP	0.01
Radionuclides	
Gross Alpha Activity	15 pCi/l
^{226}Radium + ^{228}Radium	5 pCi/l
Gross Beta Activity	50 pCi/l
Tritium	20,000 pCi/l
^{90}Strontium	8 pCi/l
Physical	
Turbidity	0.5 NTU[a]

Primary Standards	Maximum Contaminant Level (mg/l - except as noted)		
Microbiological			
Membrane Filter Technique	1/100 ml		
Multible Tube Fermentation	See Standards[b]		
Secondary Standards			
Consumer Acceptance Limits			
Color	15 Units[c]		
Copper	1.0		
Corrosivity	Relatively Low		
Iron	0.3		
Manganese	0.05		
Odor	3-Threshold Number		
Foaming Agents (MBAS)	0.5		
Turbidity	5 NTU		
Zinc	5.0		
Mineralization	Recommended	Upper	Short Term
Total Dissolved Solids or Specific Conductivity	500	1000	1500
(µmhos)	900	1600	2200
Chloride	250	500	600
Sulfate	250	500	600

[a] 1 NTU for water not exposed to significant sewage hazard or recreational use.
5 NTU for water unquestionably free from sewage hazard or recreational use.

[b] Refer to Title 22, Division 4, California Administrative Code, Chapter 15 - State Department of Health Drinking Water Regulations for details.

[c] True Color.

Table 7. Quality Requirements of Water at Point of Use by the Canned, Dried and Frozen Fruits and Vegetables Industry*

Characteristic	Canned Specialities (SIC 2032) Canned Fruits, Vegetables, Etc. (SIC 2033) Dried Fruits and Vegetables (SIC 2032) Frozen Fruits and Vegetables (SIC 2037)
Acidity (H_2SO_4)	0
Alkalinity ($CaCO_3$)	250
pH, units	6.5-8.5
Hardness ($CaCO_3$)	250
Calcium (Ca)	100
Chlorides (Cl)	250
Sulfates (SO_4)	250
Iron (Fe)	0.2
Manganese (Mn)	0.2
Chlorine (Cl)	(a)
Fluorides (F)	1[b]
Silica (SiO_2)	50
Phenols	(c,d)
Nitrates (NO_3)	10[b]
Nitrites (NO_3)	(c)
Organics:	
Carbon tetrachloride	0.2[e]
Odor, threshold number	(c)
Taste, threshold number	(c)
Turbidity	(f)
Color, units	5
Dissolved solids	500
Suspended solids	10

* Unless otherwise indicated, units are mg/l and values that normally should not be exceeded. Quality of water prior to the addition of substances used for internal conditioning.

[a] Process waters for food canning are purposely chlorinated to a selected uniform level. An unchlorinated supply must be available for preparation of canning syrups.

[b] Waters used in the processing and formulation of foods for babies should be low in fluorides concentration. Because high nitrate intake is alleged to be involved in infant illnesses, the concentration of nitrates in waters used for processing baby foods should be low.

[c] Zero, not detectable by test.

[d] Because chlorination of food processing waters is a desirable and widespread practice, the phenol content of intake waters must be considered. Phenol and chlorine in water can react to form chlorophenol, which even in trace amounts can impart a medicinal off flavor to foods.

[e] Maximum permissible concentration may be lower depending on type of substance and its effect on odor and taste.

[f] As required by drinking water standards.

Source: Reference 11

Table 8. Guidelines for Interpretation of Water Quality for Irrigation

Irrigation Problem	Degree of Problem		
	No Problem	Increasing Problem	Severe Problem
SALINITY (affects crop water availability)			
ECw (mmhos/cm)	< 0.75	0.75-3.0	> 3.0
PERMEABILITY (affects infiltration rate into soil)			
ECw (mmhos/cm)	> 0.5	0.5-0.2	< 0.2
adj. SAR [1,2]			
Montorillonite (2:1 crystal latice)	< 6	6-9[3]	> 9
Illite-Vermiculite (2:1 crystal lattice)	< 8	8-16[3]	> 16
Kaolinite-sesquioxides (1:1 crystal lattice)	< 16	16-24[3]	> 24
SPECIFIC ION TOXICITY (affects sensitive crops)			
Sodium[4,5] (adj.SAR)	< 3	3-9	> 9
Chloride[4,5] (meq/l)	< 4	4-10	> 10
Boron (mg/l)	< 0.75	0.75-2.0	> 2.0
MISCELLANEOUS EFFECTS (affects susceptible crops)			
NO_3-N (or) NH_4-N (mg/l)	< 5	5-30	> 30
HCO_3 (meq/l) overhead sprinkling	< 1.5	1.5-8.5	> 8.5
pH	{Normal Range 6.5 - 8.4}		

[1]adj.SAR means Sodium Adsorption Ration and can be calculated using the procedure given in Reference 12.

[2]Values presented are for the dominant type of clay mineral in the soil since structural stability varies between the various clay types. Problems are less likely to develop if water salinity is high; more likely to develop if water salinity is low.

[3]Use the lower range if ECw < .4 mmhos/cm;
Use the intermediate range if ECw = 0.4 - 1.6 mmhos/cm;
Use upper limit if ECw > 1.6 mmhos/cm.

[4]Most tree crops and woody ornamentals are sensitive to sodium and chloride (use values shown). Most annual crops are not sensitive (use the salinity tolerance tables in Reference 12).

[5]With sprinkler irrigation on sensitive crops, sodium or chloride in excess of 3 meg/l under certain conditions has resulted in excessive leaf absorption and crop damage.

< means less than
> means more than

Source: Food and Agriculture Organization, 1976

CHAPTER 3 - REFERENCES

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CHAPTER 4

AVAILABILITY OF ADDITIONAL WATER SUPPLIES

Introduction

One of the central tasks in this project was to document available sources of water in the study area. This chapter contains the results of our analysis of supplies available from local or imported sources in the valley.

Seven potential alternatives are available for development of additional sources of supply. These include:

1. Pajaro River runoff.
2. Runoff from Corralitos Creek and other local drainages.
3. Development of deeper groundwater aquifers.
4. Water importation.
5. Water reclamation.
6. Water conservation.
7. Desalination.

Pajaro River is a viable source of water supply in the valley, however, the quality of this water in the divertible range of flows is lower than that of groundwater in most parts of the valley. The quality of waters diverted from the Pajaro River is, however, amenable to selection, within some broad limits. Steps which may be taken to ensure the diversion of better quality water include diverting at upstream locations within and without the valley and diverting at higher flows.

Methods and Accuracies. Our analysis of surface-water sources is based on the evaluation of existing gaging records. The accuracy of such an analysis is dependent mainly on three factors:

1. Completeness of data collection.
2. Validity of streamflow data.
3. Definition of the upper and lower limits of flow ranges likely to be divertible.

Available data on streamflow, water quality and sediment transport conditions were obtained. Records gathered for this study include nearly all gages in the Pajaro drainage . The broad data base was needed primarily to describe the respective roles of the Llagas/Uvas, Pacheco/Tequisquite and San Benito sub-basins in water quality and annual and seasonal flow variations in the Pajaro River at Chittenden.

Estimates of mean seasonal or annual runoff on gaged streams have variable accuracies. They are probably valid to within 5 percent at some stations, while the poorer records may be in error by as much as 20 percent. In some cases, the volumes of diversions, net reservoir storage, or channel infiltration above gages are not known. In others, the gaging records were collected during abnormally wet or dry periods. Even periods of normal rainfall may have generated runoff significantly more or less than the long-term mean. For example, we chose the 13-year interval of 1956 through 1968 as the base period for analysis of surface-water records. This period was chosen primarily due to the unusually extensive gaging records available for this time space in the basin. Rainfall during this period at both Watsonville and Gilroy was equivalent to 98 to 100 percent of the long-term mean. Yet, runoff was significantly below average for the 40-years of record for the Pajaro River at Chittenden, and also for other larger streams in the region (Table 1). Average annual rainfall at Watsonville was about 21.5 inches during this 40-year period. The estimates of yield developed in this chapter, however, are adequate for the objectives of this planning study. Any error in these estimates is very small relative to the uncertainties which may be associated with sediment and water quality conditions.

Assessments of most other sources of additional supply, such as water imports, reclamation and desalination are largely based on previous studies. An evaluation of the availability and quality of potential supplies from deeper aquifers is presented in a separate section in this report; unlike other supplemental sources, deeper aquifer development is largely independent of institutional or regulatory considerations.

All analyses in this chapter are based on water years, which begin October 1 of the preceding year and end on September 30 of the calendar year bearing the same date. Rainfall or climatologic years by convention begin on July 1 and end on June 30. In this report, rainfall year and water year is used conjunctively for analysis purposes assuming that the rainfall during July, August and September has negligible effects on runoff, sediment yields and water quality.

Pajaro River as a Source of Water Supply

The Pajaro River is potentially the primary existing source of additional supplies. It is the only existing local source which alone could meet the estimated range of supplemental water-supply needs of the Pajaro Valley.

In the following paragraphs, gross availability of water from the river is discussed in terms of statistics which describe mean flow, seasonal fluctuations in discharge, and year-to-year variability of streamflow. Major limitations and considerations affecting the ability to divert are also discussed in the context of:

a. Lack of a suitable on-stream reservoir site in the river in the Pajaro Valley.

Table 1. Variation of Mean Annual Runoff With Period of Record, Pajaro River and Nearby Streams

Stream	San Lorenzo River at	Corralitos Creek at	Pajaro River at	Pacheco Creek near
Station	Big Trees	Freedom [a]	Chittenden	Dunneville
Drainage Area (sq. mi.)	111	27.8	1186	146
Period or Record				
Begin	1938	1957	1940	1940
Through	1980 [b]	1980 [b]	1980 [b]	1980 [b]
Mean Runoff				
Period of Record (afa)	96360	10746	102900	24340
1956-1968	88980	9995 [c]	90640	22650
1969-1980	103820	11600	107190	27010
1956-1968 as percent for period of record	92.3	-	88.1 [d]	93.1
1956-1968 as percent for 1969-1980	85.7	86.2	84.6	83.9

[a] Without adjustment for City of Watsonville diversions.

[b] Gaging record continues through present; 1980 is last available data at the time of this report.

[c] Period of record for Corralitos Creek at Freedom begins in water year 1957. Solely for the purposes of this analysis a runoff during WY1956 estimated to be 20150 ac.ft., or 1.945 times the mean for the period of record, the same ration as for the San Lorenzo River at Big Trees.

[d] Proportionately lower runoff in Pajaro River attributed in part to initial filling of several new reservoirs.

b. Water quality constraints.

c. Sediment load constraints.

d. Other entitlements and competing environmental needs.

History of Streamflow and Water Quality Influences. Watershed conditions, groundwater pumpage and stream regulation in the basin above Chittenden all affect flows in the rivers. The sequence of major events affecting the volume, quality or seasonal runoff regime in the Pajaro River is summarized in Figure 1.

Quantity of Divertible Flows. The quantity of water available for diversion from the Pajaro River has been estimated from the flow-duration curve representing the years 1956-68 and a probability analysis of the distribution of daily discharges for the period 1956-80. The flow-duration curve, prepared from a statistical summary by the U.S. Geological Survey, represents the percent of the average year that a given discharge is equaled or exceeded (Figure 2).

The volume of flows within the divertible range may be calculated from the flow-duration curve and the flow-frequency data upon which it is based. On a preliminary basis, it may be assumed that flows of less than 25 cfs are too saline for most uses, and that flows greater than 1,000 cfs contain excessive sediment.* The volume of flows within this range during water years 1,956 through 1,968 averaged 25,700 acre feet. The total mean volume of diversions would vary as a function of the percent of total flow that can be diverted at any time. A probable diversion range of 8,500 to 17,000 ac-ft. per year can be estimated for flows between 25 and 1000 cfs. The discharge of the Pajaro River during these water years averaged 12 percent below the mean for the 41-year period of record at the Chittenden gage. Using the 41-year base, the range of possible diversions would be somewhat higher than the above values.

Annual variability of flows within the divertible range can be assessed from recurrence analysis of observed discharge. This analysis includes the 1956 through 1980 water years and is presented for 10 flow-range classes within the estimated limits of divertible discharges. For the 25 years of record, the number of days in which the mean daily discharge fell within each class was determined. A probability estimator for the number of days of flow in each class was computed by the rank-order procedure. When plotted on probability paper, annual variabilities in the number of days of flow in each class may be described by a straight line (Figure 3). For example, the figure indicates that there is approximately a 40 percent chance each year that the mean daily discharge will exceed 53 cfs for 75 days. Another

*Pertinent data are presented later in this chapter.

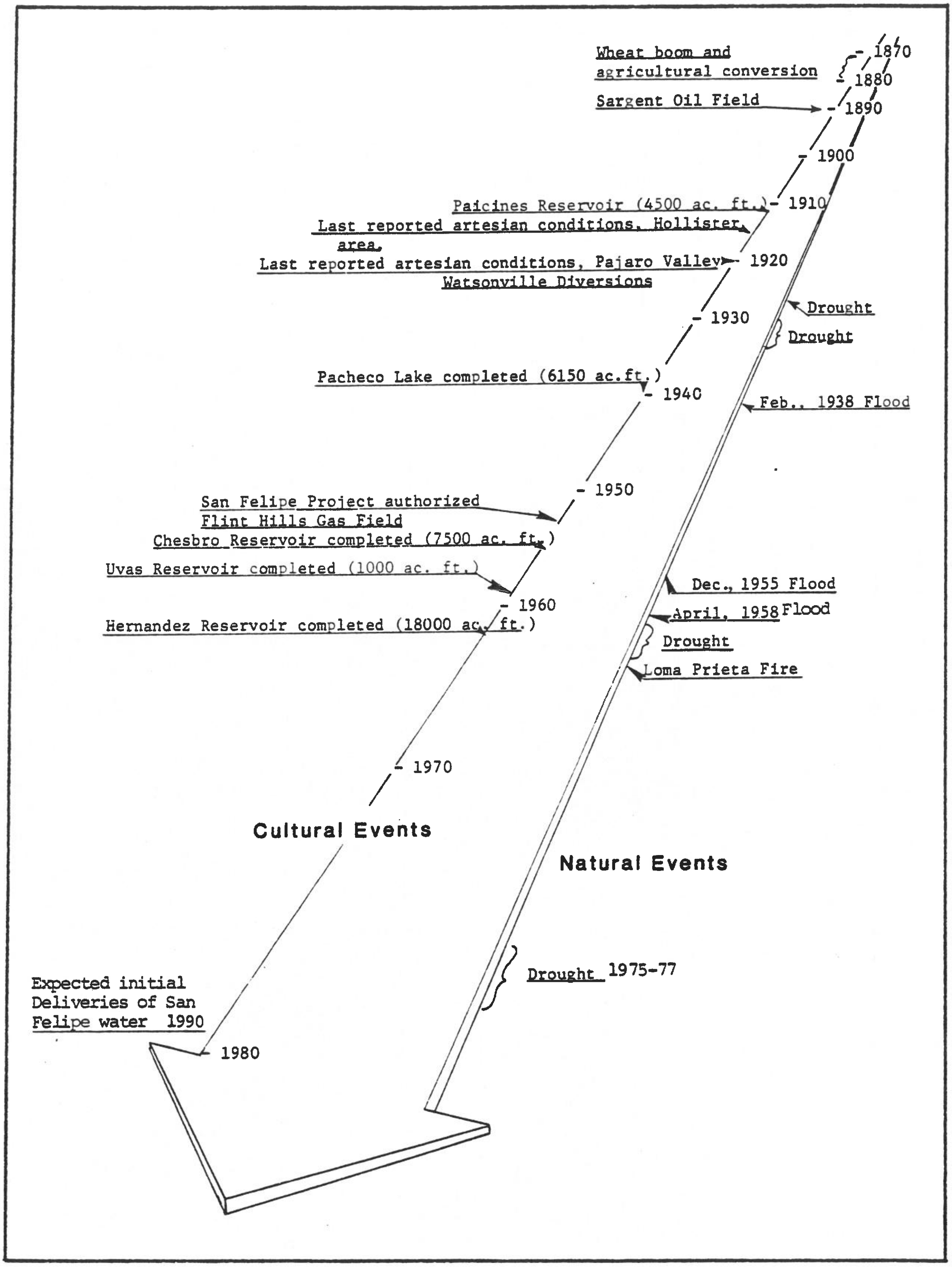
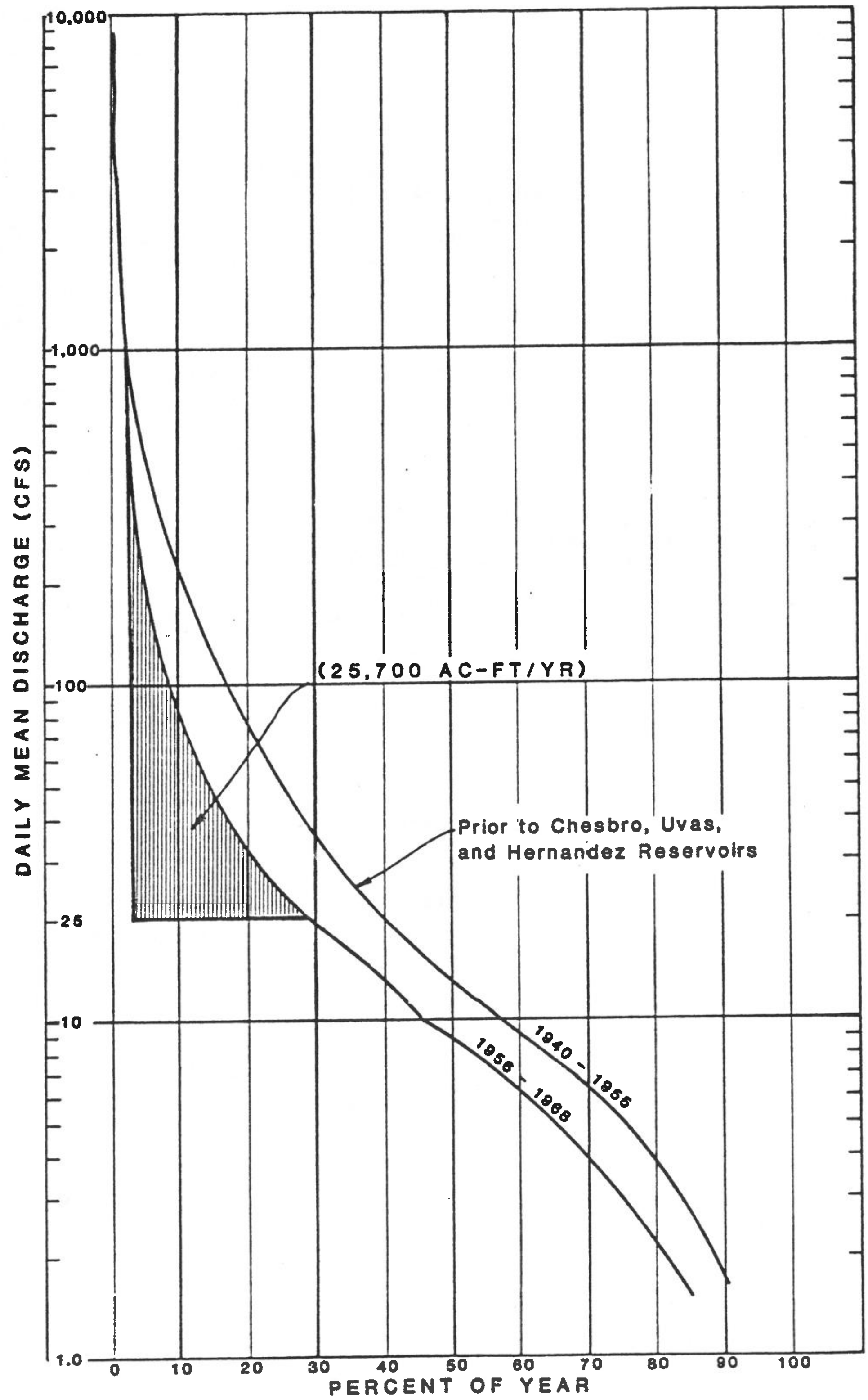


Figure 1. Sequence of major events affecting volume, seasonal distributions, or quality of water in the Pajaro River



Prepared from: Jorgensen and others, 1971. USGS open file report, vol. 1.

Figure 2. Flow-duration curve, Pajaro River at Chittenden

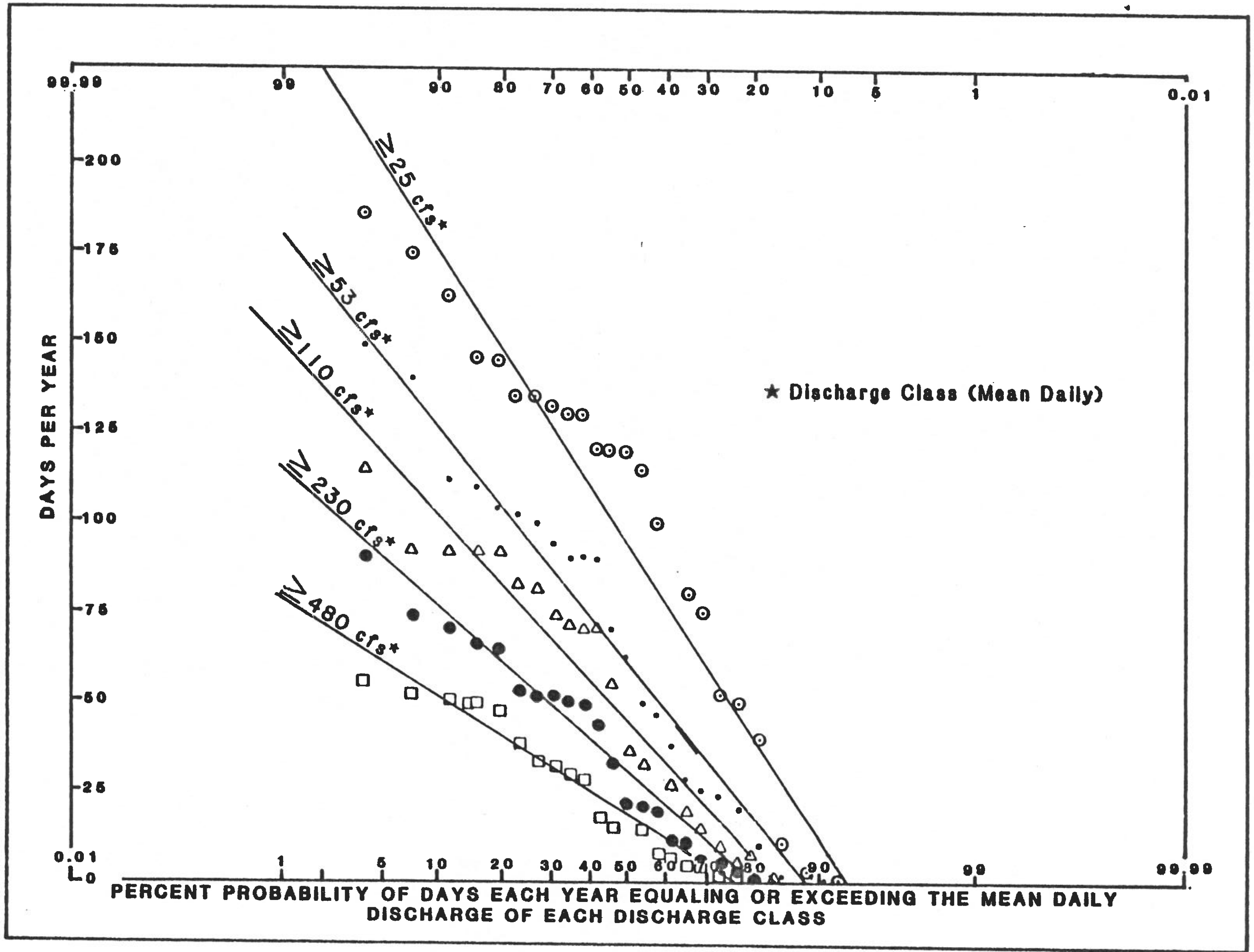


Figure 3. Annual variability of flow in the divertable range, Pajaro River at Chittenden, 1956-1980

useful transform of the probability estimator, shown in Figure 4, defines the number of days exceeding a given flow for years of varying amounts of runoff. As an example, during 75 percent of all years, there will be at least 15 days of flow equal to or greater than 100 cfs in the Pajaro River at Chittenden. Mean daily discharge will equal or exceed 100 cfs for about 46 days during a year of median runoff. In seasons with runoff greater than 90 percent of all years, roughly 104 days will have average flows exceeding 100 cfs. Flows within the divertible ranges are quantified in Table 2 for dry (75%), median (50%), wet (25%) and very wet (10%) years.

Quality of Divertible Flows. The quality of water in the Pajaro River as it enters the Pajaro Valley varies greatly with flow. Also very important are the relative proportions of flow being contributed by the Uvas, Llagas, Pacheco/Tequisquite and San Benito systems. At any given time, the ionic mix and loads of salts and contaminants passing the Chittenden gage are largely determined by the relative contributions from each source (DWR, 1968). Generally, however, the waters of the Pajaro River at moderate to moderately-high flows are of a magnesium-sodium, mixed-anion type. Pajaro River waters contain significantly greater relative loads of magnesium, sodium, sulfate and chloride than do most other natural waters in Monterey and Santa Cruz Counties. Arsenic and boron are present in greater amounts than in other natural waters of the Monterey Bay region.

Relations between flow and concentrations for each of these constituents were developed for this study. All known analyses made since 1951 by state, federal and local agencies were used in developing these relations. An example of the flow-to-dissolved solids relation is shown in summary form in Figure 5. The figure includes both our estimate of the best-fit curve and also the maximum and minimum envelopes.

These relations indicate that the salinity (level of total dissolved solids) of the river at Chittenden generally exceeds recommended maxima for domestic and food-processing use at flows of less than about 180 cfs. Total dissolved solids remain below the most conservative recommended limits for use in agriculture at most flows exceeding 30 cfs. Water quality standards and discharge thresholds for other key constituents are presented in Table 3.

There is a clear trade-off between the volume and quality of water available for additional supplies in the Pajaro Valley. On a preliminary basis, we assumed a value of 25 cfs as being the lower limit for water of acceptable quality. Assuming that 1,000 cfs proves to be the upper limit of divertible flows based on sediment considerations, mean TDS concentrations in diverted waters might be expected to fall in the range of 400 to 600 mg/l. The discharge weighted average may fall within the lower end of this range. This is lower than the median concentrations of groundwater east of Watsonville (about 850 mg/l), and equal to or slightly larger than those found in unintruded areas southwest of Watsonville (about 400 to 500 mg/l), and much lower than those reported from the river-mouth and Springfield areas affected by sea water intrusion. In order to achieve diversions of higher quality, the following options can be pursued:

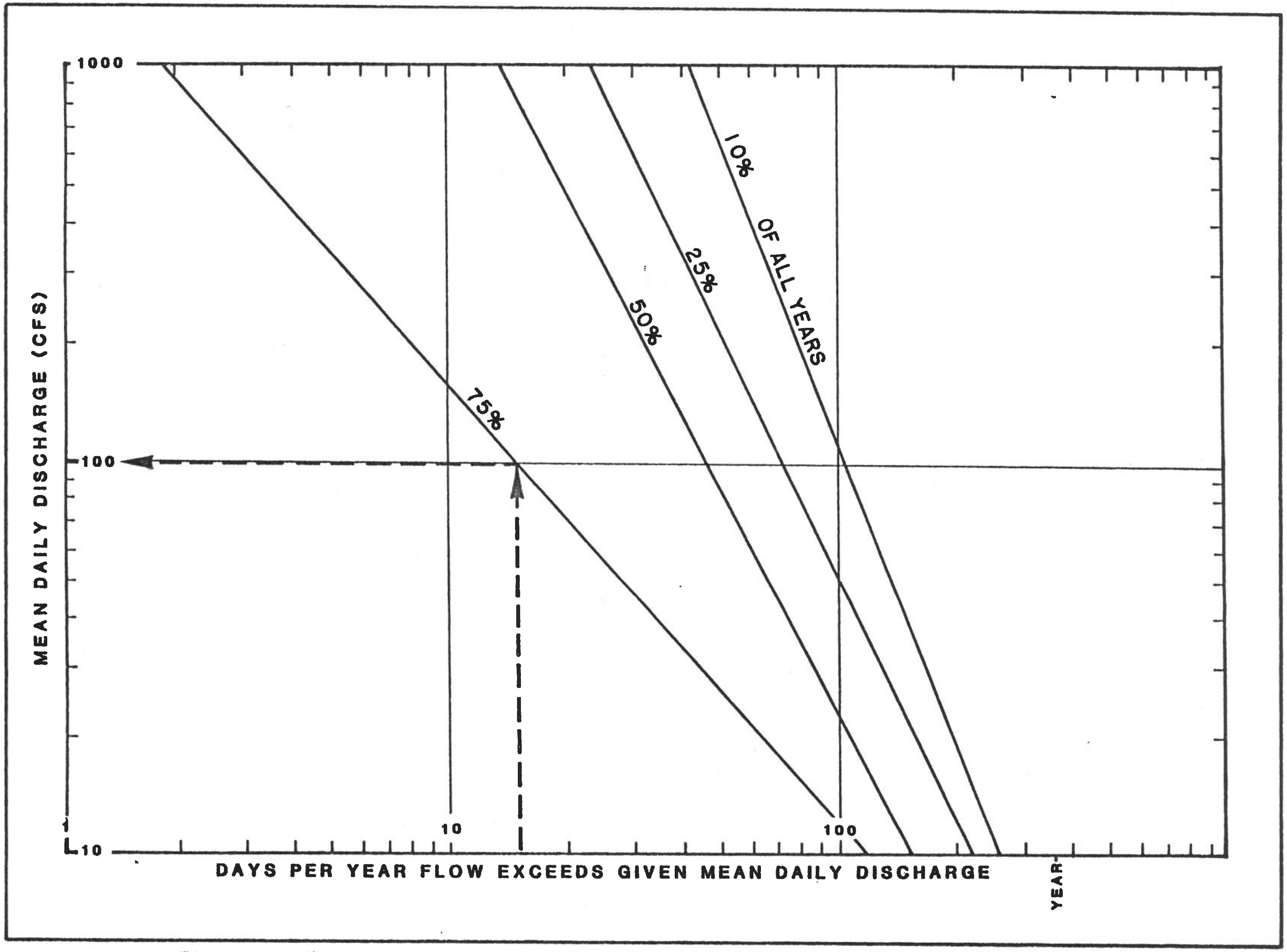


Figure 4.. Flow-Exceedance variability, Pajaro River at Chittenden, 1956-1980

Table 2. Duration of Flows Within Divertible Ranges Flow Classes, Pajaro River at Chittenden, WY1956-WY1980[a]

Discharge Range (cfs)	Class Log Mean (cfs)	Probability of Occurrence 10% Very Wet	25% Wet	50% Median	75% Dry
A. Number of Days Within Flow Class					
25-50		43	40	28	24
50-75		20	18	18	9
75-100		13	11	7	4
100-150		16	13	9	5
150-200		9	8	5	2.2
200-300		12	9	6	2.4
300-500		13	10	6	2
500-750		8	6	4	1
750-1000		5	3	2	0.6
> -1000		41	24	14	1.8
B. Number of Days With Discharge Exceeding Specified Thresholds					
≥25		180	142	94	52
≥50		137	102	66	28
≥75		117	84	53	19
≥100		104	73	46	15
≥150		88	60	37	10
≥200		79	52	32	7.8
≥300		67	43	26	5.4
≥500		54	33	20	3.4
≥750		46	27	16	2.4
≥1000		41	24	14	1.8
C. Mean Annual Flow Within Discharge Class (Acre-Feet per Year)[b]					
25-50	35.4	3019	2809	1966	1685
50-75	61.2	2428	2185	1578	1093
75-100	86.6	2233	1889	1202	687
100-150	123	3904	3172	2196	1220
150-200	173	3087	2744	1715	754
200-300	245	5831	4374	2916	1166
300-500	387	9979	7676	4606	1535
500-750	612	9711	7283	4856	1214
750-1000	866	8589	5153	3435	1031
Total annual flow, divertible range		48781	37285	24470	10386
One-third of total annual flow		16260	12428	8157	3462

[a]Source: HEA staff analysis of annual discharge summaries published by USGS.

[b]Computed by multiplication of number of days within a class by the geometric (log) mean of the class and by a factor (1.9804) converting cfs-days to acre-feet. Actual accuracy limited to that of the constituent data, or 2 significant figures.

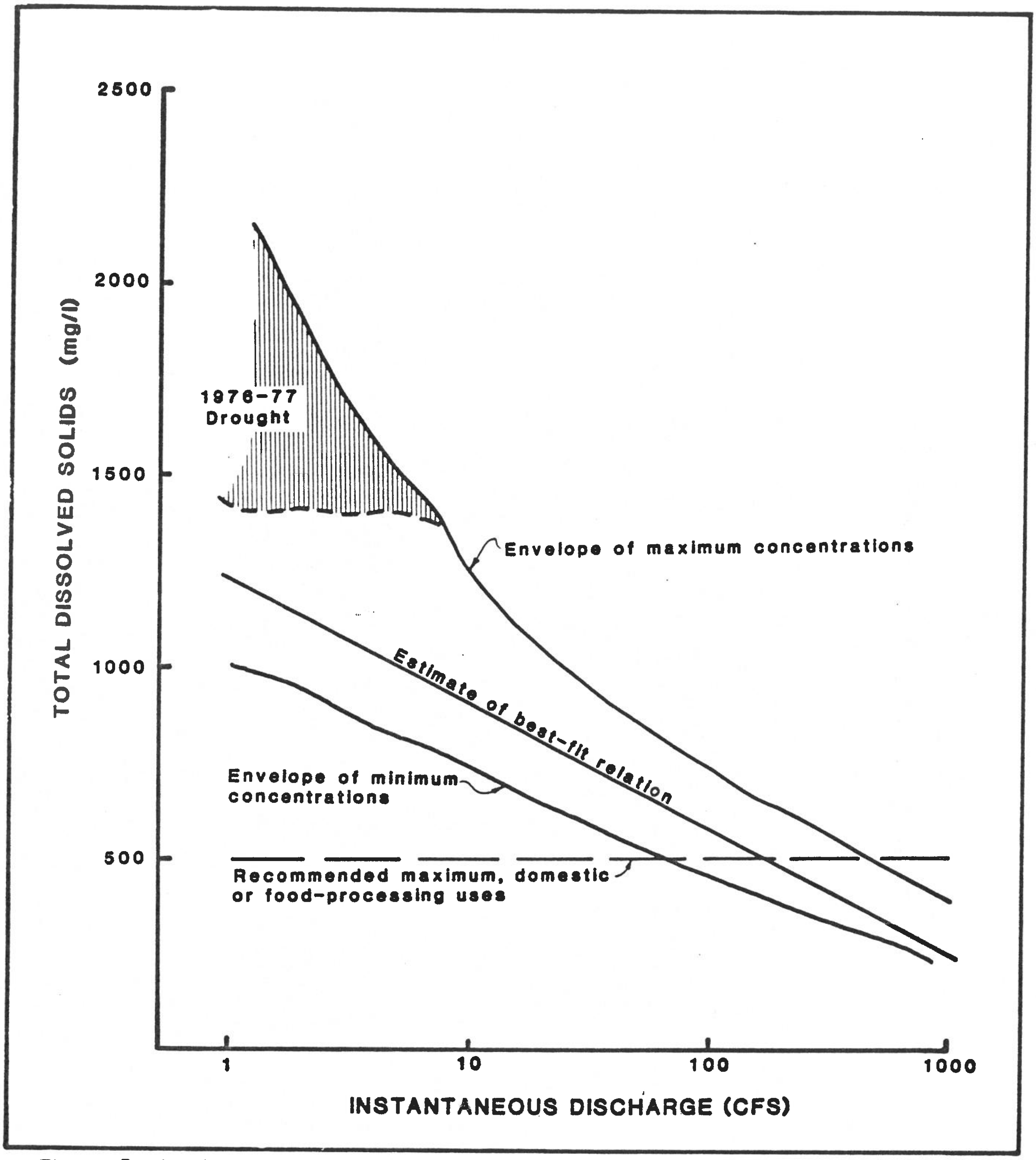


Figure 5. Variation of total dissolved solids with discharge in the Pajaro River at Chittenden, 1951-1980

Table 3. Minimum Discharge Levels in the Pajaro River for Meeting Water Quality Standards for Various Beneficial Uses

Parameter	Water Quality Standards				Required Discharge Level For Meeting The Appropriate Water Quality Level In The Pajaro River At Chittenden, cfs[d]			
	Municipal and Industrial[a]			Agricultural	Lower Limit of Quality Parameter		Upper Limit of Quality Parameter	
	Domestic	Food Processing	Soft Drink Manufacture	Most Conservative[b]	Average Conditions	Worst Case Conditions	Average Conditions	Worst Case Conditions
TDS (mg/l)	500	500		750	> 180	> 400	> 30	> 100
EC[c] (μmhos/cm)	800	800		1200	> 180	> 400	> 35	> 85
SAR				< 3				
Cl (mg/l)	250	250	500	< 142	No discharge constraint		No discharge constraint	
SO_4 (mg/l)	250	250	500		> 10	> 35	> 0.1	> 3
NO_3 (mg/l)	45	45		< 22	> 15	> 65	No discharge constraint	
B (mg/l)	1.0			< 0.75	> 10	> 40	> 4	> 20
AS (mg/l)	0.05			0.1	No discharge constraint		No discharge constraint	
Fe (mg/l)	0.3	0.2	0.3	5.0	Additional data needed		No discharge constraint	

[a] Source: Report of the Committee on Water Quality Criteria, U.S. Department of Interior, April 1968.

[b] Source: Ayers, R.S. and Westcot, D.W., 1976, Water Quality for Agriculture: FAO Irrigation and Drainage Paper No. 29.

[c] For the period 1970-80, electrical conductivity is related to total dissolved solids in the Pajaro River at Chittenden by the equation: TDS = 38.6 + 0.59 (EC)

[d] Data developed on the basis of statistical analysis of 30 years of record (1951-1980) on flow and water quality for Pajaro River, at Chittenden.

1. Divert less water, having lower mean salinities, at higher minimum flows.

2. Divert from the Pajaro River above the mouth of the San Benito River, where salinities may be appreciably lower.

3. Dilute Pajaro diversions with better-quality sources, such as imported water from Arroyo Seco or diversions from local streams.

4. Divert from the Pajaro River at flows exceeding 1,000 cfs, accepting the greater cost of these rarer, more sediment-laden diversions.

The Pajaro River also transports significant amounts of pesticides and other organic compounds (Greenlee and Ricker, 1982). Most of these compounds, however, are transported in adsorbed form, attached to particles of fine sediment. Carefully-managed settlement and filtration would minimize the concentration of these substances in the diverted waters. Additional water quality monitoring as part of a predesign program may be required to ensure that these quality parameters would not pose a constraint for municipal and industrial use of diverted waters. If the diverted waters are used exclusively for crop irrigation purposes, the quality of the Pajaro River water would be suitable for use on all crops raised in the valley.

Sediment Limitations. While the concentrations of salts generally decrease with increasing discharge, sediment concentrations increase at higher discharge levels. Suspended sediment loads in the Pajaro River are probably very high at flood stage, and are appreciable even at the upper end of the flow range considered for diversion.

Usable suspended sediment records for the Pajaro River have been collected only at the Chittenden gage, and even these are limited to a handful of measurements at flows exceeding 75 cfs. An inferred suspended sediment rating curve (Figure 6) developed on the basis of limited available data indicates that suspended sediment loads may increase with approximately the 2.6 power of streamflow. This relation, if valid, would be similar to that observed in the San Lorenzo River and other streams of comparable size in the region. Considerable additional data would be needed to establish the relation with significantly greater precision.*

Using the inferred curve in Figure 6, transport rates of 3,000 to 12,000 tons per day of suspended sediment may be expected in the river at Chittenden at flows of 1,000 cfs, the maximum discharge considered

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* Bedload transport is not included in this analysis. We know of no bedload measurements from the Pajaro River at significant sediment-moving flows. Bedload transport should be evaluated in any future detailed analysis of potential diversions from the river.

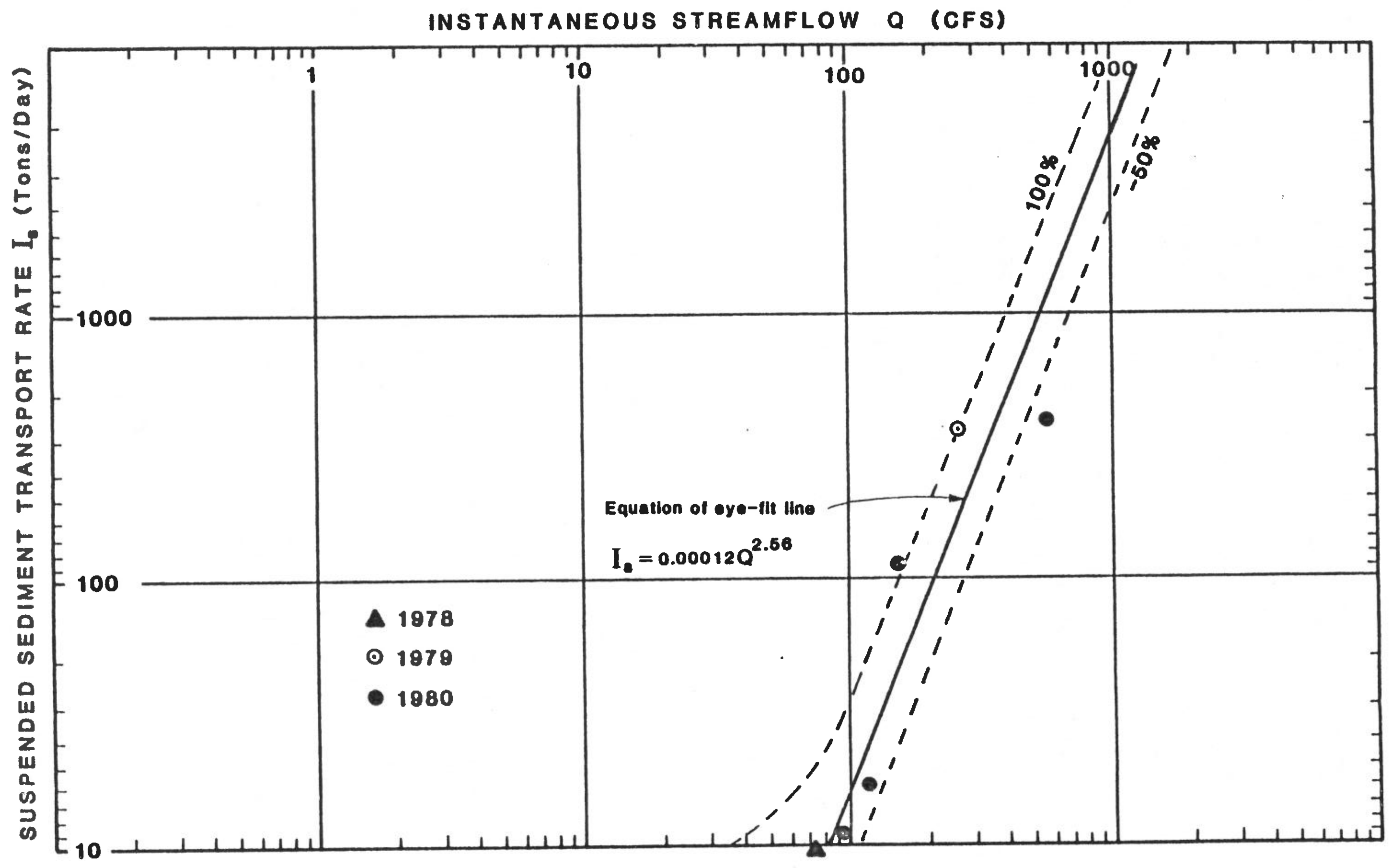


Figure 6. Inferred suspended sediment rating curve, Pajaro River at Chittenden

in this discussion for direct diversion from the Pajaro River. If the diverted water is used for recharge purposes, the sediment must be removed prior to such use. Removal is most likely to occur in settling basins and storage reservoirs. The higher the discharge at which diversion takes place, the greater the need for settling will be. Maximum rates of filling of settling basins are estimated to range from 1 to 3 ac-ft per 1,000 ac-ft of water diverted at high flow conditions. Assumptions and bases of calculation are as follows:

1. 1,000 cfs maximum flow at which diversions may occur.

2. Transport rates of 3,000-12,000 tons per day, per Figure 6.

3. Mean suspended sediment concentrations in the diversions equalling those in the stream.

4. No bedload incorporated in the diversions.

5. Complete settlement, at a mean bulk density of 65 lbs/cu. ft.

The need for the use of any settling basins would depend on the end use of the diverted water. If Pajaro River water is diverted into an off-stream storage reservoir for recharge spreading or irrigation use during the dry weather season, no additional settling beyond that achieved in the reservoir is needed.

Other Entitlements and Competing Environmental Needs. No water rights search was conducted on either the Pajaro River or the local streams. We believe, however, that most uses of these streams are on the basis of historical or traditional practice, and lack the formality of an assigned set of rights. Minimum flows considered for diversions are 25 cfs in both the Pajaro River and Corralitos Creek. It is doubtful that existing appropriations ever approach this rate of flow which is equivalent to over 11,000 gallons per minute.

Recently, Monterey County Flood Control and Water Conservation District filed an application with the State Water Resources Control Board for a permit to divert water from the Pajaro River and Pescadero Creek. A number of protests have been submitted by local governments and state agencies to the State Water Resources Control Board with respect to this water right permit. The list of the protestants include Santa Cruz County, Santa Clara Valley Water District, Aromas Water District, California Department of Fish and Game, Gavilan Water Conservation District and California Department of Parks and Recreation.

The major concerns raised in these protests include the impact of the proposed project on fish, wildlife and riparian habitat, seismic safety, loss of a potential water supply source by upstream users, and effect of flow reductions in the Pajaro River on local beach conditions. Most of the agencies filing a protest have indicated that they may withdraw their protest if certain specified conditions are met.

There are significant aquatic and riparian values associated with the Pajaro River, especially upstream of the Logan (Granite Rock) Quarry to Highway 101 near Chittenden. The Department of Fish and Game (1967) notes:

> "... the river has much cover in the form of willows on the banks, and good steelhead spawning and nursery habitat. Other fishes include the warm water game species of largemouth bass, black crappie and bluegill. Carp, hitch and other rough fish exist here also."

Resident fish between Logan and Thurwacter Road west of Watsonville (near the head of tidal influence) include rough fish such as squawfish, sucker, carp and hitch. Both reaches are especially significant as migratory pathways for the steelhead of the Uvas, Llagas, Pescadero and Pacheco Creek systems. Diversions from the river should recognize the migratory requirements of both adults and smolt.

Other habitat values and conditions are not expected to be heavily affected by diversions from the 25-1,000 cfs flow range. The environmental impact upon aquatic and riparian resources should be considered when a more specific plan is developed.

<u>Local Streams</u>

Several streams originating in the Santa Cruz Mountains cross the Pajaro Valley, conveying moderate amounts of good quality water. These streams are shown in Figure 7, with their estimated mean annual runoff. Corralitos Creek and the College Lake-Salsipuedes Creek system carry virtually all of this runoff to the Pajaro River at Watsonville. All substantial flows in these streams are derived from winter storms. Principal constraints to their development as sources of additional supply are the lack of suitable reservoir sites, limited mean annual yields, fish and wildlife needs and to a lesser and uncertain extent, water quality.

<u>Contributing Areas.</u> While these streams drain much of the Pajaro Valley, virtually all of the divertible runoff originates in the Santa Cruz Mountains. It is helpful to distinguish two very different types of runoff-producing areas:

1. Uplands: Generally those areas underlain by the Purisima Formation and older consolidated sediments and derivative soils within the Santa Cruz Mountains.

2. Lowlands: Most areas on or near the valley floor that are underlain by Aromas or younger alluvial or marine sediments and derivative soils.

The two are distinguished by a ten- or twenty-fold difference in mean amounts of runoff which they contribute to the surface-water system. Over a long term, average rates of runoff from the upland areas vary

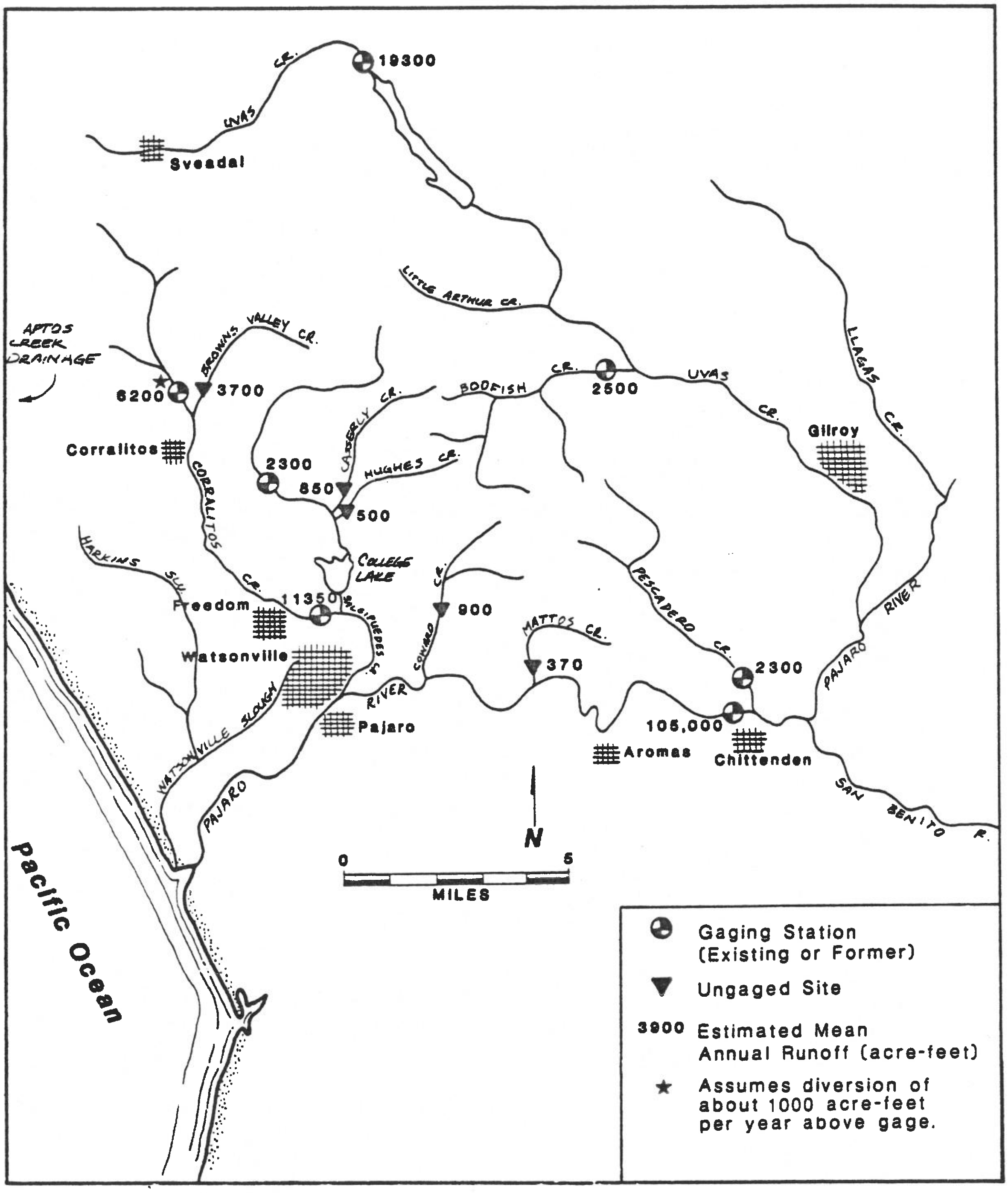


Figure 7. Estimated mean annual runoff, Pajaro Valley area

from 200 to 1,000 acre-feet per year (afa) per square mile; mean runoff from the same area of lowland soils might range from 0 to 50 afa or slightly more where urbanized or unusually rich in clays. Runoff from the lowland areas occurs primarily during the wettest years (Figure 8) and most severe storms when it is least manageable or desirable. The runoff regime of the lowland areas are more fully described in the preceding sections of this chapter.

Available Data. Serious evaluations of runoff in local streams have previously been published in Bulletin No. 5 (State Water Resources Board, 1953), in the Santa Cruz County Water-Supply Master Plan (Creegan and D'Angelo, 1968), and in City of Watsonville's water master plan (Montgomery Engineers, 1979). The following discussion might be considered as a revision of the most recent analysis, based on an updated and expanded information base. Available information on rainfall in eastern Santa Cruz County has been re-compiled and expanded by the staff of the USGS Water-Resources Division in Menlo Park. Their analysis, still unpublished and subject to review, indicates substantial changes in interpretations of mean annual rainfall in the mountainous portions of the basin. Important new records of streamflow at several gages in the local streams, covering the drought years and subsequent seasons through 1980, were also made available. We expanded the analysis to encompass records of gages in the Bodfish and Uvas Creek basins, which share common boundaries and watershed influences with the local streams of the Pajaro Valley. Finally, relatively short, older gaging records for Green Valley, Corralitos, and Casserly Creeks were located, adjusted where feasible and then used in computing mean and extreme runoff.

Methods. Mean runoff and annual streamflow variability were computed from existing data. A rainfall-to-runoff relation for the eastern Santa Cruz Mountains was developed from these data (Table 4) and is shown graphically in Figure 9. Runoff for ungaged basins (Table 5) was estimated from the eye-fitted curve, as shown on the figure.

Streamflow and Availability. The distribution of mean annual runoff throughout the northern Pajaro Valley is shown in Figure 7. The mean yearly runoff from all the local streams is estimated to be 16,300 afa. Of this total, 11,350 afa (or 70 percent), flow through lower Corralitos Creek; 15,000 afa (or 92 percent) enters the Pajaro River from the combined Salsipuedes Creek/Corralitos Creek/College Lake portion of the drainage net.

Anticipated year-to-year variability in runoff from these basins may be expressed in an analysis similar to that undertaken for the Pajaro River. We estimate that about 60 to 65 percent of these flows occur within discharge ranges likely to be divertible. This estimate is based on the observed distribution of flows for the stream gage on Corralitos Creek at Freedom, shown in Figure 10. This curve is based on data for the water years 1957 through 1968. We assumed that flows between 25 and 350 cfs in lower Corralitos Creek might be a likely range from which diversions could be made. Mean runoff within these limits averaged about 5,500 afa during this twelve-year period, for which duration data are published. Runoff for this period was about

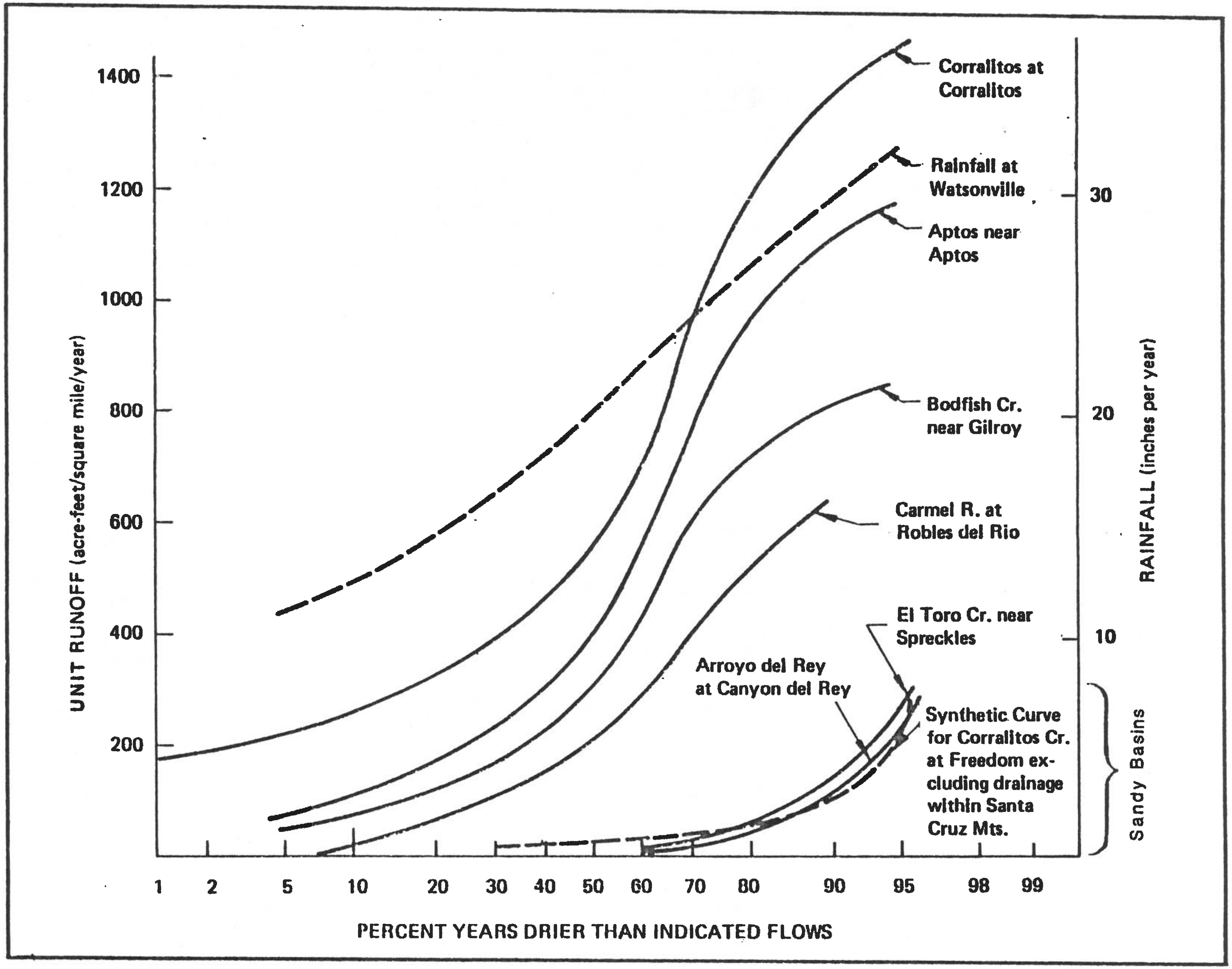


Figure 8. Differences in unit runoff between mountain and sandy valley-floor basins, Pajaro Valley and nearby areas

Table 4. Measured Runoff, Stream in or Near the Pajaro Valley[a]

Stream, Station	Mean Basin Precipitation (inches)[b]	Drainage Area Total (mi²)	Drainage Area Effective (mi²)[b]	Period of Record[c] Begin	End	%Ppt.[d]	Annual Runoff Mean (afa)	Unit (afa)/(mi²)[e]
Corralitos Creek								
near Corralitos	38	10.6	10.6	1958	1972	98%	7220[h]	681[h]
at Freedom	37	27.8	18[g]	1957	1980	99%	11360[h]	631[h]
Aptos Creek								
at Aptos	36	12.2	12.2	1959	1972	95%	5530	453
near Aptos	37	10.2	10.2	1972	1980	98%	5540	543
Green Valley Creek								
at Connell Road	36	7.05	5.	1947	1949[i]	68%	1605	321[j]
				1963	1967	97%	2232	447
Pescadero Creek								
near Chittenden	24	10.2	10.2	1971	1980	97%	2300	225
Bodfish Creek								
near Gilroy	29	7.4	7.4	1960	1980	96%	2540	343
Uvas Creek								
above Uvas Res.	42	21.0	21.	1962	1980	100%	19300	919
Uvas Creek								
at Sveadal	45	2.88	2.8	1973	1974	146%	6105	2120[b]

[a]Source: Gaging records of USGS and DWR.
[b]Mean annual precipitation and area of effective runoff-producing watershed. Excludes any large areas underlain by Aromas or alluvial sediments.
[c]Complete water years only.
[d]Percent of long-term mean precipitation recorded at Watsonville during period 1940-1980.
[e]Runoff per square mile of effective drainage area.
[f]Mean of annual runoff adjusted for year's rainfall by procedures described in text; expressed as runoff per square mile of effective drainage area.
[g]Excludes watershed downstream of the mouth of Browns Valley Creek.
[h]Mean runoff increased by 1000 afa to adjust for estimated City of Watsonville diversions.
[i]Initial period of gaging by State of California (see Bulletin No. 5).
[j]Only 2 of the 7 years of record approached or exceeded mean annual.
[k]Water years 1973 and 1974 were both wetter than average. We estimate the rainfall-normalized unit runoff might be 1060 afa/mi.², based on 20 years of rainfall-to-runoff variation for Bodfish Creek.

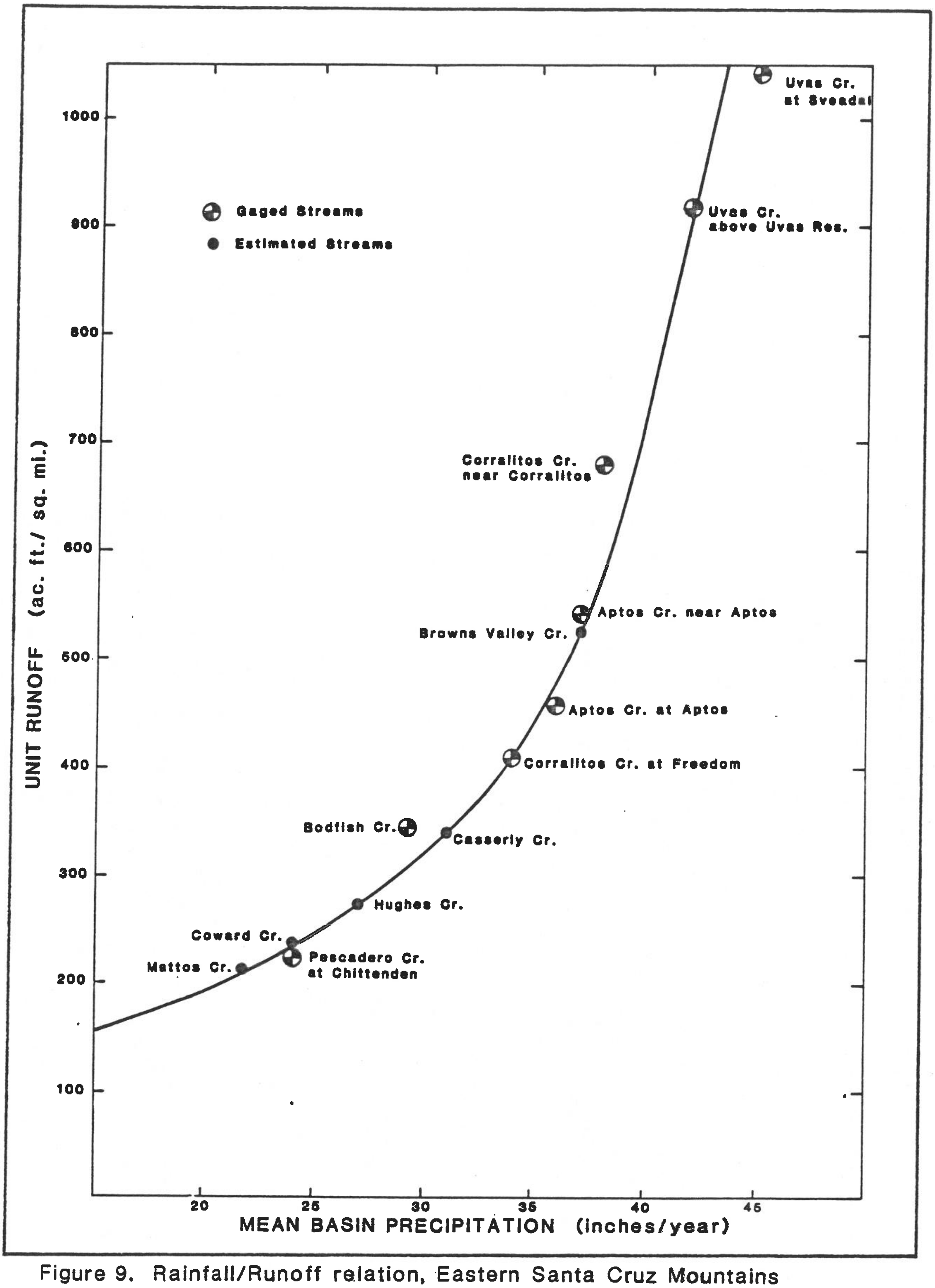
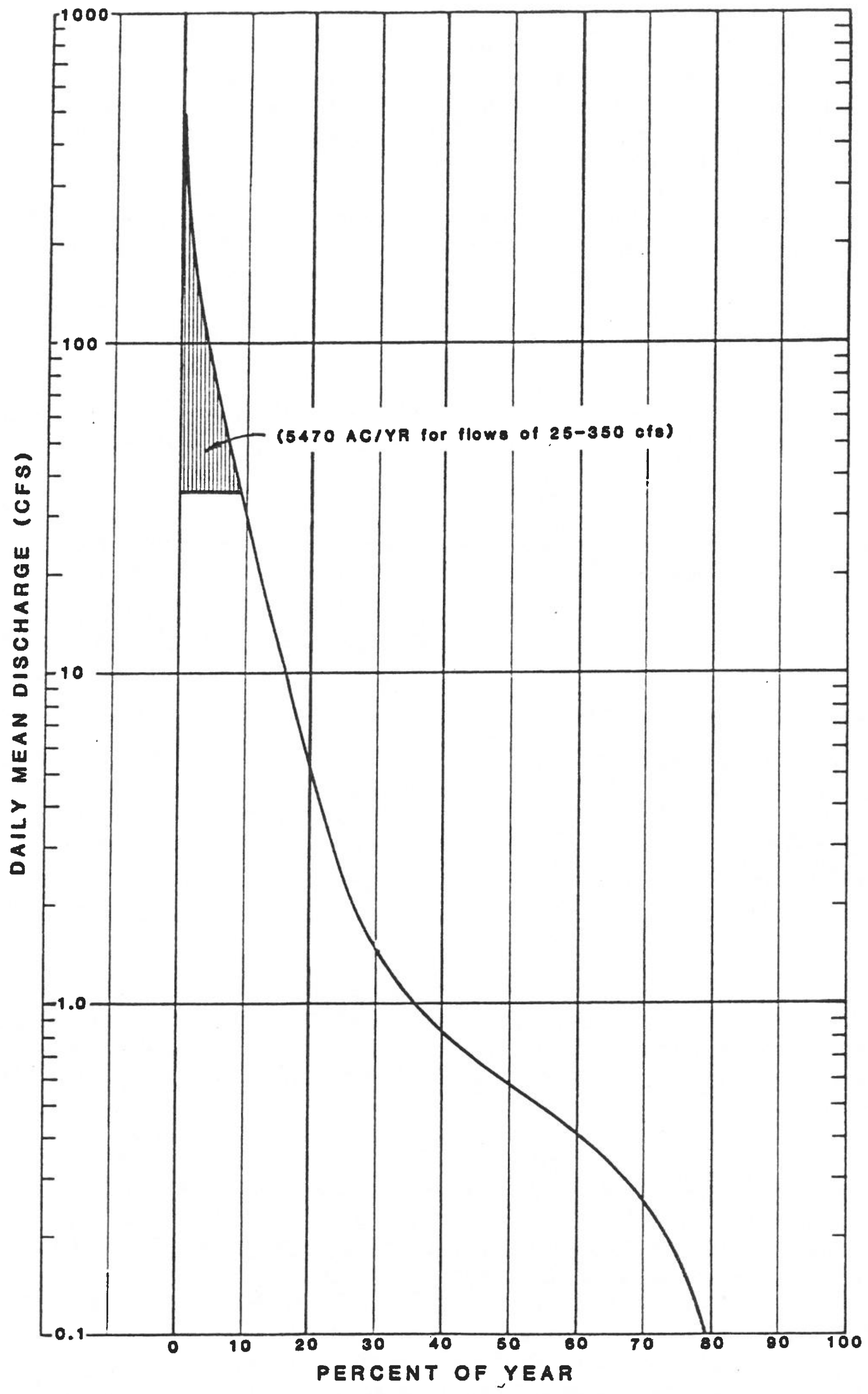


Figure 9. Rainfall/Runoff relation, Eastern Santa Cruz Mountains

Table 5. Estimated Mean Annual Runoff for Ungaged Streams, Pajaro Valley

Stream, Station	Drainage Total (mi^2)	Area Effective[a] (mi^2)	Mean Annual Rainfall[b] (inches)	Estimated Mean Annual Runoff[c] Unit (afa/mi^2)	Estimated Mean Annual Runoff[c] Total (afa)
Browns Valley Cr. at Corralitos Cr.	7.43	7.2	37	515	3700
Casserly Cr. at Casserly Road	2.53	2.5	31	335	840
Hughes Cr. at Casserly Road	1.73	1.7	27	275	470
Coward Cr. at Thompson's Grove	3.84	3.8	24	240	910
Mattos Gl. at mountain front	1.67	1.67	22	220	370

[a] Excluding larger areas underlain by Aromas Formation or alluvial sediments, which usually do not produce substantial runoff.
[b] From unpublished isohyetal map for Santa Cruz County, USGS.
[c] Based on rainfall-runoff relations defined in Figure 10.



Prepared from: Jorgensen and others, 1971. USGS open file report, vol. 1.

Figure 10. Flow-duration curve Corralitos Creek at Freedom, 1957-1968. Streamflow during this eleven-year period was about 12 percent below the mean for the 24 years of gage operation.

12 percent below the mean for the 24 years of available records at this gage. For the purpose of this preliminary analysis, we estimate that mean annual runoff, in the flow range of 25 to 350 cfs might be 6,200 to 6,300 afa, or about 60 percent of the total annual mean runoff. It may be possible to include somewhat greater or lesser flows within the range considered divertible; however, information on sediment transport rates and other constraints is not sufficient to project less-conservative limits. It should also be noted that this gage is located downstream of City of Watsonville's diversions from Corralitos and Browns Valley Creeks.

At the first level of approximation, the mean annual flow within a divertible range may be estimated using the proportion of 60 to 65 percent developed for Corralitos Creek. Maximum available diversions may also be estimated (Table 6), again assuming that no more than two-thirds of the flow in the divertible range may actually be taken:

Table 6. Estimated Mean Runoff Within Divertible Ranges and Volumes of Probable Range of Direct Diversions From Local Stream

Stream System	Mean Runoff Within Divertible Range afa	Probable Range of Direct Diversions afa
1. Lower Corralitos	6200	2100-4200
2. College Lake	2300	800-1600
3. Lower Salsipuedes (1+2)	8500	2800-5600
4. Coward Creek	600	200-400
5. Mattos Gulch	240	80-160

The annual variability of flows in lower Corralitos Creek is summarized in Table 7 and Figure 11. The relative variability probably may be generalized to the College Lake system. Annual fluctuations in smaller streams, such as Coward Creek or Mattos Gulch, are probably more extreme.

Constraints. The principal constraint to developing local streams has been their variable yields, coupled with the lack of suitable storage sites. The San Andreas fault bisects most basins; special design requirements needed to cope with the severe seismic hazards make water storage unusually costly. All potential storage sites in the Casserly, Hughes, Coward and Mattos Creek basins are within or adjacent to the fault zone (Farrington, 1974). Poor foundation properties at proposed damsites on the larger local streams have discouraged or precluded conventional reservoir development. Important possible exceptions are sites on Pescadero Creek near Chittenden, which to our knowledge have not yet been investigated.

Table 7. Duration of Flows Within Divertible Ranges, Corralitos Creek at Freedom, 1957-1980[a]

Discharge Range (cfs)	Class Log Mean (cfs)	Probability of Occurrence 10%	25%	50%	75%
A. Number of Days Within Flow Class					
25-50		54	44	36	12.3
50-75		18	14	10	2.2
75-100		9	6	3.8	0.6
100-150		9	7	3.6	0.5
150-200		4	2.9	1.6	0.2
200-350		5.2	3.8	1.6	0.1
≥ 350		6.8	4.3	1.4	< 0.1
B. Days With Discharge Exceeding Specified Thresholds					
≥ 25		106	82	58	16
≥ 50		52	38	22	3.7
≥ 75		34	24	12	1.5
≥ 100		25	18	8.2	0.9
≥ 150		16	11	4.6	0.4
≥ 200		12	8.1	3	0.2
≥ 350		6.8	4.3	1.4	< 0.1
C. Mean Annual Flow (afa) Within Discharge Class[b]					
25-50	35.4	3792	3089	2528	864
50-75	61.2	2185	1699	1214	267
75-100	86.6	1546	1031	653	258
100-150	123	2196	1708	878	122
150-200	173	1372	995	549	69
200-350	265	2733	1997	841	53
Total (25-350)	-	13824	10519	6663	1633
One-third of total	-	4608	3506	2221	544

[a]Source: HEA staff analysis of annual discharge summaries published by USGS.

[b]Computed by multiplication of number of days within a class by the geometric (log) mean of the class and by a factor (1.9804) converting cfs-days to acre-feet. Actual accuracy limited to that of the constituent data, or 2 significant figures.

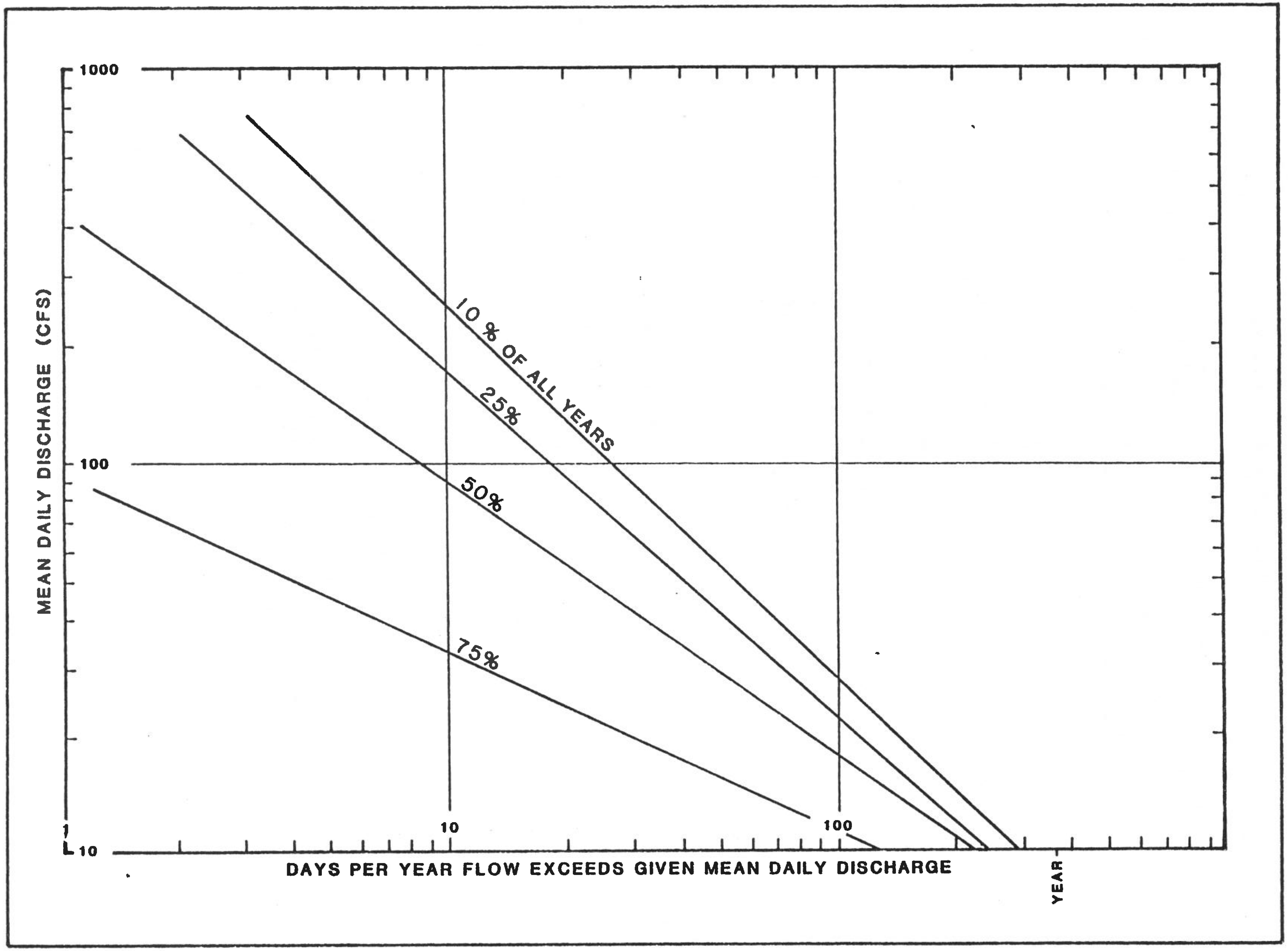


Figure 11. Flow exceedance variability, Corralitos Creek at Freedom, 1957-1980

Alternative storage might be provided either in offsite facilities or in the subsurface environment. In the past, state, federal and local agencies have tentatively proposed that local runoff be stored in either Pinto or College Lakes (State Water Resources Board, 1953; Army Corps of Engineers, 1967 and 1975; Creegan & D'Angelo/ McCandless Engineers, 1968). Pinto Lake is now committed to other uses; arising and/or regulating the level of College Lake would involve significant loss of agricultural productivity and would be complicated by ownership, institutional, and regulatory considerations.

Water quality in the local streams is generally more desirable for most uses than that of concurrent flows in the Pajaro River. From data collected during a single two-day period by the Santa Cruz County office of Watershed Management, the composition of waters in each major stream can be compared (Table 8). The sampled flows were primarily runoff from a late-season minor storm on April 25 and 26, 1978. Mean daily flow in Corralitos Creek increased from about 9 cfs on April 24 to 86 cfs on April 26, and had receded to 46 cfs by April 27. Many of the streams were sampled in the range of flows considered to be divertible. No flow was observed in Mattos Gulch. The quality of water improved systematically toward the northwest. Total dissolved solids decreased from about 550 mg/l in Coward Creek to about 130 mg/l in lower Corralitos Creek. Flows also increased to the northwest, exaggerating the water quality differences due to more dilution with storm runoff.

Storm runoff in the lower reaches of the local streams is known to contain moderate levels of nutrients, pesticides and other organic compounds and bacteria (DWR, 1968; Montgomery Engineers, 1979; Greenlee and Ricker, 1982). Most of the pesticides and other organic compounds are normally adsorbed on fine suspended sediment.

Pescadero Creek was not sampled during the late-April 1978 storm. Very few analyses of Pescadero Creek waters have been made, perhaps because the stream is not readily accessible. To our knowledge, only one analysis of waters collected at discharges exceeding summer baseflows is available. This sample -- taken December 2, 1970, by DWR staff on a day with a mean daily flow of 22 cfs (USGS records) -- contained a dissolved solids load of 347 mg/l, at a measured specific conductance of 611 umhos/cm. During summers or droughts, specific conductances of 1,100 to 1,500 umhos/cm have been observed. The Department of Water Resources reports that one sample taken from Pescadero Creek above Hatfield Creek on August 26, 1971, and analyzed at their laboratory, was a sodium-chloride water with a specific conductance of 10,200 umhos/cm. No other analyses at this station (1269.30) are available. From these and other data, we conclude that waters in Pescadero Creek at divertible flows have a composition similar to that of the adjoining Casserly Creek basin, although at slightly greater concentrations. The stream at extreme low flow may be influenced by seepages of sodium-chloride waters, presumably of "geologic" origin. Pescadero Creek enters the Pajaro River immediately upstream of the Chittenden gage.

Table 8. Water Quality in Pajaro Valley Streams During Runoff From Minor Storm of April 25, 1978[a]

Stream & Station	Date[b]	Flow (cfs)	pH (units)	EC (µmhos/cm.)	Temp (°C)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Alkalinity[c] (mg/l)	SO4 (mg/l)	Cl (mg/l)	NO_3-N (mg/l)	TDS[d] (mg/l)	FC[e] (col./100 ml)	FS[f] (col./100 ml)	Susp.[g] Solids (mg/l)
Pajaro River at Chittenden	780427	300[h]	7.7	894	20.5	50.0	50.0	84	3.4	263	166	43.6	1.27	556	12400	4000	2372
Pajaro River above Salsipuedes Cr.	780427	300[h]	8.2	1010	19.0	52.5	62.0	117	3.2	251	336	52.8	1.54	672	8400	2600	1562
Coward Creek at Pajaro River	780427	0.5	9.4	722	25.3	92.5	34.0	55.5	3.6	265	137	34.6	1.60	558	160	200	7
Kelley Lake influent	780426	2.6	8.0	655	19.5	65.0	35.0	41.2	3.3	252	55.6	37.3	0.23	405	1000	200	19
Corralitos Creek at Varni Road	780426	70[h]	8.2	179	11.5	25.0	10.0	93.2	2.0	82	39.5	7.8	0.03	131	400	3000	305
Casserly Creek at College Lake inlet	780426	1.5	8.3	544	16.1	58.0	21.5	53.6	2.6	176	44.0	37.2	0.35	348	1400	4000	18
Salsipuedes Creek at Pajaro River	780426	71.7	8.4	289	16.6	36.0	14.0	22.8	2.6	96	54.0	16.3	0.93	232	200	800	135
Pajaro River at Thurwacter Bridge	780427	370	9.4	790	16.8	40.0	46.0	80.0	3.4	212	148	43.6	1.27	549	-	-	394

[a] Samples collected and analyzed by Santa Cruz County Office of Watershed Management (Greenlee & Ricker, 1982).
[b] Year, month, day.
[c] Alkalinity as mg/l, $CaCO_3$.
[d] Total dissolved solids.
[e] Fecal coliform, colonies per 100 milliliters.
[f] Fecal streptococcus, colonies per 100 milliliters.
[g] Suspended solids, or suspended sediment; comparisons between streams should be made at equivalent flows.

Within the ranges considered for diversion, the local streams of the Pajaro basin serve to dilute the salt, bacterial, and (probably) sediment loads of the Pajaro River. Discharge-weighted dissolved-solids concentrations in the local streams average about 40 to 50 percent of those in the Pajaro River. These streams contribute a volume in the divertible ranges equal to about 15 to 20 percent of that in the river at Chittenden. The net effect is that salinities in the river below Watsonville (but above the tidal influence) are 7 to 10 percent lower than at the head of the valley near Chittenden.

Most of the local streams transport problematic sediment loads at most flows within the divertible ranges. Very little is known about sediment transport rates in these streams. If diversions are to be made from the lower portions of any of these channels, settlement or filtration may be required prior to direct use. Additional information on the rates and sizes of sediments moved by some of these streams may be needed.

Principal existing uses of these streams include those of public water supply (City of Watsonville), agricultural water supply, fish and wildlife and recreation. Withdrawals from the lower segments of these streams in the ranges considered for diversions are not expected to interfere with any existing uses. Corralitos, Browns Valley, Green Valley and Casserly Creeks all support steelhead runs (Jerry Smith and Don Alley, unpublished observations); passage requirements of these fish must be considered in the design of any diversions.

Development of Deeper Aquifers

At present, there are very few water wells in the Pajaro Valley deeper than 700 feet. Saturated sediments extend a further 1,000 to 2,000 feet beneath most of the basin. These deeper aquifers have not been seriously explored beneath the Pajaro Valley. They are best known from exploratory and production wells developed during the past six or seven years in adjoining groundwater basins. Yields and water quality from these new nearby wells have compared favorably with those from other local groundwater sources.

The small number of wells deeper than 700 feet reflect the widely-held belief that water from the deeper zones may be more costly or of poorer quality than those drawn from the shallower aquifers. They may, however, potentially prove to be the least costly and most accessible supplemental source available to Pajaro Valley users. It may also be possible to develop the deep aquifer without building a surface distribution system, a critical attribute in minimizing both the time and costs before new water becomes available. They are also perhaps the only potentially-significant new source which can be developed by individuals or groups of owners or operators.

The extent to which the deeper aquifers may be considered a developable resource is not established. Three principal uncertainties remain:

1. The geologic and hydrologic relations of the water-bearing units are generally known, but not at a level of detail adequate to project a water-supply system.

2. As there are almost no deep wells within several miles of the Pajaro Valley floor, yields and aquifer properties are not predictable with confidence. This area is likely to have somewhat lower yields as it is further from the original sediment sources and probably is composed of sediments that are slightly finer grained than better-known portions of the aquifers in the Soquel-Aptos area and in northern Monterey County.

3. The quality of waters in the deeper zones is generally most suited to agricultural uses. Anticipated salinities beneath the valley-floor area are expected to be comparable or slightly higher than those encountered near Moss Landing and Castroville.

The future of water development in the Pajaro basin depends in part on resolving these uncertainties. A more detailed analysis of the deeper aquifers is presented in Appendix B of this report.

Water Importation

We considered three possible external sources for additional water supplies:

1. Northern Santa Cruz County.

2. San Felipe Project.

3. Arroyo Seco.

Only the San Felipe and Arroyo Seco projects appear to be a reliable and major source of supply. Conveyance expense may be the principal cost for either water supply.

Northern Santa Cruz County. Traditionally, northern Santa Cruz County has been regarded as a likely source of imported water for the Pajaro Valley (State Water Resources Board, 1953: Creegan & D'Angelo/McCandless, 1968; Brown & Caldwell, 1976). Additional water-supply projects presently proposed for other portions of Santa Cruz involve yields of about 2,000 to 4,000 afa. These yields are almost fully committed. Water-supply projects in northern Santa Cruz County are too small to meet the envisioned needs of the Pajaro Valley, nor is it likely that any surplus will be available. In our opinion, significant imports of water from northern Santa Cruz County are not feasible both due to low yield of such projects and appreciable cost of transport of such supplies.

San Felipe Project. Another major source of water for the Pajaro Valley is imported water through the San Felipe Division of the Central Valley Project. The San Felipe Division is planned to supply some 200,000 acre-ft per year of Sacramento-San Joaquin Delta water to Santa Clara, San Benito, Santa Cruz and Monterey Counties. The bulk of this water will be delivered to the Santa Clara Valley via the Santa Clara conduit; 40,000 acre-ft will be diverted annually to the Hollister-Watsonville area of which 17,000 acre-ft per year will be reserved for the Pajaro Valley. No time-table is currently set for completion of the Watsonville portion of the project, however, if local governments in Santa Cruz and Monterey Counties do not apply for delivery of this water by 1990 they may lose their allocation to other users in the Central Valley Project systems (Montgomery Engineers, 1979). Projected 1991 cost of this water is estimated by the Bureau to be $37.50 per acre-ft for agricultural use and $75.00 per acre-ft for municipal and industrial use plus the cost of transportation from the Pacheco Tunnel outlet to the service area. These data were obtained through personal communication with Mr. Henry Hansen of the Sacramento Regional Planning Office, Bureau of Reclamation.

Details of the San Felipe Project facilities intended for delivering water to Watsonville area have been significantly altered from that presented to Congress in 1967 as described in the House Document 500 (HD 500). As presently structured, South Santa Clara County will be served through the Santa Clara conduit and northern San Benito County will be served through the Hollister conduit. All San Felipe water will be obtained from San Luis Reservoir and will be transported via the Pacheco Tunnel to a common distribution site near Pacheco Creek. Adequate capacity has been provided within the tunnel to supply Santa Clara, Hollister and Watsonville service areas. Similar provisions will be made in the Hollister conduit for this service area. However, since local interests have indicated that service to Watsonville would not be required for 10 to 15 years, final design of the Watsonville transport facilities has been delayed.

Arroyo Seco. Major dams and water-supply projects on the Arroyo Seco near Soledad have been under consideration at many times since the late-1890's. The Monterey County Flood Control and Water Conservation District (MCFCWCD) recently completed a feasibility analysis of this source; other recent reviews took place in the 1940's and 1960's. Existing data indicate that a large storage facility on the stream might yield on the order of 40,000 to 80,000 acre-ft per year (afa) of water with total dissolved solids of 150 to 300 mg/l. This is the highest quality source of additional waters which might be used in the Pajaro Valley.

Water Reclamation

A detailed analysis of wastewater reclamation and reuse in Santa Cruz County was carried out during wastewater management facilities planning studies for the City of Santa Cruz (Brown & Caldwell, 1978). In this project, the feasibility of transporting treated Santa Cruz wastewater to the Pajaro Valley for crop irrigation and the use of Watsonville effluent for the same purpose were investigated. The general conclusion of these studies was that secondary treated wastewater from Santa Cruz would not be suitable for crop irrigation purposes due to its poor chemical characteristics. Treated wastewater from Watsonville also has marginal chemical composition due to high dissolved solids, chloride and sodium concentration and could only be used under carefully managed conditions on soils with good drainage characteristics.

Irrigation reuse of food processing washwaters was also investigated in the Pajaro Valley (Montgomery Engineers, 1978). The results of this study showed that it would be feasible to use such washwaters for irrigation of fodder crops. The cost of this method, however, was in excess of continuing the discharge of such washwaters into the Watsonville wastewater treatment plant, and therefore, the project was not implemented.

Since the completion of the two reclamation studies cited above, there have been some changes in regulatory policy for discharge of treated wastewaters into coastal waters. It now appears probable that secondary treatment of municipal wastewater would not be required for discharge into the ocean. This change in discharge requirement makes the reclamation of wastewater even less likely in the Pajaro Valley because the use of primary treated effluent for crop irrigation is severely restricted by health authorities. The economics of food processing washwater reclamation would also become less favorable under these conditions.

The Monterey Regional Water Pollution Control Agency has been carrying out a pilot field program for evaluating the feasibility of using tertiary treated wastewater for irrigation of food crops. This project is currently in its fifth and final year. The results of the program to date indicate that no adverse health effects would be created by the use of properly treated wastewater on human food crops. The discharge capacity of the Monterey Regional Water Pollution Control Plant is about 21 million gallons per day (mgd). If this plant is converted to an advanced treatment facility, there is adequate local demand for the use of its production capacity. It is, therefore, improbable that any water would be available for export to the Pajaro Valley from this source.

Desalination

Additional water supplies might be obtained by desalination of seawater or other sources of poor quality. This water would be expensive by comparison with other sources. Probable costs in the Pajaro Valley were recently estimated to be in excess of $300 per acre-foot (Montgomery Engineers, 1979), exclusive of any pumping or conveyance charges. Some discussion has been given to subsidizing desalination by the use of "waste heat" from heavy industrial facilities in the Moss Landing area, however, serious competition for such energy sources has developed during the past several years. We doubt that desalination, even when subsidized, can serve as a cost-effective source of additional water in the Pajaro basin.

Water Conservation

Conservation practices in municipal, industrial and agricultural water use can reduce the total demand for water in the Pajaro Valley. The overall impact of such practices, however, can only be determined by detailed investigation of alternative methods for achieving conservation goals in each of the above areas.

Significant increases in energy costs in recent years may have provided an impetus for the adoption of more efficient irrigation practices in the Pajaro Valley (as reflected by reductions in the applied water demand for strawberries, celery, etc.). The results of field investigations carried out by Santa Cruz County Agricultural Extension Service under contract with AMBAG indicate that farmers in the Pajaro Valley are attaining fairly high irrigation efficiencies and in the case of some crops such as apples, artichoke and brussels sprouts, they appear to use less water than is needed by the crop. For other crops such as lettuce, cauliflower and celery, irrigation efficiencies appear to be low and could be potentially improved (Agricultural Extension Service, 1983). In a recent report, the Extension Service indicates that annual savings of 1,200 ac-ft per year could be achieved if all farmers with lands overlying perched water tables would adopt scientific irrigation scheduling methods. The net irrigation water savings over the perched water zone areas (consisting of about 13,000 acres in the valley floor areas underlain by thick clay layers, as well as semi-perched soils in old terraces found in the upper fingers of the valley and low lying hills, such as Corralitos and Casserly areas) would result in a corresponding reduction in net water withdrawal from productive aquifers. Similar savings can be achieved in other portions of the basin, however, such savings would be more beneficial in terms of a reduction in the cost of energy to farmers than in improving the hydrologic balance of the basin.

The potential for water conservation by domestic and industrial users has also been reviewed by AMBAG staff. Based on this review, it has been estimated that about 350 ac-ft of water could be saved per year if the users in the existing 10,500 connections served by the City of Watsonville water supply system install water saving devices on faucets, shower heads and in toilet tanks. This value was developed on the basis of the results of a detailed water conservation study conducted by the San Diego Association of Governments (July 1981). In this study, it was estimated that a savings of 30 gallons per day could be realized by installing the following water conservation devices: faucet aerators, in-line shower head restrictors, toilet tank flush volume reducer, water softener back flushing reduction and the use of moisture sensing devices for lawn irrigation. The initial installation cost of these devices was estimated at about $10 per dwelling unit.

No data are available on the potential for water conservation in food processing industries in the Pajaro Valley, however, because these industries utilize an appreciable volume of water it is probable that some reductions in water use can be achieved at a reasonable cost. Methods of conservation employed by food processors in the Santa Clara Valley area include the reuse of water by employing finer mesh screens, changes in the peeling operations, clarifying reuse waters, the use of advance cooling towers and avoiding the use of water for floor cleaning as much as possible. An economic incentive for such reductions may exist in the Pajaro Valley because these industries are charged on the basis of volume and organic loading levels of the process wastes discharged into the city sewer system.

In March of 1984, a number of water supply agencies, water conservation districts and wastewater management agencies in Monterey County published the final draft of a Water Conservation Plan for Monterey County (Monterey Peninsula Water Management District, 1984). The stated purpose of this plan is to provide a basis for assessment of the need for both agricultural and urban water conservation techniques, to identify those techniques that merit further examination, and evaluate the procedures for implementing these methods in Monterey County through planning policies and programs. Another objective of the plan is to enable compliance with State Water Resources Control Board Requirements for adoption of water conservation practices as a pre-requisite to approval of any new water right permits. The final draft of the water conservation plan for Monterey County contains specific recommendations for attaining conservation goals in urban and agricultural water use. When adopted, this plan would apply to the Monterey County portion of the Pajaro Valley and possibly to the service area of the proposed Pescadero Creek project.

CHAPTER 4 - REFERENCES

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CHAPTER 5

TECHNICAL ALTERNATIVES FOR WATER SUPPLY AUGMENTATION

Introduction

Technically feasible alternatives for water supply augmentation in the Pajaro Valley are discussed in this chapter. These alternatives include groundwater replenishment by surface spreading or by injection, deep aquifer development, and surface water supply delivery for crop irrigation in the coastal areas. In this chapter, these alternatives are discussed on a conceptual level and technical feasibility of each alternative is evaluated. A selection of technically feasible alternatives is also made for further analysis in the succeeding chapters of this report.

Groundwater Replenishment

Groundwater replenishment can be most effectively carried out in the coastal dunes flanking the valley floor north and south of the Pajaro River. The reasons for this are twofold. First, salt water intrusion has occurred in this area and has gradually progressed inland over several decades. Second, because of the sandy soil and subsoil conditions, the dune areas are most suitable for recharge spreading operations in the valley.

If recharge operations were to be conducted by well injection method, again the coastal area would be the best location for siting of the injection wells. Surface spreading and injection recharge alternatives are discussed briefly in the following sections:

Surface Spreading Methods. Groundwater recharge by surface spreading can be achieved by a number of methods which are discussed in detail in a publication by Blair, 1976. These methods vary on the basis of whether percolation occurs from the bottom or through the sidewalls of spreading facilities. Detailed specifications are provided in the above reference on the desirable width and depth of the spreading basins or trenches under different soil and operational conditions.

A detailed discussion of the merits and disadvantages of various spreading alternatives is beyond the scope of this report, however, considering the rather permeable soil conditions at potential recharge sites in the Pajaro Valley, the need for preserving agricultural and open space areas and technical factors which would preclude the excavation of deep trenches or basins it appears that infiltration basins or canals would be the most suitable methods for groundwater recharge in the sandy coastal areas of the Pajaro Valley.

Well Injection Method. In this method one or more wells can be used to recharge water directly in the desired aquifer(s). The main advantage of this approach is the flexibility in locating the recharge wells in areas of maximum need. In general, recharge wells are used for creating a fresh water barrier against salt water intrusion. The main disadvantage of this method of recharge is the high cost of constructing the injection wells and associated water distribution facilities, the need for highly treated water to prevent the clogging of the injection wells, and the high cost of operating the injection system. Based on all of these factors, it does not appear that a well injection recharge system would be viable in the Pajaro Valley especially since other options with less stringent requirements can be used to attain the same objectives. The use of injection wells was considered in a previous study (Brown & Caldwell, 1978). Cost data from that study will be updated for comparison with other water supply augmentation alternatives.

Surface Water Supply Delivery Systems

Under this option, local or imported sources of supply would be distributed to coastal farmers. Such deliveries would reduce pumpage from the aquifers in areas most heavily impacted by sea water intrusion. Several options can be considered for surface water delivery based on the source of supply, method of storage, and method of distribution. These options are enumerated below for the various system components:

1. Potential sources of additional supply.

   (a) Pajaro River

   (b) Other local streams

   (c) San Felipe Project

   (d) Arroyo Seco Project

2. Storage sites.

   (a) Pescadero Creek Valley

   (b) College Lake

   (c) Harkins Slough

   (d) Bolsa De San Cayetano Canyon

   (e) Hansen Slough

   (f) West Branch Struve Slough

3. Distribution methods.

   (a) Discharge to Pajaro River for direct withdrawal by farmers

(b) Distribution through primary and secondary networks of pipes or canals

Each of the above options need to be discussed in more detail to evaluate the most viable system for the Pajaro Valley area.

Deep Aquifer System

There is potential for obtaining water of suitable quality from the deeper portion of Aromas and Purisima formations in the Pajaro Valley. Production and test wells drilled into these formations to the north and south of the Pajaro Valley have indicated the existence of a potential source of supply. Some uncertainty exists, however, with regard to the sustained yield and quality of water of deeper aquifers. Drilling of test wells in the valley would be required to resolve some of these questions. A more detailed discussion of the deep aquifer system is presented in Appendix B of this report.

DETAILED ANALYSIS OF ALTERNATIVE WATER SUPPLY AUGMENTATION METHODS

Groundwater Replenishment

Groundwater recharge by surface spreading in the coastal hill areas of the valley north and south of the mouth of the Pajaro River has been proposed as a method for stemming the intrusion of sea water into the alluvial aquifer and for alleviating some of the overdraft condition in the basin. The technical questions posed in this regard pertain to the siting of recharge areas, the amount of water that can effectively be recharged into local aquifers, sources of supply for the recharge areas, and operational characteristics of the recharge systems. These issues are discussed briefly in the following sections. Data on cost requirements for the recharge operations are presented in Chapter 6.

Siting of Surface Spreading Facilities. The requisite conditions for the operation of successful surface spreading sites are as follows:

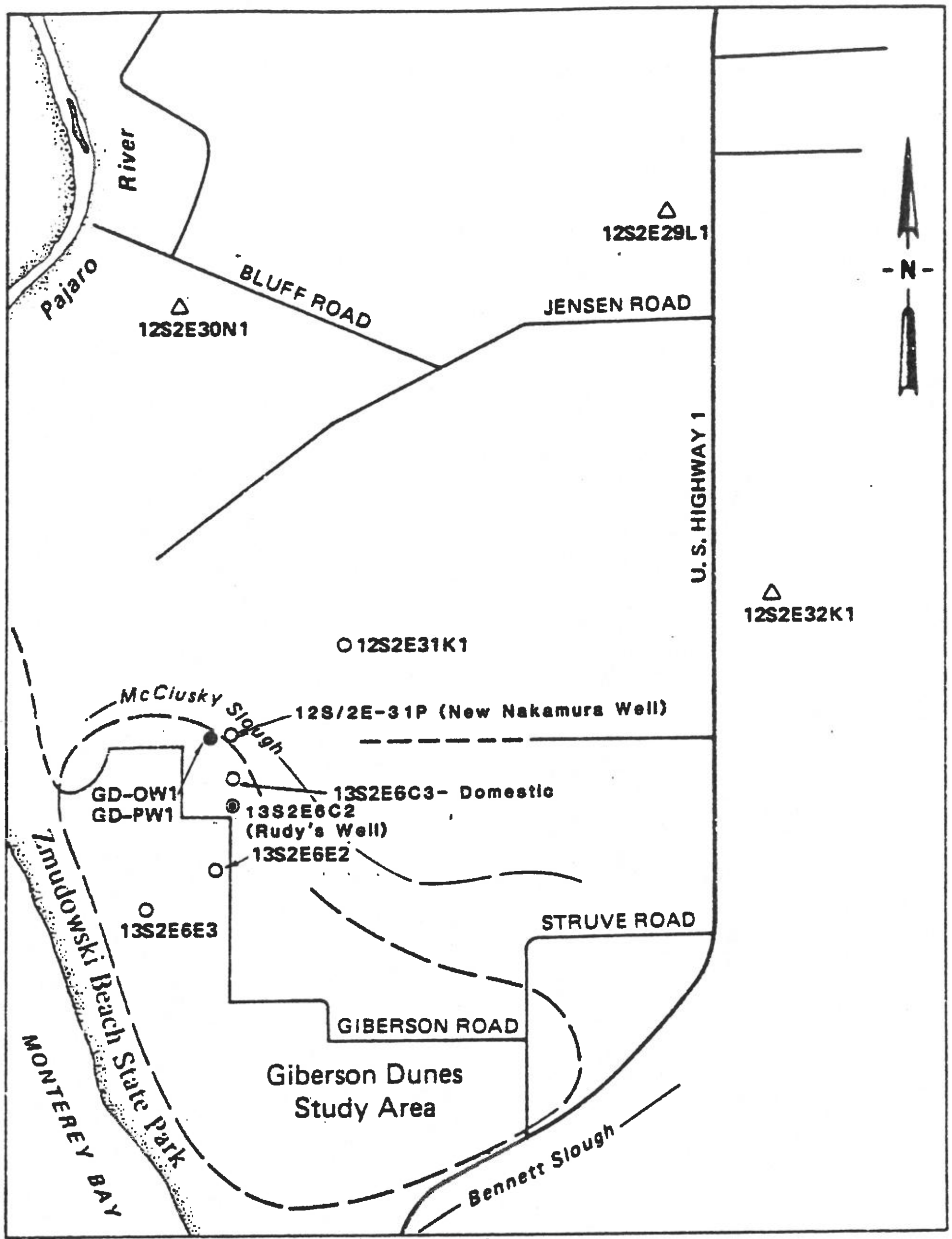
a. Permeable soil conditions.

b. Existence of geologic materials of high permeability characteristics between surface soils and the groundwater table.

c. An unconfined aquifer with high transmissivity and storage capacity characteristics.

d. Availability of space in the aquifer to store the recharged water.

Based on these criteria, two candidate sites were selected for field investigation in consultation with the TAC. These sites are located in the Giberson Dunes area in Monterey County and the San Andres Dunes area in Santa Cruz County. Field geotechnical investigations were carried out at these sites in locations identified in Figures 1 and 2. The results of these investigations are discussed in detail in a separate report prepared by Woodward-Clyde Consultants (Appendix C). These results indicate the existence of highly favorable conditions in the Springfield area and moderately fair conditions in the San Andres Dunes area. The soil types occurring in the San Andres Dunes area are highly permeable with an infiltration rate in the range of 6 to 20 inches per hour. Subsurface geologic materials in the main appear to have an acceptable permeability rate although several layers of fine materials with very low permeability characteristics were encountered in this area. These strata may or may not be areally continuous throughout these areas and depending on their thickness and areal extent may or may not create a severe constraint for recharge spreading operations. More detailed field investigations, however, would be required before serious consideration is given to a surface spreading recharge operations in the San Andres Dunes area.



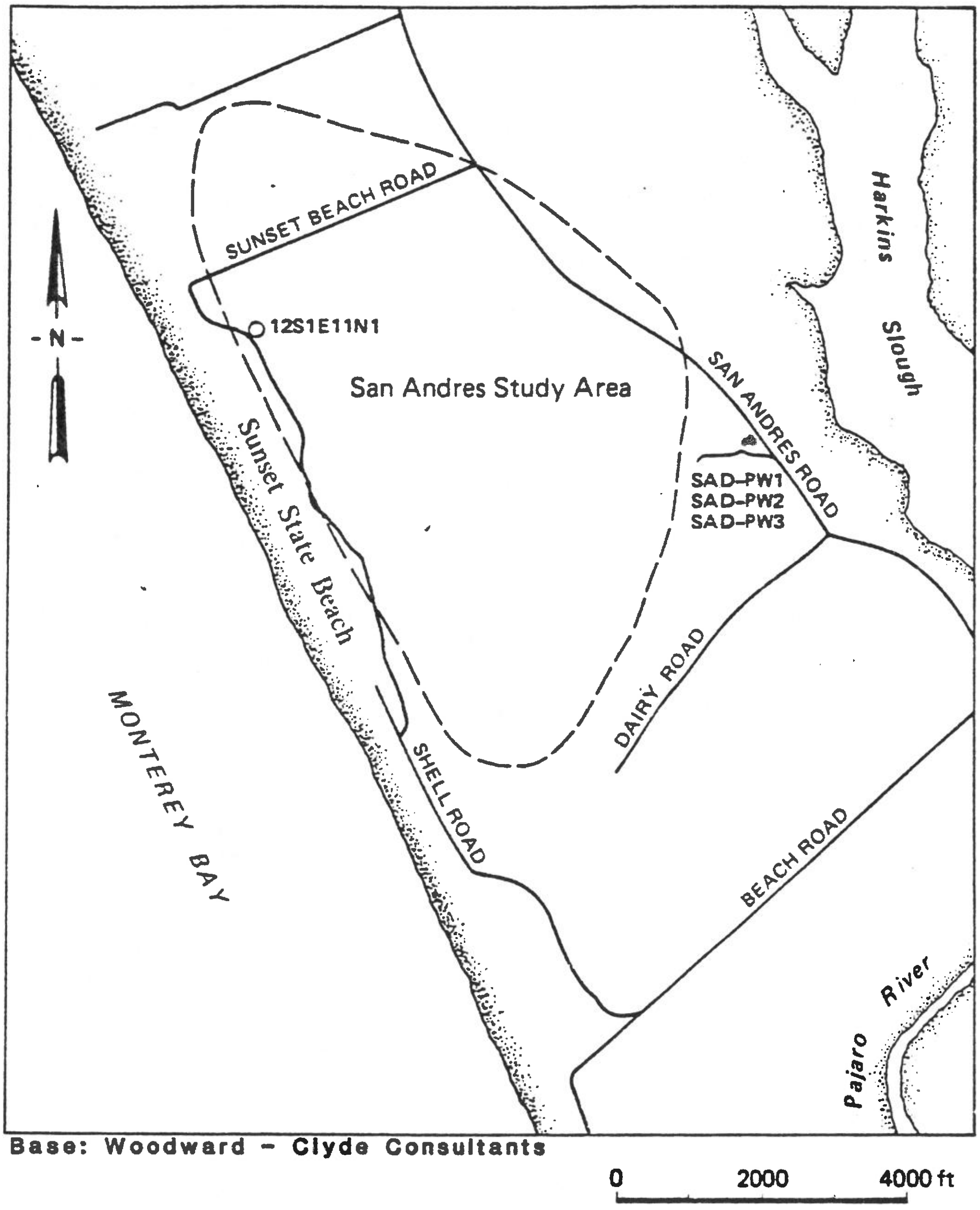
Base: Woodward – Clyde Consultants

0 2000 4000 ft

EXPLANATION

- ●• Location of WCC test holes
- o Location of well, state of California location number
- △ Approximate location of well, state of California location number
- — — Approximate boundary of Giberson Dunes Study Area

Figure 1. San Andres Dunes study area and vicinity



EXPLANATION

- • Location of WCC test holes
- ○ Location of well, state of California location number
- — — Approximate boundary of San Andres Dunes Study Area

Figure 2. Giberson Dunes study area and vicinity

In the Springfield area, the surface soils are generally less permeable than those in the San Andres Dunes area, however, both horizontal and vertical, permeability of subsurface sediments is very high. Additionally, the less permeable fine textured horizons are not as prominent as in the San Andres Dunes area.

Of the two general sites, San Andres Dunes area is situated on the periphery of a cone of depression of significant areal extent (Figure 3) and serves as a natural source of recharge for the alluvial aquifer under the valley floor. Water recharged into the dunes by surface spreading would at least partially flow into this cone of depression. The siting and configuration of recharge basins would affect the amount of recharge water that may be lost to the Bay or to the sloughs. The available aquifer volume for storing recharged water under the valley floor area was estimated by planimetering the area contained within the zero groundwater elevation contour during November-December, 1979 (Figure 3). Water year 1979 was one of normal rainfall. This area extends from the coast to the vicinity of Watsonville, and is approximately bounded by the Pajaro River to the south and the valley floor boundary to the north, and covers about 7,000 acres of land.

Based on the static volume of the cone of depression, only a small amount of water would be needed to fill this cone. Assuming a storage coefficient of 0.0001 for the confined aquifer underlying the valley floor area, for a 10 foot increase in the piezometric head over the 7,000 acre area, a volume of 70 ac-ft would go into storage. This volume does not represent the actual overdraft conditions in this area because in a confined aquifer, a much larger volume of the aquifer contributes to the discharge of each well. The low value of this number, however, indicates the difficulty of recharging a confined aquifer with surface spreading operations which would be located on a hydraulically connected unconfined formation. Moreover, the rate of flow of water through the area of interface between the dunes and the basal gravel aquifer would be fairly low and would pose another constraint to recharge by spreading in the San Andres Dunes area. Based on these factors, it does not appear that the recharge of the confined aquifers under the valley floor would be feasible by using surface spreading facilities in the San Andres Dunes area.

An extensive cone of depression also exists in the Springfield area underlying approximately 7,000 acres of land. The results of geotechnical investigations carried out by Woodward-Clyde Consultants show a specific yield of 0.01 for the general area of the aquifer in which their pumping well was located. Considering the mostly unconfined nature of the aquifers in the Springfield area, we believe that this value for specific yield may be rather low and could be attributed to the presence of local clay lenses in the area of the test well and the long duration of the pumping test needed to characterize an unconfined aquifer. The use of the porosity of near surface geologic formations in this area may provide a better indication of the amount of water that can be stored underground by recharge spreading operations. In a predominantly sandy formation, the value of porosity closely estimates the specific yield of the formation. Assuming a porosity value in the range of 0.10 to 0.15 approximately 3,500 to

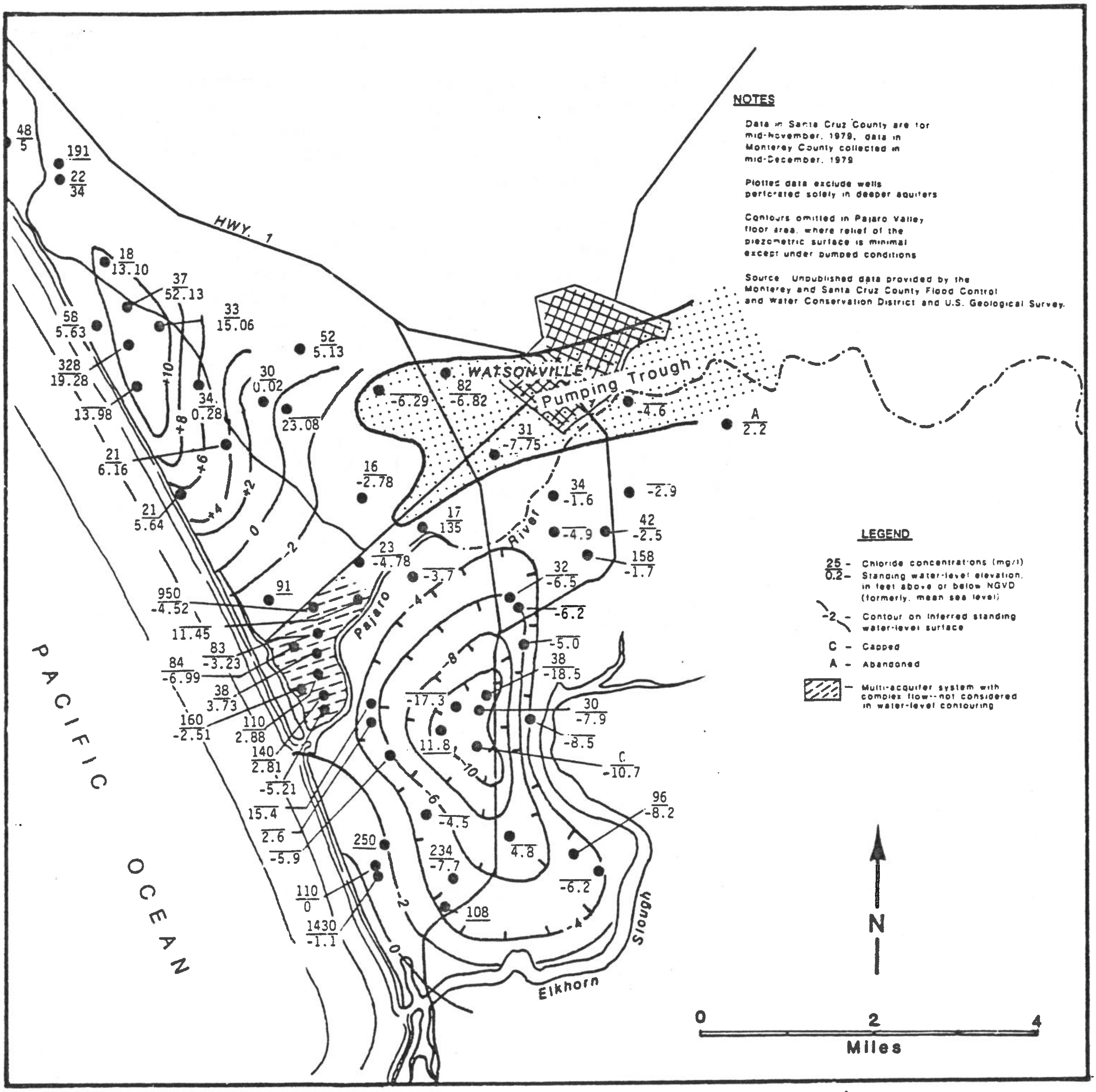


Figure 3. Standing water-level elevations and chloride concentrations, Western Pajaro Valley area, Nov. - Dec., 1979.

5,250 acre-feet of water could be recharged each year in the area underlain by the cone of depression if the water table is raised an average of five feet over this area to bring the overall water table to about sea level. This estimate is based on the assumption that the persistence of the cone of depression indicates a local annual overdraft at least equal to the volume of water needed to fill this cone. Recharge of these volumes of water could effectively alleviate the sea water intrusion problem in this area. Also, if the spreading basins are located near the center of the cone of depression, very little of the recharged volume would be lost to the Monterey Bay. Additional field studies would be required to determine specific yield and retention characteristics of the near surface formations in the Springfield area prior to the design of any recharge spreading facilities.

A detailed discussion of the hydraulic characteristics of recharge mounds in the San Andres Dunes and Springfield areas in presented in Appendix D of this report.

Alternative Sources of Additional Water Supplies

Chapter 4 of this report contains a detailed discussion of all available sources of supplemental water in the Pajaro Valley. In general, if an annual volume of 8,000 to 11,000 acre-feet of water is required for stemming salt water intrusion in the valley, the choices for alternative sources of surface water supply are immediately reduced to the following:

1. Pajaro River
2. Corralitos Creek
3. San Felipe project
4. Arroyo Seco project
5. Local deep aquifers

Depending on the location of storage facilities, direct diversion from Corralitos Creek may or may not be needed or feasible. The use of water from San Felipe and Arroyo Seco projects may or may not be viable depending on the cost of transporting such supplies to the areas of immediate need. Pajaro River appears to be an attractive source for obtaining the additional water supplies and will be evaluated in the context of storage facilities in the following sections.

Alternative Water Storage Sites. Provision of surface storage facilities will be required for groundwater recharge or direct distribution of supplemental sources of supply diverted from the Pajaro River. The alternative sites for water storage in the valley are as follows:

1. Pescadero Creek Valley
2. College Lake
3. Harkins Slough
4. Bolsa De San Cayetano Canyon
5. Hansen Slough
6. West Branch Struve Slough

The criteria for selection of one or more of these alternatives include storage capacity, proximity to the area of use, and overall cost. The estimated storage capacity of these sites is shown in Table 1.

Based on the preceding discussion on the need for supplemental water supplies and potential methods for the distribution of such supplies, it appears that Hansen Slough and Bolsa De San Cayetano sites could provide storage for adequate supplies for the purposes of alleviating salt water intrusion. Moreover, these sites are located in the vicinity of potential recharge or direct use sites. College Lake site would also be a suitable candidate if the use of either of the other two sites proves to be infeasible or if additional supplies are needed in the future. Pescadero Creek site has the advantage of providing adequate storage capacity for providing a yield of 12,000 ac-ft and a total storage capacity of 21,000 acre-feet. Major disadvantages of this site are the distance from the areas of potential use and energy costs for pumping water from Pajaro River into the Pescadero reservoir. Water can be released into the Pajaro River from the reservoir and diverted for recharge or direct use at downstream locations. Under this option, assuming that 10,000 acre-feet of water would be released into the river over a 200 day period, the excess flow in the river would amount to about 25 cfs. A number of questions can be posed with regard to this approach, the most important of which is the amount of water that could be recovered at the downstream locations and the additional cost of withdrawing the water from the river. The Pajaro River flow and quality conditions has been monitored between Chittenden gage site and Watsonville in the past. These data indicate that about five cubic feet per second (cfs) of flow is lost to the ground between these locations. No significant loss of flow is expected to occur downstream of the City of Watsonville due to the existence of thick clay formations under the river bed in this area. The cost of pumping could be partially defrayed by constructing a low head hydroelectric plant behind the Pescadero dam.

Some degradation in the quality of water flowing in the Pajaro River can also be expected, however, no data are available on the amount and quality of dry weather flows in the river below Watsonville. Water released into the river can be diverted for direct irrigation use or for recharge in the spreading basins at or near Thurwacter Bridge, the approximate head of tidal action. Degradation of this water by algae blooms or due to increased nitrogen content may pose problems for the operation of recharge spreading basins and may create clogging problems in pipelines and pumping equipment. The Regional Board recently adopted nutrient objective for the Pajaro River and Llagas Creek to minimize algal blooms in the Pajaro River. Implementation of management practices for reducing nutrient discharge to the Pajaro River should aid in reducing the incidence of algal blooms.

West branch of Struve Slough does not appear to be a viable storage site due to its rather low capacity. Also, Harkins Slough is a sensitive biological area and construction of a storage reservoir may not be feasible at this site.

Table 1. Estimated Capacity of Alternative Reservoir Sites

Site	Active Storage Depth (feet)	Storage Capacity (acre-feet)
Pescadero Creek	200	21,000
College Lake	20	5,000
Harkins Slough	20	5,000
Bolsa De San Cayetano	50	4,000
Hansen Slough	40	7,600
West Branch Struve Slough	40	2,400

Alternative Water Augmentation Methods

In order to remedy the seawater intrusion problem in the Pajaro Valley, one or more of the following actions should be undertaken:

1. Curtail the level of pumping from all wells in the coastal areas affected by seawater.

2. Provide a new source of supply to water users in the coastal areas.

3. Augment groundwater supplies by recharge spreading operations.

Exact determination of the annual volume of pumpage curtailment or the volume of additional supplies needed as well as the geographic areas where the curtailments should be carried out or new water supplies should be distributed, is normally made with the use of digital models for the actively pumped aquifers. In the absence of such a model, these determinations must, of necessity, be based on engineering judgment and by using empirical approaches because no simple mathematical formulas are available to derive the needed answers.

General groundwater contour maps drawn for a basin show smooth continuous lines representing water level elevations at various locations in the basin. In reality, these smooth lines are interpolated on the basis of water level data in wells that are sometimes a mile or more apart. Using this approach, contour lines have been developed for coastal portions of the valley which indicate a uniform landward gradient at elevations significantly below sea level in Springfield area and in the valley floor areas north and south of the mouth of the Pajaro River. Under such conditions, one would expect unimpeded flow of seawater into lower Springfield area and far inland on the valley floor areas. The absence of such severe intrusion conditions is probably due to the existence of ridges and valleys in the groundwater table or the piezometric surface, with the valleys coinciding with the alignment of pumped wells and ridges occurring at the intervals between the areas of concentration of wells. Under such conditions, fresh water would continue to flow seaward along the ridge lines and would provide a source of supply for wells located closer to the sea. However, seawater would also flow inland along the troughs formed in the water table or in the piezometric surface where such depressions extend to the aquifer outcrop areas in the Monterey Bay.

Cessation of pumping along a coastal strip of land in areas that are already intruded by seawater would most probably result in the formation of a uniform freshwater ridge in the aquifer along the coast line.

A reasonable starting point for identifying the boundaries of such a strip can be made by using the map of the areas in which water wells have been affected by seawater. If all pumping is discontinued in this area and a new source of supply is provided to existing groundwater users, a freshwater mound would form which may prevent further inland advance of seawater and possibly reverse the existing intrusion conditions. This would be contingent on maintaining existing pumping patterns beyond the intruded areas because intensified pumping inland from the coastal areas may result in further advance of seawater.

Available water level data for recent years appear to support the above conclusions. During the recent drought (1976-77), average water levels dropped by approximately 2.3 feet in upper Springfield area, 4.7 feet in lower Springfield area and 9.7 in mid-valley floor area. From 1977 through 1982, when average rainfall exceeded the long-term mean by about 31 percent, water levels recovered in the above areas by about 1.5 to 3 feet. In 1982-83 interval when rainfall exceeded the long-term mean by 119 percent, an additional two foot gain was made in the Springfield area and the piezometric levels in the valley floor area gained by about 4 feet (Table 2, Chapter 2). These data are indicative of the effectiveness of a new source of supply near the coast in alleviating the seawater intrusion problems. In the Springfield area where direct rainfall percolation is the main source of groundwater recharge, the aquifers respond quickly to increased amounts of rainfall recharge. In the lower Springfield area which is most affected by seawater intrusion, a total excess rainfall of about 5,000 ac-ft in 1982-83 wet season appears to have resulted in average increases in groundwater elevations of 2 feet. Reduction of pumping from the same area by an equivalent amount should result in more pronounced annual increases in groundwater levels.

Based on 1979 data, it is estimated that about 1,100 acres of farmed land are contained within the 100 mg/l chloride contour line in Santa Cruz County and 2,150 acres of farmed land are in a similar condition in Monterey County portion of the valley. The average annual applied water demand for the truck crops raised in these areas has been conservatively estimated at 2.00 ac-ft/ac. Therefore, an annual supply of 6,500 ac-ft. would be required if all pumping were to be discontinued in these areas. The actual annual applied water demand in these areas may be as low as 1.42 ac-ft./ac. (Table 4, Chapter 3). Therefore, a distribution system with a delivery capacity of 6,500 ac-ft. per year could potentially supply water to up to 4,600 acres of farm land in the coastal areas.

Summary

In summary, it is concluded that about 2,000 to 2,500 ac-ft of water distributed to farms in the intruded portions of Pajaro Valley in Santa Cruz County and about 4,000 to 4,500 ac-ft of water recharged into the coastal portion of the aquifers in Springfield area or distributed directly to farmers in this area would aid in stemming the flow of sea water into these aquifers. The rationale for this conclusion is based on the annual volume of water that is currently pumped for crop irrigation use in the sea water affected portions of these areas. Allowance should be made in the design of any distribution facilities constructed in these areas for further expansion of the service area if the need for such expansion is demonstrated by future monitoring data. Delivery of higher volumes of water to either of these areas can not be justified on the basis of data available at this time. Detailed analysis of groundwater elevation patterns under different pumpage regimes using the digital model currently being developed by USGS would aid in further refining the need for additional supplemental sources in the coastal portion of the valley.

Pajaro River is the major source of surface water in the valley and can provide an average of 25,000 acre-feet per year of divertible water. Other local sources such as Corralitos Creek, Pescadero Creek, and Salsipuedes Creek can also provide appreciable annual yields provided that storage facilities are constructed at some distance from the intended areas of use. Moreover, if the diversion facilities on the Pajaro River are located at any point west of the City of Watsonville, the natural flow from all of the local streams in the valley can also be tapped, thereby reducing the risk of any shortfall in the planned surface water supplies for the coastal areas. Imported water can be brought into the valley either through San Felipe project or from the Arroyo Seco project in Monterey County.

Any supplemental water developed in the valley must be diverted and stored during periods of heavy runoff for use during the dry weather season. A number of storage sites have been identified in this chapter. These sites include: Pescadero Creek Valley, College Lake, Hansen Slough and Bolsa De San Cayetano. Water stored in Pescadero Creek Canyon or College Lake could be potentially released in the Pajaro River for diversion at downstream locations. Water stored in Hansen Slough or in Bolsa De San Cayetano would most probably be distributed among farmers by a pipe or canal network. A similar transportation system could also be used for the former storage facilities, however, due to the significant distances involved, the cost of the transport system may become prohibitive.

A schematic diagram of the alternative storage sites in the Pajaro Valley is shown in Figure 4. A summary of the source and yield of these projects is presented in Table 2. Data on capital, operation and maintenance cost of these facilities is presented in the following chapter of this report.

Local deep aquifers are a potential source for obtaining supplemental water supplies in both valley floor and Springfield areas. Available data indicate a significant potential for these aquifers in areas to the north and south of the Pajaro Valley. Additional hydrologic investigations and drilling of exploratory wells, however, will be required to assess the yield and quality of these aquifers in the Pajaro Valley.

Recharge of the Pajaro Valley aquifers near the coast by surface spreading in San Andres Dunes and Springfield areas was considered in this study. The results of field investigations and analytical evaluation of these sites indicate that spreading recharge may be feasible at both sites, however, the effectiveness of recharge operations in San Andres Dunes area in relieving overdraft conditions on the Pajaro Valley floor is doubtful. Spreading recharge in the Springfield area could be carried out to stem the inland advance of seawater and augment the groundwater supplies in this area.

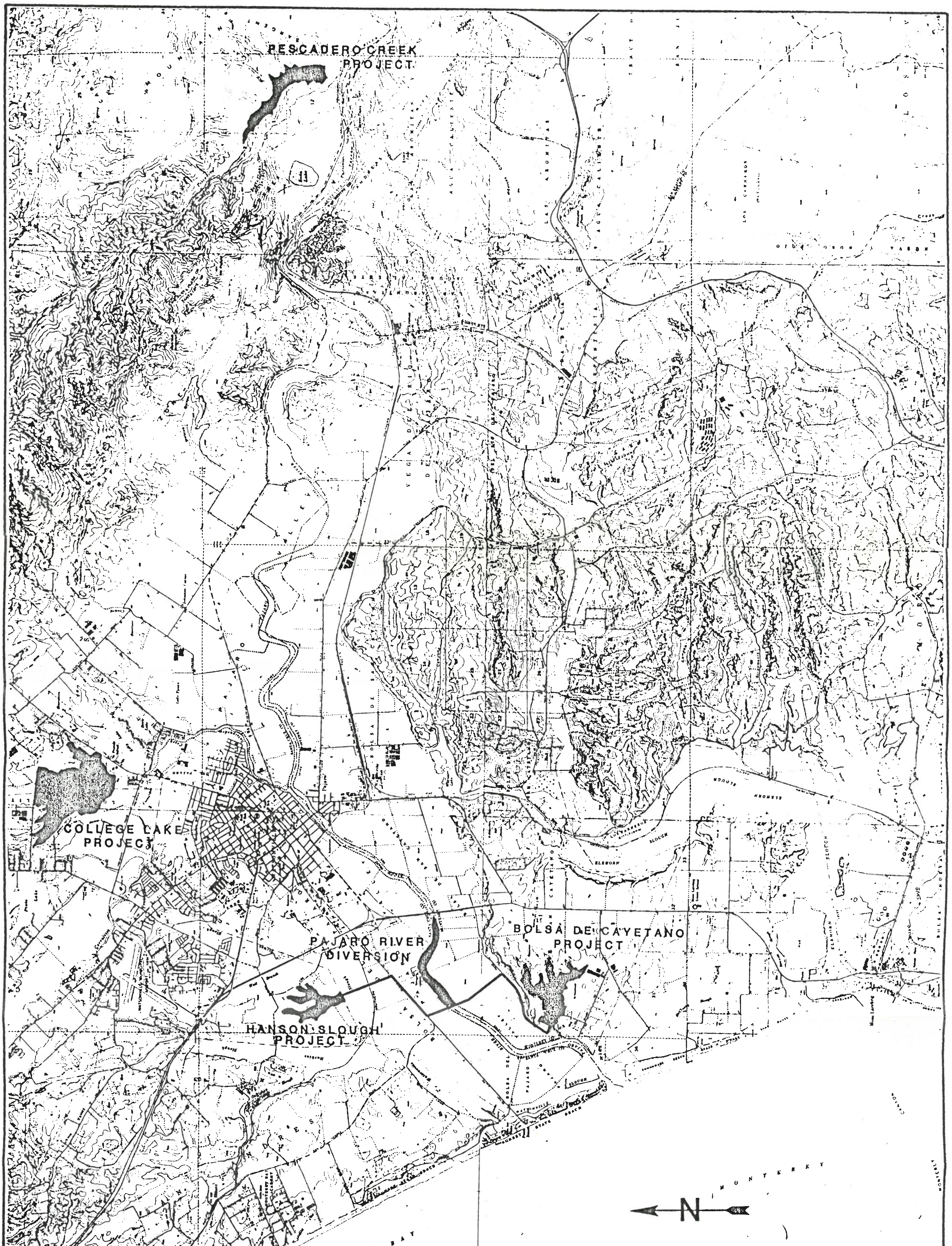


Figure 4. Alternative surface water storage sites in the Pajaro Valley

Table 2. Estimated Storage Capacity and Yield of Local Surface Water Projects

Project	Reservoir Capacity	Annual Yield	Source	Remarks
Pescadero Creek	21,000	12,000	Pescadero Creek Pajaro River	Seismic hazard problems, long distance from point of use for direct transport
College Lake	5,000	4,000 to 4,500	Pajaro River Salsipuedes Creek	Loss of farmland, relatively long distance of transport
Hansen Slough	7,600	6,000 to 7,000	Pajaro River	Environmental impact of reservoir
Bolsa De San Cayetano	4,000	3,000 to 3,500	Pajaro River	Geotechnical factors, environmental impacts

CHAPTER 5 - REFERENCES

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CHAPTER 6

ANALYSIS AND EVALUATION OF WATER SUPPLY AUGMENTATION ALTERNATIVES

Introduction

In the scope of work for this project, the main emphasis was placed on alleviating the overdraft conditions in the Pajaro Valley by augmenting recharge. During the course of this investigation it became increasingly evident that groundwater recharge may not be a universally applicable or cost-effective management tool in the basin. For this reason, the scope of work was expanded to include other water supply augmentation procedures in addition to the recharge augmentation method.

In this chapter, information on technical water supply alternatives presented in Chapter 5 is refined and a discussion is presented on environmental impacts and mitigation, and institutional aspects affecting the implementation of technical alternatives.

Technical Alternatives for Groundwater Basin Management in the Pajaro Valley

Statement of the Problem. In order to formulate any technical alternative for groundwater basin management in the Pajaro Valley, it is first necessary to identify the problems that need to be addressed by the management program. Based on detailed studies performed over the last 30 years, the following potential groundwater related problems can be identified in the Pajaro Valley.

1. Indications of long-term basin-wide groundwater overdraft. Estimates of the magnitude of such overdraft have varied over a wide range in past investigations and as yet no reliable value for the overdraft has been developed.

2. Sea water intrusion in the coastal portion of the basin extending as far as three miles inland at some locations; potential or incipient intrusion in the Elkhorn Road area.

3. Other water quality related problems arising from the heavy use of fertilizers on cropped areas overlying sandy substrates, natural recharge of poor quality surface water from the Pajaro River, and potential groundwater degradation by landfills and septic tanks.

4. Potential loss of natural recharge that may be caused by allowing development in primary recharge areas.

All of the above issues, with the exception of Item 3, fall within the scope of the present study. Water quality related problems have been addressed at length in a non-point source pollution control program developed previously by AMBAG (AMBAG, 1979). The emphasis in this Chapter is on the first two issues, i.e., overall basin overdraft and sea water intrusion in coastal areas. The question of the impact of development in primary recharge areas will be addressed in a separate chapter of this report.

The problem of basinwide overdraft and sea water intrusion are largely interwined because, in general, overdraft in coastal basins leads to sea water intrusion. Intensive local pumping near the coast can also cause sea water intrusion even though the basin as a whole may not be overdrafted, but in general, such intrusion would be of limited areal extent and would be reversed with the cessation of pumping. This does not appear to be the case in the intruded areas in the Pajaro Valley.

Overdraft would also be manifested by declining water levels throughout the groundwater basin. Although evidence of water level decline has been documented for wells in various parts of the valley (HEA, 1978; HEA, 1972; Muir, 1972), the rate of such decline (less than one foot per year) and the level of pump lift experienced throughout the valley (between 50 to 200 feet) does not justify the implementation of any major water supply augmentation project in the inland portions of the Pajaro Valley at this time, especially if no water supply augmentation projects are developed in the intruded coastal portions of the valley.

Estimated Annual Volume of Additional Needed Water Supplies. As discussed previously, the required annual volume of additional water supplies in the Pajaro Valley can best be defined as a range. For planning purposes, water storage facilities and long-distance transport lines should be designed for providing the estimated maximum demand, whereas most pumping facilities and local distribution systems can be built on a phased basis.

In this study, all viable water supply sources, i.e., San Felipe project, Pescadero Creek dam, and Arroyo Seco project , and potentially the deep aquifer can provide an annual volume of water within the range of the estimated basin-wide overdraft of 11,000 ac-ft. The main stem of local water distribution systems are also designed to enable a doubling of water delivery rates in future years. The balance of these distribution systems are, however, sized only to meet the needs of the acreage to be served during the first phase of the project.

The phasing of water distribution systems for Pajaro Valley can be carried out in accordance with the range of water supply demands shown in Table 1. Refinements in the capacity requirements at different phases and timing of implementation of expansion phases should be made on the basis of monitoring date obtained following the construction of Phase 1 facilities.

Technical Management Alternatives. Based on the preceding discussion, the primary objectives of a desirable technical program can be defined as follows:

Table 1. Estimated Annual Volume of Additional Water Supplies Required in the Pajaro Valley

Basis of Estimate	Ranking of Supply Level	Required Annual Volume of Supplies, Ac-ft/Year
Estimated Average Basin-wide Overdraft	Maximum	11,000[a]
Estimated Median Requirement	Intermediate	9,000[a]
Estimated Agricultural pumpage withdrawal from intruded coastal areas	Minimum	6,500[b]

[a] Based on hydrologic budget estimates for the basin.

[b] Based on the maximum estimated applied water demand in an area of 3,250 acres affected by saltwater intrusion (area enclosed by the 100 mg/l chloride level based on November 1979 data) in Santa Cruz and Monterey County portion of the basin. About one-third of this acreage occurs in Santa Cruz County.

a. To alleviate major sea-water intrusion problems in the coastal areas of the valley.

b. To protect and enhance natural groundwater recharge throughout the valley.

In order to attain these objectives a number of technical alternatives have been formulated as follows:

<u>Alternative T1.</u>	Recharge of alluvial aquifers in coastal areas of the valley by well injection method.
<u>Alternative T2.</u>	Recharge of alluvial aquifers in coastal areas of the valley by surface spreading method.
<u>Alternative T3.</u>	Surface distribution of water for irrigation use in intruded areas of the valley. This option includes two subalternatives, T3a and T3b.
<u>Alternative T3c.</u>	This alternative is similar to Alternative T3 with the exception that water supply would be provided from Arroyo Seco Project.
<u>Alternative T4.</u>	Surface distribution of water for irrigation use in intruded areas in Santa Cruz County portion of the valley and for surface spreading in Monterey County portion of the valley.
<u>Alternative T5.</u>	Relocation of all pumping wells from intruded areas to inland areas.
<u>Alternative T6.</u>	In-stream recharge augmentation projects.
<u>Alternative T7.</u>	Implementation of other recharge enhancement and primary recharge area protection measures.

Under alternatives T1 through T4, a new source of water supply would have to be developed either locally or by importation from other areas. Therefore, depending on the source of supply the following subalternatives can be enumerated for this purpose.

<u>Alternative WS1.</u>	A dam on Pescadero Creek, with direct diversion from Pajaro River.
<u>Alternative WS2.</u>	A low-level dam on College Lake with direct diversion from Corralitos Creek.

<u>Alternative WS3.</u>	Off-stream storage in Bolsa De San Cayetano, with direct diversion from Pajaro River.
<u>Alternative WS4.</u>	San Felipe Project water transported directly to the Pajaro Valley.
<u>Alternative WS5.</u>	San Felipe Project water using Pajaro River for transport to the valley.
<u>Alternative WS6.</u>	Deep aquifer development in the coastal portions of the valley.
<u>Alternative WS7.</u>	This alternative pertains to a proposed dam and distribution system on Arroyo Seco in Monterey County.

<u>Alternative Evaluation Procedure.</u> The alternatives listed previously were evaluated in two steps as follows:

a. preliminary evaluation
b. final evaluation

In the preliminary evaluation stage, all alternatives which would not meet the alternative evaluation criteria were eliminated from further consideration. The balance of the alternatives were then subjected to more detailed evaluation for the purpose of selecting the recommended technical management option or options.

<u>Criteria for Preliminary Evaluation of Alternatives.</u> The main criteria used to determine which project alternatives should be subjected to detailed evaluation are as follows:

1. Estimated amount of water that can be conserved in the basin or can be used to meet existing agricultural, municipal, and industrial demands by each project alternative.

2. Technical feasibility.

3. Legal and institutional feasibility.

<u>Preliminary Screening Of Alternatives</u>

A preliminary evaluation of water supply and distribution alternatives listed in the preceding section is presented in this section and the most viable alternatives are selected for more detailed analysis.

<u>Alternative T1.</u> Recharge of alluvial aquifers along the coast by injection well method would be technically feasible; however, this alternative has a number of disadvantages that would rule out the feasibility of construction of such facilities. These disadvantages are discussed below:

1. An injection recharge project would require all the elements of other project alternatives such as a new source of water supply and a pipeline for transport of water from the source to injection wells. In addition, this method would require the construction of 20 to 40 injection wells and construction of costly treatment facilities for filtration and disinfection of water prior to injection into the ground.

2. A well injection project would be highly energy intensive because of the potential use of chemicals for water treatment and due to the need for injecting water under pressure into the aquifer.

3. A significant portion (up to 50 percent or more) of the water injected into the aquifer may be lost to the Bay because the injection wells would have to be located close to the shore in order to form an effective barrier against sea-water intrusion.

4. Once a new source of supply has been developed and is transported to the areas of need, other project alternatives are available that could utilize the supplemental source of water without the need for costly and energy intensive treatment and injection facilities.

A well injection recharge project was considered for the Pajaro Valley as part of a wastewater management project (Brown and Caldwell, 1978). Although the emphasis in that project was on the reuse of treated wastewater from Watsonville facilities, the results provide an adequate estimate of the cost and feasibility of injection by recharge. In the above study, it was assumed that twenty wells each of 200-feet depth and 14-inch casing diameter would be required for injecting a maximum annual volume of about 5,000 ac-ft into the ground. The proposed distance between the wells was 1,000 feet and the line of injection wells extended 10,000 feet in each direction along the coast from the mouth of the Pajaro River. The total construction cost of treatment, transport, and injection facilities was estimated at $22,000,000 in 1976 dollars. The estimated construction cost of injection wells and the required distribution pipeline was about $5,546,000 in 1976 dollars. Comparable costs for this system in 1983 dollars would be about $8,837,000. Additional capital costs would be incurred under this alternative for treatment of raw water supplies prior to injection into the ground. These costs were estimated to be higher than the cost of the injection well system in the Brown and Caldwell report, although they may be somewhat less expensive for treatment of river water supplies which may only require coagulation, clarification, filtration and disinfection. Annual operation and maintenance cost of an injection well recharge system would also be very high due to the use of a large number of wells and the need for considerable amounts of energy and chemical feed.

For the above reasons, this alternative will not be considered further in this study.

Alternative T2. This alternative calls for recharging groundwater by surface spreading. As discussed earlier in this report, recharge by surface spreading appears feasible in the Springfield area, however, additional geologic exploration should be carried out prior to the selection of any recharge sites in this area. Virtually all recharged water would enter the Springfield pumping trough and could be re-captured in irrigation wells. Recharge of the confined aquifer underlying the valley floor area by using spreading basins in the San Andres Dunes area does not appear to be feasible. Recharge by surface spreading may be feasible in inland areas of the Valley, however, such operations would require a significantly higher annual volume of recharge to have any appreciable impact on salt water intrusion in the coastal areas and the effects of any recharge operations may not be manifested at the coast for a considerable period following the start of such operations.

Alternatives T3, T3c, and T4. All of these alternatives have a common characteristic of providing augmented supplies for direct use by farmers in the Santa Cruz County service area and for either direct use or recharge spreading in the Monterey County service area. The respective service areas are determined on the basis of chloride concentration levels in existing coastal water supply wells. These altenatives appear to be technically viable and will be evaluated further in this chapter.

Alternative T5. This alternative calls for relocating all pumping wells from the intruded areas to inland areas. The underlying assumption for this alternative is that salt water intrusion problems would be solved in the valley if the centers of concentrated pumping are moved away from the coast. A number of important technical, legal, and institutional concerns are raised by this alternative as follows:

1. Simple relocation of wells from coastal areas would not solve the overdraft problem in the valley. Although this method may provide temporary relief from sea-water intrusion, in the long run, it would result in further inland advance of the sea-water wedge.

2. Any additional agricultural pumpage in the center of the valley would compete with existing municipal and industrial pumpage. These uses also have mid-to late-summer peak demand periods.

3. Municipal and food-processing waters pumped from the central part of the basin are approaching maximum acceptable thresholds for total dissolved solids and some individual mineral constituents. Increased drawdowns in the Watsonville area are likely to induce additional inflow of very poor quality waters from the semi-perched zone and of poor quality water from the East Area.

4. Increased drawdowns in the Watsonville area would result in substantially greater pumping costs for the many users in the urban area, and would affect City of Watsonville wells, 7, 10 and 15.

5. At present, the deepest seasonal pumping trough in the basin is located in the central area. Further intensification could induce (or accelerate) groundwater salination in the Elkhorn Road area, and increase the risk of land subsidence in the populated part of the valley.

6. From an engineering standpoint, a complex network of pipelines or canals would be required to collect the water from relocated wells for distribution to original areas of demand. Construction of such a network would be a costly undertaking.

7. Legal and institutional issues involved in relocating a significant number of wells, procuring well site and transport facility right of way, and operating the proposed system would also be highly complex and this alternative would be susceptible to legal challenge in a number of areas.

Based on the above factors, it is concluded that this alternative does not merit further consideration in this study.

Alternative T6. This alternative involves the construction of recharge enhancement projects within channels east or north of Watsonville.

Channel recharge is usually enhanced by ponding of water within the stream banks to create a larger recharge area and a higher hydraulic head over the stream bed. This method can be very effective in streams traversing highly permeable terrains but may not bring about significant increases in the rate of recharge when the stream flows over formations composed predominantly of silt and clay type materials. Available volume and quality of flow during the dry weather season are other factors affecting the evaluation of channel recharge projects because impoundment of water within the stream banks is normally feasible only during the dry weather period if flooding and safety hazards are to be avoided.

Average monthly stream flow data for Pajaro River at Chittenden and for Corralitos Creek at Freedom is presented in Table 2. These data indicate that during the dry weather period (May through October) average monthly flow in the Pajaro River at Chittenden decreased from 32.39 cfs to 3.61 cfs. Construction of temporary in-stream retaining dams may enhance groundwater recharge in the Pajaro River on the average only during May and June because during the balance of the dry weather period natural flow in the river normally percolates into the ground between Chittenden and the confluence of Salsipuedes Creek with Pajaro River. The excess average monthly flow in the Pajaro River during May and June is about 1,680 and 400 ac-ft, respectively (assuming 5 cfs of effective daily natural recharge in the river). However, not all of these flows can be recharged into the stream bed because the bulk of the flow in the month of May occurs during a few days with much higher than average flow rate. Pajaro River does not have any

Table 2. Mean Monthly Flow for Pajaro River at Chittenden (1956-1981) and Corralitos Creek at Freedom (1957-1981)[a]

Month	Normal Monthly Mean, cfs	
	Pajaro River At Chittenden	Corralitos Creek At Freedom
October	3.61	1.24
November	9.45	1.79
December	113.51	13.44
January	346.03	42.86
February	480.29	47.50
March	318.75	29.74
April	256.89	24.57
May	32.39	3.88
June	11.89	0.71
July	6.57	0.28
August	4.70	0.19
September	7.03	1.09

[a]Source: U.S. Geological Survey, 1983

appreciable potential for recharge of the aquifers downstream of Watsonville due to the occurrence of thick clay horizons below the stream bed.

Data shown for Corralitos Creek in Table 2 indicate that very little flow is available for channel recharge during the dry weather period. Containment of flows during May in this creek may also interfere with anadromous fish migration.

Alternative T7. This alternative is aimed at the implementation of various recharge protection measures in natural recharge areas in the Valley and as such is the topic of a detailed discussion in the recharge protection chapters of this report.

Water Supply Alternatives WS1 through WS7. All water supply alternatives listed in the preceding section are technically feasible and appear to merit further evaluation on the basis of cost, institutional and environmental factors.

DETAILED EVALUATION OF VIABLE ALTERNATIVES

In this section, summary information is presented on the cost and environmental impacts of viable alternatives for water supply augmentation in the Pajaro Valley. These alternatives can be logically divided into two broad categories as follows:

a. Water supply alternatives.
b. Water distribution and recharge alternatives.

For simplicity, all water supply alternatives will be discussed first followed by an analysis of water distribution and recharge alternatives.

Water Supply Alternatives

Five major water supply alternatives have been evaluated for augmentation of existing groundwater supplies in the Pajaro Valley in this study. These include:

1. Pajaro River

2. Corralitos and Salsipuedes Creeks

3. San Felipe Project

4. Arroyo Seco Project

5. Deep aquifer

Water can be obtained from these sources by a number of alternatives differing mainly on the basis of reservoir location or the method of transport to a central point for discharge into the augmentation distribution network. The Pajaro River near Thurwacter Bridge has been selected as the common discharge point for all alternative water supply facilities with the exception of Arroyo Seco and deep aquifer alternatives.

In this section, information is presented on capital, operation and maintenance cost of water supply alternatives as well as environmental and institutional factors which may affect the implementation of these alternatives.

A brief description of alternative projects for providing a new source of water supply in the Pajaro Valley is presented below.

Alternative WS1. Pescadero Creek Dam With Direct Diversion From The Pajaro River. This alternative was considered for water supply augmentation as early as 1956 (Creegan and D'Angelo, January 1957) and interest in the dam has been revived recently by the filing of applications for water rights by Monterey County. The preliminary design concept developed earlier calls for the construction of a 200-foot high dam above the mouth of Pescadero Creek. This earth-fill dam would create a reservoir with 21,000 ac-ft capacity (Figure 1). Natural runoff from Pescadero Creek would be stored in the reservoir, which would supplement water diverted from the Pajaro River. Maximum diversion rates of 100 cfs (cubic feet per second) were envisioned by using several pumps with a combined capacity of 3,500 hp (horse power).

The mean yield of Pescadero Creek can be estimated at about 2,300 ac-ft per year based on gaging records for the period 1971-80 (Table 4, Chapter 4). Previously, the firm yield of this stream has been reported at 4,800 ac-ft per year. We believe that this estimate is in error based on USGS data cited above and based on regional hydrologic information discussed in Chapter 4 of this report. Back-pumping from the Pajaro River could be carried out during 23 days at 100 cfs based on median year probability distribution values (Table 2, Chapter 4). This would result in a yield of 4,600 ac-ft. An additional 2,800 ac-ft could be pumped at flows exceeding 1,000 cfs, however, the water at these flows would be heavily silt laden and may result in excessive wear on the pumping equipment. If one-third of the streamflow is diverted during days with less than 150 cfs of flow, an additional yield of 2,314 ac-ft could be obtained for a grand total of 9,700 ac-ft. The total firm yield of the Pescadero Creek reservoir would therefore be approximately 12,000 ac-ft per year for a pump back capacity of 100 cfs. This yield could be increased approximately by an additional 3,000 to 5,000 ac-ft per year if diversion pumping capacity from the Pajaro is increased to 200 cfs. In this analysis, we have only considered the option for incorporating a 100 cfs back-pumping capacity.

Alternative WS2. College Lake Dam With Direct Diversion From Corralitos Creek. Construction of a dam on College Lake has also been considered in previous studies (Brown & Caldwell, 1967). The project considered in this study would require the construction of a low dam (with about 20 feet height) at the 80 foot contour level at the discharge point from the lake, with a small saddle dam along Lake Avenue (Figure 1). This reservoir will provide an estimated storage capacity of 5,500 ac-ft for an approximate storage depth of 20 feet. Mean annual runoff of Salsipuedes Creek into College Lake has been estimated at 2,300 ac-ft per year. Therefore, direct diversion from Corralitos Creek would be required to attain a maximum yield of 5,000 ac-ft per year from the proposed College lake dam and reservoir. The diversion from Corralitos Creek to College Lake has been planned in this analysis by using a 42" pressure pipeline of 2,700 feet length and pumping facilities with combined 450 horsepower motors and 50 cfs capacity. The yield of this system could be further increased by raising the dam to the 90 or 100 foot contour levels, however, this would require the construction of extensive levees along the southern and eastern boundaries of the lake for an additional gain of about 2,500 ac-ft in storage capacity. The low level of expected additional yield from the larger reservoir would not justify the significantly higher expense of such facilities. Alternatively, a longer dam at the 100 foot contour level could be constructed about midway from the discharge point of the lake with similar storage capacity and yields as the option considered in this study. Only a dam at 80 feet contour level was considered under this alternative.

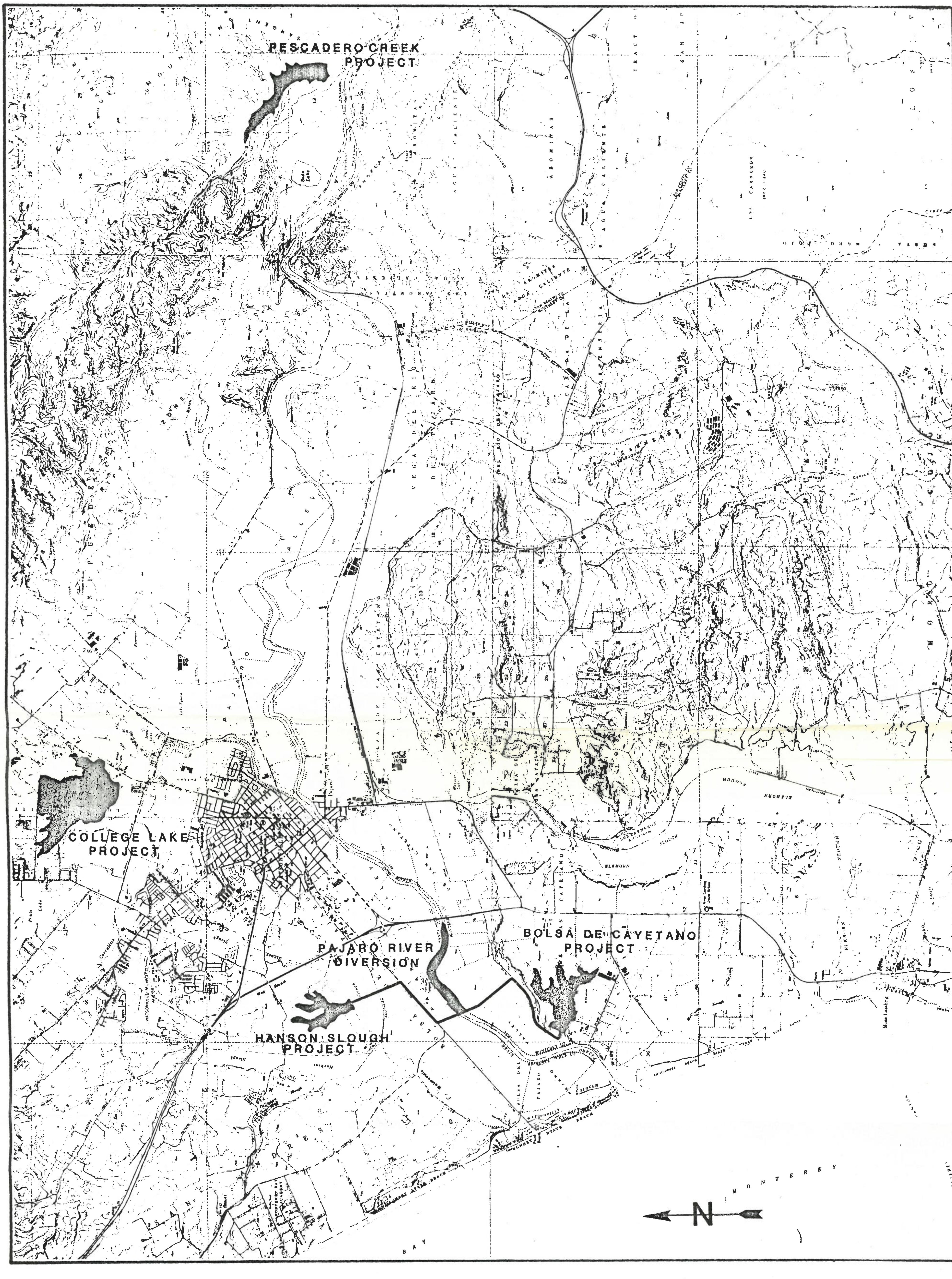

Figure 1. Alternative Dam and Reservoir Locations.

Alternative WS3. This alternative requires the construction of a dam across the mouth of the box canyon at Bolsa de San Cayetano for storing water diverted directly from the Pajaro River. An approximately 90 foot high dam constructed to the 100 foot contour level across the mouth of this canyon would create a reservoir with an estimated 60 feet average depth and an estimated active capacity of 4,500 ac-ft (Figure 1). Water would be diverted from the Pajaro River at Thurwacter bridge by using three 200 hp pumps of 40 cfs total capacity and a 10,500 foot pipeline of 36-inch diameter. These pumps would enable the diversion of more than 5,000 ac-ft per year during a year with average percipitation pattern when 40 cfs is diverted during all days for which flow in the Pajaro River exceeds 50 cfs at Chittenden gage. Because these criteria are based on flow levels at Chittenden gage the required diversion volume at Thurwacter Bridge can be attained during years of below average percipitation due to the contribution made to the flow in the Pajaro River by Corralitos and Salsipuedes Creeks. Substantial geotechnical studies will be needed to establish the feasibility of this alternative.

Alternatives WS4 and WS5. These alternatives involve the importation of San Felipe Project water into the Pajaro Valley. The difference between the two alternatives relates to the mode of transport of water from Pacheco tunnel outlet to Pajaro Valley. In alternative WS4, San Felipe project water will be released into the Pajaro River below San Felipe lake or at the Pacheco Tunnel portal and would flow by gravity to Pajaro Valley. Alternative WS5 calls for the construction of a pressure pipeline to transport the water from Pacheco tunnel or a downstream location on the Santa Clara Valley Conduit to the valley.

Current plans of the Bureau of Reclamation call for diversion of water from Santa Clara Conduit east of Gilroy into a 45" diameter pipeline which would transport the water to Watsonville area along a route paralleling the Pajaro River (Bureau of Reclamation, 1983).

Allowance is made in all affected components of the San Felipe Project for up to 17,000 ac-ft of capacity for use in the Pajaro Valley area. Due to the appreciable cost of construction, operation and maintenance of a pipeline for transporting San Felipe project water to the Pajaro Valley, it would be desirable to use the Pajaro River as a transport conduit for this water. The major problem associated with this mode of water transport is the uncertainty relating to the in-stream loss of water by evaporation, riparian vegetation use, and recharge into the ground in the stretch of the river between Pacheco Tunnel and Chittenden Pass. Due to the relatively low flow rates (20 to 40 cfs) that will be needed for irrigation and recharge augmentation by direct diversion from the Pajaro River, a significant loss of these flows between the point of discharge and the point of use may be probable. Degradation of the quality of water by poorer quality water flowing in the Pajaro River may be another constraint on the use of the river for this purpose.

Alternative WS6. This alternative relies on the development of deep wells in the Aromas, Purisima, and possibly Santa Margarita formations to supply the needed volume of additional supplies.

Limited local information on the deep aquifer exists mainly from the deep wells drilled in the Castroville and Prunedale areas of Monterey County. An 1,800 foot deep well drilled by Monterey County FCWCD in Castroville area has a yield of 2,250 gpm with a drawdown of 139 feet using a 150 hp pump which creates a total head of 173 feet at the above rate of flow. This well had an artesian head of 4 feet under static conditions in July 1979 (Monterey County FCWCD, 1983).

The well described above is capable of producing 2,000 ac-ft of water during 200 days of operation per year. By extrapolation, it appears that 3 to 7 such wells would be adequate for meeting the range of supplemental requirements in the Pajaro Valley. Major water quality and yield problems may exist with regard to the extensive development of the deep aquifers. In a study performed for Monterey County Flood Control and Water Conservation District (Ares, 1983), it was concluded that water pumped from the District deep well has a high percentage of sodium and a very high adjusted sodium adsorption ratio value which may cause severe permeability problems on clayey soils. The source of poor quality water in this well is unknown, but could be attributed to leakage through the casing from intruded higher formations.

Two other wells have also been drilled in the Purisima or older aquifers in Monterey County. In an internal memorandum prepared by Monterey County FCWCD (MCFCWCD, 1983), a review of water quality conditions in all three wells was undertaken. The results of this review point to the potential for sea water intrusion in the deep aquifer under sustained pumping operations.

Based on the above factors, the potential of the deep aquifer as a source of supply for meeting the overdraft requirements in the Pajaro Valley can only be determined on the basis of hydrologic and water quality data obtained from test wells drilled in the valley proper. A more detailed discussion on the deep aquifer formations is presented in Appendix A of this report.

Alternative WS7. This alternative involves the construction of a dam on Arroyo Seco at Pools site in Monterey County. This dam would create a 100,000 ac-ft reservoir. Water would be released from the reservoir into Arroyo Seco for rediversion and transport to Salinas River. The combined release from Arroyo Seco, Nacimiento, and San Antonio reservoirs would flow down the Salinas River channel to proposed rediversion points near Spence and Blanco Road, respectively (CH_2M Hill, 1982). The water diverted from Salinas River would be distributed in a surface network to Castroville, East Side, North County, and Fort Ord - peninsula service areas. One of the alternatives in this project calls for the delivery of 11,000 to 15,000 ac-ft of water to Elkhorn-Pajaro service area which essentially includes all of Springfield and the Monterey County portions of the Pajaro Valley floor area. It is assumed that if Arroyo Seco water is brought into the Springfield area, deliveries could also be made to the sea-water affected portions of the valley to the north of the Pajaro River. Cost data for the delivery of Arroyo Seco water to the Pajaro Valley area has been developed for Monterey County Flood Control and Water Conservation District by CH_2M Hill (1982). These data were used in this report by using an appropriate escalation factor. The cost of Arroyo Seco water includes the cost of the necessary distribution system for the Springfield area and no attempt was made at separating this cost item due to the complexity of the Arroyo Seco project.

Cost Data for Alternative Water Supply Projects. In this section, data are presented on capital, operation, and maintenance costs of alternative water supply projects. These data are shown in summary in Table 3. Data on present worth of the total annual cost of each project and the unit cost of water supplied by each source was calculated by using a 50-year useful life for all dam and pipeline components, a 10-year useful life for pump station facilities and an interest rate of 7-7/8 percent per year. These data are summarized in Table 4. Present worth of total costs represents the amount of money needed in present day dollars to defray all initial costs as well as routine operation and maintenance expenses and all facility replacement costs during the assumed useful life of the project. The total annual cost figure is equivalent to the annual installment payments if one were to borrow all of the needed funds (as represented by the present worth of total costs) at the assumed interest rate for a 50 year loan term.

The useful life of 50 years is used here as a realistic estimate of the length of time during which the project components will be in productive use. Reduction of this value to the term of marketable bonds would result in unrealistically high unit cost values. Also, the interest rate of 7-7/8 percent is the value used at the time of preparation of this report by the U.S. Bureau of Reclamation for economic analysis of water resource projects. Although this rate is somewhat lower than the current long-term bond rates, its use may be justified for consistency in comparing the San Felipe option with local water supply alternatives.

Water Distribution and Recharge Alternatives

A brief description of alternative schemes for distribution and recharge of supplemental water supplies as well as the cost of these alternative projects is presented in this section.

Alternative T3. This alternative calls for the distribution of water as a groundwater supply replacement for crop irrigation in intruded areas of the valley (Figure 2). In this analysis, it is assumed that in general, water would be released into the Pajaro River from an upstream source and would be withdrawn from the river at Thurwacter Bridge during the irrigation season. This water would be stored in a small operational storage pond near the point of diversion or would be pumped directly into the distribution system. Two options have been considered under this alternative depending on the daily duration of irrigation operations. Option I (Alternative T3a) calls for 12 hours of irrigation 6 day per week and Option II (Alternative T3b) calls for 20 hours of irrigation 6 days per week. Option I represents the prevailing mode of operation in the Valley.

Table 3. Cost Data for Alternative Water Supply Projects

Alternative No.	Description	Capital Costs, Dollars: Dam and Reservoir	Pumping Station and Pipelines	Administration and Contingencies	Total Capital Cost	Annual Operation And Maintenance Cost, Dollars
WS1	Pescadero Creek Dam[a]	17,136,000	7,013,500	6,037,350	30,186,850	232,250
WS2	College Lake Dam[b]	12,365,300	987,200	3,538,100	16,890,600	102,125
WS3	Bolsa De San Cayetano[b] Dam and Reservoir	14,967,400	2,045,200	4,508,300	21,520,900	109,857
WS4	San Felipe Project[c] with pipeline to Pajaro Valley	-	-	-	48,250,000	199,800
WS5	San Felipe Project[d] with Pajaro River Transport	-	-	-	23,000,000	24,800
WS6	Deep Aquifer Wells[b,e]	895,000[f]	250,000[g]	286,250	1,431,250	239,800[h]
WS7	Arroyo Seco Project	-	-	-	18,174,000[i]	121,000[i]

[a]Source: Creegan and D'Angelo, 1957 escalated to 1983 prices by applying a 650% escalation factor.

[b]Cost data for these alternatives was developed by Brown & Caldwell Consulting Engineers for this project.

[c]Source: Bureau of Reclamation, personal communication, 1983.

[d]Estimated from deferred capital costs on joints portions of San Felipe project.

[e]Assumes the use of 5 identical wells each with an estimated capacity of 2000 gpm as indicated by regional deep wells.

[f]For drilling and construction of wells.

[g]Cost of five pumps with 200 hp motors delivering 2,000 gpm with a total head of 300 feet with 76% efficiency.

[h]Based on an estimated power demand of 2,827,000 Kwh @ 6.5¢/Kwh and a labor cost of $56,000/year.

[i]Based on data developed by CH2M HILL, 1982 escalated by 8% from December 1981 to June 1983 cost by using ENR's Construction Cost Index. This item is 28% of the cost of Pools dam and reservoir plus Arroyo Seco-Salinas conveyance facilities. The percentage is based on the ratio of planned annual delivery of 11,000 ac-ft to the Springfield area to the annual yield of Arroyo-Seco project of 40,000 ac-ft.

Table 4. Present Worth and Total Annual Cost of Alternative Water Supply Projects

Alternative No.	Description	Present Worth Of Total Costs, Dollars	Total Annual Costs, Dollars	Unit Cost $/Ac-ft
WS1	Pescadero Creek Dam	34,215,000	2,756,700	230[a]
WS2	College Lake Dam	18,227,400	1,468,600	294[b]
WS3	Bolsa De San Cayetano Dam and Reservoir	21,885,100	1,739,100	435[c]
WS4	San Felipe Project With Pipeline to Pajaro Valley	50,729,800	4,087,300	240[d] (277.50)[e]
WS5	San Felipe Project With Pajaro River Conveyance	23,307,800	1,877,900	147[d,f] (197.00)[e]
WS6	Deep Aquifer Wells	4,696,000[g]	378,400	58[h]
WS7	Arroyo Seco Dam	19,675,800	1,585,000	144[i]

[a]Based on an estimated yield of 12,000 ac-ft per year.

[b]Based on an estimated yield of 5,000 ac-ft per year.

[c]Based on an estimated yield of 4,000 ac-ft per year.

[d]Based on an estimated yield of 17,000 ac-ft per year. The unit cost should be increased by $37.50 per ac-ft which is the estimated charge by the Bureau of Reclamation for all other components of the Central Valley Project. The unit cost is assumed to remain the same at lower diversion rates, but this matter is subject to negotiation between the parties.

[e]Estimated total unit cost of San Felipe water.

[f]Assumes a 25 percent loss for water conveyed in the Pajaro River.

[g]Based on an estimated replacement cost of pumps of $50,000 per well every 15 years, an estimated development cost of $25,000 per well every 7 years.

[h]Based on an estimated yield of 6,500 ac-ft per year. (The estimated yield of five wells with 2,000 gpm capacity during the growing season).

[i]Based on an estimated yield of 11,000 ac-ft per year.

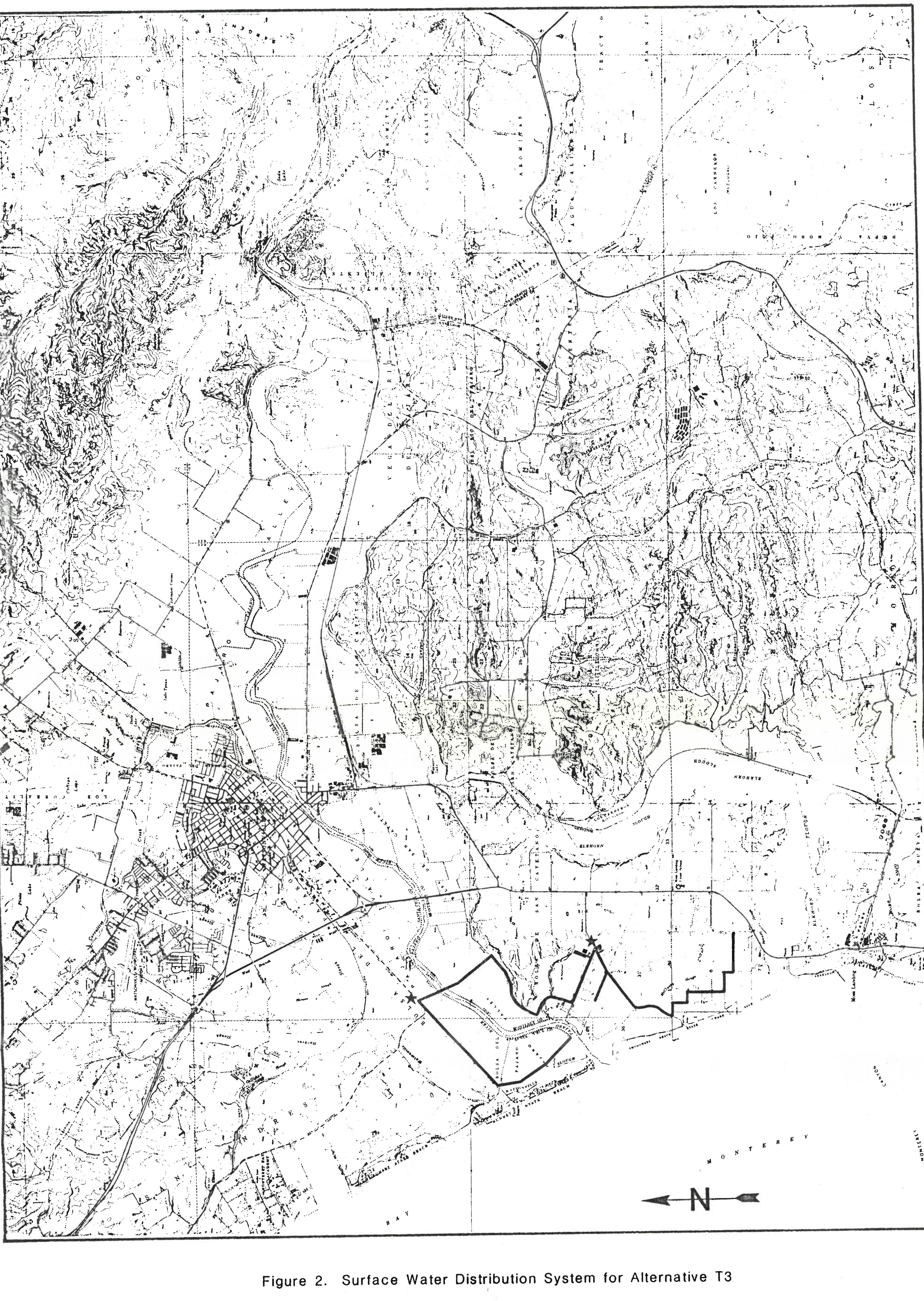

Figure 2. Surface Water Distribution System for Alternative T3

★ The pipe section between the asterisks is oversized for future expansion of the system

The components of the diversion and distribution system under this alternative are shown in Table 5.

Alternative T3c. This alternative is similar to Alternatives T3a and b with the exception that water would be supplied to Springfield and Pajaro Valley floor areas from the Arroyo Seco Dam project. One of the alternatives in this project calls for the delivery of up to 15,000 ac-ft of water to the Springfield area. It is assumed that water could be supplied from this system to the Santa Cruz portion of the valley floor area via a river crossing at Thurwacter Bridge (Figure 3).

The components of the required distribution system for the Springfield area have been developed as a part of the Arroyo Seco Dam feasibility analysis by CH_2M Hill. The cost of these components has been included in the overall cost of this source of supply under this alternative. The distribution system elements in the Santa Cruz portion of the valley would be similar to Alternative T3. These components are shown in Table 6.

Alternative T4. This alternative is similar to Alternative T3 with the exception that supplemental water delivered to the Springfield area would be recharged into the ground by spreading the water in five recharge basins of 4 acre size each and spaced at equal distance along the coast (Figure 4). One possible configuration for the spreading basins would be to divide each area into four separate basins and distribute water into these basins either simultaneously or sequentially depending on the most optimal mode of operation to be determined by field experimentation. The optimal depth of impoundment in each basin should be determined by field testing but could range between 2 to 3 feet. A list of the system components for this alternative is shown in Table 7.

Cost Data for Alternative Water Distribution Projects. Capital, operation and maintenance cost data are presented in this section for water distribution alternatives. These data are summarized in Table 8. Data on present worth and total annual cost of water distribution alternatives are presented in Table 9. An interest rate value of 7-7/8 percent was used in conjunction with a depreciation period of 10 years for pump equipment and 50 years for all other system components to develop present worth and total annual costs of various alternatives.

Ranking of Water Supply and Distribution Alternatives on the Basis of Cost

Various water supply and distribution alternatives are ranked in Table 10 on the basis of unit cost for supply and distribution of water. From these data, it appears that deep aquifer wells would provide the cheapest source of supply in the valley. However, this alternative cannot be recommended for implementation at this time because there is no assurance that water of suitable quality can be obtained from the deep aquifer in the Pajaro Valley at the required rates over an extended period of time. The relatively low cost of this alternative may justify further exploration of this option,

Table 5. Components of Water Diversion and Distribution System Under Alternative T3

Component	Size or Description	
	OPTION I 16 Hours Per Day Irrigation	OPTION II 20 Hours Per Day Irrigation
Diversion Dam	Temporary Earth Dam Built Within The Stream Banks	Same
Diversion Pumps		
hp (2 pumps)	300	300
gpm (2 pumps)	10,000	10,000
Operational Storage		
ac-ft	66	51
Distribution Pumps		
hp (3 pumps)	1,500	900
gpm (3 pumps)	24,000	15,000
Distribution Pipeline Diameter, inches		
Santa Cruz County		
First Section	30	30
Second Section	30	24
Monterey County		
First Section	42	42
Second Section	42	30
Distribution Pipeline Length, feet		
Santa Cruz County		
First Section	2,000	2,000
Second Section	14,000	14,000
Monterey County		
First Section	16,000	16,000
Second Section	16,000	16,000
Distribution Pipeline Capacity, cfs		
Santa Cruz County		
First Section	17	20
Second Section	17	10
Monterey County		
First Section	34	40
Second Section	34	20

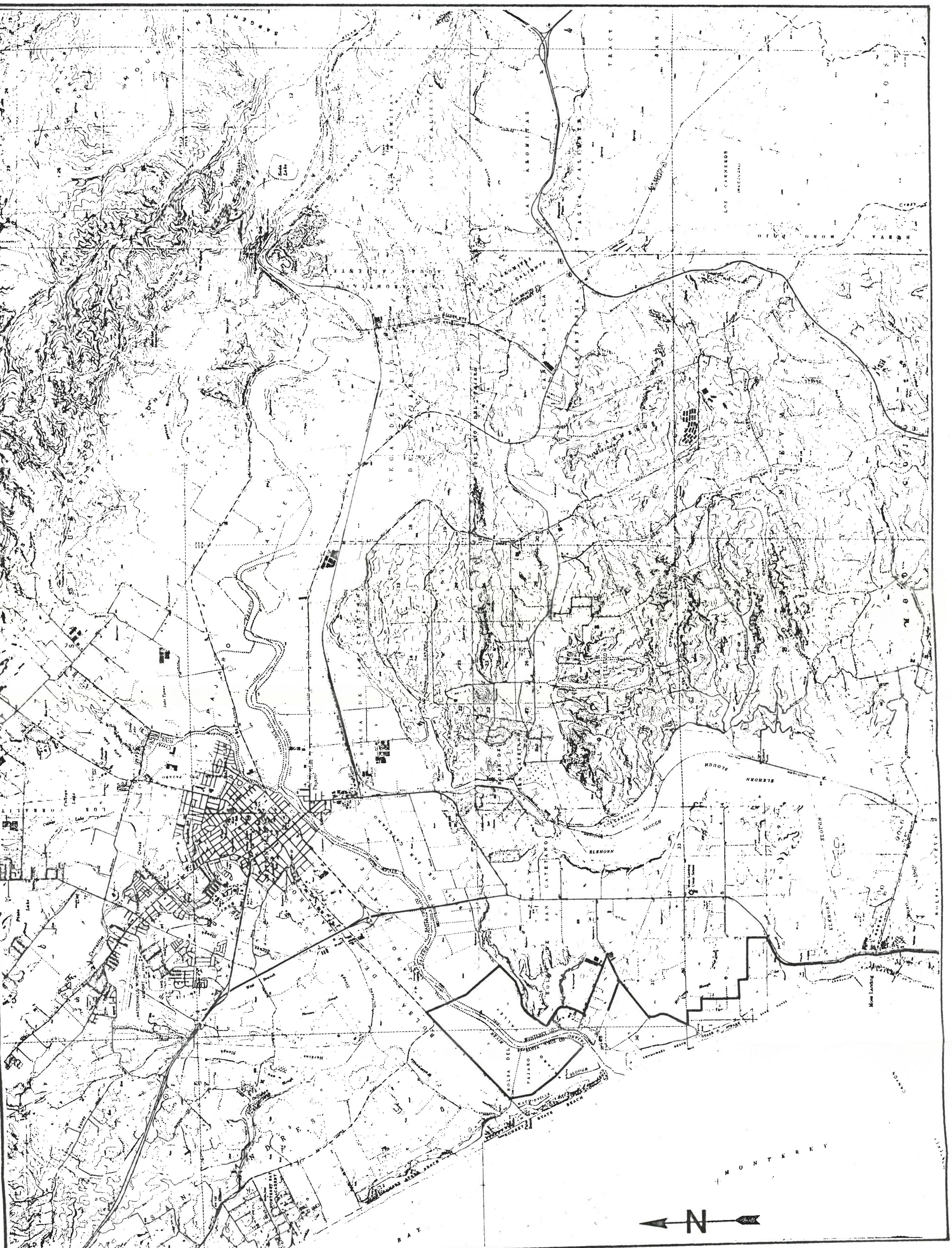

Figure 3. Surface Water Distribution System for Alternative T3c

Table 6. Components of Water Diversion and Distribution System Under Alternative T3C

Component	Size or Description: OPTION I 12 Hours Per Day Irrigation	Size or Description: OPTION II 20 Hours Per Day Irrigation
Diversion Dam	None	None
Diversion Pumps	None	None
Operation Storage Ac-ft	22	17
Distribution Pumps		
hp (2 pumps)	1,000	600
gpm (2 pumps)	16,000	10,000
Distribution Pipeline Diameter, inches		
<u>Santa Cruz County</u>		
First Section	30	30
Second Section	30	24
<u>Monterey County</u>		
First Section	36	36
Second Section	36	36
Distribution Pipeline Length, feet		
<u>Santa Cruz County</u>		
First Section	2,000	2,000
Second Section	14,000	14,000
<u>Monterey County</u>		
First Section	16,000[a]	16,000[a]
Second Section	16,000	16,000
Distribution Pipeline Capacity, cfs		
<u>Santa Cruz County</u>		
First Section	17	20
Second Section	17	10
<u>Monterey County</u>		
First Section Second Section	28[b]	28[b]

[a] These designations are not applicable to the case of Arroyo Seco Project.

[b] Based on an estimated flow velocity of 4 fps.

Figure 4. Surface Water Distribution System for Alternative T4

asins

Table 7. Components of Water Diversion and Distribution System Under Alternative T4

Component	Size or Description	
	OPTION I 12 Hours Per Day Irrigation	OPTION II 20 Hours Per Day Irrigation
Diversion Dam	Temporary Earth Dam Built Within The Stream Banks	Same
Diversion Pumps		
hp (2 pumps)	300	300
gpm (2 pumps)	10,000	10,000
Operational Storage		
Ac-ft	22	17
Distribution Pumps		
hp (3 pumps)	900	600
gpm (3 pumps)	18,000	12,000
Distribution Pipeline Diameter, inches		
Santa Cruz County		
First Section	30	30
Second Section	30	24
Monterey County		
First Section	30	30
Second Section	24	24
Distribution Pipeline Length, feet		
Santa Cruz County		
First Section	2,000	2,000
Second Section	14,000	14,000
Monterey County		
First Section	16,000	16,000
Second Section	16,000	16,000
Distribution Pipeline Capacity, cfs		
Santa Cruz County		
First Section	17	20
Second Section	17	10
Monterey County		
First Section	20	20
Second Section	12	12

Table 8. Capital, Operation and Maintenance Cost Data for Water Distribution Alternatives

Alternative No.	Description	Capital Costs, Dollars					Annual Operation And Maintenance Cost, Dollars			
		Diversion Pumps And Structures	Operational Storage Reservoir	Distribution Pumps and Pipeline Network	Right Of Way And Contingencies	Total Capital Cost	Power Cost[a]	Maintenance Cost[b]	Labor Cost[c]	Total Operation And Maintenance Cost
T3a	Surface Distribution Of Water For Irrigation Use, Option I	276,400	142,800	9,050,400	2,968,000	12,437,600	136,800	37,900	48,000	222,700
T3b	Surface Distribution Of Water For Irrigation Use, Option II	276,400	142,800	6,456,200	2,076,200	8,951,000	136,800	27,500	48,000	225,800
T3c	Surface Distribution Of Water For Irrigation, Arroyo Seco Option:[d,e]									
	Santa Cruz County	-	49,900	2,290,150	734,500	3,074,600	91,700	9,400	24,000	125,100
	Monterey County	-	-	-	-	12,744,000	325,000	-	-	454,600
T4a	Surface Distribution In Santa Cruz County, Spreading Recharge In Monterey County, Option I	276,400	49,900	5,668,600	2,799,500	8,794,400	136,800	24,000	96,000	256,800
T4b	Surface Distribution In Santa Cruz County, Spreading Recharge In Monterey County, Option II	276,400	49,900	4,864,400	2,070,500	7,261,200	136,800	20,800	96,000	256,800

[a]Assumed on the basis of 6.5¢ per Kwh.

[b]Estimated by assuming an annual cost of 0.4 percent of construction cost.

[c]Estimated by assuming an average labor cost of $24,000 per person year.

[d]Assumed irrigation duration of 12 hours per day, six days per week, in Santa Cruz County portion of the valley and current practice in Springfield area.

[e]An operation and maintenance costs for Monterey County portion of this option were obtained from the report prepared by CH2M HILL (1982) and were escalated by a factor of eight percent.

Table 9. Present Worth and Total Annual Cost of Alternative Water Distribution Projects

Alternative No.	Description	Present Worth Of Total Costs, Dollars	Total Annual Costs, Dollars	Unit Cost[a] $/Ac-ft
T3a	Surface Distribution Of Water For Irrigation Use, Option I	15,324,800	1,234,700	190
T3b	Surface Distribution Of Water For Irrigation Use, Option II	11,754,100	947,000	146
T3c	Surface Distribution Of Water For Irrigation Use, Arroyo Seco Project, Option I	23,079,700	1,859,500	169[b]
T4a	Surface Distribution In Santa Cruz County, Spreading Recharge In Monterey County, Option I	11,981,700	965,400	149
T4b	Surface Distribution In Santa Cruz County, Spreading Recharge In Monterey County, Option II	10,448,500	841,800	129

[a]Based on an estimated delivery capacity of 6,500 ac-ft per year.

[b]Based on an estimated delivery capacity of 11,000 ac-ft per year to Springfield and Santa Cruz County portion of the valley floor area.

Table 10. Ranking of Water Supply and Distribution Alternatives on the Basin of Unit Cost

Alternative No.	Description	Unit Cost $/Ac-ft	Ranking	Estimated Annual Yield Or Delivery Capacity Ac-ft
	WATER SUPPLY ALTERNATIVES			
WS1	Pescadero Creek Dam	230	4	12,000
WS2	College Lake Dam	294	6	5,000
WS3	Bolsa De San Cayetano Dam	435	7	4,000
WS4	San Felipe Project, Pipeline Transport	277	5	17,000
WS5	San Felipe Project, Pajaro River Transport	197	3	17,000
WS6	Deep Aquifer Wells	58	1	6,500
WS7	Arroyo Seco Project	144	2	11,000
	WATER DISTRIBUTION ALTERNATIVES			
T3a	Surface Distribution, Option I	190	5	6,500
T3b	Surface Distribution, Option II	146	2	6,500
T3c	Surface Distribution, Option I, Arroyo Seco	169	4	11,000
T4a	Surface Distribution And Surface Spreading, Option I	149	3	6,500
T4b	Surface Distribution And Surface Spreading, Option II	129	1	6,500

possibly by drilling one or more pilot test wells in appropriate locations. Arroyo Seco project has the second lowest unit cost at $144 per ac-ft because of the relatively high yield of this project (43,000 ac-ft per year). San Felipe project using the Pajaro River for water transport would have a unit cost of $197 per ac-ft.

Among distribution alternatives, Option T4b which calls for surface distribution of water in the Santa Cruz County portion of the basin and surface spreading of water in the Springfield area has the lowest unit cost at $129 per ac-ft followed closely by Option T3b which calls for surface distribution of water in both of the above areas with a unit cost of $146 per ac-ft. The actual unit cost of surface spreading recharge facilities in the Springfield area would be significantly higher if such facilities are located along the coast because a major portion of the recharged water would be potentially lost to the sea and would not be available for irrigation use. When considering the combined cost of water supply and distribution systems, the following rankings will be obtained:

Combination of Alternatives	Combined Unit Cost ($/ac-ft)	Ranking
WS6 and T4b	187	1
WS6 and T3b	204	2
WS7 and T3c	313	3
WS5 and T4b	326	4
WS5 and T3b	343	5
WS1 and T4b	359	6

Cost data presented in this report indicate that the deep aquifer may be the most economic source of local water supply in the Pajaro Valley, however, no actual field data are available to substantiate the yield and lift assumptions made for deep wells in our cost calculations. Due to the low cost of this source of supply, exploration of the quality and yield of the deeper formations in the coastal areas of the Pajaro Valley is indicated. The total cost of the deep aquifer augmentation source may be further reduced if these wells could be drilled in the areas of water supply need such that the new water distribution system could be reduced in size or eliminated altogether.

Among the surface supply sources, the Arroyo Seco project would be the most economic alternative for supplying water for surface distribution in both Monterey and Santa Cruz County portions of the valley. This project can deliver up to 15,000 ac-ft of water to the Pajaro Valley area which would be adequate for meeting the maximum estimated overdraft in the basin.

In summary, the following points should be noted with regard to alternative water supply and distribution facilities.

a. If local deep aquifers prove to have an adequate yield of suitable quality water, the need for a surface distribution system may be reduced or eliminated by proper siting of the deep wells. This would result in a major reduction in the cost of the supplemental source.

b. The water distribution systems envisioned for surface spreading and surface distribution are similar under all alternatives. (In the Arroyo Seco alternative, CH_2M Hill uses two parallel supply lines, one of which traverses the same path as the line laid out for this analysis). Therefore, the cost of delivering water either to farmers or to spreading basins would be approximately the same. Due to the technical difficulties in recharging a limited quantity of water in a uniform manner along a seawater intrusion front by the surface spreading method, and the fact that as much as 50 percent of the recharged water may be lost to the Bay (depending on the location of recharge sites), it appears that any supplemental water could be more efficiently used by direct distribution to areas that are most severely affected by sea water intrusion. Based on these considerations, options calling for direct use of supplemental sources should receive a higher ranking even though their unit cost is somewhat higher than that of spreading recharge alternatives.

Phasing of the Required Water Supply Projects

In the analysis of alternatives carried out in this chapter, the distribution system for direct use or combined irrigation use and surface spreading has been designed for delivery of an annual volume of 6,500 ac-ft which is the recommended initial project size for dealing with sea water intrusion problems in the valley. The viable water supply alternatives which consist of Pescadero Creek Dam, San Felipe project and Arroyo Seco Dam, have annual yields ranging from 12,000 to 17,000 ac-ft per year.

The Arroyo Seco alternative envisions the distribution of 11,000 ac-ft of water in the Springfield area alone. In our analysis, we have assumed that initially a minimum of 2,200 ac-ft of this water would be delivered to Santa Cruz County portion of the valley. Arroyo Seco distribution system in the Springfield area relies on the use of several storage ponds at various distribution points and uses conservatively sized pipelines at fairly low flow velocities. Also, this system would supply irrigation water under prevailing practices and additional deliveries may be made if a more extended schedule is adopted by local farmers. Therefore, this system appears to be capable of delivering additional volumes of water to the Santa Cruz County line. This additional water can be distributed in Santa Cruz County area of the valley, if needed, by expanding the proposed Phase I distribution system. Such an expansion would be feasible by extending the existing pipes and by providing additional booster pump and operational storage capacity.

In the proposed distribution system under Alternatives T3b and T4b, allowance is made for future expansion of the areas receiving irrigation water supplies by increasing the size of the main stem of the water supply pipeline in the service areas of both counties. This system would enable deliveries of up to 18,000 ac-ft per year (approximately 6,000 ac-ft to Santa Cruz County and 12,000 ac-ft to Monterey County) from a diversion structure on the Pajaro River.

The actual unit cost of surface spreading recharge facilities in the Springfield area would be significantly higher if such facilities are located along the coast because a major portion of the recharged water could be potentially lost to the sea and would not be available for irrigation use.

Alternative Cost Assessment Methods

The required funds for construction, operation and maintenance of the needed water supply and distribution facilities can be raised through the formation of an assessment district and by levying an annual assessment on all lands included within the boundaries of the district. Three options may exist with regard to the boundaries of such a district or the assessment procedure to be employed as follows:

1. A district including only the land areas receiving direct deliveries of water through the facilities of the groundwater management agency. The minimum acreage of land served by the proposed facilities would be about 3,250 acres. These facilities, however, can supply water to 4,600 of farmland if the unit applied water demand of the crops raised on these lands is at 1.42 ac-ft per year as reported by the Cooperative Extension Service. Furthermore, the major surface water supply augmentation projects can provide from two to three times the minimum annual volume of 6,500 ac-ft and the water distribution system can be expanded to serve twice the minimum acreage of 3,250 to 4,600 acres with the addition of parallel branch lines to the existing distribution network. Therefore, the area that could be potentially included within the boundaries of this district could range from 3,250 acres to 9,200 acres.

2. A district including all productive lands within the boundaries of the Pajaro Valley groundwater basin. The total acreage of the groundwater basin is estimated at 84,000 acres, exclusive of the land areas to the east of San Andreas fault. Land acreage that is actively used for agricultural, municipal and industrial purposes within the valley is estimated at about 42,000 acres. Open space areas, marshes and slough account for about 5,000 acres and the balance of the basin is under native vegetation.

   For groundwater management purposes, it has been assumed that all land that is actively used for commercial purposes would be subject to an assessment. Due to the lack of data on commercial uses of native vegetation lands, only a portion of the acreage of such lands has been included within the boundaries of the assessment district under this option. A total land area of 50,000 acres has, therefore, been assumed to fall within the assessment district.

3. This option uses the large assessment district identified under No. 2 above, but would also require an additional assessment to be levied against all lands receiving direct deliveries of water from the management agency facilities.

   This extra assessment would be equal to the avoided energy and well pump maintenance and replacement costs on the affected farms.

Estimates of the annual assessment fee for each of the above alternatives for the combined water supply and distribution alternatives ranked in the order of decreasing cost is presented in Table 11. These data indicate a range in the annual per acre assessment fee of $265 to $1,140 for Option No. 1, $17 to $74 for Option No. 2 and $15 to $99 for Option No. 3.

The net annual income from irrigated lands in the potential water supply augmentation zone is estimated to be in the range of $200 to $800 per acre. Accordingly, it appears that a district encompassing only the water supply augmentation zone would not be economically feasible under any of the project alternatives. A basin-wide assessment district appears to be feasible at least on a preliminary basis and especially for project alternatives with low annual assessment fees. Economic feasibility of the basin-wide district options should be evaluated further by analyzing the net income level derived from various crop types grown in the Pajaro Valley.

Table 11. Estimated Annual Assessment Fees for Alternative Augmentation Water Supply and Distribution Facilities for Different Types of Assessment Districts

Combination of Water Supply and Distributuion Projects	Annual Fees for Assessment District Alternatives, dollars/acre			
	Augmentation Zone District[a]	Basin-wide District	Modified Basin-wide District	
			Augmentation Zone[b]	Outside Augmentation Zone
WS6 and T4b	265 - 375	25	50	23
WS6 and T3b	288 - 408	27	53	25
WS7 and T3c	749 - 1,060	69	94	67
WS5 and T4b	183 - 259	17	42	15
WS5 and T3b	614 - 869	57	82	55
WS1 and T4b	782 - 1,107	72	97	70
WS1 and T3b	805 - 1,140	74	99	72

[a]The range of cost corresponds to assessment districts of 4,600 and 3,250 acres, respectively. These costs could be reduced further if the area of the augmentation zone is expanded further in the future.

[b]The assessment in the augmentation zone includes the basin-wide fee and an avoided cost of $27 per acre per year in a 3,250 acre service area. This latter cost includes pumpage cost of $11.40 per ac-ft, annual pump maintenance cost of $1,000 and annual pump replacement cost of $770 for an estimated total number of pumps of 50 in the initial service area of 3,250 acres. Other assumptions made in these calculations are as follows: average well yield, 300 gpm; average pump lift 100 ft.; average pump efficiency, 59 percent; useful well life, 50 years; useful pump life, 10 years; initial cost of pump, $10,000; annual interest rate of 12%; and electric energy cost of 6.5¢ per Kwh. No well drilling cost or initial pump costs are included because these facilities are in existence at the present time. For consistency with water supply project costs, all calculations were made for a 50-year planning period.

INSTITUTIONAL AND FINANCIAL CONSIDERATIONS

Institutional and financial arrangements for construction and operation of water supply augmentation alternatives will be in a large measure dependent on the type and scope of the groundwater management plan to be implemented in the Pajaro Valley. In general, however, construction and operation of water supply and distribution works can be undertaken directly by federal, state, county or city governments or by autonomous state agencies such as county water districts, flood control and water conservation districts, or irrigation districts. The method of raising the required capital and operating costs would vary depending on the type of agency undertaking the given project. A brief discussion on potential institutional choices for technical project alternatives is presented in this section.

Government Agencies

Federal, state or local governments could potentially undertake the construction and management of the required facilities.

Federal Government. The U.S. Bureau of Reclamation has made provisions in its San Felipe Project for delivering up to 20,000 ac-ft of water per year to the Pajaro Valley area. The components of this project which are currently under design or construction for delivering water to Santa Clara and San Benito Counties include added capacity for delivering the required volume to the Pajaro Valley. Once a contract has been signed between local agencies and the U.S. Bureau of Reclamation and appropriations are made by the Congress for these facilities, the Bureau of Reclamation would undertake the construction of the required pipeline to transport water from Santa Clara Valley conduit to a designated point in the Pajaro Valley. Construction of any local distribution facilities, however, would be the responsibility of local government agencies. The same agencies would also have to undertake total or joint operation and management of all elements of the San Felipe project by which they are served starting below the point of diversion from San Luis Reservoir.

State Government. Due to the absence of any state water projects in the general area of the Pajaro Valley, it is improbable that the state government would be directly involved in any aspect of the development of supplemental sources of water in the Pajaro Valley.

Local Governments. Local government agencies that could potentially undertake the construction and management of the required facilities include the City of Watsonville and the Counties of Monterey and Santa Cruz.

Due to the relatively large scale of the water supply augmentation projects involved and because the main objective of the project is to supplement the irrigation water sources in the coastal area, it is improbable that the City of Watsonville would take the lead role in the implementation of this project.

Santa Cruz and Monterey County governments can undertake the construction, operation, and management of projects of this type. However, the mechanism normally used for implementation of these projects is to establish special districts such as flood control and flood water conservation districts, resource conservation districts, sanitation districts, etc., for specific projects serving a limited area of the county.

Both counties currently have fully operational Flood Control and Water Conservation Districts (FCWCD). These districts can operate under the direction of five trustees who are appointed by the Board of Supervisors. Alternatively, the Boards can directly oversee the operations of the FCWCDs. This latter mode is currently in effect in Santa Cruz and Monterey Counties. Two potential limitations must be considered with respect to the choice of FCWCDs as follows:

1. The service area of each Flood Control and Water Conservation District is restricted to the county of its origin. Therefore, each district would have to operate separate facilities within its service area or a joint powers agreement would have to be developed for operating the shared components of the facilities.

2. The purpose of a flood control district is stated in the statute as follows:

   > "Control of floods and conservation of flood water; may not construct dam or reservoir without consent of Board of Supervisors of each county which may be affected", (DWR, 1978).

   The enabling acts of Santa Cruz and Monterey County FCWCD's provide similar powers to these districts subject to the same limitations as discussed above. These acts specifically indicate that the districts can conserve flood and storm waters from sources within or outside the district boundaries, but which flow into the district, for beneficial uses by spreading, storing, retaining, and causing such waters to percolate into the soil within the district. The enabling acts also empower either FCWCD to import water from outside sources for beneficial use within their respective service areas.

3. FCWCDs can issue bonds to raise needed capital for construction of flood control facilities. Such bonds can be defrayed by assessments levied against lands benefiting from the specific projects. Assessments can also be made against lands within the district boundaries to raise funds for general operations of the district.

Independent Districts

The facilities required for providing a supplemental source of water in the valley can be constructed and maintained by independent districts such as an irrigation district or a county water district. These alternatives are discussed briefly in this section.

Irrigation District. An irrigation district (ID) can be formed to "furnish water for, and put water to any beneficial use, control, distribute, salvage, etc.; any water, including sewage for beneficial use", (DWR, 1978). An irrigation district is a declared state agency and is formed by the petition of the majority of landowners, or 500 electors and/or owners, including owners of 20 percent of land in value to the Board of Supervisors of the county where most of the land in the proposed district is located, followed by the approval of the voters in the district. An ID is governed by an elected board of directors. An irrigation district would have all the necessary powers for developing and distributing new water supplies in a multicounty service area and to raise the required funds for construction and operation of such facilities. However, there is a major limitation for the use of an irrigation district for implementing a groundwater management program. The service area of an irrigation district can include only lands irrigable from a common source and by the same system. This requirement may preclude the inclusion of the entire groundwater basin within the boundaries of the district. Since a major source of capital and operating funds for the district is by levying an assessment on the lands within district boundaries, the above limitation may prevent the use of an irrigation district for implementing the types of projects envisioned in this study.

County Water Districts. A county water district (CWD) can furnish water for any present or future beneficial use; acquire, appropriate, control, conserve, store, and supply water, etc. (DWR, 1978). The territory of a CWD can include any portion of a county, or two or more contiguous counties. The district can be formed by the petition of 10 percent of the registered voters to the Board of Supervisors of the county in which all or the the greater portion of the district is located, followed by appropriate proceedings and approval by the voters who are residents of the district. A CWD is governed by an elected Board of Directors.

The advantage of a CWD over an ID is that the former may be able to include within its territory lands which are not directly benefiting from water supply and distribution facilities operated by the district and can assess an annual ad valorem tax on all property in the district, however, bond assessments can only be imposed on property in portions of the district benefiting from such expenditures. The legal implications of direct versus indirect benefit and equitable distribution of the cost of remedial projects (such as projects intended for alleviating sea water intrusion which is brought about by the impact of collective pumping in the basin) are not known and may be cause for potential legal challenges to the project. Alternatively, the State Legislature can grant additional powers to a CWD formed for the specific purpose of groundwater basin management in the Pajaro Valley. The requirements of Proposition 13 may be another complicating factor in raising any needed funds by an ID or a CWD.

Groundwater Basin Management Agency. Currently there is no legal provision for the formation of a groundwater basin management agency. In basins where court approved adjudication has been implemented the management function has also been delegated to an appropriate agency by the court. Alternatively, the legislature can pass a special bill allowing the formation of an appropriate agency and grant it the required powers for the management of the basin. This alternative will be discussed in more detail in a succeeding chapter of this report.

Recently a bill was passed by the state legislature and signed into law by the governor to create a groundwater management agency in in the Pajaro Valley upon approval of local voters (AB 1936). This Act must be approved by local residents before it can take effect. The Act will be on the ballot in November 1984. The agency envisioned under this Act would be governed by by an elected board and would have broad powers to implement reasonable measures to prevent further increases in the amount of long-term overdraft and to accomplish continuing reductions in long-term overdraft. The agency would be granted powers to carry out all pertinent management fucntions including:

1. Conducting technical investigations and data gathering tasks.

2. Enter into cooperative efforts or contracts with federal, state, and local government agencies.

3. Prepare annual reports on groundwater supplies and conditions.

4. Exercise power of eminent domain as appropriate.

5. Receive and administer private or public grants.

6. Issue bonds for raising needed funds.

7. Require registration of groundwater extraction facilities.

8. Perform groundwater management services including the regulation of groundwater replenishment programs, store and recapture water within the basin, take action to prevent unreasonable use of water within the basin, impose density limits on new wells, impose pumping limits under justified circumstances, purchase and import water, and regulate the rights of water users.

The agency would further be empowered to review future land use plans which are subject to permit regulations and make a determination of the impact of such plans on water supply and quality, land subsidence, etc. The Act prohibits approval of any land use plan which the agency determines to create an undesirable impact on the groundwater resource unless certain specified mitigation measures have been taken.

The agency would also be granted powers to impose a use fee on all future water uses and levy a charge on land for defraying the administrative costs of the management agency subject to limitations on the amount and duration of such charges and the total annual revenues collected within the basin. (The unit charge cannot exceed $5 per acre and the total basin-wide charge cannot exceed $300,000 per year; the Board of Directors can raise these fees by a five seventh vote after holding public hearings.)

The agency would also be granted enforcement powers by obtaining injunctive relief from any infringement of agency regulations and requirements. The Act further imposes civil penalties for violation of any provisions of the act or agency ordinances.

Summary

A summary review of various institutional options for groundwater management in the Pajaro Valley is presented in Table 12 for the agencies discussed in this section and for other variations of these agencies that could attain the same objectives as discussed above.

Table 12. Summary Information on the Characteristics of Various Institutional Options for Groundwater Management in the Pajaro Valley

Institutional Framework	Purpose/(s)	Indep/Dep Governing Board	Territory	Eminent Domain	Funding Mechanisms	Special Notes
Community Services Districts	Supply inhabitants with water for various purposes	3 or 5 elected directors, or county supervisors (independent or dependent)	Any unincorporated territory in one or more counties	Yes	Assessments, revenue bonds, rates or service charges, standby charges	May contract with State or U.S.
County Service Areas	Provide water service including water supply and distribution systems	County board of supervisors (Dependent)	All or part of unincorporated area of the County and City, if approved by the affected City Council	No Provision	Service fees, annual ad valorem tax assessment on taxable property or on land & improvements in areas benefited by bonds for water purposes	No provision for cooperation with State & Federal agencies
County Water Authority	Acquire water and water rights, develop, store and transport	Board of directors from each agency (Dependent)	Area of member agencies	Yes	Charges for sale and delivery annual ad valorem	Need 2 or more public agencies to form
County Water Districts	Furnish, store, acquire, and supply water for any present or future beneficial use	5 elected Directors (Independent)	Co or 2 or more contiguous	Yes	Water and sewer rates, annual ad valorem on all property benefit assessment	May contract with State and Federal agencies
County Waterworks District	Supply inhabitants with water for irrigation domestic or industrial use	County board of supervisors (Dependent)	In one County	Yes	Rates or charges, annual ad valorem on all taxable property	No provision for State and Federal cooperation

Table 12. Summary Information on the Characteristics of Various Institutional Options for Groundwater Management in the Pajaro Valley (Continued)

Institutional Framework	Purpose/(s)	Indep/Dep Governing Board	Territory	Eminent Domain	Funding Mechanisms	Special Notes
Irrigation Districts	Furnish, control, distribute may allocate under special circumstances	3 or 5 elected directors (Independent)	Land irrigatable from common source and by same system (not contiguous)	Yes	Revenue bonds, water rate, annual ad valorem assessments according to benefits	State agency DWR is actively involved in setting up and reviewing new agencies; may contract with U.S.
Municipal Utility District	Supply inhabitants and public agencies of District with water	5 directors of 5 wards (Independent)	Any "public agency" together with unincorporated territory; 2 or more public agencies	Yes	Revenue bond, rates and charge, ad valorem refunding bonds	May enter into contracts with State and U.S.
Municipal Water Districts (1911ACT)	Acquire, control, store, distribute water	5 directors (Independent)	Any county or counties and cities	Yes	Revenue bonds, water rates, water replenishment assessment	May contract with U.S. and State
Water Conservation District 1931	Conserve and store, appropriate acquire, sell, deliver, distribute, store by "spreading basins sinking wells..."	3, 5 or 7 directors (Independent)	Whole or part of one or more watershed(s)	Yes	Revenue bonds, sales of water, special assessments	May cooperate and contract with U.S. and State
Water Storage Districts	Diversion, storage conservation and distribution of water	5, 7, 9 or 11 directors, 1 vote/$100 assessed value (Independent)	Land already irrigated or susceptible of irrifrom common source	Yes	Direct assessment warrants; tolls for use of water and irrigation assessment organization and startup, interim project assessment	May cooperate and contract with State or Federal agencies DWR involved in organizing new district
Water Districts	Produce, store, distribute	Elected directors (Independent)	Land capable of beneficially using water	Yes	Revenue bonds, warrants, water rates, assessments according to benefits	May contract with State or U.S.
Water Replenishment Districts (1955)	Replenish groundwater supplies of the district	5 elected directors (Independent)	Unincorporated or both unincorporated and incorporated territory in one or more counties	Yes Limited	Rates or charges, annual replenishment assessment	May contract with State or U.S.

ENVIRONMENTAL IMPACTS OF WATER SUPPLY AND DISTRIBUTION ALTERNATIVES AND POTENTIAL MITIGATION

The environmental impacts of the major water-supply and distribution alternatives are discussed in this section: The environmental effects considered are those intrinsic to each specific proposed project. Some benefits are common to most or all of the alternatives, such as control of sea water intrusion or raising of static water levels. Excluding these from consideration provides a more meaningful comparison between alternatives.

The following discussion is intended to provide an overview of environmental effects, of the proposed alternatives, and the ways in which the main impacts might be mitigated. It should not be construed as a detailed environmental impact report. Rather, the discussion is kept at the feasibility level, in conformance with the analysis of alternatives. Similarly, the assessment is restricted to a scale comparable to that of the facilities being evaluated. Limited impacts affecting a few individual ownerships, such as noise from construction activities, are not considered. The formal CEQA and NEPA review processes can provide a more detailed analysis in conjunction with future detailed facilities planning stages of the project.

With a few important exceptions, the environmental impacts of any of the proposed alternatives are much more limited than might be expected for projects of regional scale. Several factors account for the minimal impacts:

1. The additional water supply is intended to retain existing land uses; it is a supplemental source not expected to induce new growth or changes in the use of principal resourses.

2. The Pajaro River and its watershed are large relative to the scale of most alternatives.

3. Most facilities are likely to be aligned along existing roads or levees; few new corridor-type impacts are anticipated.

4. Fisheries resources of the lower river are limited; except for facilities which destroy important upstream habitat (such as Pescadero or College Lake Dams), instream biological impacts are likely to be small.

5. Most alternatives are likely to improve water quality.

6. There are few natural areas affected.

Alternatives Evaluated

Seven water-supply and five distribution alternatives are considered in this report. Water-supply alternatives include Pescadero Creek and College Lake Dams, stream and pipeline conveyance of San Felipe Project waters, a proposed off-stream storage site at Bolsa de San Cayetano (near the mouth of the Pajaro River), Arroyo Seco project, and pumpage from the deeper aquifers. Distribution facilities incorporate both options with surface distribution and combined surface distribution and spreading elements. Alternatives are listed and ranked by cost in Table 10.

Environmental Effects

Environmental effects discussed in this section include biological, hydrologic, historical and archeological, public safety, and land-use factors. Table 13 is a summary of the changes each of the major project alternatives are likely to impose upon the environmental systems. Somewhat more than half of the matrix elements in this table are left blank, indicating that there is no measurable effect or that the specific environmental consideration is not applicable to the alternative.

The environmental considerations and major specific impacts are discussed in the following sections:

Stream Habitat. The Pajaro River system is utilized by steelhead for spawning and rearing. The young steelhead are hatched and grow in the headwaters of the major tributaries, where temperature and water quality conditions are suitable. The Pajaro River itself and the lower portions of the major tributaries support populations of rough fish (mainly sculpin, roach, squawfish) of very limited angler interest. These streams are also used by adult steelhead as they move upstream to spawn, and by smolt and returning adults migrating downstream to the ocean (Harvey and Stanley Associates, 1983).

The Pescadero Creek and College Lake projects involve construction of dams which may exclude steelhead from streams presently used for spawning and rearing. The dams will also interfere with downstream migration. Great care and expense may be required for these runs to be retained. In the case of several other comparably-sized new dams proposed for other Monterey Bay area streams, retention of the run upstream of the facility was not considered to be justified. It is possible that construction of either the Pescadero Creek or College Lake dams will result in loss of the spawning and rearing habitat upstream. The impact of these losses should be considered major.

Both the College Lake and Pescadero Creek projects will reduce migratory flows to a small or moderate degree. Reductions of no more than 25 to 30 percent are anticipated. These reductions would affect upstream migrants early in the winter season, primarily during drier years. Returning adults might also be impacted. Releases from either facility would have beneficial impact by increasing flows and reducing water temperatures during downstream migration of the smolt.

Table 13. Selected Environmental Effects of Proposed Alternatives

Environmental Factors	WS1 (Pescadero)	WS2 (College Lake)	WS3 (Bolsa)	WS4 (SFlp) (pipe)	WS5 (SFlp) (river)	WS6 (Deep aquifer)	T3a,T3c (Option I) (Surface Distribution)	T3b (Option II) (Surface Distribution)	T4a (Option I) (Combination)	T4b (Option II) (Combination)
	Water Supply Alternatives[a,f,g]						Distribution Alternatives[a]			
Biological Considerations										
Stream Habitat										
Fish passage	H, L	H, L			B					
Downstream migration	H, L	H, L	L		B					
Rough fish	M, B	H, L			B					
Riparian Habitat	H	L		L	B					
Wetlands Habitat (in Pajaro Valley)	B	L	B	B	B	B				
Hydrologic Considerations										
Water Quality	B	B	B	B	B	?[d]				
Sedimentation	B									
Historical and Archeological Considerations	?	?[d]	?[d]	?			?	?	?	?
Public Safety Elements										
Dam and Seismic Safety	H	M	L							
Flood Hazard	L	L*	L	L						
Land-Use Considerations										
Loss of Agricultural Land	L	H	H	L		L	L	L	M	M
Recreation	e									

Effects Code:

- H — Large and/or significant impact.
- M — Moderate impact.
- L — Low impact.
- B — Beneficial effects predominant.
- a — Names, codes, and options as described in alternatives discussions.
- b — Both surface delivery and recharge by spreading.
- c — Where two symbols are used; the first denotes impacts at or upstream of the proposed facility; the second denotes downstream impacts in the Pajaro River and Salsipuedes Creek.
- d — Unknown, but likely to be significant if high levels of salts exist in these aquifers.
- e — Loss of steelhead run valued by anglers is likely to result; some lake-type recreation may be incorporated into the proposed project, although limited by large seasonal and year-to-year water-level fluctuations.
- f — Arroyo Seco Project option would have no significant impact in the Pajaro Valley.
- g — Arroyo Seco Project impacts associated with the dam and other major elements are addressed in detail by MCFCWCD.

San Felipe Project waters conveyed by the river to the Pajaro Valley would benefit smolt migration as well. Depending on the point of release into the upper Pajaro system, stream-conveyed San Felipe Project supplies might be of benefit to the Pacheco Creek steelhead run. Harvey and Stanley Associates (1983) have identified enhancement of the Pacheco Creek run as one of the primary steelhead management opportunities in the central coastal area of the state. A steelhead management plan for the Pajaro River basin has been prepared in a separate 208 study for AMBAG.

Either the College Lake or Pescadero Creek projects will moderately impact the rough fish populations by flooding portions of their habitat. The College Lake habitat is presently available only intermittently. Releases from either project will improve rearing conditions in the lower tributaries and the main stem of the river.

Arroyo Seco project will impact stream habitat in Arroyo Seco Creek and Salinas River. These impacts will be addressed in detail in the required environmental impact report that will be prepared by MCFCWD for this project.

Riparian Habitat. A significant effect on riparian vegetation and habitat is expected only with the Pescadero Creek project. This project will inundate about three miles of riparian corridor, a large proportion of the total riparian resource in this tributary drainage. Additionally, the half-mile of riparian woodland downstream of the damsite will adjust to a flow regime lacking overbank flows, and will probably change in character and be reduced in size. A small amount of riparian woodland (probably less than 5 acres) would be lost to either the College Lake project or a pipeline conveying San Felipe waters. Use of the river to transmit the San Felipe releases might result in a slight enhancement of riparian environments, especially upstream of Chittenden.

Pajaro Valley Wetlands Habitats. Freshwater sloughs, lagoons, and lakes are found throughout the Pajaro Valley and the Springfield district. These are natural features which have all existed for at least several thousand years, and provide significant habitat, particularly for birds. Originally, the lagoons were sustained by groundwater. Static water levels are now 20 to 40 feet below most of these wetlands. As groundwater levels continue to fall, the character and quality of these habitat areas are likely to change. By providing additional waters to reverse the falling static level trends, each of the alternatives provides a net benefit to these wetland areas. The College Lake project entails submergence of one of these wetland areas, which has been almost entirely converted to agricultural use.

Water Quality. Most alternatives involve distribution of water of substantially higher quality than that presently found in local surface and ground waters. Use of the Pajaro River to convey supplies may result in potential increases in pesticide residues in the delivered water due to agricultural return flows entering the River during the irrigation season. This quality degradation is not expected to impose a significant problem when the diverted waters are used only for crop irrigation purposes. Extensive treatment of these waters may be required prior to any domestic or industrial process uses. One important exception is development of deeper aquifers, from which water of unknown salinity is expected; the salts content of the deeper waters are almost certain to be higher than that in the present irrigation supplies.

Sedimentation. The Pajaro River transports a high sediment load. The proposed projects will result in minimal change in the sediment transport regime of the river, although debris introduced into the distribution systems must be managed carefully. Even the largest project, on Pescadero Creek, affects less than 2 percent of the drainage area of the Pajaro River.

All projects, with one exception, are presumed to have a negligible impact on movement of sediment through the river and to the beach areas. We believe that major pulses of sediment are occasionally delivered to the main river from Pescadero Creek, perhaps following large landslides or fires. These pulses may cause bank erosion or filling of the main stream for a relatively brief period. Construction of a dam on Pescadero Creek would reduce this potential hazard, and is considered slightly beneficial.

Effect on Historical and Archeological Resources. The effects of the proposed alternatives on archeological and historical resources are largely unknown. It is customary to investigate possible impacts once a specific project has been chosen and an environmental impact statement has been authorized.

It is likely that both the Bolsa de San Cayetano and College Lake sites are areas of substantial archeological interest. These environments were probably attractive to resident Costanoan groups. Additionally, the historic Saint Francis complex borders upon the proposed College Lake facility.

Dam and Seismic Safety. Seismic safety has been identified as a major item of concern in preliminary discussions of the Pescadero Creek facility. The proposed dam is to be constructed a short distance from the San Andreas and Sargent faults. At the abutments are sandstones and mudstones which are thought to be heavily-jointed and fractured.

The College Lake facility would be situated between the San Andreas and Zayante-Vergeles fault systems. The dam would be founded on unconsolidated silts and muds, requiring careful site-specific design.

The Bolsa de San Cayetano storage site is set within unconsolidated terrace sediments rich in silts and clays. Failures in these sediments have periodically been observed along the southern wall of the Pajaro Valley floor. The geotechnical properties of this site remain to be established.

There are neighborhoods, communities, and important facilities situated downstream of both the proposed College Lake and Pescadero Creek dams. Failure of either one would place these populations and improvements at considerable risk. Seepage or failure at Bolsa de San Cayetano site would cause damages of much more limited magnitude.

Flood Hazards. None of the proposed projects appreciably decreases the magnitude of flood peaks on any of the major streams. Use of these streams to convey irrigation season releases could result in intensified riparian growth, which conceivably could reduce the flood-conveying capacities of existing flood-control facilities. The extent of this impact is likely to be minimal to minor.

Loss of Agricultural Land. The general plans of both Monterey and Santa Cruz Counties call for preservation of agricultural land uses. The College Lake and Bolsa de San Cayetano proposals involve the loss of 275 and 70 acres of seasonal and permanent agricultural land, respectively. Cultivation within College Lake is already partly limited by inundation, but production has been sustained uninterruptedly for decades. A reservoir on Pescadero Creek would inundate about 200 acres presently being used for livestock grazing.

All four transmission alternatives require minor use of agricultural land, and some disruption of agricultural activity. If spreading is used, an additional 20 to 30 acres of agricultural land will be lost.

Recreation. Only the Pescadero facility is amenable to significant recreational development. Use of the proposed Pescadero Reservoir would require adaptation to large seasonal and year-to-year fluctuations in water levels, perhaps as much as 120 to 150 feet. Additionally, waters stored in the lake might be highly turbid for an appreciable part of the season, due in part to the high sediment load in waters diverted from the Pajaro River and the delivery of very find sediment from the Pescadero Creek watershed, which is largely underlain by siltstones and mudstones. The Pescadero project is also likely to result in loss of the existing steelhead run, highly valued by local anglers.

Mitigation. The major environmental effects of the proposed water-supply and distribution alternatives are their impacts on the steelhead resource, dam safety considerations, and the potential loss of agricultural land.

In the Pajaro River and the lower tributaries, the impacts on migrating steelhead can be largely mitigated through careful regulation of flows and the use of appropriate fish screening techniques. Studies of the flows needed for migration up the Pajaro River and Corralitos/Salsipuedes Creeks can be made by a fisheries biologist, followed by a decision on which flows can and should be bypassed. Diversions on both streams should be screened. Screens have been included in the costs of both diversion facilities.

Both the College Lake and Pescadero Creek facilities could result in the loss of steelhead runs in tributaries upstream of these dams. Spawners may be prevented from reaching the headwaters; the dams will inhibit downstream migration of any adults or smolts. Mitigation could include finding ways for retaining these runs, and/or enhancement of steelhead habitat in other parts of these streams or the Pajaro watershed. Most proposed dams in the Monterey Bay region have not attempted to ladder or bypass the migrants. An effort of this sort may be made in the near future on the Carmel River, which has a much larger watershed and a substantially larger run of steelhead. Most other recently-completed dams or those under consideration have accepted the loss of the run upstream of the facility, and have attempted to mitigate their impacts by enhancing habitat in other portions of their basin or providing a freshwater fisheries at the facility.

Seismic and seepage considerations do not necessarily preclude construction of dams in areas of greater-than-normal risk. Special provisions of anticipated local problems must be included in the design and operation of such facilities. Engineering practice calls for such provisions to follow from detailed geotechnical analysis, usually undertaken during predesign studies. We note that previously-proposed dams at the Watsonville Reservoir (Corncob Canyon) and Mormon Gulch sites were abandoned following such detailed geotechnical studies.

Loss of agricultural land is an unavoidable impact of either the College Lake or Bolsa de San Cayetano projects. In either case, the loss of productive land might be considered in the context of the amount of agricultural land which can be saved from the effects of seawater intrusion. Alternatively, the additional costs and environmental impacts of other projects might be weighed against the loss of the acreage within the projects.

Comparison of Water Supply Augmentation Alternatives on the Basis of Environmental and Institutional Factors

A brief comparison of water supply and distribution alternatives on the basis of environmental and institutional factors is presented in this section.

Water Distribution Alternatives. The five water distribution alternatives evaluated in this study, in general, have similar environmental impacts except that options T4a and T4b may result in minor losses of crop land for construction of spreading recharge basins. Institutional requirements of alternatives calling for distribution of water to farmers, in general, would be more complex than the corresponding requirements for the surface spreading recharge alternative. (This option is technically feasible only in Monterey County.) Water distribution alternatives calling for extended irrigation scheduling (alternatives T3b and T4b) would impose additional institutional requirements for implementation of the extended irrigation schedule and may be less acceptable to affected farmers than options T3a, T3c or T4a.

Based on the factors discussed above, Alternatives T3a, T3b or T4a, calling for distribution of water to farmers under their existing operating schedule appear to be more desirable from an institutional and implementation perspective. The appreciable difference between the cost of these alternatives and alternatives T3b and T4b, calling for extended irrigation scheduling, however, may outweigh any disadvantages arising from the more complex institutional requirements for the latter alternatives.

Water Supply Alternatives. The seven water supply alternatives considered in this study have varying levels of environmental impact (Table 11). Some of these impacts such as seismic safety considerations for Pescadero Creek dam can be considered major and would require detailed investigation prior to selection of this alternative. Other environmental effects of these alternatives such as biological and crop land impacts vary from low to high but are mainly amenable to mitigation.

The institutional requirements of various water supply alternatives vary in the degree of complexity and potential acceptability to affected farmers and other residents of the Pajaro Valley. Formation of a groundwater basin management agency or development of joint powers agreement between appropriate county agencies would be a prerequisite for implementation of all water supply alternatives perhaps with the exception of the deep aquifer alternative. If each county were to embark on the development of a separate water supply project, a unified management structure would be required to ensure equitable sharing of the cost burden and to prevent imbalanced use of the available groundwater resources.

For the deep aquifer alternative, both the institutional and physical facility requirements could be minimal because this alternative could be conceivably implemented by individual farmers with financial support from a groundwater management fund or agency.

Summary and Conclusions

Seven water supply projects and five water distribution alternatives have been evaluated in detail in his chapter for meeting the irrigation need of farm lands in the coastal areas of the valley which are affected by salt water. The yield of the water supply projects varies from 4,000 to 17,000 ac-ft per year. A design value of 2.0 ac-ft per acre per year was used for the 3,250 acres of truck crops in the salt affected areas based on the recommendations of Santa Cruz County Agricultural Extension Service. Recent field data reported by this agency indicate that the demand levels of these crops may be as low as 1.42 ac-ft per year. Based on the design demand value, a total volume of 6,500 ac-ft of water is required to supply the intruded areas. If the lower demand values are confirmed by additional field data, the above volume can supply 1,450 extra acres of farm land, thereby enabling the expansion of the service area of the coastal water supply project if future monitoring indicates the need for such an increase.

In addition to direct distribution of water to farmers, recharge augmentation of the unconfined aquifers in the Springfield area where such an operation could be successfully carried out was also included among the options evaluated in this chapter. The results of our investigations indicate that direct recharge of the confined aquifers under the valley floor areas would not be feasible by surface spreading in the San Andres Dunes area. Also recharge spreading in inland areas of the valley would not be as effective as direct distribution of water to affected farm land areas for control of salt water intrusion

A summary ranking of the water supply and distribution alternatives on the basis of cost, technical feasibility, environmental impact, and institutional requirements is presented in Table 14. Based on cost data, it appears that the deep aquifer alternative would provide the most economical source of additional water supply in the valley followed by the Arroyo Seco project and San Felipe water transported through the Pajaro River. The cost of other water supply projects would be significantly higher than the projects listed above. Among water distribution options alternative T4b has the lowest cost followed by alternatives T3b and T4a. The remaining two alternatives have a significantly higher unit cost.

On the basis of non-monetary factors the deep aquifer alternative again ranks highest with the exception of the uncertainty associated with the yield and quality of water that may be derived from this source. The Arroyo Seco project follows as a close second and the third ranking project appears to be the San Felipe project with the Pajaro River transport. Pescadero Creek ranks fourth due to the potential concern that may be generated with regard to seismic safety and flooding hazards.

Water distribution projects, in general, fall into two categories with respect to the intangible factors: projects calling for direct distribution of water to farmers under their existing irrigation schedule which rank higher than those projects calling for extended irrigation schedules or for surface spreading of water in the Monterey County area.

Recommendations

Based on the information presented in this chapter, the following water supply and distribution alternatives are recommended in a descending order of overall ranking for implementation in the Pajaro Valley.

1. Deep aquifer supply project, plus direct distribution system to farmers in the sea water affected areas.

2. Arroyo Seco water supply project plus direct distribution system to farmers.

3. San Felipe water supply project, Pajaro River tranposrt option, with a distribution system as above.

4. Pescadero Creek water supply project, with a distribution system as above.

Table 14. Ranking of Water Supply and Distribution Alternatives on the Basis of Cost, Environmental, Technical and Institutional Factors

Alternative No.	Description	Unit Cost $/Ac-ft	Cost Ranking	Estimated Annual Yield or Delivery Capacity Ac-ft	Technical Feasibility	Environmental Impact	Institutional Complexity
	WATER SUPPLY ALTERNATIVES						
WS1	Pescadero Creek Dam	230	4	12,000	High	Moderate to High[c]	Moderate
WS2	College Lake Dam	294	6	5,000	Low[a]	Moderate	Moderate
WS3	Bolsa De San Cayetano Dam	435	7	4,000	Low[a]	Moderate[c]	Moderate
WS4	San Felipe Project, Pipeline Transport	277	5	17,000	High	Moderate	Moderate
WS5	San Felipe Project, Pajaro River Transport	197	3	17,000	High	Low	Moderate
WS6	Deep Aquifer Wells	58	1	6,500	Moderate to High	Low	Low
WS7	Arroyo Seco Project	144	2	11,000	High	Low	Moderate
	WATER DISTRIBUTION ALTERNATIVES						
T3a	Surface Distribution, Option I	190	5	6,500	High	Low	Moderate
T3b	Surface Distribution, Option II	146	2	6,500	Moderate[b]	Low	High[b]
T3c	Surface Distribution, Option I, Arroyo Seco	169	4	11,000	High	Low	Moderate
T4a	Surface Distribution and Surface Spreadking, Option I	149	3	6,500	High	Moderate[d,e]	Moderate
T4b	Surface Distribution and Surface Spreading, Option II	129	1	6,500	Moderate[b]	Moderate[d,e]	High[b]

[a] Low expected yield

[b] Uncertainty regarding the acceptability of extended irrigation scheduling to farmers and complexity of implementation

[c] Seismic safety considerations

[d] Loss of farmland for spreading basins

[e] Uncertainty with regard to the efficiency of spreading recharge operations

The above ranking is based on consideration of cost, environmental, technical and institutional factors associated with all project alternatives as discussed in detail in the preceding sections of this chapter.

CHAPTER 6 - REFERENCES

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CHAPTER 7

MANAGEMENT OPTIONS IN SANDY RECHARGE AREAS

Introduction

Much of the coastal plain of eastern Monterey Bay has been developed in dissected highly-permeable dune, littoral, and alluvial sands. Runoff from these sandy or "sand hill" basins appears to range from 0 to 8 percent of average annual rainfall, compared to 30 to 45 percent in adjoining similar-sized drainages underlain by soil and rock types with more typical infiltration rates. The contrast in runoff rates between the "normal" and "sandy" watersheds is shown in Figure 1. Minimal amounts of runoff seem to occur in two out of three years from most sandy basins. Both the amount of runoff and its percentage of rainfall increase rapidly in the wettest years. Nonetheless, runoff from the sandy basins remains a small fraction of that yielded by other watersheds.

Conversely, annual recharge is proportionately greater in sandy basins. The Pajaro Valley is one of very few groundwater basins of coastal California in which direct (rainfall) recharge exceeds stream recharge. The widespread distribution of the Aromas Formation and other sandy sediments along the periphery of the valley is mainly responsible for the large proportion of rainfall recharge.

Development of the sandy areas for residential use diminishes the pervious qualities of the soil, resulting in large increases in runoff and substantial loss of recharge. Associated impacts include accelerated erosion (including channel- and gully-cutting), loss of recharge, and damage to public roads and utilities, and perhaps, adverse effects on groundwater quality.

In this chapter, we discuss the general characteristics and distribution of sandy soils and the underlying sediments. A brief summary of field studies conducted to outline the storm hydrology of sandy basins under both urban and open-space uses is presented. Potential needs for management are identified. We discuss the importance of approaching recharge protection from a sub-watershed perspective, and the relation of recharge protection to erosion control, drainage management and water quality. After assessing the available information now used for planning, we recommend certain additional studies. Existing regulations, policies and ordinances are considered, including a number of newly-enacted programs and standards, many of which are parts of the local coastal plans (LCP's) of the two counties. We also discuss policies, programs and structural measures which may serve as parts of a recharge protection program based on a sub-watershed management concept. The final section is a summary of recharge-protection issues considered and some potential management approaches in light of the data developed during this study.

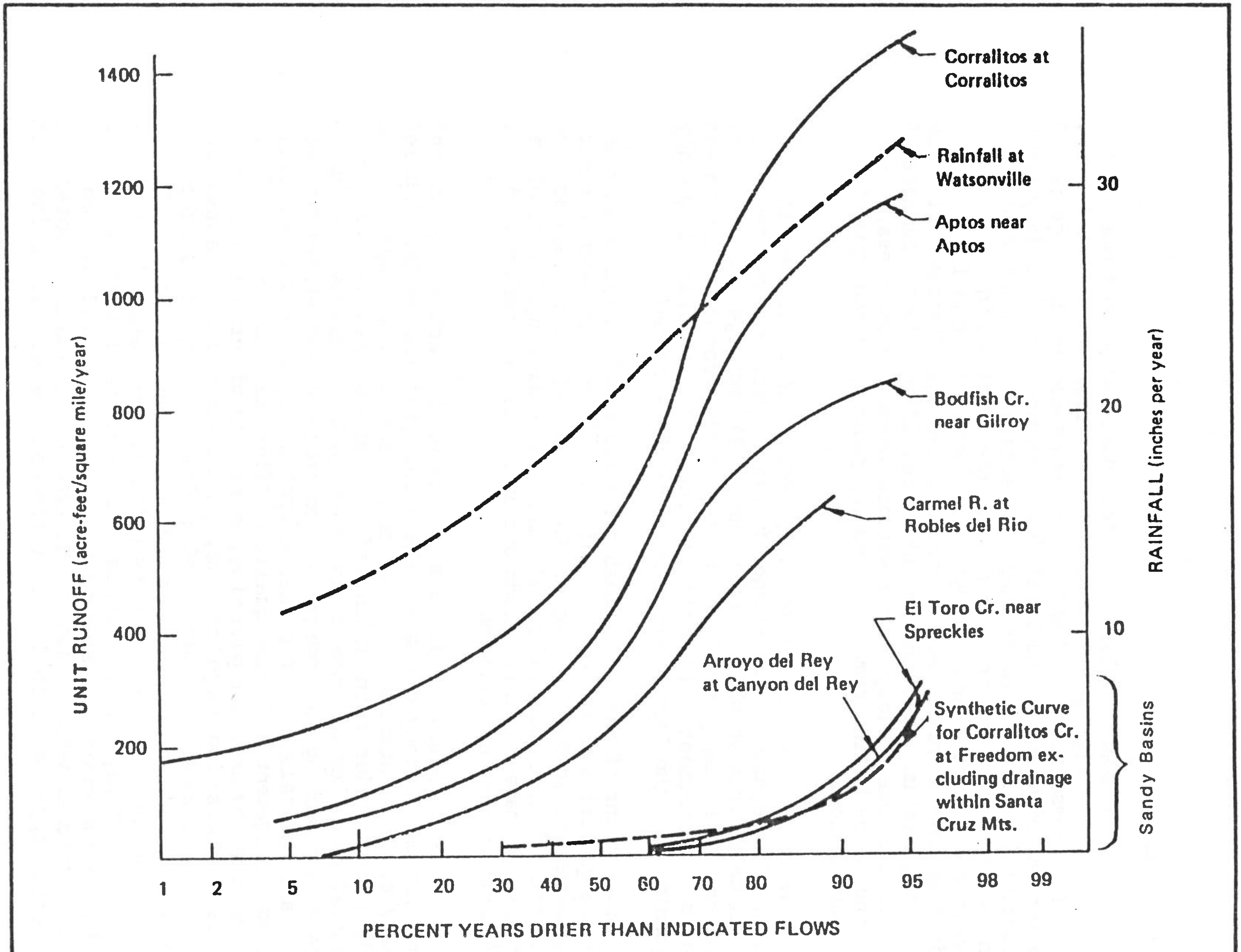

Figure 1. Exceedance frequencies of rainfall and runoff for streams in Pajaro Valley and nearby areas. Sandy watersheds (Arroyo del Rey, El Toro Creek, synthetic lower Corralitos Creek) yield only a small fraction of the runoff produced by other Monterey Bay area drainages. From HEA, 1978.

Characteristics of Sandy Watersheds. The term "sandy" is, of course, a qualitative one. It is also a relative term -- what is "sandy" in one environment might not be so regarded elsewhere. The full continuum of sandy conditions is found in the Pajaro Valley. These range from the large dunal areas along San Andreas Road, where no runoff is ever produced from the closed-contour depressions, to areas north of Corralitos (such as along Rider Road), where silty-sandy soils produce nearly as much runoff as other areas in the Santa Cruz Mountains.

We may apply the term "sandy" to the full range of these conditions. The concept of sandy watersheds is, however, useful mainly in the basins with defined valleys and which produce runoff during some storms in some or most years. Most of the valleys in the sand hills* north and south of the Pajaro Valley floor have such conditions. In many cases, these are basins which for the first time in many thousands of years are currently developing active channels, perhaps in response to changing land-use practices.

Regional Distribution of Sandy Watersheds. The eastern Monterey Bay lowland appears to have the largest concentrations of sandy watersheds in coastal California. Sandy basins occur north of the Pajaro Valley in the Corralitos, Aptos, and La Selva Beach areas; between the Pajaro and Salinas Valley floors in the Prunedale, Castroville, and Las Lomas areas; and between the Salinas and Carmel Valleys, encompassing Fort Ord and much of the El Toro and Arroyo del Rey watersheds.

These areas correspond closely with outcrops of the Aromas and Paso Robles Formations. Also included are areas of younger marine terraces and dunes, most notably along San Andreas and Giberson Roads and in Fort Ord and Seaside. Predominant soil series are Arnold, Baywood, Elder, Elkhorn, and Oceano, with most individual soil types being deep, poorly developed, and excessively drained.

Beyond eastern Monterey Bay, sandy-watershed conditions prevail in other areas dispersed through coastal California. Large areas of similar soils and topography also occur east of Morro Bay and in the vicinity of Arroyo Grande and Grover City in San Luis Obispo County; in Daly City, Colma, and the western part of San Francisco; north and east of Humboldt Bay; and near Crescent City. To a lesser degree, these conditions also occur in the Orcutt and Los Alamos area of Santa Barbara County and in part of western Sonoma County near Sebastopol and Occidental. Additionally, small areas of deeply-weathered marine sandstones with soils and hydrologic properties similar to those of

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* The term "sand hills" was apparently first used in the initial soils reports for the region (for example, Carpenter and Cosby, 1925). The context in which they used the term suggests that it was in common local usage at the time. The phrase appears in a number of recent soil, hydrologic and vegetation studies (for example, Gordon, 1977; Griffin, 1977; H. Esmaili & Associates, 1977), seemingly re-invented each time. We believe that the concept is a useful one in understanding the Monterey Bay landscape.

the eastern Monterey Bay area sand hills occur throughout the Coast Ranges. Most notable are outcrop areas of the Santa Margarita sandstone in Santa Cruz and San Luis Obispo Counties, and also in the Highway 68 corridor of Monterey County.

We believe there are three important implications to the regional distribution of sandy areas:

1. The sandy areas merit consideration as a discrete and separate environment. Hydrologic, soils, and water quality processes (among others) occur which are specific to the sandy areas.

2. Insights gained into managing the sandy watersheds surrounding the Pajaro Valley may be applied elsewhere in Santa Cruz and Monterey Counties. Similarly, recharge protection and erosion control measures used in other sandy areas in the two Counties might be suited for use in the Pajaro Valley.

3. Little technical or management assistance pertinent to the sandy watersheds is available from other areas of the state, which do not have such areas.

Storm Hydrology and Recharge in Sandy Watersheds Surrounding the Pajaro Valley

Protecting recharge, controlling erosion and managing recharge in the sandy watersheds surrounding the Pajaro Valley ultimately depends upon the cooperation of local landowners and the staff of agencies working in these areas. Their interest and cooperation rests, in turn, upon being provided with a clear, technically-sound analysis of their unusual soil/geologic system and the extent to which these can be altered by varying levels of development.

To begin addressing these needs, we developed a reconnaissance field program attempting to address the following questions:

1. What differences in peak and total runoff may be expected between undisturbed and urbanized sandy basins?

2. What natural factors affect the proportion and rate of runoff?

3. What percentage of rainfall is presently exported as runoff from the sandy basins?

4. How may county and regional agencies approach managing runoff, erosion and water quality in the sandy basins most effectively?

A reconnaissance field program oriented toward estimating the amounts and effects of lost recharge was carried out during the study. Rainfall which leaves the basin as runoff is probably not available for recharge. The program emphasized differences in runoff between residential ("urbanized") areas and those used for agriculture and open space ("non-urbanized"). We believe this to be the primary influence in a recharge-protection program.

A detailed discussion of the field investigations carried out in this study is presented in Appendix E. A summary of the approach and results of these investigations is presented in the following sections.

Technical Approach. None of the streams originating in the sandy watersheds is perennial. Most flow for only a few hours or days during the larger storms of the year. By measuring the magnitude of runoff during a number of storm events, comparisons can be made between sandy and "normal" Santa Cruz Mountains or northern Monterey County streams. Additionally, runoff rates from sandy basins with different land uses can also be compared, particularly if data can be obtained for adjacent basins with similar soils, slopes, and incident rainfall. Basins yielding more runoff, perhaps from pavement and other impervious surfaces, are areas where less of the rain is being recharged.

The volume of runoff for each individual storm can usually be estimated from the instantaneous peak discharge. When the number of storms becomes very large, the validity of the cumulative seasonal estimate diminishes rapidly, as it becomes difficult to distinguish the size of peak flows occurring one after another. Under these conditions, the volume of seasonal runoff can sometimes be better expressed from the distribution of peak discharges. The ratios of peak discharges in urbanized and non-urbanized basins are compared and discussed in this analysis.

Field Studies. Thirteen crest-stage gages were installed on small channels draining sandy areas surrounding the Pajaro Valley. The locations of the basins are shown in Figure 2, Appendix E; watershed characteristics are summarized in Table 1, Appendix E. Most of the basins were paired, with one being at least partially urbanized and the other being almost entirely in agricultural or open-space uses. One set near Corralitos includes three basins; most of one basin (4A) is a densely-developed residential area (mobile homes), a second basin (4B) is primarily in dispersed residential uses, while the last (4C) is entirely open or agricultural. The paired basins range in size from 50 to 275 acres (0.08 to 0.45 square miles). Two larger basins were also monitored — those of Freedom Blvd. Creek near Rob Roy Junction (2.55 square mile), and Larkin Valley Creek above White Road (0.73 square miles). The infiltration properties of the various soil types are summarized in Table 2 of Appendix E.

Rainfall. The field studies commenced during the 1981-1982 rainy season, and were gradually intensified during the winter of 1982-1983. Rainfall at Watsonville was about 40.1 inches in 1981-1982, and 46.2 inches in 1982-1983. Daily rainfall for the two water years are shown in Figure 3 of Appendix E, which also includes runoff crests (expressed as cfs per square mile) observed at MCFCWCD's recording stream gage on Prunedale Creek.

Methods. Instantaneous peak discharges for most of the larger storms were computed from high-water marks monitored in the field. In most cases, measured high-water marks were obtained from the crest-stage gages installed for this study. In addition, standard indirect peak discharges were computed using the conveyance method at several stations where crest-stage gages could not be installed; we also used this procedure when measurements from the crest-stage gages could not be used to compute particular storm crests.

Two distinct types of crest-stage gages were used for this study. Standard crest-stage gages such as those used by most federal agencies were installed at about half of the sites. These consist of vertical pipes within which a removable staff gage is placed; rising water within the pipe floats burnt cork chips which cling to the staff plate at the level of the storm crest once the waters begin to recede. Special "tube gages" were developed for this study for installation within culverts. These gages were made with 5/16-inch Tygon tubing bolted to the culvert walls. The tube gages recorded high-water levels with a cork chip line left on a calibrated spring-steel tape. Cork lines were read by HEA staff four or five times each during the 1981-1982 and 1982-1983 seasons.

Control structures installed for this study included both V-notch and Cipoletti weirs. Existing culverts were also used as controls. Open-channel conditions prevailed at several sites; standard indirect peak discharge measurements were made at these sites or when the capacity of the control structure was exceeded. Individual peak discharges computed by these methods are necessarily approximate, as conditions at the time of peak runoff are not also known. In general, most computed values are considered accurate to ±20 to 25 percent. Larger potential errors for small storms may have prevailed at site 4C and perhaps at site 6X, where near-bed conditions during minor storms are uncertain.

Watershed parameters were obtained from published sources, in the field, and from aerial photographs. The proportion of various soil and sediment types was estimated for each basin from the Soil Survey (U.S.D.A. Soil Conservation Service, 1979) and from published geological materials (Dupre and Tinsley, 1980; HEA, 1979; Muir, 1972). Channel slopes were established from level surveys. Hydraulic coefficients and roughness factors were estimated in the field. Drainage areas and percentage area covered by impervious surfaces were determined by point-count from 1979 and 1980 aerial photographs (1:12000) in Santa Cruz County, and 1983 aerial photographs (1:6000) in Monterey and San Benito Counties. Impervious surfaces were defined to include any covered or hard-packed areas. These included roofs, roads, driveways, parking areas, corrals, building pads at construction sites, and steep artificial embankments.

Results. Crest-stage and high-water mark data collected in the field were reduced to instantaneous peak discharges for specific storms at each gage. Peak discharges were then converted to peak runoff per unit drainage area (cfs/mi^2). Results, presented in Table 3 of Appendix E, indicate that peak unit runoff was substantially higher in channels draining small basins with significant amounts of urbanized area. Peak unit runoff increased sharply with the percentage of the basin covered by impervious surfaces. Results for the small paired watershed are summarized in Figure 1, in which the ratios of peak unit runoff are compared with the proportion of the urbanized basin covered by impervious surfaces.

Potential Needs for Management

Elsewhere in this study, the substantial cost of augmenting existing water-supply sources for the Pajaro Valley has been discussed. Similarly, the close relationship of recharge protection to erosion control, drainage management, and water quality has been described. In this section, the approximate amounts and costs of recharge losses are described, setting the context for management direction.

Potential Recharge Losses. The maximum impact of recharge loss can be estimated by supposing that all recharge areas will be converted to residential, industrial or agricultural uses which increase the rate of runoff from the ground surface and would induce hydrologic changes of the type described. Mean annual recharge losses of about 5.5 inches may be assumed over the 61 square miles of primary recharge areas, or about 18,000 acre feet per year. This value is an overestimate in that land-use conversion has already occurred in about 20 to 30 percent of the recharge areas. Additionally, recharge in many other areas is already affected by channel incision or other factors. Based on a review of the existing general plan of the two counties, it is likely that potential additional recharge losses at ultimate development would be in the range of 6,000 to 9,000 ac-ft per year.

Potential Effects on Valley-Floor Water Levels. Recharge is important not only to sustain the basin's hydrologic balance, but also to maintain water levels which minimize saltwater intrusion. The confined character of the aquifers at the mouth of the Pajaro River and elsewhere in the Springfield area serve to magnify and extend the effects of recharge. The difference in water levels following dry (no recharge) winter and a wet (high recharge) winter can be 6 to 8 feet (Stiles, 1976; Table 4 of Chapter 2, this report). The periods of high recharge serve to diminish or perhaps reverse the landward groundwater gradient associated with seawater intrusion. Recovery of water levels in the intruded areas generally begin to occur within a month or sooner after the heavy rainfall. Hence, loss of recharge serves not only to depress water levels during the subsequent pumping season, but also during the four or five months of late winter and early spring.

The alluvial aquifer of the Pajaro Valley floor is a fully-confined system. In theory, recharge to any part of the system serves to increase water levels equally throughout the confined area. Water levels in wells throughout the confined area do, in fact, respond very similarly during the months of low and dispersed groundwater pumping. Hence, all recharge areas surrounding the confined areas likely have important roles in sustaining water levels throughout the valley floor, including in the intruded coastal belt. Recharge through the

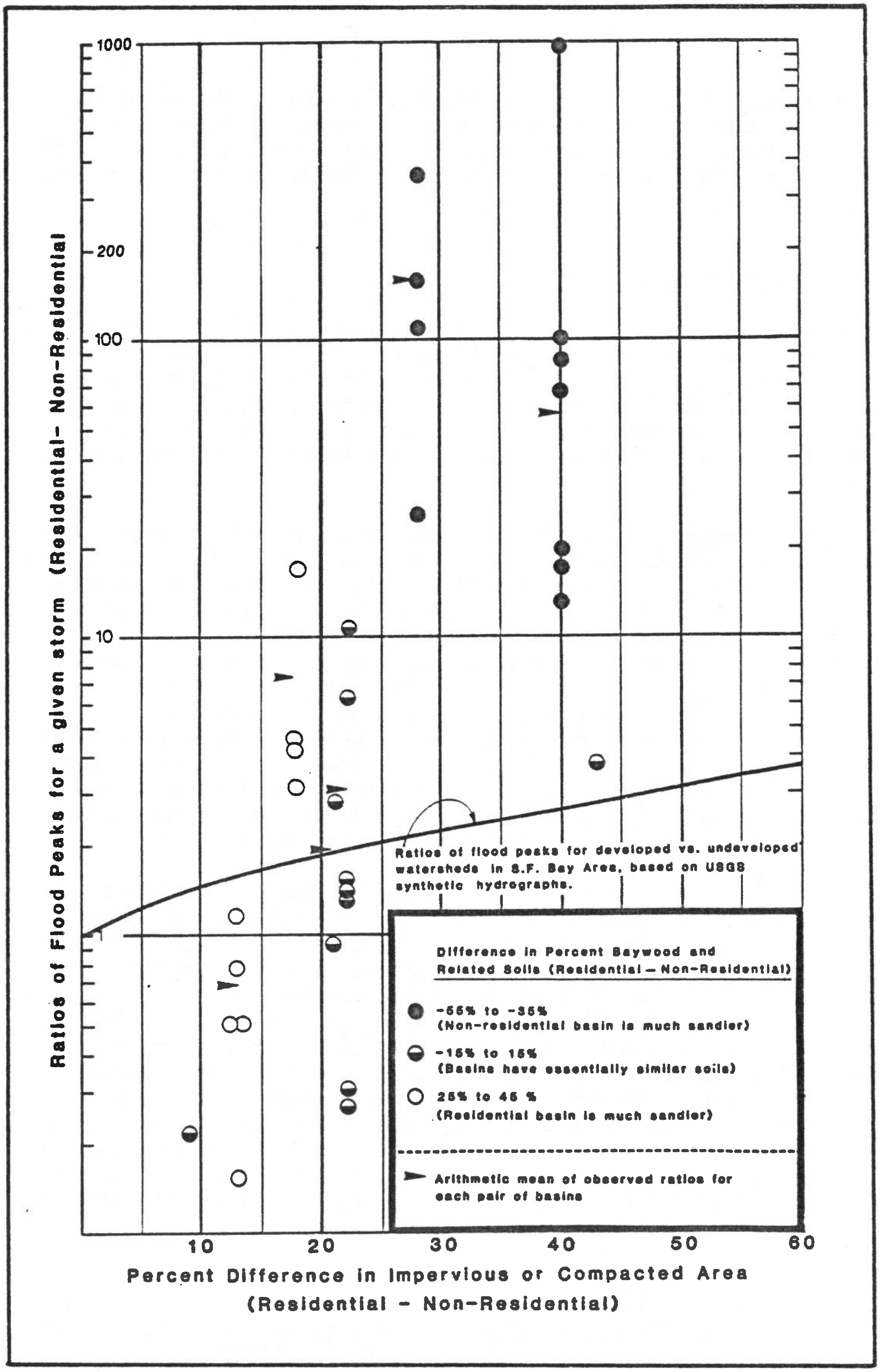

Figure 2. Ratios of flood peaks in residential and open-space sandy valleys, Pajaro Basin. Rates of peak runoff from the developed basins were many times greater than in the adjacent open-space basin. Soil types also significantly influenced the ratio of flood peaks (see text). Residential development in sandy areas increases flood peaks by a much greater proportion than in non-sandy watersheds, based on the U.S.G.S. models.

more sandy areas at the northern and southern edges of the basin probably also contribute to sustaining valley-floor water levels, although less directly or efficiently.

Potential Costs of Recharge Losses. As an example, the costs of lost recharge and related processes for individual rural residential homesites may be roughly estimated solely for the purposes of establishing a context. The Santa Cruz County Planning Department has determined that each rural residential homesite in the San Lorenzo Valley disturbs or makes impervious a total of 0.5 acres, including access roads and water tanks (Olson, 1978)*. We assume 80 percent of the recharge from this area is lost to runoff from water-balance considerations (HEA, 1978a, b; Johnson, 1980). Recharge under natural conditions can be approximated as 4 inches (in 20-inch rainfall areas) to 8 inches (in 25- to 32-inch rainfall areas). Calculated mean annual loss of recharge is one-sixth to one-fourth acre foot per acre. If this is valued at a replacement cost of $250 per acre foot, the calculated value of lost recharge per dwelling unit is $42 to $64 per year. These recharge losses are based on the assumption that once runoff is delivered into main channels it is generally lost as a source of groundwater replenishment.

Public costs of road damage, added drainage-system maintenance, and erosion and sedimentation in the sand hills of the Pajaro Valley may be about $1,000,000 annually**. Apportioned among an estimated 3,500 homes in the area underlain by the Aromas and related aquifers, drainage and associated costs may amount to an additional $200 to $300 per year per dwelling unit. Other land uses also contribute to drainage-maintenance costs, although not reflected in this analysis.

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* Riley Moore (Aromas Water District) has provided data indicating this value is reasonably applicable to the sand hills. The Seeley Road watershed (5A) had 69 homesites in 1982, in a drainage area of 245 acres. Our measurements from 1983 aerial photography (1 inch = 500 feet) indicate 18 percent of the basin to be impervious according to criteria cited above. The equivalent area is about 44 acres. An additional 6 homesites may have been developed in the intervening year, for a total of 75 units. Mean impervious area per dwelling unit in this basin is computed to be 44/75, or 0.59 acres.

** This is an assumed rather than computed cost, as no specific cost data are available. Monterey County operates a maintenance yard on San Miguel Canyon Road; about one-third of the costs of this yard might be assignable to the Pajaro basin. A larger area of sand hills is in Santa Cruz County, and a much smaller area in San Benito County. Additionally, CALTRANS must maintain the Valencia Lagoon sensitive habitat area, which receives sediment from the Freedom Blvd. (watershed 7X).

Understanding the Hydrology of Pajaro Valley Recharge Areas

Status of Existing Information. Data developed in this study has helped to establish that patterns of recharge and runoff in the sand hills differ substantially from regional norms. As the hydrology of the sand hills is fundamentally distinct, the effects of various land-use practices on runoff and erosion can be quite different from those observed elsewhere in the region. In many respects, we believe that new sets of hydrological understandings and design criteria are warranted to guide the management of water resources in the sand hills. The question can legitimately be asked, as to whether the current state of knowledge would warrant the recommendation of a new management approach. We believe that this can be done, provided that the program is envisioned as a tentative one, and is designed to evolve with new information as such data become available. The present emphasis may be placed on modifying or developing new programs and approaches appropriate to very sandy areas; gradually, new policies, practices and regulations designed for the atypical set of processes effective in the sandy areas may be brought into effect.

Scope of Recommended Studies. Four small studies are recommended to provide data which will allow specific programs to be developed for the sandy areas:

a. The existing monitoring program might be extended and/or expanded. The most critical need is to measure volumes of runoff from small sandy watersheds during years of less-extreme rainfall than occurred in 1981-1982 and 1982-1983 (Appendix E). A mixed program using recording gages, occasional intensive monitoring, and sustained operation of crest-stage gages may be most effective.

b. Professional review of aerial photographs and other historical data to establish when channel incision took place, and to identify factors (such as the degree of residential use) which may be associated with incision.

c. Simulation of runoff in small sandy watersheds (similar to those used in this study) with an appropriate model, such as that used by the Soil Conservation Service. Results of the simulation can help in establishing how the relative sandiness of the various soils affect runoff, and the inception and effects of channel incision. Because the hydrologic response of the sandy basins may differ fundamentally from other watersheds, data from items a. and b. (above) will be needed to modify any conventional hydrologic model, even before validation and calibration.

d. The role of ponds and lagoons within the sand hills in the regional recharge merits investigation. It is generally assumed that little or no recharge occurs in the natural wetlands, such as Valencia Lagoon, lower Harkins Slough, Warner Lake, or Corralitos Lagoon. There appear to be, however, no data to support or refute the commonly-held belief. Measurement of inflow and outflow from two or three such wetlands might establish the function of these ponds and lagoons in a recharge protection program.

Assumptions of Future Land Uses. Another source of uncertainty is the future distribution of land uses, particularly in the recharge areas. Projected uses are documented in general plans for the Pajaro Valley and Aptos areas (Santa Cruz County) and North Monterey County, plus the local coastal plans for the two counties. The City of Watsonville has nearly completed a new general plan. The City's Master Plan for Water Supply and Distribution extends into Corralitos and the community of Pajaro.

In part, because the processes of recharge are so different in the sand hills, we found that existing city, county, water-supply, and coastal plans could not be applied in the conventional manner to projecting the need for aquifer protection. For example, areas which are expected to remain in agricultural production are sometimes planted into strawberries and brussel sprouts. Both of these are 'row' crops grown in similar soils; however, under present agricultural practices, strawberries grown on sandy hillsides cause a loss of recharge in a manner similar to residential uses while brussel sprouts probably affect recharge in much the same way as native vegetation. The differences in the effects on recharge are substantial, perhaps differing by a factor of 10 to 20 or more. Therefore, several assumptions were made following review of the key planning documents, and have been kept constant in considering each of the management options. First, we have assumed that strawberry cultivation will exert little or no additional impact on recharge, both because of limited envisioned expansion of acreage within the sand hills and also because of improved water-conservation practices. Second, a total of about 2,500 additional residential units within the primary and secondary recharge areas are assumed in all calculations. This value is based on computed buildout of about 3,170 units in the primary recharge areas of the two counties*, plus an estimated 500 additional units in the secondary areas, adjusted downward by an estimated 700 units likely to be constructed in areas that are already largely urbanized (La Selva Beach, Corralitos, Las Lomas), and recognizing an additional downzoning of approximately 500 units likely to occur in the ongoing review of the North Monterey County general plan. This number corresponds to roughly one additional unit per 20 to 25 acres of recharge area.

Existing Recharge Protection Measures

Recharge protection might be most effectively considered as one facet of a closely-related set of management problems involving:

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* Following the recharge area and water budget analyses, these values include the outcrop area of the Aromas Formation in Aptos inland from Highway 1 (most of Santa Cruz County traffic Zones 252 and 253).

1. Erosion control
2. Recharge protection
3. Drainage management
4. Water quality protection

Guidelines, practices, and regulations pertaining to these problems are in effect in both counties. Generally, these are oriented toward one -- or at the most, two -- of these problems. In the following discussion, we consider existing programs and regulations of agencies active in the basin, and discuss the limited efforts underway elsewhere in the state. The needs and basis for revised measures, and several specific recommendations, are discussed in the final section of the chapter.

Both Santa Cruz and Monterey Counties currently have in effect numerous regulations, plans and policies which, directly or indirectly, protect the quality and quantity of groundwater recharge. These include Local Coastal Plan and General Plan policies and their implementing regulations, as well as ordinances designed for other purposes which incidentally may protect recharge areas as well (such as erosion control, grading, septic tank systems, geologic hazard and riparian corridor ordinances). In addition, many conservation practices utilized by Pajaro Basin ranchers and growers promote recharge through control and detention/retention of runoff.

Santa Cruz County Policies and Ordinances. A brief summary of Santa Cruz County policies and ordinances affecting recharge is presented below.

Local Coastal Plan Policies: Santa Cruz County's Local Coastal Program includes specific provisions for protection of water resources including groundwater quantity and quality, as detailed in Table 1. Most of these policies have been implemented through revision of the appropriate ordinances. Some of the requirements apply only to the coastal zone portion of the County, and thus only recharge areas within the coastal zone receive the extra protection.

General Plan Policies: The General Plan contains many policies relating to protecting groundwater recharge. The watershed and groundwater sections policies include 10-acre minimum parcels in existing or proposed water supply watersheds, strict erosion control requirements, retention or detention of stormwater runoff from impervious surface in water supply watersheds to predevelopment levels and study of groundwater recharge areas to determine appropriate densities and land uses. Policies and implementing programs of the drainage section require on-site detention of stormwater to maintain predevelopment runoff rates, or retention through percolation of any increased runoff from discretionary development projects in primary recharge areas; limit actual coverage of impervious material as much as possible; and propose programs to develop standards for impervious pavement allowances, investigation of previous pavement feasibility and formulation and development of criteria related to onsite detention requirements of development projects.

Table 1. Aquifer Recharge Policies (Local Coastal Program)

Section	Policy	Implementing Action
Santa Cruz County		
Erosion Control	1.5.8 Require adequate runoff control systems to maintain rates at predevelopment levels.	Included in existing erosion control ordinance.
	1.5.11 Require approval of drainage control plans as part of final site development plans.	
Watershed Protection	1.6.1 Establish 20-acre minimum parcels in water supply watersheds.	Review rural density matrix to include over-riding minimum acreage policies.
	1.6.2 Maintain open space densities in specified least disturbed watersheds with minimum 40-acre parcel size.	
Monitoring Ground-Water Recharge	1.11.1 Require minimum 10-acre parcels in primary groundwater recharge areas if onsite wastewater disposal is used.	
	1.11.2 Require stormwater retention for all new developments in primary recharge area or at minimum onsite detention.	
Water Master Plan Update	8.3.13 Address aquifer recharge possibilities (recharge protection, spreading basins and/or injection wells) in Water Master Plan update.	Include in Water Master Plan work program.
	3.4.2 Approve development proposals and grading applications that minimize displacement of flood waters.	Developing new flood hazard ordinance.
Flood Hazard	3.4.4 Require new public structures to be located outside 100-year flood plain.	
North County (Monterey County) LUP		
Water Supply	2.5.3A Require water conservation measures in all new developments including measures which maximize groundwater recharge.	
Water Quality	2.5.3B Minimize cumulative impacts on groundwater by requiring 2-1/2 acre minimum for parcels using onsite wastewater disposal.	
Erosion Control Measures	2.5.3C Require measures for maximum retention of stormwater runoff resulting from impervious surfaces as part of erosion control plans.	

Identification of Recharge Areas: Groundwater recharge areas in the County have been designated "limited", "secondary" or "primary" based on soil permeability and geology (water bearing capacity). For example, areas where moderately permeable soils occur over exposures of "high-waterbearing formations" are identified as secondary recharge areas, while the criteria for primary recharge areas requires the occurrence of high permeability soils (greater than two inches per hour) on high-waterbearing formations.

Erosion Control (Chapter 14.15 Of County Code): The basic goal of this ordinance is control of runoff in order to avoid accelerated erosion from existing and potential sediment sources. Accordingly, requirements for land clearing, project planning, erosion control plans and winter operations are set forth.

The ordinance directly protects groundwater recharge by requiring retention of all excess runoff on soils with permeabilities of greater than two inches per hour, and detention on all other soils such that runoff rates do not exceed pre-development levels. All categories of recharge areas benefit from this requirement, since the ordinance applies to all developments on a county-wide basis.

Sensitive Habitat Protection (Chapter 16.22 Of County Code): Applicable only to areas of special biotic concern (as mapped by the County Planning Dept.), the Sensitive Habitat Protection Ordinance strictly limits land disturbance in these areas, thereby avoiding accelerated runoff and reduced recharge. Only those primary recharge areas which are designated Sensitive Habitats benefit from this ordinance. Only resource-dependent uses are allowed within environmentally sensitive habitat areas, and no new development is allowed adjacent to marshes, streams and bodies of water if such development adversely affects water quality.

Any development in areas adjacent to the Santa Cruz Long-Toed Salamander habitat are subject to restrictions including minimum site disturbance (less than 15% of lot after revegetation) and less than 10% lot coverage by impervious surface. Construction of seepage pits isalso required where feasible. Similar restrictions apply to Special Forests and Grasslands in the Coastal Zone, such as the San Andreas Oak Forest.

Rural Residential Density Determination (Chapter 13.70 Of County Code): Groundwater recharge is benefitted indirectly by this ordinance, which prescribes minimum new lot sizes based on (among a total of 10 criteria), groundwater quality and quantity, water resources protection, erosion and landslide presence or susceptibility. In the coastal zone, 10-acre parcels are required as a minimum in primary groundwater recharge areas where onsite wastewater disposal is used.

Geologic Hazards (Chapter 16.02 Of County Code): Parcels subject to landslide, those with steep slopes or overlying fault zones or floodplains are subject to density limitations established under this ordinance. Consequently, primary or secondary recharge areas which overlap with geologically-constrained sites are afforded protection from high density development and the resulting increase in runoff and decrease in recharge.

Sewage Disposal (Chapter 11.76 Of County Code): Recharge areas are directly protected by septic system requirement restrictions in primary recharge areas (as indicated by U.S.D.A. Soil Conservation Service designation of specific soils information indicating high permeability). For lots created before 1920 with public water supply, 6,000 square feet or more is required for septic systems, whereas lots with private water supply must have at least 15,000 square feet. Lots created between 1970 and 1978 must be at least 15,000 sq. ft. with public water supply and one acre with private supply, whereas new lots (since 1978) must be at least one acre in size, or larger depending upon the specific area.

Agricultural Land Preservation And Protection (Chapter 14.14 Of County Code): Recharge areas are protected from coverage by impervious surfaces and accelerated runoff through regulations which prohibit the conversion of certain agricultural land types to urban uses. This ordinance is an example of a significant, while indirect, mechanism for protecting groundwater recharge areas.

Riparian Corridor Protection (Chapter 14.13 Of County Code): Limitation of development activities in riparian corridors under this ordinance is important in protecting in-stream recharge of both perennial and intermittent streams. Maintenance of a protective strip of vegetation between a development and stream is required under this ordinance.

Individual Water Systems (Chapter 11.40 Of County Code): Designed to establish standards for safe water supplies for individual water systems and to ensure that such systems do not induce contamination of aquifers, this ordinance also implements General Plan and Local Coastal Program Land Use Plan policies. Especially significant with respect to protection of groundwater quality, all new wells of unsuitable water quality are required to be sealed or destroyed unless mitigating measures can assure that the groundwater supply is protected.

Water Well Control (Chapter 11.90 of County Code): Enacted for the purpose (among others) of protecting groundwater from pollution or contamination, provisions have been made in this code for declaration of groundwater emergency in areas demonstrated to be experiencing a groundwater overdraft exceeding the safe yield. Measures such as water conservation, limitations on construction of new wells, and regulation of pumping and enlargement of existing wells are to be taken in the event of such an emergency.

Another section of the ordinance pertaining to special groundwater protection allows the Health Officer to require the submittal of electric log and geologic data for wells penetrating more than one aquifer in areas of known groundwater quality problems. This data is to be used to identify needed actions to prevent migration of poor quality water between various aquifers.

Monterey County Policies and Ordinances. Policies and ordinances of Monterey County in the area of recharge protection are summarized below.

General Plan Policies: A major objective of the Water Resources section of the draft General Plan is to protect watersheds and recharge areas, particularly those which are critical in replenishing reservoirs and aquifers. Policies outlined to meet this objective include protection of vegetation and soil in critical watershed areas,

as well as those aimed at accomplishing development and land use in a manner that would minimize runoff and would maintain groundwater recharge.

Nine area specific plans are now under preparation. Implementable programs will eventually result from these plans.

Local Coastal Plan Policies: The adopted North County Land Use Plan includes several policies directly relating to recharge protection The County has just begun the implementation of this program, thus ordinance revisions or other implementing actions have not yet been undertaken.

Erosion Control (Chapter 16.12 Of County Code): This code is similar to Santa Cruz County's ordinance and its purpose is to eliminate and prevent conditions of accelerated erosion that could, among other things, degrade water quality and disrupt water supply. The ordinance applies to both existing and potential erosion problems, and contains specific provisions relating to project planning, preparation of erosion control plan, runoff control, land clearing and winter operations. Those aspects of the regulation which pertain directly to recharge protection are: Retention of all runoff in excess of predevelopment levels on soils with high permeability (more than two inches per hour), detention of runoff on all other sites by use of berms, vegetated filter strips, catch basins, etc. Minimization of land clearing also contributes to vegetation protection with indirect recharge benefits.

Grading: The grading ordinance also requires the minimization of erosion with secondary benefits to recharge protection. Revegetation, construction of check dams, and other devices or methods are called for to control erosion from construction sites.

Pajaro Basin Agricultural Practices. Agricultural practices currently being employed by some growers and ranchers in the Pajaro Valley are contributing to maintaining the natural recharge function. Some of these practices are as follows:

a. Cover Crops - Maintenance of a cover crop is important in reducing the rate of runoff from cropped lands. Cover crops which are largely composed of volunteer vegetation (weeds) are used in most apple (and other) orchards. Similar practices should be encouraged on access roads in farmed lands.

b. Crop Residue - Crop residue when left on the field serve to retain precipitation and promote recharge. This practice is commonly used in apple orchards but seldom for row crops.

c. Protection Of Heavy Use Areas - Used to some degree by Pajaro Basin growers, coverage of dirt roads and other heavy use areas with vegetation, gravel or wood chips has the same runoff protection qualities as crop residue use.

d. Contour Farming - Roughly half of the growers utilize contour farming on steep slopes, however, slopes are often too steep for operation of equipment. Again, runoff is slowed and percolation increased, compared to non-contoured slopes.

e. Field Borders - A few ranchers plant vegetative strips as buffers or filters, which encourages recharge.

f. Fertilization - Some ranchers fertilize their pastures and rangeland which increases vegetative cover, protects the soil, reduces erosion and increases rainfall retention. "Farmettes" (small acreages used for intensive agricultural operations or grazing) should employ similar practices (along with seed).

g. Planned Grazing System - Rotating use of pastures to allow "resting" and re-vegetation ensures maintenance of good cover and therefore water retention.

h. Structures - Ponds or reservoirs on farms and ranches detain runoff, and are especially useful (for recharge) in sandy areas.

i. Grassed Waterway - Quite a few growers employ grass-lined ditches to disperse and slow runoff, which thereby increases percolation.

j. Sediment Ponds - Essentially, trenches at the bottom of sloping farmland to trap sediment and detain runoff.

k. Limited Tillage - Used for row crops, hay land and somewhat in orchards, reduced working of the soil maintains some vegetation cover, with beneficial effects on recharge as described above.

l. Windbreaks - Some Pajaro Valley growers utilize windbreaks which (among other benefits) reduces evaporation and therefore increases the amount of water which can be recharged.

State of California. The state recognizes the Pajaro Valley as an area of critical overdraft. Its present involvement in recharge protection is limited to (a) Coastal Zone oversight and (b) jurisdiction of the Regional Water Quality Control Board over point- and non-point-source pollution.

The state traditionally provides technical expertise to local and regional agencies. The eastern Monterey Bay area, however, is apparently the largest direct recharge area in coastal California, and state agencies are no more familiar than local entities with the specific recharge problems presented by this unfamiliar environment. State expertise in erosion and runoff control is, however, considerable (e.g. Amimoto, 1981) and might be selectively applied to recharge issues.

Federal Agencies. At the present time no specific and pertinent laws or regulations exist at the federal level which directly pertain to the protection of primary groundwater recharge areas. The U.S. Environmental Protection Agency is empowered under the Safe Drinking Water Act of 1974 to declare a groundwater aquifer which is the sole or principal drinking water source for an area as a sole source aquifer. Once such a designation has been made by EPA, no federal financial assistance may be provided for any project when the Administrator determines that the project would lead to the contamination of such aquifers. Generally, this precludes the use of federal funds for construction of wastewater treatment facilities or other land use activities which might contribute to further degradation of water quality. It is unlikely that this provision of the Safe Drinking Water Act would be applicable to development projects in primary recharge areas which do not pose a significant hazard to public health. A number of federal laws exist for protection of groundwater quality from improper disposal of waste materials on land or by injection into the aquifers.

City of Watsonville. No significant recharge areas occur within the city. The City of Watsonville Public Works Department provides water to limited areas underlain by the permeable Aromas Formation, mostly in the Corralitos area. Additional service to this area is anticipated in its Water-Supply Master Plan. It is also the principal user of groundwater from this part of the basin.

The City of Watsonville is indirectly involved with aquifer recharge, largely insofar as the quantity or quality of water near Corralitos is affected. Water levels and water quality in City Wells #8 and #11 are regularly monitored, and have shown no decline in recent years. The City also operates a landfill in the primary recharge areas near San Andreas Road.

Other Areas in the State. A canvass of several areas in the state including Santa Clara, Fresno, San Diego, Orange, and Los Angeles Counties, as well as the Lake Tahoe Regional Planning Agency, was carried out in this study to determine the existence and scope of any recharge protection measures in these areas. None of these areas currently have any regulations aimed at the control of natural precipitation runoff from groundwater recharge areas.

Los Angeles, Fresno, Santa Clara, and Orange Counties Flood Control and Water Conservation Districts undertake the construction and management of groundwater recharge facilities of appreciable proportions. Some of these districts raise the needed capital and operating costs for the recharge facilities through a construction fee on new projects or by levying an assessment on all property owners in their service areas.

The Tahoe Regional Planning Agency (TRPA) regulates land use activities in the Lake Tahoe drainage basin. TRPA has developed comprehensive guidelines for the control of erosion and excess runoff from lands known to yield disproportionately large amounts of runoff and erosion (TRPA Ordinance No. 81-5). These regulations are not directly pertinent to natural groundwater recharge protection; however, structural and nonstructural solutions proposed for control of erosion and excess runoff provide a valuable source of information for the analysis of available recharge enhancement measures in the study area.

Technical Options for Recharge Protection

A recharge protection program is intended to insure that the rate and total volume of rainfall runoff from primary recharge areas is not significantly increased over natural conditions for individual parcels, subdivisions, and general areas undergoing land-use change or development. In part, this objective can be attained if these projects are designed to minimize runoff.

Four general types of protective measures are considered in this report:

a. On-site structural control measures.
b. Use of native and endemic vegetation.
c. On-site waste disposal.
d. Off-site control measures.

These measures are described and discussed in this section of the report.

On-Site Structural Control Measures. Most structures intended to protect recharge were originally developed as erosion-control measures. These include:

a. Level spreaders, which convert concentrated runoff from roofs, pavement and other large surfaces to start flow over areas stabilized by vegetation.

b. Perforated slot drain, which directly recharges runoff.

c. Permeable surfacing materials and porous asphalt.

d. Infiltration trenches.

Each of the measures is explained and illustrated in detail in Appendix F.

The feasibility of on-site recharge protection is limited primarily by cost. We estimate that structural measures to control on-site runoff (and erosion), such as dutch drains, dry wells, level spreaders, and slotted drains may cost $350 to $500 per lot. Assuming a twenty year life for these structures, and an annual maintenance of $50 and an interest rate of 12 percent per year, the annual cost to install and maintain one of these measures ranges from $410 to $460 per acre-foot of water recharged if 0.17 acre-foot is retained, and ranges from $210 to $325 per acre-foot if 0.33 acre-foot per year is recharged.

Individual recharge structures could be required for existing houses, approximately 3,500 of which overlie the Aromas and related aquifers. Assuming that the structures can capture all runoff presently lost, between 595 and 1,135 acre-feet of water would be recharged, annually. The present value of the costs to install and maintain the individual recharge structures (assuming an average installation cost of $400 per house and $50 annual maintenance cost) ranges from $220 per ac-ft/yr to $425 per ac-ft/yr depending on the amount of runoff retained.

In assessing the feasibility of these measures, their utility in erosion and drainage control should also be considered. It should also be noted that the effectiveness of most structural measures depends upon the degree of maintenance. As with septic systems, a substantial number of non-functional installations can be expected over time. Also, it is possible that the additional recharge might contribute to slope instability, especially in areas with histories of sliding.

Use of Native or Drought-Tolerant Plants. Recharge may also be protected by encouraging the use of certain plants for ground cover and landscaping. The difference in evapotranspiration between irrigated (lawns, most pastures, sodded common areas, and gardens) and non-irrigated plants adapted to the local climate may be as much as 18 inches. Additionally, the local plants are probably more effective in reducing runoff and controlling erosion. Given 2,500 new residential units, about 1,400 acre feet of recharge may be protected by encouraging the use of native or other drought-tolerant plants over an average area of 0.5 acre per unit.

A variety of native plants are naturally found in the coastal sand hills of Monterey Bay (Griffin, 1977). Many are commercially available for landscaping. Both county agencies and the resource conservation districts offer plant lists and some technical assistance. Extensive use of such species conforms particularly well with the spirit of Santa Cruz County's Sensitive Habitat designation.

The cost of installing local or other non-irrigated vegetation is generally comparable to or slightly greater than establishing lawns. Maintenance costs are significantly lower. Plantings must be planned to conform with fire safety standards.

On-Site Waste Disposal. Increased use of septic systems and other on-site waste disposal facilities might effectively increase recharge, although with some deterioration of water quality. Tradeoffs between the two considerations have been considered in detail for the Castroville-Prunedale region, a sand-hill area adjoining the

Pajaro basin to the south (H. Esmaili & Associates, 1978b). Since that time, a number of new on-site waste-disposal procedures have come into use, and which may yield effluent of higher quality.

Assuming 2,500 new units are to be constructed in the primary recharge areas, the total volume of effluent available for recharge is about 550 to 600 acre feet per year. Some of these units, however, will be served by a centralized sewerage system. Thus, the basin-wide increment which may be gained by managing residential wastewater for recharge is at most 200 acre feet annually. This falls below the threshold of regional significance, although these considerations may be of some importance in individual situations.

Off-Site Recharge Management Measures. There is a general trend toward managing runoff from urbanizing areas on a watershed basis, even in non-sandy terrains (for example, Crouse et al., 1983).

Earlier in this report, we noted that a watershed-type approach may be most effective in protecting recharge in the sand-hill areas. A program oriented to this goal would involve:

1. Protecting swales and lower slope areas, to sustain present rates of recharge.

2. Preventing development of a continuous channel, protecting existing recharge through the floors of the valleys.

3. Off-setting increased runoff elsewhere in the sub-watershed by augmenting recharge through the valley floors, probably with the use of retention ponds and/or recharge basins.

Of these three elements, preventing channel development is perhaps most important. While it is not yet possible to establish how much of the recharge loss occurs within each hydrologic link, the data from this study indicate that the development of a well-defined channel may be the principal factor in increasing the amount of runoff. Recharging of the smaller amounts of storm runoff through the unchanneled valley floors can possibly be accomplished with retention basins similar to the larger stock ponds now used in the sand-hill valleys.

Both the soils and alluvium underlying the valley floors tends to be finer-grained than those of the ridges and slopes (Carpenter and Cosby, 1925; H. Esmaili & Associates, 1978b). The alluvium is generally of moderate permeability, but it is commonly mantled by silts, clays, and organic deposits which are often several feet deep. Rates of percolation through these deposits are extremely variable. The soil surveys, however, indicate that most of the valley-floor soils can sustain infiltration of at least 0.2 inches per hour, and often considerably more.

Pending further studies, it is likely that a typical watershed-type recharge protection program may involve the following elements:

1. Dedicated waterways, from minor swales to valley floors, in which no turf-disturbing uses would be allowed; these might be grazed, but otherwise would not be maintained.

2. Where necessary to prevent channel incision, grade-control or gully-head stabilization structures.

3. Recharge basins, with periodic maintenance required.

We estimate off-site measures might be used effectively in about 80 percent of the area in the primary recharge areas and perhaps 60 percent of the secondary recharge areas. Different approaches and strategies are appropriate to the local conditions in various areas. The codes of the two counties also influence the set of measures which might be chosen.

It is possible, however, to envision a representative case involving conversation of a significant part of a sand-hill valley to residential use. Assuming a 250-acre watershed, we believe that about 60 to 100 acre-feet per year of recharge might be protected with these off-site measures. Off-site costs would range from minimal (with dedicated waterways only), to a maximum of $100 to $250 per acre-foot per year (with grade-control structures and two maintained retention basins with capacities of 10 to 30 acre-feet). Flood-control and erosion-control benefits would also accrue from such a program; the benefit-weighted cost of recharge water could be appreciably less in some cases. No allowance has been made for land costs, in the belief that such land is not buildable or that it is likely to be kept open to meet some of the other development requirements.

The City of Marina presently uses neighborhood-scale recharge basins as its primary means of drainage management. Most of the 49 recharge basins are the size of one or two residential lots, dedicated to the city (or a county service district which preceded incorporation in 1975) at the time of subdivision or development. The city's Public Works Department continues to install occasional basins up to one-half acre in size to meet local drainage problems. Recharge rates of 12 to 30 inches per hour are reported from the basins, with little or no decrease over the years.* Maintenance procedures include annual removal of surface films (primarily oil and grease) and accumulated sediment. Maintenance costs average about $80 to $100 per basin. Additionally, natural ponds distributed through the dunes in the western part of Marina are deliberately used to receive and recharge urban drainage; there is a long-standing policy discouraging land disturbance or development within several vertical feet of the highest known stands of these water bodies. No other maintenance or management is provided for these ponds. All of these "recharge basins" are operated primarily for drainage control. The value of the recharged

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* Comparable infiltration rates may be expected in Primary I and some Primary II areas within the Pajaro basin; rates that are much lower—perhaps by an order of magnitude or more—should be anticipated in most other recharge classes, although conditions vary locally.

water is considered incidental, even though the Marina area is also affected by sea-water intrusion. Water-supply needs of the community are served by a county water district, separate from the city, which does not share directly in the cost of acquiring, constructing, or operating these facilities. Don Wilson, Monterey County Public Works, and Bob DiMaggio, Public Works Director for the City of Marina, provided the above information.

Institutional and Financial Considerations

Any institutional and financial program for recharge protection might address six major challenges:

1. The areas of recharge surround the basin, while the most intensive use of water occurs in center of the Pajaro Valley; there is geographical separation between the areas to be protected for their recharge values, and those in which much of the benefit of recharge protection will eventually accrue.

2. Recharge protection may be considered as a separate water-management issue, but it is likely to be more effectively addressed in conjunction with erosion control, drainage management, and water quality protection, and perhaps other watershed-management issues; existing ordinances, programs, and agency responsibilities are not generally organized with the larger management perspective in mind.

3. Many of the most promising technical options for recharge protection are off-site measures which may require cooperation among adjoining ownerships and some new or modified planning approaches.

4. Four separate land-use jurisdictions need to be convinced of the need for and means of implementing a recharge protection program if the full benefits are to be realized.

5. Further study of the relationships between soil types, land uses, and runoff in the recharge areas is indicated to best plan and test the efficiency of a recharge protection program.

6. Any basin-wide protection program must recognize the constraints on funding, maintenance and enforcement posed by current fiscal policy in California.

Responsible Agencies and Entities

Recharge protection can and is being carried out by a variety of county and state agencies. A number of existing or potential independent local agencies and other entities may also serve these functions. Table 2 summarizes the functions and powers of these organizations in recharge protection, both as they presently exist and as they could

Table 2. Existing and Potential Responsibilities of Institutions for Recharge Protection

Agency or Entity	Existing Responsibilities					Potential Role in Recharge Protection		Capabilities and Powers				Operating Scale
	Recharge Protection	Erosion Control	Drainage Management	Water Quality	General Watershed Management	On-Site Measures	Off-Site Measures	Inspection & Enforcement	Condem-nation	Ad Valorem Taxation	Other Fees & Taxes	
<u>County</u>												
Flood Control & Water Conservation District	✓		✓	✓	✓	Design standards	Design standards; monitoring	d	✓	✓	✓	Sub-regional
Planning Department	a	✓	a	a	✓	Implementing; educating	See text	✓	e	-	d	Sub-regional
Public Works Department		d	✓			Design standards	Pond & structure maintenance	-	e	-	d	Sub-regional
Building Inspection		✓				Oversee installation	Inspect during construction	✓	-	-	d	Local
Environmental Health				✓	d	Standards for dry wells	Insure suitable water quality	✓	e	-	d	Sub-regional
County Service District	g	g	g	-	-	Maintain	Install and/or maintain	✓	✓	-	✓	Local or sub-regional
<u>Independent</u>												
Resource Conservation District	c	✓	✓		✓	Technical assistance	Technical assistance	-	c	✓	-	Sub-regional
Water Management Agency	g	g	g	g	g	Establish requirements	Operations and maintenance	?	✓	✓	✓	Regional
Homeowners Association						Maintenance	Maintenance	-	-	-	✓	Local
County Water District	g		g	g		None	Install or maintain facilities	✓	✓	✓	✓	Sub-regional
<u>Regional</u>												
AMBAG	b	b		✓	b	Recommended standards	Recommended frameworks; plan and fund future studies	-	-	-	-	Regional
<u>State</u>												
Coastal Commission	✓	f		d	✓	Density limits	Habitat protection	✓	✓	-	d	Regional
Regional Water Quality Control Board		✓		✓	✓	None	Regulate quality of water being recharged	✓	c	-	d	Regional
Division of Safety of Dams			✓			None	Safety of larger facilities	✓	✓	-	d	Local

[a] Planning and advisory role; can also require mitigative measures by conditioning certain permits and variances.
[b] General planning and advisory role only.
[c] Within authorization or charter, but not presently pursued.
[d] Narrow and limited.
[e] Through Board of Supervisory and/or District Attorney.
[f] Limited to beach and bluff areas; LCP's call for improved erosion control at the County level.
[g] No existing agency; similar agencies elsewhere in State are involved in these functions.

potentially take form in the Pajaro basin. Some of the capabilities and powers affecting recharge protection are also summarized. A final item in the table addresses the difference between where recharge takes place in the Pajaro basin, and where the water is principally beneficially used; entities are identified as having local management responsibilities (generally limited to the site or sub-watershed scale) or having sub-regional (including some of both recharge and heavy-use areas), and regional (entire basin) scale of operations.

County Agencies. Each county has several departments involved in managing lands or resources linked to recharge protection. These departments have staff members who are generally assigned to certain areas of the county. In many cases, these individuals have particular familiarity with water-management issues in the sand hills and other recharge areas. Flood Control and water conservation districts and county service districts, while technically separate entities distinct from the departments, are both immediately directed by the Boards of Supervisors of the two counties and are served by staff who either belong to the other departments or work in an analogous framework. We group these two districts with the other county agencies for the purposes of this report. The following discussion focuses on these concerns. In our view, the first three considerations in recharge management are largely a result of the unusual recharge conditions prevalent in the Pajaro basin. There is, as a result, relatively little precedent upon which institutional and financial requirements may be based. To a great degree, the form that any ultimate recharge-protection program will take will depend on the number of modified or new approaches that can be adopted for the particular recharge system of the Pajaro Valley.

Flood Control and Water Conservation Districts: Both Monterey and Santa Cruz Counties have flood control and water conservation districts which serve the entire territory of the county. The districts have broad water-management powers under the state code, which include protecting or managing recharge. In Monterey County, the district (MCFCWCD) has primary responsibility for water-resources development, and serves as the main watershed-management agency. Among its other functions, the district operates an intensive recharge program in the Salinas Valley, assesses existing rates of recharge in specific areas, monitors rainfall and runoff, and determines which areas are benefiting from various types and locations of recharge. MCFCWCD has established a number of zones throughout the county, in which special assessments support projects meeting particular local needs. In the Pajaro basin, these include Zone 1, including most of the valley floor south of the river, which maintains the levees and ditches in that area. Zone 7 encompasses most of the sand-hill area between the Pajaro Valley floor and the area of Blackie Road, near Prunedale and Castroville in the Salinas groundwater basin. This zone was formed to support studies of water availability and water quality within its borders. Santa Cruz County operates a county-wide flood control and water conservation district which recently has been closely integrated with the Planning Department.

Flood control and water conservation districts are traditionally supported by ad valorem taxation. Taxes are assessed within zones established in areas where the benefits are accrued. Several overlapping zones may be used to provide multiple benefits. Each zone may incur indebtedness to pay for facilities benefiting all areas within the zone, with assessments levied to pay for the projects or facilities. Neither a flood control district nor a zone may extend across a county line; however, cooperative efforts between adjoining districts are not uncommon.

Planning Departments: The planning departments of the two counties serve many watershed-management functions. Their immediate role in recharge protection includes:

a. Identifying and establishing protection regulations for areas of recharge.

b. Implementing standards for retention, detention, and drainage in areas of new development or land-use change.

c. Serving as lead agency for assessing the impact on recharge of planned changes in land use.

d. Developing means of protecting sensitive values or areas often associated with recharge, such as unusually erodible soils or sensitive habitats (Santa Cruz County) or water-supply watersheds (Monterey County).

e. In Santa Cruz County, the Planning Department is the primary agency responsible for watershed management and water-supply planning at the county level, and enforces most of the ordinances described above.

f. Administering the requirements and provisions of the local coastal programs.

The Planning Department of the City of Watsonville serves the first three functions. None of the primary recharge areas identified for the Pajaro basin are within Watsonville's incorporated area.

Planning departments are directed by a planning commission appointed by and immediately responsible to the board of supervisors of the two counties or the Watsonville City Council. All are supported from general-fund revenues, and to a lesser degree from fees. In recent years, the Santa Cruz County Planning Department has also received a number of grants from state and federal agencies for specific watershed-management projects, some of which have been indirectly related to recharge protection.

Public Works: The Public Works departments of the two counties maintain public roads, ditches, and culverts using general fund revenues. These departments also serve as staff for a variety of drainage districts and other special districts (known as County Service Agencies in Santa Cruz County), which pay a fee for such services.

Building Inspection: Building inspectors have a limited formal role in watershed management within the recharge areas, mainly in erosion control. In Monterey County, the Director of Building Inspection is charged with enforcing the erosion control ordinance, and for deciding whether variances from the provisions of the ordinance should be allowed. Building inspectors serve a very significant function in implementing standards for retaining runoff on-site, or detaining runoff where this is infeasible. Both counties have ordinances establishing criteria for delivery of runoff from building sites to the receiving streams. The ability to meet these criteria in the field depends largely on the skill and judgment of the building inspection staff.

Environmental Health: The environmental health staffs of the two counties have a limited role in recharge protection in that they establish and enforce standards for wells (including dry wells), and will be involved in ensuring that any recharged waters not adversely affect potability of supplies from nearby wells.

County Service Districts: County Service Districts (or Agencies) are usually intended to provide a more intensive level of a public service to an area within the county where this is needed. A wide range of services can be provided through a county service district, from libraries to sewer maintenance; recharge protection is not specifically cited as a service district function, although "public water supply" and "water supply and distribution" are specified. Fees must be proportional to the benefits received, and are generally assessed on a <u>per capita</u>, per acre, or per parcel basis. The County Board of Supervisors establishes the district and acts as its board of directors. Service districts are widely used for drainage management in Monterey County and also in Santa Cruz County. They provide utilities and some urban services in isolated communities throughout Santa Cruz County, including some relatively new beach-front clusters such as Sand Dollar Beach and Place de Mer. Service district boundaries are limited to a single county, with no other limitation; the entire county can be a service district for specific purposes.

<u>Independent Districts or Entities.</u> Private organizations or local governmental agencies with directors separate from the board of supervisors or city council are considered as independent.

Resource Conservation Districts: Resource Conservation Districts are active in both Monterey and Santa Cruz Counties. Although county-level agencies, the districts are closely affiliated with various USDA departments, and utilize professional staff of the Soil Conservation Service. Their major priority is control of upland erosion, traditionally focussed on agricultural areas. They are empowered, however, to consider a broad range of soil, water, and agricultural resources, and which would logically include recharge protection or management. The RCD's are funded from general tax revenue, and also obtain supplemental grants from federal, state, and occasionally private sources. A board of directors appointed by the county's Board of Supervisors directs policy and establishes funding priorities. The area of Resource Conservation District must fall within one county.

The Monterey and Santa Cruz County RCD's have a history of conducting joint programs. The two agencies are presently cooperating in sponsoring and directing the "Strawberry Hills Study", described earlier in the chapter, in which soil loss and runoff from fields in the sand hills are being investigated.

Groundwater Basin Management Agency: There is presently no such agency in the Pajaro basin. Recently, a bill was passed by the state legislature to establish a groundwater management agency in the Pajaro Valley. The content of this bill has been summarized in Chapter 2 of the report. This bill has been signed into law by the governor and will be placed on the ballot in November 1984 for approval by local voters.

Homeowners Associations: Homeowners associations or similar organizations of local landholders can undertake operation and maintenance of drainageways, basins, and other facilities which encourage recharge. As it is doubtful that members of such groups would benefit appreciably from the recharged water, these facilities would be managed for their erosion-control and drainage-management values. Managed drainageways, grade-control structures and recharge basins are all valid means of meeting Santa Cruz County's runoff-retention and erosion-control requirements; these could also serve as acceptable mitigative elements for developments in Monterey County. Inspection and enforcement of agreements to maintain such facilities would fall on existing county agencies.

County Water Districts: County water districts can manage water for any present or future beneficial use. It may store, control, conserve, and supply water, all functions involved in protection and management of recharge. These districts are governed by an elected board, and can serve more than one county (a local example being the Aromas Water District). It may include lands which are not directly benefiting from some or all of its services.

County water districts normally obtain much or most of their revenues from the sale of water. They may also assess ad volorem taxes. The districts may sell bonds. Bond assessments are restricted to property directly benefiting from programs supported by the bonds.

These districts can function at a variety of scales up to entire basins, such as the Marina, San Lorenzo Valley, and Soquel Creek County Water Districts.

<u>Regional Agencies.</u> AMBAG is the sole regional agency with jurisdiction in most of the Pajaro basin. San Benito County, originally an AMBAG member, is no longer affiliated with the organization. AMBAG's role is primarily investigative and advisory, with no specific regulatory or land-management responsibilities. The agency has attracted federal support for a wide variety of water-related issues, and may be able to eventually obtain additional "seed" funding.

<u>State Agencies.</u> Three state agencies have immediate responsibilities related to the managed recharge in portions or all of the Pajaro basin.

California Coastal Commission: Broad powers were granted to the commission by voters of the state in 1970. With the approval of local coastal plans, most of the responsibility for land and resource management in the coastal zone has been assigned to the two counties, although the state commission retains certain appellate, professional, and administrative responsibilities. Agriculture in the coastal zone is one of the top priorities of the Coastal Commission; additionally, its policies specify protection of aquifer recharge within the coastal zone. Hence, support for programs involving the management or protection of recharge may be anticipated both at the county and state level. Approval of any adopted program and of all related facilities within the coastal zone may be required.

Central Coastal Regional Water Quality Control Board: The regional board is charged with protecting the quality of waters within its assigned area, which includes all of the Pajaro basin. The board sets standards for water quality in each area, and grants permits for engineered recharges facilities which generally set water-quality requirements for its operation. The regional board maintains a non-degradation policy especially if any treated wastewater is to be recharged into the aquifer throughout the basin. If waters recharged through retention ponds were of significantly poorer quality than local groundwater, the board could restrict or prohibit recharge.

As it happens, many of the sandy natural recharge areas in the state occur within the Central Coastal Region. The professional staff serving the board has considerable experience in technical aspects of water movement through very sandy environments, and may be able to provide needed expertise. Also, the State Water Resources Control Board is empowered to seek and distribute state and federal grants for water-resources management, and may be a potential source of funding for future planning studies or pilot facilities.

Division of Safety of Dams: A branch of the Department of Water Resources, DSOD has established certain standards for design and construction of dams exceeding 25 feet in maximum height or impounding more than 50 acre feet of water. While often adding appreciably to the cost of such structures, these standards provide an important measure of public safety in a region of known seismicity, such as eastern Monterey Bay. We anticipate that nearly all retention or recharge basins will be smaller than these threshold sizes.

Institutional Options for Recharge Management

General goals for assessing administrative frameworks for recharge protection may be outlined. First, if the benefits of protected recharge are to be most effectively realized, emphasis should be placed on developing a more thorough understanding of the unique processes affecting recharge and runoff in the sand hills. Second, an integrated program for managing recharge, runoff, erosion and sedimentation, and water quality may be substantially more effective than single-purpose management by a large number of agencies at different levels. Third, it is appropriate to consider development and application of planning tools specific to the sand-hill and recharge areas.

Specific administrative and technical options for recharge protection by agency types are considered in the following paragraphs.

County-Level Agencies

Flood Control and Water Conservation Districts:

(1a) Zones of benefit might be formed in each county with boundaries extending from the edges of the basin to the Pajaro River. These would be established by majority vote following a petition signed by at least 10 percent of the registered voters within the proposed boundaries.

Areas within this sub-regional zone would be receiving various kinds of benefits to varying degrees. In the recharge areas, drainage management, erosion control and perhaps water quality benefits would be realized, while areas on the valley floor would benefit from greater quantity and (locally) quality of recharge, diminished pumping costs, and drainage management or flood control. The ability of a flood control and water conservation district to operate and to raise funds given these differing sets of benefits is questionable. Considerable legal research will be needed before this option can be pursued with some realistic hope of implementation.

(1b) Existing county-wide districts can undertake some or all of the recommended functions and studies earlier in this chapter.

(1c) Continued operation of the stream gage on Prunedale Creek is, we believe, especially important. It is the principal long-term source of information on runoff and (perhaps) recharge in sandy basins. Presence of a recording rain gage within the watershed at Echo Valley enhances interpretation of the runoff data.

(1d) Installation of additional stream gages might be considered both on Freedom Blvd. Creek above Highway 1 and on Carneros Creek above Las Lomas. Information gathered at these locations is expected to have broad region-wide applications.

Planning Departments:

(2a) New definitions of watercourse applicable to the sandy basins might be developed. At present, encroachment and development in the flood prone areas are regulated through the subdivision and development permit approval process. Specific policies are contained in the County General Plan and in the North County Land Use plan. The grassy channel-less drainageways of the sand hills do not meet the definitions of stream or watercourse in existing county codes. Yet, these appear to be important recharge areas and potential sources of serious erosion and drainage problems if a channel incision occurs. Preparation of an inventory of these drainageways might aid in improved regulation of future development in these areas.

(2b) Adopt measures granting density incentives for minimizing impervious surface in both major and minor subdivisions.

(2c) Require on-site recharge measures within primary recharge areas, and developing means to encourage maintenance and continued effectiveness over the years.

(2d) Develop measures and/or incentives to minimize irrigated areas in newly-approved projects; educate existing residents and encourage landscaping not requiring irrigation.

Certain functions listed for other agencies could also be undertaken by Planning Department in Santa Cruz County's land-management framework.

Public Works:

(3a) In the City of Marina, the cost of recharge is borne entirely by drainage management. The Public Works Departments of both counties and the City of Watsonville might assess their current

maintenance costs in sand-hill areas, and how these might be affected by on-site and (particularly) off-site recharge-protection measures.

Building Inspection:

(4a) Building inspectors might receive special in-service training in the particular problems of the sandy areas, notably the importance of preventing channel incision.

(4b) Additional erosion-control inspection staff might be assigned to the sand hills and/or other recharge areas. The costs would have to be borne by the general fund, unless supplemental funding or revenues from special districts were made available.

Environmental Health:

No options for additional involvement appear warranted at this time.

County Service Districts:

(6a) County Service Districts might be formed in the recharge areas to provide erosion-control, drainage management and flood-control services. Recharge protection would be an incidental benefit, which would remain supported by the other services (as in the City of Marina).

(6b) As above, except that one or more additional service districts in each county can be established in the areas outside of the recharge zones, but which benefit from the recharge. These nearly valley-wide districts could be responsible for part of the cost of operating off-site recharge basins.

Independent Agencies and Entities

Resource Conservation Districts:

(7a) The economic feasibility analysis of the Strawberry Hills "river basin" study might be expanded to include the value of recharge which might be gained through the various on-site or off-site agricultural practices under consideration. This may involve a moderate additional staff-time cost, which would be borne by the RCDs unless other entities were willing to share in the expense.

(7b) Part of the cost of recharge basins may be eligible for federal cost-sharing arranged by the RCDs through the Agricultural Stabilization and Conservation Service. Such funds would be available only in proportion to the contribution of the recharge basin to erosion and sedimentation control. Both the concept and specifics of cost-sharing require approval by the RCD boards. To a large degree, ASCS funds used for partial cost-sharing of off-site measures would not be available for other RCD priorities.

Water Management Agency:

(8a) There is no existing agency of this type, and there is no apparent source of funding solely for recharge protection and management. The groundwater management agency established by the legislature for the Pajaro Valley, if approved by local voters, can carry out the required recharge protection measures. The WMA would have to determine the relative proportion of recharge, erosion-control, drainage-management and water-quality benefits being accrued in the recharge areas and elsewhere in the basin, and levy fees based on values. With electoral approval, zones of benefit can be established within areas served by a WMA.

Homeowners' Association:

(9a) Homeowners' associations or other private entities might maintain on-site and off-site facilities. Again, the recharged water is not a value which accrues to the association; rather, maintenance would emphasize erosion and drainage control. This option is most attractive if other public agencies are precluded from recharge protection or erosion control by fiscal or other constraints.

County Water District:

(10a) A basin-wide district could be formed, which would levy varying taxes and fees in different parts of the basin, once the relative values of service is established. This district could receive title or easements to the floors of valleys or swales which might be granted in the course of land development. These would be treated in much the same manner as rights-of-way for any water-distribution system on the valley floor. Remaining unresolved questions pertain as to how this district would interact with existing districts (such as Central or Aromas Water Districts) or with the City of Watsonville's service area in and around Corralitos.

(10b) A county water district might be formed in the valley-floor areas, which as one of its functions would subsidize recharge basins in the sandy areas. The basins and other off-site measures would be operated by service districts, homeowners' groups, and/or other local entities.

Regional Agencies

Association of Monterey Bay Area Governments:

(11a) AMBAG could undertake some or all of the additional studies discussed in this chapter, with assistance from its constituent members and/or funds from state or federal sources. Pilot investigations may be fundable, as the findings appear applicable in other sandy areas elsewhere in the state or the nation as a whole.

(11b) AMBAG could coordinate a conference or provide a similar forum in which the particular management problems of Monterey Bay Area sand hills might be analyzed. The twin focuses of this conference might be on measures for recharge protection and how a coordinated program of drainage management, recharge protection, erosion control, and water-quality enhancement might be achieved.

State Agencies

No management options appear indicated at this time.

Summary

1. Unlike most coastal valleys, percolating rainfall is the principal source of net recharge in the Pajaro basin. The rainfall recharge occurs primarily in sandy areas of subdued ridges and hollows surrounding most of the main valley floor. Recharge through these sand hills has been instrumental in sustaining water quality in the basin, and in reducing the rates and effects of salt-water encroachment.

2. The sand hills characteristically have unusually low rates of runoff, averaging about 0 to 8 percent of the mean annual rainfall. By contrast, runoff from most Santa Cruz Mountains or Santa Lucia Range streams is typically 30 to 45 percent of the annual average rainfall. A much higher proportion of the annual rainfall is retained in the permeable soils and sediments of the sand hills, eventually reaching the developed aquifer systems.

3. Conversion of almost any watershed to residential uses tends to increase both the amount of seasonal runoff and the peak runoff rates during floods. In the sand hills surrounding the Pajaro

Valley, these effects are magnified many-fold. For this project, we studied pairs of adjacent small watersheds; one of each pair was at least partly in residential uses, and the other was largely used for orchards or open space. The flood crests we measured for the urbanized basins were typically 10 to 60 times greater than those observed for the same storms in the "undeveloped basins". These flood-peak ratios ranged from 0.3 to 185 times higher runoff in the urbanized member of the pair. While other land uses, soil types, and other influences can also serve to increase the relative runoff amounts, the existing data strongly suggest that at least one of the major regional land uses can appreciably and adversely affect rates of recharge.

4. Runoff from the sand hills previously flowed over grassy and channel-less valley floors. During the past several decades, many or most of these valleys have developed active and incising channels. Peak runoff and sediment yields from these new and unstable channels are largely responsible for damage to drainage facilities and roads, and for sedimentation of significant habitat areas such as Valencia Lagoon, Warner Lake, Corralitos Lagoon, and portions of Elkhorn Slough. Most of the new channels are associated with recent residential development, or (in some cases) hillside agriculture.

5. The additional runoff attributable to conversion of sand-hill basins to residential uses is estimated on a preliminary basis to be about 20 to 25 percent of mean annual rainfall. This increment is runoff corresponds to a loss of 4 to 5 inches of recharge in areas with 20 inches per year, and 6 to 7 inches in areas where rainfall averages 30 inches.

6. A number of existing measures tend to protect recharge, most notably the erosion-control ordinances and coastal plans of the two counties. The rural-residential density matrix of Santa Cruz County and point-source controls exerted by the Regional Water Quality Control Board are also especially significant. Other important measures are discussed in Chapter 5. With the exception of the coastal plans, none of these measures explicitly cite recharge protection as a goal.

7. Existing concepts of primary recharge areas in the sand hills are resulting in the loss of natural recharge in the valley. Current practice is to define recharge areas on the basis of soil types which have high permeabilities—generally more than 2 inches per hour. Such soils generally cover 20 to 60 percent of the area of most sand-hill basins; yet more than 90 or 95 percent of the mean rainfall is recharged over the entire basin. Apparently, much of the runoff from the less-permeable soils infiltrates through the sandy valley floors, and is recharged to the groundwater system. Stockponds and several types of shallow wetlands characteristic of the sand hills probably also contribute to runoff retention and possibly to recharge. A watershed-type perspective is a promising alternative to what we believe is an overly-restricted "soil-type" definition of recharge area. It is, therefore, recommended that the procedure for identifying primary recharge

areas be modified to take into account the presence or absence of natural drainage courses. All basins in which most of the natural precipitation is recharged into the ground should be classified as primary recharge areas regardless of the permeability characteristics of individual soil types within those basins.

8. An integrated water-management approach for the sand hills might be carefully and immediately considered, incorporating:

   a. Recharge protection
   b. Erosion control
   c. Drainage management
   d. Water quality control

   Because of the unique sand-hill hydrology, these management issues are all strongly inter-related. Existing measures, while generally quite successful in meeting their limited objectives, are resulting in large current and deferred costs to the two counties. From the preliminary data, we project that lost recharge and damage to roads and drainage facilities costs each county about $200 to $300 annually per homesite developed in the sand hills, excluding erosion and water-quality impacts which cannot be quantified at this time.

9. The eastern Monterey Bay area has perhaps the greatest extent of sand hills in coastal California. This means that local agency staff are probably most familiar with these problems, and most new techniques and approaches to recharge protection of the sandy areas may need to be locally developed.

   Many of the other areas also affected by sandy soils and the need for recharge protection are in Santa Cruz and Monterey Counties. Among these are Bonny Doon, Quail Hollow, Scotts Valley, portions of the Santa Cruz "Mid-County", Fort Ord, the El Toro and Arroyo del Rey watersheds, and the King City area. Insights developed in the Pajaro Valley regarding recharge protection, erosion control, drainage management, and water quality may be usefully applied to these other areas, and vice-versa.

10. On-site structural measures for increasing infiltration and controlling runoff in developing areas are described. Most of these measures have been implemented in other parts of the state for erosion-control or drainage management, and not specifically for recharge protection. Other measures to conserve runoff reaching the floors of the swales and hollows are also highly appropriate for use in the sand hills, and should be applied once the factors influencing runoff from these small basins are better understood.

11. Because the costs associated with lost recharge are high, and because of the limited current knowledge, additional work appears warranted in describing the hydrologic system and in developing planning tools specifically adapted to water management in the sand hills.

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CHAPTER 8

GROUNDWATER BASIN MANAGEMENT ALTERNATIVES IN THE PAJARO VALLEY

Introduction

Several approaches have been used for groundwater basin management in California. These methods range from adjudication of the safe yield of the basin among existing groundwater users at one extreme to regular monitoring of water level and quality conditions at the other end of the spectrum. Intermediate programs include direct management of pumpage without formal adjudication, indirect regulation of pumpage by levying pump use taxes, and augmentation of basin supplies by conservation and development of in-basin water resources or importation of supplies from outside the basin.

Formal groundwater basin management programs imposing some degree of restriction on pumping levels have usually been instituted when a determination has been made, either through judicial proceedings or by consensus among water users, that a severe condition of overdraft exists in the basin. The severity of overdraft conditions may vary from basin to basin, but usually the determination of such a condition is made on the basis of recorded evidence of prolonged basinwide decline in groundwater levels and attendant intrusion of saline water in the coastal basins. In the absence of such conditions, the scope of the management program has normally been limited to increasing the available supplies by recharge augmentation or by direct distribution of imported supplies, although this alternative has also been selected in several basins with manifested-overdraft conditions.

At present, the emphasis of most of the existing groundwater management plans in the state is on supply augmentation through new facilities and structures such as dams, reservoirs and recharge basins. Usually little or no emphasis is placed on protecting natural recharge areas in the basin.

In the Pajaro Valley, a rather unique combination of hydrologic conditions prevail which may necessitate a new approach for management of groundwater resources in the basin. These conditions can be summarized as follows:

1. Intrusion of saline waters into water bearing formations in the coastal areas of the valley presently affecting an area of about 3,300 acres.

2. Very slow or indiscernible long-term declines in water levels in most inland areas.

3. Dependence of groundwater availability and quality on the valley floor on recharge through the sandy hills surrounding the valley. Runoff from these hills may be significantly increased by channelization of the drainage basins as the

result of development or certain agricultural practices. Loss of recharge from these areas may lower water levels and also deplete inflow into the valley floor areas.

Groundwater management options for the Pajaro Valley have, therefore, been selected to reflect local hydrologic conditions. A detailed discussion of these alternatives is presented in the following section of this report. These alternatives are evaluated on the basis of cost, institutional complexity, political viability and environmental impacts. A qualitative ranking is developed for the various alternatives on the basis of the above factors. A more detailed analysis of the recommended groundwater management program is carried out in the concluding section of this chapter.

Management options in the Pajaro Valley vary depending on the scope of the management program and the geographic areas that would be encompassed within the jurisdiction of the selected management agency. Various management options in the valley are listed below:

Alternative M-1.	No action (continuation of existing programs)
Alternative M-2.	Comprehensive management of all groundwater use activities in the basin.
Alternative M-3.	Selective management of specific identified problem areas.
Alternative M-4.	Implementation of water conservation practices.

A detailed discussion of these management alternatives is presented in the following sections.

Alternative M-1. No Action (Continuation of Existing Programs)

One option for groundwater management in the Pajaro Valley is to continue the current patterns of groundwater use, monitoring of water levels and quality conditions, regulation of land use and enforcement of water pollution control laws and regulations. This option would impose no additional direct cost on the residents and property owners in the valley beyond the costs currently incurred for carrying out the existing groundwater related programs. Also, this alternative does not require the formation of new institutions, development of new laws and regulations, and in general, undertaking all other needed actions which would be necessary for implementing any new management programs.

The disadvantage of the no action alternative is that it could entail major indirect costs if increased pumpage and/or loss of recharge results in the aggravation of seawater intrusion conditions in the basin. The impact of this alternative could best be evaluated through the use of a digital model for the basin. Different scenarios for pumpage withdrawal and land use patterns could be simulated with the model to evaluate the resulting distribution of water levels in the basin. These data could also be used to determine the probable rate of advance of seawater intrusion in the basin.

Alternative M-2. Comprehensive Groundwater Management

This alternative calls for the comprehensive management of all aspects of groundwater resource utilization, land use, water quality protection and groundwater monitoring in the Pajaro Valley. A detailed description of various functional areas for this plan and the proposed approach for carrying out each of these functions in presented below:

Function	Approach
a. Establishment and administration of the management program.	1. Establish an independent groundwater basin management agency or form a management agency by joint powers agreement between existing agencies based on existing or new legislative authority. 2. Recruit or assemble technical and administrative staff to carry out the mandate of the management program.
b. Develop more detailed information on the geologic structure of major groundwater resources including multiple aquifer regimes in the coastal portions of the basin.	1. Review available well logs for the basin and prepare more detailed geologic cross sections along appropriate transects in the basin. 2. Identify and map major aquicludes and aquitards affecting groundwater occurrence and movement in the basin.
c. Inventory all existing wells and determine total pumpage withdrawal.	1. Require registration of all wells within a specified period. Obtain information on well location and aquifer designation, well characteristics, pump horsepower, pump lift, static water level, pump discharge, total annual pumpage, water use type, characteristics of use, etc. 2. Require the installation of flow meters on all wells where one does not currently exist.

d. Determine the sustained safe yield of the basin.

1. Develop and calibrate a digital model for the basin at a level of detail which would enable simulation of water level changes under various pumping regimes in individual zones of the confined aquifer area and in discrete subareas of the basin such as East area, Springfield area, Pajaro Valley floor, terrace areas, etc.

2. Identify all hydrologic parameters in the model which have been estimated and have not been verified by field measurement.

3. Conduct the required field studies to accurately determine the components of the hydrologic budget for the basin including:

   i. Unit and total annual crop evapotranspiration demands.

   ii. Unit and total annual native vegetation evapotranspiration demands.

   iii. Total annual precipitation and precipitation runoff from sandy and non-sandy watersheds.

   iv. Geologic formation hydraulic conductivities at key locations and the corresponding aquifer transmissivities.

   v. Annual subsurface flow into and out of the basin.

   vi. Annual inflow and outflow volumes for the perched water table zone.

4. Conduct the required field studies to determine the impact of development in sandy watersheds on the rate of natural recharge from these areas.

5. Simulate water level conditions in the basin under existing and projected future land use scenarios using historical records of precipitation over a representative long-term period.

6. Determine the sustained safe yield of the basin by adjusting the levels of pumpage withdrawal and development in sandy watershed or an incremental basis to arrive at long-term steady-state water level conditions in the basin.

7. Determine the extent of basin-wide overdraft and the corresponding required supplemental sources of water to avoid irreversible salt water intrusion and significant drops in the water level under projected alternative land use scenarios.

e. Develop and implement a water supply management program.	The objective of this program will be to bring supply and demand into balance on a sustained basis. The scope of the water supply management program will depend on the results of yield studies described above. Alternative approaches for this program are listed below:

1. Adjudicate groundwater supplies in the basin. In this method, the sustained safe yield of the basin would be allocated among existing users on the basis of different criteria such as the reasonable level of beneficial use, historic demand level, etc. and no additional pumping would be allowed from the basin in excess of the long-term safe yield value.

2. Develop supplemental sources of water to meet any excess demand above the sustained yield of the basin. Based on data developed in this study, the potential alternative sources of supply in

the order of priority in the Pajaro Valley are likely to be as follows:

i. Local deep aquifers,
ii. Arroyo Seco Dam project,
iii. San Felipe project,
iv. Pescadero Creek Dam project

3. Develop a supplemental source to meet the minimum demand for preventing the advance of seawater intrusion in the basin and for supplying lands overlying the intruded areas. Viable sources of supply for this option are the same as described under item 2 above. Also, bring demand and supply into balance by taking the following additional actions:

   i. Establish conservation measures and require the implementation of such methods by agricultural, industrial and domestic water users.

   ii. Implement recharge source protection measures in all sandy watersheds. The scope of these measures could range from adoption of open space zoning to incorporation of recharge protection measures in all existing and proposed development projects.

   iii. Develop approaches and vehicles for incorporating recharge protection measures in all new developments in sandy watersheds.

f. Develop and implement the required groundwater monitoring programs.

1. Continue the existing water level and water quality monitoring programs carried out by Santa Cruz and Monterey County Flood Control and Water Conservation Districts.

2. Supplement the existing programs by intensifying monitoring of wells perforated in alluvial, deltaic, and Aromas aquifers in the Elkhorn Road area, where the potential for intrusion from Elkhorn Slough area exists and where chloride levels have sharply increased in at least one well (12S-2E-16Q1).

3. Several new wells should be added to the monitoring network in and near the intruded zone at the mouth of the Pajaro River. Efforts to increase the density of the monitoring wells at a distance of one to two miles from the coast should also be made. Any inactive well in these areas should be maintained as a dedicated monitoring well. The two flood control districts should make measurement of water level and quality during the same months of the year.

g. Develop sources of funding for management activities and construction, operation and maintenance of water supply and distribution facilities.

1. Levy a fee against all users of groundwater in the basin in proportion to the average annual volume of water pumped over the most recent five-year period and to be adjusted annually thereafter. Annual pumpage could be determined by using estimated unit demand values for different land use categories.

2. Levy an ad-valorem tax against all real property in the basin. The use of this method may not be feasible due to restrictions imposed by Proposition 13 on all new property taxes.

3. Levy a fee against all groundwater users in the basin as under No. 1 above plus an additional fee for all users receiving supplemental water from the management agency facilities. This additional fee can be calculated on the basis of unit energy costs for pumping water from on-farm wells, total volume

of water pumped per year and annual avoided cost for operation and maintenance of pump and well facilities.

4. Establish a fee for all new development projects in sandy watersheds to provide funding for implementation of any required recharge protection facilities at the watershed scale.

h. Analyze all proposed development projects for impact on natural recharge sources and on the hydrologic balance in the basin.

1. Evaluate the impact of any new development project on the hydrologic balance of the basin by simulating water level conditions in the basin by taking into account the demand imposed by the given project. The simulation should be carried out over a representative period including normal variations in rainfall and runoff in the basin. The simulation process should include both the impact of net withdrawals for the project and any loss of recharge which may be caused by the proposed development.

   If any project is determined to cause adverse irreversible impacts on the hydrologic budget in the basin, the agency should deny or appropriately condition approval for such project.

i. Develop and implement a groundwater pollution control program.

1. Assist the Regional Water Quality Control Board in identifying any sources of groundwater pollution in the basin and in monitoring compliance with any discharge requirements issued by the Board.

2. Work closely with the County Health Departments, the Regional Water Quality Control Board and State Department of Health Services to develop and implement construction, monitoring and management guidelines for under-

ground hazardous materials storage tanks and transport pipelines and for handling and disposal of hazardous and toxic substances.

Function	Approach
j. Develop and implement enforcement procedures.	1. The agency should develop appropriate rules and regulations setting out compliance procedures, appeal processes, and penalties for violation of any of the agency rules.

Alternative M-3. Selective Management of Specific Identified Problem Areas

In this alternative, the emphasis of the management activities would be limited to dealing with specific identified problem areas. The results of this study and previous investigations carried out in the basin indicate that saltwater intrusion and recharge source protection are the major problems requiring management action in the Pajaro Valley. The various functional areas for this management alternative and feasible approaches for carrying out these functions are discussed below.

Function	Approach
a. Establishment and administration of the management program.	1. Establish an independent groundwater basin management agency or form a management agency by joint powers agreement between existing agencies based on existing or new legislative authority.
	2. Recruit or assemble the required technical and administrative staff to carry out the mandate of the management program.
b. Develop more detailed information on the geologic structure of major groundwater resources including multiple aquifer regimes in the coastal portions of the basin.	1. Review available well logs for the basin and prepare more detailed geologic cross sections along appropriate transects in the basin.
	2. Identify and map major aquicludes and aquitards affecting groundwater occurrence and movement in the basin.

c. Determine the sustained safe yield of the basin.

1. Develop and calibrate a digital model for the basin at a level of detail which would enable simulation of water level pumping regimes in individual zones of the confined aquifer area and in discrete subareas of the basin such as East area, Springfield area, Pajaro Valley floor, terrace areas, etc.

2. Identify all hydrologic parameters in the model which have been estimated and have not been verified by field measurement.

3. Conduct the required field studies to accurately determine the components of the hydrologic budget for the basin including:

   i. Unit and total annual crop evapotranspiration demands.

   ii. Unit and total annual native vegetation evapotranspiration demands.

   iii. Total annual precipitation and precipitation runoff from sandy and non-sandy watersheds.

   iv. Geologic formation hydraulic conductivities at key locations and the corresponding aquifer transmissivities.

   v. Annual subsurface flow into and out of the basin.

   vi. Annual inflow and outflow volumes for the perched water table zone.

4. Conduct the required field studies to determine the impact of development in sandy watersheds on the rate of natural recharge from these areas.

5. Simulate water level conditions in the basin under existing and projected future land use scena-

rios using historical records of precipitation over a representative long-term period.

6. Determine the sustained safe yield of the basin by adjusting the levels of pumpage withdrawal and of residential and agricultural development in sandy watersheds on an incremental basis to arrive at long-term steady-state water level conditions in the basin.

7. Determine the extent of basin-wide overdraft and the corresponding required supplemental sources of water to avoid irreversible salt water intrusion and significant drops in the water level under projected alternative land use scenarios.

d. Develop and implement a water supply management program.

The objective of this program will be to bring supply and demand into balance on a sustained basis. The scope of the water supply management program will depend on the results of yield studies described above. Alternative approaches for this program are listed below:

1. Develop a supplemental source to meet the minimum demand for preventing the advance of seawater intrusion in the basin and for supplying lands overlying the intruded areas. Based on data developed in this study, potential alternative sources of supply in the order of priority in the Pajaro Valley are likely to be as follows:

   i. Local deep aquifers
   ii. Arroyo Seco Dam project
   iii. San Felipe project
   iv. Pescadero Creek Dam project

   Further, bring demand and supply into balance by taking the following additional actions:

i. Establish water consevation measures and require the implementation of such methods by agricultural, industrial and domestic water users.

ii. Implement recharge source protection measures in all sandy watersheds. The scope of these measures could range from adoption of open space zoning to incorporation of recharge protection measures in all existing and proposed development projects.

iii. Develop design criteria and construction standards for incorporating recharge protection measures in all new development projects in sandy watersheds.

e. Develop and implement the needed groundwater monitoring programs.

1. Continue the existing water level and water quality monitoring programs carried out by Santa Cruz and Monterey County Flood Control and Water Conservation Districts.

2. Supplement the existing programs by intensifying monitoring of wells perforated in alluvial, deltaic, and Aromas aquifers in the Elkhorn Road area, where the potential for intrusion from Elkhorn slough area exists and where chloride levels have sharply increased in at least one well (12S-2E-16Q1).

3. Several new monitoring wells should be added to the monitoring network in and near the intruded zone at the mouth of the Pajaro River. Efforts to increase the density of the monitoring wells at a distance of one to two miles from the coast should also be made. Any inactive well in these areas should be maintained as a dedicated monitoring well. The two

flood control districts should make measurement of water level and quality during the same months of the year.

f. Develop sources of funding for management activities and construction, operation and maintenance of water supply and distribution facilities.

1. Levy a fee against all users of groundwater in the basin in proportion to the average annual volume of water pumped over the most recent five-year period and to be adjusted annually thereafter. Annual pumpage could be determined by using estimated unit demand values for different land use categories.

2. Levy an ad-valorem tax against all real property in the basin. The use of this method may not be feasible due to restrictions imposed by Proposition 13 on all new property taxes.

3. Levy a fee against all groundwater users in the basin as under No. 1 above plus an additional fee for all users receiving supplemental water from the management agency facilities. This additional fee can be calculated on the basis of unit energy costs for pumping water from on-farm wells, total volume of water pumped per year and annual avoided cost for operation and maintenance of pump and well facilities.

4. Establish a fee for all new development projects in sandy watersheds to provide funding for implementation of any required recharge protection facilities at the watershed scale.

g. Analyze all proposed development projects for impact on natural recharge sources and on the hydrologic balance in the basin.

1. Evaluate the impact of any new development project on the hydrologic balance of the basin by simulating water level conditions in the basin by taking into account the demand imposed by the given project. The simulation should be carried out

over a representative period including normal variations in rainfall and runoff in the basin. The simulation process should include both the impact of net withdrawals for the project and any loss of recharge which may be caused by the proposed development.

If any project is determined to cause adverse irreversible impacts on the hydrologic budget in the basin, the agency should deny or appropriately condition approval for such a project.

h. Develop and implement a groundwater pollution control program.

1. Assist the Regional Quality Board in identifying and sources of any sources of groundwater pollution in the basin and in monitoring compliance with any discharge requirements issued by the Board.

2. Work closely with the County Health Departments, the Regional Water Quality Control Board and State Department of Health to develop and implement construction, monitoring and management guidelines for underground hazardous materials storage tanks and transport pipelines and for handling and disposal of hazardous and toxic substances.

i. Develop and implement enforcement procedures.

1. The agency should promulgate appropriate rules and regulations setting out compliance procedures, appeal processes, and penalties for violation of any of the agency rules.

Alternative M-4. Implementation of Water Conservation Practices

The main emphasis of this management alternative is to promote water conservation practices among municipal, industrial and agricultural water users in the basin. Various management functions and alternative approaches for achieving these functions are listed below. The water conservation plan adopted for Monterey County and the irrigation scheduling method developed by Santa Cruz County Cooperative Extension Service can be used in the development of the required basin-wide conservation program.

Function	Approach
a. Establish conservation policies for municipal, industrial and agriculture water users in the basin.	1. Develop uniform codes, ordinances, and policies for adoption by counties and municipal agencies requiring water conservation practices in the Pajaro Valley. 2. Encourage existing domestic water users to install water saving devices on faucets, shower heads, toilet tanks, appliances, etc. Require the installation of such devices in all new buildings in the valley. 3. Require implementation of water conservation practices by all industrial operations in the valley with emphasis on heavy water users, such as canning and food processing industries. 4. Promote the adoption of conservation practices among all farmers and particularly on farm lands which overlie the perched water table zone by promoting the use of the irrigation scheduling methods developed by Santa Cruz County Cooperative Extension Service.
b. Raise the required funding for promotion of water conservation measures.	1. Levy a fee on all domestic, commercial and industrial water users for the development and implementation of municipal water conservation programs. 2. Levy a fee on all industrial wastewater dischargers and water users for the development and implementation of industrial water conservation programs.

3. Levy a water use fee on all irrigated crop lands in the valley for the development and implementation of agricultural water conservation programs.

4. Secure grants or funding through the State Department of Water Resources, Office of Water Conservation.

Evaluation of Alternative Groundwater Basin Management Plans

Alternative groundwater basin management plans are evaluated in this section on the basis of cost, institutional complexity and political viability. A subjective ranking is developed on the basis of these factors and recommendations are made on the order of preference of various management plans in the valley.

Alternative M-1. No Action. This alternative requires no new institutional arrangements and no direct costs of implementation. The economic, environmental and social consequences of no action, however, could be very adverse if saltwater intrusion conditions deteriorate in the coastal areas and if the intrusion front advances further inland in the valley floor and in Springfield areas.

The consequences of the No Action alternative will depend in large part on the future levels of pumping in the basin and on the level of development in natural recharge areas in the basin. Three possible scenarios can be considered for evaluating the impact of this alternative as follows:

1. No Change in Pumpage and Minimal Development in Natural Recharge Areas. Many areas in the valley have shown gradual, long-term declines in water levels over periods of several years with balanced periods of high or low rainfall. These declines may be ameliorated or aggravated to varying degrees; in some wells, sustained declines have been reversed during the past several wet winters with no change in pumpage. We anticipate that water levels will continue over periods of many years to decline at rates averaging 0.1 to 0.3 feet per year in sub-areas where previous water-level declines have occurred. An important exception is the East Area, between Pajaro Gap and Watsonville, where sustained annual declines of 0.5 feet have been observed over a period of 30 years. In most other areas, rainfall offsets existing pumpage, and will probably continue to do so unless recharge rates are diminished through changes in the use of the land or channels. Seawater intrusion conditions may remain stable or worsen very gradually over the long-term period under this scenario for water use.

2. Increased Pumpage Withdrawal with Minimal Development in Natural Recharge Areas. Under any development scenario calling for increased pumpage withdrawal from the basal alluvial gravels and Aromas aquifer, it is highly probable that the extent and severity of seawater intrusion would increase, and the rate of decline of water levels in the basin would accelerate especially in areas of concentration of pumping wells.

3. Increased Pumpage Withdrawal Accompanied with Reductions in the Rate of Natural Recharge. Increased development in the basin, especially in areas currently covered by natural vegetation, could result in a net increase in pumpage withdrawal from the aquifers. If such development occurs in primary recharge areas, an appreciable loss in the rate of natural recharge can also be expected to occur. The impact of this mode of development on the rate of expansion of intruded areas and pumping lift levels in the basin would be a function of the rate of increase in pumpage and the rate of loss of natural recharge. Significant adverse impacts on groundwater levels and quality could be expected if such changes occur over an appreciable acreage in the valley.

The present pattern of development in the valley and existing land use plans indicate both an increasing pumpage trend and increased development in sandy watersheds in the basin. The combined effect of increased pumpage and loss of natural recharge could be as much as 10,000 ac-ft per year in the basin by the year 2000.

Although no direct costs would be incurred if no management plan is implemented in the basin, indirect costs of inaction should be recognized as the ultimate cost of this alternative. The magnitude of such indirect costs can only be estimated on a general basis at this time. These costs should be refined when a digital model is available for the basin.

The costs of no action could be considered under the following categories:

1. Increased Pumpage Costs. The cost of pumpage of water increases in direct proportion to the pump lift. The amount of electric energy in KWh which is needed to lift an acre foot of water from a given depth can be calculated by the following formula based on an assumed pump efficiency of 60 percent:

$$E = 1.70 h$$

in which E = electric energy in KWh, and h = pump lift in feet. If the overall water level in the Pajaro Valley declines on the average at the rate of 0.5 foot per year between now and year 2000, the added cost of electric energy at the current rate of 6.5 cents per KWh for a total annual pumpage of 72,000 ac-ft would range from $4,000 per year in 1984 to more than $64,000 in year 2000. This cost would continue to increase indefinitely into the future until pumping levels are stabilized by bringing supply and demand into balance. If the rate of decline in water levels exceed 0.5 foot, the added energy costs would increase in direct proportion to the actual drop in water levels. These added costs do not appear to impose a significant burden on the farming operations in the valley.

2. Cost of Modification of Existing Wells. If water levels decline significantly in the alluvial aquifer, it may become necessary to deepen the shallower wells which penetrate only this water-bearing formation or to lower the pump bowls in order to maintain the yield of these wells. Deepening of existing wells may or may not be feasible depending on well characteristics. When feasible, this would involve appreciable expenditures depending on the casing diameter, the additional depth of drilling, pump diameter, etc. No estimate of these costs can be made without detailed field investigations, however, the cost for individual wells could range between $4,000 to 50,000.

3. Cost of Seawater Intrusion. In the absence of any groundwater management program to bring supply and demand into balance and to protect the natural recharge sources in the basin, it is reasonable to assume that seawater intrusion conditions will be aggravated over the long-term period in the Pajaro Valley. The extent of such aggravation, however, cannot be determined with any certainty in the absence of a digital model for the basin. In this report, it is attempted to provide a range of estimates for the probable costs of increased seawater intrusion in the valley.

   The acreage of farmland that is to some extent affected by seawater intrusion has increased from about 1,000 acres in the early 1950's to about 3,300 acres at the present time. Estimated pumpage withdrawal from the basin has increased from 25,000 to 65,000 ac-ft per year over the same period. The combined effect of increased pumpage and loss of natural recharge due to development is estimated to translate into an additional 8,000 to 10,000 ac-ft of net withdrawal from the basin over the next 20-year period. Based on the long-term historical behavior of the aquifers in the basin, it can be assumed that at a minimum, the seawater-affected areas would expand at the rate of 0.06 acres per additional ac-ft of withdrawal from the basin. Therefore, the seawater intrusion front as delineated by the 100 mg/l chloride concentration level could encompass an additional 600 acres during the next 20-year period assuming a combined stress of 10,000 ac-ft. on the basin by added pumpage withdrawal and loss of natural recharge. The advance of the intrusion front, however, not only would expand the area affected by saltwater, but could also intensify the severity of intrusion in all or parts of the areas that are currently affected by seawater. It is reasonable to assume that some of the agricultural wells that currently produce water of marginal quality would have to be abandoned under the condition described above. If it is assumed that severe aggravation of water quality occurs under one third of the area currently affected by seawater intrusion and if it is assumed that water of suitable quality could be obtained from deeper local aquifers, the total annual cost of the replacement supply would be approximately $120,000 (based on the estimated unit cost of water of $57 per ac-ft from the deep aquifers developed in Chapter 6).

The hydrologic budget estimates developed in this study indicate that the aquifers in the valley are in a state of overdraft. Under such conditions, additional pumpage from the basin could result in a significant expansion of the intruded area and may necessitate the development of an alternative source of supply for all lands that are currently affected by seawater intrusion. The minimum annual cost of the alternate source of supply would be about $435,000 assuming that the local deep aquifers could provide the needed supply. This cost could increase or decrease in direct proportion to the area that may be actually affected by saltwater.

Economic Impact. The No Action alternative may cause significant adverse economic impacts on the coastal farmers if the quality of groundwater continues to deteriorate in these areas necessitating the abandonment of existing wells and drilling of new deeper wells and possibly forcing the abandonment of farming operations in the more severely intruded areas. In the absence of any new groundwater management plan for the basin, the economic consequences of any of the possible scenarios under this option would be borne by the farmers in the affected areas. Some secondary impacts would also be caused in the remainder of the basin due to the loss of job opportunities, loss of personal income and the associated decrease in private sector sales. Quantitative data on the economic impact of this alternative is presented below under two possible scenarios for groundwater conditions in the coastal areas of the valley.

1. Abandonment of existing wells. Under this option, it is assumed that all wells within the existing intruded areas would have to be abandoned and deeper wells would have to be drilled either at the same locations or further inland on each farm. This atlernative differs from the deep aquifer water supply augmentation option because it is improbable that individual farmers would undergo the expense of drilling a deep well with uncertain water yield and quality conditions. Therefore, we have assumed that any new well would have a maximum depth of 800 feet and would yield on the average 300 gpm of water. The annual production of such a well would be about 130 ac-ft under existing irrigation practices (a schedule of twelve hours per day, six days per week and about eight months per year). Accordingly, a total of 50 such wells would be needed to provide 6,500 ac-ft per year to the existing intruded area of approximately 3,250 acres. Assuming that all of these wells are drilled during

a 20-year interval from 1985 to 2004 and at an estimated cost of $100,000 per well, the total annual cost of this undertaking over a 50-year planning period at 12 percent interest rate would be about $115,000 per year. Maintenance and replacement cost of these wells is not considered in this analysis because such costs would be incurred regardless of whether the wells were relocated or not. The 50-year amortization period is used in this analysis so that the cost data can be compared with the cost of water augmentation facilities on an equal basis.

2. Abandonment of farming operations. If groundwater quality in the intruded areas becomes unsuitable for crop irrigation and if no other source of supply were available to these lands, irrigated crop farming may have to be abandoned in these areas. The primary economic impact of abandonment of farming operations will be exerted on the farmers whose lands become unproductive. In addition, secondary impacts will also be felt by the surrounding communities due to the loss of sales, personal income and jobs. These impacts are discussed briefly in the following sections.

    a. Primary Impacts. The annual costs associated with the loss of coastal farmlands will depend on the net income derived from these lands. Assuming a net income in the range of $200 to $800 per acre per year, this loss can be translatted into total annual costs over a 50-year planning period at 12 percent annual interest rate as shown in Table 1.

Table 1. Estimated Annual Cost of Lost Income from Abandonment of Farming Operations

Assumed Loss of Farmland, Acres	Estimated Range of Annual Cost, Dollars — Estimated Net Income per Year, Dollars: 200	800
1,000	92,000	368,000
3,000	276,000	1,104,000

b. Secondary Impacts. Loss of crop production on an appreciable acreage of land in the Pajaro Valley will create secondary economic impacts in the larger community due to the loss of interchange between the farmers and other sectors of the economy. The gross impact of such losses has been estimated by Mr. George Goldman on the basis of an economic input-output model developed by the California State Department of Water Resources (Cooperative Extension, University of California, 1983). These results are summarized in Table 2 and indicate that potentially significant secondary impacts could result from the loss of 3,000 acres of farmland in the Pajaro Valley. Because the effect of the secondary impact would be spread over and possibly beyond the two-county area, it is not feasible to attribute these costs on a per acre basis without additional detailed economic analysis.

In summary, the long term direct economic impact of the No Action alternative could range from $35 to $340 per acre of the area currently affected by seawater intrusion for the different scenarios discussed in this section.

Environmental Consequences. Environmental impacts of the No Action alternative may vary depending on the severity of future seawater intrusion problems, the extent to which groundwater levels decline in the basin, and the type of actions taken in response to these problems.

Under worst-case conditions, the following potential impacts could materialize in the basin.

1. Declining water levels may necessitate the deepening of the water wells or lowering of pump bowls at an appreciable cost to farmers. This cost could range from $4,000 to $50,000 per well depending on the required level of work (the upper limit pertains to the drilling of a new well). These expenses may create a hardship on the affected farmers and could result in economic dislocations.

2. Extensive intrusion of coastal lands may result in large scale abandonment of farming in these areas. In such an event, significant pressures may be created for the development of these lands for non-agricultural uses which may cause potentially adverse effects in terms of aesthetic values and agricultural and air resources of the Pajaro Valley.

3. Extensive development of sandy watersheds may result in increased erosion and sediment transport from these areas. The additional sediment loads may affect fish habitat conditions in the local streams and may also have a potential impact on biological resources of the Monterey Bay in the areas near the mouth of the Pajaro River.

Table 2. Estimated Secondary Economic Impacts of the Loss of 3,000 Acres of Crop Land in the Coastal Areas of Pajaro Valley[a]

Economic Effects	Lettuce[b]	Artichokes[b]	Total
Loss of Direct Sales	$ 6,750,000	$3,553,500	$10,303,500
Decrease in Private Sector Sales	$13,992,750	$7,366,406	$21,359,156
Loss of Personal Income	$ 6,473,250	$3,407,807	$ 9,881,057
Loss of Full-Time Equivalent Jobs	281	148	429

[a]These estimates were developed by Mr. George Goldman of Cooperative Extension, University of California at Berkeley.

[b]Assuming the loss of 1,500 acres of lettuce and 1,500 acres of artichokes.

Political Viability. Due to an increased awareness of the need for protecting the groundwater resources of the Pajaro Valley and sustaining the agricultural economy of the basin, it is improbable that the No Action program would be an acceptable approach for managing the water resources of the valley.

Alternative M-2. Comprehensive Groundwater Basin Management. This alternative would provide a means for managing every aspect of groundwater use in the Pajaro Valley. Implementation of this alternative would require the establishment of a sizable institutional structure, the imposition of an appreciable annual levy on water users and close regulation or monitoring of all water uses in the basin. A more detailed discussion on the requirements of this plan is presented in the following paragraphs.

Cost. The costs associated with Alternative M-2 would be incurred for the administration of the management plan, conduct of the required field investigations and planning studies, and development of the needed supplemental sources. These costs are summarized in Table 3. These data indicate that Alternative M-2 may require an annual expenditure of about $340,000 for routine administrative costs plus a total one-time expenditure of $200,000 to $700,000 for research investigations and possible adjudication of the basin. An additional cost of $300,000 to $420,000 would be incurred by farmers for installing water meters on their existing wells.

Institutional Complexity. Implementation of a comprehensive groundwater management program requiring the metering of all wells, regulation of groundwater use in all parts of the valley and possible adjudication of groundwater supplies would require a fairly complex institutional structure involving engineering, legal and administrative disciplines. In developing the cost estimates, shown in Table 1, a minimum administrative framework has been assumed for this management option. It is highly probable that a more extensive organization would be needed to implement a comprehensive management program especially if groundwater adjudication is selected as the means of bringing water supply and demand into balance in the basin.

Political Viability. The need for a comprehensive groundwater management program entailing the regulation and monitoring of all water use activities in the basin and possible adjudication of the groundwater resources may not be apparent to most water users in the basin especially since this program may impose appreciable costs on all water users. Assuming the validity of this assumption, the chances of success for a program of this type through the electoral process appears to be low.

Alternative M-3. Selective Management of Major Problems. This alternative is, in general, similar to Alternative M-2 with the exception that the emphasis of this management approach would be on the protection of natural recharge sources, development of a replacement water supply source for intruded areas of the basin and promotion of water conservation practices among all water users in the valley. Under this management option, no restriction would be imposed on existing water users in the basin although all future development

Table 3. Estimated Cost of Implementation of Management Alternative M-2

Item	Annual Cost (dollars)	Total One Time Costs (dollars)
Salaries, Overhead & Operation [a]	240,000	
Research Investigations[b]	-	100,000 - 200,000
Water Supply Management		
Adjudication[c]		100,000 - 500,000
Development of Supplemental Sources[d]		Variable depending on project type
Monitoring[e]		5,000 - 10,000
Water Conservation Program[f]	100,000	
Cost of Water Well Meters[g]		300,000 - 420,000
TOTAL	340,000	505,000 - 1,130,000[h]

[a]Based on the following assumptions: Program manager $36,000 per year, two technical staff members each @ $27,000 per year, clerical and drafting staff at $30,000 per year, and overhead expenses of 100% of direct salaries.

[b]Estimated range of cost for carrying out the hydrologic investigations needed to obtain accurate data for various components of the hydrologic budget. This is a one time total cost.

[c]This cost would vary depending on the complexity of the adjudication process and depending on whether this process is challenged in the courts. The numbers presented are purely speculative.

[d]The cost of alternative sources of supply are discussed in detail in the preceding chapters of this report.

[e]Estimated cost of constructing a new monitoring well in the Elkhorn road area. No additional monitoring costs are anticipated beyond those incurred currently by the two counties.

[f]About 90% of this cost would be required for development and implementation of an irrigation scheduling program. The balance is the estimated cost of implementing a domestic and industrial water conservation plan.

[g]This cost item would be incurred by individual farmers and is estimated on the basis of unit cost of about $500 to $700 for an assumed total number of wells of 600 in the valley.

[h]Exclusive of the cost of water supply augmentation projects.

plans would be reviewed by the management agency for analysis of their impact on the hydrologic balance and seawater intrusion conditions in the basin.

Cost. The costs of Alternative M-3 are summarized in Table 4 and indicate an annual management cost of $292,000 plus one-time miscellaneous costs of $105,000 to $210,000.

Institutional Complexity. Institutional requirements for this option are less complex than that for Alternative M-2. This is due to the absence of requirements for detailed monitoring of water use rates, and the emphasis of the program on non-adjudicatory management procedures. The organizational structure and the type of the management agency would be similar for Alternatives M-2 and M-3.

Political Viability. Alternative M-3 addresses major existing and potential groundwater problems in the Pajaro Valley without imposing stringent requirements on existing water users. Although the costs associated with this plan may not be significantly below the cost of Alternative M-2, the chances for securing support from the water users and obtaining voter approval for this plan may be appreciably higher.

Alternative M-4. Implementation of Water Conservation Practices. This management alternative involves only the implementation of water conservation practices among municipal, industrial and agricultural water users in the valley. If stringent conservation practices are put into effect among all water users in the valley, the probable range of net annual water savings in ac-ft. among the three groups would be as follows:

Irrigated Agriculture	1,200	
Domestic Users	350	
Industrial Users	300 - 500	(estimated)
Total	1,850 - 2,050	

The estimated range of water savings for agricultural water users were developed by the Santa Cruz County Cooperative Extension Service and correspond to the adoption of irrigation scheduling procedure and conversion to drip irrigation method, respectively. The estimated water savings for domestic users were developed by AMBAG staff based on the potential savings reported in the literature and the number of existing connections in the City of Watsonville. No reliable estimate is available for potential industrial water savings and the value used above is purely speculative at this time.

Cost. The annual cost of the water conservation management alternative is estimated at about $100,000 per year for the option including irrigation scheduling. The cost of Municipal water conservation would involve a one-time cost of $100,000 if all of the existing customers install the required water saving devices. No estimate of the cost of industrial water conservation can be made at

Table 4. Estimated Cost of Implementation of Alternative M-3

Item	Annual Cost (dollars)	Total One Time Costs (dollars)
Administration[a]	192,000	
Research Investigations[b]	-	100,000 - 200,000
Water Supply Management		
Development of Supplemental Sources[c]		Variable depending on project type
Monitoring[d]		5,000 - 10,000
Agricultural Water Conservation Program[e]	100,000	
TOTAL	292,000	105,000 - 210,000[f]

[a]Based on the following assumptions: Program manager $36,000 per year, one technical staff member each @ $30,000 per year, clerical and drafting staff at $30,000 per year, and overhead expenses of 100% of direct salaries.

[b]Estimated range of cost for carrying out the hydrologic investigations needed to obtain accurate data for various components of the hydrologic budget. This is a one time total cost.

[c]The cost of alternative sources of supply are discussed in detail in the preceding chapters of this report.

[d]Estimated cost of constructing a new monitoring well in the Elkhorn road area. No additional monitoring costs are anticipated beyond those incurred currently by the two counties.

[e]About 90% of this cost would be required for development and implementation of an irrigation scheduling program. The balance is the estimated cost of implementing a domestic and industrial water conservation plan.

[f]Exclusive of the cost of water supply augmentation projects.

this time due to the lack of data on the type of conservation practices that could be adopted by food processing industries in the Pajaro Valley.

Institutional Complexity. Water conservation programs can be carried out through the existing institutional structures in the Pajaro Valley. Agricultural water conservation can be promoted through the combined effort of the Cooperative Extension Service offices in each county. Domestic and industrial water conservation programs can be implemented by the City of Watsonville.

Political Viability. A water conservation program which does not impose a major burden on water users should have a high level of acceptability among the residents of the valley. A management program which would be limited to the promotion of water conservation practices, however, will not provide an adequate solution for any of the groundwater problems encountered in the Pajaro Valley.

Ranking of Alternative Management Programs

Based on the results of the preceding discussion, a qualitative ranking for alternative management plans was developed and is presented in Table 5. The parameters included in the ranking process consists of management cost, effectiveness of the proposed plan in dealing with groundwater resource related problems, institutional complexity for implementing the plan, political acceptability of the plan to water users in the basin, and general environmental impact of the plan. Quantitative rankings are assigned to each of these parameters in Table 5.

Based on the review of these parameters, the four management alternatives can be ranked in the order of preference as follows:

1. Alternative M-3. Problem Oriented Management
2. Alternative M-2. Comprehensive Management
3. Alternative M-4. Water Conservation
4. Alternative M-1. No Action

Table 5. Summary Ranking of Alternative Groundwater Management Plans

Alternative No.	Title	Management Cost	Effectiveness	Institutional Complexity	Political Viability	Potential Environmental Impact	Overall Ranking
M-1	No action	None[a]	Nill	Low	Low	Adverse	Low
M-2	Comprehensive Management	High	High	High	Low to moderate	Favorable	Moderate
M-3	Problem Oriented Management	Moderate	High	Moderate	High	Favorable	High
M-4	Water Conservation	Low to High	Low	Low	High	Moderate	Low

[a]This alternative may have significant potential long-term indirect costs which may be caused by declining water levels and sea water intrusion.

RECOMMENDED GROUNDWATER MANAGEMENT PROGRAM

The recommended groundwater management program for the Pajaro Valley (Alternative M-3) is discussed further in this section by providing a more detailed description of various elements of the management program.

Institutional Structure

Institutional mechanisms for implementing various elements of a groundwater management plan in the Pajaro Valley have been discussed in Chapters 6, 7 and 8 of this report. The recommended management plan can be implemented through the formation of a special agency or district or by joint powers agreement among existing county agencies such as the County Flood Control and Water Conservation Districts. If the existing agencies are chosen for the management program, the enabling act of these agencies would need to be modified with respect to funding mechanisms and for implementation of recharge source protection measures.

The agency selected to implement the groundwater management program must meet the following requirements:

1. Ability to operate within a multiple county service area.

2. Ability to implement a groundwater management plan and raise revenues from all water users in the basin for all activities of the agency regardless of whether such users are served by any physical facilities constructed by the agency.

3. Ability to raise funds for financing the construction of all needed facilities, research investigations and administrative activities of the agency through any of the following mechanisms:

    a. benefit assessments,
    b. user charges,
    c. revenue bonds,
    d. ad-valorem assessments, and
    e. recharge protection facility fees on new development projects.

4. Ability to enter into contracts with local, state or federal agencies.

5. Governance by an independently-elected board of directors.

6. Ability to review all new development projects in the valley for evaluating the impact of such projects on the overall hydrologic balance and on natural recharge sources of the basin and to exercise a veto power or require appropriate mitigation on such projects if the management agency determines that they would create adverse long-term impacts.

The powers of the selected management agency should be confined to the following function:

1. Conduct all routine administrative functions that are required for the discharge of the agency's duties and responsibilities.

2. Carry out all needed investigations, studies and design projects, etc., for the following purposes:

    a. better define the hydrologic and hydraulic characteristics of all aquifers in the basin,

    b. quantify the impact of development on natural recharge sources,

    c. monitor water level and quality conditions in the basins, and

    d. select appropriate sources of water supply augmentation in the basin.

3. Design and construct all required water supply augmentation facilities to serve the areas that are affected by seawater intrusion.

4. Develop approaches and standards for incorporation of recharge source protection facilities in all development projects that are proposed in natural recharge areas in the basin.

5. Design, construct and operate watershed scale recharge protection facilities in sandy watersheds of the basin to intercept and percolate into the ground any excess runoff that may be generated by existing and future land development in these watersheds.

Administrative Structure

The administrative structure of the groundwater management agency would normally evolve in relation to the responsibilities and work load of the agency. If existing agencies such as the County Flood Control and Water Conservation District are selected to implement the management program, an advantage would be gained due to the existence of an established administrative structure with extensive experience in the Pajaro Valley.

The management agency could be organized along functional lines in the manner indicated in Figure 1.

The functional areas shown in Figure 1 may require the services of one or more technical staff members depending on the speed with which these problems are addressed and depending on the complexity of

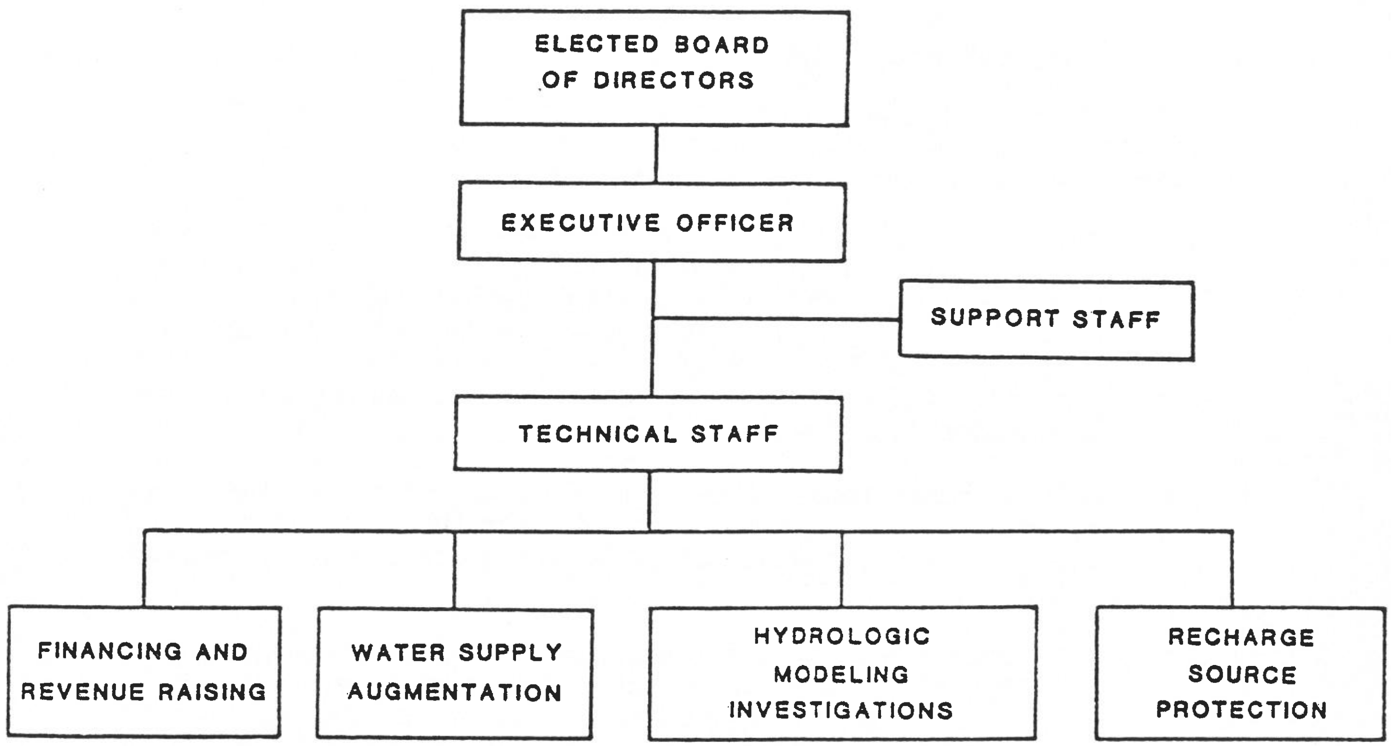


Figure 1. Suggested adiministraton structure for the proposed Groundwater Mangement Agency

the issues to be investigated in each area. Some of the needed studies and investigations could be performed through contracts with other government agencies or professional consultants under the supervision of the management agency staff.

It is suggested that initially, the management agency could consist of the executive officer, one technical and two support staff members.

Recommended Management Approach

The major tasks to be undertaken in the course of implementing the recommended groundwater management plan in the valley are discussed briefly in the following paragraphs:

1. Develop a digital model for the basin at a level of detail which would enable the simulation of water level changes under various pumping regimes in discrete subareas of the basin. The U.S. Geological Survey is currently developing a computer model for the basin. This model, once calibrated and adjusted, could most probably meet the needs of the management agency.

2. Conduct the required field studies to determine the components of the hydrologic budget for the basin. A brief discussion on the required field investigation is presented below:

   a. Determine unit and total annual crop evapotranspiration demands. The Cooperative Extension Service has been conducting field studies on the determination of crop evapotranspiration demand in the valley over the past two years. These studies should be continued until adequate data have been collected for the major crops grown in the valley.

   b. Determine unit and total annual native vegetation evapotranspiration demand. No field investigation has been carried out in the Pajaro Valley to determine evapotranspiration demands of native vegetation. Bulletin 5 of the State Department of Water Resources contains detailed estimates of the expected range of evapotranspiration demand for native vegetation. A better understanding of water use by native vegetation in the valley is needed for determining the annual volume of natural recharge in the basin. Field studies should be carried out to quantify annual water demand by native vegetation under different soil, climate and water table conditions in the valley. These studies may necessitate the use of precipitation gages, evaporation pans and soil moisture sensing devices at a number of locations throughout the valley.

c. Determine total annual precipitation and precipitation runoff from sandy and non-sandy watersheds. Accurate data on annual runoff under various soil, geologic and climatic regimes in the basin are needed for estimating the sustained safe yield of the basin. Adequate historic data on natural precipitation are available in the valley to enable the determination of total precipitation amounts without the need for extensive field data gathering. Supplemental field data would be required on runoff rates from sandy and non-sandy watersheds under existing land uses in the basin.

d. Determine the annual subsurface flow into and out of the basin. Estimates of these components of the hydrologic budget have been developed in this study and in previous investigations. These estimates, however, have been based on approximations of the relevant hydrologic and hydraulic parameters. A better definition of these parameters would be required to refine the estimates of the sustained safe yield of the basin. The digital model currently under development by USGS may provide a tool for refining the estimates of these parameters.

e. Determine annual inflow and outflow volumes from the perched water table zone. A perched water table of poor chemical characteristics underlies about 13,000 acres of land in the Pajaro Valley floor and some terrace area. Excess applied irrigation water and incident rainfall percolating into this zone constitutes an appreciable volume of water. Due to the existence of extensive clay layers between the perched table and the productive water bearing alluvium, virtually no recharge from this water body can be expected. Water level contours and water quality conditions in the productive zones appear to confirm this conclusion. An accounting for the volume of water entering the perched table zone, however, would be useful for refining the hydrologic budget estimates for the basin. This objective could be attained by developing an inventory of surface drainage discharges from this area through the Pajaro River, Watsonville Slough and other agricultural drainage courses and by quantifying subsurface outflow to the Bay and the rate of downward percolation into the underlying water bearing formations.

3. Conduct the required field studies to determine the impact of land development in sandy watersheds on the rate of natural recharge from these areas.

Field investigations carried out under this project indicate that development in sandy watersheds can lead to accelerated runoff and possible reductions in the rate of natural recharge from these watersheds. More detailed field studies are, however, needed to establish a quantitative relationship between the following parameters:

a. The extent of development,

b. relative distribution of sandy soils in the watershed,

c. annual and episodic volumes of runoff, and

d. other watershed related parameters such as slope, total annual precipitation, etc.

These investigations would require the selection of control and developed watersheds with similar soil, hydrologic, and climatic characteristics in different parts of the valley and the installation of recording gages on natural drainage outlets in these watersheds. Data for a minimum period of two years would be needed to make preliminary assessments of the impact of development on the rate and volume of runoff in these watersheds. The gaging stations should be kept in operation until an adequate data base has been developed in the basin.

4. Perform the required analysis using information gathered in the preceding steps to determine the following parameters needed for proper management of the groundwater basin:

   a. Sustained safe yield of the producing aquifers,

   b. the extent of the basinwide overdraft, and

   c. the minimum amount of supplemental water supply needed to avoid irreversible saltwater intrusion and significant drops in the water levels in the basin for projected alternative land use scenarios.

5. Develop a supplemental source of water for seawater intruded areas. Available information indicates that seawater intrusion in the coastal portions of the valley has been gradually worsening over the past 30-year period. A parallel pattern can be observed between the increased pumpage withdrawal from the basin and the expansion of seawater affected areas near the coast. Based on the results of this investigation, the following alternative sources of supply can be developed in the Pajaro Valley. These alternatives are listed below in the order of economic viability, based on the analysis carried out in this study:

   a. Local deep aquifers
   b. Arroyo Seco dam project
   c. San Felipe project (Pajaro River transport)
   d. Pescadero Creek project

Detailed information on physical facility requirements and the cost of these alternatives is presented in Chapter 6 of this report. A minimum yield of 6,500 ac-ft per year would be required as the Phase 1 of any water supply augmentation project. Additional supplies may be needed in the future depending on the effectiveness of the Phase 1 program in stemming seawater intrusion and depending on future changes in the overall rate of pumpage and natural recharge in the basin.

Due to the significant cost savings that might be achieved through the use of the local deep aquifers, the management agency should immediately proceed to investigate the viability of this source of supply by drilling a number of test wells and at least one production well penetrating the Purisima Formation in the valley floor or Springfield areas. Data collected from these wells should be analyzed to determine aquifer characteristics, water quality conditions, well yield and drawdown patterns around the production well.

Based on the results of such analysis, a determination should be made on the potential yield of the aquifer, recommended well sites, proper well spacing, depth of well, recommended perforation intervals, etc.

6. Implement a Water Conservation Program. The management agency should develop and implement a water conservation program for domestic, industrial and agricultural water users in the basin. The emphasis of all of these programs should be on the dissemination of educational materials to encourage the various water users to undertake water conservation practices on a voluntary basis. Mandatory conservation practices should also be required for all new homes, industrial and commercial facilities that are constructed in the future in the valley. A more detailed discussion is presented below on various elements of the water conservation program.

   a. Domestic water conservation. The focus of the domestic water conservation plan should be on the dissemination of educational materials to homeowners explaining the need for water conservation and distributing low cost shower head, faucet and toilet tank water conserving devices. The building codes in the valley should also be modified to require the installation of water conserving devices in all new structures constructed in the future.

   b. Industrial water conservation. An appreciable potential may exist for reducing process water use in food processing and canning industries in the valley. No specific investigations have been carried out to determine the feasibility and methods of conservation for the industry. Such studies would properly fall within the purview of the affected industries.

Currently, all industries are discharging their process wastewater into the City of Watsonville's sewerage system. These discharges are assessed a monthly fee which is based on the volume of wastewater, as well as the suspended and dissolved organic materials contained in the waste stream. These monthly charges may create an economic impetus for the industries to undertake voluntary water conservation programs.

c. Agricultural water conservation. The Santa Cruz County Cooperative Extension Service has estimated that agricultural water conservation could result in net savings of 1,200 ac-ft per year in areas underlain by a perched water table if the farmers adopt scientific irrigation scheduling procedures. Adoption of scientific irrigation scheduling would involve no added cost on the part of the farmers and the scheduling service could be provided by the staff of the management agency or the cooperative extension service at an annual cost of $100,000.

Any reduction in agricultural water use in the perched water table areas would result in improvements in the hydrologic balance of the basin because water percolating into the perched zone does not return to the underlying productive aquifers. Agricultural water conservation, however, should be encouraged on all farmed lands in the basin.

7. Groundwater monitoring. The management agency should continue the groundwater monitoring program that is currently being carried out by both county water conservation and flood control districts. These programs each include a number of wells distributed throughout the valley with the highest concentration occurring near the coast. We recommend that a thorough review of all the monitoring wells is undertaken to ensure that adequate construction details are available for each well and that a sufficient number of these wells are perforated only in the alluvium and in the underlying Aromas deposits. The elevation of the reference point of these wells should also be checked in the field to ensure the validity of the water level readings.

The current schedule of water level and quality monitoring during spring and fall is adequate for groundwater management purposes and should be continued in the future. Due to the potential for seawater intrusion into the Pajaro Valley through the Elkhorn Slough and the Elkhorn Road gap, it is recommended that one or more wells on the valley floor near Elkhorn Road be incorporated in the monitoring program.

8. Groundwater pollution control program. In general, the responsibility for water pollution control in the valley rests with the Central Coast Regional Water Quality Control

Board. This Board monitors all land use activities and wastewater treatment and disposal operations to ensure compliance with applicable state and federal pollution control laws and regulations. Currently, no discharge requirements exist for diffuse sources of pollution such as tailwater runoff or deep percolation from irrigated agricultural lands. The Regional Board, however, can issue discharge requirements for sanitary landfills, dairies, feedlot operations and any other land use activity which may generate a waste stream that would be discharged onto land or into the waters of the United States. The Board may also specify pretreatment requirements for industrial waste that are discharged into municipally-owned wastewater treatment facilities.

The Environmental Health Divisions of the two counties are responsible for monitoring and regulation of on-site wastewater disposal systems for sanitary wastes generated by residential, commercial or industrial land uses. They discharge these regulatory functions in compliance with the overall waste discharge policies and regulations of the Regional Board.

A potential source of groundwater pollution that heretofore has not been regulated in most of the nation consists of underground storage tanks and transport pipelines containing hazardous materials. These tanks are normally used at industrial plants, gasoline stations, pesticide manufacturing or formulating sites, etc. The materials stored in such tanks can vary widely depending on the type of industrial or commercial activities. Currently, the regulation of the use and disposal of hazardous substances is vested in U.S. Environmental Protection Agency through a host of federal legislations including the Resource Recovery and Conservation Act, Toxic Substances Control Act, Drinking Water Act, Clean Water Act, etc. EPA has thus far limited its regulatory effort to large uncontrolled hazardous material disposal sites. The State Department of Health Services, State Water Resources Control Board and the Regional Boards are also actively involved in the regulation and control of hazardous materials handling, treatment, and disposal activities. The focus of state activities has also been on larger handlers of hazardous substances.

Recent federal and state legislations have expanded the scope of regulatory activities to smaller producers of hazardous substances. At the State level, the California legislature has passed two laws regulating underground containers of hazardous materials. AB2013, Cortese Bill, requires the State Water Resources Control Board to compile a statewide inventory of all such containers. AB1362, Sher Bill, requires local governments to inspect and permit underground tanks. Currently, the State Board is requiring the filing of registration statements from all owners of underground tanks. No formal regulations have as yet been issued by the State Board with regard to monitoring requirements for existing tanks or on installation standards for new tanks. Both Santa Cruz and Monterey County Board of Supervisors have adopted ordinances for regulation of underground tanks. These ordinance, however, must comply with the minimum requirements to be established by the State Board in the near future.

Due to the unique hydrogeologic characteristics of the Pajaro Valley and the potential for widespread contamination of groundwater aquifers in the event of an accidental spill of hazardous materials in sandy watersheds, it is recommended that the groundwater management agency develops criteria and regulations for the design, installation, retrofitting and monitoring of all hazardous materials in underground tanks and transport pipelines in the basin.

Potential Legal Issues

Some of the potential legal issues that may arise if the proposed groundwater management plan is implemented are as follows:

1. Potential legal challenge to any hydrologic impact assessment process selected by the management agency for reviewing new development projects in the valley.

2. Potential legal challenge to requiring the incorporation of recharge protection measures in new development projects in sandy watersheds.

3. Potential challenge to levying any assessments on water users or on lands that do not receive a direct benefit from agency constructed facilities.

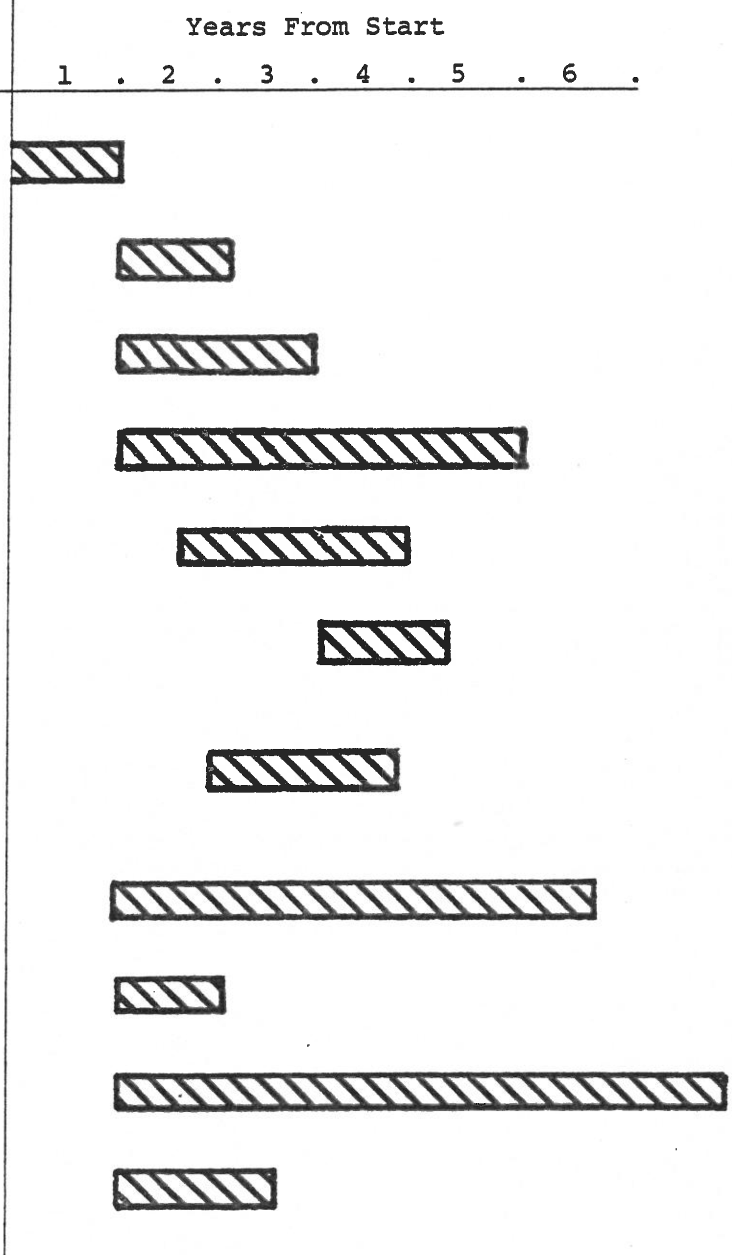
4. Possible challenges to water supply augmentation projects constructed by the agency on the basis of environmental, public safety, or water right issues.

Implementation Schedule

A suggested schedule for implementation of the recommended groundwater management program in the Pajaro Valley is presented in Figure 2. The time frame presented for various program elements is intended as a general guide and would undoubtedly be modified during the implementation process. Based on this schedule, it is anticipated that a groundwater management agency can become fully operational within two to three years after the passage of the enabling legislation depending on the institutional structure established for the agency. If an existing agency such as the FCWD is enabled by the legislature to manage the basin under the guidance of the County Boards of Supervisors, the entire program could probably be implemented more expeditiously than would be the case under an independently-run management agency. In the latter case, the agency

Figure 2. Recommended implementation schedule for the Pajaro Valley Groundwater Management Program

No.	Item
1	Establish Institutional Framework
2	Establish Administrative Structure
3	Establish Revenue Raising Procedures
4	Conduct the Required Investigations and Studies
5	Design and Construct Water Supply Augmentation Facilities
6	Develop Regulations for Recharge Source Protection in Sandy Watersheds
7	Develop Procedures for Analysis of Hydrologic Impacts of New Development Projects
8	Conduct Routine Groundwater Monitoring
9	Develop Enforcement Procedures
10	Develop and Implement Water Conservation Programs
11	Develop Guidelines for Construction and Monitoring of Underground Hazardous Material Storage Tanks



would most probably require an infusion of funds from the county governments on a loan basis to finance the organization of the administrative structure and establish revenue raising procedures for the management agency.

CHAPTER 8 - REFERENCES

Goldman, George and Marian O'Regan, Estimating Economic Impacts in California: The Central Coast Area Input-Output Model, Cooperative Extension Service, Division of Agricultural Sciences, University of California, Special Publication 3289, March 1983.

APPENDIX A

REVIEW OF WELL EVALUATION REPORT, SANTA CRUZ COUNTY,
PAJARO GROUNDWATER PROTECTION ZONE

APPENDIX A

REVIEW OF "WELL EVALUATION REPORT, SANTA CRUZ COUNTY - PAJARO GROUNDWATER PROTECTION ZONE," LUHDORFF & SCALMANINI, CONSULTING ENGINEERS, JUNE 1983"

This report was prepared under contract with Santa Cruz County Environmental Health to evaluate 22 currently active-production wells in the Pajaro Groundwater Protection Zone. Among other objectives, the study was to recommend corrective actions for wells which may be serving as a conduit for movement for poor quality water from the alluvial aquifer to the Aromas aquifer or vice versa. The groundwater protection zone has been designated by Santa Cruz County as the area in which chloride concentration in well water is equal to or exceeds 100 mg/l. The present limits of the area in Santa Cruz County are the coast line, the Pajaro River, the northern boundary of Sections 23 and 24 (T12S, R1E) and a line connecting the midpoint of the northern and eastern boundaries of Section 24.

This report appears to question the conclusions reached in all previous investigations regarding the occurrence of seawater intrusion in the coastal portions of the Pajaro Valley aquifers. Due to this factor, the Technical Advisory Committee requested a more detailed review of the report.

This report indicates that only 12 out of the 22 known wells listed by the County Health Services could be located in the field or for which water quality data and construction information could be identified. A summary of the information presented for these 12 wells in Luhdorff & Scalmanini report along with additional pertinent data are presented in Table 1.

In a discussion of groundwater quality conditions in the Santa Cruz County portion of the Pajaro Groundwater Protection Zone, this report makes the following statement:

> "The only significant water quality problem in the Santa Cruz County portion of the Pajaro Groundwater Protection Zone which could be identified on the well logs was poor quality ground water within the first 100 to 120 feet from the surface. In general, the calculated quality of this ground water ranged between 1400 and 3200 parts per million total dissolved solids. Beneath that point, water quality in the alluvial and Aromas formations was generally calculated to have TDS cocnentrations between 400 and 800 ppm. One exception was Well 9 which, in its performated interval, had a calculated TDS concentration of about 950 ppm."

We disagree with the above statement for the reasons discussed below:

Table 1. Summary of Available Data on Well Construction and Water Quality Conditions in Pajaro Groundwater Protection Zone, Santa Cruz County, California

Data Reported by Luhdorff & Scalmanini[a]							Approx. Distance from the Coast (miles)	cl, mg/l (Water Surface Elevation)[b]										
Env. Health Well No.	Assessor's Parcel No.	USGS Well No.	Well Depth (ft.)	Seal Depth (ft.)	Perfora-tions (ft.)	Chloride (mg/l)		7/70	8/71	7/72	11/74	4/75	8/75	11/75	4/76	11/76	3/82	7/82
6	52-171-20	12S1E24N1 City of Wats.	675'*	0-312*	535-675'*	260	0.5	26	--	38	50 (-1.5)	26 (-0.6)	38 --	30 (-1.0)	31 (-3.0)	49 (-8.0)	260 (-5.30)	-- --
9	52-171-20	12S1E23J4 City of Wats.	680'*	0-350*	350-380'	140-180 *	0.3	--	110	110	118	--	124	128	--	--	--	-- (-25.00)(9/81)
12	52-231-03	12S1E25F1	604'	0-400*	400-604'	94-112 *	0.4	170 --	150 --	174 --	-- (2.5)	174 (0.8)	170 --	146 (1.0)	115 (-0.2)	168 (-2.7)	170 (3.9)	160 (-8.9)
13	52-231-03	12S1E25G1 *	600'	Unk.	490-600'*	27-69 *	0.6	30	--	34	34 (0.1)	54 0.5	30 (-4.7)	30 0.3	37 (-3.2)	37 (-9.2)	51 (-6.5)	37 --
14	52-231-04	12S1E25B3 *	580'*	Unk.	495-505'*	80-190 *	0.5	--	80 --	82 --	90 (5.2)	122 (0.5)	86 (-1.8)	90 (2.2)	96 (0.2)	-- (-8.8)	160 (-2.8)	120 (-18.3)
15	52-231-30	12S1E25B1 * (G2)	174'*	Unk.	135-168'*	51	0.6	--	--	--	--	--	--	--	--	--	--	--
18	52-231-05	12S1E24Q1	600'	Unk.	Unk.	18-46 *	0.7	58	--	26	22 (2.9)	22 --	18 (-4.7)	18 (2.6)	-- (0.6)	-- (-4.9)	20 (2.0)	34 (-19.3)
19	52-231-05	12S1E24L1	163'	Unk.	147-162'	-----	0.5	--	110	86	86 (0)	-- (0.2)	70 (-4.2)	-- (1.4)	-- (4.6)	75 (-6.1)	61 (0.70)	130 (-10.00)
21	52-231-06	12S1E24H1 *	510'*	0-270*	360-380'* 470-500'	-----	1.0		--	--	--	--	--	--	--	--	(180(7/81) (-13.0)E	20 (9/81) (-14.46)
23	52-231-07	12S1E24L3	196'	0-80*	120-165'*	52-83 *	0.8	--	450 --	466 --	-- (0.2)	-- (-1.8)	402 (-4.2)	338 (0.3)	392 (-4.7)	357 (-4.7)	54 (-0.80)	62 (-12.50)
27	52-171-20	12S1E23R1 *	220'*	Unk.	190-220'*	-----	0.14	34	--	58	98	114	118	130	143	160	310(10/78) --	310(8/79) (0.0)
31	52-181-15	12S1E24G1	180'	Unk.	144-160'* 40-160'	1100	0.90	30 --	-- --	58 --	-- (-3.30)	90 --	118 (-6.0)	114 0	98 (-5.5)	207 (-6.5)	850(7/79) (-17.8)	1100(9/81) (-9.33)

a Supplemented by additional information on well no., depth, chloride level, etc. by HEA as indicated by an asterisk.

b In feet with respect to mean sea level.

1. The first 100 to 120 feet of the sediments in the intruded areas of Pajaro Valley floor in Santa Cruz County is composed predominantly of thick layers of stiff, plastic "blue" clays described in nearly all well logs that are available for this area. These clay layers act as a barrier to the movement of water in any direction.

2. The upper zone (120 feet) fo the alluvial formation does not yield any significant quantities of water and none of the existing known productive wells are perforated in this zone.

3. Any downward percolation of poor quality shallow perched water and of any water which may be contained in the pore space of this zone is extremely slow and could not account for degradation of water quality in wells that are perforated in deeper zones.

4. The blue clays extend from the coast northward and eastward beyond Watsonville. Waters of comparable salinity are found above the clays throughout the valley. (HEA, 1978). Deteriorating water quality is found beneath the blue clays only in the area near the coast, even though greater drawdowns are observed in the Watsonville area.

5. Saline waters have been reported in and above the blue clays since the shallow zones were first tested in 1908 and 1951. Yet deterioration in water quality in the aquifers near the river mouth has been observed since the late 1960's and early 1970's, when piezometric levels began to remain below sea level for much or most of the year.

6. The ionic composition of waters above and below the blue clays are markedly different. Any appreciable leakage from the clays would be reflected in waters with more similar balances of ions.

Available data on groundwater quality condition in the area discussed in this report indicate a gradual deterioration of quality over time both in the alluvium and Aromas aquifers. A review of data shown in Table 1 provides adequate support for this conclusion. None of the 12 wells listed in this table are perforated within the first 120 feet from the surface. All the logs of the wells for which the seal depth is known indicate that the drillers tend to seal the well down to or slightly above the uppermost perforations. Accordingly, poor quality conditions in wells ranging in depth from 150 to 680 feet cannot be attributed to poor quality water in the top 100 to 120 feet of the formations consisting mostly of clay materials.

The report by Luhdorff & Scalmanini appears to consider only one or two points in time in making conclusions with regard to water quality conditions in the groundwater protection zone. For example, the report makes the following statement with regard to Well 12S/1E-24G1 (County Well No. 31).

"This well has experienced the most dramatic change in water quality. 1971 data included electrical conductivity of 554 micromhos/cm. and 36 mg/l chloride. There is no data between 1971 and 1978, but since then electrical conductivity has been reported up to 4,000 micromhos/cm. and chlorides up to 1,200 mg/l. There is no one obvious explanation for the major change in groundwater quality in this well. There are other existing wells of similar depth and completion interval (County wells, 2a, 15, 19 and 23) which are closer to sources of poor quality water, i.e. Monterey Bay and the tidal reaches of the Pajaro River, but which continue to produce good quality water. On that basis, it can be concluded that the entire aquifer system in the 140 to 185 foot depth interval has not been intruded with seawater. Two possible explanations for the quality deterioration in Well 31 are as follows. One, the well has possibly experienced casing failure in the upper 120 feet, as described in the log response above. The poor quality waters in that shallow zone, described in the next section, are consequently contaminating the well. Two, the nature of alluvial deposits in the area could be channelized. If so, Well 31 could be completed in a highly permeable channel which is hydraulically connected to the Bay or tidal portion of the River. Slightly depressed water levels could thus have resulted in more rapid landward flow of poor quality water through the permeable channel while other wells of similar depth remain relatively unaffected outside the channel."

Several comments should be made with regard to this paragraph:

1. As indicated in Table 1, this well has been monitored on a regular basis during the 1971-78 period.

2. Water quality conditions in this well deteriorated gradually from 1970 to 1976. Data for 1979 indicate significant increase in chloride concentration and a large drop in water level elevation. The latest available data for 1981 show a continuing increase in chloride concentration in spite of some recovery in the water level elevation.

3. Water quality conditions observed in county wells No. 19, 23 and 31 as indicated by data presented in Table 1 provide clear evidence of seawater intrusion in the basal gravel aquifer in the groundwater protection zone. These wells which have all been monitored regularly since 1970, show a fluctuating but generally increasing trend in chloride concentration and a generally direct relationship between chloride levels and water level elevation in the well.

Other data presented in Table 1 indicate that deeper formations in the groundwater protection zone are also affected by seawater intrusion. This impact can be observed in the 190-220 foot interval for County Well No. 27 (12S/1E-23R1), in the 350-380 foot interval, for County Well No. 9 (12S/1E-23J4: City of Watsonville Well 13), and in the 400-675 foot interval for County Well Nos. 6, 12, and 14. All of these wells show elevated chloride levels above normal background concnetrations, increasing trends in chloride concnetration with time, and increasing trends in the decline of watêr level below sea level. Even Well Nos. 13 and 18 which currently yield good quality water appear to follow the trend of other wells in this area.

APPENDIX B

RECONNAISSANCE ASSESSMENT OF POTENTIAL
WATER SUPPLIES FROM DEEP AQUIFERS, PAJARO VALLEY

APPENDIX B

RECONNAISSANCE ASSESSMENT OF POTENTIAL WATER SUPPLIES FROM DEEP AQUIFERS, PAJARO VALLEY

Introduction

The Pajaro basin has been gradually subsiding for the past 6 million years relative to surrounding uplands. Sediments have accumulated to depths of 1500 to 3500 feet throughout much of the valley floor and foothill areas. An additional 500 to 1000 feet of slightly older sandstones and shales, a sequence known to yield developable water in nearby areas, underlies these deposits in the central, southern, and far western portion of the basin.

Few water wells in the Pajaro basin are deeper than 700 feet. Potentially, additional water supplies may be drawn from the remainder of the sedimentary units above the basement of granitic and consolidated sedimentary rocks.

In recent years, several wells in the lower Salinas Valley and near Moss Landing have been successfully developed at depths of about 1200 to 1800 feet.

Initial Intent of the Task. The initial intent of this subtask was to explore the feasibility of developing the "deep aquifers". At the inception of the management study, we knew that a few new wells were being developed nearby, that the quality was likely to be problematic and might only be suited to agriculture, and that the capital and operations costs were likely to be appreciable. The approach to be taken in assessing the deep aquifers emphasized cost comparisons with other water-supply sources in the basin.

The analyses in Chapter 6 of this report have established that costs of water pumped from deep aquifers can compare favorably with surface and conjunctively-managed supplies. Provided that yields of 2000 gallons per minute (gpm) were sustained and that the quality of water were suitable, waters from the deep aquifers might be developed at costs of $44 per acre foot. These values apply to production at the wellhead; no distribution costs are included in this unit cost. Other questions such as the occurrence and groundwater quality can now be addressed at a level commensurate with the reconnaissance nature of this task.

Since the inception of the management study, detailed investigations of deep aquifers have been authorized by Monterey County and the Soquel Creek County Water District. We have attempted to integrate some new data developed in these studies into the groundwater-management planning process in the Pajaro basin. Neither study, however, will be completed before the conclusion of the 208 program.

The Monterey County Flood Control and Water Conservation District has been evaluating the groundwater potential of the deep aquifers in selected areas. Much of this work has been done by geologist Richard

Thorup, who is completing a reconnaissance assessment of the entire deep zone system south of the Pajaro River. He has courteously provided an abstract of his findings prior to publication so that this work may be considered in the Pajaro Groundwater Management Study. He concludes that the deep aquifers are of regional extent. They are found along the eastern side of the Salinas Valley from San Ardo to Marina and the Springfield area, continuing beneath the bay to outcrop along the upper walls of Monterey Canyon. It is his view that the characteristic sand horizons extend beneath the Pajaro Valley, possibly into the Aptos area. Between Chualar and the coast, the environment in which the sediments were deposited changed from primarily alluvial (Paso Robles Formation) to predominantly marine (Purisima Formation). Both formations lie above the Miocene marine shales (Monterey Formation), which contains water thought to be saline. In all of the fourteen wells in Monterey County developed solely in the deeper aquifers, water quality is either Class I or in the high quality range of Class II irrigation waters. The zones are recharged primarily from the Salinas River and secondarily from rainfall. He estimates that percolation from the Salinas River and through the alluvium averages 65,500 acre feet per year.

Scope of Work. In keeping with the reconnaissance nature of this study, five analyses covering a range of issues were conducted. First, existing borehole data for wells and test holes penetrating the deep aquifers were collected and interpreted. The available data includes geologic and geophysical logs for approximately fifteen test holes drilled by various oil exploration companies, plus about ten drillers' and/or geophysical logs for water wells surrounding the Pajaro Valley. Second, repository data for samples, cores, and cuttings drawn from the exploratory test holes were collected and analyzed. Third, the sedimentologic variations within the principal water-bearing units were described, using recent reports or unpublished data. Particular emphasis was placed on lateral variations in the Aromas and Purisima Formations, based in part on inferences regarding the sources of sediment comprising these formations. Fourth, the hydrogeologic and water quality information developed during the past several years from new wells in the deep aquifers were summarized. Finally, relationships between recharge and water quality were considered.

Geology

"Deep aquifers" in the Pajaro Valley are water-bearing sands occurring at depths greater than those presently developed for groundwater (about 700 feet). The water-bearing zones are part of two or three formations which occur throughout the eastern Monterey Bay area, both onshore and offshore. These include the lowermost part of the Aromas Formation, and various sandy horizons occurring within the Purisima Formation (Figure 1). Data from northern Monterey County indicate that the Santa Margarita Sandstone may be a significant water-bearing unit in that area, and similar units appear to extend into the southern and eastern portions of the Pajaro basin. Sedimentary textures usually vary both laterally and with depth within each formation.

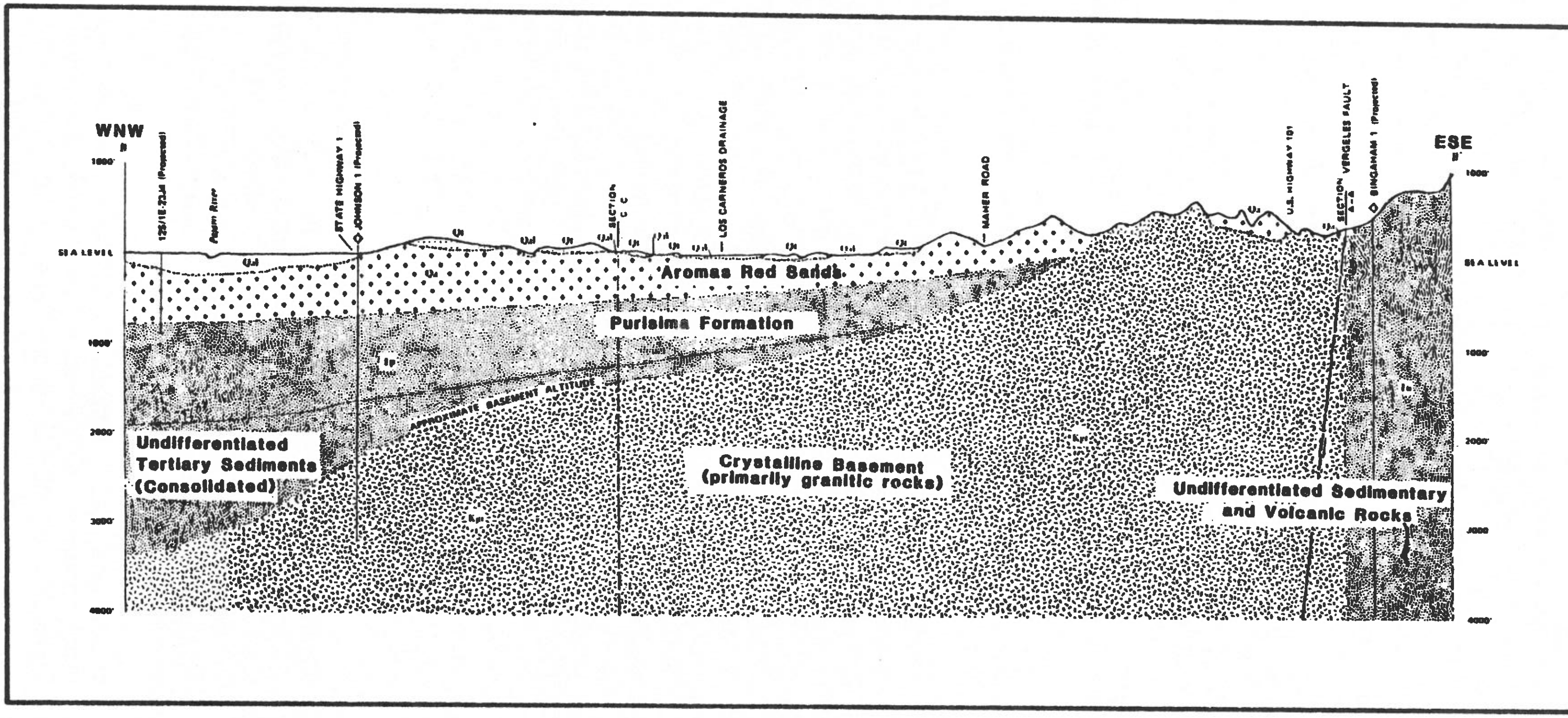


Figure 1. Geologic Section Through the Southern Pajaro Basin. The deep aquifers incorporate the Purisima and lowermost Aromas Formations. The undifferentiated Tertiary deposits are considered to be non-water-bearing, except for the upper 50 to 250 feet, which may be Santa Margarita Sandstone. Section extends from intersection of San Andreas and Beach Roads eastward and slightly southward to Highway 101 near Dumbarton Road. From Johnson, 1983.

Lower Aromas Formation. The Aromas sediments are shallow marine, estuarine, dune, and stream deposits. They grade southward into the coarser Paso Robles Formation, primarily continental stream and fan deposits. To the north, they gradationally overlie the uppermost Purisima sediments. In exposures along the coast near Aptos, no sharp changes in textural or structural characteristics are evident (R. Stuart, pers. comm.); discontinuities are more easily recognized inland along the mountain front, but still might be considered slight.

The Aromas sediments are primarily of granitic origin. At least three major source areas may be recognized:

a) From the northwest, as Sierran and Santa Cruz Mountains debris introducted by littoral or longshore processes.

b) From the east, as streamborne materials discharging from precursors to the Santa Clara and Hollister Valleys (Dupre, 1975).

c) From the south and east, as debris from the proto-Salinas River and other local drainages.

The Aromas sediments were deposited during multiple rises and falls of sea level (Dupre and others, 1980). Sharp discontinuities within the formation are common. Nonetheless, the formation appears to become finer toward the center of the Pajaro basin, the area most removed from sources of coarse debris. The limited available data suggest that estuarine deposits (generally with poor aquifer properties and water quality) are prevalent beneath Larkin Valley and the Chain of Lakes (HEA, 1979). Test holes drilled for the City of Watsonville and other wells have confirmed a predominance of clays in these areas to depths to 600 feet or more. Aromas sediments at the basin periphery tend to be coarser and yield more water. North of the Pajaro River, wells in the coastal areas underlain by the Aromas Formation traditionally have much higher yields than their inland counterparts, perhaps reflecting a supply of sand-sized material transported along the coast (HEA, 1978). Similar material may extend beneath Monterey Bay, where the Aromas Red Sands outcrop on the north side of Monterey Canyon for a distance of three to eight miles west of Moss Landing (Greene and Clark, 1979).

The Aromas sediments are 300 to 800 feet thick throughout most of the Pajaro basin. They are found to depths of about 500 to 900 feet below sea level beneath the Pajaro Valley floor, where they are partly developed. A large area of the formation remains essentially unexplored to the north and west of the valley, to the vicinity of Harkins Slough. The City of Watsonville has recently been developing a pioneer well in this area.

The Aromas aquifer is a likely important pathway for recharge of the deeper sediments, both onshore and beneath Monterey Bay. Purisima and other sediments beneath the Aromas sands are often hydraulically non-continuous with Aromas sands and frequently are separated by barriers of fine-grained sediments, but lateral discontinuities and erosional surfaces probably allow exchange of waters (Figure 2), particularly when viewed from a basin-wide perspective.

Purisima Formation. The Purisima Formation includes a wide range of detrital sediments derived from several sources under diverse environmental conditions. Consolidated and partly-consolidated siltstones, sandstones, and shale predominate north of the Pajaro Basin. Partly-consolidated sandstones and siltstones are prevalent to the south. The types of sediments vary by location and with depth, sometimes considerably.

Recent paleomagnetic studies indicate that the local Purisima sediments were deposited through a period of about four million years (Figure 1). The general structure and physiography of the Monterey Bay area evolved during this period, including initial uplift of the present Santa Cruz Mountains and Gabilan Range, and continuing uplift of the Santa Lucia Range. Both the Pajaro and Salinas structural basins first assumed their modern forms as Purisima sediments were deposited.

The variability of the Purisima sediments reflects deposition in a dynamic basin during a period of active faulting and accelerating deformation. Multiple sources of sediment affected the rates and locations of deposition, particularly of the lowermost and upper parts of the unit. Sea level fluctuated in response to global climatic patterns,with the magnitude increasing during the latter stages of Purisima deposition. Recent work indicates that deposition was periodically interrupted, commonly with some local erosion.

Recent interpretations establish that the Purisima sediments were deposited in progressively shallower environments. The oldest may be continental slope or perhaps bathyl deposits, followed by deposits representative of outer and inner continental shelf, near-shore, and tidally-influenced environments. (e.g., Stuart, in press; Greene, 1970; Greene and Clark, 1979). Generally, the most uniform sediments in the sequence are those interpreted as shelf deposits. The relatively thick deposits of sand found in the middle part of the depositional sequence generally produce the greatest groundwater yields in San Mateo County and in the Soquel Aptos area. Some of the more permeable members beneath Castroville and Marina formed in portions of the shallow-water zones where coarse sediments delivered from the then-growing Salinas Valley drainage network and erosion of the Santa Lucia Range sediments delivered from nearby continental sources were being deposited.

Five subdivisions or members within the Purisima Formation are recognized in San Mateo County, where the unit has been most closely studied (Cummings and others, 1962). Hickey (1968) recognized three informal subdivisions in the Soquel-Aptos area. The coarsest sediments, producing by far the highest yields, are in the central third of the formation. Greene (1970) identified seven members in the Purisima-age offshore sediments in northern Monterey Bay. No subdivisions are explicitly recognized in northern Monterey County, although it is generally recognized that the lowermost and upper parts of the formation are coarsest and produce the greatest yields.

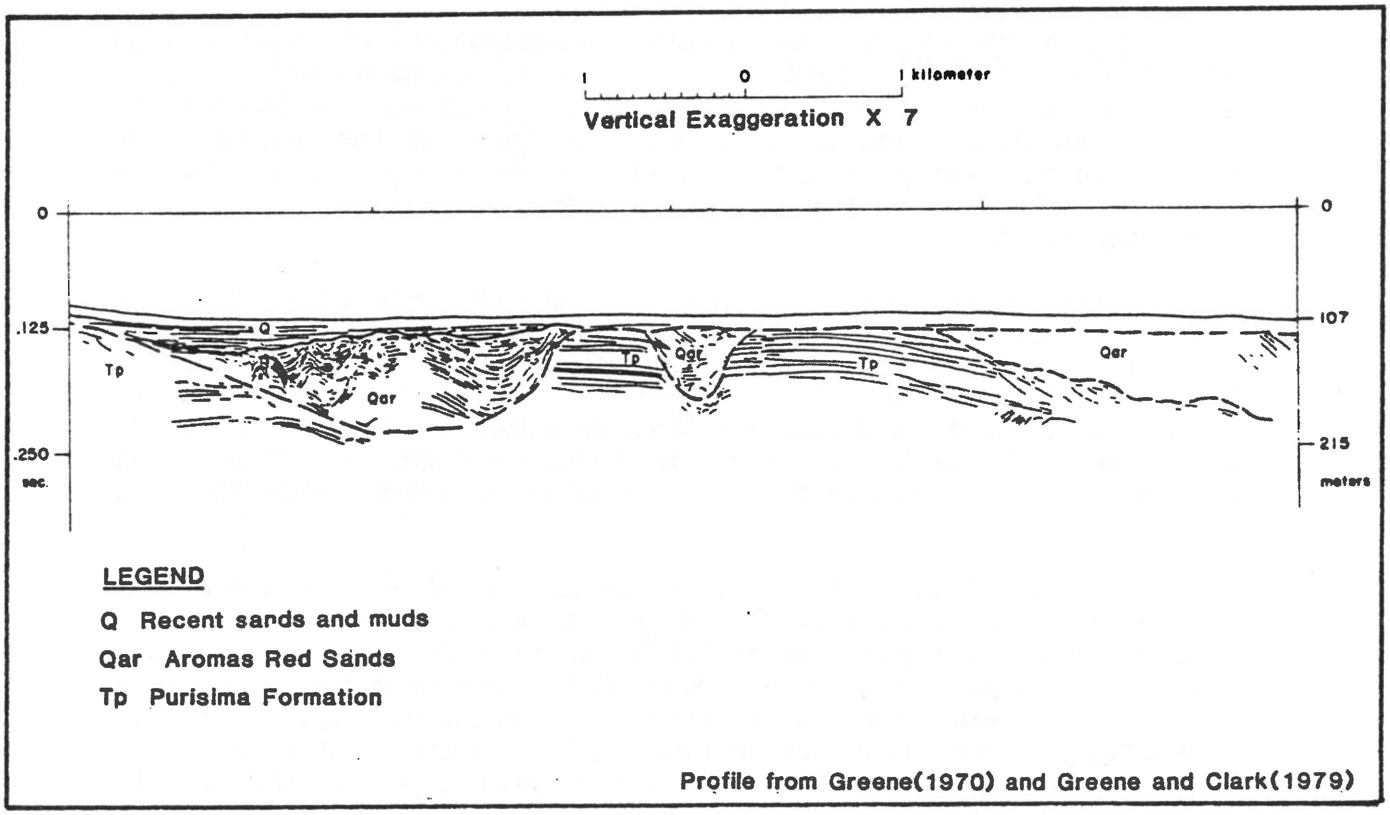


Figure 2. Relation of Purisima, Aromas, and Recent Sediments Beneath Monterey Bay. Interpretive line drawing of high-resolution seismic profile shows dune, stream, and estuarine sediments of the Aromas Formation within valleys cut into the upper Purisima sediments. Exchange of groundwater between the two is likely. The extent to which this system is isolated from Monterey Bay waters by about 25 feet of silts, sands, and clays remains to be established. Section parallels coast approximately 2.5 miles offshore, between Sunset and Zmudowski Beaches.

These descriptions of the stratigraphy and locations of water-bearing units within the Purisima sediments are disparate and partly conflicting. They significantly complicate any evaluation of the formation's potential as a source of water, as very few wells have been drilled in the Pajaro Valley area. The existing geologic data do, however, suggest certain valley-wide or regional trends. Generally, the properties of the lowermost sediments strongly reflect the rocks on which they were deposited. The coarsest and most potentially-productive water-bearing zones are found where the underlying material is sandstone or various granitic rocks; fine-grained siltstones and mudstones are prevalent where the lower Purisima overlies Monterey shale and older shales and mudstones. Marine sediments largely derived from volcanic terrains dominate the central part of the formation. These are coarsest and bear most water in the northern part of the basin, nearest the probable sources. Sands which entered from the southeast and south form the coarsest and most permeable units in the upper part of the formation. As these trends are critical to understanding the basin, they are further described in the following four paragraphs.

First, the character of the lowermost Purisima sediments varies considerably throughout the area. At Santa Cruz, where the Purisima sediments are exposed overlying older mudstone, the lower several hundred feet of the formation are fine-grained and diatomaceous. They are only slightly water-bearing, and (at least locally) contain water of poor quality (Muir, 1980; Hecht and others, 1982). The lower zones of the Purisima are also rich in silt and clay in the Corralitos area, where deposition was on top of older fine-grained sediments. Elsewhere, the lower zones consist largely of medium to coarse angular sands, which bear significant amounts of water, sometimes of excellent quality. These are areas in which the lower zones seem to reflect abundant local availability of sand from the underlying granitic rocks or arkosic sandstones. In many areas, the lower part of this relatively coarse sequence may be composed of Santa Margarita sediments.

Second, sands of volcanic origin are common or predominant components of the water-bearing zones in the Purisima Formation, particularly north of Monterey Bay. Studies in San Mateo County established that volcanic sands were deposited principally from the north (e.g., Beaulieu, 1971); a similar source is suggested by the work in the Soquel and Aptos areas, summarized by Hickey (1968)*. From well logs and descriptions of sidewall samples, it appears that sizes of the volcanic sands generally decrease southward from San Mateo County to Aptos and Marina. The proportion of the water-bearing zones with

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* The volcanic sediments probably originated mainly from erosion of the extensive Miocene and Pliocene andesites of the Sierra Nevada, with contributions from the Pliocene volcanic cetners in Sonoma County and the Quien Sabe area of San Benito County (Beaulieu, 1971). Another secondary source may have been erosion of the volcanic units and derivative sediments north of the Vergeles Fault.

prevalent volcanic sands and silts also appears to decline from about 90 percent in San Mateo County to the Soquel-Aptos area (about 65 percent in the Camp McQuaide borehole, T12S/R1E-11M1), to probably less than half in the Monterey County and Marina wells. It is uncertain whether significant volcanic sands are present at all in the Paso Robles and Purisima sediment beneath Salinas and to the south.

Third, much of the sediment deposited in the Purisima originated from the southeast, as the present-day Salinas Valley began to develop. The amount and coarseness of the sediment contributed from this source decreased northwestward toward the center of the basin in the Pajaro Valley. Sediment delivery from the southeast seems to have gradually accelerated over the period during which the Purisima sediments were deposited.

Fourth, the axis of the Salinas has moved progressively west and south since the valley began to open. The axis of the valley was considerably to the north and east during late-Purisima times, perhaps along the present lower slopes of the Gabilan Range (Dohrenwend, 1979; Greene and Clark, 1979). The smaller precursors to the present Salinas River probaby entered the Purisima sea east and southeast of Prunedale. The thick lenses of permeable sands which often develop at the mouths of streams seem to rapidly become finer to the west. These thicker sand units capable of sustaining production wells are more likely to be encountered in the upper Purisima sediments in the southern part of the basin, generally within Monterey County.

Hickey (1968) evaluated the water-bearing potential of the entire Purisima Formation in the Soquel-Aptos area. He concluded that the "B" or middle unit exhibited the most favorable aquifer properties, although these diminished toward the east. He also found that specific capacities of about 4 gallons per minute per foot of drawdown were typical of the "C" or upper unit in the Aptos area. Using a somewhat different approach, consultants to the Soquel Creek County Water District have assessed the water-bearing properties of the aquifer based on an assumed transmissivity of about 12,000 gallons per day per foot of aquifer width (Luhdorff and Scalmanini, 1981). The two sets of findings are broadly consistent. Somewhat higher values are reported from Monterey County wells developed in the deep aquifer, although the coarsest and seemingly most productive zones occur in the non-marine Paso Robles sediments which interfinger with and partially overlie the Purisima Formation.

One of the more complete test hole evaluations available for the region was conducted by Texaco at the Camp McQuaide prospect (12S/1E-11M1). Located on the present grounds of the Monterey Bay Academy near Sunset Beach, it was situated midway between the Soquel-Aptos and Monterey County areas. The tests emphasized two zones in the middle part of the unit where minor oil staining had been found, and where the geophysical logs suggested that moderately-favorable reservoir properties might occur. Results (analyzed and compiled in Table 1) suggest that relatively high permeabilities and porosities may be anticipated, at least in the coarser zones investigated by the petroleum companies.

Table 1. Properties of Middle Purisima Sediments, Camp McQuaide Prospect[a/], Texaco Blake #1[b/]

Sample No.	Depth (ft.)	Sediment Type	Porosity (percent)	Permeability (millidarcies)	Chloride Concentration (mg/l)
1	1650.5	Gray Clayey Silty Sand[e/]	24	373	—
2	1652.5		28	330	9780
3	1653.5		25	128	—
4	1655.5		27	205	—
5	1656.5		26	169	9610
6	1658.5		32	23	—
		Mean	27.0	205 md	9670 mg/l
		Approx. Hydraulic Conductivity[g/]		2.5-5 gpd/ft²	
7	1860.5	Grayish Green Sandy Shale[f/]	30	1090	—
8	1863.5		25	201	10430
9	1866.5		26	127	—
10	1868.5		28	1135	—
11	1876.5		36	1670	—
12	1879.5		34	1310	7980
13	1882.5		30	1325	—
14	1885.5		28	261	—
15	1888.5		29	896	10290
16	1891.5		30	1385	—
		Mean	29.6	940 md	9570 mg/l
		Approx. Hydraulic Conductivity[g/]		11-22 gpd/ft²	

a/ Located in Sec. 11, T12S, R2E, presently Monterey Bay Academy. Total depth = 2463 feet.

b/ Data from geologist's log. Schlumberger sidewall reports and Core Laboratories reports (Texaco, 1953)

c/ Laboratory estimate from sidewall percussive samples; should be considered qualitative.

d/ From free-draining water in sidewall percussive samples.

e/ Composed of 50-80 percent fine to coarse sand; 10-30 percent very fine sand; 10-20 percent clay.

f/ Composed of 80-90 percent medium to dark gray-green soft shale; 10-20 percent sand and silt.

g/ Adjusted to assumed field temperature of 74°F, based on geothermal gradient of one degree Fahrenheit per 100 feet of depth. Water temperatures near Marina have been warmer (reported 87 to 90 degrees) which would increase the effective hydraulic conductivity.

Results from the Camp McQuaide test hole are compared in Table 2 with similar tests conducted on boreholes in the Castroville and Marina areas of Monterey County. Only the clearly marine portions of the Pliocene sequence tapped by these wells were included in the comparison. As with petroleum exploration, the samples from these deep wells are strongly biased toward the most-permeable sediments found in the sequence. The tests from the Camp McQuaide prospect suggest porosities slightly lower than those in the Monterey County wells, with roughly equivalent permeabilities. The omitted Monterey County samples, from the sandier onshore Paso Robles sediments, were commonly two to three times as permeable and had porosity values averaging about two percent greater. It should be noted that these test results are only approximations (particularly for permeabilities), and that they pertain to the more favorable zones in the sequence.

Perhaps the greatest of all uncertainties regarding the potential of the Purisima aquifers is the quality of water likely to be found. Hickey (1968) concluded that quality of waters in the various zones of the Purisima sediments in the Soquel-Aptos area decreased with depth. The same pattern holds true for some, but not most, of the Monterey County wells. Hickey and virtually every subsequent evaluator of water-development potential have noted that the Purisima, sediments originally contained salt water, and that the present quality of waters drawn from these units depends upon the extent of subsequent "flushing." Virtually all salts have been replaced within the aquifer in the Monterey County wells. The concentrations of chloride reported from the Camp McQuaide well are approximately half of those found in sea water, so the degree of flushing is considerably less beneath at least portions of the Pajaro basin. Electric logs of several oil test holes northwest of Freedom suggest that the middle and lower Purisima Formation may contain relatively saline water some distance inland from the coast. It is possible that salinity gradients toward the center of the Pajaro basin exist from both the Aptos and Salinas Valley limbs of the basin throughout much of the sequence of Purisima sediments. If true, exploration of these aquifers toward the southern edge of the Pajaro basin would be indicated.

Santa Margarita Formation. Underlying the Purisima Formation and its equivalents are the Santa Margarita and Monterey Formations. The Santa Margarita Sandstone is an aquifer of regional significance. Typically 50 to 250 feet thick, the Santa Margarita sands normally produce water of excellent quality (HEA, 1982; Muir, 1982). The Monterey Formation, primarily composed of mudstones, shales, diatomites and occasional sand stringers, is widespread throughout coastal California. The formation thickens from several hundred feet beneath the Watsonville area to several thousand feet beneath Monterey Canyon and the Salinas Valley. The Monterey Formation is not known to yield water in quantities significant to agriculture; waters drawn from this unit often contain excessive concentrations of sodium, chloride, sulfate, cadmium and total dissolved solids (H. Esmaili & Associates, 1978). We consider the top of the Monterey shales to be the base of the developable water-bearing sedimentary sequence. This occurs at depths of about 1500 to 2500 feet beneath most of the basin.

Table 2. Regional Variability of Estimated Porosity and Permeability in Purisima Sediments, Eastern Monterey Bay Area[a/]

Well Name	Texaco Blake #1		Fontes #1	Marina #10
Well Number	12S/1E-11M1		14S/2E-22	14S/2E-32
Area	San Andreas		SE of Castroville	Marina
Depth Interval, (Purisima & related sediments[b/])	1100-2350[c/]		1250-1675	995-1550+
	Gray Silty Sand	Gray-Green Sandy Shale		
Sidewall Samples				
Number	5	10	7	5
Depth Range(ft.)	1650-1660	1850-1900	1274-1610	1049-1480
Porosity				
Mean (percent)	27.0	29.6	28.6	32.6
Range (percent)	24-32	25-36	24-33	29-38
Permeability				
Mean (millidarcies)	205	940	730	520
Range (millidarcies)	23-373	127-1385	280-1190	210-890
Estimated Hydraulic Conductivity (gpd/ft^2)	2.5-5	11-22	8-15	5-10

a/ See footnotes, Table 1 for explanation of parameters.

b/ May include Santa Margarita Sandstone; excludes Paso Robles sediments in Fontes and Marina wells (stratigraphy of Thorup, 1976).

c/ Approximate.

The Santa Margarita aquifer may be a developable source of groundwater supply for the Pajaro Valley floor. It would likely be developed in combination with the basal Purisima and other "deep" aquifers. There are major uncertainties regarding the extent of the unit, its aquifer properties, and the quality of water likely to be produced. The best available data are for wells five to ten miles away. An exploratory program focused on these lowermost of the developable units will be necessary before the amount and quality of water can be established.

The Santa Margarita Sandstone outcrops in the Branciforte Creek drainage northwest of the Pajaro basin and south of Fort Ord and elsewhere in Monterey County. The sands are rich in quartz and other granitic material; volcanic debris is almost entirely absent. Drillers recognize the Santa Margarita as a "white", "beach" or "granitic" sand, contrasting sharply with the typically blue, green, or grey and siltier Purisima sandstones, often rich in volcanic debris.

In much of the Soquel, Aptos, and Corralitos and Prunedale areas, the Santa Margarita is not clearly recognized from the fragmentary evidence available. It is possible that the unit is absent in these areas, due perhaps to erosion prior to deposition of the lower Purisima. Significant thicknesses of medium and coarse angular, white sands (which we interpret as possibly Santa Margarita sandstone or equivalent) occur in the other northern Monterey County wells, in oil test holes in the Elkhorn Slough area, and probably in some exploratory holes in southern Santa Cruz County.

Water quality in the Santa Margarita aquifer, where known, is generally excellent. Where the unit is extensively developed, total dissolved solids concentrations are commonly 100 to 250 milligrams per liter (mg/l). Developed parts of the Santa Margarita, however, are shallower and are generally near the areas of recharge. Water quality probably deteriorates with distance from the recharge area. It is therefore very difficult to project the quality of waters drawn from the Santa Margarita sediments beneath the Pajaro Valley floor. We note that total dissolved solids in samples from several northern Monterey County wells developed partially in the Santa Margarita are in the range of 500 to 800 mg/l. If these samples are characteristic of waters from this aquifer, we may speculate that the recharge area might be in the vicinity of Fort Ord, or about 8 to 12 miles to the south. Wells in the Pajaro Valley would penetrate the Santa Margarita where the probable recharge area is somewhat further, and waters might be of somewhat poor quality. Additionally, the path and extent of recharge from the Santa Cruz Mountains is not clear. The only applicable data are indications of high-quality waters occurring in the basal Purisima aquifer (identified in Soquel Creek County Water District's exploration program; see below), suggesting that the Santa Margarita sands beneath the valley may receive recharge from the north.

Recent Wells Developed in the Deep Aquifers

During the past four years, several wells and test holes have been developed in the deeper aquifers. Most of these wells are in the general area of Castroville and Moss Landing. Two wells are situated in the Aptos/Corralitos area. These wells and test holes are an important new set of data describing deep-aquifer potentials.

1. Well No. 14S/2E-6L1 (Monterey County's "Castroville Well"). This test hole was commissioned by the Monterey County Flood Control and Water Conservation District specifically for the purpose of exploring the "deep aquifer" potential. The stated intent in drilling was "to determine if the (Castroville) Service Area could provide groundwater from within its own borders from the deep zone to fulfill the requirements of the area". It might serve as one example for possible future exploration of the deeper aquifers in the Pajaro area.

The borehole penetrated to about 1700 feet, and was eventually developed with perforations at 860 to 1540 feet. The perforated interval includes multiple sand units in what is believed to be the Paso Robles and/or Aromas Formations, and the Purisima and Santa Magarita Formations. The well was initially artesian, with water rising several feet above the casing. During pump tests at 2100 gallons per minute in 1977 and 1979, stablilized drawdowns of 164 and 132 feet, respectively, were observed. Specific capacities in these two tests were about 12 and 16 gallon per minute per foot of drawdown, comparable to specific capacities observed in many wells developed in the Aromas aquifer of the Pajaro Valley. Reported specific conductances of samples from this well have ranged between 800 and 900 umhos/cm; estimated concentrations of total dissolved solids might be 500 to 600 mg/l.

2. Well No. 13S/1E-36J1. (Coastal well, about one mile west of Well No. 14S/2E-6L1). This well, used for domestic supply, was constructed by deepening an existing intruded well originally developed in the 400-foot aquifer. Its present depth is comparable to the County's well. Specific conductance of samples from the well were about 800 umhos/cm when the well was completed in 1977, and have fluctuated between 1040 and 1200 umhos/cm in six subsequent analyses. The increase may be attributable to leakage through the grouted well seal (Taylor, 1983).

3. Well No. 13S/2E-19Q3. (Well between Moss Landing and Castroville, near Molera Road). This 1600-foot well, drilled in 1980, is perforated at depths of 1220 to 1550 feet. The well was originally tested at 1500 gpm, with a stabilized drawdown of 235 feet. The apparent specific capacity is about 6.4 gallons per minute per foot of drawdown.

Partial water-quality analyses have been reported for eight separate dates, beginning with well development:

Date	Specific Conductance (umhos/cm @ 25° C)	Chloride (mg/l)
1980	1190	248 developing
1980	1065	210
Spring 1981	1100	218
August 1981	1040	194
May 1982	1200	245
June 1982	1140	225
August 1982	1065	210
October 1982	1380	300

Variations in water quality is apparent, and may be due to leakage from the upper intruded zones (Taylor, 1983).

Of some interest is that the electric log for this well suggests that water quality improves gradually with depth over the deepest 1000 feet of the well.

4. The Soquel Creek County Water District is extensively studying the water-supply potential of the entire Purisima sequence in the Soquel and Aptos Creek drainages. Among the exploratory and monitoring wells developed by the district are two deep boreholes relevant to the Pajaro basin. The first, in the hills north of Cabrillo College, was drilled to granitic basement at approximately 1600 feet. No water-quality data are yet available. The second is located at the Central Water District maintenance yard (11S/1E-4Q), and has a total depth of about 1750 feet. At the base of this well there is a sandy zone which the project geologist considers to be characteristic of the lowermost Purisima Formation. Concentrations of total dissolved solids in samples of water thought to be representative of this lower zone are about 190 mg/l, determined electrometrically. Dissolved solids concentrations in zones above this lower sand layer are considerably higher, but have not been analyzed. Granitic basement at this site is projected to be at a depth of about 2350 feet, based on correlations to nearby exploratory oil boreholes*.

5. Well No. 11S/1E-2K (Pleasant Valley). Penetrating the upper 800 feet of the Purisima Formation, this well supplies a commercial agricultural operation with water of high quality. The well produces from a 600-foot sequence described by the driller as sands, sandstones, and alternating sands and silts, with only two clay interbeds. Two analyses at the beginning and end of the 1975-1977 drought yielded equivalent specific conductance values of about 400 umhos/cm (assumed total dissolved solids of about 250 mg/l).

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* Mr. Joseph Scalmanini kindly provided the unpublished information in the above paragraph, from his work for the Soquel Creek County Water District. Data should be considered work-in-progress, subject to re-interpretation or revision.

The driller's log for this well notes a 10-foot interval of redwood at the 210-foot depth, immediately above one of the two blue clay zones. Gravels and red sediments lie above the redwood. We interpret this sequence as recording a shallow marine or estuarine environment, indicating that Stuart's interpretation of the upper Purisima and lower Aromas Formations as storm deposits is applicable well inland.

6. Marina Well No. 10. The Marina County Water District recently completed a production well in marine sediments of Purisima age. The well is perforated between depths of 920 feet and 1515 feet, with a cement seal between the 770 feet and the surface. The well produces a sustained yield of 1500 gallons per minute (gpm) at a sustained drawdown of about 110 feet. Computed specific yields are about 12 to 15 gpm per foot drawdown. Step-drawdown and constant-rate well tests were performed, and water-level recovery was analyzed. Estimated transmissivities from these aquifer tests were 30,000 to 50,000 gallons per day per foot (Geoconsultants, 1983). These values equal or approach transmissivities reported in the Pajaro basin from similarly-constructed production wells in the Aromas Sands.

Water quality tests were made throughout the test well and development programs. Specific conductance typically varied between 500 and 600 micromhos/cm. General mineral and trace element analyses made on samples drawn for the completed and developed well showed total dissolved solids of 365 mg/l, chloride of 45 mg/l, and sodium of 82 mg/l. Typical of waters drawn from the Purisima sediments, anions were mixed, with sulfate and chloride present in approximately equal quantities on a milliequivalent basis (HEA, 1979).

The sediments from which this well draws were deposited on the southern limb of the subsiding Purisima basin. At the time, the Santa Lucia Mountains and Sierra de Salinas were undergoing rapid uplift. A source of plentiful sandy debris was available from a shoreline which probably was never further than 5 to 10 miles away. Also, the southern limb of the basin is most distant from the sources of fine-grained volcanic debris, and was separated by the basin trough from the areas through which this material was delivered. The geologic log for the Marina well is dominated by "gray-tan, fine to medium sands" as opposed to gray, black, or green silty sands prevalent in the Purisima deposits of southern Santa Cruz and northern Monterey Counties. The Marina Well shares with its northern counterparts several key geologic characteristics including granitic debris near the base, gray sands (suggestive of volcanic sediment contributions) in the central part of the sequence, and a gradual and texturally-variable transition to the overlying Aromas and Paso Robles sediments.

Recharge and Water Quality

Wells developed in the deep aquifers both northwest and southeast of the Pajaro Valley yield waters of variable quality. Most commonly, concentrations of total dissolved solids fall within the range of 500 to 800 or 900 mg/l. These levels are excessive for long-term use as municipal and industrial supplies, but are acceptable for most agricultural purposes. The desirability of these waters would decrease considerably with increasing salinity or concentrations of sodium or chloride.

It is reasonable to assume that salinities in the deep aquifers beneath the Pajaro Valley will be similar to or greater than those reported at the edge of the basin. Throughout coastal California, concentrations of dissolved solids commonly increase with depth and/or distance from the area of recharge. Table 3 summarizes known water quality* and its relation to local geology and the distance to the inferred recharge area. Specific conductance does vary with recharge distance to a moderate degree. Other factors, however, seem to be causing the most extreme water-quality differences. These may be due to the presence of residual marine waters within parts of the formation, to leakage from intruded zones penetrated by the wells, or (in many cases) to lateral changes in the sedimentary textures within water-bearing zones.

Cost and Administrative Considerations

Development of the deeper aquifer systems appears to be an attractive water-supply option provided that water is available in sufficient quality and quanity. If successful, development of the deep aquifer might yield a sustained supply at a cost of about $60.00 per acre foot. Details of the estimate are given in Table 6-3 of the main report.

Factors to be considered in assessing the feasibility of developing the deep aquifer include:

1. No direct evidence regarding the likely yields and quality of water from any of the deep aquifers are available. Well yields and capacities used in projecting costs are those experienced in the lower Salinas basin, five to ten miles to the south. While probably continuous with the deeper zones in the lower Salinas Valley, deep aquifers in the Pajaro Valley are likely to be somewhat finer-grained and physically deeper. If continuous with the deeper zones of the lower Salinas Valley, the Pajaro deep aquifers are nearer the center of the depositional basin. As a result, they are likely to be found at somewhat deeper depth, and are likely to be texturally finer than the equivalent horizons to the south or north. They may also be further from the areas of principal recharge, and might be expected to contain dissolved solids in concentrations equal to or somewhat greater than those of the lower Salinas Valley. In absence of data, it is not possible to predict whether any of these features could appreciably alter the rate or cost of well yields.

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* Specific conductance is used as a water quality index in Table 1. An estimate of total dissolved solids concentration in milligrams per liter may be computed by multiplying the specific conductance (in umhos/cm at 25 C) by a factor of 0.6 or 0.65.

Table 3. Water Quality and Estimated Distance from Recharge Areas, Wells in Deep Aquifers near the Pajaro Valley

Well	Geologic Units[a]	Perforated Interval (feet)	Sample Date	Specific Conductance (µmhos/cm)	Estimated[b] Recharge Distance (mi)	Remarks
11S/1E-1G1	Tpc	-1000	1/13/75	482	0.5	Watsonville City Well #11
11S/1E-2K1	Tpc	440-760	8/31/77	400	0.5	Pleasant Valley area
11S/1E-4Q	Tpa	@ 1700	1983	@ 300	0.5 to 5(?)	Unpublished data
11S/2E-4I	Tpb	220-270	10/20/76	450	0.5	Upper Green Valley Road
11S/2E-25E4	Tpa	317-377	9/09/71 10/20/76	692 360	0.5	Peckham Road area
12S/1E-11M1	Tpa	None	10/54	@ 29000	10 to 20(?)	Texaco Blake borehole
13S/2E-17	Qab	700-950	8/14/78	1113	0.5 to 5 (?)	PGE Well #4
13S/2E-16	Qa	309-844	6/01/82	550	0.5 to 5 (?)	PGE Well #8 Sulfate = 9.7 mg/1[c]
13S/2E-19Q3	Tp, Tsm (?)	1220-1550	6/82 8/82	1140 1065	5 to 20(?)	Between Castroville and Moss Landing
13S/1E-36J1	Tp, Tsm (?)	1298-1448	1977 1980-1982	800 1040-1200	5 to 10(?)	
14S/2E-6L	Tp, Tsm (?)	860-1540	1976 8/82	830 845	5 to 10(?)	Monterey County well
Marina #10	Tp	920-1500	3/83	540	0.5 to 5	Sulfate = 67 mg/1

a/ Geologic units key:

Tp	Pliocene marine shales and sands, primarily Purisima Formation
Tpa, Tpb, Tpc	Subdivisions of Purisima Formation recognized in Santa Cruz County (Hickey, 1968; Muir, 1972)
Tsm	Miocene and early Pliocene light-colored sandstones, primarily Santa Margarita Formation
Qa	Aromas Red Sands and/or Paso Robles Formation
Qab	Basal unit of Qa

b/ Representative distance range from the recharge area, as estimated by HEA staff.

c/ Low concentrations of sulfate are considered characteristic of waters from the Aromas aquifer in this area.

2. Pumpage from the deep aquifer would probably constitute a new source of water for the areas of overdraft near the coast. It would likely be only partially a source of new water to the basin as a whole, because an undetermined proportion of the additional yield would be met by accelerated leakage from the upper water-bearing zones. Additionally, most water budgets for the Pajaro basin have directly or indirectly included recharge to the Purisima aquifers in regional estimates of recharge and outflow. The potential for seawater intrusion into the Purisima Formation also exists and should be evaluated prior to the extensive development of the deep aquifers.

3. It may be possible to develop the deep aquifer without building a surface distribution system. This attribute is a critical factor in favorable cost comparisons of deep-aquifer water.

4. Exploration and utilization of deep aquifer water may be achieved both simply and quickly. Wells of comparable depth are being drilled in the region. A minimum of environmental and permit review would be anticipated.

5. The degree of local control for this program is essentially complete. Nearly all other programs under consideration are affected to a greater or lesser degree by changes in cost subsidies or by changes in land-use practices elsewhere in the state.

6. Development of the deep aquifer is likely to provide the greatest net environmental benefits of all alternatives under consideration, barring unforeseen circumstances and provided that quality of water is satisfactory. It is fully compatible with the goals and policies of both counties' local coastal programs.

7. Future water resource development in the Pajaro basin will be strongly influenced by the presence or absence of significant supplies from the deep aquifer. The remaining uncertainties may need to be answered before other additional sources of water may be developed. The cost of exploring the potential of the deep aquifer is small relative to the cost of constructing any alternative source which may supply comparable amounts of water.

CONCLUSIONS

1. The deep aquifers are set of water-bearing sands at depths below those presently developed for groundwater. The properties of these units vary considerably, both laterally and with depth. In recent years, a number of production wells have been developed in deep aquifers in adjoining groundwater basins. Most new wells are designed to draw from two or more water-bearing units.

2. The deep aquifers beneath the Pajaro Valley are best known from wells developed in these units to the northwest and southeast. These units have been able to sustain capacities usable for irrigation.

3. A very large volume of water is stored in the deeper aquifers beneath the Pajaro basin. The extent to which it may be considered a developable resource is not established. There are three principal uncertainties:

    a. The stratigraphy and sedimentologic relations of the water-bearing units are generally known, but not at a level of detail adequate to project a major water-supply well system.

    b. As there are no deep wells within several miles of the Pajaro Valley floor, yields and aquifer properties are not predictable with either ease or certainty. This area is more remote from the sources of most deposited material, and probably has finer-grained sediments, than the better-known portions of the deep aquifers in the Soquel-Aptos area and in Monterey County.

    c. Quality of waters drawn from the deeper aquifers are variable, but are generally suited for agricultural uses. Laboratory analyses and interpretation of related geophysical logs indicate that groundwaters typically contain 200 to 1200 mg/l dissolved solids in the Castroville area. Fragmentary results from the Aptos and Corralitos areas are suggestive of a similar range. However, analyses from the Casserly and San Andreas Road areas indicate that waters containing 5000 to 30,000 mg/l occur within the target units.

       Waters are of a sodium chloride type, with some constraints on uses related to sodium content. Potential constraints may also exist with respect to boron content of some of the wells tapping the deep aquifer.

4. While water quality remains a critical uncertainty, two considerations bear special mention:

    a. The concentrations of both total dissolved solids and sodium generally increase with distance from the likely recharge areas.

b. For planning purposes, total dissolved solids concentrations of 600 mg/l should be anticipated for waters from wells developed in deep aquifers beneath the Pajaro Valley. Supplies from the deep aquifers are most appropriately intended for irrigation.

5. The most promising areas for developing the Purisima and related aquifers are along the southern edge of the Pajaro basin. It is likely that aquifer properties and water quality will be both more favorable in the Monterey County part of the study unit.

   Further exploratory work will be needed before the potential of the deep aquifers beneath the intruded areas can be established at the same level of detail used in the analysis of the water-supply alternatives.

6. It may be possible to develop the deep aquifer without building a surface distribution system, a critical attribute in favorable comparisons of the time and cost needed in developing supplies from this source.

7. The deep aquifer is likely to provide the greatest net environmental benefit of the various alternative water supply sources under consideration.

8. The future of water resource development in the Pajaro basin depends in part on resolving the uncertainties regarding the volume and quality of water which may be obtained from the deep aquifers. The cost of exploring the potential of the deep aquifer is small relative to the cost of constructing any alternative source which may supply comparable volume of water.

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APPENDIX C

RESULTS OF DRILLING AND HYDROGEOLOGIC
TESTING IN THE PAJARO VALLEY AREA, CALIFORNIA

RESULTS OF DRILLING
AND HYDROGEOLOGIC TESTING
IN THE PAJARO VALLEY AREA,
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The Pajaro Valley ground-water basin is over drafted by approximately 20,000 acre feet per year. This overdraft is causing declining ground-water levels and gradual increases in ground-water salinity. These problems, and others expected if the overdraft is sustained, may be alleviated or completely offset by a program of recharge augmentation. Woodward-Clyde Consultants (WCC), working in association with HEA/A division of J.H. Kleinfelder and Associates, has been directed to conduct field studies in specific areas in the Pajaro Valley area in order to evaluate the effects of recharge augmentation. The Giberson Dunes area, located 6 miles south of Watsonville, California and the San Andres Dune area, located 5 miles southwest of Watsonville, are the specific sites that were studied by WCC in addressing this charge.

2. PURPOSE AND SCOPE OF INVESTIGATION

The purpose of Woodward-Clyde Consultants' investigation was to assess the feasibility of recharge augmentation at two specific sites in the Pajaro Valley area: Giberson Dunes and San Andres Dunes. At both sites, infiltration holes were drilled and tested. Samples were collected for lab permeability testing. An aquifer test was performed at the Giberson Dunes site in order to assess the hydrogeologic characteristics of the shallow aquifer at that site. The geologic and hydrologic information obtained from the field operations was used to assess the effectiveness of recharge augmentation at the two study sites.

3. FIELD METHODS

Field investigations were performed at the two sites mentioned above. Drilling of infiltration holes was completed using an auger rig equipped with a California Modified Sampler for the collection of samples for lab permeability tests. Hollow-stem augers were used to place 2-inch PVC in the boreholes. Once in place, the shallow test wells were logged with a gamma ray probe to supplement the geologic log produced from a description of disturbed samples collected by hand from the auger.

Infiltration tests were performed in the shallow test holes to provide estimates of infiltration rates at the two sites. Constant head tests were performed by maintaining a constant water level in the test hole with a controlled and measured flow of water from a water truck. The flow was controlled by a gate valve and measured with a 3/4 inch Zurn totalizing flowmeter. The tests were planned to be performed long enough to allow a saturated envelope of water to form in the soil and for steady state conditions to be reached. However, functional limits of the equipment used prevented the tests from being run for an extended period of time.

An aquifer pumping test was conducted at the Giberson Dunes area. An existing irrigation well with an electrical turbine pump (set to an unknown depth) was used as the pumping well. An observation well was constructed by hollow stem auger. The test was conducted for 3 days and included 2 days of pumping. Water levels were measured in the observation and pumping wells with electric sounding probes and a steel tape. Discharge from the pumping well was measured with a Collins flowmeter.

4. GIBERSON DUNES AREA

4.1 HYDROGEOLOGIC SETTING

The Giberson Dunes area is adjacent to Monterey Bay, located about one mile southeast of the mouth of the Pajaro River (Figure 1). The area has a slightly undulating surface interrupted by McClusky slough. The area is bordered by a 50 foot terrace approximately 1.5 miles east of the bay.

The geology of the area is very complex. Several different processes have been at work in the area producing eolian, alluvial, fluvial and marine deposits (H. Esmaili and Associates, 1978). Dune sands dominate the surface deposits and are as much as 40 feet thick in the area. Alluvial deposits, possibly associated with the Salinas River, are thought to occur to a depth of about 200 feet. In some locations, fine-grained estuarine deposits as much as 50 feet thick interrupt the alluvial deposits. Underlying the alluvium is older alluvium and/or terrace deposits of unknown thickness. The Aromas Formation, which locally seems to contain substantial thicknesses of well sorted quartzose sand, is found at depth. Further to the east, terrace deposits, overlain by older dunes, are dominant in the subsurface above the Aromas Formation.

The main water-yielding deposit in this area is the alluvial aquifer. Substantial amounts of ground water are obtained from this aquifer for irrigation purposes. Specific capacity (well yield divided by drawdown) of wells completed in the alluvial aquifer have been found to vary from 0.5 to 10 gpm/ft (H. Esmaili and Associates, 1982). These values give approximate estimates of transmissivity of from 1000 to 20,000 gpd/ft. Some wells are completed in the deeper Aromas Formation and have specific capacities equal to or greater than those reported for wells in the alluvial aquifer.

In general, ground-water levels from wells completed in the alluvial aquifer have shown a decline over the past years as a result of increased ground-water pumpage. For example, well number 12S2E31K1 (see Figure 2) which was perforated from a depth of 164 to 219 feet, has shown a decline of about 8 feet from 1959 to 1982. Near Zmudowski State Beach, well number 13S2E6E3, which was perforated from 148 to 187 feet, has shown less of a decline. Irrigation pumpage has caused local depressions in the potentiometric surface, and has caused ground-water to flow toward these areas.

Ground-water quality in the Giberson Dunes area has become relatively poor since about 1960. Chloride and nitrate concentrations have increased in some wells. For example, wells 13S2E6E3 and 13S1E1A1 (see Figure 2), completed in the alluvial aquifer, increased in chloride concentration from about 250 ppm to over 1000 ppm from 1962 to 1977 (M.H. Esmaili and Associates, 1978). Nitrate concentrations for wells 12S2E29L1, 12S2E32K1, and 12S2E30N1 had risen to between 90 to 130 ppm in 1975. Elevated nitrate concentrations are restricted to the Giberson Dunes and lower Springfield mesa areas.

4.2 DRILLING AND TESTING

On December 6 and 7, two test holes, designated as GD-OW1 and GD-PW1, were completed in the vicinty of the New Nakamura well. GD-OW1 was drilled to 120 feet and completed as an observation well by installing 2-inch PVC casing. The casing was pre-slotted from 75 to 105 feet below ground surface. GD-PW1 was drilled to a total depth of 20 feet, and completed with 2-inch PVC slotted from a depth of 10 to 20 feet. GD-PW1 served as an infiltration test hole.

4.2.1 Geology

During the drilling phase of GD-OW1 and GD-PW1, geologic/lithologic logs were prepared based on 1) the auger cuttings, 2) a drive sample collected at a depth of 31 feet, and 3) the rate of drilling. Drive samples were obtained using the California Modified Sampler through the hollow-stem auger. The logs are presented in Appendix A.

Examination of the drill cuttings indicate that the area is underlain predominately by loose, unindurated silty sand, with minor thin interbeds of silty clays. The sand is composed mostly of quartz, and is fine-to-medium grained at a shallow depth and more coarse grained with gravel at greater depths. The finer sand at shallower depths is probably dune sand while the coarse-grained sand and gravel is probably alluvial deposits. The transition between these two deposits cannot be determined exactly from the drill cuttings, but is estimated to be at a depth of about 35 feet. This is based qualitatively on 1) the fact that cuttings from below about 35 feet show an increase in coarse sand and gravel and 2) the gamma ray log shows a change in response at about this depth. The deeper Aromas Formation was probably not encountered in this boring.

The lithologic information summarized above was supplemented with a gamma ray log obtained in GD-OW1. The gamma log is presented in Figure 3. The gamma ray log can be separated into three zones:

1. A zone of relatively high gamma radiation at a depth of 5 to 14 feet interpreted as sandy soil containing potasium from potassium-rich fertilizer.

2. A zone of intermediate gamma radiation at depths of 18 to 22 feet and 30 to 34 feet interpreted as silty clay.

3. A zone of relatively low gamma radiation at a depth of 35 to 105 feet interpreted as predominantly silty sand and gravel.

These interpretations are in agreement with the lithologic logs presented in Appendix A.

4.2.2 Infiltration Tests

Due to time and equipment constraints, a complete infiltration test could not be carried out on the shallow test hole GD-PW1. GD-PW1 was briefly tested on

December 9, 1982. Water was pumped into the test hole at approximately 4 gpm, but because the infiltration rate was so high, a constant head could not be maintained in the test hole. Therefore, it was not possible to determine an exact infiltration rate.

4.2.3 Laboratory Permeability Tests

A laboratory permeability test was run on a clayey sample obtained from GD-OW1 from a depth of 30.5 - 31.0 feet. This test indicated a saturated vertical hydraulic conductivity of 2.0 x 10^{-8} cm/sec. Additional samples could not be obtained because the geologic materials were composed mostly of loose sand. When wet, these sands would flow into the hollow stem auger when sampling and inhibit proper sample collection.

4.2.4 Aquifer Pumping Test

In order to determine aquifer characteristics of the deposits underlying the Giberson Dunes area, a constant discharge aquifer test was performed in the area. An existing irrigation well known as the New Nakamura Well (State of California number 13S2E6C1), located approximately 3000 feet east of Zmudowski State Beach near McClusky Slough (Figure 2), was used as the discharge well. A 2-inch PVC observation well, GD-OW1, was installed 39.5 feet west of the New Nakamura Well by hollow stem auger. The driller's log reports that the New Nakamura Well was constructed of 12-inch diameter casing with factory punched slots from 88 to 124 feet below ground level. The well was reportedly gravel packed with 3/8-inch gravel without a sanitary seal. GD-OW1 was slotted from a depth of 75 to 105 feet.

The New Nakamura Well was pumped at a constant discharge of 500 gallons per minute (gpm) for 2850 minutes during December 9 to 11, 1982. Discharge was measured using a Collins flowmeter attached to a 6.25-inch ID irrigation pipe and was directed into McClusky slough 500 feet to the north. The water was pumped with an in-place turbine pump driven by electric power.

Fluid levels (water plus oil) in the pump well were measured with a steel tape for the first 200 minutes of pumping until the tape became stuck in the well. (Oil on the water surface made it difficult to measure the true water level, but since relative water levels were needed, the actual fluid level in the well sufficed for analysis). Water levels in observation well GD-OW1 were monitored with an electric sounding probe during the test as frequently as was needed to define drawdown versus time plots for analysis. Water levels were also measured in the shallow test hole GD-PW1 (located about 30 feet west of the pumping well) using an electric sounding probe. Fluid levels were measured in an irrigation well known as Rudy's well (State of California well number 13S2E6C2) located about 800 feet south of the pumping well. Temperature and specific conductance were measured once every two hours during the test.

Water levels in the above mentioned wells were not monitored prior to the performance of the aquifer test. Thus, the effects of other natural factors on ground-water levels during the test (such as rainfall and tidal and atmospheric fluctuations) could not be evaluated. Several days before the aquifer pumping and infiltration tests were conducted, there were several heavy rainstorms. No rainfall measurements were made. However, these factors are thought to have such a limited effect on the water-level test data that the analytical results as presented here are not changed.

The pumping phase of the test was completed on December 11, 1982 at 0815 hours. Recovering water levels were measured for 1530 minutes until 1000 hours December 12, 1982. The same instrumentation was used to measure recovering water levels except that an electric sounding probe was used in the pumping well 60 minutes after cessation of the test.

Water-level data from GD-OW1 was used to evaluate the aquifer characteristics (including transmissivity, storativity, specific yield, and hydraulic conductivity) of the shallow aquifer in the Giberson Dunes area. Since the pumping well is completed to a depth of 124 feet, only the first 100 feet of saturated deposits could be evaluated. The static water level at the test site is 21 to 22 feet below ground level. Based on the driller's log for the New Nakamura Well and cuttings from augering completed during this phase of work, the sediments from 22 to 124 feet are dominated by sand and gravel. The sand is predominantly fine-to-medium grained. Fine-grained gravel is predominant in the lower part of the interval tested. Some relatively thin layers of sandy clay occur in the upper 10 feet of the saturated zone. Based on the above hydrostratigraphy, the aquifer tested is either unconfined or semi-unconfined.

Water-level data collected from GD-OW1 during pumping and recovery periods were plotted as drawdown versus time data on both log-logarithmic and semi-logarithmic paper and as residual drawdown versus the ratio, t/t' (time since pumping started divided by the time since pumping stopped), on semi-logarithmic paper. Figure 4 is a log-logarithmic plot of drawdown versus time for GD-OW1. Several types of analyses were applied to this plot. The analyses differ depending on the type of hydrostratigraphy assumed for the tested zone. The two main types of analysis applied were Hantush's leaky aquifer analysis (1955, 1956) and Boulton's unconfined aquifer analysis (1954, 1963). In the former case, the aquifer is assumed to have a cover layer which has vertical flow and releases water from storage to the underlying aquifer. Boulton's analysis assumes consistent aquifer properties from the free surface to the depth of pumping. In both analyses, it is assumed that the aquifer has an impermeable base. Application of type curves for both analyses indicates favorable curve matching with Boulton's type curves for a r/D value of 0.1. Boulton's analysis involves applying type curves to both early- and late-time data. The early-time type curve match gives a transmissivity of 140,000 gpd/ft and a storativity (storage coefficient) of 8.6×10^{-4}. The late-time type curve match gives a transmissivity of 150,000 gpd/ft and a specific yield of 7.7×10^{-3}. The values of transmissivity and an aquifer thickness of 103 feet result in a value of hydraulic conductivity of from 1400 to 1500 gpd/ft^2 (.067 to 0.071 cm/sec).

The value of specific yield noted above should be considered as a lower estimate becuase the test was not performed for a long time period. In some cases, aquifer pumping tests in unconfined aquifers should be conducted for several days to accurately determine the specific yield of the aquifer. It is evident from curve matching to the late-time Boulton-type curve (Figure 4) that drawdown data from an extended aquifer test would probably provide a higher estimate of specific yield. In addition, because the aquifer is probably not an ideal unconfined aquifer, the specific yield parameter may be low in part due to a semi-unconfined condition.

The Boulton analysis is more favorable because the aquifer tested appears to be unconfined. Unconfined aquifers require fairly careful analysis because of the potential for "delayed yield" which normally produces a flattening of the drawdown plot after an initial increase and before a second late-time increase in drawdown. This phenomenon is accounted for in Boulton's analysis. In addition, during pumping, vertical flow near the free surface is not accounted for in this analysis. Drawdown data are adjusted if lowering of the free surface is significant when compared with the total aquifer thickness. Such an adjustment was not necessary for these test data.

An additional factor to be considered is partial penetration of both the pumping and observation well. The pumping well is completed in the lower 35 percent of the aquifer tested (depth of 88 to 124 feet) and the observation well GD-OW1 is completed in about 30 percent of the aquifer (above a depth of 105 feet). It is generally accepted that the effects of partial penetration are negligible if the observation well is more than two aquifer thicknesses (in this case 200 feet) from the pumping well. After reviewing the information available on the effects of partial penetration in unconfined aquifers, it was concluded that this condition would not severely affect the analysis for two reasons: 1) the open interval of the observation well is adjacent to that of the pumping well and 2) the ratio of horizontal to vertical hydraulic conductivity is not high.

Standard techniques of analysis were also applied to a semi-logarithmic plot of drawdown versus time data for GD-OW1 (Cooper and Jacob, 1946). The plot and calculations are shown on Figure 5. Straight-line analysis is applied to the late time data which result in a transmissivity of 130,000 gpd/ft, a hydraulic conductivity of 1300 gpd/ft^2, and a specific yield of 0.012. These values agree well with those obtained from the Boulton analysis.

Water-level data from the New Nakamura Well were limited because of the difficulties encountered with measuring the water level in the well. Incomplete but fairly accurate data from the pump well can be projected based on the response of GD-OW 1. Total drawdown in the pumping well was probably about 17 feet at the end of the test. Thus the specific capacity of the New Nakamura Well at the end of the test is projected to be about 29 gpm/ft.

Plots of residual drawdown versus the ratio t/t' for both the pump well and the observation well generally support the results presented above. Data were collected up to a t/t' value of three, which would indicate that water levels would recover to static conditions. This suggests that the aquifer tested is not limited in areal extent.

The shallow test hole, GD-PW 1, was monitored during the test and gradually rose from a pre-test level of 14.89 feet to a level of 14.68 feet one day after the aquifer pumping was concluded. GD-PW 1 is completed in a perched ground-water zone and apparently was unaffected by pumping of the New Nakamura Well. The gradual rise of the water level is attributed to recharge from precipitation, which had occurred previous to the performance of this test. Analytical results presented above would not be affected if observation well GD-OW 1 was similarly affected during the test.

Rudy's well, located about 800 feet to the south of the test site, was measured during the test and showed a rise of 0.65 feet after one day of recovery. It is projected that the total affect of pumping on Rudy's well was about 0.75 feet. These data indicate that the aquifer tested is laterally continuous to the south and that pumping can affect the aquifer for relatively large distances.

As mentioned earlier, water quality parameters were measured throughout the test. Temperature remained constant at 17°C throughout the test. Specific conductance was 2400 umhos/cm (at 25°C) 150 minutes into the test and 2770 umhos/cm (at 25°C) 15 minutes before the conclusion of the test. Figure 6 shows a semilogarithmic plot of specific conductance versus time and indicates how the specific conductance increased throughout the test. These data clearly reveal that ground water with matching to the late-time Boulton-type curve (Figure 4) that drawdown data from an extended aquifer test would probably provide a higher estimate of specific yield. In addition, because the aquifer is probably not an ideal unconfined aquifer, the specific yield parameter may be low in part due to a semi-unconfined condition.

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higher total dissolved solids concentrations entered the well. It is believed that the pumped ground water is derived in part from the west where saline water from Monterey Bay has migrated inland and intruded fresh-water aquifers. These data are also an indication of the continuity of the aquifer toward the west. The extent of continuity is unknown.

A final comment should be made in reference to the hydrologic relationship of McClusky Slough with the near-surface aquifer tested at Giberson Dunes. The drawdown data from GD-OW1 do not indicate that the underlying aquifer is in hydraulic communication with McClusky Slough. This is evident from Figure 5 which shows continuously increasing drawdown with time and an accelerated increase in drawdown after 600 minutes.

5. SAN ANDRES DUNES AREA

5.1 HYDROGEOLOGIC SETTING

The San Andres Dunes Area is adjacent to Monterey Bay and is located about two miles northwest of the mouth of the Pajaro River (see Figure 7). The area has a gently undulating topography which is as high as 150 feet (MSL). The southwest part of the area forms relatively high cliffs above Sunset State Beach.

Geologic information for the area is sparse, but drillers' logs from just northwest and southeast of the area suggest that dune sand as much as 100 feet thick exists over the area. Underlying the dune sand is an undetermined thickness of terrace deposits. Drillers' logs indicate that the deposits are mostly sandy with gravel and thin blue clay interbeds. The well sorted sand of the Aromas Formation underlies the terrace deposits. To the southeast torward the Pajaro Valley, alluvium occurs from the ground surface to a depth of about 200 feet.

Most wells in the surrounding area are believed to be completed in the Quaternary Aromas Formation. Fifteen wells within a few miles both northwest and southeast of the area are completed to total depths of from 196 to 767 feet with perforations as deep as 380 feet (H. Esmaili and Associates, 1978). Well yields are reported to be as high as 1600 gpm with specfic capacity values ranging from 2.8 to 37.0 gpm/ft. Estimates of transmissivity values from these data indicate a range of from 9,000 to 70,000 gpd/ft.

Ground-water level data are limited for the immediate area, but it is thought that on the southwest side of San Andres Road on the ground-water flows in a southwesterly direction toward the bay. Northeast of San Andres Road, flow is northeast, east and southeast. Southeast of the area flow is toward the Pajaro Valley which is topographically lower than the San Andres dunes area.

Water quality data are also limited for the San Andres dune area. From 1972 to 1977, sampling of ground water in the area indicated nitrate concentrations of from

10 to 90 ppm. Since 1970, increases in chloride concentrations have been reported in well 12S1E11N1 located northwest of the site area (Figure 7).

5.2 DRILLING AND TESTING

During the periods November 30 to December 1 and December 7 to December 8, 1982, three borings designated as SAD-PW1, SAD-PW2 and SAD-PW3 were completed in the northeast corner of Tao's strawberry farm near San Andres Road (see Figure 7). Initially only two borings were planned at this location, but drilling of SAD-PW1 was stopped prematurely when the drilling rig broke down. SAD-PW1 was abandoned at a depth of 60 feet and completed as a test hole with 2-inch PVC casing. The PVC casing is pre-slotted from a depth of 45 to 55 feet.

SAD-PW2 was drilled to a total depth of 100 feet, and completed with 2-inch PVC casing which is pre-slotted from a depth of 88 to 98 feet. SAD-PW2 is located 150 feet from SAD-PW1.

SAD-PW3 was drilled to a depth of 20 feet approximately 5 feet from SAD-PW2. Two-inch PVC casing, pre-slotted from a depth of 10 to 20 feet, was placed in this borehole to complete the hole as an infiltration well.

SAD-PW1 is located about 205 feet from the center of San Andres road, near the northern boundary line of Tao's property. SAD-PW2 and SAD-PW3 are also near this boundary line and about 50 feet away from the center of San Andres Road centerline. The ground surface at SAD-PW1 is estimated to be about 10 feet higher than the ground surface at SAD-PW2 and SAD-PW3.

5.2.1 Geology

Based on the drill cuttings, drive samples and the drilling rate, lithologic logs were prepared and are presented in Appendix A. Gamma ray logs were also run in SAD-PW1 and SAD-PW2 and are shown in Figures 8 and 9.

As is the case at the Giberson Dunes area, this area is also predominantly underlain by unindurated loose sands. The following conclusions were made from interpretations of lithologic and gamma ray logs obtained in boring SAD-PW2.

- From a depth of 0 to 35 feet the deposits are predominantly composed of brown, brownish-grey and light grey fine-to-medium grained silty sand. The sand consists mostly of subrounded to well-rounded grains of quartz. The deposits contain thin interbeds of silty clay. These deposits are interpreted to be dune sand.

- From a depth of 35 to 41 feet the deposits were poorly sorted silty sandy gravel with angular rock fragments (up to one inch) and thin interbeds of silty clay. These are interpreted to be alluvial deposits.

- From a depth of 41 to 100 feet the drill cuttings were a sandy mud slurry. The sand grains were fine-to-coarse grained consisting mostly of quartz with some mafic minerals. These deposits are interpreted to be alluvial and/or terrace deposits.

The contact between the dunal and alluvial deposits occurs at depth of about 20 feet in boring SAD-PW1 (Figure 8). This indicates the variable depth at which this formation contact occurs throughout the study area.

The gamma ray log for SAD-PW2 indicates a relatively clayey interval at a depth of 85 to 91 feet.

5.2.2 Infiltration Tests

Constant head infiltration tests were performed on SAD-PW1, SAD-PW2, and SAD-PW3 on December 9 and 10, 1982 using a procedure described in the U.S. Bureau of Reclamation's Earth Manual. The method and equipment used was briefly described in Section 3.0.

The tests consist of measuring the flow rate that is discharged into the open or cased test holes. The constant flow rate, the constant head above the static water level in the well, and the well dimensions, are used to determine the infiltration rate of material tested. Using the appropriate equation (U.S. Bureau of Reclamation, 1968), the following values of hydraulic conductivity (or infiltration rate) were calculated:

- SAD-PW1: 4.6×10^{-5} cm/sec
- SAD-PW2: 6.4×10^{-4} cm/sec
- SAD-PW3: 7.3×10^{-4} cm/sec

Test data and calculations are presented in Appendix B.

The values obtained are relatively low which may indicate that the materials are less permeable than they appear. SAD-PW1 and SAD-PW3 are completed near the regional water table and a shallow perched zone, repectively, and constant head tests performed on these boreholes are a reflection of the infiltration rate in the materials near the corresponding free surfaces. The values for infiltration rates are most likely lower estimates since the PVC casing was not slotted its entire length. Depth to static water level in SAD-PW1 and SAD-PW3 was 51 feet and 10 feet, respectively.

The results of the test performed on SAD-PW2 may be misleading because the test well is completed below the water table. A constant head test performed on this well should be performed for a significant period of time in order to measure a declining flow rate. The data collected from an extended test would allow more accurate determination of the hydraulic conductivity of the deeper zone.

5.2.3 Laboratory Permeability Tests

Two drive samples were collected at the San Andres Dunes site. One sample was collected from SAD-PW1 at a depth of 15.0 to 15.5 feet. The other sample was collected from SAD-PW3 at a depth of 7.0 to 7.5 feet. A sample could not be obtained from a depth of 85 to 91 feet in SAD-PW2. Drive sampling below a depth of 30 to 40 feet was difficult for the same reasons mentioned in Section 4.2.3. The following values of vertical permeability were obtained from the variable head lab permeability tests:

- SAD-PW1 (depth of 15 to 15.5 feet): 1.5×10^{-8} cm/sec
- SAD-PW3 (depth of 7.0 to 7.5 feet): 2.1×10^{-8} cm/sec

Both samples consisted of silty clay. Vertical permeability values of 1.5×10^{-8} and 2.1×10^{-8} are in good agreement with this description.

6. GENERAL EFFECTS OF ARTIFICIAL RECHARGE

It is concluded from the data and information presented in this report that conditions are, in general, favorable for artificial recharge in both the Giberson Dunes and San Andres study areas. Although relatively impermeable interbeds of silty clay were encountered in the unsaturated zone, these interbeds are not of significant thickness and probably not of great lateral extent to inhibit downward-percolating recharge water. Moderate infiltration rates were calculated from infiltration test data, but further detailed infiltration tests which simulate actual recharge conditions should be conducted before design and implementation of specific recharge facilities. The ability of near surface aquifers to spread recharge waters throughout both study areas is good. This fact is supported by the high value of the transmissivity derived from the aquifer-pumping test performed in the Giberson Dunes study area.

The thickest interbeds of relatively impermeable silty clay in the unsaturated zone at both sites are no greater than 5 feet. Moreover, these units are probably intercalated with silty sand and sand silt. Artificial recharge water, whether ponded or spread over the ground surface, would move horizontally across any impermeable interbeds until more permeable material was encountered; it would then move directly downward. Because of the complex depositional history, clayey interbeds are not thought to be laterally extensive. In the unsaturated zone, the effect of these clayey interbeds would be to spread recharge water across a subsurface area larger than the surface area covered by the recharge operation. The horizontal spread of recharge water in the unsaturated zone is closely related to the nature of these more impermeable interbeds. The occurence of a few, thin silty clay interbeds is not a significant deterrent to artificial recharge.

The values of infiltration rates (or permeability) estimated from tests performed during this study are moderate and are lower than would be expected for the type of deposits observed in drill cuttings. However, as explained previously, these estimated values are considered to be lower bounds for infiltration rates. These values should be used with caution in any detailed analysis of the effects of artificial recharge on the ground-water regime in both study areas. For example, the amount of seepage from recharge basins should not be calculated by application of Darcy's law in the vertical direction using the infiltration rates in this report. Seepage from either recharge or spreading basins is a complex and dynamic problem. Seepage rates are variable with time and depend on several soil properties. Before a recharge facility is designed, tests should be performed which simulate the actual conditions of the recharge facility (for example, a 100- by 100-foot pond to simulate a larger square-shaped recharge basin). The total seepage rate and ground-water levels around the recharge facility should be monitored for a relatively long period of time.

Field studies completed during this investigation indicate that the underlying saturated deposits are excellent for transmitting recharge water. Drilling and testing in Giberson Dunes Study area showed that there is at least 95 feet of permeable saturated deposits which are laterally extensive for at least 800 feet from the New Nakamura Well. Compiled hydrogeologic information for the Giberson Dunes study area and vicinity also indicate favorable conditions for recharge except for the possible occurrence of a relatively thick clay layer near Zmudowski State Beach. In the San Andres Dunes study area, at least 60 feet of permeable deposits were found at the drilling site. The areal extent and permeability of these deposits are unknown because drillers' logs are sparse for this area and no aquifer tests were performed.

7. SUMMARY AND CONCLUSIONS

1. Drilling near the New Nakamura Well in the Giberson Dunes area indicates that the area is underlain predominantly by loose, unindurated silty sand with minor thin interbeds of silty clays to a depth of 120 feet. Fine gravel is more common near the total drilling depth of 120 feet. Dune sands are predominant in the upper 35 feet, while alluvial deposits are predominant at a depth of 35 to 105 feet.

2. An infiltration test performed on a shallow test hole at the Giberson Dunes study area indicates relatively high infiltration rates. A lab permeability test performed on a sample of silty clay from a depth of 31 feet indicates a vertical permeability of 2.0×10^{-8} cm/sec. Infiltration is not thought to be restricted by interbeds of silty clay since they are not of significant thickness and are probably not laterally extensive.

3. Perched ground-water conditions exist at the Giberson Dunes study area.

4. An aquifer pumping test performed on the New Nakamura well indicates that the near surface aquifer (at a depth of from 22 to 124 feet) has a transmissivity of about 140,000 gpd/ft, a hydraulic conductivity of 1400 gpd/ft (0.067 cm/sec) and a specific yield of 0.01. The value of specific yield would most likely be higher if a long-term aquifer test were performed. The aquifer tested is unconfined or semi-unconfined. In addition, the aquifer is laterally extensive as evidenced by measureable drawdown in a distant well, an increase in specific conductance during the test, and projections of complete recovery from recovery plots. The aquifer has no obvious hydraulic communication with McClusky slough.

5. Drilling in the San Andres Dunes study area next to San Andres Road indicates that to a depth of 100 feet, the area is underlain predominantly by loose, unindurated sands with thin interbeds of silty clay in the upper 40 feet. The

first 35 feet of deposits are interpreted to be dune sand. The deposits from a depth of 35 to 100 feet are interpreted to be alluvial and/or terrace deposits.

6. Infiltration tests performed on two test holes indicate infiltration rates of 4.6×10^{-5} cm/sec and 6.4×10^{-4} cm/sec at a depth of 50 and 10 feet, respectively. These values are considered to be lower bounds for infiltration rates.

7. Laboratory permeability tests performed on samples of silty clay from SAD-PW1 (depth of 15 feet) and SAD-PW3 (depth of 7 feet) indicate vertical permeabilities of 1.5×10^{-8} cm/sec and 2.0×10^{-8} cm/sec, respectively. As in the Giberson Dunes study area, interbeds of silty clay are not thought to be of significant thickness or areal extent to prevent artificial recharge.

8. Perched ground-water conditions exist at the San Andres Dunes study area.

9. The Giberson Dunes and San Andres Dunes areas are suitable for ground-water recharge augmentation sites.

8. REFERENCES

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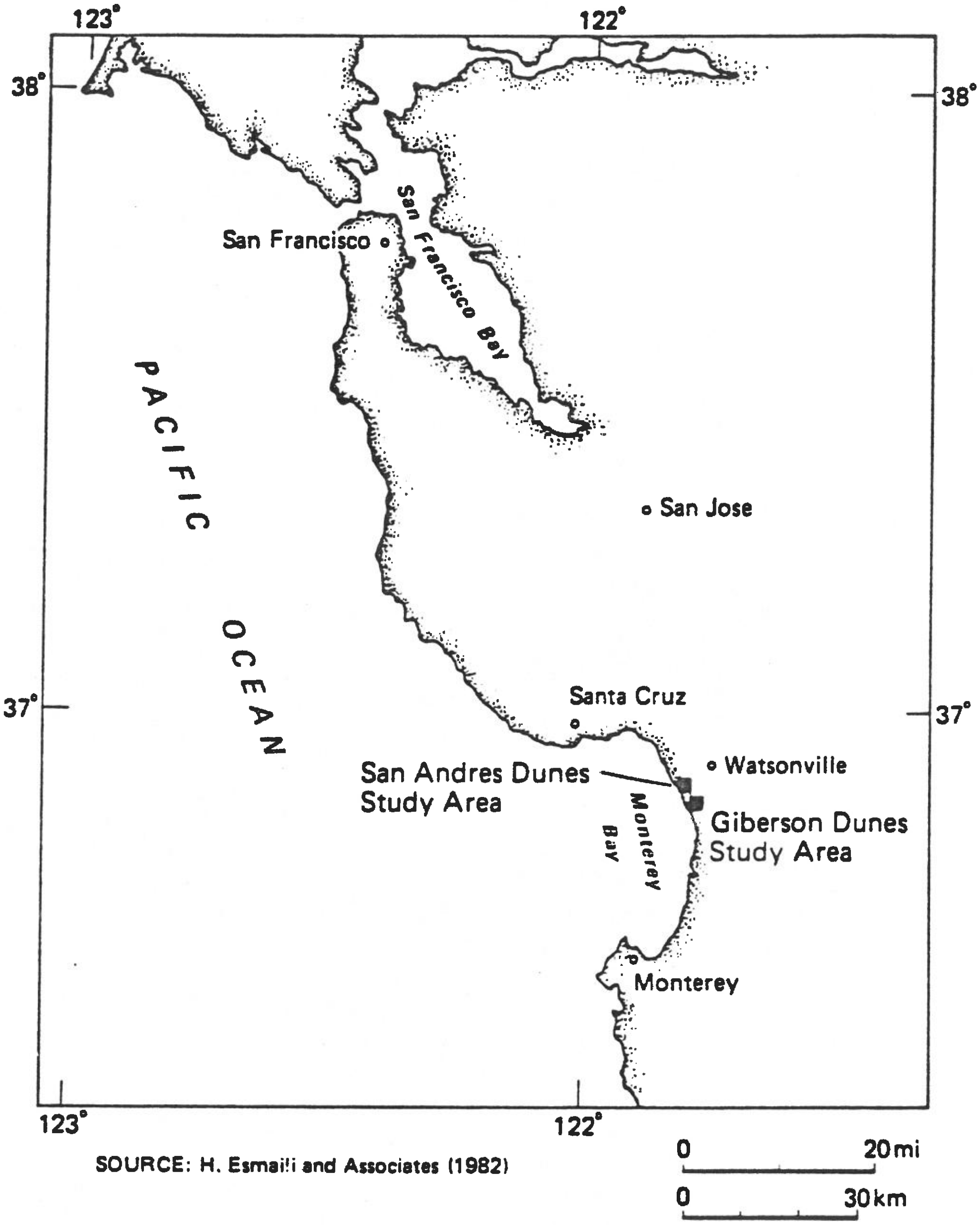
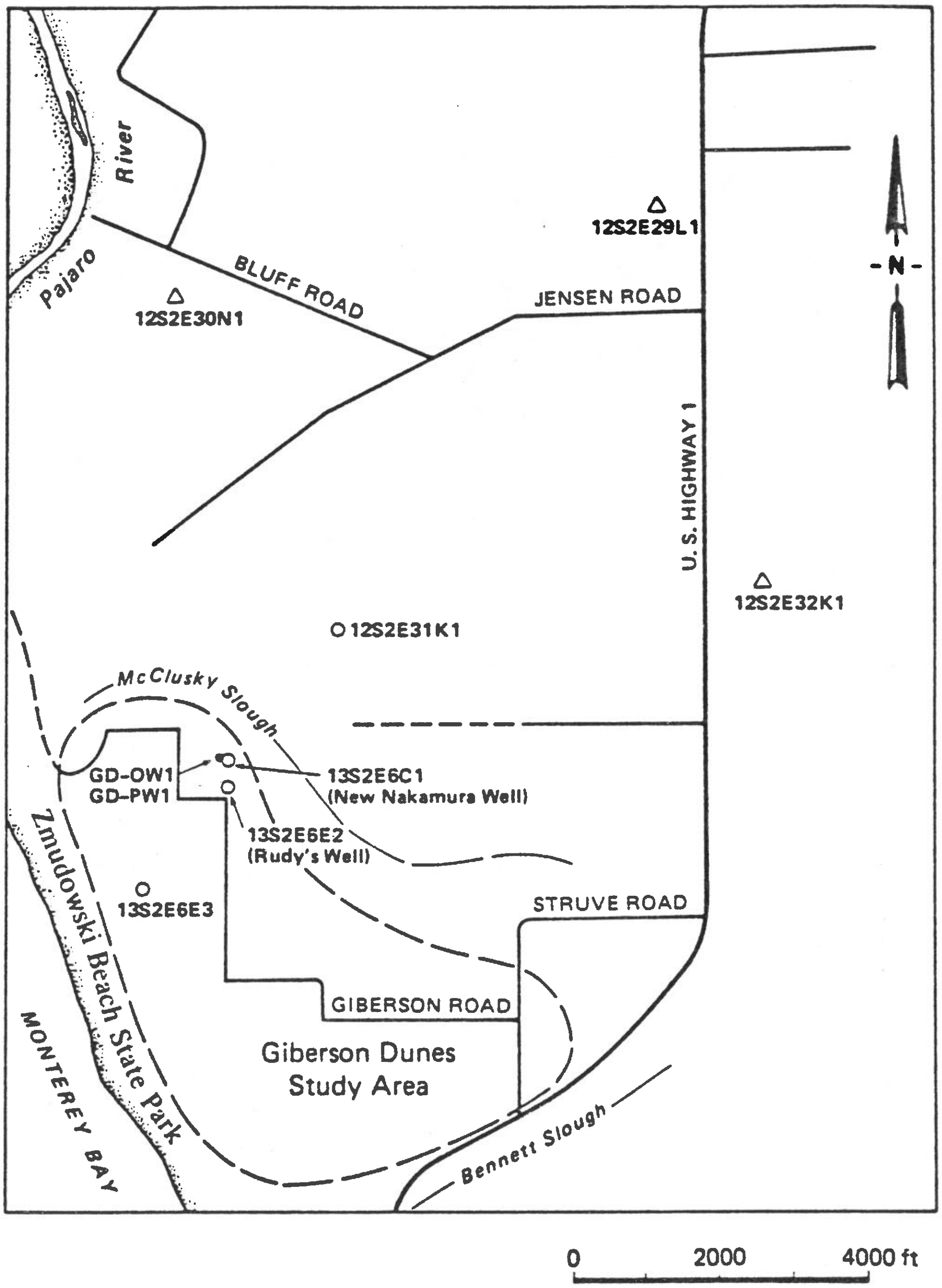
FIGURES



SOURCE: H. Esmaili and Associates (1982)

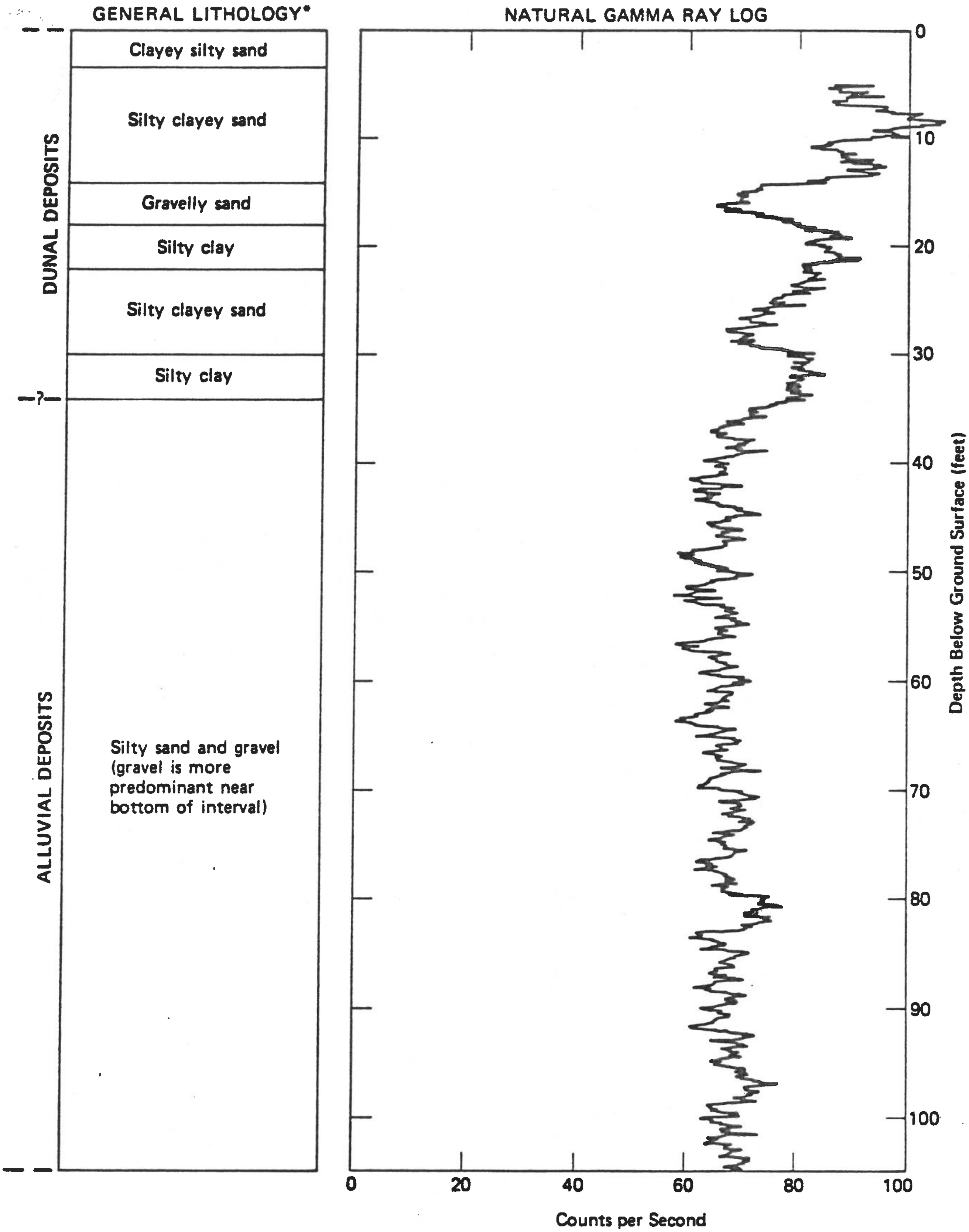
Project No. 15116A	Pajaro Valley	LOCATION OF GIBERSON DUNES AND SAN ANDRES DUNES STUDY AREAS	Figure 1
Woodward-Clyde Consultants			



EXPLANATION

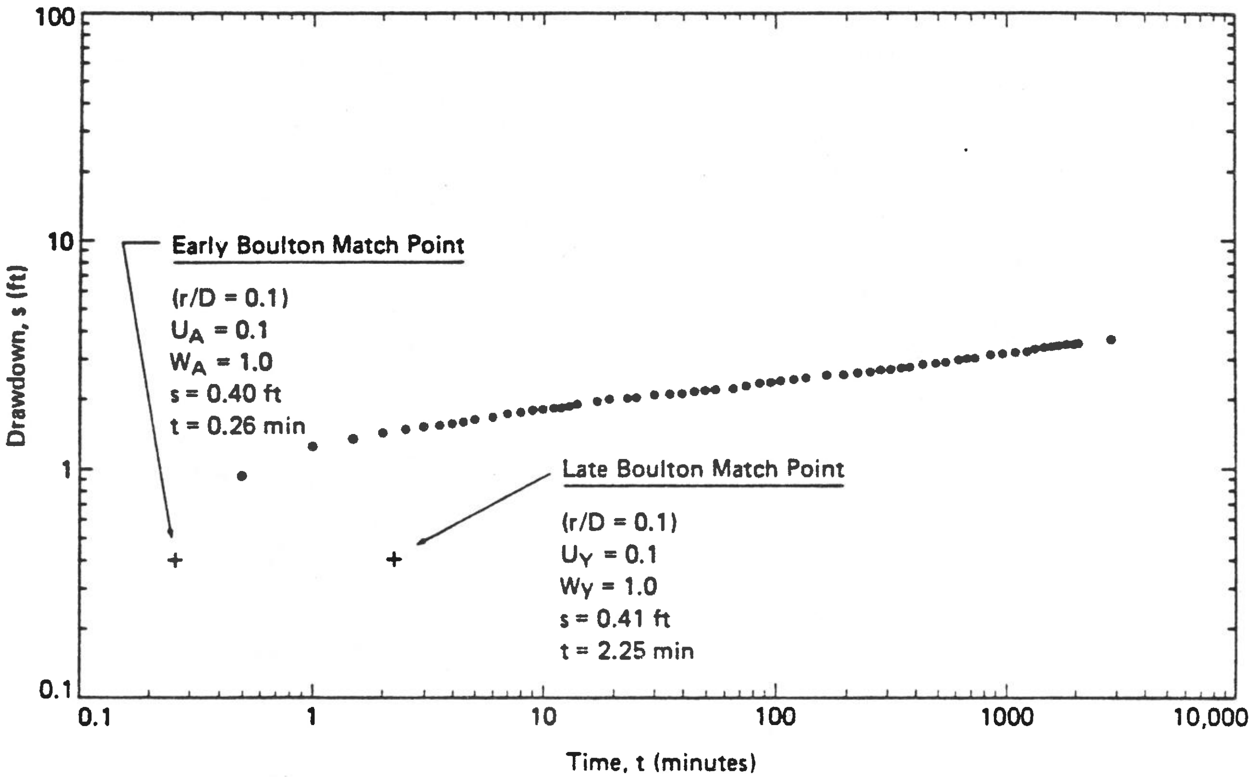
- • Location of WCC test holes
- o Location of well, state of California location number
- △ Approximate location of well, state of California location number
- — — Approximate boundary of Giberson Dunes Study Area

Project No. 15116A	Pajaro Valley	GIBERSON DUNES STUDY AREA AND VICINITY	Figure 2
Woodward-Clyde Consultants			



* General lithology is based on lithologic and gamma ray logs

Project No. 15116A	Pajaro Valley	NATURAL GAMMA RAY LOG AND GENERAL LITHOLOGY OF GD-OW1	Figure 3
Woodward-Clyde Consultants			



Q = 500 gpm, r = 39.5 ft, b = 103 ft

Early Time Boulton

$$T = \frac{114.6Q}{s} W_A = \frac{(114.6)\ (500)}{0.40}\ (1) = \underline{140{,}000\ \text{gpd/ft}}$$

$$K = T/b = \frac{140{,}000}{103} = \underline{1400\ \text{gpd/ft}^2}$$

$$S = \frac{TU_At}{1.87r^2} = \frac{(140{,}000)\ (0.1)\ (1.8 \times 10^{-4})}{1.87\ (39.5)^2} = \underline{8.6 \times 10^{-4}}$$

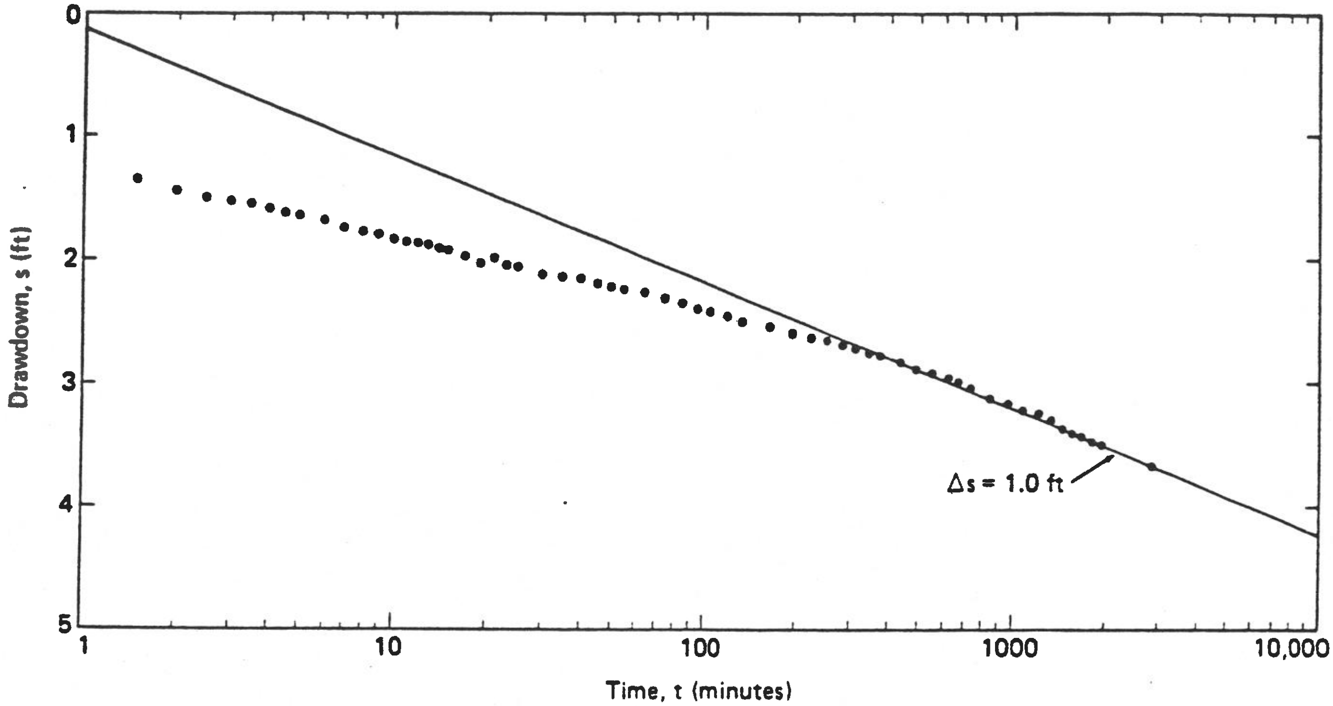
Late Time Boulton

$$T = \frac{114.6Q}{s} W_Y = \frac{(114.6)\ (500)}{0.41}\ (1) = \underline{140{,}000\ \text{gpd/ft}}$$

$$K = T/b = \frac{140{,}000}{103} = \underline{1400\ \text{gpd/ft}^2}$$

$$Sy = \frac{TU_Yt}{1.87r^2} = \frac{(140{,}000)\ (0.1)\ (1.6 \times 10^{-3})}{1.87\ (39.5)^2} = \underline{7.7 \times 10^{-3}}$$

Project No. 15116A	Pajaro Valley	LOG-LOGARITHMIC PLOT OF DRAWDOWN VERSUS TIME FOR GD-OW1 DURING CONSTANT DISCHARGE TEST OF NEW NAKAMURA WELL	Figure 4
Woodward-Clyde Consultants			



$Q = 500$ gpm, $r = 39.5$ ft, $b = 103$ ft

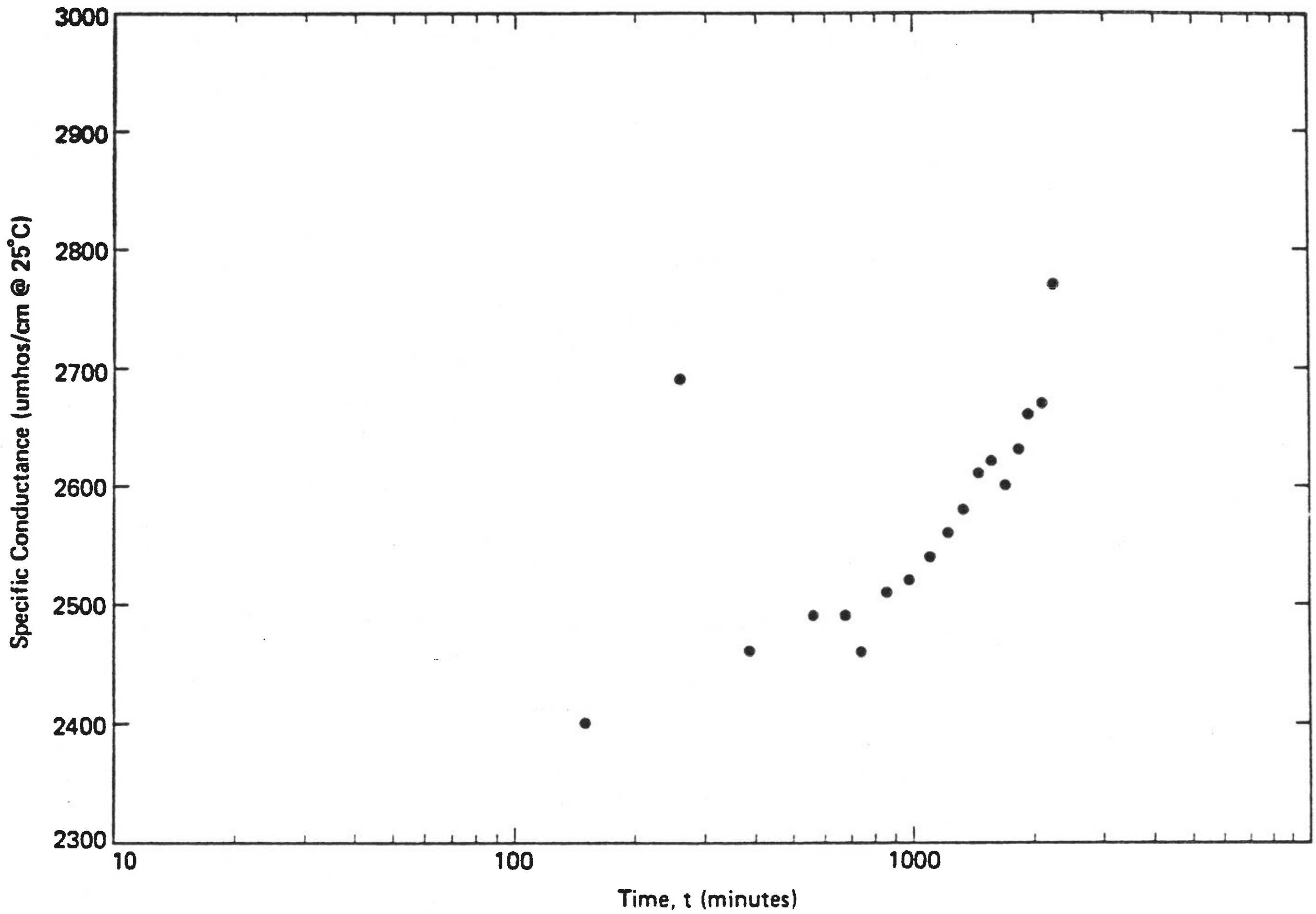
$\Delta s = 1.0$ ft, $t_o = 5.1 \times 10^{-4}$ days

$$T = \frac{264Q}{\Delta s} = \frac{264\ (500)}{1.0} = \underline{130{,}000 \text{ gpd/ft}}$$

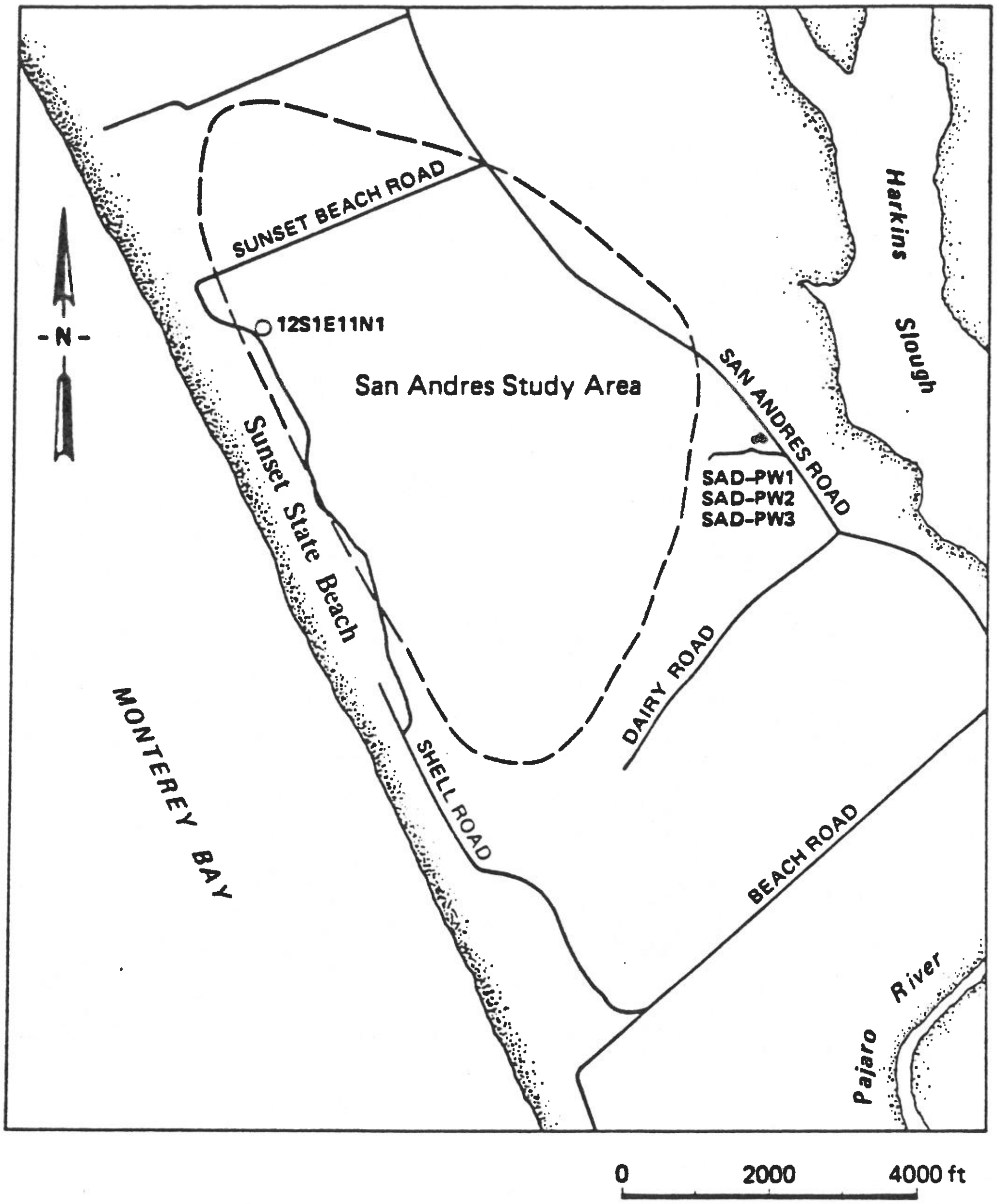
$$K = \frac{T}{b} = \frac{130{,}000}{103} = \underline{1300 \text{ gpd/ft}^2}$$

$$S_y = 0.3T\ (t_o/r^2) = 0.3\ (130{,}000)\ \frac{5.1 \times 10^{-4}}{39.5^2} = \underline{0.013}$$

Project No. 15116A	Pajaro Valley	SEMI-LOGARITHMIC PLOT OF DRAWDOWN VERSUS TIME FOR GD-OW1 DURING CONSTANT DISCHARGE TEST OF NEW NAKAMURA WELL	Figure 5
Woodward-Clyde Consultants			



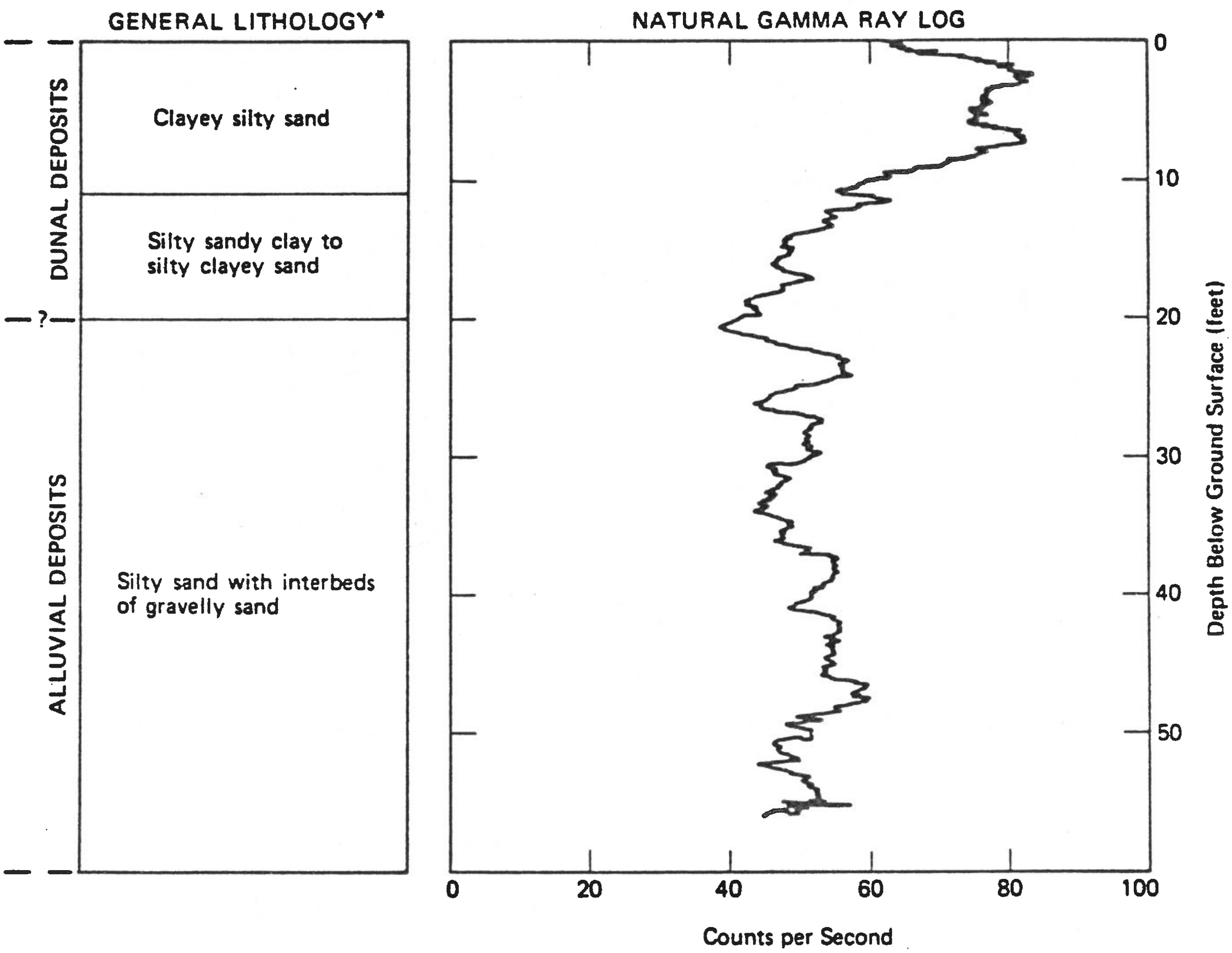
Project No. 15116A	Pajaro Valley	SPECIFIC CONDUCTANCE VERSUS TIME DURING CONSTANT DISCHARGE TEST OF NEW NAKAMURA WELL	Figure 6
Woodward-Clyde Consultants			



EXPLANATION

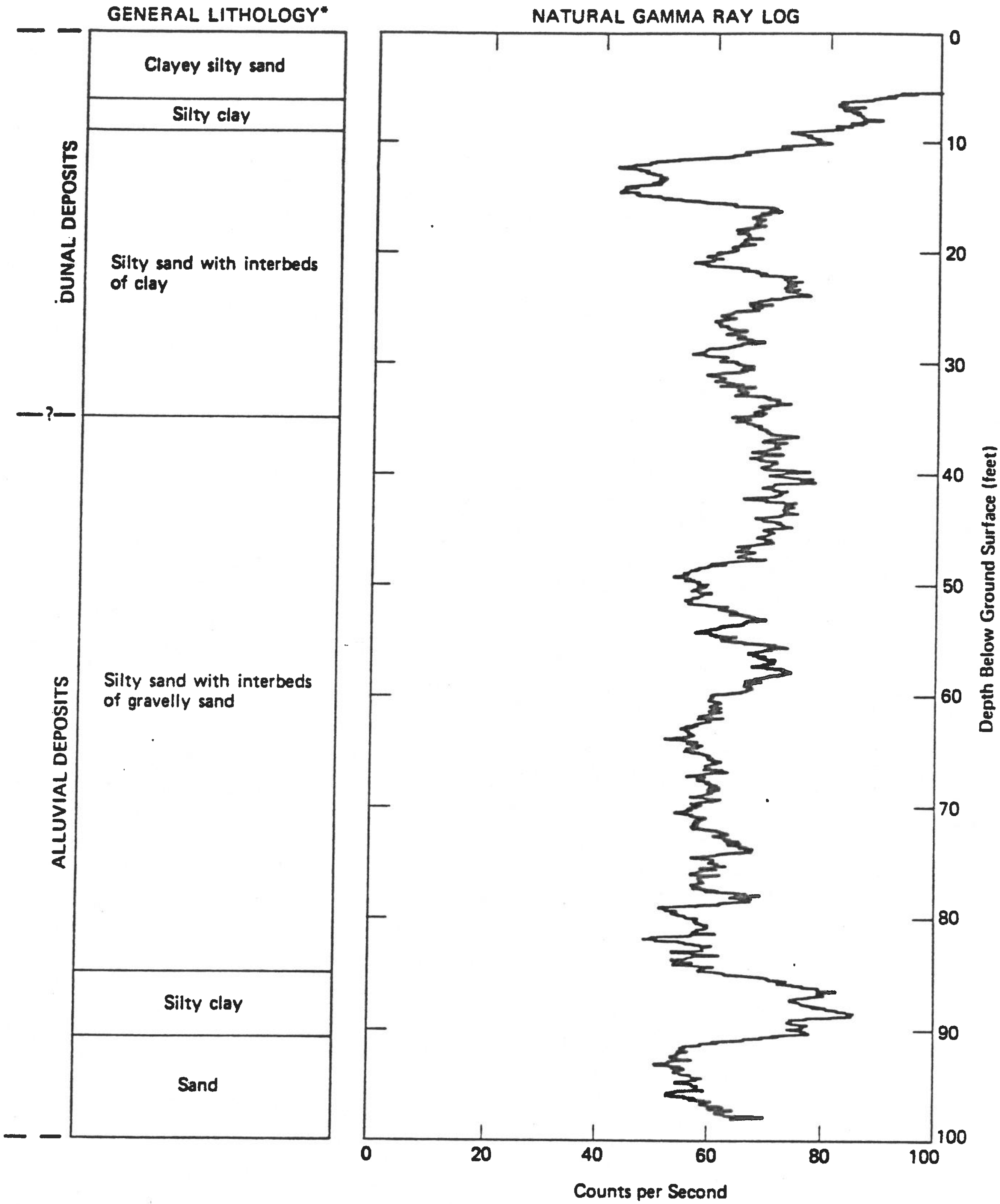
- • Location of WCC test holes
- o Location of well, state of California location number
- — — Approximate boundary of San Andres Dunes Study Area

Project No. 15116A	Pajaro Valley	SAN ANDRES DUNES STUDY AREA AND VICINITY	Figure 7
Woodward-Clyde Consultants			



* General lithology is based on lithologic and gamma ray logs

Project No. 15116A	Pajaro Valley	NATURAL GAMMA RAY LOG AND GENERAL LITHOLOGY OF SAD-PW1	Figure 8
Woodward-Clyde Consultants			



* General lithology is based on lithologic and gamma ray logs

Project No. 15116A	Pajaro Valley	NATURAL GAMMA RAY LOG AND GENERAL LITHOLOGY OF SAD-PW2	Figure 9
Woodward-Clyde Consultants			

APPENDIX A

BORING LOGS

APPENDIX A

TABLE OF CONTENTS

Woodward-Clyde Consultants

PROJECT NAME PAJARO NO. 15116A

BORING LOCATION: GIBERSON DUNES		ELEVATION AND DATUM: 20 ft (MSL) Estimated from topo map	
DRILLING AGENCY: Kleinfelder	DRILLER: BRUCE INCLAN	DATE STARTED / DATE FINISHED: 12/6 – 12/7	
DRILLING EQUIPMENT: Acker Truck mounted rig		COMPLETION DEPTH: 120 feet	SAMPLER: CALIF. MOD.
DRILLING METHOD: Hollow stem auger	DRILL BIT	NO. OF SAMPLES: DIST.	UNDIST. 2
SIZE AND TYPE OF CASING: 2-inch PVC		WATER ELEV.: FIRST	COMPL. 21.6 ft* 12-9-82
TYPE OF PERFORATION: Pre-Slotted 2" PVC	FROM 75 TO 105 FT.	LOGGED BY: Thomas Zakaria.	CHECKED BY: * from TOC
SIZE AND TYPE OF PACK: N/A	FROM TO FT.		
TYPE OF SEAL: NONE	FROM TO FT.		

DEPTH (FEET)	DESCRIPTION	GRAPHIC LOG: Lithology	GRAPHIC LOG: Piezometer Installation	Water Content	Piezometer Data	SAMPLES: Type No.	SAMPLES: Recov. ft.	SAMPLES: Penetra Resist (Blows/6 in.)	REMARKS (Drill Rate, Fluid loss, Odor, etc.)
0–3	silty sand, dk. brown, some clay (minor), silts ≈ 30-40%, sands ≈ 70-60%; sands mostly subrounded qrtz, vf to med grain size								start drilling 14.00.
3–14	silty clayey sand, lt. brown, sands med-coarse grained, 20-30% fines, 80-70% sands, some plasticity. cuttings shows increasing moisture. cuttings carries more coarser sands								

FIELD LOG OF BORING NO. GD-OW-1 SHEET 1 of 7

Woodward-Clyde Consultants

PROJECT NAME PAJARO NO 15116A

DEPTH (FEET)	DESCRIPTION	GRAPHIC LOG: Lithology	GRAPHIC LOG: Piezometer Installation	Water Content	Piezometer Data	SAMPLES: Type No	SAMPLES: Recov ft	SAMPLES: Penetra Resist (Blows/6 in)	REMARKS (Drill Rate, Fluid loss, Odor, etc)
15									
16									
17									
18	cuttings carries more gravels and coarse sand,								
19	sandy gravel/gravelly sand. gravels and sand subrounded to rounded, wet. ≈ 10% fines, 75% sands, 15% gravels upto 1/2 inch								
20									
21									
22									
23	cuttings carries more fines and clays								
24									
25	siltyclays, lt grey, mottled with iron oxide orange stains med. stiff, med stiff.								
26									
27	(real position of this silty clays might be ≈ 20 ft)								
28	?								
29									
30	silty clay, bluish gray, med plasticity med stiff, with plant remains at bottom of sampler silt clay with sand and oxide stains color.						X	3	
31							X	6	
32									

FIELD LOG OF BORING NO. GD-OW-1 SHEET 2 of 7

Woodward-Clyde Consultants

PROJECT NAME PAJARO NO. 15116A

DEPTH (FEET)	DESCRIPTION	GRAPHIC LOG: Lithology	GRAPHIC LOG: Piezometer Installation	Water Content	Piezometer Data	SAMPLES: Type No	SAMPLES: Recov ft.	SAMPLES: Penetra Resist (Blows/6 in.)	REMARKS (Drill Rate, Fluid loss, Odor, etc.)
33	no cuttings.								
34									
35									
36									
37	Cuttings as slurry								
38									
39	cuttings more sandy and come up as slurry, must be in saturated zone								
40	silty sands, wet, loose								tried to obtained sample, no recovery loose wet sands.
41									
42									
43									
44									not able to sample each time plug raised from hollow stem sands flows into hollow stem
45									
46	cuttings come up as sandy slurry								→
47									
48									
49									
50									

FIELD LOG OF BORING NO. GD-OW-1 SHEET 3 of 7

Woodward-Clyde Consultants

PROJECT NAME PAJARO NO. 15116A

DEPTH (FEET)	DESCRIPTION	GRAPHIC LOG: Lithology	GRAPHIC LOG: Piezometer Installation	Water Content	Piezometer Data	SAMPLES: Type No	SAMPLES: Recov ft	SAMPLES: Penetra Resist (Blows/6 in.)	REMARKS (Drill Rate, Fluid loss, Odor, etc.)
51									
52									
53									
54									
55									
56									
57									
58									
59									
60	Same as before								
61									
62									
63									
64									
65									
66									
67									
68									

FIELD LOG OF BORING NO. GD-OW-1 SHEET 4 of 7

Woodward-Clyde Consultants

PROJECT NAME PAJARO NO. 15116A

DEPTH (FEET)	DESCRIPTION	GRAPHIC LOG: Lithology	GRAPHIC LOG: Piezometer Installation	Water Content	Piezometer Data	SAMPLES: Type No.	SAMPLES: Recov. ft	SAMPLES: Penetra Resist (Blows/6 in.)	REMARKS (Drill Rate, Fluid loss, Odor, etc.)
69									
70									
71									
72									
73									
74									
75									
76									
77									
78									
79									
80									
81									
82									
83									
84	suspects, starts drilling into								(based on cuttings which contains gravel in slurry,
85	gravel's, subrounded - rounded gravels and sand.								which starts coming up when auger is at 95-100 ft depth
86									

FIELD LOG OF BORING NO. GD-OW-1 SHEET 5 of 7

Woodward-Clyde Consultants

PROJECT NAME PAJARO NO. 15116A

DEPTH (FEET)	DESCRIPTION	GRAPHIC LOG: Lithology	GRAPHIC LOG: Piezometer Installation	Water Content	Piezometer Data	SAMPLES: Type No	SAMPLES: Recov ft	SAMPLES: Penetra Resist (Blows/6 in.)	REMARKS (Drill Rate Fluid loss Odor, etc.)
87									
88									
89									
90									
91									
92									
93									
94									
95	Cutting slurry starts carrying gravels, rounded to subrounded, very coarse sand to pea gravel size								
96									
97									
98									
99									
100									
101									
102									
103									
104									

FIELD LOG OF BORING NO. GD-OW-1 SHEET 6 of 7

Woodward-Clyde Consultants

PROJECT NAME PAJARO NO. 15116A

DEPTH (FEET)	DESCRIPTION	GRAPHIC LOG Lithology	Piezometer Installation	Water Content	Piezometer Data	SAMPLES Type No	Recov. ft	Penetra. Resist. (Blows/6 in.)	REMARKS (Drill Rate, Fluid loss, Odor, etc.)
105									
106									
107									
108									
109									
110									
111									
112									
113									
114									
115									
116									
117									
118									
119	end of drilling.								
120	TD = 120 ft install observation well - 2" slotted PVC 75-105' - 2" solid PVC 0-75' logged inside PVC casing using gamma ray tool								

FIELD LOG OF BORING NO. GD-OW-1 SHEET 7 of 7

Woodward-Clyde Consultants

PROJECT NAME PAJARO NO. 15116 A

BORING LOCATION: GIBERSON DUNES		ELEVATION AND DATUM: 20 ft (MSL), Estimated from topo map	
DRILLING AGENCY: Kleinfelder	DRILLER: BRUCE INCLAN	DATE STARTED / DATE FINISHED: 12/7 – 12/7 /1982	
DRILLING EQUIPMENT: Acker Truck mounted drilling rig		COMPLETION DEPTH: 20 feet	SAMPLER: CALIF. MOD
DRILLING METHOD: Hollow Stem auger. 3¼" ID	DRILL BIT: 6¼" OD	NO. OF SAMPLES — DIST.:	UNDIST.: 0
SIZE AND TYPE OF CASING: 2-inch PVC		WATER ELEV. — FIRST:	COMPL.: 14.89 ft* / 24 HRS: 12-9-82
TYPE OF PERFORATION: Pre-slotted 2" PVC	FROM 10 TO 20 FT.	LOGGED BY: T ZAKARIA	CHECKED BY:
SIZE AND TYPE OF PACK: N/A	FROM TO FT.		* from TOC
TYPE OF SEAL: NONE	FROM TO FT.		

DEPTH (FEET)	DESCRIPTION	GRAPHIC LOG: Lithology	GRAPHIC LOG: Piezometer Installation	Water Content	Piezometer Data	SAMPLES: Type No	SAMPLES: Recov (ft)	SAMPLES: Penetra Resist (Blows/6 in.)	REMARKS (Drill Rate, Fluid loss, Odor, etc.)
0–3	silty clayey sand, dk brown, ≈30% fines, 70% sands, fine to med sands, subrounded to rounded, mostly quartz								Spud ± 10 ft from GD.CW#1
3–5	silty clayey sand as above but lt brown color and sand are of coarser size								
9–14	cuttings are sandy and of coarser size grains		screen 10–14+						

FIELD LOG OF BORING NO. GD-PW#1 SHEET 1 of 2

Woodward-Clyde Consultants

PROJECT NAME PAJARO NO. 15116 A

DEPTH (FEET)	DESCRIPTION	GRAPHIC LOG Lithology	GRAPHIC LOG Piezometer Installation	Water Content	Piezometer Data	SAMPLES Type No	SAMPLES Recov. ft	SAMPLES Penetra Resist (Blows/6 in.)	REMARKS (Drill Rate, Fluid loss, Odor, etc.)
15									
16									
17									
18									
19									
	TD= 20ft								
20	install PVC for percolation test 10-20ft slotted PVC 0-10 ft blank PVC annular space left open								

FIELD LOG OF BORING NO. GD-PW #1 SHEET 2 of 2

Woodward-Clyde Consultants

PROJECT NAME PAJARO NO. 15116A

BORING LOCATION SAN ANDRES DUNES, TAO'S property		ELEVATION AND DATUM 110 ft (MSL) estimated from topo map	
DRILLING AGENCY Kleinfelder & Ass.	DRILLER BRUCE MCCLAN	DATE STARTED / DATE FINISHED 11/30 - 12/1 /1982	
DRILLING EQUIPMENT Acker truck mounted drilling rig		COMPLETION DEPTH 55 feet	SAMPLER CALIF MOD.
DRILLING METHOD Hollow stem auger 3¼" ID	DRILL BIT 6¼" OD	NO. OF SAMPLES DIST.	UNDIST. 6
SIZE AND TYPE OF CASING 2" PVC		WATER ELEV. FIRST	COMPL. 52.2 ft* 24 HRS 12-7-82
TYPE OF PERFORATION Pre-Slotted 2" PVC	FROM 45 TO 55 FT.	LOGGED BY T. ZAKARIA.	CHECKED BY: *from TOC
SIZE AND TYPE OF PACK N/A	FROM TO FT.		
TYPE OF SEAL NONE	FROM TO FT.		

DEPTH (FEET)	DESCRIPTION	GRAPHIC LOG: Lithology	Piezometer Installation	Water Content	Piezometer Date	SAMPLES: Type No	Recov ft	Penetra Resist (Blows/6 in.)	REMARKS (Drill Rate, Fluid loss, Odor, etc.)
0–2	Silty sand, brown, (dune sand ?), loose fine to med grained, wellgraded ≈5-10% fines. sand grains mostly quartz, rounded to subrounded.								rig spud at NE corner of the Tao's strawberry field at ≈ 12.00 hrs weather cloudy, windy some rain. located ± 205 ft from centerline of the San Andres Rd.
7.5	silty sand as above but darker colored.								
11.5	silty clayey sand, dk. grey to black, wet/saturated, cuttings sticky and cohesive, increasing fines ≈ 20%								perched water ?
13.5	silty, sandy clay, olive/lite grey, sticky, med. stiff, med plasticity, includes plant remains, ≈ 50% sands ≈ 5% fines								

Depth scale: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

FIELD LOG OF BORING NO. SAD-PW # 1 SHEET 1 of 4

Woodward-Clyde Consultants

PROJECT NAME PAJARO　　NO. 15116A

DEPTH (FEET)	DESCRIPTION	GRAPHIC LOG: Lithology	GRAPHIC LOG: Piezometer Installation	Water Content	Piezometer Data	SAMPLES: Type No	SAMPLES: Recov. ft.	SAMPLES: Penetra. Resist. (Blows/6 in.)	REMARKS (Drill Rate, Fluid loss, Odor, etc.)
15	sandy silty clay, lt grey, ≈ 50% fines ≈ 50% sands						X	7	16-17' drive sample (MC sampler) soil samples saved in 2½" brass tubes.
							X	10	
16	. sands are of vf to med grain . med stiff med plasticity								
17									
18									
19									
20	silty sand　sample [illegible] sampler, shows as wet, sand loose)						C	14	20-21' sample [illegible]
							O	36	
21									
22	cuttings starts coming T as silty sand slurry lt grey color . vf to med grained sand, well sorted mostly quartz, [illegible] mafic minerals, ≈ 20-30% fines ↓ Color more brown								
23									
24									
25	clayey silty sand, lt. brownish grey sample not loose has some cohesive ness. sands mostly vf to f grained ≈ 30-40 silts sand grains are mostly . quartz, sub rounded to rounded fine texture, Sample damp & moist but not wet. ?						Y	6	
							Y	15	
26									
27									
28									
29									
30	clayey silty sand, lt brownish grey, f to med sand, mostly quartz sand. wet, ≈ 15% fines 85% sands						X	23	
							X	31	
31	clayey silty sand, brownish grey, with iron oxide orange stains, has appearance of weathered lithic material, includes angular lithic fragments upto ¼ inch size,								at this depth a water level of 4'3 11/30/82, 14:00 hrs
32									

FIELD LOG OF BORING NO. SAD-PW-1　　SHEET 2 of 4

Woodward-Clyde Consultants

PROJECT NAME PAJARO NO 15116A

DEPTH (FEET)	DESCRIPTION	GRAPHIC LOG: Lithology	GRAPHIC LOG: Piezometer Installation	Water Content	Piezometer Data	SAMPLES: Type No	SAMPLES: Recov ft	SAMPLES: Penetra Resist (Blows/6 in.)	REMARKS (Drill Rate, Fluid loss, Odor, etc.)
33–34	slurry like cuttings, silty clayey sand								at 15:00 hrs, starts raining
34–38									driller claim that hammer cannot be used to drive sampler during rain, to risk to safety to use catheads when its wet. Tried to obtained samples by pushing sampler with a hydraulic feed, but not successful. Decide to con[illegible] drilling [illegible]? [illegible]
37	clayey silty sand, reddish brown, loose, wet, fine to med grained quartz sands ≈ 5-20% fines?								
41	no cuttings, no samples drilling rate smooth and easy.								
46	thin gravell interbed?								rig rattles and bounces.
47–48	drilling continues smoothly								
50									drilling starts developing problems with plug being stuck in hollow stem auger.

FIELD LOG OF BORING NO. SAD-PW-4 SHEET 3 of 4

Woodward-Clyde Consultants

PROJECT NAME: PAJARO   NO. 15116A

DEPTH (FEET)	DESCRIPTION	GRAPHIC LOG: Lithology	GRAPHIC LOG: Piezometer Installation	Water Content	Piezometer Data	SAMPLES: Type No	SAMPLES: Recov ft.	SAMPLES: Penetra Resist (Blows/6 in.)	REMARKS (Drill Rate, Fluid loss, Odor, etc.)
51									
52									
53									
54									
55									
56									* [illegible] to get [illegible] unstuck. flowing sand immediately [illegible] hollowstem to ± 5 ft
57									* driller was not able to [illegible] auger's when he tried to get [illegible] at the bottom of hollowstem
58–60	Coarse sand and fine gravel in sandy silty matrix (from material stuck to auger bit)								* drawworks drum slipping because it's wet by the rain * decides to continue drilling [illegible]
60	TD = 60 ft install Ø 2" PVC casing. 45-55 feet slotted PVC 0-45 feet solid PVC annular space left open, and partly filled by natural sluffed material of bore hole wall								12/1/80 * get plug [illegible] * start to continue drilling. * driller discovers that rig [illegible] hydraulic down pressure * rig must be repaired before it can continue drilling * trip out [illegible] * install PVC casing * gamma ray [illegible]

FIELD LOG OF BORING NO. SAD-PW-1   SHEET 4 of 4

Woodward-Clyde Consultants

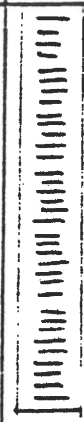
PROJECT NAME PAJARO NO. 15116A

DEPTH (FEET)	DESCRIPTION	GRAPHIC LOG: Lithology	GRAPHIC LOG: Piezometer Installation	Water Content	Piezometer Data	SAMPLES: Type No	SAMPLES: Recov ft	SAMPLES: Penetra Resist (Blows/6 in.)	REMARKS (Drill Rate, Fluid loss, Odor, etc.)
51									
52									
53									
54									
55									
56									* [illegible] to get a unstuck flowing sand immediately [illegible] hollowstem to 55ft
57									* [illegible] was not able to [illegible] augers when he tried to get [illegible] at the bottom of hollowstem
58	Coarse sand and fine gravel in sandy silty matrix (from material stuck to auger bit)								* drawworks drum slipping because its wet by the rain
59									* decided to continue drilling next day.
60	TD=60ft								12/1/85
	install Ø2" PVC casing 45-55 feet slotted PVC 0-45 feet solid PVC annular space left open, and partly filled by natural sluffed material of bore hole wall								* get plug [illegible] * start to continue drilling. * driller discovered that rig [illegible] its hydraulic down pressure * rig must be repaired before it can continue drilling * trip out [illegible] * install PVC casing * [illegible]

FIELD LOG OF BORING NO. SAD-PW-1 SHEET 4 of 4

Woodward-Clyde Consultants

PROJECT NAME PAJARO   NO 15116A

DEPTH (FEET)	DESCRIPTION	GRAPHIC LOG: Lithology	GRAPHIC LOG: Piezometer Installation	Water Content	Piezometer Data	SAMPLES: Type No	SAMPLES: Recov ft	SAMPLES: Penetra Resist (Blows/6 in.)	REMARKS (Drill Rate, Fluid loss Odor, etc.)
51									
52									
53									
54									
55									
56									* [illegible] to get [illegible] unstuck flowing sand immediately [illegible] hollow stem to ± 58 ft
57									* [illegible] was not able to [illegible] augers [illegible] to get [illegible] at the bottom of hollow stem
58	Coarse sand and fine gravel in sandy silty matrix (from material stuck to auger bit).								* drawworks drum slipping because it's wet by the rain
59									* decides to continue drilling [illegible]
60	TD = 60 ft								12/1/80
	install Ø 2" PVC casing								* get plug [illegible]
	45-55 feet slotted PVC								* start to continue drilling.
	0-45 feet solid PVC								* driller discovers that rig [illegible] hydraulic down pressure
	annular space left open, and partly filled by natural sluffed material of bore hole wall								* rig must be repaired before it can continue drilling
									* trip out [illegible]
									* install PVC casing
									* [illegible]

FIELD LOG OF BORING NO. SAD-PW-1   SHEET 4 of 4

Woodward-Clyde Consultants

PROJECT NAME: PAJARO — NO. 15116A

BORING LOCATION: SAN ANDRES DUNES		ELEVATION AND DATUM: 700 ft (MSL), Estimated from topo map	
DRILLING AGENCY: KLEINFELDER	DRILLER: BRUCE INCLAN	DATE STARTED / DATE FINISHED: 12/7 – 12/8 /82	
DRILLING EQUIPMENT: ACKER TRUCK MOUNTED RIG		COMPLETION DEPTH: 98 feet	SAMPLER: CALIF. MOD
DRILLING METHOD: Hollow stem auger	DRILL BIT: ϕ 6¼"	NO. OF SAMPLES — DIST.:	UNDIST.: 4
SIZE AND TYPE OF CASING: 2-inch PVC		WATER ELEV. — FIRST:	COMPL.: 47.72 ft* — 24 HRS.: 12-9-82
TYPE OF PERFORATION: Pre-slotted 2" PVC	FROM 88 TO 98 FT.	LOGGED BY: T. ZAKARIA	CHECKED BY:
SIZE AND TYPE OF PACK: N/A	FROM TO FT.		
TYPE OF SEAL: NONE	FROM TO FT.		* from TOC

DEPTH (FEET)	DESCRIPTION	GRAPHIC LOG: Lithology	GRAPHIC LOG: Piezometer Installation	Water Content	Piezometer Data	SAMPLES: Type No.	SAMPLES: Recov. ft.	SAMPLES: Penetra Resist (Blows/6 in.)	REMARKS (Drill Rate, Fluid loss, Odor, etc.)
0	silty sand, dk brown, (dune sand) fine to med grained sub. rounded - rounded sands mostly qrtz, some mafic minerals ≈ 15% fines. 85% sands								located 45 feet from center line of San Andres Rd at [illegible]
7	cuttings carries dk grey, silty clays								
10	sandy silty clay / clayey silt, grey with iron oxide stains						X	①	
							X		
11	silty clay sands, reddish brown								

FIELD LOG OF BORING NO. SAD-PW-2 — SHEET 1 of 6

Woodward-Clyde Consultants

PROJECT NAME PAJARO NO. 15116A

DEPTH (FEET)	DESCRIPTION	Lithology	Piezometer Installation	Water Content	Piezometer Data	Type No	Recov ft.	Penetra Resist (Blows/6 in.)	REMARKS (Drill Rate, Fluid loss, Odor, etc.)
15	color changes to lt grey silty clayey sands.								
19–20	cuttings come out as slurry, wet. silty sands, lt grey								
25	silty sand, lt grey, coarse grained, subrounded-rounded, loose, wet, mostly qtz grains with iron oxide stains						X	28	
							X	35	
30	silty sands, olive grey - brownish grey, and lite grey matrix ≈ 5-10% silts ≈ 90% sands, med to coarse, subrounded-rounded, mostly qtz grains.								

FIELD LOG OF BORING NO. SAD-PW-2 SHEET 2 of 6

Woodward-Clyde Consultants

PROJECT NAME PAJARO NO. 15116A

DEPTH (FEET)	DESCRIPTION	GRAPHIC LOG: Lithology	GRAPHIC LOG: Piezometer Installation	Water Content	Piezometer Data	SAMPLES: Type No	SAMPLES: Recov ft	SAMPLES: Penetra Resist (Blows/6 in)	REMARKS (Drill Rate, Fluid loss, Odor, etc)
33–35	drill rig occasionally bounced, indication of more gravelly beds (thin beds)								
35–40	gravelly sands, silty and some (clay?) angular fragments mixed with subrounded - gravels and sands very poor graded, ±15% fines, 50% sands, 35% gravels. grey brown matrix color with iron oxide staining coloring								
40–41	silty clay, lt brownish grey, thin beds?, med plast, med stiff.								
41–45	silty, gravelly, sands, brownish grey + iron oxide stains								
45–50	very coarse sands + gravels up to 1 inch ϕ. damp (not as clumpy) ±40% gravels, 55% sands, 5% fines } rel. loose. gravel fragments consist of sandstone pebbles + dk intrusive components.								
50	sands, grey, very coarse to coarse relatively well graded								

FIELD LOG OF BORING NO. SAD-PW-2 SHEET 3 of 6

Woodward-Clyde Consultants

PROJECT NAME PAJARO NO. 15116A

DEPTH (FEET)	DESCRIPTION	GRAPHIC LOG: Lithology	GRAPHIC LOG: Piezometer Installation	Water Content	Piezometer Data	SAMPLES: Type No	SAMPLES: Recov ft	SAMPLES: Penetra Resist (Blows/6 in.)	REMARKS (Drill Rate, Fluid loss, Odor, etc.)
51	subrounded - rounded, qtz grains predominant, wet / saturated ,								
52									
53	cuttings starts coming out as slurry of sand.								Sampling is difficult every time plug raised from hollow stem, augers filled up with flowing sand.
54									
55									
56									
57									tried at 55-56, 60-61, 75-76, 80-81
58									
59									decide to drill without sampling. install piezometer in well at 100 ft
60									
61									
62									
63	no distinctive changes observed in cuttings.								
64									
65									
66									
67									
68									

FIELD LOG OF BORING NO. SAD-PW-2 SHEET 4 of 6

Woodward-Clyde Consultants

PROJECT NAME PAJARO NO. 15116A

DEPTH (FEET)	DESCRIPTION	GRAPHIC LOG: Lithology	GRAPHIC LOG: Piezometer Installation	Water Content	Piezometer Data	SAMPLES: Type No	SAMPLES: Recov ft	SAMPLES: Penetra Resist (Blows/6 in.)	REMARKS (Drill Rate, Fluid loss, Odor, etc.)
69									
70									
71									
72									
73									
74									
75									
76									
77									
78									
79									
80									
81									
82									
83									
84									
85									
86									

FIELD LOG OF BORING NO. SAD-PW-2 SHEET 5 of 6

Woodward-Clyde Consultants

PROJECT NAME PAJARO   NO. 15116A

DEPTH (FEET)	DESCRIPTION	GRAPHIC LOG: Lithology	GRAPHIC LOG: Piezometer Installation	Water Content	Piezometer Data	SAMPLES: Type No.	SAMPLES: Recov ft	SAMPLES: Penetra. Resist (Blows/ 6 in.)	REMARKS (Drill Rate, Fluid loss, Odor, etc)
87									
88									
89									
90									
91									
92									
93									
94									
95									
96									
97									
98									
99									
100	TD=100ft								

in led PVC.

88-98 ft slotted PVC

0-88 solid PVC.

and logged by gamma ray taol inside PVC casing.

FIELD LOG OF BORING NO. SAD-PW-2   SHEET 6 of 6

Woodward-Clyde Consultants

PROJECT NAME: PAJARO — NO. 15116A

BORING LOCATION: SAN ANDRES DUNES		ELEVATION AND DATUM: 700 ft (MSL) Estimated from topo map	
DRILLING AGENCY: Kleinfelder	DRILLER: BRUCE INCLAN	DATE STARTED / DATE FINISHED: 12/7 – 12/7/82	
DRILLING EQUIPMENT: Acker truck mounted drilling rig		COMPLETION DEPTH: 20 feet	SAMPLER: CALIF. MOD.
DRILLING METHOD: hollow stem auger	DRILL BIT: 6 1/4" OD	NO. OF SAMPLES: DIST.	UNDIST. 2
SIZE AND TYPE OF CASING: 2-inch PVC		WATER ELEV.: FIRST	COMPL. 11.75 ft* 24 HRS 12-9-82
TYPE OF PERFORATION: Pre-slot 2" PVC	FROM 10 TO 20 FT.	LOGGED BY: T. ZAKARIA	CHECKED BY:
SIZE AND TYPE OF PACK: N/A	FROM TO FT.		
TYPE OF SEAL: NONE	FROM TO FT.		* from TOC

DEPTH (FEET)	DESCRIPTION	Lithology	Piezometer Installation	Water Content	Piezometer Data	Type No	Recov ft	Penetra Resist (Blows/6 in.)	REMARKS (Drill Rate, Fluid loss, Odor, etc.)
0–1	Silty sand, dk brown, fine to med grained, subrounded - rounded quartz sand grains.								Spud ± 5 ft from SAD-PW-2
5	grades to more dk brown color								
~6.5	---								
7	Silty clay, black, med stiff, med plasticity, includes plant remains.						X	6	
8							X	9	
9	Silty clayey sand, brownish grey with med ironoxide stains. cohesive matrix, moist - damp sands fine to med grained ≈20-25% fines								
10–14			slotted screen						
13	Grades to more grey color								

FIELD LOG OF BORING NO. SAD-PW-3 — SHEET 1 of 2

Woodward-Clyde Consultants

PROJECT NAME PAJARO NO. 15116A

DEPTH (FEET)	DESCRIPTION	GRAPHIC LOG: Lithology	GRAPHIC LOG: Piezometer Installation	Water Content	Piezometer Data	SAMPLES: Type No.	SAMPLES: Recov. ft.	SAMPLES: Penetra Resist (Blows/6 in.)	REMARKS (Drill Rate, Fluid loss, Odor, etc.)
15	silty sands, lt grey, fine - med grained mostly quartz sands								
16									
17									
18									
19									
20	TD = 20 ft								
	install ø 2" PVC for percolation test. 10-20 ft slotted PVC 0-10 ft solid PVC annular space left open								

FIELD LOG OF BORING NO. SAD-PW-3 SHEET 2 of 2

APPENDIX B

INFILTRATION TEST DATA AND CALCULATIONS

APPENDIX B

INFILTRATION TEST DATA AND CALCULATIONS

The infiltration test data were analyzed using an equation presented in the Earth Manual by the U.S. Bureau of Reclamation (1968) under "Field Permeability Test", designation E-19. The equation for Condition III was used which requires that the height of the water in the test well be greater than the amount of head applied during the performance of the test. For the estimation of the coefficient of permeability (or infiltration rate) under such a condition, the following equation was used:

$$K = \frac{525{,}600 \frac{Q}{2\pi} \log_e (h/r)}{h^2 \left[\left(\frac{h}{T_u}\right)^{-1} - \frac{1}{2} \left(\frac{h}{T_u}\right)^{-2} \right]} \left(\frac{\mu_t}{\mu_{20}} \right)$$

where, K = coefficient of permeability, feet per year;

h = height of water in test well (distance from constant head level to base of test well) feet;

T_u = amount of head applied above static water level during steady-state conditions, feet;

r = radius of well, feet;

Q = discharge rate of water to test well for steady-state (constant head) conditions, cubic feet per minute;

μ_t = viscosity of water at measured temperature, T; and

μ_{20} = viscosity of water at 20° C.

For all calculations, μ_t / μ_{20} was assumed to be equal to 1.

The results of calculations using the test data and the equation for Condition III follow for SAD-PW1, SAD-PW2, and SAD-PW3. For each test common datums were used for measurements of depth to water.

The test results are presented below.

SAD-PW1

Data

Depth to static water level: 50.88 feet

Depth of borehole: 55 feet

Depth to constant head level during test: 0.17 feet

$r = 0.260$ feet

$Q = 1.2$ gpm $= 0.16$ ft^3/min

Calculations

$h = 54.83$ feet

$T_u = 50.71$ feet

$K = 48$ feet/year $=$ 4.6×10^{-5} cm/sec

SAD-PW2

Data

Depth to static water level: 47.67 feet

Depth of borehole: 98 feet

Depth to constant head level during test: 40.25 feet

$r = 0.260$ feet

$Q = 4.38$ gpm $= 0.586\ ft^3/min$

Calculations

$h = 57.75$ feet

$T_u = 7.42$ feet

$K = 660$ feet/year $= \underline{6.4 \times 10^{-4}\ cm/sec}$

SAD-PW3

Data

Depth to static water level: 9.58 feet

Depth of borehole: 20 feet

Depth to constant head level during test: 0.66 feet

$r = 0.260$ feet

$Q = 2.08$ gpm $= 0.278$ ft^3/min

Calculations

$h = 19.34$ feet

$T_u = 8.92$ feet

$K = 750$ feet/year $=$ 7.3×10^{-4} cm/sec

APPENDIX D

HYDRAULIC CHARACTERISTICS OF RECHARGE MOUNDS

APPENDIX D

HYDRAULIC CHARACTERISTICS OF RECHARGE MOUNDS

In the absence of a comprehensive digital model of the groundwater basin, analytical discussion of the hydraulic characteristics of recharge mounds is of necessity confined to idealized conditions which are amenable to mathematical solutions. In general, the geology of the San Andres Dunes area and the interface between the dunes and the underlying terrace deposits with the alluvial aquifer is very complex and the characteristics of any recharge mound created in this area would not be amenable to simple mathematical solutions. The Springfield area on the other hand has a more simple geology and the aquifer to be recharged lies directly under the potential spreading basins. For these reasons, the fate of the recharge mound could be more easily evaluated in this area. A brief discussion on the expected configuration of the mounds and their impact on the target aquifers is presented in the following sections.

San Andres Dunes Area. In this area, the recharge sites would be located in dune hills at sites having a desirable soil and geologic characteristic and requiring the minimum pumping lift for the applied water. A hypothetical diagram of the actual water table in this area is shown in Figure 1. Idealized analytical solutions for mounds of this type have been presented in the literature (Baumann, 1965). The recharge mound may either have a two dimensional or three dimensional geometry depending on the shape of the spreading basin. Long rectangular spreading basins lying perpendicular to the natural direction of groundwater flow create a two dimensional mound whereas equidimensional spreading basins create a three dimensional mound. Due to the geologic complexity of San Andres Dunes area and because of the need for recharging the alluvial aquifer along an extended front, it is concluded that a strip recharge basin or a number of such basins would be most desirable for this area. The alluvial aquifer under the valley floor is confined by thick deposits of clay and silt, however, this aquifer interfaces with the dunes and terrace deposits from the ground surface to a depth of about 200 feet along the northern edge of the valley floor. It is probable that rainfall on sand dunes is a significant source of recharge to the alluvial aquifer. Any groundwater mound created in the dunes by surface spreading could increase the subsurface flow of water from the dunes and terrace deposits into the alluvial aquifer and it would offset the existing pumping cone in direct proportion to the volume of water recharged into the ground.

When water is recharged into the ground through a strip spreading basin, a mound wave is created which grows in magnitude until a boundary is reached. This boundary could either consist of a lateral control such as a trench or a well field or a potential control such as the surface of the spreading basin. In the presence of a lateral control, the mound grows in height until it reaches the surface of the spreading ground and a so-called potential flow regime will develop. If recharge is discontinued at any stage, the mound will drain itself in the course of time provided that there is a lateral control - or a point of extraction from the mound. In the San Andres area, a lateral

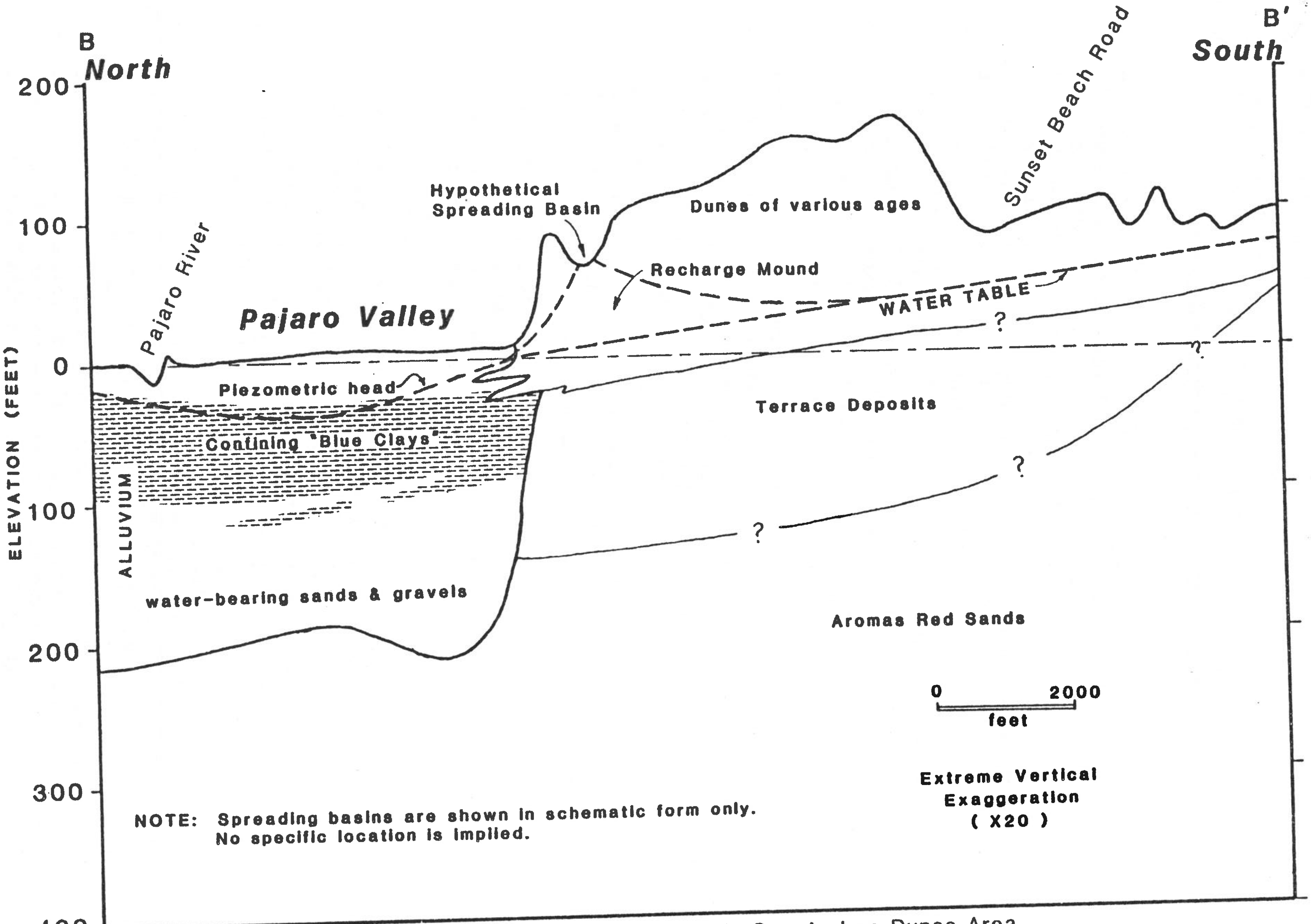


Figure 1. Estimated configuration of recharge mounds in San Andres Dunes Area.

control exists due to topographic conditions of the area as shown in Figure 1 where the dunes interface with the less permeable upper portions of the alluvium. An unknown volume of any recharged water may be lost by drainage into sloughs or into the perched tables in the alluvium. This loss may be amenable to control by proper siting of the recharge basins and by regulating the spreading cycles to avoid excessive build-up of the mound in areas close to the edge of the valley floor.

Mathematical Solutions for Recharge Mounds. A simplified differential equation expressing the change in the combined height of the mound and the native groundwater as a function of time has been proposed as follows:

$$\frac{\partial y}{\partial t} = \frac{K}{\mu} \left(a_o \frac{\partial^2 y}{\partial x^2} - i \frac{\partial y}{\partial x}\right)$$

The geometric relationships used in this equation are shown graphically in Figure 2. Other parameters in the above equation are as follows: K = coefficient of hydraulic conductivity, a = saturated depth of the aquifer, = specific yield of the geologic formation, and i = slope of the impermeable stratum underlying the water bearing formation. Various solutions have been proposed for this equation based on differing simplifying assumptions and analytical procedures. One such solution for a stable mound is as follows:

$$y' = \left(\frac{L}{\pi}\right) \frac{H}{L_u L_d} \sum_{n=1}^{n=\infty} \frac{\cos (n\pi x/L) - (-1)^n \cos (n\pi(x+Lu-Ld/L)}{n^2}$$

in which $-L_u < x < L_d$ and $L_u + L_d = L$

Other geometric relationships are shown in Figure 2b.

A simplified linear approximation for the maximum mound height can be obtained from the following three equations:

1. Zone III - In this zone,

$$y' = \left(\frac{q}{Ka_o} - i\right) (L_d - x)$$

in which y' = mount height and q = the unit rate of recharge through a one foot long segment of the spreading basin.

2. Zone II - In this zone the mound surface is considered parallel to, and the distance H above the initial groundwater surface. H can be calculated from the equation for Zone III at a distance x = o.

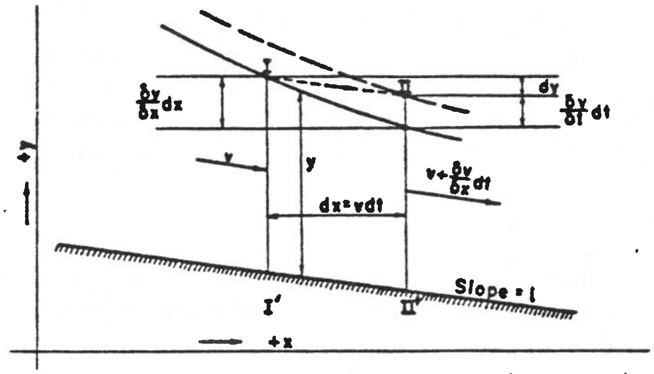


Figure 2a. Partial profile of unsteady groundwater prism

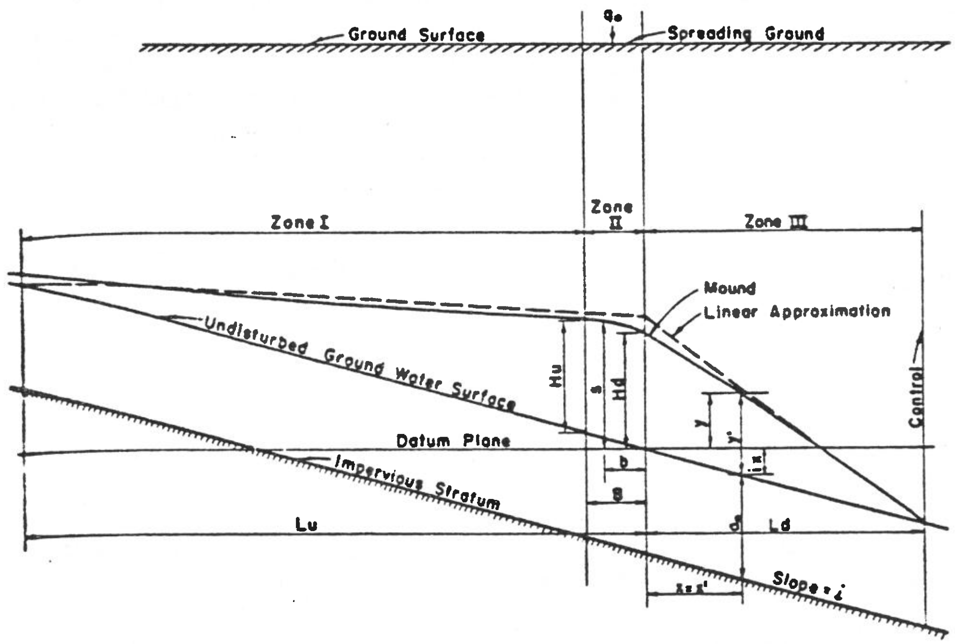


Figure 2b. Straight line approximation of stable mound for i≠0

Source: Baumann, 1965.

The numerical values derived here are highly speculative and are based on the assumption that all of the recharged water will go into storage in the mound. In reality, there is a significant pumping trough under the valley floor and pumping from the aquifer is carried out almost year-round in this part of the valley. Also, a recharge operation in the dunes may result in direct seepage from the resulting mound into sloughs and surface drainage ditches. Therefore, the recharge mound may never reach the dimensions shown above even if that were in the realm of physical possibility. Instead, the recharge mound may stabilize at much smaller dimensions under conditions in which the outflow to the pumping cone and seepage into sloughs would almost equal the rate of recharge from the spreading basin. A significant amount of water recharged in this area may flow out to the Monterey Bay. Also, subsurface clay layers may cause the creation of perched water tables and lateral spreading of the recharge mound away from the intended target aquifer.

As indicated previously, the rate of recharge through a 100 square feet strip of the spreading basin in San Andres Dunes area would be about 1.83 acre-feet per year (assuming 200 days of active recharge), therefore, if it is desired to recharge about 5,000 acre-feet per year into the ground at this site, the required area of spreading basins would be about 6.27 acres assuming a recharge efficiency of 100 percent. The feasibility of recharging such a large volume of water into the alluvial aquifer from San Andres Dunes area is doubtful. Moreover, the existence of intermittent clay layers in the Dunes and the significant elevation difference between the Dunes and the alluvium may mitigate against successful recharge of the target aquifers from this area.

Springfield Area. In the Springfield area, recharge operations can be carried out either in the Giberson Dunes area or in the lower Springfield Mesa. Giberson Dunes area has highly permeable oceano soils with a permeability value in the range of 6 to 20 inches per hour. Relatively few horizons of fine textured materials were encountered in the observation holes drilled at this site. Also, the aquifer tests indicated that the water bearing formations have a satisfactory hydraulic continuity in the general Giberson Dunes area.

The lower Springfield Mesa contains top soils with more restricted permeability and requires a higher pumping lift for the recharge waters. However, it may be possible to attain satisfactory rates of recharge on selective soils in this area. At depths greater than 80 to 100 feet, the subsurface conditions should be similar to those in the Giberson Dunes area. Little is known about the characteristics of the upper 80 feet of sediments in this area. The major advantage of this area over Giberson Dunes is that none of the recharged water would be lost to the sea or sloughs, and could be recharged into the center of the Springfield area cone of depression. Additional geologic exploration is indicated if this alternative is to be pursued.

If the recharge basins are located along the longitudinal axis of the cone of depression, the recharge mound would have a symmetrical bell shaped form in the absence of active pumping. Pumping, however, would affect the shape of the mound to an unknown extent. A schematic diagram of a recharge mound superimposed on the groundwater table in the lower Springfield Mesa is shown in Figure 3.

Land area requirements for spreading basins which would enable the recharge of 3500 acre-feet of water per year in this area may range between 5 to 40 acres depending on the sustained rate of infiltration that can be maintained in the spreading basins.

If spreading facilities are located in the lower Springfield Mesa or the Giberson Dunes area, the height of the recharge mound would be constrained by the depth of the unsaturated formation between the ground surface and the water table. Under these conditions, the height grows until it reaches the surface of the spreading basins; latteral controls also exist on the expansion of the mound because the mound would stop expanding laterally when the water table discharges above ground at the approximate elevation of sea level. Therefore, in the absence of pumping, the recharge mound would have a maximum height of 90 feet in the lower Mesa area and would expand latterally for a distance of one mile before reaching the ground surface. Thereafter, the mound would remain stable and the rate of recharge would be equal to the discharge rate from the point of exposure. Due to active year-around pumping in the Springfield area, however, the mound would most probably not attain a stable condition and the rate of recharge would not be constrained by geologic conditions of the area. A similar recharge mound condition could also develop if recharge facilities were located in the Giberson Dunes area with a resultant significant loss of the recharge water to the Monterey Bay.

Additional analysis of recharge mound configurations would be required prior to the design and construction of such facilities in the Springfield area.

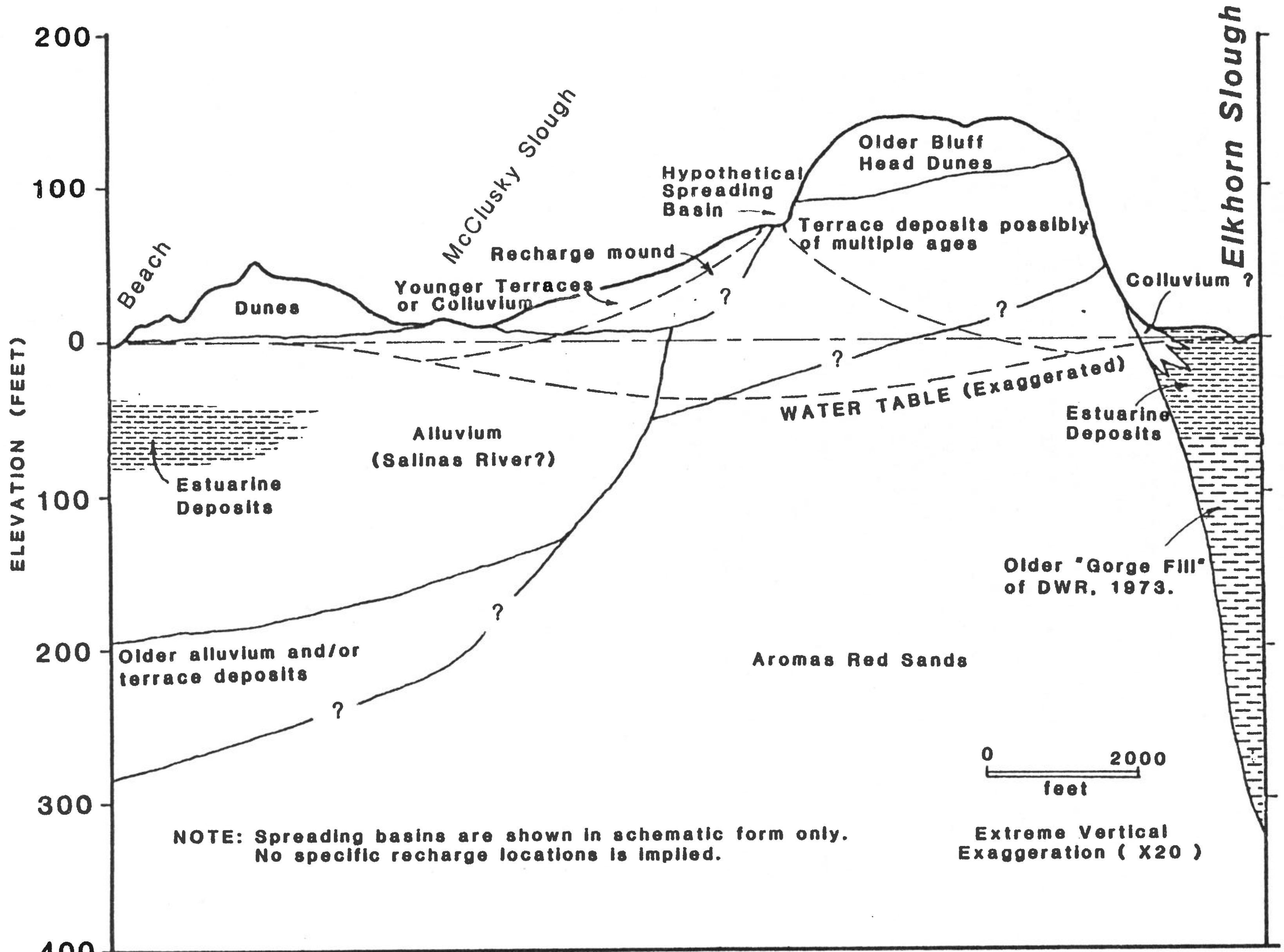


Figure 3. Estimated configuration of recharge mounds in Springfield Area.

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APPENDIX E

STORM HYDROLOGY AND DEFINITION OF SAND-HILL RECHARGE AREAS
PAJARO BASIN

APPENDIX E

STORM HYDROLOGY AND DEFINITION OF SAND-HILL RECHARGE AREAS PAJARO BASIN

Background

This appendix provides a more detailed description of the hydrologic processes in sand-hill areas surrounding the Pajaro Valley. It includes monitoring results for peak runoff of individual storms in thirteen small sandy basins during the winters of 1981-82 and 1982 and 1983. These results, plus findings of a number of recent geologic and soils studies, have led to a re-definition of primary and secondary recharge areas in the Pajaro groundwater basin.

Storm Hydrology and Recharge in Sandy Watersheds Surrounding the Pajaro Valley

Protecting recharge, controlling erosion and managing recharge in the sandy watersheds surrounding the Pajaro Valley ultimately depends upon the cooperation of local landowners and the staff of agencies working in these areas. Their interest and cooperation rests, in turn, upon being provided with a clear, technically-sound analysis of their unusual soil/geologic system and the extent to which these can be altered by varying levels of development.

To begin addressing these needs, we developed a reconnaissance field program attempting to address the following questions:

1. What differences in peak and total runoff may be expected between undisturbed and urbanized sandy basins?

2. What natural factors affect the proportion and rate of runoff?

3. What percentage of rainfall is presently exported as runoff from the sandy basins?

4. How may county and regional agencies approach managing runoff, erosion and water quality in the sandy basins most effectively?

A reconnaissance field program oriented toward estimating the amounts and effects of lost recharge was carried out during the study. Rainfall which leaves the basin as runoff is probably not available for recharge. The program emphasized differences in runoff between residential ("urbanized") areas and those used for agriculture and open space ("non-urbanized"). We believe this to be the primary influence in a recharge-protection program.

Technical Approach. None of the streams originating in the sandy watersheds is perennial. Most flow for only a few hours or days during the larger storms of the year. By measuring the magnitude of runoff during a number of storm events, comparisons can be made between sandy and "normal" Santa Cruz Mountains or northern Monterey County streams. Additionally, runoff rates from sandy basins with different land uses can also be compared, particularly if data can be obtained for adjacent basins with similar soils, slopes, and incident rainfall. Basins yielding more runoff, perhaps from pavement and other impervious surfaces, are areas where less of the rain is being recharged.

The volume of runoff for each individual storm can usually be estimated from the instantaneous peak discharge. When the number of storms becomes very large, the validity of the cumulative seasonal estimate diminishes rapidly, as it becomes difficult to distinguish the size of peak flows occurring one after another. Under these conditions, the volume of seasonal runoff can sometimes be better expressed from the distribution of peak discharges. The ratios of peak discharges in urbanized and non-urbanized basins are compared and discussed in this analysis.

Previous and Ongoing Studies. The anomalous runoff patterns from the sandy basins surrounding the valley floor were described by HEA for the Buena Vista and Prunedale areas (HEA, 1978a,b). Monterey County has maintained a stream gage on Prunedale Creek, one of the largest of the sandy watersheds, since 1971. Santa Cruz County Planning Department and the U.S.D.A. Resource Conservation District (RCD) staffs for Santa Cruz and Monterey Counties have begun analysis of the hydrology of sandy basins surrounding the Pajaro Valley. Soil Conservation Service studies are also proposed in the Santa Margarita outcrop area of Scotts Valley and Quail Hollow. The Monterey Peninsula Water Management District, with funding from the California Department of Fish and Game, is currently monitoring several streams in low-runoff basins on the north side of Carmel Valley; HEA is assisting in this study, in which similar sets of measurements are being made. Data collected at the U.S. Geological Survey gages on El Toro Creek and Arroyo del Rey in northern Monterey County are also applicable, although about 20 percent of each basin is underlain by consolidated rocks and thinner, less-permeable soils.

The effects of agricultural practices on runoff and erosion are being studied by USDA Soil Conservation Service staff members, with support and direction from the Resource Conservation Districts of Santa Cruz and Monterey Counties. The boards of the two RCDs have designated the sand hills as a "high priority work area" affected by "critically eroding conditions". As such, their "Strawberry Hills" study will be receiving additional funding and personnel commitments over the next year or two. According to Bruce Eisenman, study director, an early draft of their report is presently (December, 1983) undergoing review within the agency, and will be available for review in the spring months of 1984.

The Strawberry Hills investigation uses the format of a Soil Conservation Service river basin study. It emphasizes the costs related to soil loss and sedimentation, and discusses recommended and cost-effective practices for their control. Aquifer recharge and the potential value of runoff for managed recharge are not being considered in the present report draft, but might be added at a later date if supported by sufficient agency interest.

From discussions with the SCS and RCD staffs, we understand that they have observed much greater runoff from strawberry fields than from adjacent grass- or brush-covered control areas. The general pattern of runoff and channel development in sub-watersheds with hillside agriculture seems similar to that described in this report for areas undergoing residential development.

Field Studies. Thirteen crest-stage gages were installed on small channels draining sandy areas surrounding the Pajaro Valley. The locations of the basins are shown in Figure 1; watershed characteristics are summarized in Table 1. Most of the basins were paired, with one being at least partially urbanized and the other being almost entirely in agricultural* or open-space uses. One set near Corralitos includes three basins; most of one basin (4A) is a densely-developed residential area (mobile homes), a second basin (4B) is primarily in dispersed residential uses, while the last (4C) is entirely open or agricultural. The paired basins range in size from 50 to 275 acres (0.08 to 0.45 square miles). Two larger basins were also monitored — those of Freedom Blvd. Creek near Rob Roy Junction (2.55 square mile), and Larkin Valley Creek above White Road (0.73 square miles). The infiltration properties of the various soil types are summarized in Table 2.

Rainfall. The field studies commenced during the 1981-1982 rainy season, and were gradually intensified during the winter of 1982-1983. Rainfall at Watsonville was about 40.1 inches in 1981-1982, and 46.2 inches in 1982-1983**. Daily rainfall for the two water years are shown in Figure 2, which also includes runoff crests (expressed as cfs per square mile) observed at MCFCWCD's recording stream gage on Prunedale Creek.

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* At present, runoff from areas planted to strawberries is atypically high. We anticipate improved runoff and erosion control practices will be effected in the near future. Basins with any significant acreage in strawberries were excluded from this study.

** Rainfall has been recorded at the Watsonville Water Works Station since 1915. Mean annual precipitation for this station is about 21 inches. Records for this and predecessor stations within the City through 1872 have been compiled and published by the Watsonville Register Pajaronian. Prior to 1982-1983, the greatest seasonal total previously measured was about 43.7 inches in 1889-1890. Rainfall during the winters of 1981-1982 and 1982-1983 rank third and first, respectively, for the 112 years of extended record. All rainfall and runoff data are unofficial, and subject to review.

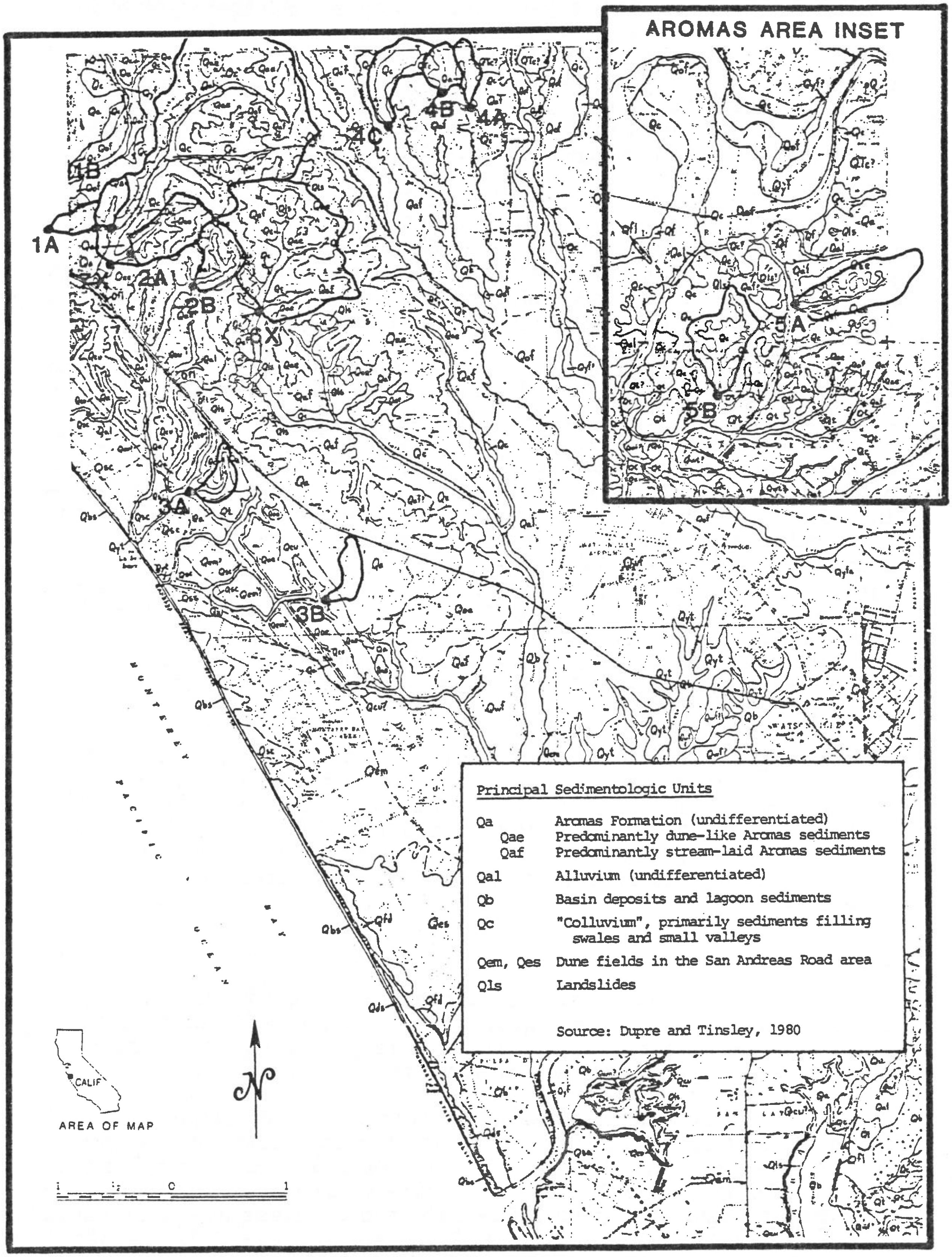

Figure 1. Location of sandy study watersheds and underlying sediments, Pajaro Valley.

Table 1 Characteristics of Monitored Small Drainages in the Sand-Hill Recharge Areas Surrounding the Pajaro Valley

Code[a]	Name	Channel[b] Type	Drainage Area (acres)	Drainage Area (sq. mi)	Mean Annual[c] Precipitation inches	Soil Type Distribution[d]		Impervious[e] Area (%)	Land-Use Pattern: Existing	Land-Use Pattern: General Plan	Existing Zoning	
1A	Wallace Ave. at 2127 (Randall home)	Gutter	90	0.14	28"	Baywood Elkhorn Tierra-Wats.	22% 60% 18%	40	Suburban; estates (minor)	Suburban	R-1	100%
1B	Aptos Orchards at Aptos Assembly Chruch	Access road rut	50	0.08	27"	Baywood Elkhorn	70% 30%	nil	Orchard; chaparral	Agricultural	Agricultural	100%
2A	Aptos High School at campus entrance	Culvert	161	0.25[f]	26"	Baywood Elkhorn Ben Lomond	40% 35% 25%	18%	High school and chaparral	Institutional	Unclassified[g]	100%
2B	Moon Valley Cr. above Gieseke home	Incised, stable	146	0.23[f]	25"	Baywood Elkhorn Tierra-Wats. Depositional[h]	15% 50% 20% 15%	nil	Agricultural	Agricultural	Unclassified[g] Agricultural	
3A	Mar Monte Dr. at 162 (Hayden home)	Incising stream	59	0.09	23"	Baywood Elkhorn Elder Tierra-Wats.	15% 45% 25% 15%	28%	Suburban, grass-lands, eucalyptus	Suburban	R-1-9	100%
3B	Unnamed Valley near Spring Valley Road	Barely discern-ible grassed channel	56	0.09	22"	Baywood Elkhorn Elder Pfeiffer	60% 30% 5% 5%	nil	Agricultural	Agricultural	Agricultural	100%
4A	Rancho Corralitos ditch at Hames Road	Steep paved ditch and culverts	86	0.14	30"	Baywood	100%	43%	Mobile homes; grassland and chapparral	Dispersed Suburban	Rural residential[g]	
4B	Enos Lane ditch at Hames Road	Steep paved ditch and culverts	76	0.12	30"	Baywood	100%	22%	Dispersed suburban	Dispersed Suburban	Rural residential	
4C	Merk Valley Creek at Hames Road	Box culvert	120	0.19	31"	Baywood Pfeiffer	90% 10%	nil	Orchards, chaparral	Agricultural	Agricultural	100%
5A	Seeley Road Valley	Newly incising	275	0.45	19"	Arnold	100%	16%	Dispersed residential	Dispersed residential	Not available	
5B	Unnamed Creek at Carneros Road	Small channel from marshy area	168	0.26	19"	Arnold	100%	7%[j]	Dispersed resi-dential and grassland	Dispersed residential	Not available	
6X	Larkin Valley Creek at White Road	Stable, and well-developed, with vegetated banks	465	0.73[f]	25"	Baywood Elkhorn Pfeiffer Tierra-Wats. Others	5% 30% 20% 15% 30%	5%	Sparse resi-dential and limited ag.	Agricultural and dispersed resi-dential	Agricultural Rural residential Unclassified	50% 20% 30%
7X	Freedom Blvd. Creek at Aptos High Road	Unstable and[i] rapidly incising	1130	2.55	26"	Baywood Elkhorn Others	60% 20% 20%	18%	Rural and sub-urban residential; open space, agricul-tural, institutional	Intensification of existing use	Primarily rural residential	

a/ Watershed locations shown in Figure 1. Watersheds with codes ending in "A" are at least partially urbanized; codes ending in "B" denote non-urbanized conditions, except for 4B, which is intermediate between 4A (urbanized) and 4C (no homes)

b/ Well-defined, paved or large channels are caused by and tend to contribute to greater storm peaks

c/ Estimated from Rantz, 1971

d/ Generalized from Soil Surveys of Santa Cruz (1979) and Monterey (1975) Counties

e/ Determined from point counts using 1979 aerial photograph, 1" = 1000', in Santa Cruz County; 1983 aerial photographs, 1" = 500' in Monterey and San Benito Counties

f/ Less than 10 percent but more than 1 percent of this basin affected by small agricultural impoundments

g/ Zoning bears "BS" notation, indicating need for Board of Supervisors approval prior to significant development

h/ Fluvaquent haploxerolls of SCS; these are soils affected by regular deposition from tributaries and slopework

i/ Channel cross-sectional area increased eight- to ten-fold during January 1982 storm

j/ Virtually all impervious areas (as of 1982) are along ridgetops surrounding the upper part of the basin

Table 2. Infiltration and Related Properties of Major Soil Types
Sand-Hill Areas Surrounding the Pajaro Valley[a]

Soil Series[b]		Material	Hydrologic Soil Group	Depth Interval	Available Water Capacity		Infiltration Rates	Sand Content[c]	Erodibility Factor
Code(s)	Name			(in)	unit (in/in)	total (in)	(in/hr)	(%)	
105-107	Baywood	Qd, Qae, Qc	A	0-17 17-56 56-61	0.07-0.10 0.06-0.09 0.04-0.05	1.2-1.7[d] 2.3-3.5 0.2-0.2 3.7-5.4 [e]	6.0-20[f]	75 75 80	0.15[f]
112	Ben Lomond	Qa, Qaf[g]	B	0-19 19-46	0.10-0.12 0.09-0.15	1.9-2.3 2.3-3.8 4.2-6.1	2.0-6.0	50 40	0.17
125	Danville	Qc, Qal	C	0-17 17-29 29-65	0.14-0.17 0.12-0.16 0.12-0.17	2.4- 2.9 1.4- 1.9 4.3- 6.1 8.1-10.9	0.2 -0.6 0.06-0.2 0.2 -0.6	35 30 50	0.28 0.24 0.15
130	Elder	Qt, Qd, Qal, Qc	B	0-23 23-60	0.10-0.15 0.10-0.15	2.3-3.4 3.7-5.5 6.0-9.0	0.6-2.0	45	0.32
133-136	Elkhorn	Qaf, Qa, Qt	B	0-21 21-61	0.10-0.14 0.16-0.18	2.1- 2.9 6.4- 7.2 8.5-10.1	 0.2-0.6	50 35	0.32 0.28
139	Fluvaquentic Haploxerolls	Qal, Qc	-		Properties variable and unknown				
157-158	Nisene/Aptos	Qae, Qa	B	0-10 10-58	0.09-0.13 0.15-0.18	0.9-1.3 7.2-8.6 8.1-9.9	2.0-6.0 0.6-2.0	50 45	0.20
159-160	Pfeiffer	Qaf, Qt	B	0-38 38-66	0.07-0.10 0.07-0.10	2.7-3.8 2.0-2.8 4.7-6.6	2.0-6.0 2.0-6.0	40[h] 45[h]	0.17
174-175	Tierra-Watsonville	Qt, Qaf	D	0-14 14-66	0.09-0.17 0.02-0.04	1.3-2.4 1.0-2.1 2.3-4.5	0.6-2.0 <0.06	50 30	0.32 0.28
AkD, AkF	Arnold	Qa, Qc	A	0-48	0.05-0.09	2.4-4.2	6.0-20	n.d.	0.15

Geologic Unit Key (after Dupre and Tinsley, 1980)

- Qal — Undifferentiated valley-fill alluvium
- Qc — Undifferentiated swale-fill alluvium ("colluvium" of Dupre and Tinsley)
- Qd — Unconsolidated dunes (Qem, Qes, Qfd, Qds of Dupre and Tinsley)
- Qt — Unconsolidated marine terrace deposits (Qcu, Qoc, Qsc, Qwf, Qyt)
- Qa — Undifferentiated Aromas Formation sediments
  - Qae — Dunal (eolian) Aromas sediments
  - Qaf — Stream (fluvial) Aromas sediments

Hydrologic Soil Groups

- A Soils having high infiltration rates (low runoff potential) when wet and during long-duration storms
- B Soils having moderate infiltration rates when wet and during long-duration storms
- C Soils having slow infiltration rates when wet and during long-duration storms
- D Soils having very slow infiltration when wet and during long-duration storms

a/ Principal sources of data are the soil surveys of Santa Cruz (1979) and Monterey (1975) Counties
b/ Soil series generalized for runoff properties; codes identify component soils described in county surveys
c/ Typical percentage of material retained between #10 and #200 sieves. These values are approximate, and intended only to illustrate major textural differences
d/ Range of available water capacity within depth interval
e/ Range of available water capacity in entire soil profile, a maximum estimate of seasonal infiltration prior to "recharge"
f/ Single value applies to entire profile
g/ Ben Lomond soils, when developed on Aromas sediments, occur largely on north-facing slopes
h/ Pfeiffer soils contain 10 to 45 percent gravel and rock fragments

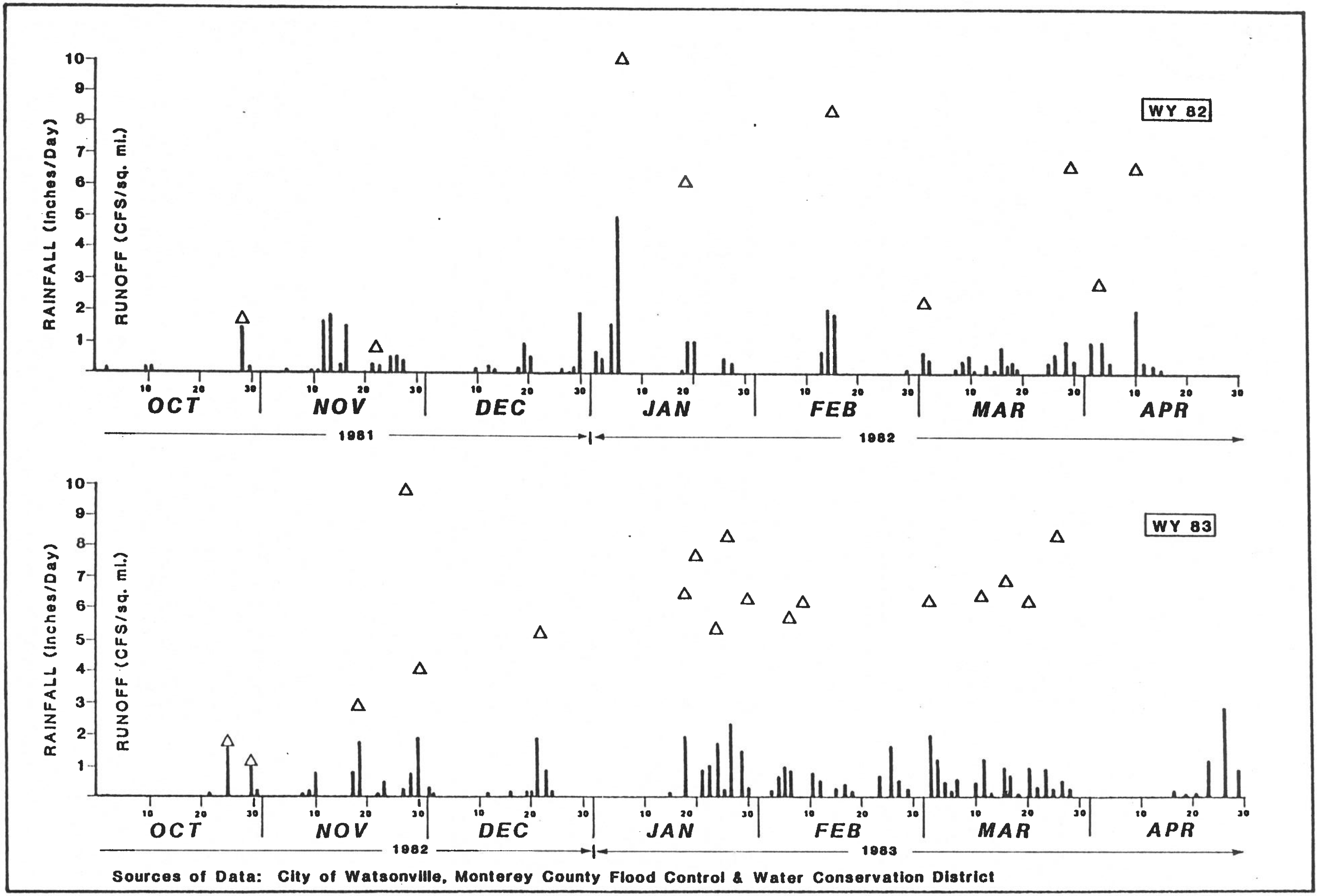

Figure 2. Daily rainfall and observed runoff crests for water years 1982 and 1983, Pajaro Valley area. Daily rainfall data (bars) are for Watsonville Water Works. Runoff crests (expressed as cfs per mile) for the Prunedale Creek basin are shown as triangles.

It should be noted that often it was not possible to clearly establish the crest for individual storms. In many cases this was due to failure of the culvert or HEA control structure. At Carneros Road (5B), road reconstruction raised the culvert by several feet, which suppressed the HEA weir, rendering the data invalid. The crest-stage gage near Spring Valley Road (3B) was vandalized and could not be replaced during the 1982 season. The culvert downstream from Rancho Corralitos (4A) frequently was partially blocked by debris or sediment; as we could not establish hydraulic conditions at the time of the crest, the peak discharges could not be computed. The Seeley Road valley (5A), which did not have a distinguishable channel in its lower portion prior to this study, developed an incised channel during the two wet years. An eight-foot weir installed for this study was undercut and washed away several times. Table 3 has been edited to include only results supported by the clearest and most valid observations. Questions regarding specific observations are discussed in the text or the tables.

Methods. Instantaneous peak discharges for most of the larger storms were computed from high-water marks monitored in the field. In most cases, measured high-water marks were obtained from the crest-stage gages installed for this study. In addition, standard indirect peak discharges were computed using the conveyance method at several stations where crest-stage gages could not be installed; we also used this procedure when measurements from the crest-stage gages could not be used to compute particular storm crests.

Two distinct types of crest-stage gages were used for this study. Standard crest-stage gages such as those used by most federal agencies were installed at about half of the sites. These consist of vertical pipes within which a removable staff gage is placed; rising water within the pipe floats burnt cork chips which cling to the staff plate at the level of the storm crest once the waters begin to recede. Special "tube gages" were developed for this study for installation within culverts. These gages were made with 5/16-inch Tygon tubing bolted to the culvert walls. The tube gages recorded high-water levels with a cork chip line left on a calibrated spring-steel tape. Cork lines were read by HEA staff four or five times each during the 1981-1982 and 1982-1983 seasons.

Control structures installed for this study included both V-notch and Cipoletti weirs. Existing culverts were also used as controls. Open-channel conditions prevailed at several sites; standard indirect peak discharge measurements were made at these sites or when the capacity of the control structure was exceeded. Individual peak discharges computed by these methods are necessarily approximate, as conditions at the time of peak runoff are not also known. In general, most computed values are considered accurate to ± 20 to 25 percent. Larger potential errors for small storms may have prevailed at site 4C and perhaps at site 6X, where near-bed conditions during minor storms are uncertain.

Watershed parameters were obtained from published sources, in the field, and from aerial photographs. The proportion of various soil and sediment types was estimated for each basin from the Soil Survey

Table 3: Observed Peak Rates of Unit Runoff[a/] During Water Years 1982 and 1983, Sandy Study Watersheds, Pajaro Basin (all data preliminary and subject to revision)

Code	Gage Location	Drainage Area (mi²)	Impervious Area (%)	Peak Runoff Per Unit Area (cfs/mi²): Water Year 1982 Storms					Water Year 1983 Storms							
	Storm Date			Oct. 27	Jan. 4	Feb. 16	Mar. 1	Apr. 10	Oct. 26	Nov. 29	Nov. 30	Dec.22	Jan. 27	March[e/]	April[e/]	May[e/]
	Rainfall Intensity[b/] (maximum 60 min. duration)			1.2	nd	nd	0.4	0.4	0.8	0.4	nd	0.4	1.2	nd		
	Rainfall for storm (Watsonville)[c/]			1.46	6.44	3.37	0.93	2.74	1.39	2.69	2.69	2.41	5.83	6.98	3.15	0.78
	Peak Unit Runoff, Prunedale Creek (cfs/mi²)[d/]			1.38	10.2	8.46	6.68	6.96	1.36	9.96	3.96	5.18	7.91	8.05		
1A	Wallace Avenue[f/] at Randall home	0.14	40	26.	1050.				38.	15.		180[g/]	180[g/]	180[g/]	95.	2.3
1B	Aptos Orchards at Aptos Assembly Church	0.08	0	0.38	78.				0	0.9		9.7	2.1	1.7	tr.	0
2A	Aptos High at entrance	0.25	18	115.	820.					44.		375.	390.	590.	280.	4.7
2B	Moon Valley Creek above Giesecke's	0.23	0		195.	96.	54.	160.		2.5				125.	83.	4.0
3A	Mar Monte at Hayden home	0.09	28.		380.							83.	180.	280.		
3B	"Pleasant Valley" near Spring Valley Road	0.09	0		14.4							0.23	1.14	2.5	1.14	
4A	Rancho Corralitos ditch at Hames Road	0.14	43.		490.				1.0							
4B	Enos Road ditch at Hames Road	0.12	22.		175.				1.1	37.		580.[g/]	580[g/]	580[g/]	280.	10.6
4C	Merk Valley Creek[b/] at Hames Road	0.19	0	665.	135.					130.		56.	95.	410.	190.	41.
5A	Seeley Road Valley at Aromas Fire Station	0.45	16				0.87					5.4[f/]		11.6		
5B	Unnamed stream at Carneros Road	0.26	7.				tr.			1.9		25.[f/]				
6X	Larkin Valley Creek at White Road	0.73	5.		260.	190.	180.			64.	25.	29.	140.	190.	160.	6.0
7X	Freedom Blvd. Creek at Aptos High	2.55	18.	0.09	122							47.	107.	94.	24.	3.1

a/ All values expressed in cfs/sq. mi. to account for differences in drainage area. Unit peak discharges for any given storm tend to be higher in the smallest basins. This occurs in all watershed types and is not an interest property of the sandy soils

b/ Data provided by Susan Perkins, USDA Soil Conservation Service

c/ Data provided by Ken Barrett and Ken Fox, City of Watsonville

d/ Data provided by Gene Taylor, Monterey County Flood Control and Water Conservation District

e/ Data from correlated stations not yet available. Peaks assumed to be March 1 or 24, April 28, and April 30 or May 1

f/ Peak runoff in west gutter. East gutter may convey an additional 10-15%. Flows on January 4, 1982 covered virtually entire width of road

g/ Evidence of culvert flowing full

(U.S.D.A. Soil Conservation Service, 1979) and from published geological materials (Dupre and Tinsley, 1980; HEA, 1979; Muir, 1972). Channel slopes were established from level surveys. Hydraulic coefficients and roughness factors were estimated in the field. Drainage areas and percentage area covered by impervious surfaces were determined by point-count from 1979 and 1980 aerial photographs (1:12000) in Santa Cruz County, and 1983 aerial photographs (1:6000) in Monterey and San Benito Counties. Impervious surfaces were defined to include any covered or hard-packed areas. These included roofs, roads, driveways, parking areas, corrals, building pads at construction sites, and steep artificial embankments.

Results. Crest-stage and high-water mark data collected in the field were reduced to instantaneous peak discharges for specific storms at each gage. Peak discharges were then converted to peak runoff per unit drainage area (cfs/mi^2). Results, presented in Table 3, indicate that peak unit runoff was substantially higher in channels draining small basins with significant amounts of urbanized area. Peak unit runoff increased sharply with the percentage of the basin covered by impervious surfaces. Results for the small paired watershed are summarized in Figure 3, in which the ratios of peak unit runoff are compared with the proportion of the urbanized basin covered by impervious surfaces.

Discussion of Principal Influences

Many factors affect the magnitude and duration of storm runoff. Among those we believe to be most important in the sandy basins are:

1. Drainage area
2. Amount and intensity of rainfall
3. Soil type
4. Extent of development (impervious areas)
5. Antecedent soil moisture conditions
6. Hillside slopes
7. Valley slopes and channel development

Other factors may be significant under some circumstances.

In the following sections, the effects of these watershed influences are described and assessed. The structure of the field study was designed to minimize differences attributable to drainage area size or to rainfall. Each of the paired basins were of very similar size. Because the basins were generally near or contiguous to their pair, similar amounts and intensities of rainfall can be reasonably assumed. Nonetheless, the effects of basin size and rainfall must be considered to allow the sandy basins to be compared with the larger, montane watersheds in Santa Cruz and Monterey Counties with extended gaging histories.

Similarly, antecedent soil moisture, basin slopes, and extent of channel development each affect the amount and magnitude of runoff. Each of these may be of proportionately greater influence during years drier than 1982 and 1983.

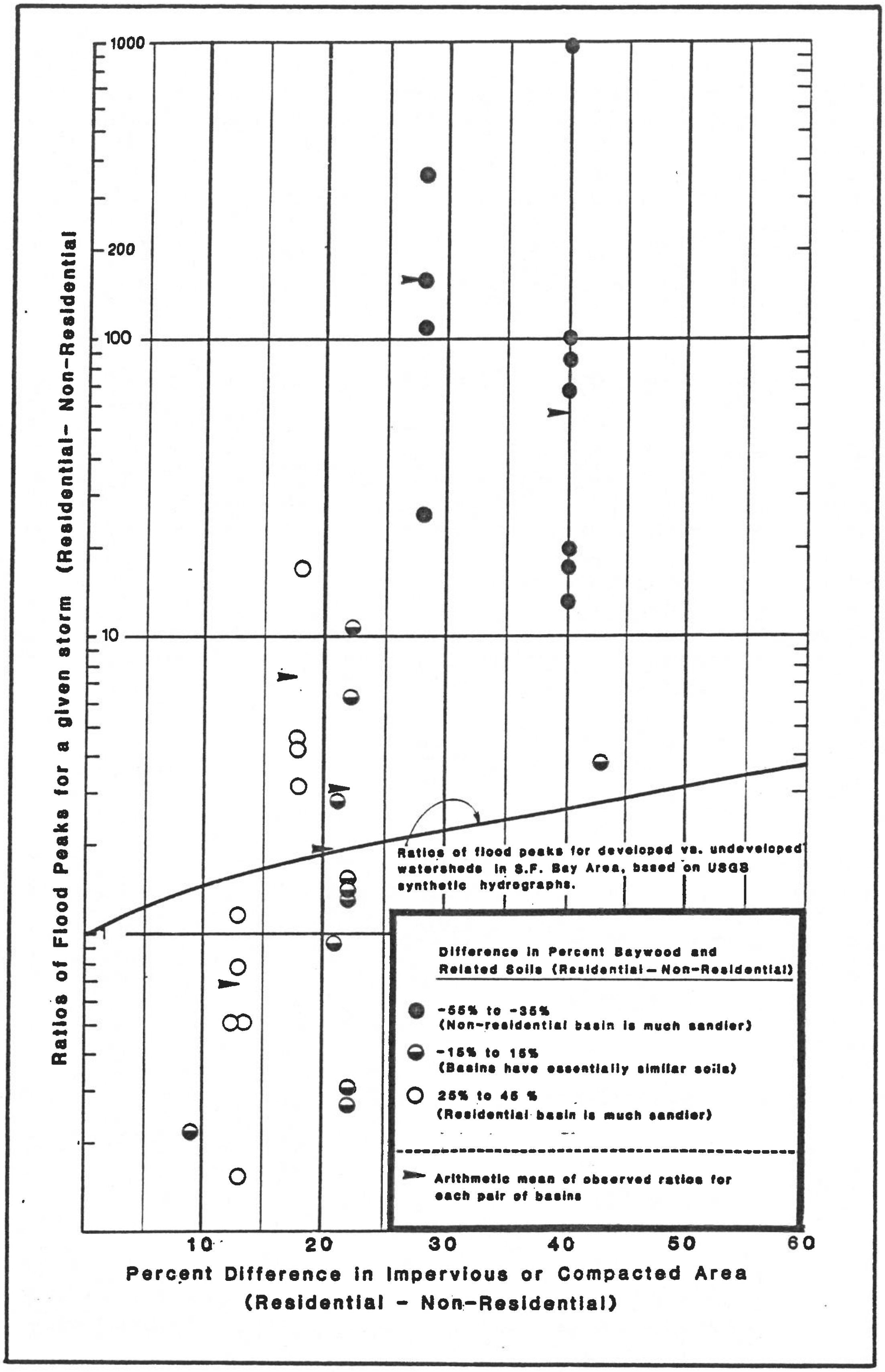

Figure 3. Ratios of flood peaks in residential and open-space sandy valleys, Pajaro Basin. Rates of peak runoff from the developed basins were many times greater than in the adjacent open-space basin. Soil types also significantly influenced the ratio of flood peaks (see text). Residential development in sandy areas increases flood peaks by a much greater proportion than in non-sandy watersheds, based on the U.S.G.S. models.

Drainage Area. In most environments, drainage size and rainfall are generally considered to be the principal determinants of runoff. Regional runoff relations are generally based on these two factors. The U.S. Geological Survey has developed methods for estimating peak discharges for events of given frequencies based solely on these two factors (Rantz, 1971). As an example, the discharge (in cfs) for a storm crest with an expected recurrence of two years (Q_{p2}) can be estimated by the equation:

$$Q_{p2} = 0.069\,A^{0.91}\,P^{1.97} \tag{1}$$

in which drainage area (A, in square miles) and mean annual basinwide precipitation (P, in inches) are the two independent factors. The peak discharge is nearly — but not quite — proportional to drainage area*. Peak discharges vary more sharply with basin size in non-sandy watersheds in the Monterey Bay area, perhaps because the terrain is steeper or the storm patterns differ from those in the San Francisco Bay Area. Peak discharges for moderate events vary with approximately the 0.75 power of drainage basin size. Hecht (1983) found that bankfull discharge or the 1.5-year storms followed the following relation:

$$Q_{p1.5} = 71A^{0.73} \tag{2}$$

for 20 Monterey Bay area streams with drainage basins of 0.5 to 110 square miles. With this equation, a basin of ten square miles yields only 54 percent of the runoff per square mile compared with a watershed of one square mile. The difference is appreciable, and may influence interpretation of the data in Table 3. Assuming that a similar relation is applicable to sandy basins, runoff per unit area may be expected to decrease significantly with the size of the watershed. The smallest drainages (0.08 to 0.10 square miles) might be expected to have 2.5 times higher unit runoff than the largest study watershed (2.6 square miles), all other factors being equal.

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* An exponent of 1.0 for the area factor (A) would indicate that equal amounts of runoff per unit area generated by basins of various sizes. The actual exponent of 0.91 reflects higher unit runoff from smaller basins. For example, computed peak runoff using this relation from a basin of 1 square mile and 20 inches of mean annual rainfall would be 25.2 cfs, while runoff from a basin of 10 square miles would be 205 cfs, or 20.5 cfs/sq. mi.

We have attempted to minimize differences due to the effects of drainage area in two ways. First, all data are expressed as runoff per unit area, generally cfs/sq. mi. Second, all small sandy watersheds used in this study were chosen to be of roughly identical size to their pair. The pairing of watersheds data therefore negates the influence of basin area on the magnitude of flood crest. These effects, however, must be considered when comparing the results of the very small watershed studies to larger, gaged basins. They should also be incorporated into any analysis involving Prunedale Creek. For example, flood crests for the January 1982 storm (Table 4), although larger on a per-unit-area basis in the small "urbanized" sandy basins, are relatively less than those for the larger, montane basins, once adjusted for the effect of basin size. Again, the assumption is made that flood peaks are generally proportional to the 0.73 power of watershed area. Observed peak rates of runoff in the urbanized small watersheds proved to be 10 to 80 percent of those expected based on the measurements from the larger basins (such as Aptos, Branciforte and Soquel Creeks). Rainfall amounts and intensities for the storm diminished sharply from Aptos to Salinas, where the January 4-5, 1982 event was a normal winter storm; the rainfall gradient also influenced the magnitudes of peak runoff rates in the small sandy basins. We conclude that urbanized sandy basins in the Aptos area yielded runoff peaks for this one storm approaching or equalling those of the larger Santa Cruz Mountains watersheds once approximately adjusted for the effects of drainage area and rainfall pattern.

Rainfall. Mean annual rainfall in the small sandy basins ranges from about 19 to 31 inches. Differences in peak runoff rates may be expected both between individual sandy basins and between the study basins and the larger watersheds with sustained gaging histories.

Regional runoff relationships such as those developed by the U.S. Geological Survey (equation 1) express the strong influence of rainfall. For example, peak discharge increases with nearly the square of precipitation (exponent of 1.96 in equation 1) for a storm of relatively low recurrence. All other factors being equal, the wettest sandy basins might be expected to yield runoff crests 2.6 times higher than those in the driest*. Total mean annual runoff in a basin receiving 31 inches of rainfall per year might be expected to be appreciably higher than in a basin averaging 19 inches per year. Figure 4 indicates that the wetter basin would average 1.9 times more total runoff if both were not underlain by sandy soils.** A roughly similar ratio probably prevails under sandy conditions, again assuming all other factors being equal.

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* Computed as the ratio of mean annual rainfalls (31/19) raised to the 1.96 power.

** The duration of this figure is discussed more completely in the assessment of surface-water resources in the Pajaro Valley.

Table 4 Peak Discharge and Unit Runoff for Storm of January 1982 Coastal Santa Cruz and Monterey County Unregulated Streams [a]

Code	Stream	Station	Watershed		January 1982 Storm		Source
			Type	Area (sq. mi.)	Peak flow (cfs)	Unit Runoff (cfs/sq. mi.)	
Large, Montane Watersheds							
11161800	San Vicente Cr.	near Davenport	Normal	6.07	@ 2100	346	USGS[b]
11160500	San Lorenzo R.	Big Trees	Normal	106.	29900	282	USGS
11161500	Branciforte Cr.	below Carbonera	Normal	17.3	6650	384	USGS
	Arana Gulch	above La Fonda	Normal	2.65	760	287	HEA, 1982
11160000	Soquel Cr.	at Soquel	Normal	40.2	9650	240	USGS
11159600	Aptos Cr.	near Aptos	Normal	10.2	3930	385	USGS
11159200	Corralitos Cr.	near Freedom	Mixed	27.8	5600	201[c]	USGS
11154100	Bodfish Cr.	near Gilroy	Normal	7.4	1050	142	USGS
	Prunedale Cr.	at Reese Circle	Sandy	7.3	75	10.3	MCFCWCD[d]
	Tularcitos Cr.	near Carmel Valley	Mixed	55.0	130	2.4[e]	MPWMA[f]
Partly-Urbanized Small Sandy Watersheds							
1A	Wallace Ave.	at 2127 Wallace	Sandy	0.14	150.	1050	
2A	Aptos High School	at entrance	Sandy	0.25	205.	824	
3A	Mar Monte Rd.	at 162 Mar Monte	Sandy	0.09	35.	387	
4A	Rancho Corralitos	at Hames Rd.	Sandy	0.14	68.	490	
4B	Enos Lane	at Hames Rd.	Sandy	0.12	21.	175	
5A	Seeley Rd. Cr.	at Carpenteria Rd.	Sandy	0.45	@ 60.	133	
Non-Urbanized Small Sandy Watersheds							
1B	Aptos Orchards	at Aptos Assembly	Sandy	0.08	6.	76.5	
2B	Moon Valley Cr.	above Gieseke home	Sandy	0.23	45.	198.	
3B	Unnamed stream	near Spring Valley Rd	Sandy	0.09	1.3	14.4	
4C	Merk Valley Cr.	at Hames Rd.	Sandy	0.19	25.	134.	
5B	Unnamed stream	at Carneros Rd.	Sandy	0.26	unknown	unknown	
Other Sandy Watersheds							
6X	Larkin Valley Cr.	at White Rd.	Sandy	0.73	180.	246.	
7X	Freedom Blvd. Cr.	at Aptos High Rd.	Sandy	2.55	310.	122.	

a/ All data preliminary and subject to review

b/ USGS data provided by Vincent Piro and Wendell Ayres

c/ Unit runoff of 311 cfs/sq. mi. if sandy areas are excluded

d/ Unpublished data provided by Gene Taylor, MCFCWCD

e/ Rainfall amounts for this storm diminished rapidly southward from Corralitos; although a high-recurrence event in the Santa Cruz Mountains, this was only a moderate winter storm in the Monterey Peninsula area

f/ Unpublished data provided by Graham Matthews and Matt Kondolf, MPWMA

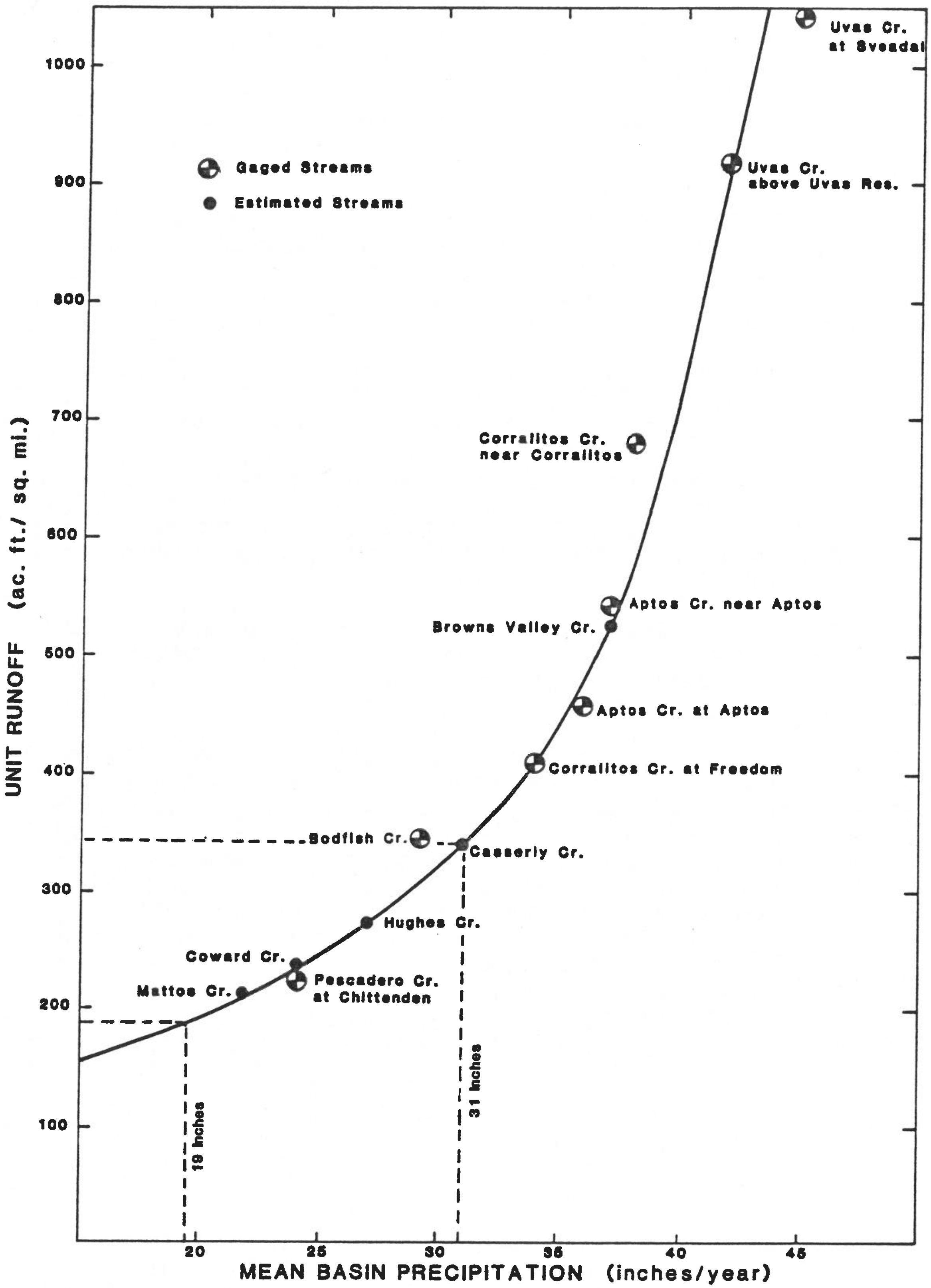

Figure 4. Rainfall/Runoff relation, Eastern Santa Cruz Mountains

We attempted to minimize rainfall-related differences in this study by concentrating the monitored watersheds in the wetter part of the Pajaro basin, generally along Freedom Blvd. One pair of basins was located in the lower rainfall zone typical of the southern half of the basin; accurate data from this pair of basins proved to be sparse, and an adjustment for rainfall cannot be developed from these observations. Differences in mean annual rainfall among the other monitored basins are probably small*, although rainfall amounts and intensities vary appreciably during individual storms or seasons.

Rainfall Intensity. No general significant relationship between maximum one-hour rainfall intensity and peak discharge could be developed from the data in Table 3. High-intensity rainfall should, in theory, result in much higher runoff peaks in small, sandy basins. Absence of a valid relation seems due to at least three factors:

a. Much of the area of the basins remained saturated for appreciable periods during these two years of high rainfall. Prolonged partial-area saturation seems to be atypical of these basins. The variable degree of ground saturation may have overwhelmed the effects of rainfall intensity.

b. Rainfall intensities seldom exceeded one inch per hour, and may not have been sufficient to create runoff in the more-permeable soils.

c. Intensities for periods of less than one hour may be of greater use in predicting peak runoff; short-duration data for these storms are not yet available.

Channel Development. Many of the valleys in the areas of sandy soils have developed or are presently developing active channels. In most cases, runoff was previously conveyed along grassy valley floors lacking defined channels. Most of the channels are presently incising and extending headward. During the study period, we noted considerable incision and channel development in three urbanized (Mar Monte, Freedom Blvd., and Seeley Road) and one non-urbanized (Aptos Orchards; downstream of the gage) basin. Figure 5, from field sketches made just before and after the January 1982 storm, is typical of the relative rates of channel growth during the two wet years. It should be noted that there are some relatively stable channels in the sand hills, including "Moon Valley Creek" (site 2B) above Highway 1 and Larkin Valley Creek.

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* The U.S. Geological Survey has published two isohyetal maps of the study area (Rantz, 1971b; Hofferd, 1980). Bud Hofferd has subsequently located long-term rainfall records for an additional 5 or 6 stations within the Pajaro basin, and plans to incorporate these data in the next round of maps.

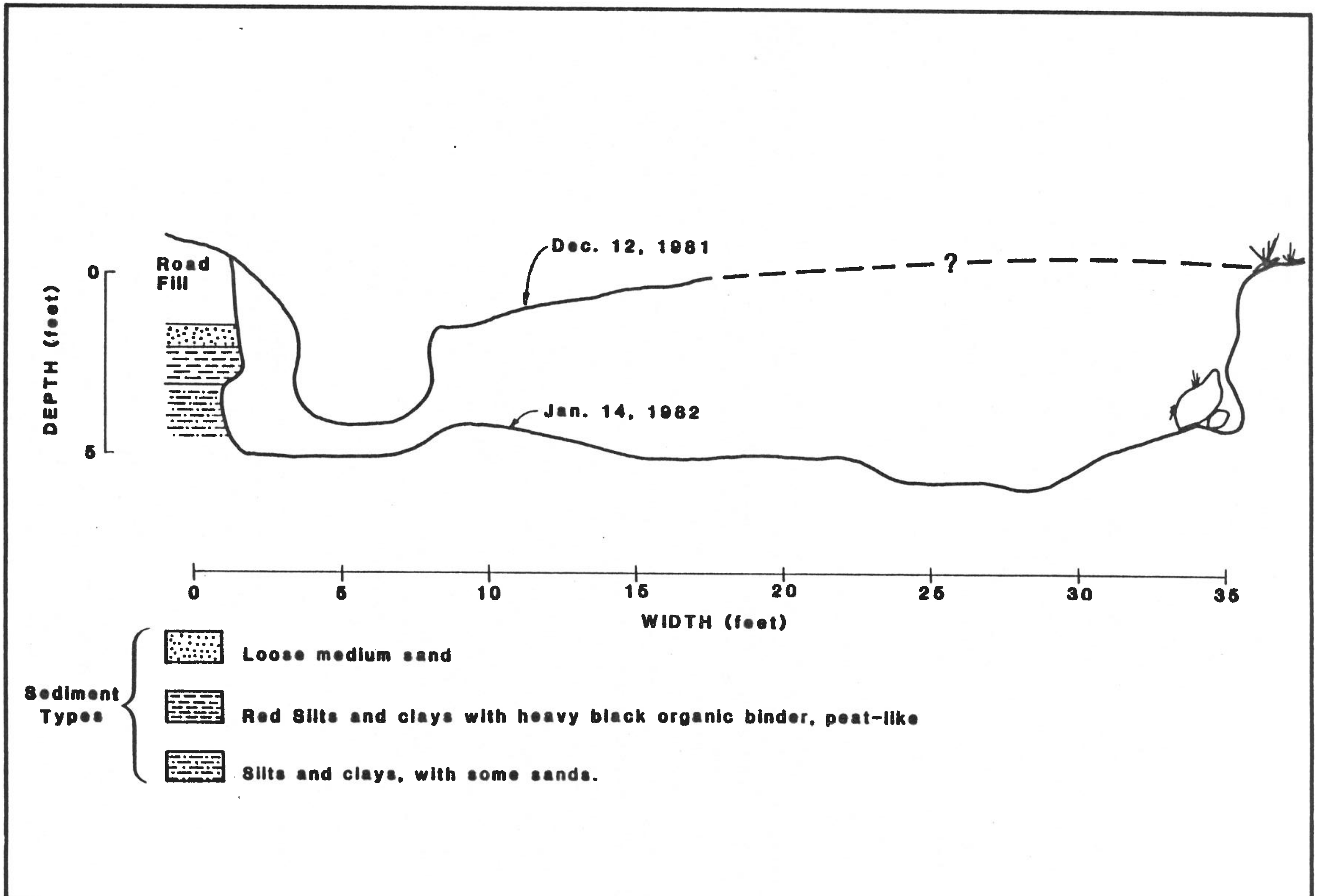

Figure 5. Channel incision, Freedom Blvd. Creek, near Aptos High School. Most activity associated with event of Jan. 4-5, 1982, although three other major storms occured in the period between observations. Traced from field sketches made with a measuring tape.

An indication of the importance of channel development on the runoff regime can be found in comparing pairs of basins which differ primarily in this respect. Table 5 affords two such comparisons, one for a pair of small drainages near Aptos High School, and the other for the two largest watersheds considered in this study: Prunedale Creek and Freedom Boulevard Creek. The two small basins are located on opposite sides of Freedom Boulevard, and have very similar rainfall, slopes, and percentages of very sandy soils. They differ in land use and to a certain extent in drainage area. From a hydrologic perspective, the land-use difference is manifest partly as radically different drainage densities. Aptos High School is situated in the center of a bowl-shaped valley, whose developed portion is drained by numerous gutters and ditches into a single arterial culvert. By contrast, the main drainageway of the Aptos Orchards basin is a small and discontinuous rut in the overgrown service road which meanders through the orchard. Overland flow from the steep slopes ringing the valley and from the orchard itself must travel several hundred feet across the relatively flat, sandy valley floor before reaching the embryonic channel system.

Runoff crests per unit area in the Freedom Boulevard drainage area are consistently 10 to 12 times larger than in the Prunedale Creek watershed. Slopes, vegetation, and the character of development are similar in the two drainages. They differ primarily in the extent of drainage development, rainfall, and watershed area. Differences in rainfall and drainage area may account for about 23 and 28 percent, respectively, of this difference (based on Figure 4 and Equation 2). Assuming all other factors being equal, the five- or six-fold residual difference in peak runoff from the two basins seems atrributable to the extent of drainage development. Freedom Boulevard Creek has developed a large channel during the past two years (see Figure 6) which extends the full length of its main stem. Additionally, drainage ditches along Cox Road, a major tributary valley, have been paved and placed in culverts. Small channels have developed in two left-bank valleys which were previuosly grassy swales. The drainage network is now nearly completely integrated. A small portion of the Prunedale Creek watershed is an integrated set of ditches draining lower Langley Canyon and the area of the Highway 156 interchange. Other major side valleys are drained by incipient or discontinuous channels, or by channels so obstructed by grass and brush that conveyance is minimal. Some valleys are separated from even this limited drainage network by ponds and lakes, some of which are natural (see discussion in previous section). The segmented and non-integrated character of the drainage network serves to diminish crest flows and to encourage additional recharge in this area of perceived water shortage.

Peak rates of runoff from basins with incised, well-developed or paved channels are much higher than those from basins which have retained their grassy drainageways. It remains unclear the extent to which one causes the other. For management purposes, reducing the magnitude and duration of flood peaks can prevent channel development of an incised channel. Similarly, stockponds and detention basins or grade-control structures can serve to reduce flood crests and also augment recharge.

Table 5. Comparisons Of Individual Storm Peaks Between Basins With And Without Intensive Channel Development

Basin Descriptors	Pair #1[a] (Small Basins)		Pair #2 (Larger Basins)	
Code[b]	2A	1B	7X	--
Stream	Aptos High School	Aptos Orchards	Freedom Blvd. Cr.	Prunedale Cr.[c]
Station	Campus Entrance	At Church	At Aptos High	At Gage
Drainage Area (sq. mi.)	0.25	0.08	2.55	7.5
Channel Development	Heavily guttered	Minimal	Extensive	Moderate And Discontinuous
Mean Annual Rainfall (inches)	26"	26"	26"	18"
Percent of Basin With Very Sandy Soils	65%	70%	75%	90% (est.)
Percent of Basin, Impervious Area	18%	0	18%	20% (est.)
Storm Dates and Peak Discharges (cfs/sq.mi.)				
October 27, 1981	115	0.38	0.09	1.4
January 4, 1982	820	78	122[d]	10.2
February 16	-	-	-	8.5
March 1	-	-	-	2.3
April 10	-	-	-	6.7
October 26, 1982	-	0	-	1.3
November 29	44	0.9	-	4.1
December 22	375	9.7	47	5.2
January 27, 1983	390	2.1	107	7.9
March 1 (?)	580	1.7	94	9.0
April 25 (?)	260	tr.	24	
May 1 (?)	4.7	0	3.1	

[a] Basins 24 and 1B are located on opposite sides of Freedom Blvd. near Aptos High School.
[b] See Table 3 and Figure 2
[c] Monterey County Flood Control and Water Conservation District's gage at Reese Circle, 1 mile south of Highway 156. Data preliminary and subject to review.
[d] Prior to the January 4, 1982 storm, this stream had a small and discontinuous channel.

Channel development is an ongoing process throughout the areas of sandy soils surrounding the Pajaro Valley. It is especially prevalent in areas underlain by Aromas Formation and derivative soils and sediments. Perhaps 25 to 50 percent of the Aromas-type valleys have actively incising or widening channels. Cumulative damages caused by this process in all sandy areas of the three counties may be in the millions of dollars annually, most noticeably in road maintenance and flooding. Loss of soil and of recharge is also widespread. In the Pajaro basin, habitat damage is most evident at Valencia Lagoon, but many other important water bodies are also being filled, including Corralitos Lagoon, Merk and Warner Lakes, and the Spring Valley marshes. At present, these problems are approached individually. Recognition of channel incision as a widespread condition in the sandy soil areas of the three counties could be an important first step in developing a more effective integrated drainage management and erosion control program.

Estimates Of Recharge Losses. Given the present data, it is not yet feasible to directly estimate the recharge losses in the urbanized basins. Federal agency data for rainfall, storm crests, and storm durations are not yet available in final form for the 81-83 period, in part due to the large number of storms.

A rough estimate of the range of increased runoff (lost recharge) can be developed by graphic methods from the available data. For example, runoff crests for the January 1982 storm (Figure 6) indicate that the responses of the urbanized sandy basins are more nearly similar to those of the large montane watersheds than those of the non-urbanized sandy basins. To adjust the peak runoff data for drainage area (see above), lines may be drawn from the approximate median of each group at a slope equivalent to that of equation 2*. Peak discharges per square mile during this storm for watersheds with a drainage ara of two square miles are projected to be about 600, 330, and 60 cfs for large montane, urbanized sandy, and non-urbanized sandy basins, respectively. Data for other storm events are fragmentary, but indicate the same general pattern.

The longer-term data from gaging stations (Figure 1; HEA, 1978a) indicate mean runoff is often 35 to 40 percent of mean annual rainfall in the large montane basins, and perhaps 3 to 5 percent in the sandy watersheds. If the increase in runoff is roughly proportionate to the

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* Equation 2 relates the presumed dominant peak discharge to the 0.73 power of drainage area. Figure 6 is based on discharge per unit area. The area-adjusted lined in the figure have slopes on logarithmic paper of -0.27, reflecting the division by drainage area. If equation 1 is used, a slope of -0.09 (0.91-1.00) would apply.

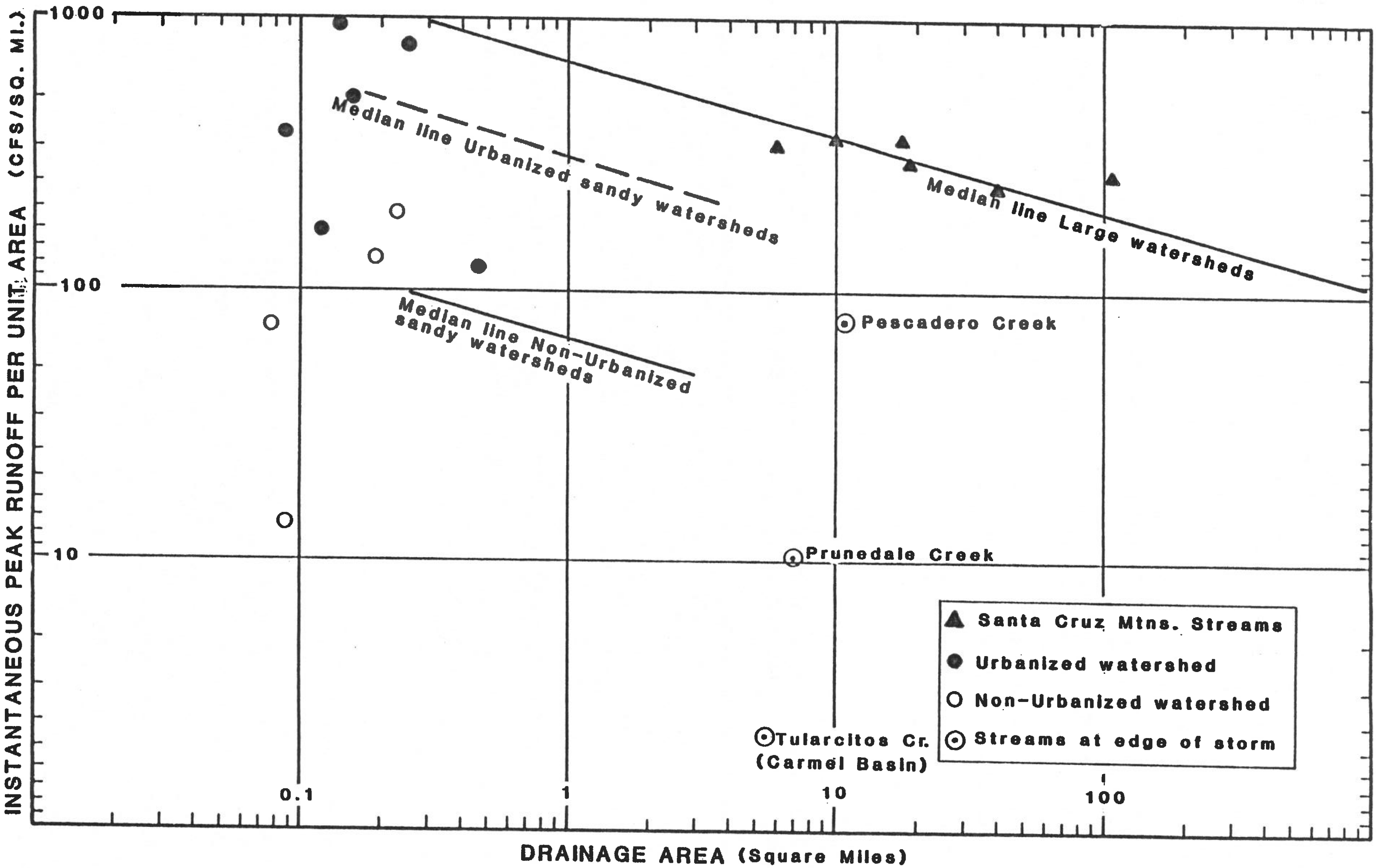

Figure 6. Area-adjusted "Equivalent Runoff" for January 1982 Storm. Median lines are guidelines for "equivalent storms" for large watersheds in the Santa Cruz Mountains, and for sandy urbanized and non-urbanized basins. All curves eye-fit. This is a preliminary form of analyses which should not be used after more complete 1982 and 1983 gaging data become available. Data from Table 4.

differences in storm crests* between the "developed" sandy basins and the mountain basins, then runoff from the developed sandy basins might be about 25 or 28 percent of mean seasonal rainfall. The additional runoff attributable to urbanization, or about 20 to 25 percent, corresponds to the loss of about 6 to 7 inches per year of recharge in an area with 30 inches mean annual rainfall, or 4 to 5 inches annually in the 20 inches per year rainfall zone.

While this rough estimate is based on many assumptions, it can serve to help assess the effects of rural residential uses on the overall basin hydrologic balance. For example, conversion of a small sand-hill valley totaling 500 acres to residential uses might result in mean recharge losses of about 200 acre feet per year in the 20-inch rainfall zone or 250 to 300 acre feet in areas with 30 inches of mean rainfall. We emphasize that this is a preliminary form of analysis. It provides a working set of values for use in management-plan devel opment, and should be revised when more detailed runoff data have been collected for various sandy watersheds.

Recharge Processes And Areas

In this section, four specific issues regarding the processes and areas through which recharge occurs are addressed as follows:

1. Alternative approaches to recharge management are discussed. Present practice is to define primary recharge areas based on the mapped extent of permeable soils. Such soils, however, generally cover 20 to 60 percent of the area of most sand-hill basins. (See, for example, Table 1). Yet, only a few percent of the mean annual rainfall leaves the basin as runoff during most years. Therefore, nearly all of the rainfall on the less-permeable soils is also retained. Undoubtedly many different factors and processes are involved which indicate that entire sub-watersheds have appreciable recharge importance. Therefore, a watershed-type perspective may be warranted in evaluating areas of significant recharge potential.

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* Once a channel network has developed in a sandy basin, both the peaks and duration of runoff from most storms begin to converge toward the regional or "montane" norm. We believe it is reasonable to make such an approximation (for the general-planning purposes of this study) when there is a relatively small difference in peak runoff. The approximation should not be made in comparing basins with sharply differing flood crests, as the natural processes influencing the rate of runoff (and hence, the shape of each hydrograph) may be entirely different. For example, the estimates of differences in mean runoff volumes discussed in the next few sentences differ by factors of about three to five, even though the flood-peak ratios typically range from 10 to 60.

2. The hydrogeology of recharge is also further explored. Particular emphasis is placed upon infiltration processes and landforms which may be affecting recharge rates through the floors of the grassy valleys.

3. There have been several major contributions to knowledge of the sand-hill environment during the past five to eight years. These are briefly discussed in light of the two previous items.

4. Possible new classifications of primary recharge areas are also presented. A map showing the main areas of primary and secondary recharge is presented.

Alternative Concepts of Primary Recharge Areas. A goal of land management in the most important recharge areas is to prevent significant loss of annual inflow to the aquifer system. Present practice is to identify primary recharge areas based on mapped soil types. According to current standards primary recharge areas are defined as soils with infiltration rates exceeding two inches per hour. The areas actually shown on present planning maps as primary recharge areas have two additional properties not explicitly defined. First, infiltration rates in all horizons within these soils exceed the two-inch threshold; second, designated recharge areas overlie and are in hydraulic continuity with developed aquifers. The present approach to defining primary recharge areas is among the most advanced of the available planning strategies. In addition, implementation seems to have been thorough and sensible.

It is likely, however, that present concepts of primary groundwater recharge area may be excessively narrow. Soils with overall permeabilities exceeding two inches per hour generally cover only 20 to 60 percent of most sand-hill watersheds. Yet, a very small proportion of rainfall usually leaves the watershed in the form of runoff. Even the less-permeable soils have low effective runoff rates, perhaps in part because rainfall runoff from the slopes may eventually infiltrate into the sandy soils and sediments in the flat-bottomed hollows and valleys.

It is rainfall falling over the entire small watershed, then, that is recharged. Thus, the "sand-hill valley" might be usefully taken as the fundamental land unit for protecting and managing recharge. This approach might be considered a minor variant of the watershed perspective incorporated in both counties' general plans and related implementing documents. The main difference is that the sand-hill watersheds can be considered as sources of recharge rather than runoff. Watersheds yielding minimal runoff are those of the greatest value. The planning process might become oriented primarily toward managing the entire small watershed rather than just its most pervious portions.

Processes and Landforms Affecting Recharge Within Each Valley. In the previous section, some potential advantages in treating each separate valley as a recharge unit were outlined. Because the sand hills are a distinct and relatively unfamiliar land type, some of the features and processes most affecting recharge are briefly described in this section. Emphasis is on the lower slopes and valley floors, which may serve several key functions in retaining and recharging storm runoff. Figure 7 schematically shows a section of a typical sand-hill basin. We recognize four general slope elements, affected by different processes and generally underlain by different soil types.

Ridge Crests: Crests of ridges through the Pajaro basin sand hills are broad, and generally gently sloping or nearly flat. South of the Pajaro Valley, some of the crests are underlain by semi-consolidated sandstones which produce a knobby topography; the overall form of the crest remains broad and gently-sloped. Many individual ridges are sufficiently flat, broad, and continuous to support commercial agriculture (e.g., Rancho Road) or to serve as the locations of significant residential areas (e.g., Calabasas Road, Rifle Range Road). Soils and sediments of the crests are usually conducive to retaining runoff and allowing percolation to the regional water table.

Side Slopes: The steeper slopes beneath the crests are typically underlain by thinner soils less able to retain rainfall and recharge the regional system. These are erosional surfaces, although rates of erosion from these areas are typically very low under natural conditions. Slopes with sunny aspects (southeast-, south-, or west-facing slopes) most often support chaparral; north- or east-facing slopes frequently support a low hardwood forest. The latter have developed somewhat deeper forest-type soils, significantly richer in organic matter and clays. These differences are expressed nearly everywhere in the sand hills as asymmetric valleys, with steeper north-facing slopes. We can speculate that, prior to the past 100 years, the brush-covered slopes produced runoff and erosion mainly following wildfires or extremely intense storms. The shadier forested slopes retained runoff under most conditions, producing sediment primarily as the result of deep-seated land-slips or occasional gullying. The valleys may have remained unchanneled because the two slopes were affected principally by different types of processes, seldom producing pulses of runoff or sediment at the same time.

The effect of most land uses is to reduce the differences in the storm response of the two slopes. With both slopes producing runoff from the same storms, the likelihood of channel incision is considerably increased. Fortunately, both counties tend to indirectly discourage development of the steeper north-facing slopes through erosion-control and grading ordinances, and through Santa Cruz County's rural-density matrices. Preventing channel incision should be a major goal of recharge- and watershed-protection programs in these areas. We believe that sustaining the balance and diversity of runoff- and sediment-producing processes will be helpful in preventing or limiting the extent of incision.

Depositional Or "Colluvial" Slopes: Virtually all sand-hill valleys have pronounced, gently-sloping lower slopes. These are formed on sandy outwash from the upper slopes. Soils are sandy, and usually show minimal development. Thin horizons of mixed sand and silt, often

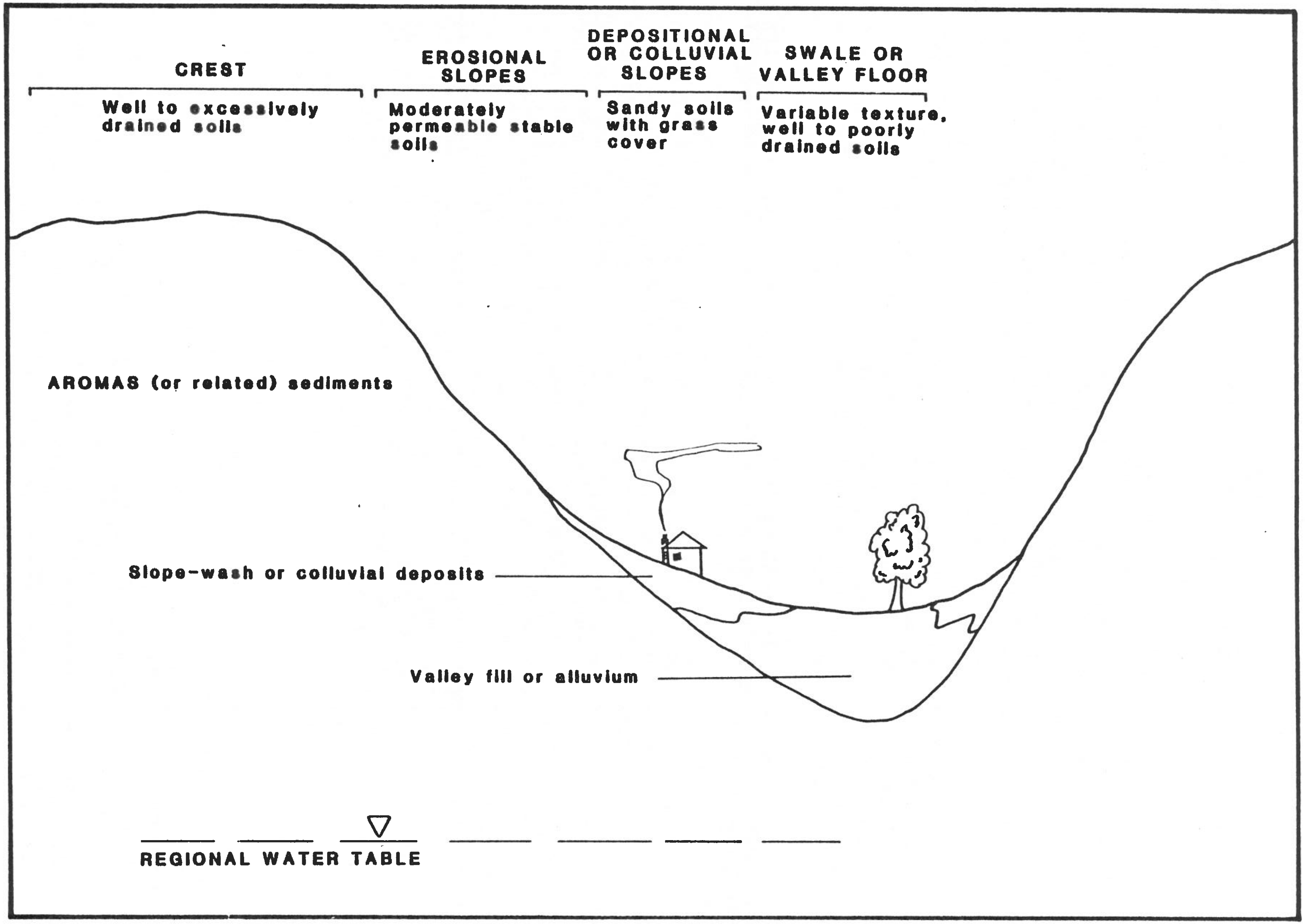

Figure 7. Schematic section of a sand-hill valley. Slope segments and related processes are described in the text.

with some charcoal between them, can sometimes be seen in pits and fresh roadcuts. Generally, these deposits are extensively re-worked by burrowing rodents.

The depositional slopes generally cover about 25 to 30 percent of each sandy basin, with the exception of the areas of recent dunes. The slopewash deposits* from each side merge in the smaller valleys, which might properly be termed "swales". We believe that the lower slopes are very important in detaining runoff and minimizing storm crests. They may well be significant in the basin-wide recharge budget, although little is known about their soils or runoff properties (e.g., Table 2).

Valley Bottoms: The valley bottoms are flat to very-gently sloping surfaces in section. They overlie alluvial fill, typically 10 to 20 feet deep in the upper valleys and up to 150 feet deep near the coast. The alluvium fills the much deeper valleys cut during glacial periods, when sea level in Monterey Bay was as much as several hundred feet lower than at present.

There are at least three unusual aspects to the alluvium of the sand hills which affect their runoff-retention and recharge properties:

1. The upper several inches to several feet of alluvium are commonly loose, sandy material (e.g., Figure 6). This material, although often mapped as Arnold or Baywood soils, may be deposits resulting from the past 200 years of accelerated erosion rates. It often overlies much finer clays and organic-rich sediments with lower infiltrabilities. Many valley floors have properties allowing the rapid assimilation of the first several inches of rainfall or runoff.

2. Three types of small wetlands are characteristic of these valley floors. Each results from the originally-very low rates of erosion and runoff in these watersheds. All three serve to retain runoff, diminish storm crests, and probably to promote recharge.

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* Dupre and Tinsley (1980) map these features as "colluvial deposits", a term conventionally used for slope deposits that move chiefly by creep and mass wasting (Hunt, 1972). The term connotes a clay-rich and hetergeneous mass with generally low permeability. We prefer the use of slopewash deposits or any similar term, such as the Soil Conservation Service's <u>haploxeroll fluvaquent</u>, which depicts their water-laid, sandy and permeable character.

a. Fan-dammed ponds. Typical of the heads of valleys in the sandiest areas, these are formed when two slopewash fans merge at the center of the valley. These low dams become permanent and self-perpetuating features once vegetation can become established. The result is a low marshy area of one or two acres immediately upstream, often only a foot or two in depth. This is, however, sufficient to retain some floodflows and all sandy sediments introduced from upstream.

b. Valley-confluence ponds. These form at the junction of two valleys of roughly equal size in the sandier areas. The inferred processes of formation are shown in Figure 8. Echo Valley along San Miguel Canyon Road is perhaps the clearest and largest local example. Others occur in the Ellicott and Spring Valley Road areas of Santa Cruz County, and the Harrington Road area of Monterey County, plus a number of other locations.

   These wetlands typically are several acres in size, and are heavily vegetated. They serve as effective sedimentation basins and may reduce flood runoff to a moderate or major degree. Several valley-confluence ponds occur in the Prunedale Creek basin, which has appreciably lower unit rates of peak runoff than other sand-hill basins with comparable soils and rainfall.

c. Drowned-valley lakes. The largest wetlands occur at mouths of the larger sand-hill valleys, where they are dammed by the alluvium of the Pajaro and Salinas Rivers or other major regional streams. The sand-hill drainages have natural sediment yields so low that they have not filled to the grades of the major regional streams, which have aggraded to the current and higher sea level. The mouth of these valleys form large and often perennial wetlands. Among these are Warner Lake, Lower Harkins and Galligan Sloughs, Valencia Lagoon, Merk Road Lake, Corralitos Lagoon, and probably the so-called "Chain of Lakes" (Pinto, College, Kelley, Tynan, and Drew) north of Watsonville.

   All of these wetlands serve to retain storm runoff and settle sediment. While their beds are commonly a heavy organic muck of minimal permeability, they may likely serve to recharge some retained waters, especially at higher stages. Very little is known about the role of these larger wetlands in affecting runoff, water quality, and recharge in the Pajaro Valley.

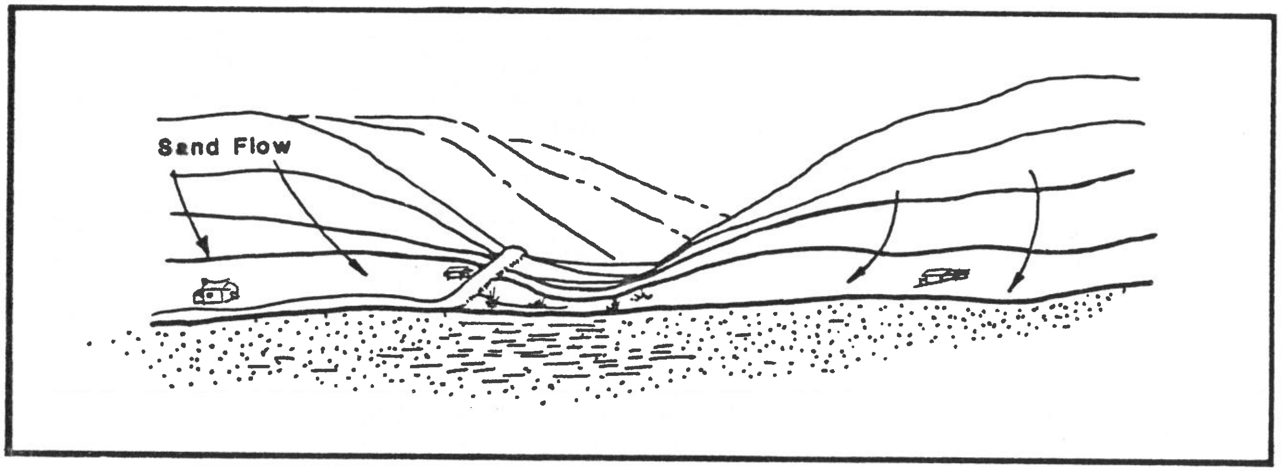

Figure 8. Inferred evolution of valley-confluence ponds, Sand Hills of Eastern Monterey Bay. In areas of very high soil infiltration rates, runoff rates are minimal. Little sandy material can be transported along the valleys during storms, although slopes continue to deliver sandy debris to the valley floors. Direct sand inflow from the hillslopes does not take place at the confluence; a low-permeability horizon may develop by accumulation of clays and organic debris.

Other Recent Studies Related To Recharge. There have been a number of studies completed over the past five years which affect perceptions of the relative distribution and importance of recharge areas in the Pajaro Valley. Among these are several bearing particular mention.

First, the Soil Survey for Santa Cruz County was released by the USDA Soil Conservation Service. This 1979 study mapped the sand-hill basins at a much finer degree of resolution than had previously been done. The slope elements discussed in the previous section could be distinguished in large measure as an outgrowth of the soils mapping.

Second, the sedimentology and depositional chronology of the Aromas Formation and closely-related younger deposits has been described by Dupre and Tinsley (1980). Their work distinguishes several different ages and types of dune deposits along San Andreas Road and in the Springfield area. They also recognized distinct depositional environments within the Aromas Formation, principally dunefields and alluvium. The ancient windblown deposits (Qae, Figure 2) are considerably more permeable than the fluvial (stream) deposits, shown as Qaf. Dupre and Tinsley did not distinguish dune and stream sediments within the Aromas Formation in some areas in Aptos and to south of the Pajaro Valley floor.

Two theses nearing completion are clarifying the relationship between the Purisima and Aromas Formations. This work by Bob Stuart (U.C. Santa Cruz) and Vic Madrid (U.C. Davis) suggest that there was a major hiatus during deposition of the upper Purisima sediments, following which coarser and more permeable sediments were deposited as the uppermost Purisima and Aromas Formations. This work suggests that portions of the uppermost Purisima outcrop areas (included as part of the unit shown as Tpc on most local geologic maps) may merit inclusion in the primary recharge areas affecting the Pajaro Valley. Upper Valencia Creek, Rider Creek, and lower Browns Creek historically have produced much higher summer flows than other eastern Santa Cruz Mountain streams, a strong indication that this concept has hydrologic merit. As these studies and other investigations of the upper Purisima sediments are completed, current concepts of the northward limits of recharge areas in the valley should undergo periodic review.

Recharge Areas. As a result of these studies and the analyses conducted for this project, an alternative assessment of recharge areas for the Pajaro Valley can be proposed. This reassessment is based in part on the "small watershed" or valley as the fundamental recharge unit, as discussed above. We recognize that this analysis is a departure from existing codes and conventions, but feel it to be an appropriate approach in light of the high costs of other potential sources of water supply within the basin.

A division of the sand-hill and nearby areas into four "primary" recharge classes and one type of "secondary" recharge class is proposed (Table 6). All four primary classes yield less than an estimated 10 percent of their rainfall as runoff when in native vegetation. They are distinguished on the basis of stratigraphy, probable runoff percentage, and potential management strategies. Secondary

Table 6. Generalized Recharge Classes Proposed For Pajaro Regional Recharge Protection

Class	Sediment Type	Sediment Unit[a]	Remarks
Primary Recharge Areas			
I. Primary (Dunefield)	Young, unconsolidated dunes yielding little or no runoff	Qbs, Qem, Qes, Qfd	Limited to San Andreas and Giberson Road areas
II. Primary (High)	Older dunes; portions of the Aromas Formation in which wind-blown sediments predominate; overlying terrace deposits; terraces mantled by dunal sands	Qae, Qcu, Qod, Qoe, Qsc	Sand-hill valleys near La Selva Beach and along Freedom Blvd. and Calabasas Road; much of Monterey and San Benito County areas underlain by Aromas sediments; selected other areas
III. Primary	Aromas sediments of mixed depositional environment; colluvium of the sand hills; alluvium of smaller and medium-sized valleys; stream-laid Aromas sediments near and east of Corralitos	Qa, Qaf[b], Qal[c], Qc, Qof[c], Qyf[c]	Aromas outcrop in much of Valencia and Green Valley basins and adjoining areas; much of Monterey County areas underlain by Aromas sediments; selected other areas
IV. Primary (Low)	Aromas sediments deposited in stream and estuarine environments, primarily in the Larkin and Moon Valley areas; coastal terrace deposits underlain by horizons limiting infiltration	Qaf[b], Qwf[d], Qyf[c], Qyt[d], others	Primarily along Larkin Valley, White, Buena Vista, Wheelock, and Salinas Roads; selected other areas
Secondary Recharge Areas			
Secondary	Terrace deposits in northern and western Pajaro Valley where underlying aquifers are unconfined, Coward fan; uppermost Purisima Formation near Corralitos	Qf[d], Qtc, Tpc[e], others	These units usually transmit substantially less recharge than those above, but are of general regional importance where extensive. Only larger areas shown. See text for the discussion

a/ Sedimentary unit shown on Quaternary geologic map of the Pajaro basin by Dupre and Tinsley (1980). See figure 2 of this report. We consider the underlying sediments to generally be the most important of several key factors affecting recharge rates, although important exceptions are noted.

b/ Alluvial sediments within the Aromas Formation have varying characteristics. Typically, these become finer to the west and southwest, although the coastal section may differ. In the Larkin Valley area, numerous silt and clay members occur, and sometimes predominate. The Aromas sequence in this area includes heavy clays thought to be estuarine (HEA, 1979).

c/ Recharge potential of alluvial sediments estimated from soil properties, drainage density, and water-quality characteristics.

d/ Soils, drillers reports, and other data used to estimate recharge characteristics of terrace deposits which have sharply and locally varying sedimentary textures.

e/ Upper portion of the upper Purisima Formation, perhaps above the depositional hiatus identified by Stuart (in prep.).

areas are those with demonstrated hydraulic continuity with developed aquifers, but which have significant lower recharge rates. In many cases, these have runoff rates intermediate between those of the "sandy" and "normal Santa Cruz Mountains" cases, and generally approaching the latter. The locations of the delineated recharge areas are shown in Figure 9.

There are some marked and widespread differences in recharge rates through the soils and sediments of the Pajaro Basin. These differences, described in following sections, are significant in the management of the region's water resources. We have made several assumptions and exclusions to simplify recharge-area delineation. First, mapping has been limited to recharge units of regional significance. As a working basis, units through which less than 200 to 300 acre feet is recharged annually could not readily be defined, and are not shown on the map. These are not shown on the map, which is intended for use at the regional scale. Secondly, the map specifically incorporates only rainfall ("direct") recharge; channel recharge is a separate set of processes, considered elsewhere in this and other studies. Third, recharge areas north and east of the San Andreas fault have not been shown, as these do not appear to be hydraulically continuous with the regional groundwater system (Muir, 1972; HEA, 1978), and are of localized extent. Finally, planning and design decisions related to recharge protection at the scale of the individual parcel should be based on site-specific data.

Primary Recharge Areas: Four classes of primary recharge areas are recognized due to the unique hydrogeologic conditions prevalent in the Pajaro Valley. All four classes are of primary regional significance; others have particular local importance in sustaining groundwater mounds or water quality. Generally speaking, primary classes III and IV are equivalent in many of their properties to alluvial and foothill primary recharge areas in many parts of California. Classes I and II reflect the widespread distribution of dunefields in recent sediments and those deposited throughout the past three or four million years.

Boundaries of the recharge areas are drawn along watershed divides where possible. This practice follows suggestions earlier in this chapter to orient management practices toward the sand-hill valley as the fundamental recharge unit.

The characteristics of each recharge class are described in Table 6. In most areas, the textures of the soil and underlying sediments were considered as predominant influences. The recharge map strongly reflects the depositional environments delineated by Dupre and Tinsley (1980). Soils and drainage densities were heavily weighed in estimating recharge classes of sediments on the floors of the valleys. Other hydrogeologic data were also incorporated in this analysis. There are approximately 61 square miles of primary recharge areas shown in Figure 9.

Secondary Recharge Areas: There are several diverse areas which, in aggregate, contribute appreciably to direct recharge in the basin. Rates of infiltration are significantly lower than in the primary

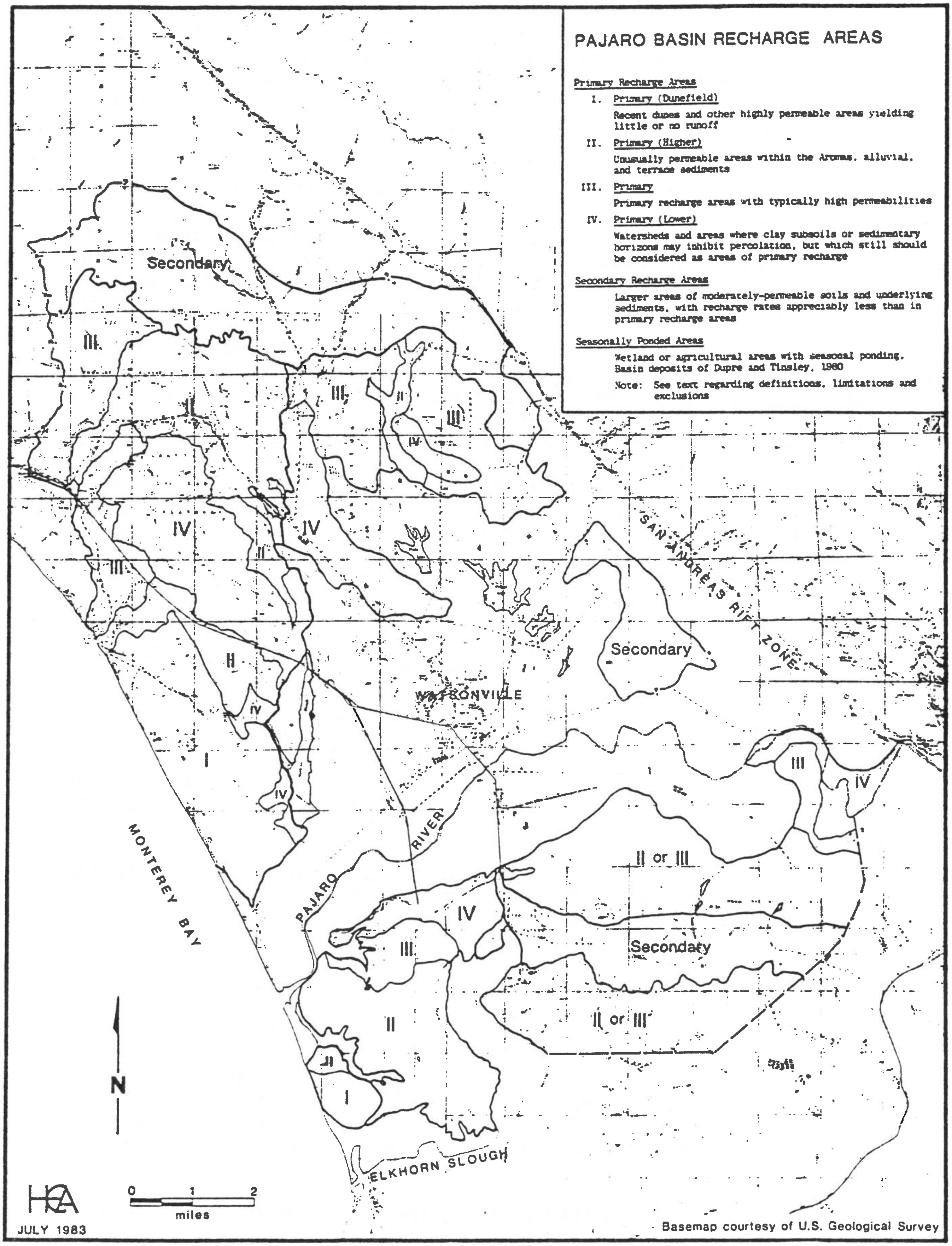

Figure 9. Pajaro Basin recharge areas

areas. Well-defined stream channels occur throughout the secondary areas at moderate densities. Most secondary recharge areas are used for agricultural, residential, and silvicultural purposes.

Three large secondary recharge units have been identified on the map, totalling about 19 square miles. Each area has distinct physical characteristics. The largest unit includes portions of the Santa Cruz Mountains foothills in the Corralitos, Valencia, and Salsipuedes watersheds. These are areas of moderately-permeable forest and woodland soils, generally underlain by the uppermost Purisima sediments. As discussed earlier, these sediments are related genetically to the lower Aromas sands, although they now are visibly more indurated and less permeable. Rider, Corralitos, and Browns Valley Creeks gain virtually all of their dry-season flow as they pass through the secondary recharge areas (State Water Resources Board, 1953; J. Smith, upubl. data; HEA, 1984). It is clear that substantial storage and discharge to streams occurs throughout this unit. The extent to which recharge from this unit eventually reaches the valley-floor aquifers is not known. We suspect that significant recharge does occur, based in part on the low concentrations of salts in deep wells nearby. The northern border of this unit is poorly defined. Although rainfall increase to the north, slopes are generally steeper, soils are thinner, and the underlying rock types are considerably less permeable and more intensely folded. These adverse conditions are less pronounced east of Corralitos Creek, where the secondary recharge area could conceivably extend northward to the San Andreas fault. We have conservatively drawn this boundary further to the south, given the absence of data.

The fan of Coward Creek and several smaller adjoining streams together constitute another secondary recharge area. The soils are of moderate infiltrability, generally 0.2 to 0.6 inches per hour in the least permeable horizon; this is about 10 times greater than in the older terrace soils nearby. The underlying sediments include significantly fewer heavy clay beds, perhaps due to erosion by Coward Creek. The hydrogeologic environment in this area is more fully discussed in the Coward Creek folio prepared earlier for this study.

The last of the larger secondary recharge areas encompasses the terraces and valley floor of Carneros Creek. The unit is a complex and fine-grained mosaic of differing soil and geologic types. Terrace deposits in this unit are typically rich in clay; soils developed on the terraces have heavy subsoils with minimal infiltrabilities. The swales and ravines draining the sides of the valley are usually underlain by younger and more permeable materials. The valley-floor alluvium has variable recharge characteristics, but these generally seem intermediate. The area receives relatively little rainfall and is relatively densely drained. We believe that recharge through this diverse terrain is appreciably less than through the sand hills north and south of the valley.

APPENDIX F

ON-SITE MEASURES FOR RECHARGE PROTECTION

APPENDIX F

ON-SITE STRUCTURAL MEASURES FOR RECHARGE PROTECTION

Structures described in this appendix are considered suitable means of controlling runoff from individual homesitesand roads in the sand hills surrounding the Pajaro Valley. Most structures were originally developed as erosion-control measures. Major sources for the discussion below include:

1. Tahoe Regional Planning Agency 1978 Handbook of Best Management Practices for Erosion and Runoff Control.

2. High Sierra Resource Conservation and Development Council's 1981 Erosion and Sediment Control Guidelines.

3. Department of Water Resources' Erosion and Sediment Control Handbook (Amimoto, 1981).

These reports are the main available sources which contain a detailed technical discussion of erosion and sediment control facilities appropriate to the slopes and soils found in the hills surrounding the Pajaro Valley*. These facilities can also serve the purpose of recharge enhancement in areas with high soil permeability, such as the sand-hill areas of the Pajaro basin.

Most of the facilities discussed below have been implemented in over 500 projects in the Lake Tahoe basin and elsewhere in the state over the past four years. An effort is currently under way by the Tahoe Regional Planning Agency (TRPA) to revise and consolidate their recommended runoff control measures based on the experience gained during recent years. A revised Handbook of Best Management Practices is expected to be published at the conclusion of TRPA's ongoing program.

Recharge protection and erosion control can be attained conjunctively by implementing appropriate erosion and runoff control measures for individual parcels or structures. The emphasis in this discussion is, however, on measures which would maximize the deep percolation of rainfall runoff at the site.

Dry Well: A dry well is a gravel-filled pit or trench which is used to store and infiltrate surface runoff. The use of a dry well may be advisable on parcels requiring the installation of runoff and erosion control facilities; however, unless the soils have moderate to

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* In applying any of the structural runoff control measures recommended for the Sierra to the Pajaro Basin, it should be kept in mind that no provision for frost protection would be required in the Pajaro Valley.

several feet below the bottom of the well, no significant recharge advantage is gained by using dry wells. Schematic cross sections of typical dry wells are shown in Figure 1. The required surface area of dry wells varies as a function of the volume of excess runoff that should be percolated in a given time period and the rate at which water percolates in the ground. The use of several shallow dry wells may be preferable to the use of one dry well unless space limitations preclude the use of multiple small wells. In the absence of pilot field data, the use of one shallow dry well under each roof downspout may be adequate to percolate the excess runoff in soils of moderate to rapid permeability and where groundwater is at appreciable depth below the bottom of the dry well. Additional dry wells may be required to percolate excess runoff generated from other paved areas.

The cost of installation of dry wells per dwelling unit is estimated at $500 for six dry wells of 18 inch diameter and 5 feet depth.

Spreading On Level Ground: The objective of this method is to spread the runoff from impermeable surfaces such as roofs, parking lots, pavements, etc. on permeable level areas where it can percolate. The spreading area may consist of the landscaped portions of the parcel or any other unpaved areas (such as home gardens, lawns, or orchards) which may be suitable for this purpose.

On sloping surfaces, a level spreader can be constructed as shown on Figure 2. The level spreader would aid in converting concentrated runoff into sheet flow for discharge over areas stabilized by vegetation. This system could attain both erosion control and runoff reduction objectives provided that the soil has moderate to rapid permeability characteristics.

Assuming that up to five level spreaders will be required around an average-sized single-family dwelling unit, the initial cost of this alternative would be about $360 per dwelling unit.

Perforated Slotted Drain: Slotted drain is a perforated drain pipe constructed with a continuous slot inlet. Surface runoff is collected along the entire pipe length and is percolated into the ground through perforations in the pipe. The drain pipe may be constructed from corrugated metal pipe. These pipes should not be installed on grades in excess of 3 percent to avoid any slope stability problems.

Schematic diagrams of a slotted drain pipe is shown in Figure 3. Diameter and length of the required slotted drain pipe and therefore the cost of installation would depend on rainfall runoff conditions and permeability characteristics of soils at the project site.

The cost of installation of 100 feet of 12 inch diameter slotted drain pipe is estimated at about $500 per dwelling unit.

Reduction Of Runoff From Impervious Surfaces: Almost all of the rain falling on impervious surfaces runs off from such areas and may be lost as a source of groundwater recharge depending on permeability characteristics of natural or artificial drainage courses and the

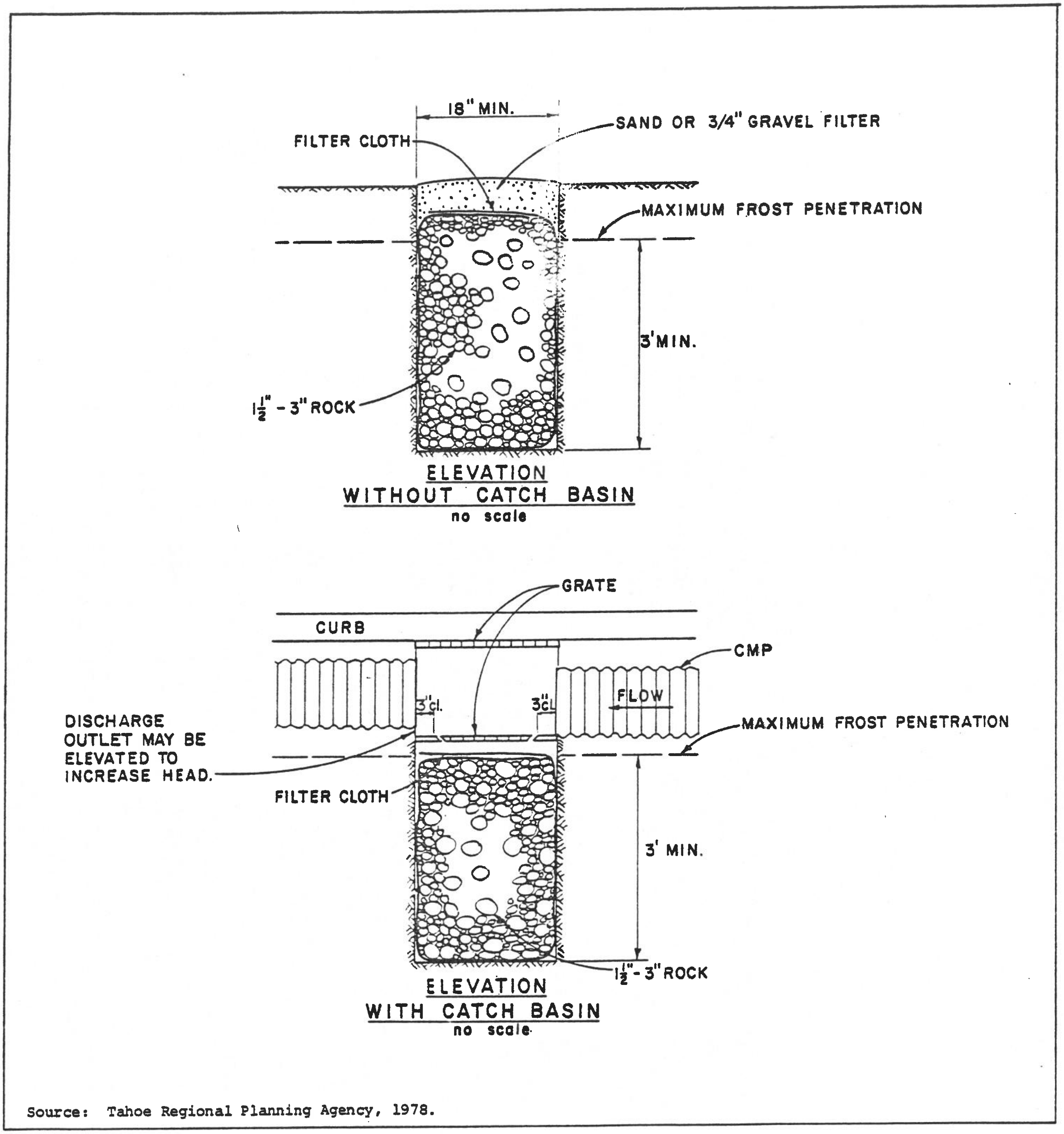
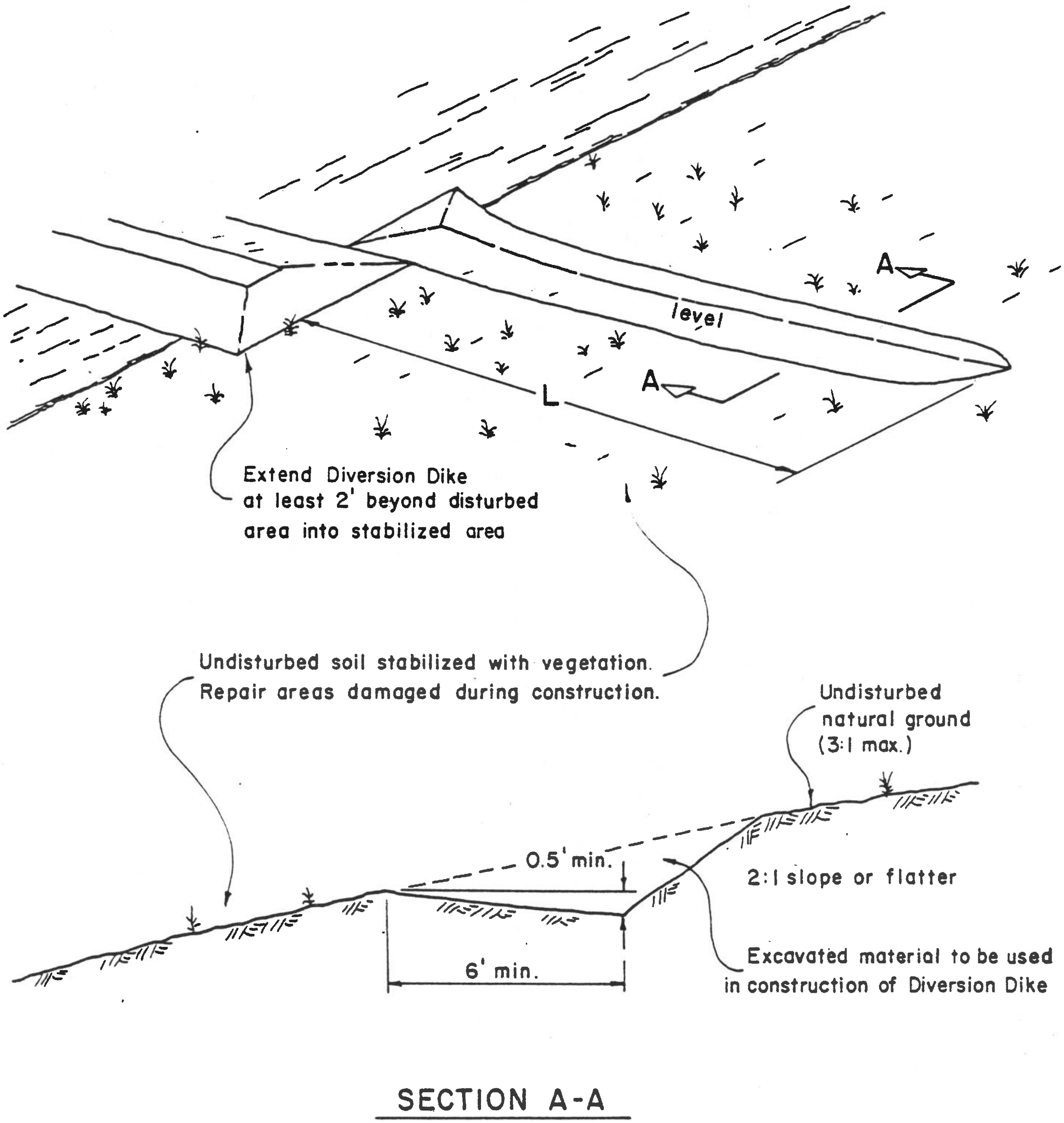
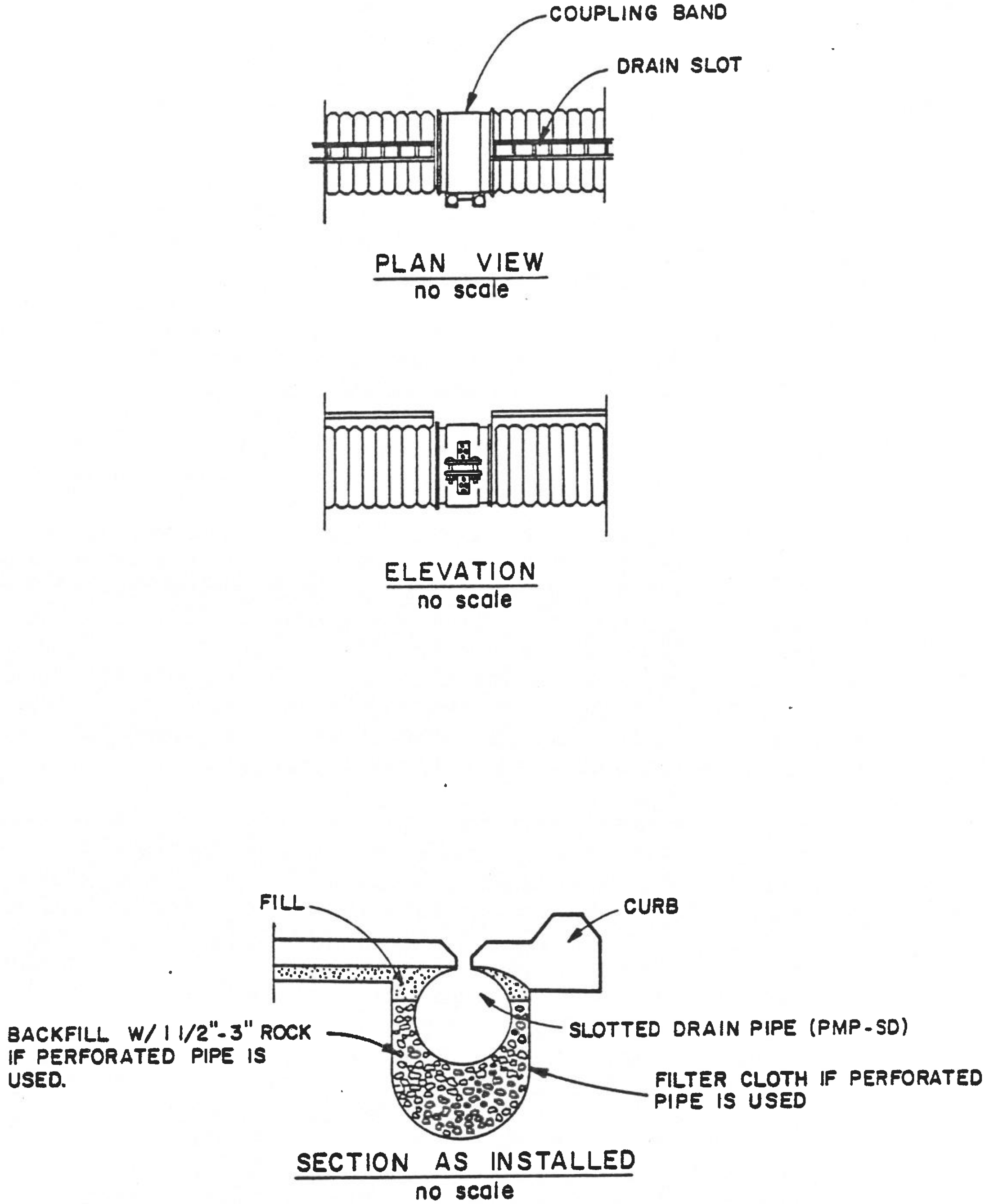


Figure 1. Designs for Dry Wells Suited for Soils and Sediments of High Infiltrability



Source: Tahoe Regional Planning Agency, 1978.

Figure 2. Schematic Design of Level Spreader



Source: Tahoe Regional Planning Agency, 1978.

Figure 3. Representative Installations of Slotted Drain Pipe in Soils of High Infiltrability

final point of drainage. One method of compensating for any loss of recharge is to facilitate the percolation of natural precipitation into the ground at or near paved areas.

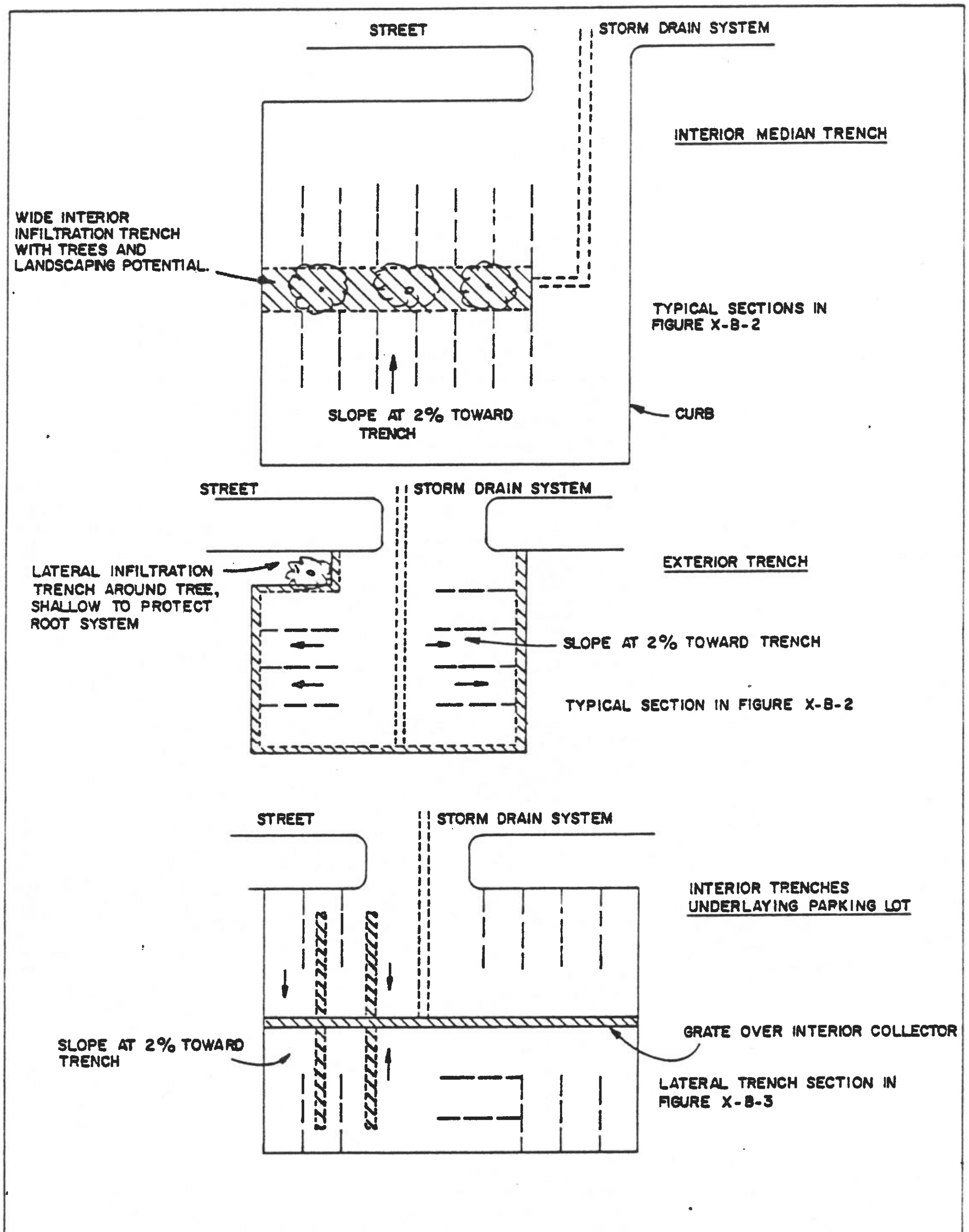
A number of methods can be employed to attain the preceding goal as follows:

a. Permeable surfacing materials for driveways, parking areas, roadways, etc., in primary recharge areas. The surfacing may consist of gravel or crushed rock especially in areas of seasonal or low intensity use.

b. Porous pavement materials. Porous asphalt pavement has been used on highways and airport runways over the past 10 to 15 years. The use of other porous pavements such as various concrete lattice blocks have also been tested in various experiments sponsored by U.S. EPA (Field, et.al., 1981). These porous pavements have many advantages such as the attenuation of runoff rate and volume, increased groundwater recharge, improved erosion control, and enhancement of water quality in receiving surface waters. The disadvantages include the probability of clogging, increased potential for groundwater contamination by toxic material spills or normally occurring pollutants and lack of specifications in existing building codes for this type of pavement construction. Available cost data indicate that porous pavements compare favorably with the traditional impervious pavement and storm drain combination system (ibid.).

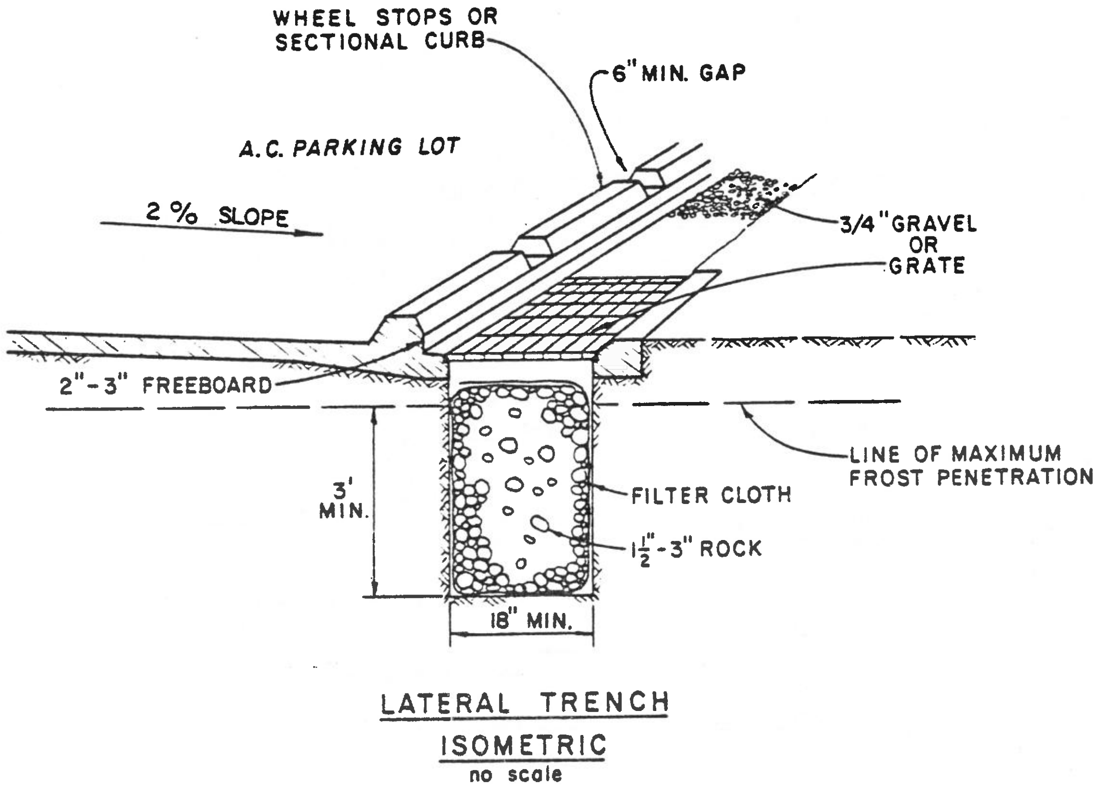
c. Parking area infiltration trenches. These trenches are similar in design to dry wells, discussed previously. The trenches should be connected to an off-site storm drainage system to avoid flooding hazards during storm events exceeding the design capacity of the trench system. Schematic diagrams for infiltration trenches and a permeable parking slab system are shown in Figures 4 through 7.

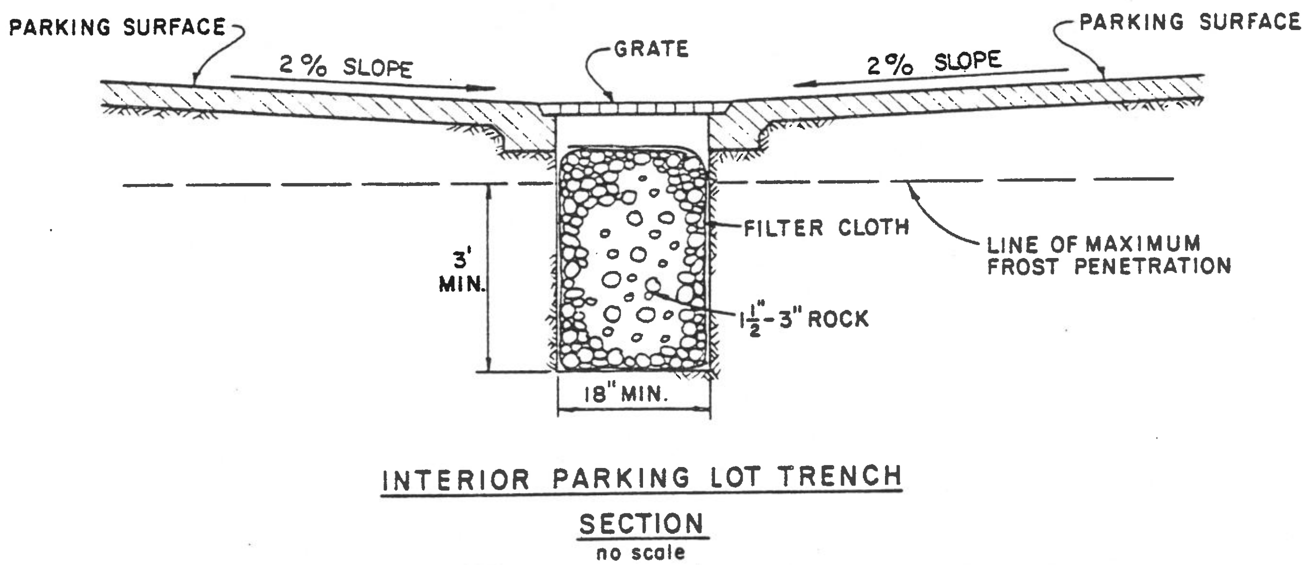
   A recommended design storm for providing storage capacity in infiltration trenches, porous pavements and other runoff reduction facilities is the 2-year, 6-hour storm. In the Monterey Bay area the use of a 10-year, 1-hour storm may be more advisable; it would also be consistent with the requirements of the Santa Cruz County Erosion Control Ordinance. Off-site storage or conveyance facilities must be provided for storms generating more runoff.



Source: Tahoe Regional Planning Agency, 1978.

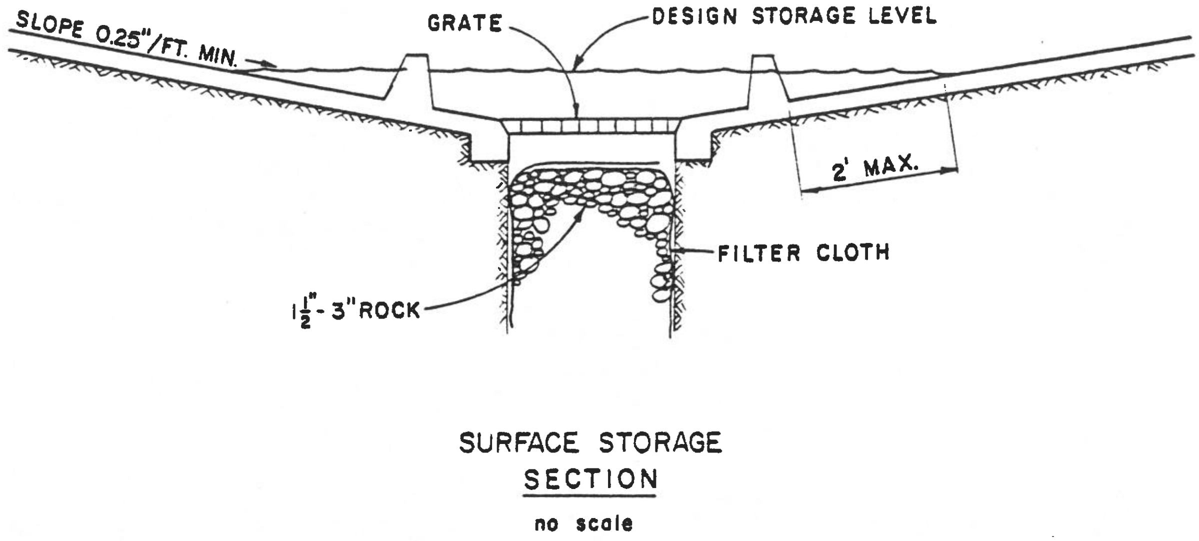
Figure 4. Use of Infiltration Trench to Augment Recharge in Parking Lots and Other Large Areas of Diminished Surficial Infiltrability

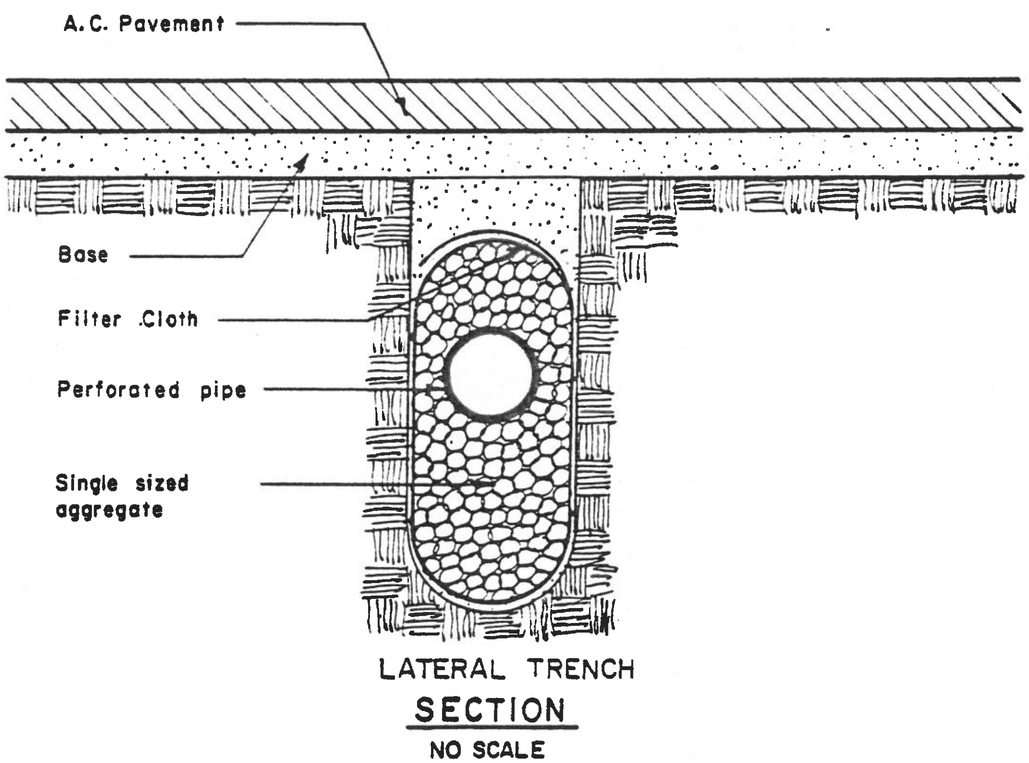




Source: Tahoe Regional Planning Agency, 1978.

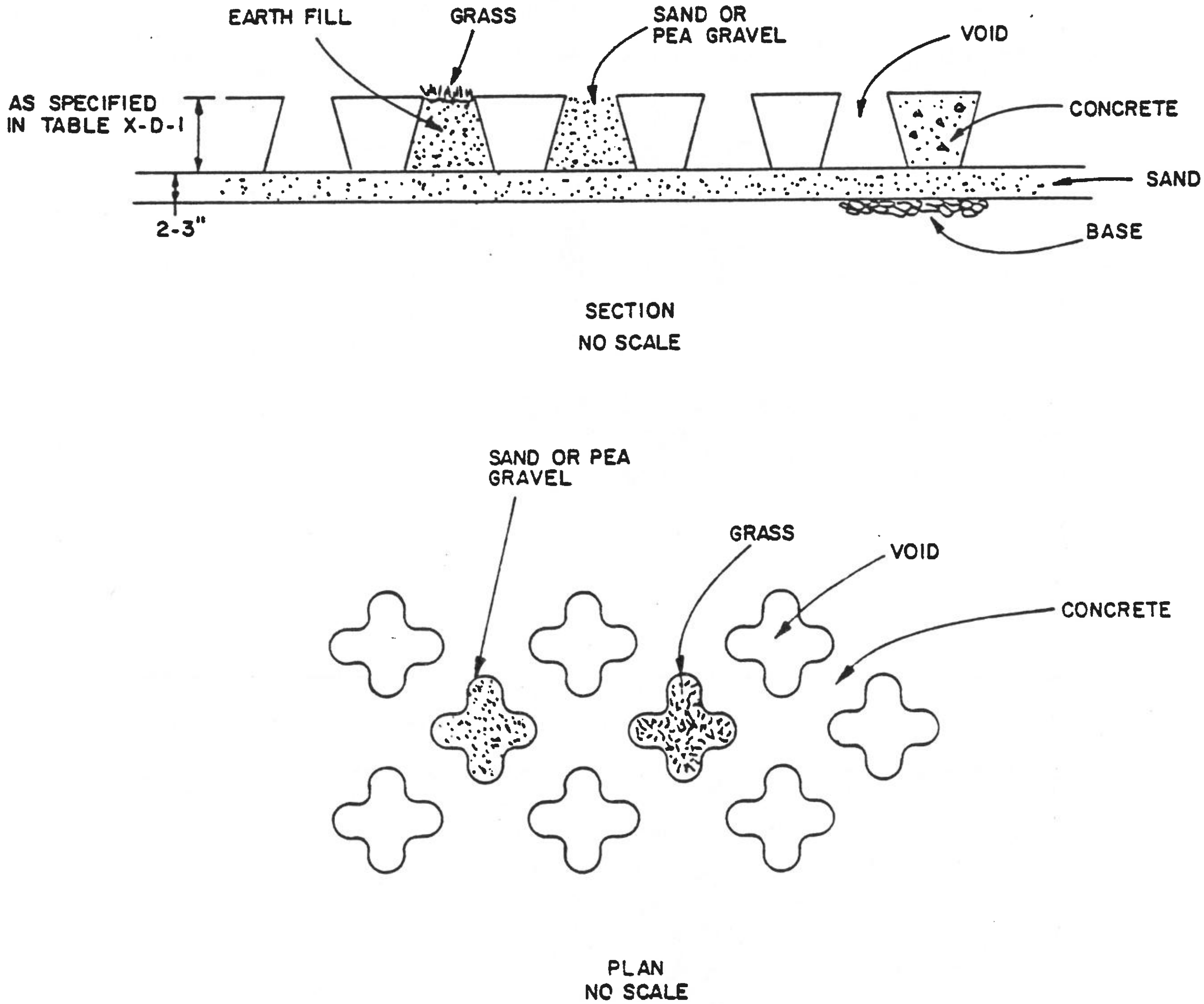
Figure 5 Typical Designs for Parking Lot Infiltration Trenches Suited for Highly-Permeable Soils and Sediments





Source: Tahoe Regional Planning Agency, 1978.

Figure 6. Detail of Infiltration Trench Construction



Source: Tahoe Regional Planning Agency, 1978.

Figure 7. Typical Design of Permeable Parking Slabs