RECONNAISSANCE LEVEL REPORT

POTENTIALS FOR YIELD AUGMENTATION THROUGH WEATHER MODIFICATION

PREPARED FOR THE

BOARD OF DIRECTORS
SANTA BARBARA COUNTY WATER AGENCY

BY THE STAFF OF

SANTA BARBARA COUNTY WATER AGENCY

* *

OCTOBER 27, 1977

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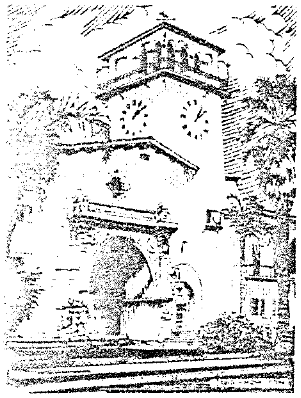
Santa Barbara County Water Agency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October 27, 1977

Honorable Board of Directors
Santa Barbara County Water Agency
105 East Anapamu Street
Santa Barbara, CA 93101

RE: Report: POTENTIALS FOR YIELD AUGMENTATION THROUGH WEATHER MODIFICATION

Gentlemen:

Submitted herewith is the Report: "Potentials for Yield Augmentation through Weather Modification." This report has been prepared by the staff of the Santa Barbara County Water Agency as one of a series of reports to your Board pursuant to Phase I of the Water Agency's Program of Action for Water Resources Planning.

Weather modification (cloud seeding) is of particular interest to Santa Barbara County inasmuch as this county has served as a target area for several seasons of both experimental and operational weather modification in years past. Weather modification represents a way in which local water supplies may be augmented under appropriate circumstances. However, despite the demonstrated ability of cloud seeding to augment rainfall, there is an astonishing lack of firm information available as to the effects of increased rainfall to produce additional water supply in surface water reservoirs and groundwater basins. A number of public and private agencies in the Western United States have been engaged in research and/or operational programs of weather modification, some for several years and others only recently. Out of these experiences, additional information will inevitably result, establishing improved relationships between augmented rainfall and augmented water supply. For the present, however, nearly all of the water supply findings reported herein are the result of original work on the part of the Water Agency staff, based upon data analyses. The work thus reported should be considered as indicative of possible results and also as preliminary in nature.

The report finds the following with respect to rainfall augmentation by cloud seeding:

- Over a period of years, weather modification can increase normal precipitation by as much as 15 to 25 percent, excluding flood producing storms, which would not be seeded anyway because of the potential risk.

- Cloud seeding appears to be most effective when conducted from aircraft upwind of the target area rather than from ground stations. This conclusion is based upon the extensive studies of the North American Weather Consultants under sponsorship of the U.S. Naval Weapons Center, China Lake.

- Cloud seeding is most productive during wet years and least productive during dry years. Aside from storable water supply, augmented rainfall under controlled cloud seeding may benefit dry-farmed areas, and urban areas simply as a result of the additional precipitation and (in the case of urban areas) temporarily reduced need for domestic irrigation.

- The best prospects for seedable storms involving Santa Barbara County are frontal storms during the general period of November through April and characterized by periodic updraft conditions known as "convective bands." Occasional tropical storms and thunderstorms appear to be too scattered and unpredictable in occurrence to be considered for rainfall augmentation.

In the matter of surface water supply augmentation resulting from cloud seeding, the report finds as follows:

- An approximate relationship exists between increased rainfall due to cloud seeding and increased runoff resulting from such increased rainfall. It appears that over a period of years, including both wet years and dry years, an expected 15 percent increase in rainfall from cloud seeding may probably increase stream runoff by about 20 to 30 percent. Such a range of increase appropriately discounts the flood producing storms, inasmuch as they would not be seeded anyway, and also the scattered rainy season storms during dry years, because the watersheds would normally be too dried out to be very effective in producing runoff.

° The degree to which cloud seeding augmented runoff can increase surface water supply via reservoirs is largely dependent upon the manner in which such reservoirs are operated, assuming that the reservoirs were properly sized with respect to their tributary watersheds.

° For example, if a reservoir is designed, in part, for water conservation via groundwater recharge, as is the case of Twitchell Reservoir, the weather modification yield augmentation potentials would appear better than in the case of a safe yield operated reservoir, such as Cachuma Reservoir. In the case of Twitchell Reservoir, the conservation operation has been considered to have increased the groundwater recharge to Santa Maria Groundwater Basin by about 20,000 acre-feet per year (AFY). An increased inflow to the reservoir could largely be reflected in corresponding regulated releases from the reservoir for subsequent percolation in the Santa Maria River stream channel below Fugler Point. On the other hand, with a safe yield operation, such as at Cachuma Reservoir, it is necessary to retain a relatively large pool in storage in order to ensure that those safe yield computed quantities can reliably be withdrawn annually and delivered to the Water Agency's member units during a critical, dry period of about 7.6 years (corresponging to 1943-44 through 1950-51). This means that there is reduced potential for capturing and retaining the augmented runoff in such a safe yield operated reservoir.

- Determination of augmented water supply in surface reservoirs attributable to cloud seeding operations would require detailed operational studies beyond the reconnaissance level scope of this report; however, reasonable approximations of the augmented yield are possible, when due allowances are made for evaporation losses from the additional impounded runoff and the fact that no augmentation occurs at all during years of reservoir spill without cloud seeding.

- Under the foregoing qualifications, the following estimates have been made for reservoir yield augmentation that might be achieved as the result of operational weather modification programs:

Reservoir	Type of Operation	w/o cloud seeding	w/cloud seeding	Increase in Cloud Seed. Yield, % **
Cachuma (205,000 AF)	safe yield	24,800	26,200	5
Gibraltar (9,300 AF)	safe yield*	1,600	1,730	8
Jameson (6,140 AF)	safe yield	950	1,000	5
Salsipuedes (52,000 AF)	safe yield	2,850	3,050	7
"	groundwater replenish.	6,500	7,000	7.5
Round Corral	groundwater replenish.			
(82,000 AF)		6,700	7,800	16
(50,000 AF)	"	5,500	6,300	14
Twitchell (240,000 AF)	groundwater replenish.	Not specifically determined		Determined as streambed percolation enhancement for both the Cuyama and Sisquoc Rivers

*Actually Gibraltar Reservoir is operated on a conjunctive use basis, for which augmentation has not been estimated.

**Surface reservoir-yield augmentation by rainfall augmentation is assumed as 40 percent of theoretical. Of the remaining 60 percent, one-third is assumed lost by evaporation and phreatophytes and two-thirds as recoverable via groundwater basin recharge in downstream basins. All numbers are approximate.

Note: Bookman-Edmonston Engineering, Inc. estimated the yields for both Salsipuedes and Round Corral Reservoirs, utilizing Water Agency runoff augmentation values.

- Groundwater basin yield can also be increased by augmented rainfall resulting from weather modification. Additional deep penetration of rainfall can occur, particularly during wet years, as the result of the increased precipitation. Also, increased streambed percolation can occur as the result of the augmented runoff resulting from cloud seeding. It is necessary to consider such groundwater yield increases on a case by case basis.

- Approximations of possible augmented groundwater basin yield due to operational weather modification programs were made (numbers rounded off), as indicated below, all numbers being tentative:

Groundwater Basin	w/o cloud seeding	w/cloud seeding	Increase due to Cloud Seeding, %
Carpinteria	4,500	4,950	10
Montecito	1,200	1,450	21
Santa Barbara	1,800	1,990	10
Goleta	4,100	4,600	12
Santa Ynez Uplands	9,700	13,400	38
Lompoc Area	27,000	29,000	7
San Antonio	10,000	12,600	26
Santa Maria	93,000	106,000	14
Cuyama	10,600	12,300	16

- Although no specific investigations were made of the potentials for cloud seeding augmented yields of reservoirs operated conjunctively with groundwater basins, it is expected that such yields might significantly exceed the yields of safe yield operated reservoirs and groundwater basins without artificial recharge.

- Weather modification is still evolving as a technology and is becoming increasingly attractive to water resource management agencies as a potential means of augmenting water supply yields. Many of the previously held notions about cloud seeding's robbing downwind areas of rainfall otherwise received and not being amenable to reasonable control appear to be fading in the light of increasing evidence to the contrary. There are environmental impacts to be anticipated from cloud seeding operations, and not all of these may be beneficial. However, cursory consideration indicates that from Santa Barbara County's standpoint, the beneficial effects should clearly outweigh the adverse effects. Liability for effects of weather modification rests with the operators of the seeding project and they are licensed by the (California) State Department of Water Resources. Few, if any, successful lawsuits have been placed against such operators.

- The apparent unit costs of "new water" created by weather modification are exceptionally low, primarily because of the negligible need for capital investment. Approximate cost values for total theoretical yields (including both surface water and groundwater) are in the range of \$4 to \$8/AF.

- The foregoing preliminary estimates of the potential yields, impacts, and costs of operational weather modification programs for Santa Barbara County do not represent firm figures, because there are still several uncertainties. However, these estimates are so promising that there is good reason to believe that weather modification programs should be pursued carefully and thoughtfully and that, eventually, such programs may become an integral part of the water resources management of Santa Barbara County.

- The Water Agency should seriously consider a program for operational cloud seeding within the next few years and preferably to be implemented by the end of the current drought as currently foreseen.

The undersigned will be happy to discuss the attached report with your Board at your convenience.

Respectfully submitted,

CHARLES H. LAWRANCE
Engineer-Manager

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Cooperative Extension, George Goodall
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Regional Water Quality Control Board, Kenneth Jones
State Water Resources Control Board, J. Bryson
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California Legislative Delegation

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POTENTIALS FOR YIELD AUGMENTATION THROUGH WEATHER MODIFICATION

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Accum	Accumulated
AF	acre-feet, a volume of water equal to one foot depth over one acre area
AFY	acre-feet per year
cfs	cubic feet per second
CNG	cloud nucleating generator
CWD	County Water District
EIR	Environmental Impact Report
LACFCD	Los Angeles County Flood Control District
M&I	municipal and industrial
mo.	month
MRI	Meteorology Research Inc.
NAWC	North American Weather Consultants
ppm	parts per million
SB Co.	Santa Barbara County
SCE	Southern California Edison Company
SCVWD	Santa Clara Valley Water District
UCSB	University of California at Santa Barbara
USGS	United States Geological Survey
VAFB	Vandenberg Air Force Base

I - INTRODUCTION

POTENTIALS FOR YIELD AUGMENTATION THROUGH WEATHER MODIFICATION

I - INTRODUCTION

BACKGROUND

Santa Barbara County Water Agency's Board of Directors adopted a "Program of Action for Water Resources Planning" on June 24, 1975. This was a systematic series of determinations of current and future water needs for the several localities of the County together with an appraisal of the adequacies of current water supplies and the development potentials of local and imported supplies. Alternative means of water supply supplementation to be considered included conjunctive use of surface reservoirs and groundwater basins, construction of new dams or enlargement of existing dams, reuse of reclaimed wastewater, mining of groundwater and importation of Northern California water from the State Water Project.

During the winter of 1975-76, it was determined desirable to add weather modification potentials to the alternatives for supplemental water supply being considered in the "Program of Action for Water Resources Planning," and this was done formally by action of the Board of Directors on February 9 , 1976. Such an action was logical in view of the considerable practical experience developed within Santa Barbara County on weather modification to increase rainfall and water supply and to investigate cloud seeding phenomena.

Past cloud seeding practices had produced information on how much increase in rainfall might be expected from weather modification. However, it remained to be determined how this information could be converted into increased water supply. It was felt that serious consideration should be given to this potential for additional water supply, as it might be proven comparatively economical. In addition, it might well enhance a conjunctive use management program in increasing yields over a period of years.

GOALS

Initial goals of the study were to determine approximate:

- Incremental yields in rainfall, runoff, and deep percolation to groundwater basins resulting from weather modification optimized for water supply.
- Storm patterns amenable to augmented water supply yield through weather modification.
- Short-range and long-range costs, benefits and detriments of optimal cloud seeding programs.

In addition, it was intended to identify possible and probable environmental consequences of cloud seeding programs that might be considered for Santa Barbara County.

It was hoped to be able to express as much of the foregoing as possible on a statistical basis.

AVAILABLE DATA

Precipitation Data

Rain gages have been maintained in various coastal, valley and mountain locations in Santa Barbara County for many years by the U. S. Weather Bureau (now the National Weather Service) and the Santa Barbara County Flood Control and Water Conservation District. A few municipal gages have also been operated, notably by the City of Santa Barbara at Gibraltar Dam, and the City of Lompoc. Most of these rain gages have been of the manual type, but a few have been of the hourly recording type.

Runoff Data

Stream flow data have been compiled for many years on selected streams at selected locations in Santa Barbara County by the U. S. Geological Survey. The results of daily, monthly and annual gagings are summarized and published by the U.S.G.S. under various titles depending on the year in question. The years 1950-1960 are summarized in Water Supply Paper 1735, Compilation of Records of Surface Water of the United States, Part II Pacific Slope Basins in California. Since 1960 the data have been published in annual reports entitled Water Resources Data for California, Part I, Volume 1.

Cloud Seeding Data

Historic cloud seeding data for Santa Barbara County have been recorded by North American Weather Consultants, who have been the technical consultants and operators of all weather modification operations involving the County up to the present. General data as to storm episodes and cloud seeding operations are included in the several reports published on such operations, as discussed subsequently. Detailed metorological data are not included in such reports but are in the files of North American Weather Consultants (NAWC).

Watershed Model

Santa Barbara County Flood Control and Water Conservation District have a simulation model of the Santa Ynez and Sisquoc River systems and San Antonio Creek system. This mathematical model was developed by Hydrocomp, International, a consulting firm who has provided services for the District. The model is designed and operated to determine potential channel flows and flooding conditions so that appropriate measures may be taken by the District in design of structures to control and/or accommodate floods and in warnings to the public whenever unregulated flood flows are anticipated.

The Hydrocomp computer model relates hourly precipitation at four representative watershed locations to runoff and channel flow in the affected stream segments. The model takes into account such items as air temperature, antecedent precipitation, soil moisture, soil mantle depth and permeability, topography and various other watershed characteristics, all relevant to predicting water stage and discharge in the several reaches of the stream segments.

In a previous consideration of the possibilities of assessing effects of cloud seeding upon watershed runoff, it was tentatively planned that hourly precipitation data for four key stations (located at Juncal Dam, Gibraltar Dam, Santa Ynez and Surf, respectfully) be adjusted by NAWC to show a best estimate of precipitation in the following cases:

- Randomized cloud seeding as actually observed during the 1967-74 program.
- No cloud seeding at all.
- Cloud seeding optimized for water supply.

The adjusted hourly precipitation figures would then be fed into the Hydrocomp model to calculate runoff in the Santa Ynez River Basin under the above arrangements. A sequel to this step would be selection of a few more historical years of varying climatological types for a similar detailed analysis, including some years of extreme drought conditions. A predictor curve would then be constructed permitting extrapolation for estimation of incremental runoff due to cloud seeding in any year or series of years(34).

For reasons of priorities and budget limitations, the Water Agency decided to defer any such action to a later date. However, if the Hydrocomp model work by the Flood Control and Water Conservation District were to be expanded for flood control purposes, it was contemplated that additional effort might be requested by the Water Agency in order to extend the analyses to include incremental runoff from cloud seeding.

II - WEATHER MODIFICATION EXPERIENCE IN

SANTA BARBARA COUNTY

II - WEATHER MODIFICATION EXPERIENCE IN SANTA BARBARA COUNTY

GENERAL

There has been considerable weather modification activity within Santa Barbara County, conducted by North American Weather Consultants in 15 rainy seasons out of the last 27, as itemized below:

Rainy Season	Coverage	Sponsor	Nature & Purpose
Most of 1950-51	Upper Santa Ynez Drainage Basin	City of Santa Barbara & Montecito CWD	To increase precipitation and runoff
1951-52 & 1952-53	Santa Barbara Co. Santa Barbara Co.	S.B.Co. Water Agency S.B.Co. Water Agency	Increase yields of watershed
Early 1955	Santa Barbara Co.	S.B.Co. Water Agency	Increase yields of watershed
1956-57 through 1959-60	Santa Barbara Co. and Ventura Co.	joint venture of nine agencies	randomized seeding
1967-68 through 1973-74	Santa Barbara Co. (North of Santa Ynez Mountain Range)	U.S. Naval Weapons Center	Special research (randomized cloud seeding)

EARLY EXPERIENCES IN RAINFALL AUGMENTATION

Initial Work, 1950-51

The City of Santa Barbara and the Montecito County Water District contracted with North American Weather Consultants to perform and study the seeding of clouds in the Upper Santa Ynez Drainage Basin during the winter of 1950-51 (December 1950 through April 1951). The procedure followed was to seed any of the clouds of all the cyclonic winter storms as they passed over Santa Barbara County (29). Silver iodide was used to seed the storms from upwind ground locations in various combinations of fixed and mobile units.

The practice of seeding <u>all</u> of the storms prevented the statistical calculation of probabilities which could be attached to different possible influences. In effect, this cloud seeding approach limited the amount of control data and therefore may have obscured potential factors involved.

The method of evaluation involved the use of isopercentile maps. For each station reporting precipitation, a figure was computed which represented the percentage of normal seasonal precipitation which that particular storm produced. Stations of equal percentages were connected with smooth curves. Areas on the watershed were then identified where such percentage values were abnormally high with respect to surrounding area. It was considered highly probably that such abnormally high precipitation areas had experienced positive effects of the cloud seeding.

Based upon the foregoing assumptions, the following findings were made:

- Of seventeen candidate storm periods which were seeded, eight storm periods produced sizeable precipitation. (It had been known that several of the storms that were seeded, were marginal from the standpoint of potential positive results.)

- As an estimate, cloud seeding effects (when experienced) increased precipitation in the northern portion of the drainage basin by about 60% over that which would have occurred normally.
- In the southernmost part of the basin along the Santa Ynez River, increases in precipitation (with two exceptions) were too small to be distinguished from random natural variations.
- There was no noticeable increase in runoff, and this was blamed on the sparsity of storms between which the watershed was able to dry out.
- It would have been more productive of runoff if the cloud seeding program had commenced during the storms of November 1950 (instead of waiting until December), inasmuch as the dryness of the watershed had first to be overcome before runoff benefits could be achieved. It normally requires a foot of precipitation on the watershed to develop significant runoff, at the beginning of the rainy season.

- It would have been advantageous to have offshore smoke generators to take advantage of southerly winds in candidate storms.

This method of evaluation of cloud seeding effects assumes that for any unseeded storm, all stations will report the same percentage of normal seasonal precipitation. In actuality, all storms have a wide variation of relative intensities. In fact, unseeded storms plotted in a similar fashion to the seeded storms produced the same type of percentage variation. In addition to this problem, there was another. The times of operation and the location of the generators were only generally linked to the "increases" in precipitation. There is really no way to determine whether the "increases" would have occurred where and when they did in the absence of seeding.

As a first attempt, this study provided a good foundation for future studies. However, the methodology used probably does not warrant firm quantification of incremental rainfall due to cloud seeding.

Early Work, 1951-52

North American Weather Consultants were again contracted to perform cloud seeding, this time by the County Water Agency. The methods followed were more refined than the previous year but still were not entirely statistically sound for research purposes.

The procedure originally to be followed called for cloud seeding all storms from November through April. As it developed, however, the storms in the second half of January and all of February were not seeded. This was because the reservoirs were full and the ground was so saturated that excessive run-off would cause flooding. In fact, one unseeded storm on January 15, 1952, dumped 9.7 inches at the Gibraltar Dam rain gauge in a single day.

For cloud seeding, more stationary generators were installed than during the previous year, and aircraft generators were tried out for the first time. This allowed for more flexibility and control of where and when the seeding was done. In addition, a more extensive system of rain gauges was used, providing a more accurate pattern of rainfall than previously.

The methods of evaluation were also better than those of the previous year. Isopercentile maps were used again but this time they were based on monthly rather than seasonal norms. In this method, an unequal distribution of percent of normal is interpreted as due to the cloud seeding. It does not correct for the possibility of an "abnormal" distribution of rainfall that could easily happen because different types of storms have different intensities relative to geographic areas.

In addition to isopercentile maps, scatter diagrams were prepared using the precipitation values from the target area and the control area and plotting them as ordered pairs on a graph. A regression line was determined, through the method of least squares, which representedthe rainfall of one station as a function of the rainfall at another, assuming this function is linear. The least squares method also assumes that the distribution of observations of rainfall follows a "normal" bell-shaped curve. These assumptions may be questionable. A more serious question may be that this method implies that the variance is constant. In other words, no matter how much rain falls, the variability around the regression line remains constant. Empirically this is not true, as scatter points tend to fan out with heavier precipitation.

The control area wasdesignated as the San Luis Obispo area north to Paso Robles. This area was picked because it was upwind of cloud seedings for Santa Barbara County. Unfortunately, the control area did receive some effects of cloud seeding in the Carrizo Plain area during the months of November and December 1951. This tends to weaken the results, as a totally unaffected control is essential for true statistical comparison.

The seeding was accomplished for all eligible storms during the period except for the month of February (during which seeding was deliberately suspended) and for selected storms in January and March which were seeded only partially or not at all. As noted above, seeding was suspended as a result of watershed saturation whereby excessive precipitation, as from cloud seeding, might have produced excessive runoff. The silver iodide seeding involved 1,024 hours, 28 minutes total seasonal operation of 14 fixed mainland generators, 1 fixed generator on Santa Rosa Island, 1 mobile ground generator, and (for certain storms) an aircraft-mounted generator.

Based upon the assumptions noted above and the actual rain gage observations made, the report for the 1951-52 weather modification activities produced the following findings:

- County-wide precipitation was about 24% in excess of what could have been expected if there had been no seeding. This ranged from an inferred increase due to cloud seeding of 10 to 15% in the western plains to as high as 93% in the mountainous section.
- Of a total of 13 storms which were seeded, 8 produced positive results, 3 showed minor results, and 2 registered negligible or doubtful results. The weak storms were least effectively seeded and the strong storms most effectively seeded.

- Cloud seeding was indicated to have produced beneficial results throughout the target area. The effectiveness of the cloud seeding was evaluated on the basis of comparison of precipitation results within the target area with precipitation experienced in comparable localities (San Luis Obispo and Paso Robles) well upwind of the target area and presumably unaffected by the cloud seeding. (Analyses included consideration of cloud seeded rainfall experience on both a storm basis and monthly basis as compared to monthly normal and on a seasonal basis as compared to seasonal normal.)
- Local effectiveness of cloud seeding could also be demonstrated by the scatter diagrams which related normal precipitation in the target area with that in the control area. When a straight line plot (regression line) showing such normal relationship between target area precipitation and control area precipitation was paralleled by a line measuring 2 standard deviations greater than the regression line, this provided a quick index of cloud seeding significance. Any plotted experience lying outside the parallel

line was considered the result of cloud seeding and not of chance alone. On this basis, it was indicated that positive effects were consistently felt from cloud seeding at Gibraltar Dam, Juncal Dam, Pattiway, and Santa Barbara for the months of January and March 1952 as well as for the entire rainy season. Somewhat less positive and/or consistent results were experienced for Los Alamos, Santa Maria and Surf.

° The positive effects of the cloud seeding frequently carried into Ventura County and even into San Luis Obispo County.

° Certain types of storms occur wherein the cloud seeded precipitation in the target area is high with respect to that in the control area (San Luis Obispo and Paso Robles), while in other storms the reverse is decidedly true. NAWC felt that the variations in target to control area relationships were apparently corrected with well-defined general storm characteristics. The most logical approach in cloud seeding therefore involved categorizing storms both for purposes of seeding and for purposes of evaluating seeding results. This was the so-called "weather type of evaluation" and involved 4 storm types, in particular. On this basis, the Upper Santa Ynez Basin was found to have received 14.10 inches of excess (cloud seeding benefit) rainfall during the 1951-52 season, the South Coast Plain 5.91 inches excess, and the Northwest area 1.46 inches excess.

In reviewing the NAWC report (30), it was noted that the total rainfall of the season (excluding February) for Santa Barbara County was 190% of the normal. A figure of 166% was determined for the control area. The difference is 24% (or 3"-4") which NAWC attributed to cloud seeding. In fact, NAWC felt that this was an underestimate, since the control area rainfall was unintentionally enhanced in November and December. These inferences assume a stable relationship between precipitation for the two target and control areas, respectively. This relation must be unaffected by the passage of time, wet or dry cycles, or different types of storms. However, the Statistical Laboratory at the University of California at Berkeley has shown it is not a stable relation (1). It is easy to see that the centers of approaching storms may vary with geographical movement. Accordingly, it is conceivable that a storm could produce much more rain in the Santa Barbara area than in the control area solely because it was a different type storm. The failure to isolate this variable, in particular, detracts from the numerical results of the program. Although there may have been definite precipitation increase due to cloud seeding, it was still impossible to assign a numerical value to the results. However, the program did add to the body of information on the subject, produced generally beneficial results, and paved the way for more refined operations in the future.

Early Work, 1952-53 - Cloud seeding by NAWC continued under contract with Santa Barbara County Water Agency for the year 1952-53. This year many of the drawbacks from the previous year were corrected.

During the period December 1952 through May 1953, 15 storms were seeded, involving 16 stationary mainland generator stations, 1 station on Santa Rosa Island, 1 mobile generator and an aircraft generator. Not all generators were used in each storm. The aggregate seasonal generator operation was 1,549 hours, 56 minutes.

Basically the same procedures were followed as with previous years. All storms were seeded unless ground conditions favored the possibility of floods.

From the standpoint of scientific procedures designed to evaluate incremental yield from cloud seeding, indiscriminate seeding of storms is a fundamental error which was not corrected until 1957. The problem is that if all storms are seeded then it is impossible to calculate probabilities attached to possible influences other than the seeding. Without unseeded storms there is less control on the experiment and the influences responsible for variations in target-control relationships cannot be separated distinctly.

Improvements were made in the 1952-53 program, however, in the statistical method of evaluation. The scatter diagram-regression line method was used, and this time storms were classified by type. As a winter storm moves across California it may produce more rain in the control area than the target area or vice versa. Usually it depends on the latitude of the center of the storm. This was the criterion used in classifying the storms. Rather than employing scatter diagrams for the County as a whole, the County-wide target area was subdivided into three areas: the Northwestern Area (Santa Maria), the South Coastal Plain, and the Upper Santa Ynez Basin. Scatter diagrams were prepared for each area and each type of storm. If the current data points were located significantly above the regression line and the historic data points, then it was claimed that cloud seeding was responsible.

The NAWC report for the 1952-53 program (2) claimed cloud-seeding-induced precipitation increases of 2.07 inches for the Santa Maria to Los Alamos area, 2.39 inches for the Santa Barbara to Goleta area, and 2.17 inches for the Gibraltar to Juncal area. The data for the 1951-52 program were re-analyzed using these methods, and increases of 1.46 inches for the Santa Maria area, 5.91 inches for the South Coast and 14.10 inches for the Upper Santa Ynez Basin were computed.

The NAWC report concluded that for the more frequent type of storms encountered, the increased precipitation could not have been due to chance alone. For the less frequent type of storms, additional evidence would be required before this could be established.

The 1951-52 and 1952-53 program and data analyses appeared to improve the techniques for evaluation of incremental precipitation, but certain statistical deficiencies remained. As in the 1951-52 program, the regression line method still assumed that the precipitation in one area is a linear function of that in another area. The method also ignored the incidence of a wider spread of data points that are seen when larger amounts of rainfall are involved. Unless this variable variance is taken into account, the increases of rainfall claimed for larger storms may not be valid.

The NAWC report on the 1952-53 program (2) does not elucidate on the method of determination of numerical precipitation increases presented. However on inspection of the scatter diagrams, one finds current data points above and below the regression lines. In fact, most current data points appear surrounded by historical data points, implying no reason to assume cloud seeding effects. In only two cases were there current data points well above the regression line and the historical data points. The conclusion warranted appeared to be that cloud seeding was having a positive effect on some storms, but not necessarily all storms. The quantification data appeared questionable from the report analyses presented.

Early Work, 1954-55 - Santa Barbara County Water Agency renewed its contract with NAWC and cloud seeding was performed from January 1955 to April 1955. Though the period was shorter than previous years, substantial results were shown. The procedures remained unchanged. All storms (14 in number) were seeded. There were 1,020 generator hours during the season, involving 13 fixed mainland generator stations and one fixed station on Santa Rosa Island.

As discussed in connection with the previous reports, the practice of indiscriminate seeding of storms limits the amount of control data and fails to account for the influence of seeding one storm might have on the following storms. In addition, the procedures followed by the different generator operators may have varied. This impairs the statistical validity of the findings.

The methods of evaluation were not presented in great detail in the NAWC report (3). The results were determined by predicting the rainfall from each storm and comparing it to the observed precipitation.

Presumably rainfall was predicted through the use of scatter diagrams and regression lines for each target area and each storm type. However, this is not discussed in the report.

From the results claimed in all of the reports, it cannot be denied that cloud seeding has caused differences in precipitation. However, these differences cannot be measured with a high degree of accuracy.

The NAWC report (3) claimed increases of 5.09 inches in the Upper Santa Ynez Basin, 2.62 inches in the Middle Santa Ynez Basin, 4.71 inches for the South Coast and 1.35 inches for Cuyama Valley. For the South Coast this amounts to an average of 0.33 inch per storm (4.71 inches/14 storms). This was based upon an evaluation method specifically designed by the University of California Statistical Laboratory and the State Division of Water Resources.

It was noted that despite the success of the artificial nucleation program in producing extra precipitation over the Santa Ynez Basin (2 to 5 extra inches during January through April), the total seasonal precipitation was near normal, and the conditions for producing an effective yield from rainfall to runoff were poor. Among unfavorable factors were lack of a prolonged wet spell during the January-March period to saturate the subsoil and the presence of a prolonged period of cloudless weather from mid-March through mid-April. These combined to deplete greatly the sub-soil moisture reserves and to minimize the yield of the wet period which occurred during the last two weeks of April.

Review of the data of the NAWC report for 1954-55 operations shows variable results from the cloud seeding. It is indicated that sometimes the effect was positive, negative or zero. Thus, from a rigorous standpoint, the evidence appears more circumstantial than documentary. It is not until later studies that the control is adequate to isolate the correct variables.

Early Work, 1957-1960

In January, 1957, the Santa Barbara Project was initiated, representing a joint effort of some seven different agencies to test the effectiveness of weather modification. It was the first time that randomized seeding had been tried. The control areas included the Channel Islands, the San Simeon to Cape San Martin coastline and the San Luis Obispo-Morro Bay area. The target area was all of Santa Barbara County. Ventura County was added as a target in 1958. The seeding was done from ground generators which were fired depending on a 50 percent probability decision. As a storm approached, 12 hour blocks of time were allotted for seeding. This was a major weakness of the project. The seeding was done according to arbitrary time periods rather than according to the storm characteristics. An extensive network of raingages was used which was an improvement over previous studies. Unfortunately, rainfall during these years was erratic. The first year (1957-58) saw flood periods, while the next year was extremely dry. Conclusions drawn by the Statistical Laboratory at Berkeley who evaluated the project, indicate an average of 10-20 percent increase in precipitation due to seeding. Their conclusions are not on firm ground however, because the experiment was not completely randomized, and the use of 12-hour blocks of time allowed too much influence from the type of storm which passed thru. It was recommended that future experiments be related to parts of the storm's "anatomy." This led to the development of convective band studies (28).

LATER EXPERIENCES WITH CONVECTIVE BAND SEEDING

Description

This work was the so-called Santa Barbara Convective Band Seeding Test Program. The U.S. Naval Weapons Center, China Lake, was the sponsor, and North American Weather Consultants, with their affiliate Aerometric Research, Inc., carried out the operation. The program involved the seeding of winter frontal storms reaching the California coast (4). It was divided into two phases which are compared in Table II-1.

Phase I lasted from 1967-71 and consisted of mainly pyrotechnic silver iodide, ground-based seeding from the El Capitan Lodge near Refugio Pass. Phase II ran from 1970-74, overlapping Phase I. Initially, it consisted of an extended source of freezing nuclei, using a combustion generator burning a silver iodide/ammonium iodide/acetone solution delivered from an upwind aircraft flown along the band axis of the storm. Ground-based seeding was resumed in 1971 as part of Phase I, but using a stationary version of the solution-combustion generator to provide a backup capability (4).

The procedures followed in these seven-year experiments were more sophisticated than previous ones. Instead of dealing with regression lines, storm types and scatter diagrams, the experiments concentrated upon individual convective bands within the frontal storms, using a statistically sound approach. A random system of seeding was used so that the results proceeding from unseeded bands could be compared with those of seeded bands. Upon the approach of a storm, all personnel were notified and positioned. As the first convective band was identified (via the Vandenberg AFB radar), the generator operator was alerted. When the band was over the generator, the operator checked his predetermined sequence of random choices as to whether to seed or not. The decision was kept secret so as not to influence the evaluation procedures. An extensive telemetered

Table II-1

COMPARISON OF PHASE I AND PHASE II CLOUD SEEDING OPERATIONS

	Type of Operation	Dates of Operation	Seeding Site	Basis for Seeding Decision	Seeding Source and Output Rate	Primary Area of Effect
Phase I	Ground Based	1967-68 thru 1970-71 4 seasons	Refugio Pass elev. 1,065m	50/50 Choice Band by Band	Point Source Pyrotechnic Fusees 1,600 gm/hr	Upper Santa Ynez Valley Northeastern SB County West Ventura Co. Southwest Kern County
Phase II	Ground Based	1971-72 thru 1973-74 3 seasons	Refugio Pass elev. 1,065m	50/50[b] choice storm by storm	Point Source Acetone-Silver Iodide Burner 700 gm/hr	San Rafael Wilderness Northeastern SB County
	Air Based	1970-71[a] thru 1973-74 4 seasons	10-30 km strip of Coastline Point Conception to Point Buchón	50/50[b] choice storm by storm	Aerial Line Acetone-Silver Iodide Burner[c] 700 gm/hr	3 bands oriented north-south 1) Lompoc & north 2) SB, Santa Ynez & Sisquoc Watershed 3) Ventura to Taft

a/ Aerial seeding began during the last year of Phase I.

b/ Exceptions occurred whenever the generator failed to ignite.

c/ On two occasions, pyrotechnic flares were dropped into the clouds rather than having used the acetone burner.

raingage network and radar were used to track the convective band as it moved through the County. Measurements were taken to record the duration of the band, precipitation from the band, and temperature and pressure in the band. When all of the data had been recorded and organized according to convective bands and storms, the seeding decision was revealed and an analysis made.

In the evaluation analysis, the precipitation data at each station for all of the seeded bands were compared with those of all of the unseeded bands. The ratio between the two amounts was used. The same thing was done for the other parameters measured (temperature, pressure and duration). A statistical test was then applied to these ratios to see if the seeded samples were significantly different (more so than just by chance). The results of the test were presented in map form (see fig. IV-3 through IV-8) showing So. California from Los Angeles to Monterey. Areas which had significant precipitation increases were darkened. Areas with significant precipitation decreases were hatch marked. For Phase II, the maps show three general areas, oriented North-South within the County, which showed significant increases. They are oblong areas, roughly parallel to the aerial seeding path, stretching from Lompoc into Ventura County. Unfortunately, other areas on the map show increases and these areas are upwind of the cloud seeding operations. These occurences are in areas that normall receive very small amounts of rain.

Therefore, small amounts of excess rain appear significant when seen on a percentage basis. In most cases, the data come from only one raingage for the entire area. When subjected to statistical significance tests, these data appear to be due to chance variation, more so than to the seeding operations.

Findings

The results from these two-phased experiments indicate that rainfall was increased over a large area due to the cloud seeding. Besides the primary area, near the seeding, effects were observed consistently in an area 150-200 km (93-125 mi.) from the seeding source at an angle of 20° to 40° to the right of the 700 mb flow. This extra-area effect was not observed in any previous experiments.

The primary mode of evaluation of convective band seeding was comparison of rainfall from bands within a test area of about 27,000 square kilometers, containing approximately 100 raingages available for analyses (4). On the basis of statistical results, it was concluded that seeding convective bands is an efficient means of increasing precipitation, with increases on the order of 50 to 100 percent indicated within seeded bands and 25 to 50 percent for the storm total (4). The convective bands tend to widen and possibly slow down after seeding, indicating that much of the increase in precipitation is due to a change in the duration of band precipitation rather than an increase in intensity (4).

The conclusions reached from this comprehensive study appear valid. Cloud seeding, particularly convective band seeding, has an effect over an area much larger than previously considered. The increase in the extended area is generally larger in percentage than in the primary target area. The magnitude of the extended area effects is 30-50 percent per storm but can be raised to 50-100 percent if only the best convective bands are seeded. A problem arises, however, in that the distance between the seeding area and this extended target area is 120 to 240 km (75 to 150 mi.). It is apparent that there is some difficulty in containing the effects of cloud seeding to one specific area. Departures from the target area will occur due to variations of individual storm characteristics such as wind speed and direction.

III - WEATHER MODIFICATION EXPERIENCES

AND STUDIES ELSEWHERE

III - WEATHER MODIFICATION EXPERIENCES AND STUDIES ELSEWHERE

LOS ANGELES COUNTY FLOOD CONTROL DISTRICT

General

This large and active agency has concentrated its weather modification activities in the coastal watersheds of the San Gabriel Mountains. The major drainages of these mountain watersheds are the San Gabriel River (with its major tributary, the Rio Hondo) and the Los Angeles River. Major groundwater basins lie within the inland valleys traversed by these streams and in the coastal plain through which the drainage passes to the Pacific Ocean. A highly developed system of mountain flood control reservoirs and debris basins is able to regulate much of the watershed runoff. Valley flood control basins also exist (some under the control of the U.S. Army Corps of Engineers) along with extensive flood control channels and spreading grounds at canyon mouths and on the valley floor. This high degree of system development and coordinated operations make it possible for the Los Angeles County Flood Control District to capture much of the normal yield and also incremental yield from cloud seeding.

District Program

Cloud seeding has been practiced by the District generally since the 1961-62 rainy season with occasional interruptions occasioned by actual flood and/or heavy erosion potentials. The purpose has been to increase rainfall over the 500 square mile southerly-draining, mountainous watershed area of the San Gabriel Mountains previously described. The District has found the program to be beneficial.

Highlights of the District operation, as described in its November 1975 Final Environmental Impact Report on Cloud Seeding in the San Gabriel Mountains for the 1975-76 Storm Season (5), are as follows:

- The cloud seeding is employed to increase precipitation in certain watersheds, thereby resulting in additional runoff into District reservoirs for later release into spreading grounds and groundwater recharge.
- Seeding is confined to storms which will tend to increase runoff over the target areas, during the October to May season whenever the storm forecast, watershed conditions and reservoir conditions indicate that the runoff can be captured without risk of flood or excessive erosion. No seeding is done with the intent of affecting areas outside the target area nor when a flood-producing storm is forecast.
- District cloud seeding employs only ground-based systems of either propane-fired or solid state pyrotechnic type. The former are used continuously when active, but the latter are fired intermittently, with the objective

of concentrating the silver iodide smoke dissemination within the periodic, high moisture "bands" that characterize Southern California storms. These are the so-called convective bands that generally occur every two to six hours and last approximately one to two hours. The rainfall bands are tracked by telemetered rain gages as they pass over the target area.

- The increased rainfall from convective band seeding is primarily due to increased duration, not intensity.
- Cloud seeding for the target area is only practicable when three essential conditions are met simultaneously:
  a. Uplifting and convective currents must be adequate to carry the silver iodide crystals into the clouds.
  b. The wind must be from the west and southwest, and
  c. The -5°C (22°F.) temperature level within the clouds must be below 10,000 feet elevation.
- There are about 10 to 20 storms per year in the San Gabriel Mountains, and only about 75 percent of these meet the seeding criteria.
- The control area for the cloud seeding rainfall analysis in the San Gabriel Mountains is the main Los Angeles Basin area.

- The cloud seeding program increases rainfall over the target area an average of one inch per year or five percent of the average rainfall on the target area.
- The control area for runoff has been the Lytle Creek watershed, which is sufficiently far from the target area as not to be affected by the seedings but is still physiographically similar to the target area.
- Throughout the program's history of artificial nucleation the increased runoff in the target area has averaged 10 to 20 percent, according to analysis of the data. The greater percentage increase in runoff than in precipitation is due to the effects of antecedent rainfall.
- The apparent increased yield of watershed runoff represents a measured approach to weather modification in which no cloud seeding is undertaken over areas recently subjected to fire or earthquakes nor is seeding undertaken when large storms having flood potential are expected. Seeding is terminated whenever rainfall exceeds five inches for a storm.
- The annual cost of the program (in 1975) averaged $50,000 and the average annual gain in conserved runoff was 7,345 acre-feet.

- Runoff increments resulting from cloud seeding are apportioned in accordance with existing laws or court settlements as if they were natural runoff.
- During the 13 seasons reported in the EIR, the typical number of generators operated has been 14 or 15 and the typical seasonal aggregate operational hours about 800. The average emission of silver iodide has been about 4,500 grams (about 10 pounds) per season. Currently four ground-based seeding devices are used. Seeding is both continuous and intermittent.

SOUTHERN CALIFORNIA EDISON COMPANY

Big Creek Cloud Seeding Project

Southern California Edison Company (SCE) has several hydroelectric developments in the Southern Sierra Nevada. Since 1950, SCE has sponsored weather modification activities directed at increasing the snowpack in the upper San Joaquin River Basin above Big Creek (6). The program has used a sophisticated system of remote telemetered controls and automatic equipment, including cloud nucleating generators (CNG). North American Weather Consultants has conducted the project as a contractor to SCE.

The so-called Big Creek Cloud Seeding Project began in 1950 with an original three manually operated generators for silver iodide smoke. There were 12 generators some 15 years later. During the 15-year period 1950-51 through 1964-65, a total of 43,806 hours of CNG operation were experienced involving 887 hours and an average of 49 CNG hours per seeded day (6). During the last 13 years of this period, the CNG hours per season ranged between about 2,000 to 4,000, the variation depending upon the number of seedable storms.

Evaluation of Results

During the 15-year period, 1950-51 through 1964-65, the effectiveness of cloud seeding was appraised by incremental runoff in the San Joaquin River as surmised by the runoff in a control river, in this case the Merced River in a drainage basin to the north of the target area. Runoff in the target area, as gaged on the San Joaquin River near Florence Lake, was indicated to be five to eight percent higher than that in the control area, as gaged on the Merced River at Pohono Bridge near Yosemite. The probability that this excess was due to chance was calculated to be no more than three percent (6). The investigators noted that the Big Creek area was ideally suited for a runoff comparison, as flow during the runoff period (March-August) is 90 percent of the total annual flow and that the runoff is mostly attributable to snowpack melt, with but little influence from summer rains(6).

In determining the relationship between the target area and control area, NAWC used a 29-year base period (1922-50), which included both extremely wet and dry years. The runoff period selected was March through August, and the data were given a square root transformation for purposes of normalization and to suppress the effects of extreme years. Correlation and regression equations were determined by the method of least squares. Points for seeded years were plotted on the regression line diagrams of target area runoff versus control area runoff.

OTHER CALIFORNIA CLOUD SEEDING OPERATIONS

Kings River Conservation District

The Kings River Conservation District reportedly has had at least 13 years of cloud seeding experience involving the Kings River Basin in the Southern Sierra Nevada, beginning in 1954 (7). This watershed lies immediately southerly of that of the San Joaquin River, the target area of SCE's operations. The Kings River Basin operations generally are confined to winter storms (as are the SCE operations) and employ both ground-based generators and aircraft-based generators. Silver iodide is the more common seeding material, although some dry ice seeding has been done in the Kings River Project. The average generator hours range between 2,000 and 4,000 hours per season. Runoff increases are reportedly six to eight percent, attributable to cloud seeding and correspond to five to six percent increases in precipitation. The operations normally involve precipitation upon existing snowpack or wetted watersheds, much of which is at fairly high elevations (7). Weather modification practiced following early winter season precipitation yields runoff that is relatively inexpensive. In 1967 price levels, this was reportedly in the range of $ 0.50 to $1.00/AF (7).

Santa Clara Valley Water District

Santa Clara Valley Water District (SCVWD) began a cloud seeding program in 1955 and have continued it to the present. As a result of the California Environment Quality Act of 1970, SCVWD were required to assess the environmental impacts of their project in order to continue it. The resulting Weather Modification Program Environmental Impact Report by Henningson, Durham and Richardson, Ecosciences Division, December 1975, is the source of the information presented here.

This cloud seeding program has used ground based and aircraft generators at various times in its history. Since the 1965-66 season the district has operated its own equipment rather than hiring private weather modification companies. The current program utilizes twenty-one ground based generators. Thirteen of these are located along the ridge of the Santa Cruz Mountains. The remaining eight are located east of Santa Clara Valley in the Diablo Mountain Range. The target area includes the eastern side of the Santa Cruz Mountains, Santa Clara Valley and the Diablo Range.

The effects of the project have been evaluated by SCVWD. Over the long run, an average annual increase of 10-15 percent in rainfall was indicated. An increase of 13 percent in rainfall corresponded to an additional 15,000 acre-feet of water per year. It was not indicated how much of this increase was realized in groundwater recharge versus runoff. The effect of the program has been minimal in very dry years and enhancement of rainfall was unnecessary in very wet years.

The annual operating costs of the program are shown below. The costs shown during seasons of no seeding are due to purchase of materials and maintenance of equipment. The increase in costs shown in 1973-74 is due to the institution of a new testing procedure.

Year	Actual Annual Operating Cost
1968-69	22,700
1969-70	5,000*
1970-71	1,200*
1971-72	15,200
1972-73	21,500
1973-74	41,050

* no seeding

The value of the benefits received ranged from $120,000 to over $350,000. These figures were determined in the following manner. The average annual increase of 2 inches in precipitation over 710 square miles corresponded to approximately 75,000 acre-feet. Of this, 20 percent or 15,000 acre-feet were assumed to be available as usable ground and surface water. The minimum value of this water for agriculture is $8.00 per acre foot or $120,000 total. Approximately 75 percent of existing supplies are used for M & I purposes with a value of $30.00 per acre foot. The benefit determined with this value is over $350,000.

San Luis Obispo County Flood Control & Water Conservation District

San Luis Obispo County has solicited and received proposals from several weather modification firms with bids ranging from $28,000 to $120,000 annually. The proposed program will use ground based generators and an expected benefit-cost ratio ranging from 40:1 to 16:1.

Other Programs

Sacramento Municipal Utilities District and San Bernardino Valley Municipal Water District have practiced cloud seeding in differing sections of the State, involving the Northern Sierra Nevada and the San Bernardino Mountains, respectively.

Results in both areas are believed beneficial, but scientific data as to precipitation and runoff augmentation are meager.

Monterey County Flood Control and Water Conservation District contracted North American Weather Consultants to perform cloud seeding during March and April of 1972 and November 1972 thru March 1973. Three previous dry winters had lowered reservoir levels and cloud seeding was undertaken to increase precipitation in the San Antonio-Nacimiento Watershed. A network of eight ground generators were utilized, located along the coast from Cambria to Lucia. Seeding was non-randomized and a control area could not be selected due to cloud seeding programs to the north and the south. As a result, evaluation analysis was limited to computation of precipitation as a percent of normal. The values of the target area were compared to those of surrounding areas through use of isohyetal maps. The most noticeable effect seemed to be in the northeast portion of the target area near King City. No definite conclusions could be drawn, however, due to a lack of an extensive network of raingages and the availability of a more reliable means of evaluation (8).

BUREAU OF RECLAMATION PROGRAMS

Arizona Weather Modification Research Program

The Bureau of Reclamation, Office of Atmospheric Water Resources, has sponsored the Arizona Weather Modification Research Program as part of the Bureau's "Project Skywater." This program was a successor to a series of studies performed at Flagstaff, Arizona by Meteorology Research, Inc. (MRI) and the affiliated Atmospheric Research Group under the Atomic Energy Commission, the National Science

Foundation, the U. S. Army, and the U. S. Forest Service during the 1960's (9). The program's objective was "to develop and demonstrate quantitative engineering techniques of cloud-seeding in various localities for augmentation of economically beneficial amounts of precipitation." The study involved both isolated clouds and large storm systems, to learn of their behavior both with and without cloud-seeding.

In the isolated cloud study, it was found that the tops of small clouds were too warm to respond to ice phase seeding (seeding with ice nuclei) and large clouds would not respond to such seeding because their tops were already cold enough for total freezing to occur naturally. However, intermediate size clouds responded dramatically to seeding, because the seeding provided enough ice nuclei to initiate freezing between the two extremes of -8°C. and -25°C. The latent heat of fusion liberated by the freezing would intensify the cloud's circulation, making the cloud top grow higher and increasing the cloud's precipitation. A randomized seeding project showed cloud-top increases of 5,900 ft, precipitation increases of 2.00 mm, and increases in rainfall duration of 10 min., due to the seeding with silver iodide from cloud base (9).

Project Skywater

The Bureau of Reclamation's research and operational programs in the Western United States (including Flagstaff, Arizona area) have developed certain criteria as to cloud-seeding principles. The cold-cloud process (for cloud-seeding) involves coalescence among cloud droplets to develop raindrops. At least part of the cloud must be colder than 32°F. (10), and clay particles, naturally present, may serve as the freezing nuclei. The warm-cloud process also involves condensation nuclei to initiate precipitation, the nuclei normally being compounds of sulfur and chlorine. Precipitation management is effected through manipulating the quantity and type of nuclei present.

Skywater experience indicates that orographic west-to-east storms vary in natural capability for precipitation and in amenability for cloud-seeding, depending upon cloud-top temperature. Clouds whose top temperature is between 32°F and -9°F produce very fine precipitation, much of which remains aloft and becomes dispersed. Cloud seeding with microscopic particles of silver iodide commonly increases precipitation 30 to 50 percent over normal. When the cloud top temperature is lower than -9°F, precipitation occurs naturally and cloud seeding can effectively reduce the natural snow production by producing fine ice particles subject to dissipation by winds.

Skywater experience (10) has also revealed the following:

- Cloud-seeding does not apparently result in a decrease in downwind precipitation beyond the target area. In fact, downwind increases have been noted without any decreases.
- Summer cumulus clouds may sometimes be seeded beneficially, but there are many complexities and a fairly narrow set of conditions within which cumulus clouds can be seeded to produce significant rainfall at all while avoiding potentially damaging hail. Cloud diameter, cloud thickness, updraft velocities, cloud droplet size spectrum, and cloud water content in liquid and vapor states are all significant factors.
- If sufficient freezing nuclei are introduced into a stable cloud whose growth is inhibited by an overlying, stable atmospheric layer, the growth of ice crystals can liberate heat enough to raise the cloud layer up to 2°C., causing a dramatic convective breakthrough and possible growth upwards for several thousand feet. Increased precipitation results thereby.
- Drought-alleviation has been practiced, apparently successfully, by Project Skywater personnel in Texas, Arizona, and Oklahoma. Drought conditions, once established in an area, tend to persist as a result of moisture depletion. Lacking soil

moisture, vegetative evapotranspiration is reduced and solar radiation becomes translated into sensible heat. Thus, above-average rainfall is needed to restore plant water-use as well as to restore streamflow and groundwater to normal levels.

- Systematic studies of 12 western major river basins, mountain massifs, and gaging stations for incremental runoff attributable to weather modification during the 1952-71 period (11) considered historical precipitation and rawinsonde data together with massif and other watershed characteristics. A computer model study was then conducted to determine what unimpaired runoff would have been produced for the various tributaries and main streams of the river basins if cloud seeding had been practiced under appropriate conditions during this historical 20-year period. The difference between such computed runoff and the historic gaged runoff represents the supposed incremental runoff due to cloud seeding, had it been practiced. Seasonal climatological characteristics, elevations of massifs, topography and vegetation, and all other relevant aspects were considered in the model.
- Highlights of the results of the Project Skywater are summarized in Table III-1. It is quite significant that the study is confined to interior (not coastal) watersheds whose capacity to produce runoff water is principally by orographic (mountain-

TABLE III-1

HIGHLIGHTS OF HISTORIC POTENTIAL STREAMFLOW INCREASES IN 12 MAJOR WESTERN RIVER BASINS
FOR THE 1952-1971 PERIOD
FROM BUREAU OF RECLAMATION SKYWATER STUDY[a]

River Basin	Watershed Massifs[b]		No. Gaged[c] Tributaries	Incremental Runoff[d]			Flood Frequency[e] or Potential
	No.	Area, sq. mi.		AFY	AFY/Acre of Massif	% of Ave.	
Upper Colorado	7	20,800	12	1,315,000	0.1	-	Rare
Rio Grande	3	3,366	4	209,300	0.1	-	-
Truckee	2	832	1	129,000	0.24	38	Occasional
Walker	1	-	2	82,000	-	-	Rare
Humboldt	2	1,316	1	98,000	0.12	-	Occasional
Sacramento	3	5,887	7	1,858,000	0.49	-	Some
North Platte	2	1,209	2	164,000	0.21	20	Remote
Laramie	2	-	1	42,000	-	-	-
Gila	2	7,314	5	239,000	0.05	-	Operational
Snake	8	11,623	11	1,055,000	0.14	-	Some
Upper Missouri	4	21,000	10	1,837,000	0.14	-	Snowmelt type
San Joaquin	3	-	10	1,020,000	0.31-0.38	-	Substantial
Tulare Lake	2	-	-	497,000	0.17-0.27	-	-
Deschutes	1	-	2	244,000	0.20-0.22	-	-
Bear-Wasatch	3	-	8	579,000	-	-	Rare
Yakima	2	-	4	352,000	0.22-0.27	-	Occasional

TABLE III-1 Cont'd

a/ This was a computer study, using a cloud-seeding model for the development of precipitation-temperature diagrams based on historical precipitation and rawinsonde data. The "area of effect" model employed detailed upwind sounding data, terrain features, seeding source (natural or artificial) information, and cloud top data or estimates. Precipitation episodes were identified with associated sounding station and time lags.

b/ The mountain massifs contributing to runoff in each basin were identified. There were 33 massifs in the 12 major basins, some being independent mountain ranges and, in some cases, divisions along a mountain range due to differences in orientation and/or topography. Precipitation was identified for the 33 massifs, which were subdivided by elevation zones within each study watershed, each such zone being treated independently for physical and hydrologic characteristics as well as estimated incremental precipitation during each specified season of analysis. Selected index precipitation stations represented each massif and described quantity of precipitation subject to weather modification throughout the 20-year period. Seeding was assumed applicable during the period October through April. Average seasonal isohyetal maps were used to describe a real distribution of individual season precipitation amounts over elevation zones and massif units.

c/ Incremental precipitation values were converted to runoff and accumulated according to massif, elevation zone and study watershed. Supplemental snow course and stream flow data add to the development of hydrologic characteristics of the season within the productive massif areas.

d/ Incremental runoff represents production from massif units within each study watershed prior to regulation and incremental consumptive use by man. Results represent additional supply available within the watershed and possibly subject to depletion or regulation before reaching downstream gaging stations. Time-distribution of runoff was estimated by season for index subwatersheds, considering quantity of precipitation, elevation distribution, forest cover and other factors of influence. Areal distribution of incremental precipitation, particularly snowpack was based upon average isohyetal maps for seasonal precipitation.

e/ Flooding potentials are related to rainfall intensity at various watershed elevations, seasonal precipitation and air temperature patterns, and watershed characteristics. High elevations, such as for Upper Colorado Basin, generally produce winter snowpack and spring snowmelt. Such basins have little potential for winter rainfloods. Although warm storms may occasionally be a flood factor, lower elevation massifs are likely to be more apt to produce flooding.

> induced) precipitation. The tributary areas, in effect, are mountain massifs only, with runoff resulting from various combinations of snowmelt and direct rainfall-runoff. Flood potentials vary widely, depending upon circumstances and the characteristics of the watershed, the highest massifs generally having the least potentials for flood production. Incremental runoff via cloud seeding appeared to range between 0.05 ft/yr and 0.49 ft/yr and to average about 0.2 ft/yr.

The Colorado River Basin Project Act of 1968 directed the Secretary of the Interior to develop a general plan to meet the future water needs of the Western United States and to determine the most economical means of augmenting the water supply of the Colorado River, considering all possible sources including weather modification. In December 1970, the Bureau of Reclamation began seeding operations on the Colorado River Basin Pilot Project, the largest winter orographic seeding experiment in the United States (32). The techniques being developed were for seeding only those storms from which additional snowfall may be obtainable without contributing to avalanche hazard, excessive snow removal problems, or other inconveniences. It was estimated that with an applied research and engineering effort, present (1975) techniques could become operational by 1980. Runoff from incremental precipitation in the massifs of the Upper Colorado (upstream of Lee Ferry) increases substantially with increases in elevation, both as a result of increased precipitation subject to treatment and increased efficiency of runoff in the alpine regions (11).

With respect to the Upper Colorado River Basin incremental runoff calculations for the 20-year period 1952-71 referred to above, the following are of interest::

- The watershed area seeded (massifs) was 20,866 sq. mi. or 19.37 percent of the total Upper Basin watershed (tributary to Lake Powell).
- During the 20-year study period, the average total runoff was 9.96 million AFY, of which the cloud seeding incremental runoff represented 1.32 million AFY or nearly 13.3 percent.
- The heaviest incremental runoff was most frequently experienced in June, with May being the next heaviest. The June incremental runoff, on the average, was about 32.9 percent of the total incremental runoff during the study period.
- The year of highest total runoff (17.96 million AFY) also witnessed the year of highest total incremental runoff (2.05 million AFY) and highest June incremental runoff (0.76 million AFY).
- The year of lowest total runoff (5.04 million AFY) witnessed the third lowest total incremental runoff (0.98 million AFY) and also the third lowest June incremental runoff (0.23 million AFY).

- The year of lowest total incremental runoff (0.94 million AFY) occurred during the third lowest year of total runoff (6.10 million AFY) and witnessed the lowest June incremental runoff (0.21 million AFY).

From consideration of the foregoing, it may generally be concluded that:

- Cloud seeding increased the runoff by 15.3 percent on the average, during the 20-year study period.
- Cloud seeding was most effective when there were numerous storms available for seeding which would have produced significant runoff even without seeding. The highest incremental runoff augmented the highest natural runoff by 12.9 percent (1952).
- Cloud seeding was least effective when there were relatively few storms available for seeding which would have yielded only modest runoff on their own. During the year of lowest incremental runoff, cloud seeding increased the natural runoff by 19.4 percent. During the year of lowest total runoff, cloud seeding increased the natural runoff by 24.1 percent.

IV - YIELD AUGMENTATION APPROXIMATIONS

FOR SANTA BARBARA COUNTY

IV - YIELD AUGMENTATION APPROXIMATIONS FOR SANTA BARBARA COUNTY

FACTORS TO BE CONSIDERED

General

The objective of any cloud seeding program to be undertaken for Santa Barbara County would be to augment the local water supply and, in so doing, to minimize any potential adverse effects. Secondary benefits sought would be to enhance rangeland and dry-farming operations by agriculturalists. It should be strictly an operational program, for there would be no purpose in conducting additional experimental or research work. This has been adequately concluded with the recent seven-year study of North American Weather Consultants et. al. under sponsorship of the U. S. Naval Weapons Center (4). The U. S. Bureau of Reclamation's Project Skywater experimentation and pilot project work are continuing to add to the general knowledge of weather modification as are certain operational programs previously described.

Seeding Criteria

The physics of natural rainfall are complex and enhancement of the process is equally involved. Wind direction and cloud top temperature are the two most important variables which are examined in order to decide whether seeding should be carried out. In the Phase I and II operations in Santa Barbara the seeding procedure started with the identification of a convective band either by radar or telemetered raingages. Next, the wind direction was checked to determine if the effects of seeding would fall on the target area. Whenever possible, the cloud temperatures were measured and transmitted by radiosonde. It is known that seeding will be beneficial only if cloud top temperatures range from -23°C to -8°C (-9°F to 18°F) (11). Once these seeding criteria were met, the decision was made on a 50/50 random choice basis as to whether seeding would actually take place. The procedure to be followed in an operational program of seeding would be the same, except that when all criteria are met the seeding would take place all of the time. One additional criteria would have to be met, however, and that is that no flood potential existed. This would depend on watershed conditions and the character of the approaching storm.

Cyclical Precipitation Patterns

It is common knowledge that precipitation is subject to random variations and that periods of surplus and periods of deficiency combine statistically to produce long term averages. Surplus or "wet" periods usually contain episodes of heavy rainfall and runoff, including occasional flooding, and are normally more significant than dry periods in recharging both surface water reservoirs and groundwater basins. Deficiency or "dry" periods tend to have more widely dispersed storms with somewhat less intense rainfall and runoff than "wet" periods. In an effort to depict these "wet" and "dry" periods, the Water Agency staff generated Figure IV-1 which shows the accumulated departure from the mean for Santa Barbara rainfall from 1770 to the present. Precipitation levels from 1770 to 1867 were developed from rainfall indices worked out by H. B. Lynch in his report to Metropolitan Water District, Rainfall and Stream Runoff in Southern California since 1769, August 1931. Rainfall prior to 1867 (when the Santa Barbara gage was installed) was estimated by Lynch on the basis of mission crop records, military weather observations, private diaries, and other sources of information collected during his research. The actual amounts of precipitation are shown in the bar graph at the bottom of Figure IV-1. This raw data was filtered using a seven-year running average, the result of which is shown in the middle of Figure IV-1. This filter eliminates wide fluctuations in precipitation giving a smoother bar graph which displays long term trends. The span of seven years was chosen as a good intermediate time period since wet and dry periods typically last from 9 to 16 years (a complete wet and dry cycle usually taking about 26 years to complete). The upper curve in Figure IV-1 shows the plot of the accumulated deviation from the norm of the filtered data. Wet periods are indicated by sections of the curve which trend upward. Dry spells, conversely, are indicated by downward trending sections. The position of the curve above or below the zero line is not as important as the steepness of the slope of the curve. The steeper the curve, the more severe the period was. The

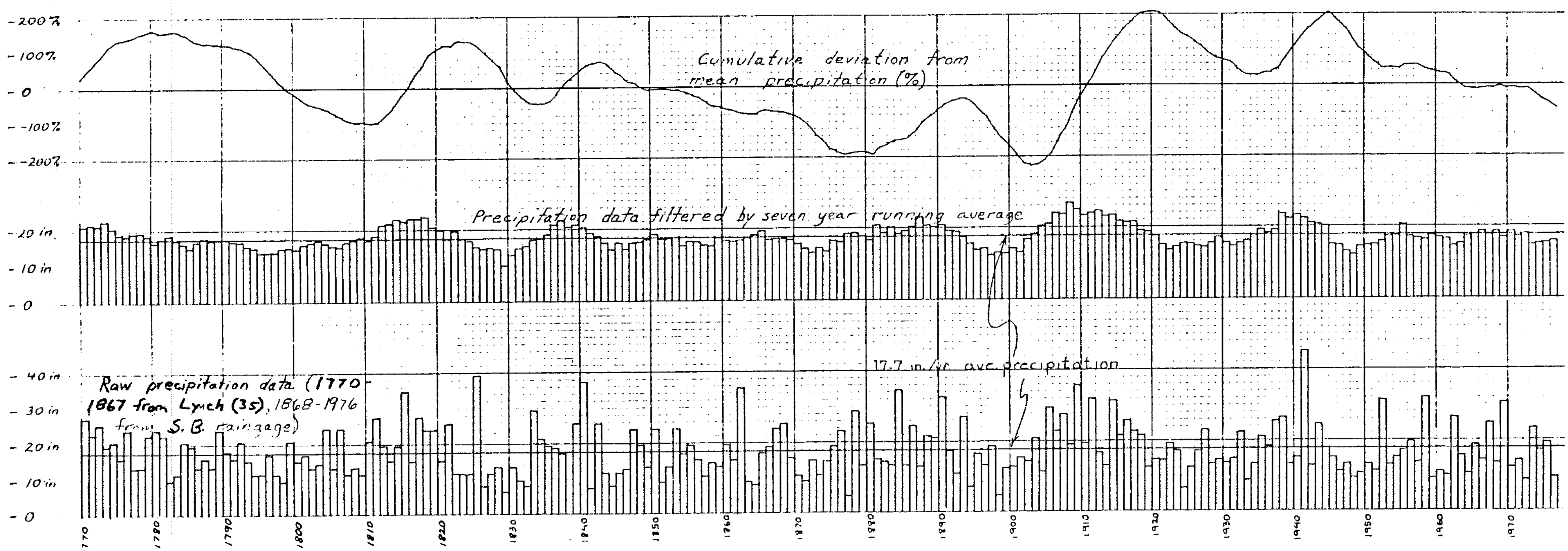


Figure IV-1

LONG TERM RAINFALL TRENDS

most severe drought according to this graph, then, was the period 1894-1903. This period was followed by an intensely wet period from 1905 thru 1918. It appears that there are no repetitive cycles shown in this curve, although the period 1834 to 1873 is remarkably similar to the period 1945 to 1976.

Seasonal Patterns

Santa Barbara County, like the rest of Southern California, experiences a rainy winter and a dry summer. Over 90 percent of the yearly average rainfall is witnessed between November and April. About 60 percent of the average (17.67 inches for Santa Barbara gage) falls during December, January, and February. The average monthly rainfall over a 109 year period (1867-1976) for November thru April is shown below:

Month	Average Rainfall (SB gage) (inches)
November	1.59
December	3.13
January	3.92
February	3.65
March	2.73
April	1.25
TOTAL	16.27

Watershed Conditions

The lack of rain during summer and early fall means that the watersheds tend to dry out completely by late summer, frequently extending into mid- or late-autumn. Rainfall early in the "rainy season," October through April, merely tends to overcome moisture deficiency in the watershed without producing beneficial runoff. If cloud seeding is successful in increasing early season storm precipitation, the chances of having a saturated watershed and subsequent runoff are improved. The effectiveness of cloud seeding in runoff production is generally dependent upon having the proper types of successive storms sufficiently close in time to prevent the watershed from drying out between storms. Inasmuch as storms tend to be more frequent and productive of precipitation during wet years, this implies that the effectiveness of cloud seeding has greater potential during wet periods than during dry periods. This holds true for groundwater recharge as well. Recharge of groundwater basins occurs naturally from deep percolation of precipitation in both upland and valley areas and from stream bed percolation. There must be sufficient rainfall in such surface areas to overcome soil moisture deficiencies and to move the soil moisture downward past the root zones of vegetation in order to be effective for recharge. Saturation of topsoil layers is easier achieved with wet years type rainfall than with the more meager and dispersed rainfall characteristic of dry years. Similarly, wet period rainfall and accompanying runoff are normally much more effective in streambed type recharge than that of dry periods. Thus, cloud seeding would be of greater significance normally during wet years than dry years in groundwater recharge.

Flood Potentials

In minimizing any potential adverse effects cloud seeding operations would have to be suspended whenever conditions were conducive to flooding. One of these conditions would be when a watershed has been denuded by uncontrolled fire. In these cases, seeding operations could be suspended until the watershed vegetation has a chance to recover. Such has been the case with L.A. County Flood Control District's program in the San Gabriel Mountains. Whenever runoff from a burned watershed would not create flooding problems nor contribute to the siltation of a reservoir, cloud seeding operations could be continued, possibly with an alteration of procedures to create a change in target area.

Flooding potential can exist in an unburned watershed if it is totally saturated. The distribution and frequency of rainfall throughout the season combined with evaporation rates and vegetative requirements will determine when a watershed is saturated. Once saturated, the watershed will cause more of the rainfall to runoff directly, increasing flood danger. Then, the intensity of the rainfall is the important factor in contributing to floods. Intense storms, when forecast, could be avoided in a seeding program. Otherwise, the best approach to limiting flood potential is to suspend operations after a certain amount of rainfall has fallen in a given period of time. L.A. County Flood Control District suspends their operation after 5 inches of rain in any given storm. During January of 1969, cloud seeding was halted after almost 10 inches of rain within one week (at S.B. airport), just prior to the floods on the 25th and 26th. It is not always possible to predict flooding potentials, as was the case in February of 1969 when seeding occurred throughout the flooding on the 24th and 25th. An operational program would be more conservative in its seeding than the Phase I and II programs because it would not be concerned with getting a large data sample for evaluating procedures. The operational program would be concerned primarily with filling the reservoirs and recharging the groundwater basins. An operational program would most likely have been suspended just prior to the first flood period in 1969 and would not have been resumed until the following winter.

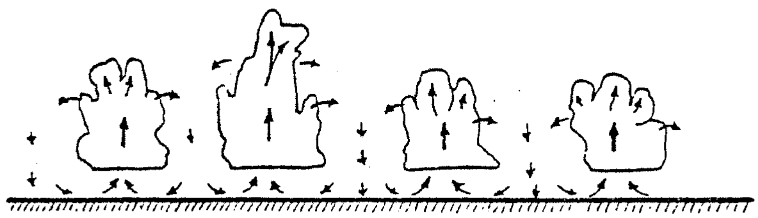
RAINFALL AUGMENTATION

Methodology Used

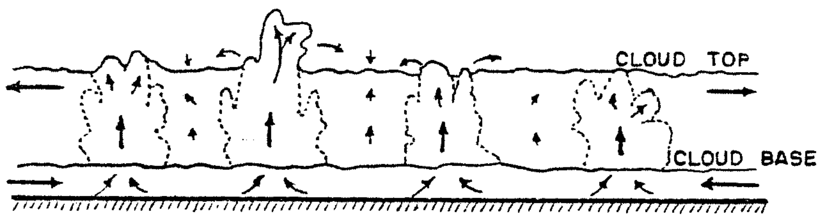
The general approach taken in evaluating potential increases in precipitation involved the comparison of seeded versus non-seeded convective bands. Data were obtained from the final report, Santa Barbara Convective Band Seeding Test Program, Naval Weapons Center, October 1975. For each type of operation (Phase I ground based, Phase II ground based, and Phase II air based), the average precipitation for seeded and non-seeded bands were compared. Their ratios at different rain gage stations in watersheds under consideration were averaged to develop an overall percentage increase in precipitation for each watershed.

As discussed in section II, cloud seeders have experimented with different observational units in their studies. Originally, entire storm seasons were seeded, and later only certain storm periods. The next type of observational unit was a finite time period such as the 12-hour time blocks used from 1957-1960. In each program, the investigator had tried to follow the life cycle of the storm systems and to develop a sample of treated and non-treated cases. The convective band as an observational unit has proved to be the most successful of all the attempts.

As shown in Figure IV-2, convective bands or cells are areas of strong updrafts. These updrafts carry the seeding nuclei to the upper reaches of the band. Super-cooled water vapor in the cloud freezes on the nuclei, forming larger and larger ice crystals. These eventually fall out of the clouds as precipitation. Typically, convective bands move slowly, taking one to one and a half hours to pass a given point. Bands are usually spaced three to four hours apart. Each storm has an average of three seedable convective bands, although the number may range from one to six or more. Convective bands account for an average of 50-60 percent of the total annual precipitation in Santa Barbara County (4). This must be kept in mind upon examining the results of the Phase I and II programs, for while increases in band precipitation may be substantial, the increase in overall precipitation is only half these amounts. Convective band precipitation is even less of a factor in areas of higher elevation because of the increase in orographically induced precipitation.

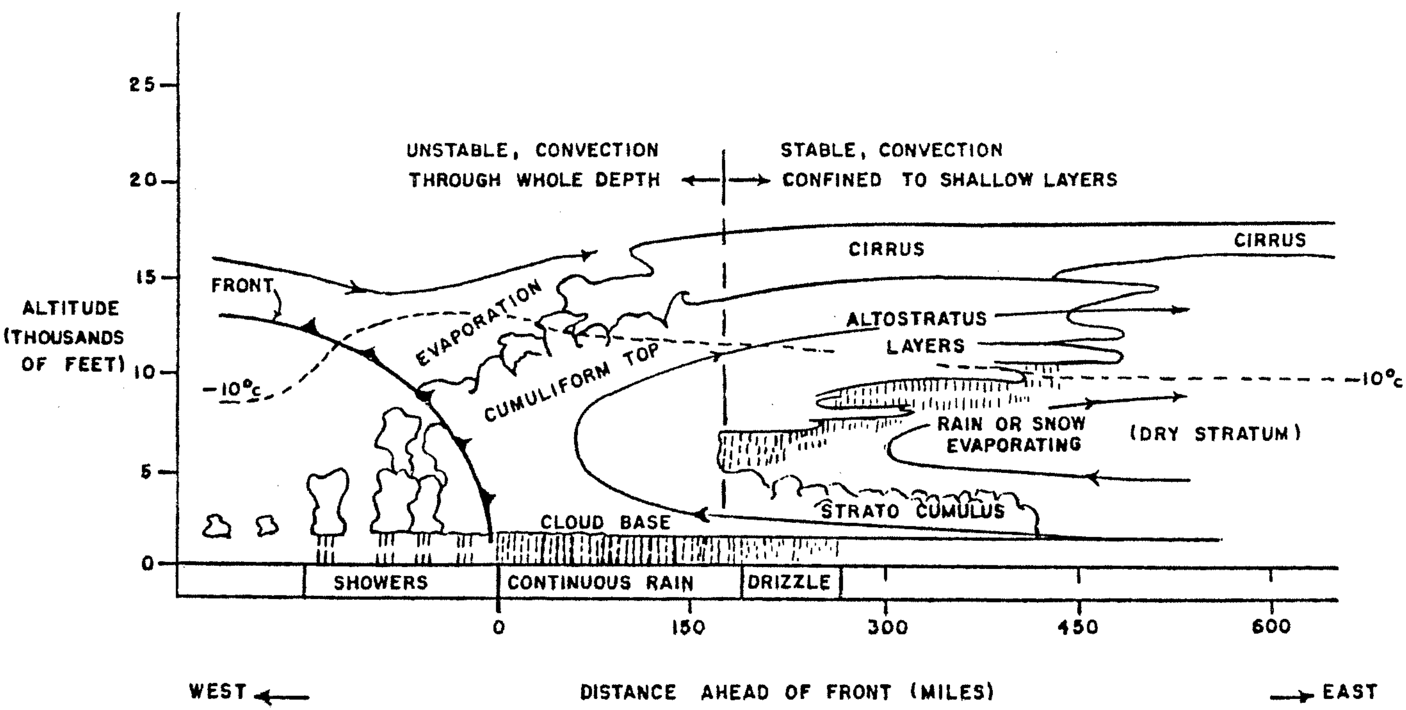


(a) CONVECTION CELLS IN CLEAR AIR



(b) CONVECTION CELLS EMBEDDED IN CLOUD MASS

CONVECTIVE ACTIVITY



VERTICAL CROSS SECTION OF A CALIFORNIA WINTER STORM (31)

FIGURE IV-2

Shown below is a summary of the number of convective bands in each operating phase:

Phase	Seeded	Not Seeded
Phase I - ground	56	51
Phase II- ground	20	10
Phase II- air	18	27
Totals	94	88

The data sample for Phase I was the largest and the nearest to the 50/50 random design. Phase II ground seeding was the smallest sample. Unfortunately, this sample also suffered from an extremely uneven distribution of rainfall. Of the 20 seeded bands, more than half produced little, if any, precipitation. Of the 10 unseeded bands, two were exceptionally heavy rain producers, dropping one to four inches at many stations. This resulted in a seeded/not seeded ratio of less than one for most stations during Phase II ground operations.

Approximation of Augmentation

Table IV-1 shows the rainfall augmentation for the Upper Santa Ynez Valley. There were seven rain gages in the watershed which were used in the Phase I and II programs. For each gage, the precipitation for all seeded bands was averaged and compared by ratio to the average precipitation from unseeded bands. This was done for the Phase I bands, the Phase II ground seeded bands, and the Phase II air seeded bands. For each gage, the weighted average of

Table IV-1

CLOUD SEEDING DATA SUMMARY FOR SANTA YNEZ RIVER[a/]

Rain Gage[b/] Number	Type of[c/] Operation	No. of Convective Bands		Avg. Precip. per Band[d/]		Ratio
		Seeded	Not Seeded	Seeded	Not Seeded	Seeded/Not Seeded
M 105	a	44	37	0.460	0.246	1.87
M 105	b	20	10	0.355	0.601	0.59
M 105	c	16	26	0.491	0.353	1.39
M 105	d	80	73	0.440	0.333	1.32
M 230	a	55	50	0.519	0.320	1.62
M 230	b	20	10	0.408	0.785	0.52
M 230	c	18	25	0.508	0.353	1.44
M 230	d	93	85	0.493	0.384	1.28
N 14	a	54	49	0.297	0.204	1.46
N 14	b	12	6	0.247	0.170	1.45
N 14	c	13	16	0.198	0.141	1.41
N 14	d	79	71	0.273	0.187	1.46
N 15	a	53	45	0.416	0.304	1.37
N 15	b	14	10	0.418	0.663	0.63
N 15	c	16	20	0.368	0.292	1.26
N 15	d	83	75	0.407	0.349	1.17
N 17	a	45	34	0.298	0.259	1.15
N 17	b	12	7	0.274	0.397	0.69
N 17	c	13	15	0.270	0.270	1.00
N 17	d	70	56	0.289	0.279	1.04
E 1253	a	53	47	0.329	0.227	1.45
E 1253	b	18	6	0.310	0.677	0.46
E 1253	c	17	25	0.379	0.248	1.53
E 1253	d	88	78	0.335	0.268	1.25
S 232	a	55	50	0.614	0.412	1.49
S 232	b	20	10	0.425	0.708	0.60
S 232	c	17	26	0.548	0.328	1.67
S 232	d	92	86	0.561	0.421	1.33
Totals	a	359	312	0.422	0.285	1.48
and	b	116	59	0.357	0.601	0.59
Weighted	c	110	153	0.407	0.293	1.39
Averages	d	585	524	0.406	0.323	1.26

Footnotes for Table IV-1 :

a/ Data were obtained from Santa Barbara Convective Band Seeding Test Program, Naval Weapons Center, October 1975.

b/ M 105 is at Los Prietos Ranger Station; M 230 is at Gibraltar Dam; N 14 is on Santa Cruz Creek; N 15 is at the Nash-Boulden Ranch; N 17 is at Happy Hollow Guard Station; E 1253 is at Cachuma Lake; S 232 is at Juncal Dam. For more specific locations, see Appendix A of the report cited in footnote a.

c/ The letters shown correspond to the following operations:

a = Phase I ground operations 1967-1971

b = Phase II ground operations 1970-1974

c = Phase II air operations 1970-1974

d = Sum Total of above operations

d/ Average precipitations is given in inches.

the three operations was developed as were the weighted averages of each operation for all of the gages. The results shown in Table IV-1 are that Phase I ground seeding increased precipitation from convective bands in the Santa Ynez watershed by an average of 48 percent; that Phase II air seeding increased band precipitation an average of 39 percent; that seeded band precipitation was 59 percent of unseeded band precipitation for Phase II ground seeding; and that on an average basis, band precipitation in the Upper Santa Ynez watershed was increased 27 percent. Phase II ground operations suffered from an extremely small sample size which unfortunately distorts the true picture. Of the 30 sample bands for Phase II ground operations, twenty were seeded while 10 were left unseeded. Most of the seeded bands produced no precipitation, while a few of the unseeded bands were exceptionally high rain producers. This can be seen by observing the higher than normal average precipitation per band for Phase II ground operations in Table IV-1 at stations M 105, M 230, N 15, E 1253, and S 232. Stations N 14 and N 17 did not record the few exceptionally heavy unseeded bands and display a more normal average precipitation per band.

Table IV-2 summarizes the Phase I and Phase II results in terms of the ratios of seeded band precipitation and unseeded band precipitation. These ratios were arrived at by averaging the results from rain gages representative of each watershed. The detailed data for each watershed are shown in the Appendix.

Analysis of Results

Table IV-2 shows the results of the Water Agency analysis of the data. Each number was derived in the manner described in the previous section. Basically, the final ratios represent the average of groups of rain gages within each watershed. The results of Phase I and Phase II air seeding indicate definite increases in band precipitation. The overall annual increases for each watershed are half the percentage shown, since band precipitation accounts for only about 50% of the total annual precipitation in Santa Barbara County.

The results of Phase II ground seeding were disappointing and can be misleading. They are "primarily due to the relatively small number of cases and to the uneven random draw that saw several bands with large totals fall into the not seeded category" (4). The data are presented for completeness and should not be construed as an indication of decreases in precipitation due to cloud seeding. Even with the Phase II ground seeding data included, the combined data for all operations between 1967 and 1974 show significant increases in all but three watersheds. Unlike the results formulated by North American Weather Consultants, the Water Agency data were not scrutinized using statistical tests.

The analysis of Phases I and II done by North American Weather Consultants concerned itself with the entire network of gages rather than just certain areas. Each station

Table IV-2

SUMMARY OF SEEDED/NOT SEEDED RATIOS FOR BAND PRECIPITATION[a/]

Watershed	Phase I 1967-1971	Phase II 1971-1974		Phases I & II Combined
	Ground Based	Ground Based	Aerial	
Cuyama River above Buckhorn Canyon	1.35	0.45	1.34	1.10
Santa Maria Valley	1.01	0.70	1.29	1.00
Sisquoc River above Round Corral	1.28	0.68	1.77	1.28
San Antonio Creek	1.09	0.56	1.41	1.02
Salsipuedes Creek	0.73	0.46	1.39	0.99
Santa Ynez River above Cachuma Dam	1.48	0.59	1.39	1.26
San Jose Creek (South Coast)	1.48	0.58	1.37	1.21
Carpinteria Creek (South Coast)	1.28	0.61	1.32	1.12

a/ Data for each watershed are averages of data from representative raingages. For derivation of averages see Appendix. Where numbers shown are greater than one, seeded band precipitation was greater than not seeded band precipitation. Band precipitation accounts for about 50 percent of the annual precipitation in SB County.

was analyzed for precipitation increases and effects on band duration. There was an attempt at determining effects of various temperatures and pressures. The results of the precipitation analysis were presented in map form and are shown in Figures IV-3 thru IV-8. It should be stressed that the overall pattern in the figures is more significant than the absolute value of the ratio number (4).

Figure IV-3 shows the areas of equal seeded/not seeded ratios for band precipitation for Phase II air seeding. As shown, the areas of greatest effect are three parallel bands running north-south across Santa Barbara and Ventura Counties. These bands are all parallel to the path followed by the airplane.

Figure IV-4 displays the areas of statistical significance for the Phase II air operations. The statistical significance is based on the application of the Wilcoxon, Mann-Whitney U test which is a standard, non-parametric, statistical test. It compares the two samples (seeded and not seeded) by ranking and determines whether there is a significant difference in their means. Most of the data showed significance levels over 10%. This indicates that the probability is greater than 10% that the difference in means may be due to chance alone. Therefore, those stations with significance levels less than 10% represent very conclusive results. For Phase II air operations, 21 stations were 10% or better with 9 being better than 5%.

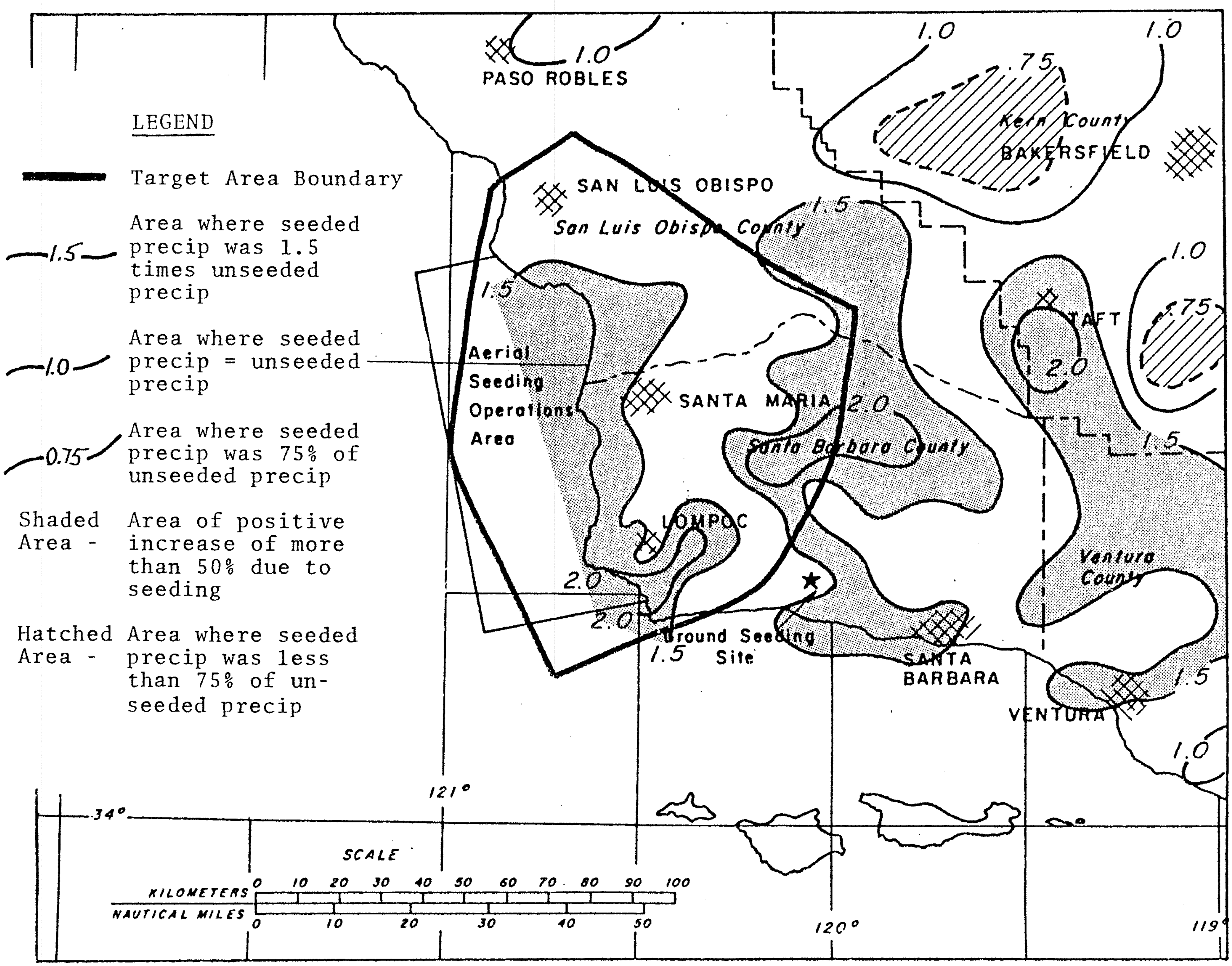


Figure IV-3 Seeded/not-seeded ratios of band precipitation for Phase II aerial operations, 1970-7 seasons; 18 seeded and 27 not-seeded bands. (4)

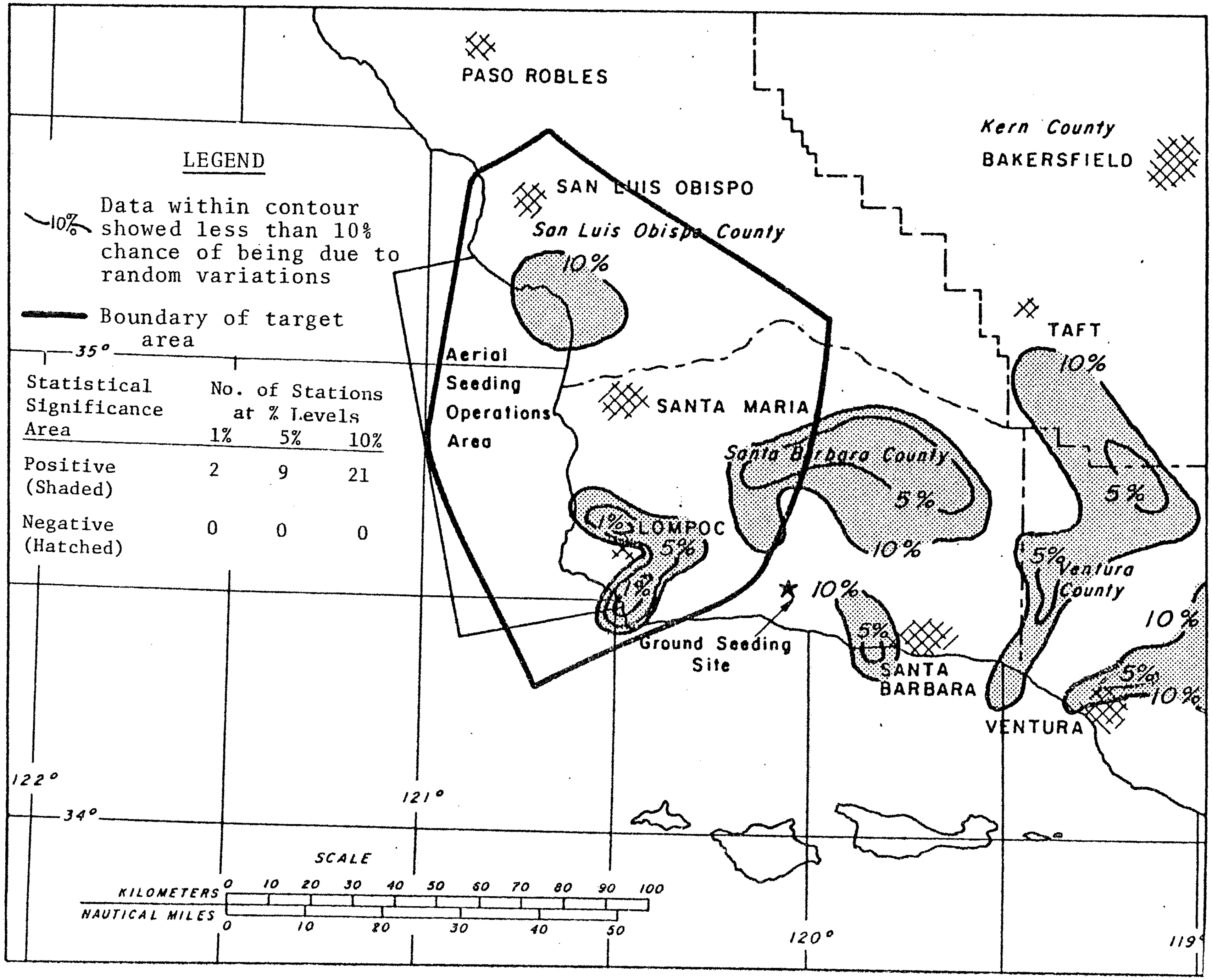


Figure IV-4 Areas of statistical significance associated with band precipitation ratios, Phase II aerial operations, 1970-74 seasons. (4)

Figure IV-5 shows the areas of equal seeded/not seeded ratios for band precipitation during Phase I ground operations. The two major areas of effect are generally downwind of the seeding site, which is to be expected. Figure IV-6 shows the areas of statistical significance associated with Phase I ground seeding. Twenty-seven stations had statistical significance of 10% or better.

Figures IV-7 and IV-8 deal with Phase II ground operations. It can be seen that there were areas which indicated positive results, but that most of the region shows negative results. Yet only six stations have significance levels better than 10 percent for the negative results. One of these is in the target area.

A similar analysis concerning convective band duration is presented in the Naval Weapons Center report. The results indicate that seeded bands tend to slow down in their movement across the county. The areas which showed the most effect correspond directly with the areas which showed increments in precipitation. A temperature analysis is also presented which indicates that the seeding was more effective on the warmer clouds. When the 500 mb temperature was less than -22°C, seeding of the convective bands failed to increase, and in some cases is thought to have decreased the precipitation.

An attempt was made to correlate change in surface pressures associated with cloud seeding. Theoretical calculations showed that pressure should be reduced due to heating of the air by the latent heat of fusion in the

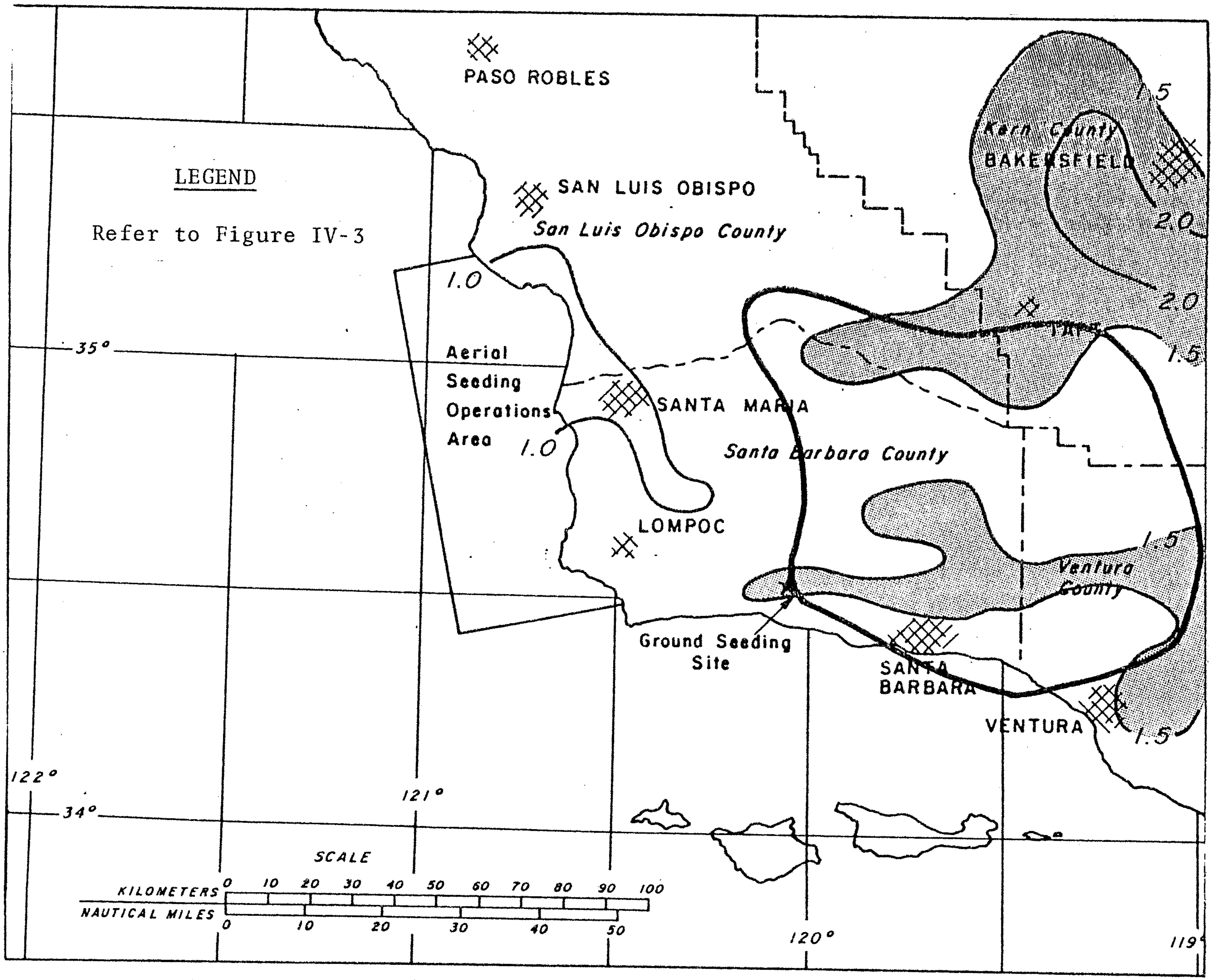


Figure IV-5 Seeded/not-seeded ratios of band precipitation for Phase I ground operations, 1967-71 seasons; 56 seeded and 51 not-seeded bands (4)

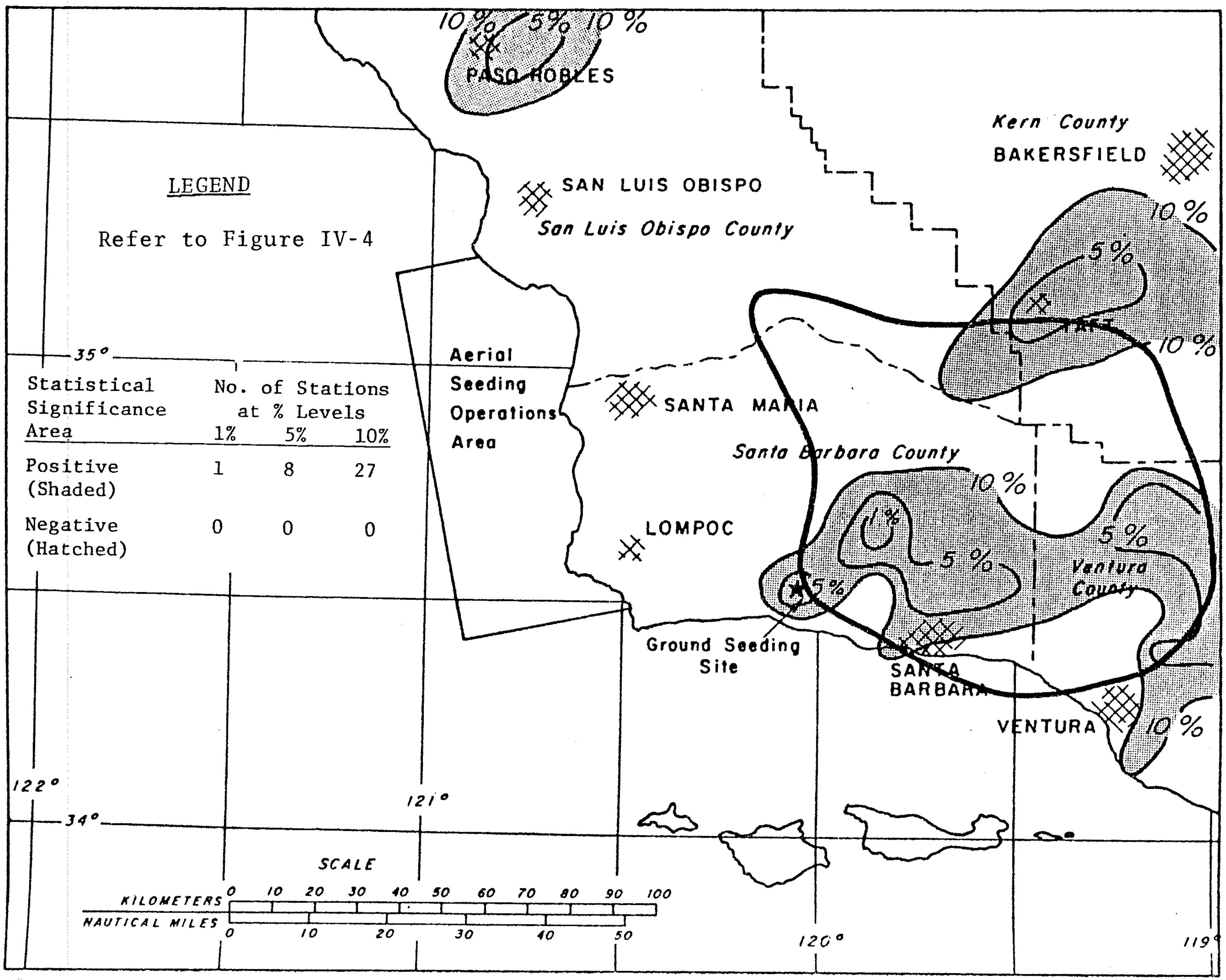


Figure IV-6 Areas of statistical s ificance associated with band precipitation ratios, Phase I ground operations, 1967-71 seasons (4)

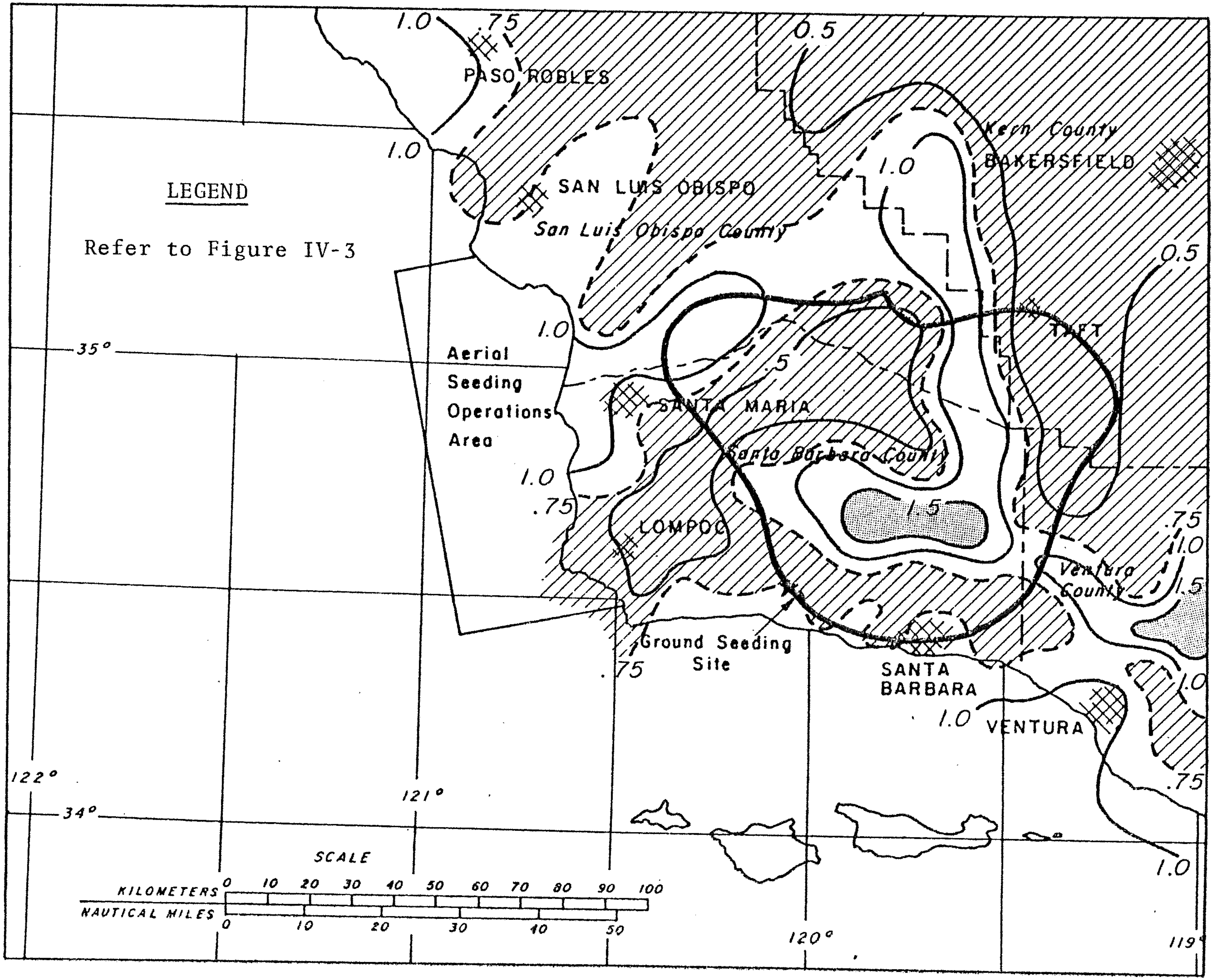
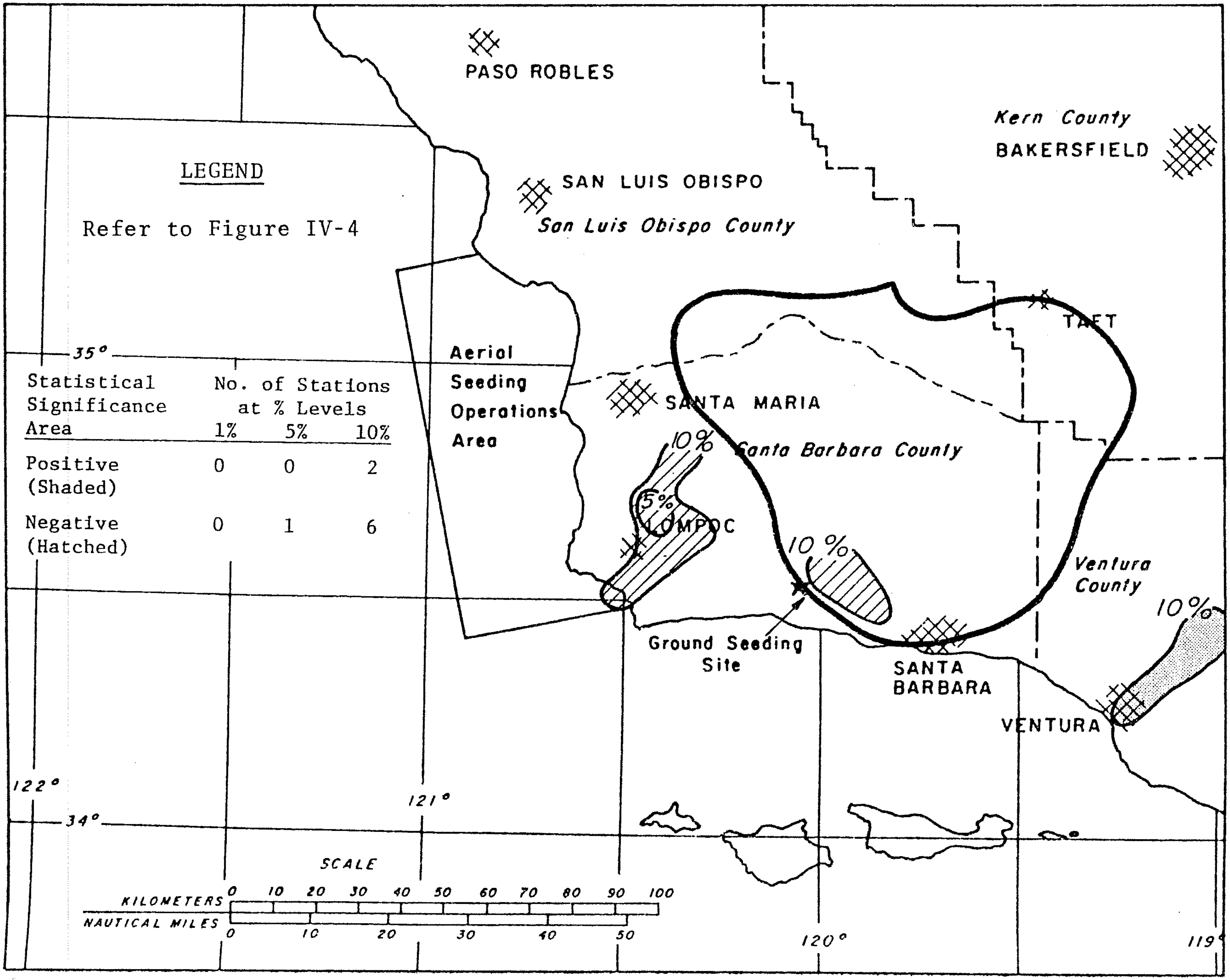


Figure IV-7 Seeded/not-seeded ratios of band precipitation for Phase II ground operations, 1971-74 seasons; 20 seeded and 10 not



Statistical Significance Area	No. of Stations at % Levels 1%	5%	10%
Positive (Shaded)	0	0	2
Negative (Hatched)	0	1	6

Figure IV-8 Areas of statistical sig icance associated with band precipitation ratios. Phase II ground operations. 1971-74 seasons [4].

nucleating zone and associated updraft increases. Analysis of Phase II data showed some pressure decreases, but none of the data showed high statistical significance.

RUNOFF AUGMENTATION

Methodology Used

The basic approach taken in estimating runoff expected increases due to cloud seeding involved the development of a relationship bewween rainfall and runoff. On Santa Barbara County, conspicuous streamflow occurs only after periods of rainfall. Most streams are dry throughout the summer. Daily records exist for rainfall at various locations and for streamflow in various streams. The Water Agency staff collected daily records for the major watersheds for a selection of "wet," "dry," and "normal" years. An attempt was made to display the runoff-rainfall relationship by plotting the accumulated runoff versus the accumulated precipitation for 30-day periods during the rainy season. In general, the graphs show that rainfall which comes later in the season produces more runoff than similar amounts of rain early in the season. This is to be expected, since the watershed is more likely to be saturated by the end of the rainy season. This graphical approach was abandoned in favor of another, since it could not be used to determine increments from cloud seeding.

The methodology eventually adopted involved the calculation of runoff as a percent of the rainfall over the watershed. Again, 30-day periods were used, each picked to include "whole" storm periods (i.e. whenever possible, storm periods were not split up into separate 30-day periods). For each 30-day period, the runoff over and above the estimated base flow was calculated. This net runoff was compared with the total rainfall during the period by converting both quantities to equivalent units (acre-feet). Rainfall over the watersheds was estimated (in inches) using the records of a nearby raingage, and converting by an index factor based on S.B. County Flood Control isohyetal maps. By multiplying by the watershed acreage and dividing by twelve, the total applied water was calculated. Runoff (in cfs days) was converted by multiplying by the number of seconds in a day (86,400) and dividing by the number of cubic feet in an acre-foot (43,560). Runoff was divided by rainfall to see what percent of rain came off as streamflow. This figure was plotted for each storm period against the total rain for the period. Generally, periods of larger amounts of precipitation had a larger percent of runoff. This is due to the flashy nature of runoff in most Santa Barbara County watersheds. Prior watershed conditions and the intensity of the rainfall are additional variables to the relationship which were not accounted for in these graphs (see Appendix for graphs).

In order to calculate the expected increments in runoff from cloud seeding, it was decided to assume a standard increase in precipitation (15% based on previous results) and apply this increase at each point on the graph. When all of the data were plotted, trend lines were drawn according to the pattern of data points. Sometimes it was possible to draw three trend lines corresponding to runoff early in the season, the middle of the season, and at the end. For each data point not on a trend line, a line parallel to the trend line was drawn through this point. Finally, for each point, the augmented precipitation was determined (actual plus 15%), located on the trend line, and a new percent of rainfall as runoff was read off the ordinate. Using this percentage, the augmented runoff was calculated.

Once the watershed is saturated, any increment in precipitation will run off directly. It is at this point that cloud seeding can be the most effective in producing incremental runoff. At the same time however, flood potential becomes a hazard to be avoided. The calculated increments in runoff had to be revised to account for periods during which seeding operations would most likely have been suspended. Of the sample years which were used, the following had substantial floods: 1951-52, 1957-58, 1961-62, and 1968-69. Whenever one of these years was used in the analysis, certain 30-day periods were corrected to reflect flooding conditions.

These procedures estimated the expected runoff increment during the <u>storm season</u> resulting from a 15% increase in precipitation. They do not address the problem of identifying increases in runoff which would be evident during the remainder of the year. Although this additional increment is relatively minor, the Water Agency attempted to quantify it. Using data for the Sisquoc River, a family of curves were drawn which approximated the decay in streamflow (in the absence of any additional rain) from different initial levels of flow. For each year under consideration, the augmented remainder of the year runoff was calculated, as were the augmented runoff amounts for the gaps between 30-day periods. The end result showed that with the remainder of the year runoff figured in, the percentage increase in runoff was two to four percent higher than without it accounted for. The methodology used to obtain these results was exceedingly tedious, however, and it was not carried out for any of the other water courses. The overall results can be viewed as conservative, then, and may be increased a few percent to account for remainder of the year runoff.

Approximation of Augmentation

Tables IV-3 thru IV-8 show the final results for each of the watersheds. The percent increase in runoff which was determined corresponds to a 15 percent increase in rainfall and makes allowance for the suspension of operations during flood periods. The range for increases was from 12 percent to 42 percent (excluding those years which were reduced to account for the suspension of operations). It must be noted that while this range is

Table IV-3
CUYAMA RIVER RUNOFF INCREASES CORRESPONDING TO 15 PERCENT RAIN AUGMENTATION a/

Rain Year	Storm Season Precip. over Watershed (inches) b/	Total Actual Runoff (AF) c/	Actual Storm Season Runoff (AF)	Remainder of Year Runoff (AF)	Revised Augmented Storm Season Runoff (AF)	Revised Augmented Total Year Runoff (AF)	Runoff Increment (AF)	Percent Increase
1962-63	8.47	295	166	129	225	354	59	20.0
1964-65	3.37	543	543	-0-	756	756	213	39.2
1966-67	13.73	37,760	34,785	2,975	45,783	48,758	10,998	29.1
1971-72	2.35	559	516	43	659	702	143	25.6
1972-73	17.47	13,190	12,366	824	15,623	16,447	3,257	24.7
1973-74	13.69	3,750	3,134	616	4,709	5,325	1,575	42.0
1974-75	11.19	2,090	1,870	220	2,601	2,821	731	35.0

a/ Storm periods E & L revised to account for flood potential (see Appendix for storm period designation

b/ Average Precipitation over Watershed = 13.0"

c/ As measured at USGS gage below Buckhorn Canyon

Table IV-4

SALSIPUEDES CREEK RUNOFF INCREASES CORRESPONDING TO 15 PERCENT RAIN AUGMENTATION a/

Rain Year	Storm b/ Season Precip. over Watershed (inches)	Total c/ Actual Runoff (AF)	Actual Storm Season Runoff (AF)	Remainder of Year Runoff (AF)	Revised Augmented Storm Season Runoff (AF)	Revised Augmented Total Year Runoff (AF)	Runoff Increment (AF)	Percent Increase
1966-67	19.03	6,710	5,748	962	6,246	7,208	498	7.4
1967-68	11.32	777	539	238	637	875	98	12.6
1970-71	10.64	1,180	824	356	1,008	1,364	184	15.6
1971-72	7.10	517	382	135	455	590	73	14.1
1972-73	31.82	15,660	14,281	1,379	19,308	20,687	5,027	32.1
1973-74	22.23	5,320	4,233	1,087	5,826	6,913	1,593	29.9
1974-75	22.62	13,780	12,248	1,532	15,869	17,401	3,621	26.3

a/ Storm period B revised to account for flood potentials (see Appendix for storm period designations)

b/ Average Precipitation over Watershed = 20"

c/ As measured at the USGS gage near Lompoc

Table IV-5
SAN ANTONIO CREEK RUNOFF INCREASES CORRESPONDING TO 15 PERCENT RAIN AUGMENTATION a/

Rain Year	Storm b/ Season Precip. over Watershed (inches)	Total c/ Actual Runoff (AF)	Actual Storm Season Runoff (AF)	Remainder of Year Runoff (AF)	Revised Augmented Storm Season Runoff (AF)	Revised Augmented Total Year Runoff (AF)	Runoff Increment (AF)	Percent Increase
1967-68	6.49	933	635	298	746	1,044	111	11.9
1970-71	9.79	859	616	243	889	1,132	273	31.8
1971-72	6.77	775	323	453	426	879	104	13.4
1972-73	20.74	5,620	5,245	375	7,302	7,677	2,057	36.6
1973-74	15.60	2,790	2,231	559	3,185	3,744	954	34.2
1974-75	15.87	2,280	1,792	488	2,425	2,913	633	27.8

a/ No revisions needed

b/ Average Precipitation over Watershed = 15"

c/ As measured at the USGS stream gage near Casmalia

Table IV-6
SAN JOSE CREEK RUNOFF INCREASES CORRESPONDING TO 15 PERCENT RAIN AUGMENTATION a/

Rain Year	Storm Season Precip. over Watershed (inches) b/	Total Actual Runoff (AF) c/	Actual Storm Season Runoff (AF)	Remainder of Year Runoff (AF)	Revised Augmented Storm Season Runoff (AF)	Revised Augmented Total Year Runoff (AF)	Runoff Increment (AF)	Percent Increase
1961-62	30.18	3,360	3,246	114	3,300	3,414	54	1.6
1963-64	10.16	304	207	97	278	375	71	23.4
1966-67	25.78	4,080	3,746	334	3,985	4,319	239	5.9
1970-71	16.39	488	357	131	458	589	101	20.7
1973-74	21.74	905	702	203	940	1,143	238	26.3
1974-75	25.08	1,920	1,808	112	2,381	2,493	573	29.8

a/ Storm periods C, I, and J revised to account for flood potential (see Appendix for storm period designations)

b/ Average Precipitation over Watershed = 25.6"

c/ As measured at the USGS gage near Goleta

Table IV- 7

SANTA CRUZ CREEK RUNOFF INCREASES CORRESPONDING TO 15 PERCENT RAIN AUGMENTATION a/

Rain Year	Storm[b/] Season Precip. over Watershed (inches)	Total[c/] Actual Runoff (AF)	Actual Storm Season Runoff (AF)	Remainder of Year Runoff (AF)	Revised Augmented Storm Season Runoff (AF)	Revised Augmented Total Year Runoff (AF)	Runoff Increment (AF)	Percent Increase
1967-68	15.55	3,580	2,669	911	3,235	4,146	566	15.8
1970-71	21.40	7,170	5,771	1,399	7,360	8,759	1,589	22.2
1971-72	13.33	2,280	1,807	473	2,509	2,982	702	30.8
1972-73	37.39	19,910	17,320	2,590	23,449	26,039	6,129	30.8
1973-74	24.31	7,220	5,801	1,419	7,989	9,408	2,188	30.3
1974-75	25.51	8,570	7,575	995	9,625	10,620	2,050	23.9

a/ No revisions needed

b/ Average Precipitation for Watershed = 26"

c/ As measured at the USGS gage near Santa Ynez

Table IV-8
SISQUOC RIVER RUNOFF INCREASES CORRESPONDING TO 15 PERCENT RAIN AUGMENTATION a/

Rain Year	Storm[b/] Season Precip. over Watershed (inches)	Total[c/] Actual Runoff (AF)	Actual Storm Season Runoff (AF)	Remainder of Year Runoff (AF)	Revised Augmented Storm Season Runoff (AF)	Revised Augmented Total Year Runoff (AF)	Runoff Increment (AF)	Percent Increase
1966-67	21.66	108,400	84,407	23,993	94,940	118,933	10,533	9.7
1967-68	11.93	11,530	6,669	4,861	8,717	13,578	2,048	17.8
1970-71	12.33	15,630	10,520	5,110	13,598	18,708	3,078	19.7
1971-72	4.58	7,260	4,478	2,783	6,142	8,925	1,665	22.9
1972-73	35.33	46,370	38,461	7,909	53,366	61,275	14,905	32.1
1973-74	21.25	19,950	16,407	3,543	21,532	25,075	5,125	25.7
1974-75	19.14	18,310	15,508	2,502	20,819	23,321	5,011	27.4

a/ Storm period A was revised to account for flood potential (see Appendix for storm period designations)

b/ Average Precipitation for Watershed = 22"

c/ As measured at the USGS gage near Sisquoc substantial, the actual amounts of incremental runoff vary considerably. During wet years, incremental runoff can be much greater than during a dry year, even though the percentage increases may be the same. It is an unfortunate reality that cloud seeding is of little help in a dry year and may be unnecessary in a very wet year. Its value lies in the effect it has on runoff during years of average precipitation. The years 1973-74 and 1974-75 were considered average rain years, and potential runoff increases were calculated for all of the watersheds shown in Tables IV-3 thru IV-8. Increments range from 24 to 42 percent, and assume a 15 percent increase in rainfall. The predicted runoff increments for the six watersheds were 11,670 AF and 12,620 AF for 1973-74 and 1974-75, respectively.

Approximation of Yields

The determined increments for a cloud seeding program appear substantial, however, not all of these increments can be considered as yields. The yield of these expected runoff increments can be divided between surface reservoir yields and groundwater recharge via stream seepage. Recharge will be considered in subsequent sections of this report. Extra reservoir yields depend mainly on whether the water is released for groundwater recharge, or whether it is drawn off as a safe yield for surface deliveries. In general, the incremental yield for a groundwater recharge reservoir will approach the increases in runoff. This yield is limited by the capacity of the reservoir and the existing condition of the groundwater basin. For Twitchell Reservoir, the capacity is great enough to limit spills to rare years. And it seems likely that the Santa Maria Groundwater Basin could easily accept an incremental yield to Twitchell since it accepted such a large amount during and after the floods of 1969. Actual increased yield for Twitchell was not individually calculated. It is included in the stream seepage increments.

Yield estimates for potential reservoirs were made by Bookman & Edmonston in their Engineering Study of Potential Dam Projects, April 1977 (12). These estimates included incremental yields as a result of cloud seeding, based on information provided by the Water Agency. One such potential reservoir would be located on Salsipuedes Creek. The water could be used for surface deliveries to Lompoc, or it could be released on a regulated basis for groundwater recharge in the Lompoc Plain. The groundwater replenishment type operation appears to be more feasible economically. The incremental yield for this choice of reservoirs was estimated to be 500 AFY. It was based on preliminary data developed by the Water Agency, and assumed that cloud seeding would enhance precipitation by 6 percent, and runoff by 9 to 14 percent. Subsequent studies by the Water Agency have suggested that an operational program (in particular an aerial program) may have a more substantial impact on rainfall and runoff. Therefore, this incremental yield should be viewed as a conservative figure.

The other potential reservoir would be located just below Round Corral Canyon on the Sisquoc River. The stored water would be released in conjunction with Twitchell Reservoir water for maximum recharge benefits in the Santa Maria Groundwater Basin. The Bookman & Edmonston report (12) indicated incremental yields of 800 AFY for the 50,000 acre-foot capacity, and 1,100 AFY for the 80,000 acre-foot reservoir. These figures were based on data developed by the Water Agency. It was assumed that cloud seeding enhanced precipitation by an average of 14%, and runoff by 4 to 5 percent in dry years, and 18 to 20 percent in wet years.

Incremental yields for certain Santa Ynez reservoirs were more difficult to estimate since the reservoirs are operated on a safe yield basis. During years of heavy runoff most of the increment due to seeding may be lost when reservoirs spill. In addition, during years with low flows, some of the incremental runoff will be conserved for later use. In order to estimate the increase in safe yield, mass curves were drawn for each reservoir showing the accumulated net inflows. On the basis of these graphs, the most critical dry period was chosen. Inflows into the reservoir were increased by 20 and 30 percent (see Table IV-7) to approximate the low and high results of cloud seeding efforts. Mass curves were then drawn for these augmented inflows. The safe yield can be determined, given the usable capacity of the reservoir. A tangent is drawn from the high point on the mass curve just prior to the critical dry period. The tangent is drawn in such a manner that the maximum departure from the mass curve does not exceed the specified reservoir capacity. The slope of the tangent line, then,represents the rate at which water could be safely removed from the reservoir without running out of water. Shown below is a summary of the results. The graphs and inflow data are shown in the Appendix.

Reservoir	Assumed Usable Capacity (AF)	Length of Critical Period (Years)	Assumed Safe Yield (AFY)	Range of Increment (AF)
Cachuma	188,700	7.58	24,800	2,200-4,400
Gibraltar	7,200	4.67	1,600	240-360
Jameson	5,880	5.67	950	90-120

It must be noted that these increments do not account for increased evaporation losses and increased releases to satisfy prior downstream rights. To allow for these, it was assumed that 20% would be lost to increased evaporation and phreatophytic consumption. For the remaining yield, it was assumed that half would be released downstream and half would be realized as surface deliveries. In this respect then, yield from Cachuma could theoretically increase 900-1,800 acre-feet per year for both surface deliveries and downstream releases. Similarly, yield from Jameson could theoretically increase 40-50 AFY and from Gibraltar 100-150 AFY. These yields also represent both surface deliveries and downstream releases.

It is difficult to assign a firm incremental yield to Gibraltar since it is operated on a conjunctive use basis as opposed to safe yield. The actual yield from this reservoir is dependent on the maximum diversion allowed during the course of the rainy season. No attempt was made to estimate an increase for the reservoir operated on this basis since an answer might involve exploring sensitive water rights questions, which is beyond the scope of this report.

In order for the Cachuma Member Units to actually realize incremental yields from the reservoir, a more exact increase of the yield would have to be determined by the Bureau of Reclamation who regulates the project. The Bureau is currently investigating possible cloud seeding yields to Santa Barbara and Ventura Counties. They are developing computer models of various watersheds, including the Santa Ynez River, with hopes of predicting augmented streamflow. Results of their studies will be forthcoming.

GROUNDWATER RECHARGE AUGMENTATION

Rainfall Infiltration

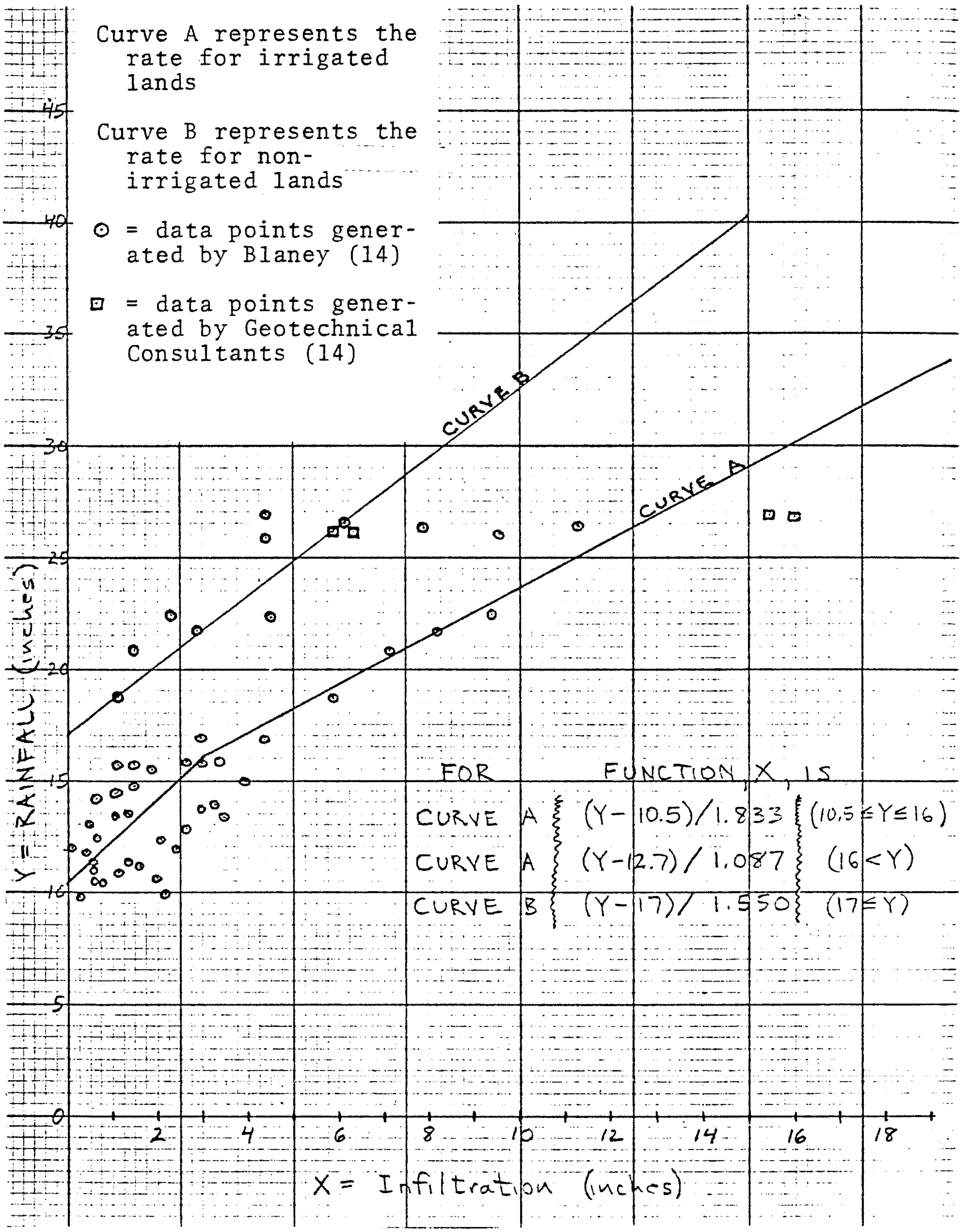
Natural recharge to groundwater basins occurs through the deep percolation of rainfall and seepage losses from streams. As cloud seeding enhances rainfall and runoff, it will also enhance the recharge of the various groundwater basins. The methodology used to determine increments of recharge was based on methods of H. F. Blaney. In 1933, Blaney made direct measurements of rainfall infiltration in areas of various soil types and vegetative cover in Ventura County. In 1956, he studied the same problem in the Lompoc area. Results from both studies seem to agree, and his methodology is generally accepted as the best available approximation of deep percolation rates for Santa Barbara County. Geotechnical Consultants, Inc. presented Blaney's data and their own model in their Carpinteria report (14). On the basis of these data, the Water Agency drew the graphs shown in Figure IV-9. These lines were drawn as the best approximation of the data points. Their equations were programmed into a computer so that annual infiltration amounts could be generated. These amounts depended on yearly precipitation, recharge area, and the extent of irrigated agriculture in the recharge area. In general, no infiltration will occur with less than 10 inches of precipitation, and no more will occur after 30 inches. The amount of water which percolates is also dependent on consumptive use by vegetation, the intensity, duration, and amount of precipitation, and the permeability of the soil. Citrus type land cover allows much percolation, since there are shallow roots, and a relatively high soil moisture content is maintained by irrigation. Any irrigated agricultural area increases deep penetration of rainfall because the soil is already moist. Much of the initial rainfall during the rainy season goes toward overcoming soil moisture deficiency in areas of native vegetation.

In order to calculate rainfall infiltration, it was necessary to know the extent of the recharge and confined area and how much irrigated agriculture exists in these areas. Table IV-9 shows these data. The figures for irrigated agriculture were determined by planimetering the maps produced by the Geography Remote Sensing Unit at UCSB in the Agricultural Land Use Survey, 1975. For each basin, these acreages were put into the computer

Figure IV-9

RAINFALL INFILTRATION CURVES

FOR SANTA BARBARA COUNTY



Tabl IV-9

IRRIGATED ACREAGE WITHIN GROUNDWATER BASINS

(Values in Acres)

Groundwater Basin	Recharge[a/] Area	Confined[a/] Area	Area of Irrigated Agriculture[b/]		Non-Irrigated Area	
			in Recharge	in Confined	in Recharge	in Confined
Carpinteria	4,360	3,260	3,080	1,140	1,280	2,120
Montecito	4,300	-	750	-	3,550	-
Santa Barbara	3,400	-	150	-	3,250	-
Goleta	5,870	5,150	1,070	610	4,800	4,540
Santa Ynez Uplands	88,000	-	4,650	-	83,350	-
Lompoc Plain	6,400	8,400	3,700	4,900	2,700	3,500
Lompoc Uplands	29,180	-	2,180	-	27,000	-
San Antonio	66,000	-	4,730	-	61,270	-
Santa Maria	77,000	30,000	33,000	15,000	44,000	15,000
Cuyama	163,200	-	13,800	-	149,400	-

a/ Figures for Carpinteria and Montecito were obtained from Geotechnical Consultants, Inc. reports. Figure for Santa Barbara is from USGS WSP 1859 A. Figures for Goleta are SBCWA estimates and represent the Upson recharge area plus alluvial fingers. Data for Santa Ynez Uplands, San Antonio Cuyama, Santa Maria and Lompoc Plain are SBCWA estimates. Figure for the Lompoc Plains is from Blaney, et al..(24)

b/ Values determined by planimetering maps made by UCSB, GRSU during their 1975 Agricultural Land Use Study.

program and infiltration data were generated according to annual rainfall. This was done over a variety of base periods which lasted at least 45 years. The average infiltration was then computed. This figure reflects current agricultural acreage, and therefore cannot be considered to be the historic average infiltration. The next step involved running the computer program again, this time with each annual rainfall increased by a percentage corresponding to the results of Phases I and II cloud seeding. The increase in average infiltration for each basin is shown in Table IV-10.

Stream Seepage

Seepage losses from streams occur only in the recharge areas of a groundwater basin. Once the streamflow reaches a confined-water area, percolation is minimal. Ideally, seepage loss is measured by the difference between two stream gages - one just upstream of the recharge area, and one just downstream of the recharge area. Unfortunately, there are few such arrangements in the county. It can, however, be estimated on the basis of flow duration curves, rainfall-runoff records, and the characteristics of the stream. Cloud seeding-induced runoff increases enhance seepage loss by increasing the depth of streamflow, the wetted surface area in the streambed and the duration of flows. In order to measure the effect which cloud seeding would have, the Water Agency tried to develop runoff/seepage loss curves. Since runoff increments had

Table IV-10

RAINFALL INFILTRATION INCREASES DUE TO CLOUD SEEDING

Groundwater Basin	Average Precip. (inches)	Basin Recharge Area (acres)	Average[a] Annual Infiltr. (AF)	Augmented[a] Average Annual Infiltr. (AF)	Increase due to Cloud Seeding	Percent Increase	Percent Increase in Precip.
Carpinteria	17.3	4,360	1,600	2,100	500	31.3	16
Goleta	17.8	5,870	1,405	1,956	551	39.2	18
Montecito	17.8	4,300	848	1,181	333	39.3	18
Santa Barbara	17.8	3,400	551	778	227	41.2	18
Santa Maria	13.4	77,000	8,899	12,651	3,662	41.2	15
San Antonio	15.0	66,000	6,329	9,637	3,308	52.3	20
Santa Ynez Uplands	15.8	88,000	11,416	15,796	4,380	38.4	19
Lompoc Plain	14.2	6,400	2,949	3,453	504	17.1	19
Lompoc Uplands	14.2	29,180	2,758	4,010	1,252	45.4	19

a/ Values reflect current (1975) agricultural conditions

Table IV-11

STREAM SEEPAGE INCREMENTS DUE TO CLOUD SEEDING

Groundwater Basin	Estimated[a/] Annual Recharge Due to Seepage	Percent Range of Runoff Increments from Cloud Seeding	Percent Range of Seepage Increments from Cloud Seeding	Range of Amounts of Increments
Carpinteria	940	20-30	8-12	75-113
Montecito	400	20-30	8-12	32-48
City of SB	400	20-30	8-12	32-48
Goleta	1,400	20-30	8-12	112-168
Santa Ynez Uplands	3,100	15-30	6-12	186-372
Lompoc Plain	4,150	15-30	6-12	249-498
Santa Maria	68,000	15-30	10-20	6,800-13,600
San Antonio	2,000	10-35	4-15	80-300
Cuyama	13,000	20-40	8-18	1,040-2,340

a/ Figure for Carpinteria was obtained from Geotechnical Consultants, Inc. report (14). Figure for Montecito and Santa Barbara is a mid value for the range given by USGS in WSP 1859. The Goleta amount is from reference (22). Data for Santa Ynez Uplands is from reference (23). Data for the Lompoc Plain and Santa Maria are SBCWA estimates. Data for San Antonio is from reference (19). Data for Cuyama is from (16).

been determined, the corresponding seepage increment could be calculated from these curves. The results are shown in Table IV-11. The range of increases in stream seepage for the Lompoc Plain and for Santa Maria were the only values calculated by the Water Agency. The other values are conservative guesses based on these calculations. The Santa Maria Basin would receive the most benefits, due to the regulation of flows by Twitchell Dam. The effect on the Cuyama Basin is high, since seepage from streams accounts for the major share of recharge. Streams on the South Coast were treated equally due to their similiarity. The larger range of values for San Antonio reflect the larger range of runoff increments. Seepage losses in the San Antonio are limited by the narrowness of the stream channel, and by high groundwater levels over the lower reaches.

SUMMARY OF YIELDS

Table IV-12 displays a summary of the theoretical benefits expected from cloud seeding. Yields from Round Corral and Salsipuedes were included for completeness but were not figured in the totals since the reservoirs do not exist. The total theoretical yields from cloud seeding range from 17,540 to 36,400 AFY.

Table IV-12

THEORETICAL YIELDS FROM AN OPERATIONAL CLOUD SEEDING PROGRAM[a]

	Surface Water Incremental Yields (AFY)										Groundwater Incremental Yields (AFY)							
	Cachuma[b]		Gibraltar[c]		Jameson		Salsipuedes[d]		Round Corral[d]		Downstream[e] Release Increment		Rainfall Infiltration		Stream Percolation		Total Yields	
Locale	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Carp	100	200	-	-	-	-	-	-	-	-	-	-	230	500	80	110	410	810
Summr	10	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	20
Mont	80	160	-	-	40	50	-	-	-	-	-	-	140	300	30	50	290	560
SB	280	560	100	150	-	-	-	-	-	-	-	-	90	200	30	50	500	960
Gleta	300	600	-	-	-	-	-	-	-	-	-	-	230	500	110	170	640	1,270
SYnez	130	260	-	-	-	-	-	-	-	-	260	500	2,200	4,700	190	370	2,780	5,830
Bltn	-	-	-	-	-	-	-	-	-	-	260	500	-	-	-	-	260	500
SRita	-	-	-	-	-	-	-	-	-	-	260	500	-	-	-	-	260	500
Lompc	-	-	-	-	-	-	(500)	(500)	-	-	260	500	800	1,750	250	500	1,310	2,750
S Ant	-	-	-	-	-	-	-	-	-	-	-	-	1,500	3,300	80	300	1,580	3,600
SMaria	-	-	-	-	-	-	-	-	(800)	(1,100)	-	-	1,700	3,700	6,800	13,600	8,500	17,300
Cuyma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1,000	2,300	1,000	2,300
Total	900	1,800	100	150	40	50	(500)	(500)	(800)	(1,100)	1,040	2,000	6,890	14,950	8,570	17,450	17,540	36,400

Footnotes for Table IV-12:

a/ Values shown assume a 15 percent increase in rainfall and a resulting 20 to 30 percent increase in runoff.

b/ The total incremental yield for Cachuma was calculated and apportioned according to Period 4 (1975-1980) entitlement percentages.

c/ Yield was determined on the basis of safe yield analysis. Gibraltar is currently operated on a conjunctive use basis.

d/ Values in parentheses not included in totals. See Bookman-Edmonston, April 1977 Reconnaissance Level Report, "Engineering Study of Potential Dam Projects."

e/ Downstream releases from the three Santa Ynez River reservoirs may increase as a result of cloud seeding. It was assumed that the net benefit to the reservoirs would be split equally between downstream rights and the surface yield beneficiaries after accounting for increased evaporation losses.

V - COST CONSIDERATIONS

V - COST CONSIDERATIONS

General

The costs of cloud seeding vary with the type of program and its extent. It has already been demonstrated that further research-type programs would be redundant. In addition, they tend to be less cost effective. Operational programs, on the other hand, maximize benefits by seeding all suitable convective bands and minimize costs by not seeding when conditions are not favorable to precipitation enhancement.

Type of Seeding

The method by which the cloud seeding nuclei are introduced to the storm is a main factor in determining costs. Generally speaking, the costs of ground based seeding are less than those of an aerial program. Savings result from elimination of the need for Vandenberg AFB radar and personnel and of course, the aircraft. The benefits of ground seeding, however, are concentrated closer to the seeding site. The results of Phase I ground seeding indicated that maximum benefits occurred in the Upper Santa Ynez watershed. In contrast, the Phase II aerial seeding produced effects mainly on the agricultural areas in the western portion of the county. Ground seeding could have more extensive effects if additional seeding sites were established. Aerial programs still maintain the advantage of flexibility of the target area. Thus, certain areas where watersheds were burned out could be avoided if necessary. In terms of cost effectiveness then, aerial seeding over Santa Barbara County would be better than ground seeding. It is possible, however, that a combination of the two types of seeding may be even more cost effective. Such a program was recommended for emergency drought relief by North American Weather Consultants in their Proposal for Cloud Seeding in SB Co., February 1976 (25).

Cost Estimates

The costs of various programs around the western U.S. were reviewed, but provided only "ball park" estimates. Each program is unique to its area and its costs vary considerably. The Water Agency staff estimated costs by extrapolating the costs submitted by NAWC for a 2 month emergency program (25). These estimates were subsequently reviewed and revised by NAWC and are presented below.

Estimated Costs
6 Month Ground Program

1.	Set-up, Retrograde, Final Report	1,500
2.	Monthly Fixed Costs - 6 mo x $6,800/mo	40,800
3.	Estimated Reimbursable Costs	
	Ground Pyrotechnics - 60/mo x 6 mo x $110 .	39,600
	Rawinsondes - 20/mo x 6 mo x $100 .	12,000
4.	Miscellaneous Costs	
	EIR	30,000
	TOTAL	$123,900

Estimated Costs
6 Month Aerial Program

1.	Set-up, Retrograde, Final Report	$ 6,800
2.	Monthly Fixed Costs - 10,000/mo x 6 mo	60,000
3.	Estimated Reimbursable Costs	
	Aircraft Flight Hrs. - 30 hrs/mo x 6 mo x $140	25,200
	Rawindsonde - 20/mo x 6 mo x $100	12,000
4.	Miscellaneous Costs	
	VAFB Radar Technicians	4,000
	EIR	30,000
	TOTAL	$ 138,000

Estimated Costs
6 Month Aerial and Ground Program

1.	Set-up, Retrograde, and Final Report	$ 6,800
2.	Monthly Fixed Costs - 6 x $10,600	63,600
3.	Estimated Reimbursable Costs	
	Ground Pyrotechnics - 60/mo x 6 mo x $110	39,600
	Aircraft Flight Hrs - 30 hrs/mo x 6 mo x $140	25,200
	Rawinsondes - 20/mo x 6 mo x $100	12,000
4.	Miscellaneous Costs	
	VAFB Radar Technicians	4,000
	EIR	30,000
	TOTAL	$ 181,200

The totals are annual costs (except the EIR) for 6 month programs. Cloud seeding would only be worthwhile if carried out between November and April, due to lack of suitable storms during the balance of the year. The set-up, retrograde, and final report costs include aircraft modification and personnel time for the final report. Monthly fixed costs include meteorologist and technician time, aircraft lease, rawinsonde receiver lease, and miscellaneous equipment. Reimbursable costs will vary with the number of seeding opportunities. The cost of an environmental impact report should be considered as an initial cost only. If cloud seeding were continued on an annual basis, the cost of updating the EIR would be significantly less than its initial cost.

Unit Costs

According to Table IV-12, annual yields from cloud seeding would range from 17,540 to 36,400 AFY. These are based on an average increment to rainfall of 15 percent for the entire county. The ground seeding costs as outlined above should not be applied to these estimated yields since this type of program would not benefit the entire county. Aerial seeding would result in these yields, provided there were enough storms to seed. The unit costs would range from 4 to 8 dollars an acre-foot. The actual amount which is calculated is not as important as the magnitude of these unit costs. Costs will vary from year to year, depending mainly on the weather. But even in years with few seedable storms, the cost of the extra water produced is in the neighborhood of $10-20/AF. These unit costs are low compared to alternative sources of water, yet one must also consider the reliability of this source as an additional factor. Yields from cloud seeding are only as predictable as the weather.

VI - ENVIRONMENTAL AND LEGAL CONSIDERATIONS

VI - ENVIRONMENTAL AND LEGAL CONSIDERATIONS

ENVIRONMENTAL CONSIDERATIONS

General

An environmental impact report would be required preceding the implementation of any type of cloud seeding program. Exceptions can occur only when a state of emergency is declared. This type of EIR has been compiled by other agencies in California, most notably the Los Angeles County Flood Control District (5) and the Santa Clara Valley Water District (27). Both agencies are involved in operational cloud seeding programs. In addition, the Bureau of Reclamation and other agencies are performing ecological investigations throughout the Western U.S. Many of these programs are ongoing and concerned mainly with the long term effects of cloud seeding. However, certain aspects of these studies do not pertain to the Santa Barbara area due to environmental differences. For example, research concerned with snowpack duration and avalanche potential is not relevant to conditions in Santa Barbara County. Snowfall in Santa Barbara is usually limited to elevations over 3,000 feet and is very transitory. The environmental aspects of cloud seeding that do pertain to the Santa Barbara area can be grouped under physical, biological, or socio-economic impacts.

Physical Impacts

Cloud seeding, through associated increases in rainfall and runoff, may affect the topography of an area. Increased rainfall results in decreased slope stability and increased runoff speeds the erosion process. Quantification of these negative impacts is impossible. Erosion is dependent to a great extent on the intensity of the rainfall and cloud seeding does not effect this facet of a storm. Instead, the seeding of convective bands tended to widen and slow them, thus increasing the duration of rainfall. As discussed before, potential problems such as flooding and erosion from burned out watersheds can be forecast and avoided by altering the operation procedures. North American Weather Consultants is already under contract with the Santa Barbara County Flood Control District to forecast potential flood producing storms (25).

Other physical impacts which were brought up in the Santa Clara Valley report (27) included potential increases in radiation fogs due to increased soil moisture and potential decreases in soil subsidence rates because of reduced overdraft of groundwater basins. Air quality is not significantly affected by the silver iodide particulates. Water quality is also not affected since silver iodide is highly insoluble and is usually present only in such minute concentrations as to be difficult to detect.

Biological Impacts

Cloud seeding will affect lifeforms in two ways -- the increase in rainfall and the presence of larger amounts of silver iodide. Each of these factors will affect both terrestrial and aquatic organisms but in differing ways.

There may be changes in the distribution of individual species due to minor expansions and contractions of their habitat ranges. This is a result of prolonging the wet season, which can alter the balance between competing organisms. It must be noted that the pattern of rainfall through the rainy season is not being affected. The timing of the storms as they proceed over the area would still be "natural."

Of major concern is the effect of an increased presence of silver and iodine will have on certain organisms. The ionic concentrations are quite small, and their effects are currently being evaluated. In terms of the concentration of iodine in seeded rainfall it has been said that a human would have to drink 130 gallons of seeded rainfall to eat the same amount of iodine as in his salted breakfast eggs (27). Likewise, the concentration of silver in rainwater is small, being equivalent to that of seawater (.0001 - .0003 ppm). There is little danger to birds or mammals since their livers remove silver so that it does not accumulate as do lead and mercury. There may be problems with the buildup of silver in the soil, especially around ground generator sites. Evidence so far indicates this is currently thought to be negligible and studies are continuing.

Aquatic organisms may be more susceptible to harm from the increased presence of silver ions. Silver iodide is only slightly water soluable. The silver ion can be absorbed from aqueous solution by vegetation and sediments. It is more toxic to fish than land animals and very toxic to micro-organisms (27). Studies to evaluate long term effects as such are being conducted in association with the Bureau of Reclamation's Project Skywater.

Socio-Economic Impacts

Increased water availability has always increased the value of Southern California land. Population growth usually accompanies an increased water availability. In this respect, cloud seeding must be evaluated for its growth inducing impacts. The quantities of additional water made available in years of average rainfall may be considerable enough to overcome local deficiencies in some water short areas. This additional supply, however, does not seem sufficiently reliable or adequate to solve long-term shortages such as in certain South Coast areas under water connection moratoria. In this respect it is unclear as to whether cloud seeding could be considered to have a growth inducing impact.

Two possible impacts considered by the Santa Clara Valley Study (27) involved traffic accidents and recreation. Traffic accident rates in California are related directly to the weather. Increased rainfall may result in increased traffic accidents. Recreational activity, likewise, may be adversely affected due to increased duration of storms. Both impacts are extremely difficult to quantify.

Finally, the impacts of cloud seeding on land use, specifically agricultural land, must be evaluated. Rainfall is an integral part of the success of dry farming in Santa Barbara County and can help reduce the costs of irrigated agriculture through reduced irrigation. At the same time, however, excess amounts and poor timing of rainfall may be equally detrimental to various types of farming. The needs of all agricultural interests would have to be evaluated and included in the design of the cloud seeding programs. Such has been the case in the Sacramento Valley where a Department of Water Resources sponsored, summer cloud seeding program has been halted to avoid crop damage. The program started in July, 1977 with the aim of reducing fire danger, providing some soil moisture, and increasing streamflows for livestock, fish, and wildlife. Seeding operations were carried out in late September which brought objections by farmers who did not want rain over croplands at harvest time. The program was halted in response to these objections (36).

LEGAL CONSIDERATIONS

General

The potential exists for legal problems associated with a weather modification program. There are no existing laws which affect this practice other than state regulations requiring licensing, insurance and reporting by weather modification firms. It is felt that legal problems will be solved on a case by case basis through common law procedures (26). Those cases which are decided then represent precedents by which future litigation may be resolved. To date, however, no judgments against cloud seeders have been made. Many cases have been filed but only a handful have even reached court. These fall into three general categories: Liability for damages, ownership of increased rainfall, and downwind effects.

Flood Liabilities

Lawsuits have been filed against cloud seeding operators for reparation on damages resulting from floods. Loss of crops, property and life can combine to create enormous settlement figures. Cloud seeders usually carry liability insurance which can range into the millions. Yet, settlement amounts are usually far greater than insurance limits. These limits are meant to cover court costs only. Needless to say, a cloud seeding program must be suspended when flooding potentials exist. Awareness of existing watershed conditions and the characteristics of approaching storms should provide enough of a warning to prevent a seeding induced disaster.

One particular suit which is pending was filed by residents in Rapid City, South Dakota. They are charging the Bureau of Reclamation with negligence in monitoring the activities of the South Dakota School of Mines. The school was performing cloud seeding research for the Bureau in 1972 when a devastating flood struck. The suit has been delayed and final judgment is not expected soon (33).

Claims to Benefits

In areas where money is spent on cloud seeding by private organizations, there is the possibility of dispute over who may claim the benefits and how much can be claimed. Incremental runoff amounts would be difficult to enumerate in court. As such, runoff would most likely be divided according to existing law. In the case of Santa Barbara County, cloud seeding would be publicly sponsored, but there might be some disagreement as to ownership of incremental runoff and incremental groundwater basin yield. Possibly, runoff under the influence of cloud seeding might be regarded as runoff under normal conditions and rights pertaining to diversion and impoundment might apply accordingly. However, other interpretations are conceivable. Also, it is possible that an operational program of cloud seeding might warrant recomputation of safe yields from surface water reservoirs so operated. This might require agreements among potentially contesting parties. Cloud seeding augmented groundwater basin yields would supposedly be distributed among the various pumpers from the affected basin. This might be feasible in case a basin has been adjudicated, following the Los Angeles County Flood Control District precedent, but it might not be as easy in other cases.

Downwind Decreases

Perhaps the most common concern about cloud seeding is that increased rainfall in one area results in decreased rainfall downwind. Of all the studies made to date, none has indicated this to be true (33). The precipitation from a passing storm is influenced by a dynamic process. As moisture drops from a cloud it is constantly replaced with water from the rest of the air mass. Seeding is thought to enhance the efficiency of the rainfall process causing more precipitation for the same amount of moisture in the cloud. Not all of the nucleating agent drops out of the cloud with rainfall, but, instead some of it drifts along providing condensation nuclei for precipitation later in the life of the storm.

This accounts for observed increases in rainfall downwind of target areas. Such was the case with Phase II air seeding where positive results were observed as far downwind as Ventura and Los Angeles Counties. If there were to be a lawsuit concerning decreases related to cloud seeding, the plaintiff would have an extremely difficult task in proving such decreases. Essentially, he would be required to do as much as cloud seeders have had to do in proving their point. This would require years of research and data collection.

VII - SUMMARY AND CONCLUSIONS

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SUMMARY

Historical Experiences in Rainfall Augmentation

1. Cloud seeding has been performed in Santa Barbara County during 15 of the past 27 rain seasons. The earliest endeavors suffered from a lack of statistical refinement in their attempts to evaluate the effectiveness of the seeding. Later studies (Phases I and II) were able to express the effects quantitatively with a high degree of statistical significance.

2. The later studies concluded that precipitation within convective bands was increased 50 to 100 percent, resulting in an increase of 25 to 50 percent for the total storm precipitation.

3. It was demonstrated that the area of enhancement (target area for augmented rainfall) was fairly well predictable, but that increased rainfall also occurred downwind of the predicted cutoff point.

Experiences Elsewhere

4. Various agencies in California and other sections of the western United States have practiced weather modification for purposes ranging from snowpack augmentation to hail suppression. Those agencies which have engaged in projects most similar to that which could be implemented in Santa Barbara County are Santa Clara Valley Water

District and Los Angeles County Flood Control District.

5. The results of operational cloud seeding in Santa Clara Valley indicate average annual increases in rainfall of 10 to 15 percent.

6. For the Los Angeles County program, rainfall has increased an average of one inch or five percent of the average rainfall on the target area. Corresponding increases in runoff amounted to 10 to 20 percent.

7. The Bureau of Reclamation, under its Project Skywater, is sponsoring numerous progrmms for both summer and winter seeding. Results to date are comparable with other projects' results, and evaluations are continuing.

Theoretical Yields

8. Table IV-12 within this report summarizes the theoretical yields to be realized from increases of 15 percent in rainfall. These indicated increases are in the range of 5 to 8 percent for surface reservoirs on a safe yield basis, and 7 to as much as 38 percent for groundwater basins. These preliminary estimates are believed conservative, since cloud seeding may increase precipitation by a larger factor, especially in wet years.

9. The majority of the increased yield would be in the form of increased groundwater recharge through rainfall infiltration and stream seepage. Increased yields from reservoirs are limited by their storage capacities and safe yield type operation (in many instances) which does not normally allow much storage space for capture of

additional runoff.

Environmental Impacts

10. All evidence to date indicates that the environmental impacts of cloud seeding are relatively minor. The major effect that it has on the environment is to produce increased precipitation and thus extend somewhat the wet season. This has not been found to be detrimental.

11. The buildup of silver iodide in the environment has not been found to be significant in the short run. The amounts used on an average basis are slight, and the area of dispersal is quite large (thousands of acres). Long term effects of a buildup of silver iodide are currently being investigated by the Bureau of Reclamation.

Legal Considerations

12. The potential exists for legal disputes related to weather modification activities. Persons who file suit for damages related to floods are faced with a difficult task in proving that the flood was specifically caused by seeding. Plaintiffs claiming damages to crops from untimely, seeding-induced rainfall may also have difficulties in advancing their cases, particularly when cloud seeding is responsibly conducted.

13. As cloud seeding becomes more exact, proof of such an occurrence may be facilitated. Problems may arise as to ownership of "new" water in groundwater basins and stream flows.

14. Since actual increments to a system are difficult to pinpoint, these disputes would probably be settled by existing water rights law .

15. Problems associated with claims of downwind decreases should not arise since no information to date supports such a claim. In fact, the opposite condition has proved to be the case.

CONCLUSIONS

1. An operational cloud seeding program, such as might be contemplated for Santa Barbara County, would probably be capable of augmenting precipitation over Santa Barbara County by an average of 15 to 25 percent above normal.

2. Increases in rainfall are due to increased duration rather than intensity.

3. The presence of a naturally occurring storm system is required before cloud seeding may be effectively performed. In this respect, cloud seeding is more effective during years of greater rainfall than otherwise, due to the increased number of seeding opportunities.

4. Effectiveness of seeding is dependent on cloud temperatures, particularly cloud top temperatures. It has been shown that the storms between November and April are most likely to have the proper cloud temperatures conducive to effective seeding.

5. Runoff increases in the order of 20 to 30 percent may generally be expected from a 15 percent increase in rainfall.

The fact that runoff increments are greater than rainfall increments is primarily due to the effects of antecedent rainfall which saturates the watershed and enhances runoff.

6. The yields to be expected from cloud seeding range from about 17,500 to 36,000 AFY primarily in the form of increased groundwater recharge. These yields are average amounts with lesser amounts realized in dry years and possibly greater amounts in wet years.

7. Aerial seeding has a wider area of effect than ground seeding and is much more flexible for changing target areas. The possibility of a combined aerial and ground seeding program exists and may allow an even greater target area.

8. The average annual cost of aerial cloud seeding for Santa Barbara County is estimated at about $140,000. A major portion of this cost is the environmental impact report which would cost more initially than its annual updating. The cost of a combined aerial and ground seeding program would be at least $180,000 annually.

9. Unit costs of water produced by cloud seeding range from $4 to $8/AF. This assumes that average precipitation occurs. In years of subnormal rainfall, unit costs may go up, whereas in years of above normal rainfall they may go down.

10. Environmental impacts currently appear to be minor, although a detailed study of potential problems particular to Santa Barbara County will be necessary to assess this aspect.

11. Legal problems may develop as the result of cloud seeding, mainly with regards to ownership of increments to the water supply. It is assumed that these disputes may be settled according to existing water rights law, with incremental runoff and groundwater being treated as "natural." Problems related to potential flood damage suits must be avoided by the suspension of seeding whenever certain criteria are met. Crop damage suits would appear to be somewhat less of a potential problem, assuming cloud seeding activities were to be confined to the normal rainy season.

12. The major limitation to cloud seeding benefits is their reliability. In effect, they are only as reliable as the weather. Cloud seeding can neither prevent droughts nor end them. It is most beneficial during years of average and above average rainfall.

13. Having augmented storage capacity in surface reservoirs and/or in surface reservoirs operated conjunctively with groundwater basins may improve the yields of wet year cloud seeding. This aspect has not been evaluated herein.

14. The benefits of a cloud seeding program clearly appear to outweigh the drawbacks. Accordingly, weather modification should be considered as a viable source of long range water supply under appropriate circumstances.

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REFERENCES

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APPENDIX

APPENDIX

Effects of Seeding on Rainfall During Phases I and II

The following tables detail the results shown in Table IV-2 (p. IV-16). For each watershed, raingages were selected which would best represent rainfall over the watershed. The precipitation amounts at each station for each convective band were summed up for each type of operation. The average precipitation per band was then found and seeded band precipitation was compared to unseeded band precipitation by ratio.

Table IV-SA

CLOUD SEEDING DATA SUMMARY FOR SAN ANTONIO CREEK AREA[a/]

Rain Gage[b/] Number	Type of[c/] Operation	No. of Convective Bands Seeded	No. of Convective Bands Not Seeded	Avg. Precip. per Band[d/] Seeded	Avg. Precip. per Band[d/] Not Seeded	Ratio Seeded/Not Seeded
A 42	a	24	17	0.239	0.161	1.48
A 42	b	8	8	0.325	0.415	0.78
A 42	c	11	16	0.242	0.178	1.36
A 42	d	43	41	0.256	0.217	1.18
S 201	a	56	51	0.212	0.197	1.08
S 201	b	19	10	0.157	0.472	0.33
S 201	c	17	22	0.278	0.206	1.35
S 201	d	92	83	0.213	0.233	0.91
S 202	a	52	47	0.233	0.207	1.13
S 202	b	20	10	0.233	0.362	0.64
S 202	c	18	27	0.291	0.191	1.52
S 202	d	90	84	0.245	0.220	1.11
S 203	a	45	40	0.241	0.246	0.98
S 203	b	19	10	0.221	0.559	0.40
S 203	c	17	22	0.339	0.257	1.32
S 203	d	81	72	0.257	0.293	0.88
S 204	a	53	49	0.228	0.230	0.99
S 204	b	20	10	0.219	0.457	0.48
S 204	c	18	27	0.268	0.197	1.36
S 204	d	91	86	0.234	0.246	0.95
N 24	a	-	-	-	-	-
N 24	b	11	8	0.178	0.226	0.79
N 24	c	11	17	0.370	0.136	2.72
N 24	d	22	25	0.274	0.165	1.66
N 1	a	49	46	0.189	0.163	1.16
N 1	b	16	10	0.232	0.203	1.14
N 1	c	18	24	0.263	0.178	1.48
N 1	d	83	80	0.213	0.173	1.23
Totals and Weighted Averages	a	279	250	0.222	0.204	1.09
	b	113	66	0.217	0.389	0.56
	c	110	155	0.291	0.206	1.41
	d	502	471	0.236	0.231	1.02

Footnotes for Table IV-SA:

a/ Data were obtained from Santa Barbara Convective Band Seeding Test Program, Naval Weapons Center, October 1975.

b/ A 42 is at the Barca Ranch; S 201 is at Los Flores Ranch; S 202 is at the Confaglia Ranch; S 203 is at Luis Ranch; S 204 is at the Los Alamos Fire Station; N 24 is at the Diamond T Ranch; N 1 is at Casmalia. For more specific locations, see Appendix A of the report cited in footnote a.

c/ The letters shown correspond to the following operations:

a = Phase I ground operations 1967-1971

b = Phase II ground operations 1970-1974

c = Phase II air operations 1970-1974

d = Sum Total of above operations

d/ Average precipitation is given in inches.

Table IV-C

CLOUD SEEDING DATA SUMMARY FOR CUYAMA RIVER AREA[a/]

Rain Gage[b/] Number	Type of[c/] Operation	No. of Convective Bands Seeded	No. of Convective Bands Not Seeded	Avg. Precip. per Band[d/] Seeded	Avg. Precip. per Band[d/] Not Seeded	Ratio Seeded/Not Seeded
A 44	a	13	9	0.232	0.178	1.30
A 44	b	15	5	0.168	0.200	0.84
A 44	c	13	21	0.327	0.234	1.40
A 44	d	41	35	0.239	0.215	1.11
A 41	a	21	12	0.219	0.142	1.54
A 41	b	9	3	0.101	0.413	0.24
A 41	c	11	17	0.276	0.200	1.38
A 41	d	41	32	0.208	0.198	1.05
N 8	a	38	35	0.183	0.150	1.22
N 8	b	17	8	0.059	0.138	0.43
N 8	c	16	23	0.129	0.087	1.48
N 8	d	71	66	0.141	0.127	1.11
A 45	a	13	9	0.122	0.098	1.24
A 45	b	11	4	0.085	0.278	0.31
A 45	c	16	21	0.113	0.058	1.95
A 45	d	40	34	0.108	0.094	1.15
E 9283	a	32	31	0.110	0.093	1.18
E 9283	b	8	5	0.093	0.306	0.30
E 9283	c	6	14	0.032	0.108	0.30
E 9283	d	46	50	0.097	0.119	0.82
S 221	a	55	49	0.081	0.055	1.47
S 221	b	16	7	0.032	0.030	1.07
S 221	c	12	18	0.069	0.057	1.21
S 221	d	83	74	0.070	0.053	1.32
Totals	a	172	145	0.140	0.104	1.35
and	b	76	32	0.087	0.194	0.45
Weighted	c	74	114	0.165	0.123	1.34
Averages	d	322	291	0.133	0.121	1.10

Footnotes for Table IV-C:

a/ Data were obtained from Santa Barbara Convective Band Seeding Test Program, Naval Weapons Center, October 1975.

b/ A 44 is at the Adams Ranch; A 41 is at the Rinconada Ranch; N 8 is at the Johnston Ranch; A 45 is at McPherson Peak; E 9283 is at the Ventucopa Ranger Station; S 221 is at the Cuyama Ranch. For more specific locations see Appendix A in the report cited in footnote a.

c/ The letters shown correspond to the following operations:

a = Phase I ground operations 1967-1971

b = Phase II ground operations 1970-1974

c = Phase II air operations 1970-1974

d = Sum Total of above operations

d/ Average precipitation is given in inches.

Table IV-SM

CLOUD SEEDING DATA SUMMARY FOR THE SANTA MARIA AREA[a/]

Rain Gage[b/] Number	Type of[c/] Operation	No. of Convective Bands		Avg. Precip. per Band[d/]		Ratio
		Seeded	Not Seeded	Seeded	Not Seeded	Seeded/Not Seeded
E 7946	a	56	51	0.174	0.175	0.99
E 7946	b	20	10	0.158	0.217	0.73
E 7946	c	18	27	0.282	0.220	1.28
E 7946	d	94	88	0.191	0.194	0.98
N 27	a	-	-	-	-	-
N 27	b	11	3	0.106	0.053	1.99
N 27	c	9	11	0.336	0.166	2.02
N 27	d	20	14	0.210	0.142	1.48
S 235	a	56	51	0.179	0.179	1.00
S 235	b	20	10	0.152	0.190	0.80
S 235	c	18	27	0.274	0.237	1.16
S 235	d	94	88	0.191	0.198	0.96
S 256	a	17	9	0.209	0.187	1.12
S 256	b	15	7	0.198	0.353	0.56
S 256	c	18	21	0.266	0.189	1.41
S 256	d	50	37	0.226	0.220	1.03
Totals	a	129	111	0.181	0.179	1.01
and	b	66	30	0.157	0.223	0.70
Weighted	c	63	86	0.283	0.219	1.29
Averages	d	258	227	0.200	0.200	1.00

Footnotes for Table IV-SM:

a/ Data were obtained from Santa Barbara Convective Band Seeding Test Program, Naval Weapons Center, October 1975.

b/ E 7946 is at Santa Maria Airport; N 27 is at the Albertoni Dairy; S 235 is at the Santa Maria County Road Yard; S 256 is at the Sisquoc Fire Station. For more specific locations see Appendix A of the report cited in footnote a.

c/ The letters shown correspond to the following operations:

a = Phase I ground operations 1967-1971

b = Phase II ground operations 1970-1974

c = Phase II air operations 1970-1974

d = Sum Total of above operations

d/ Average precipitation is given in inches.

Table IV-SP

CLOUD SEEDING DATA SUMMARY FOR SALSIPUEDES CREEK AREA[a/]

Rain Gage[b/] Number	Type of[c/] Operation	No. of Convective Bands: Seeded	No. of Convective Bands: Not Seeded	Avg. Precip. per Band[d/]: Seeded	Avg. Precip. per Band[d/]: Not Seeded	Ratio Seeded/Not Seeded
S 257	a	12	8	0.220	0.300	0.73
S 257	b	13	4	0.456	0.538	0.85
S 257	c	10	21	0.385	0.292	1.32
S 257	d	35	33	0.355	0.324	1.10
S 259	a	-	-	-	-	-
S 259	b	13	8	0.273	0.594	0.46
S 259	c	10	18	0.475	0.328	1.45
S 259	d	23	26	0.361	0.410	0.88
Totals and Weighted Averages	a	12	8	0.220	0.300	0.73
	b	26	12	0.365	0.575	0.63
	c	20	39	0.430	0.309	1.39
	d	58	59	0.357	0.362	0.99

Footnotes for Table IV-SP:

a/ Data were obtained from Santa Barbara Convective Band Seeding Test Program, Naval Weapons Center, October 1975.

b/ S 257 is at Rancho San Julian; S 259 is at the Johns Manville Plant. For more specific locations see Appendix A in the report cited in footnote a.

c/ The letters shown correspond to the following operations:

a =	Phase I ground operations	1967-1971
b =	Phase II ground operations	1970-1974
c =	Phase II ground operations	1970-1974
d =	Sum Total of above operations	

d/ Average precipitations is given in inches.

Table IV-SJ

CLOUD SEEDING DATA SUMMARY FOR SAN JOSE CREEK[a/]

Rain Gage[b/] Number	Type of[c/] Operation	No. of Convective Bands		Avg. Precip. per Band[d/]		Ratio
		Seeded	Not Seeded	Seeded	Not Seeded	Seeded/Not Seeded
N B	a	54	50	0.286	0.182	1.57
N B	b	20	10	0.158	0.208	0.76
N B	c	18	27	0.379	0.246	1.54
N B	d	92	87	0.276	0.205	1.35
S 212	a	37	39	0.619	0.412	1.50
S 212	b	16	10	0.414	0.518	0.80
S 212	c	16	25	0.569	0.441	1.29
S 212	d	69	74	0.560	0.436	1.28
S 242	a	43	45	0.345	0.240	1.44
S 242	b	13	1	0.334	1.450	0.23
S 242	c	12	18	0.478	0.339	1.41
S 242	d	68	64	0.366	0.287	1.28
S 261	a	-	-	-	-	-
S 261	b	19	5	0.323	0.922	0.35
S 261	c	13	20	0.518	0.387	1.34
S 261	d	32	25	0.402	0.494	0.81
Totals and Weighted Averages	a	134	134	0.397	0.268	1.48
	b	68	26	0.298	0.512	0.58
	c	59	90	0.481	0.350	1.37
	d	261	250	0.390	0.323	1.21

Footnotes for Table IV-SJ:

a/ Data were obtained from Santa Barbara Convective Band Seeding Test Program, Naval Weapons Center, October 1975.

b/ NB is at North American Weather Consultants Office; 5212 is at San Marcos Summit; S 242 is at San Marcos Trout Club; S 261 is at the Stubchaer residence in Goleta. For more specific locations see Appendix A of the report cited in footnote a.

c/ The letters shown correspond to the following operations:

a = Phase I ground operations 1967-1971

b = Phase II ground operations 1970-1974

c = Phase II air operations 1970-1974

d = Sum Total of above operations

d/ Average precipitation is given in inches.

Table IV-CC

CLOUD SEEDING DATA SUMMARY FOR CARPINTERIA CREEK WATERSHED

Rain Gage[b/] Number	Type of[c/] Operation	No. of Convective Bands		Avg. Precip. per Band[d/]		Ratio
		Seeded	Not Seeded	Seeded	Not Seeded	Seeded/Not Seeded
N 25	a	-	-	-	-	-
N 25	b	20	10	0.231	0.292	0.79
N 25	c	15	22	0.317	0.244	1.30
N 25	d	35	32	0.268	0.259	1.03
S 208	a	51	46	0.247	0.231	1.07
S 208	b	18	7	0.223	0.371	0.60
S 208	c	17	27	0.280	0.230	1.22
S 208	d	86	80	0.249	0.243	1.02
S 231	a	51	47	0.411	0.285	1.44
S 231	b	20	8	0.403	0.790	0.51
S 231	c	16	22	0.369	0.262	1.41
S 231	d	87	77	0.401	0.331	1.21
Totals	a	102	93	0.329	0.258	1.28
and	b	58	25	0.288	0.473	0.61
Weighted	c	48	71	0.321	0.244	1.32
Averages	d	208	189	0.316	0.281	1.12

Footnotes for Table IV-CC:

a/ Data were obtained from Santa Barbara Convective Band Seeding Test Program, Naval Weapons Center, October 1975.

b/ N 25 is 2 miles southeast of Carpinteria; S 208 is at the Carpinteria Fire Station; S 231 is at the South Portal of Doulton Tunnel. For more specific locations, see Appendix A of the report cited in footnote a.

c/ The letters shown correspond to the following operations:

a = Phase I ground operations 1967-1971

b = Phase II ground operations 1970-1974

c = Phase II air operations 1970-1974

d = Sum Total of above operations

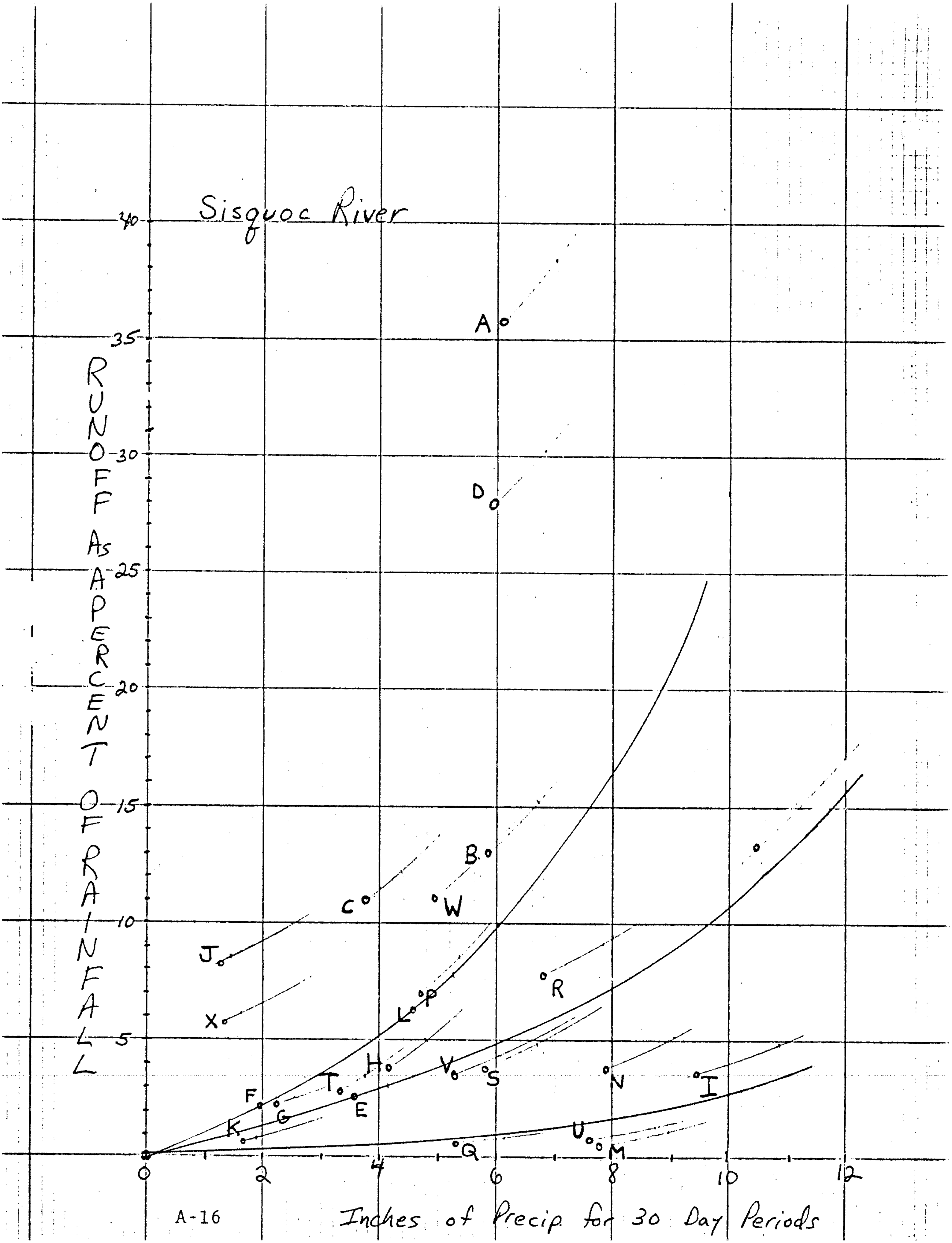
d/ Average precipitation is given in inches.

Runoff Augmentation

The following tables and graphs detail the methodology used to approximate runoff augmentation for the various watersheds. First, 30-day periods were selected and assigned a letter for easier reference. The precipitation over each period was found and compared by ratio to the runoff during the period. Allowance was made for varying base flows. The percent of precipitation which became runoff was then plotted on a graph against the precipitation during the period. Trend lines were drawn connecting periods of similar time periods (early, mid-winter, or spring). Through each point on the graph an arc was drawn parallel to the most representative trend line. The precipitation during the period was then augmented 15 percent and a new percent of rain as runoff was read from the graph. Using this percentage the "new" runoff was calculated and compared to the actual.

Sisquoc River

Rain Year	30 Day Period from	to	Alpha Code	Accum. Precip. (inches)	Accum. Runoff (cfs days)	Accum. Base flow (cfs days)	Accum. Runoff above base flow	Runoff as % of Precip.	Augment Precip (15% incr.)	New % of Rainfall as Runoff	Augmented Accum Runoff above Baseflow	Actual Storm Season Runoff (AF)	Remainder of Yr. Runoff	Total Year Runoff (AF)	Augmented Storm Season Runoff (AF)	Augmented Total Year Runoff (AF)	Percent Increase
1966-67	11/20/66	12/19/66	A	6.11	16,638.2	90	16,548.2	35.9	7.02	38.4	20,372.3	33,001.4			40,586.4		
"	1/21/67	2/19/67	B	5.83	6,361	600	5,761	13.1	6.70	15.2	7,696.5	12,616.9			16,455.9		
	3/2/67	3/31/67	C	3.78	4,227	1,080	3,147	11.0	4.35	12.2	4,008.4	8,384.1			10,092.7		
	4/1/67	4/30/67	D	5.94	14,825	2,250	12,575	28.0	6.83	30.2	15,592.4	29,404.9			35,390.0		
				21.66								84,407	23,993	108,400	102,525	126,518	16.7
1967-68	11/17/67	12/16/67	E	3.58	715.5	0	715.5	2.6	4.12	3.1	965.6	1,419.2			1,915.3		
"	12/18/67	1/16/68	F	1.95	373.9	51.0	322.9	2.2	2.24	2.4	406.2	741.6			906.9		
"	1/27/68	2/25/68	G	2.23	548	165	383	2.3	2.56	2.5	483.6	1,086.9			1,286.5		
"	3/6/68	4/5/68	H	4.17	1,725	510	1,215	3.9	4.80	5.0	1,813.5	3,421.5			4,608.5		
				11.93								6,669	4,861	11,530	8,717	13,578	17.8
1970-71	11/25/70	12/24/70	I	9.44	2,571	12.0	2,559	3.6	10.86	4.8	3,939.3	5,099.5			7,837.3		
"	12/26/70	1/24/71	J	1.24	2,283	1,500	783	8.3	1.43	8.6	929.6	4,528.3			4,819.1		
"	4/1/71	4/30/71	K	1.65	449.9	360	89.9	0.7	1.90	0.8	114.9	892.4			942.0		
				12.33								10,520	5,110	15,630	13,598	18,708	19.7
1971-72	12/1/71	12/30/71	L	4.58	2,257.4	30.0	2,227.4	6.4	5.27	7.7	3,066.5	4,477.5	2,783	7,260	6,141.9	8,925	22.9
1972-73	11/10/72	12/9/71	M	7.78	326.4	48.0	278.4	0.5	8.94	1.1	743.2	647.4			1,569.3		
"	1/1/73	1/30/73	N	7.87	2,317.4	57.0	2,260.4	3.8	9.05	5.1	3,489.1	4,596.5			7,033.6		
"	2/3/73	3/4/73	O	10.43	10,994	420	10,574	13.4	11.99	17.0	15,402.4	21,806.3			31,383.3		
"	3/5/73	4/3/73	P	4.67	5,753	3,300	2,453	7.0	5.36	8.5	3,445.6	11,410.9			13,379.7		
				35.33								38,461	7,909	46,370	53,366	61,275	32.1
1973-74	11/12/73	12/11/73	Q	5.32	311	30	281	0.7	6.12	0.8	369.8	616.9			793.0		
"	1/1/74	1/30/74	R	6.81	4,139	141	3998	7.8	7.83	9.2	5,443.5	8,209.6			11,076.8		
"	2/19/74	3/20/74	S	5.83	2,218	540	1,678	3.8	6.70	4.8	2,430.5	4,399.3			5,891.9		
"	3/21/74	4/19/74	T	3.29	1,604	900	704	2.8	3.78	3.5	1,000.6	3,181.5			3,764.8		
				21.25								16,407	3,543	19,950	21,532	25,075	25.7
1974-75	12/3/74	1/1/75	U	7.60	471.8	33	438.8	0.8	8.73	1.3	858.0	935.8			1,767.2		
"	1/30/75	2/28/75	V	5.27	1,425.8	39	1,386.8	3.5	6.06	4.4	2,015.2	2,828.0			4,074.4		
"	3/2/75	3/31/75	W	4.94	4,454	300	4,154	11.1	5.68	12.8	5,498.2	8,834.4			11,500.5		
	4/1/75	4/30/75	X	1.33	1,618	1,050	568	5.7	1.52	6.1	702.8	3,209.3			3,476.6		
				19.14								15,808	2,502	18,310	20,819	23,321	27.4



Sisquoc River
RUNOFF As A PERCENT OF RAINFALL
40
35
30
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20
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10
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0
2
4
6
8
10
12
A
D
B
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W
J
X
R
L
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H
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F
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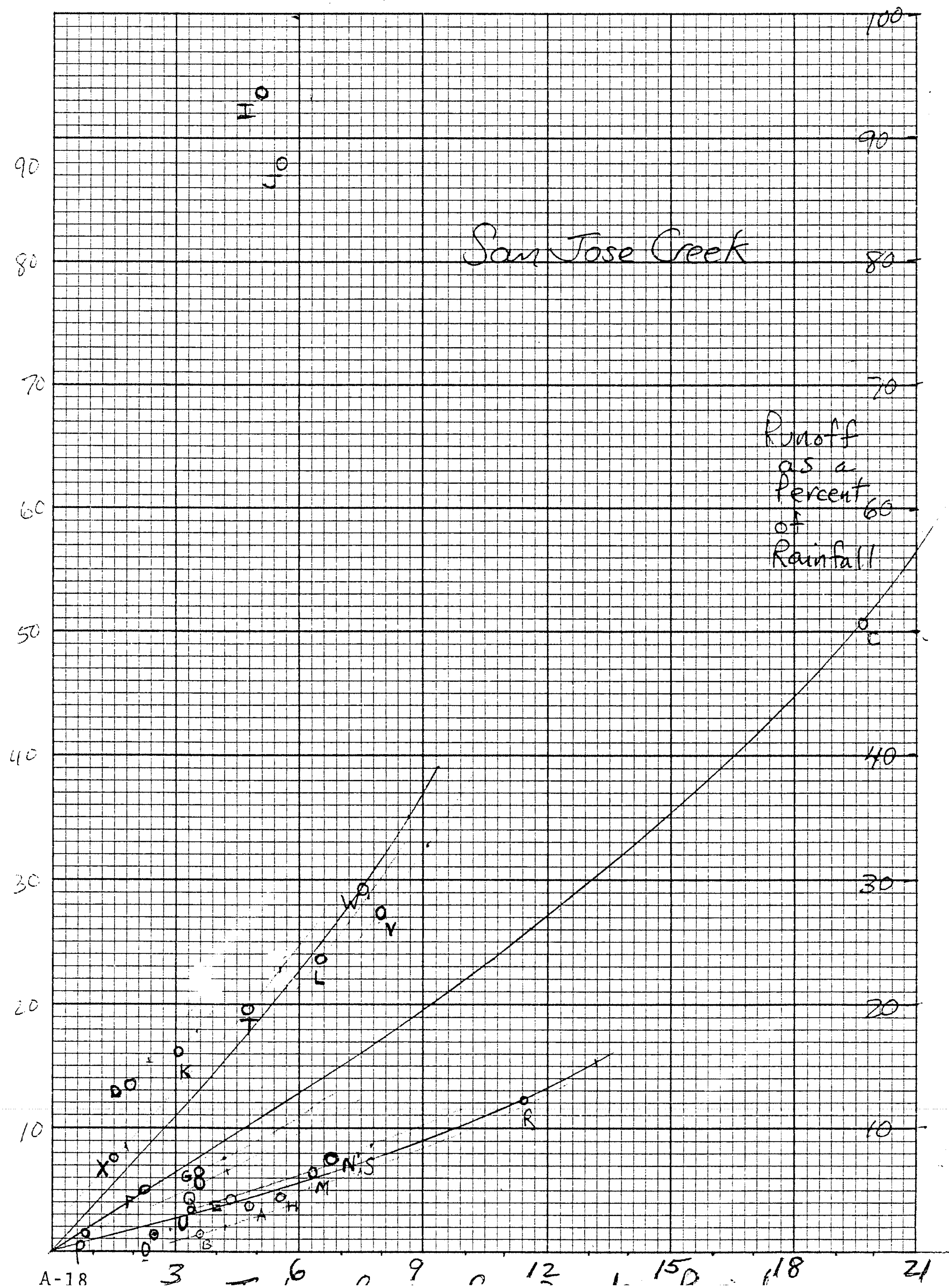
E
K
V
S
N
I
U
M
Q
Inches of Precip for 30 Day Periods

SAN JOSE CREEK

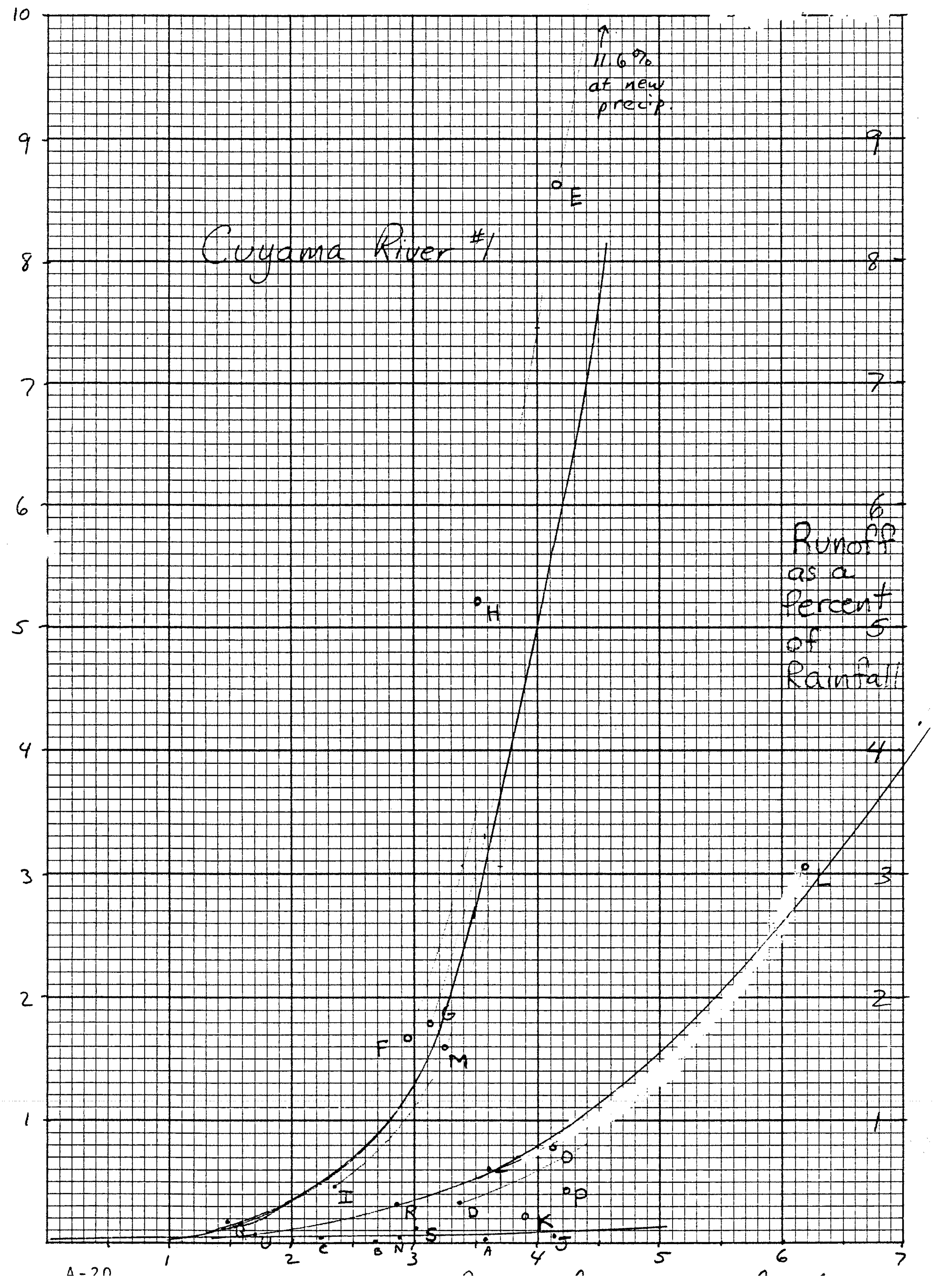
Rain Year	30 Day Period from	30 Day Period to	Alpha Code	Accumulated Precipitation inches	Accum. Runoff cfs days	Accum. Base Flow cfs days	Accum. Runoff above Base flow	Runoff as % of Precipitation	Augmented Precip. (15% incr.)	New % of Rainfall as Runoff	Augmented Accum Runoff above Base flow	Actual Storm Season Runoff (AF)	Remainder of Yr Runoff	Total Year Runoff (AF)	Augmented Storm Season Runoff AF	Augmented Total Year Runoff AF	[illegible]
961 - 62	11/20/61	12/19/61	A	4.87	35.8	9.0	26.8	3.7	5.60	4.5	37.3	70.9	–	–	91.7	–	29.3
"	1/1/62	1/30/62	B	3.57	17.2	9.0	8.2	1.5	4.11	2.0	12.2	34.1	–	–	42.0	–	23.[illegible]
"	2/1/62	3/2/62	C	19.75	1504.5	12.0	1492.5	50.9	22.71	65.0	2,184.7	2,978.9	–	–	4,349.5	–	46.[illegible]
"	3/4/62	4/2/62	D	1.99	81.8	42.0	39.8	13.5	2.29	15.5	52.5	162.0	–	–	187.1	–	15.[illegible]
totals				30.18								3,246	114	3,360	4,670	4,784	42.[illegible]
963-64	11/1/63	11/30/63	E	4.39	36.0	9.0	27.0	4.1	5.05	6.1	45.6	71.3	–	–	108.1	–	51.[illegible]
"	1/16/64	2/14/64	F	2.16	28.7	12.0	16.7	5.2	2.48	5.6	20.6	56.8	–	–	64.5	–	13.[illegible]
"	3/11/64	4/8/64	G	3.61	39.6	6.0	33.6	6.3	4.15	7.7	47.3	78.4	–	–	105.5	–	34.[illegible]
totals				10.16								207	97	304	278	375	23.4
1966 - 67	11/1/66	11/30/66	H	5.45	41.4	6.0	35.4	4.4	6.17	5.1	47.3	82.0			105.5		28.7
"	12/1/66	12/30/66	I	5.11	726.3	15.0	711.3	93.8	5.88	99.9	869.4	1,438.1			1,751.1		21.8
"	1/20/67	2/8/67	J	5.51	751.2	30.0	721.2	88.2	6.34	93.1	873.6	1487.4			1,789.1		20.[illegible]
"	2/22/67	3/23/67	K	3.07	106.9	33.0	73.9	16.2	3.53	17.9	93.5	211.7			250.5		18.[illegible]
"	3/30/67	4/28/67	L	6.64	265.9	33.0	232.9	23.6	7.64	28.5	322.3	526.5			703.5		33.6
totals				25.78								3,746	334	4,080	4,600	4,934	20.9
1970 - 71	11/4/70	12/3/70	M	6.37	67.6	6.0	61.6	6.5	7.33	7.9	85.7	133.8			181.6		35.7
"	12/16/70	1/14/71	N	6.66	83.5	9.0	74.5	7.5	7.66	8.7	98.6	165.3			213.0		28.9
"	2/16/71	3/17/71	O	2.39	18.5	12.0	6.5	1.8	2.75	1.9	7.7	36.6			39.0		6.6
	4/1/71	4/30/71	P	0.97	11.0	9.0	2.0	1.4	1.12	2.0	3.3	21.8			24.4		11.9
totals				16.39								357	131	488	458	589	20.[illegible]
1973 - 74	11/10/73	12/9/73	Q	3.64	34.6	4.5	30.1	5.6	4.19	6.6	40.9	68.5			89.9		31.2
"	12/27/73	1/25/74	R	11.43	225.5	21.0	204.5	12.1	13.14	15.3	297.5	446.5			630.6		41.[illegible]
"	3/1/74	3/30/74	S	6.67	94.5	21.0	93.5	7.4	7.67	8.8	99.9	187.1			219.6		17.4
totals				21.74								702	203	905	940	1143	26.[illegible]
1974 - 75	11/26/74	12/25/74	T	4.80	146.5	4.5	142.0	19.9	5.52	22.8	186.3	290.0			377.8		30.3
"	12/26/74	1/24/75	U	3.29	27.4	9.0	18.4	3.8	3.78	3.9	21.8	54.3			61.0		12.3
"	1/30/75	2/28/75	V	7.96	349.2	21.0	328.2	27.8	9.15	32.9	445.5	691.4			923.7		33.6
"	3/1/75	3/30/75	W	7.51	357.4	30.0	387.4	29.4	8.64	35.0	447.6	707.7			945.6		33.6
	4/1/75	4/30/75	X	1.52	32.8	15.0	17.8	7.9	1.75	8.5	22.0	64.9			73.3		12.9
totals				25.08								1,808	112	1,920	2,381	2,493	29.8


San Jose Creek
Runoff as a Percent of Rainfall
10
20
30
40
50
60
70
80
90
100
3
6
9
12
15
18
21

A-18

Cuyama River

Rain Year	30 Day Period from	to	Alpha Code	Accum. Precip (inches)	Accum Runoff (cfs days)	Accum Base Flow (cfs days)	Accum. Runoff above Base Flow (cfs days)	Runoff as a % of Precip	Augmented Precip (15% incr.)	New % of Rainfall as Runoff	Augmented Accum. Runoff above Baseflow		Actual Storm Season Runoff (AF)	Remainder of Year Runoff	Total Year Runoff (AF)	Augmented Storm Season Runoff (AF)	Augmented Total Year Runoff (AF)	Percent Increase
1962-63	1/30/63	2/28/63	A	3.58	25.6	0	25.6	0.030	4.11	0.045	44.0		50.8			87.2		
"	3/9/63	4/7/63	B	2.67	20.1	9.0	11.1	0.018	3.06	0.020	14.6		39.9			46.7		
"	4/8/63	5/7/63	C	2.22	38.0	12.0	26.0	0.049	2.56	0.056	34.1		75.4			91.3		
				8.47									166	129	295	225	354	20.0
1964-65	3/31/65	4/29/65	D	3.37	273.8	0	273.8	0.342	3.87	0.414	380.9		543.1	0	543	755.5	756	39.2
1966-67	12/1/66	12/30/66	E	4.15	8,530.4	0	8,530.4	8.642	4.78	11.6	13,168.0		16,919.8			26,118.3		
"	1/22/67	2/20/67	F	2.95	1,313.0	129.0	1,184.0	1.685	3.40	3.05	2,462.7		2,604.3			5,140.6		
"	3/12/67	4/10/67	G	3.11	1,511.0	180.0	1,331.0	1.799	3.58	3.30	2,807.9		2,997.0			5,926.5		
"	4/11/67	5/10/67	H	3.52	6,183.0	1800.0	4,383.0	5.243	4.04	7.46	7,172.4		12,263.8			17,796.4		
				13.73									34,785	2,975	37,760	54982	57,957	53.5
1971-72	12/21/71	1/19/72	I	2.35	259.9	0	259.9	0.466	2.70	0.518	332.4		515.5	43	559	659.2	702	25.6
1972-73	11/10/72	12/9/72	J	4.14	61.3	0	61.3	0.062	4.76	0.092	104.1		121.6			266.4		
"	1/4/73	2/2/73	K	3.90	221.3	4.5	216.8	0.234	4.49	0.330	351.8		438.9			706.7		
"	2/3/73	3/4/73	L	6.19	4,538.8	33.0	4,505.8	3.063	7.12	4.20	7,106.0		9,002.6			14,160.0		
"	3/6/73	4/4/73	M	3.24	1,413.3	180.0	1,233.3	1.604	3.72	3.05	2,697.5		2,803.2			5,707.5		
				17.47									12,366	824	13,190	20,780	21,604	63.8
1973-74	11/12/73	12/11/73	N	3.88	33.8	6.0	27.8	0.030	4.46	0.051	54.1		67.0			119.1		
"	1/4/74	2/2/74	O	4.12	776.4	12.0	764.4	0.781	4.73	1.17	1,316.6		1,540.0			2635.2		
"	3/1/74	3/30/74	P	4.21	493.9	60.0	433.9	0.434	4.84	0.548	630.7		979.6			1,370.0		
"	3/31/74	4/29/74	Q	1.48	275.8	210.0	65.8	0.187	1.70	0.209	84.6		547.0			584.3		
				13.69									3,134	616	3,750	4,709	5,325	42.0
1974-75	12/3/74	1/1/75	R	2.85	233.7	7.5	226.2	0.334	3.28	0.397	309.6		463.5			628.9		
"	2/1/75	3/2/75	S	3.03	108.0	10.5	97.5	0.135	3.49	0.186	154.2		214.2			326.7		
"	3/4/75	4/2/75	T	3.61	547.9	21.0	526.9	0.614	4.15	0.756	746.3		1,086.7			1,521.8		
"	4/3/75	5/2/75	U	1.70	53.1	24.0	29.1	0.072	1.96	0.082	38.2		105.3			123.4		
				11.19									1,870	220	2,090	2,601	2,821	35.0



Cuyama River #1
116% at new precip.
Runoff as a Percent of Rainfall
E
H
G
F
M
I
R
D
K
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O
L
S
J
U
C
B
N
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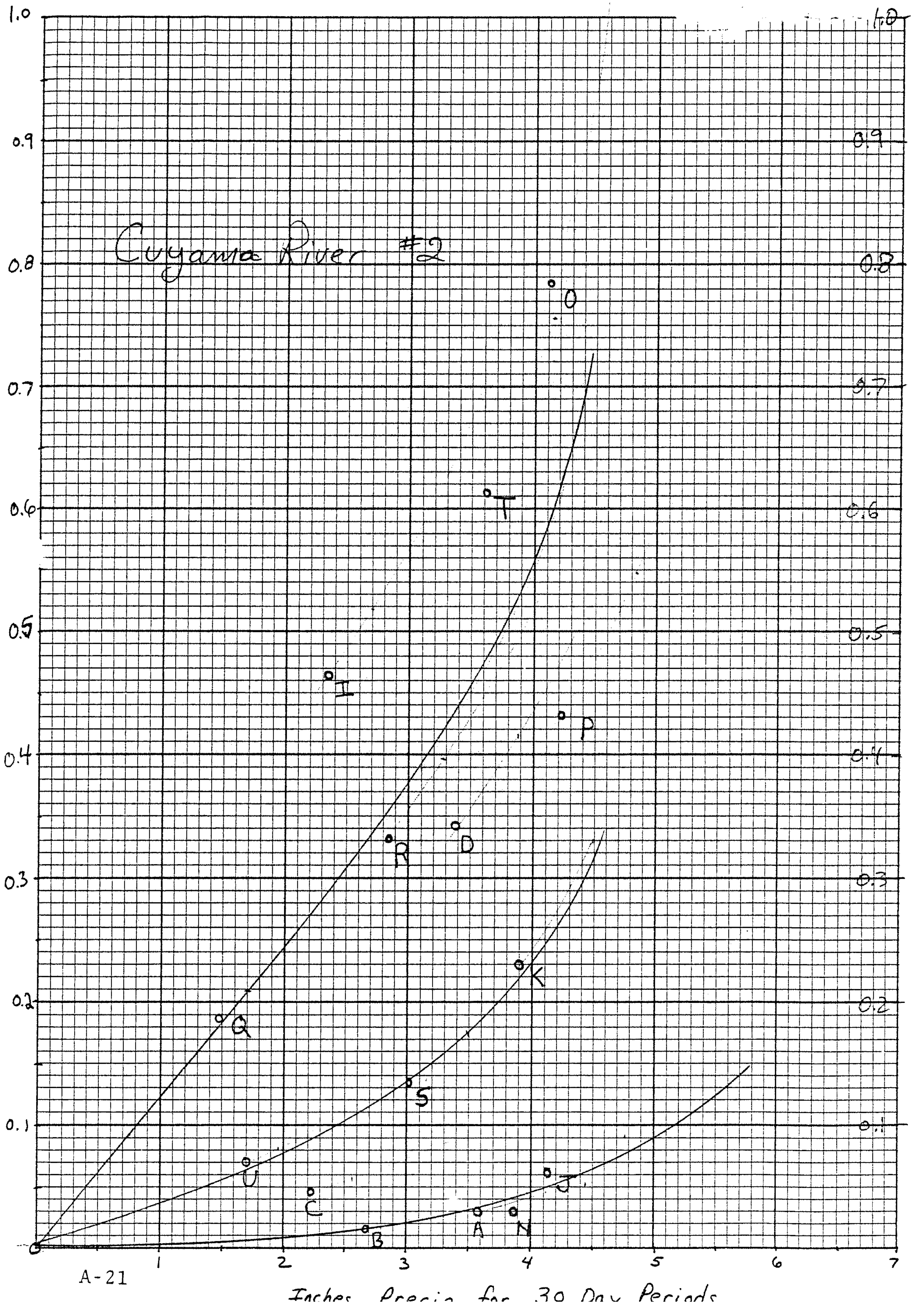
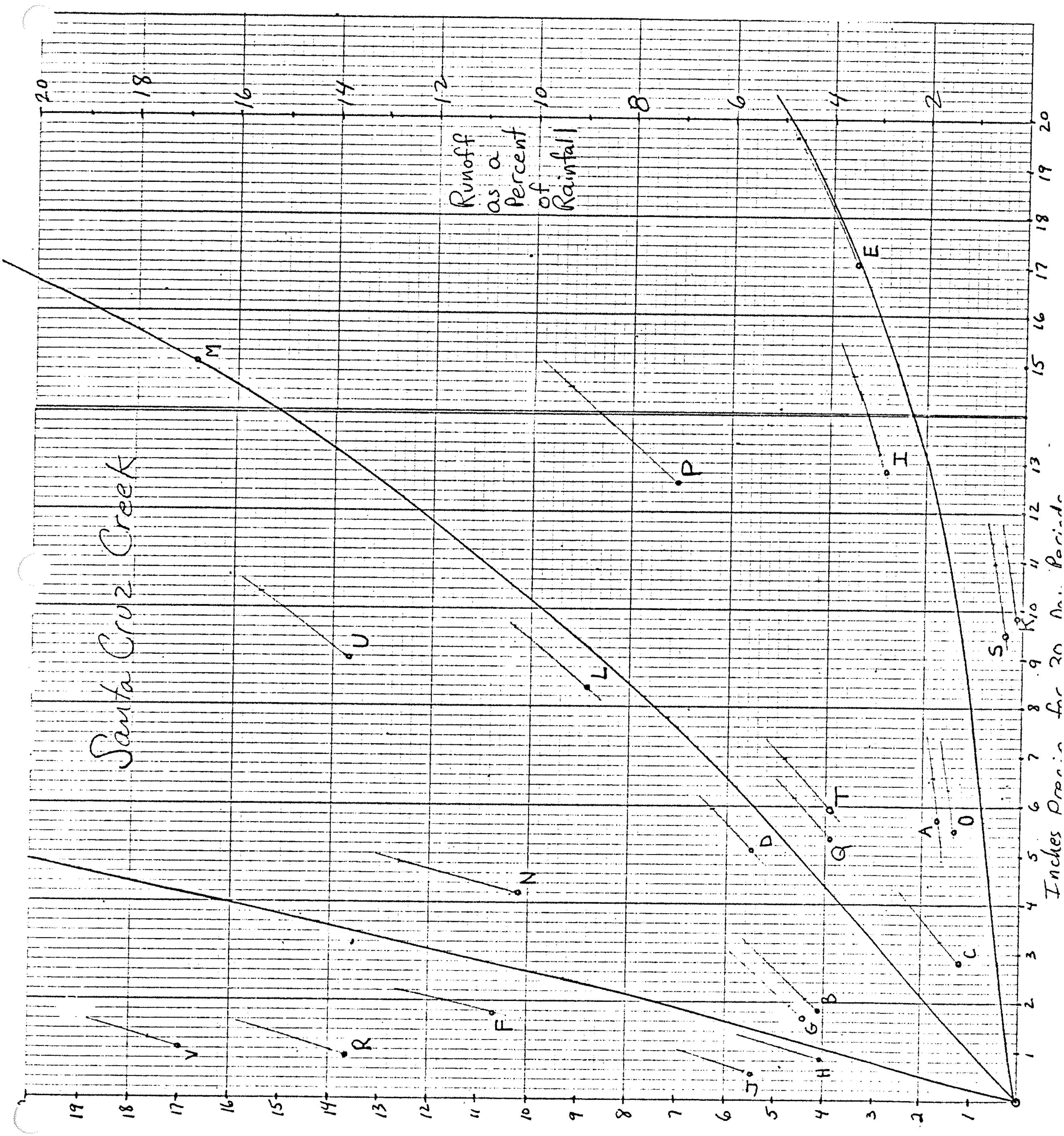
LITHO IN U.S.A.


Cuyama River #2
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1
2
3
4
5
6
7
O
T
I
P
R
D
K
Q
S
U
C
J
B
A
N
Inches Precip for 30 Day Periods

SANTA CRUZ CREEK

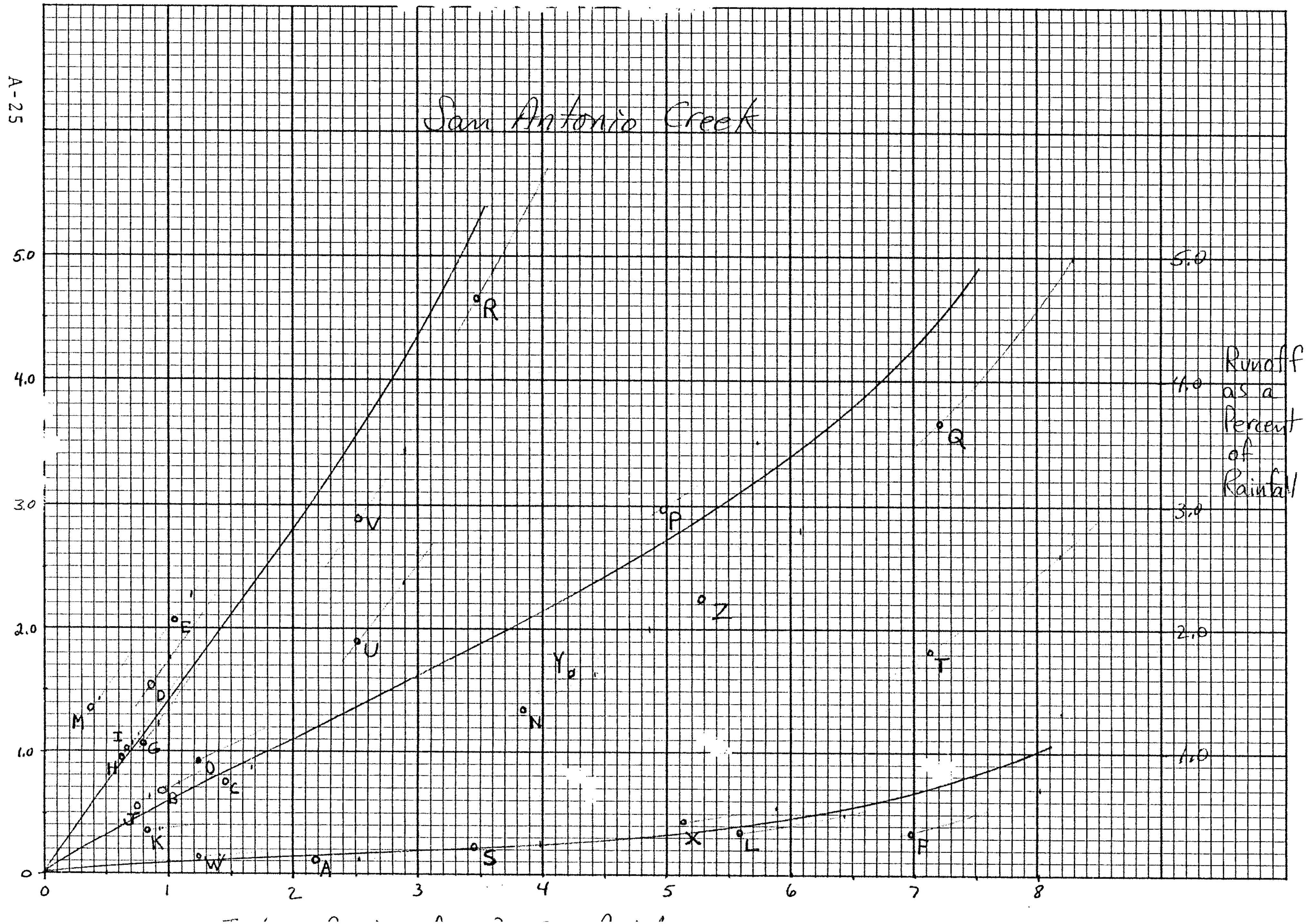
Rain Year	30 Day Period from	30 Day Period to	Alpha Code	Accum. Precip. (inches)	Accum. Runoff (cfs · days)	Accum. Base flow (cfs · days)	Accum Runoff above Base flow	Runoff as a % of Precip.	Augmented Precip (15% incr.)	New % of Rainfall as Runoff	Augmented Accum. Runoff above base flow	Actual Storm Season Runoff (AF)	Remainder of the Year Runoff	Total Year Runoff (AF)	Augmented Storm Season Runoff (AF)	Augmented Total Year Runoff (AF)	Percent Incr.
1967-68	11/18/67	12/17/67	A	5.73	199.9	7.5	192.4	1.69	6.59	1.80	236.0	396.5			483.0		
"	12/18/67	1/16/68	B	1.81	217.7	69.0	148.7	4.13	2.08	4.37	181.0	431.8			495.9		
"	1/26/68	2/24/68	C	2.84	265.9	195.0	70.9	1.26	3.27	1.60	104.0	527.4			593.0		
"	3/7/68	4/5/68	D	5.17	662.2	93.0	569.2	5.53	5.95	6.30	745.3	1,313.5			1,662.8		
				15.55								2,669	911	3,580	3,235	4,146	15.8
1970-71	11/26/70	12/25/70	E	17.06	1,199.9	0	1,199.9	3.54	19.62	4.75	1,854.3	2,380.0			3,677.9		
"	12/25/70	1/24/71	F	1.76	1,126.0	750.0	376.0	10.74	2.02	11.50	463.1	2,233.4			2,406.2		
"	2/16/71	3/17/71	G	1.64	348.5	204.0	144.5	4.43	1.89	4.69	176.0	691.2			753.7		
"	4/1/71	4/30/71	H	0.94	235.3	159.0	76.3	4.08	1.08	4.85	104.3	466.7			522.3		
				21.40								5,771	1,399	7,170	7,360	8,759	22.2
1971-72	12/22/71	1/20/72	I	12.82	725.6	0	725.6	2.84	14.74	3.56	1,070.7	1,439.2			2,123.8		
"	1/27/72	2/25/72	J	0.51	185.3	129.0	56.3	5.55	0.59	5.60	65.4	367.5			385.5		
				13.33								1,807	473	2,280	2,509	2,982	30.8
1972-73	11/11/72	12/10/72	K	9.85	24.2	0	24.2	0.12	11.33	0.34	76.6	48.0			152.0		
	1/1/73	1/30/73	L	8.38	1,481.5	6.0	1,475.5	8.85	9.64	10.30	1,975.1	2,938.5			3,929.4		
	2/3/73	3/4/73	M	14.96	5023.4	15.0	5,008.4	16.83	17.20	21.00	7,188.8	9,963.8			14,288.4		
	3/5/73	4/3/73	N	4.20	2203.0	1,350	853.0	10.21	4.83	12.60	1,210.9	4,369.6			5,079.5		
				37.39								17,320	2,590	19,910	23,449	26,039	30.8
1973-74	11/16/73	12/15/73	O	5.52	151.8	0	151.8	1.38	6.35	1.47	185.7	301.1			368.3		
"	12/26/73	1/24/74	P	12.59	1,813.2	27.0	1,786.2	7.13	14.48	9.26	2,667.7	3,596.4			5,344.9		
"	3/1/74	3/30/74	Q	5.35	572.8	153.0	419.8	3.94	6.15	4.63	566.8	1,136.1			1,427.7		
"	4/1/74	4/30/74	R	0.85	387.0	156.0	231.0	13.66	0.98	13.97	271.7	767.6			848.4		
				24.31								5,801	1,419	7,220	7,989	9,408	30.3
1974-75	12/4/74	1/2/75	S	9.53	74.4	0	74.4	0.39	10.96	0.58	126.5	147.6			250.9		
"	1/31/75	3/1/75	T	5.97	472.7	3.0	469.7	3.95	6.87	4.82	658.5	937.6			1,312.0		
"	3/5/75	4/3/75	U	8.96	2,505.2	63.0	2,442.21	13.70	10.30	15.45	3,167.7	4,969.0			6,407.9		
"	4/5/75	5/4/75	V	1.05	767.0	411.0	356.0	17.04	1.21	17.60	422.9	1,521.3			1,654.0		
				25.51								7,575	995	8,570	9,625	10,620	23.9


Santa Cruz Creek
Runoff as a Percent of Rainfall
Inches Precip

A-24

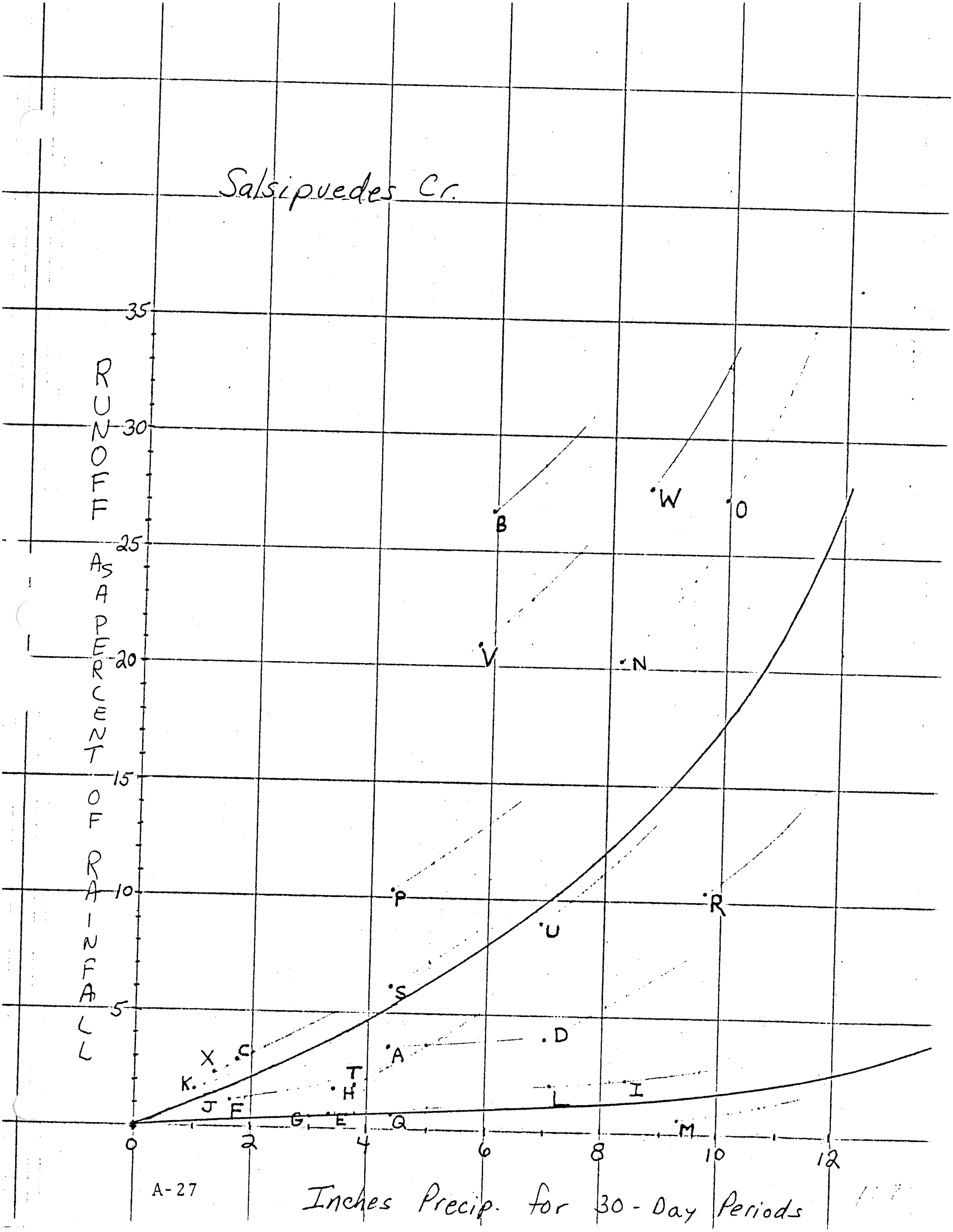
SAN ANTONIO CREEK

Water Year	30 Day Period from	to	Alpha Code	Accumulated Precipitation (inches)	Accum. Runoff (cfs days)	Accum. Base Flow (cfs days)	Accum. Runoff above Base flow (cfs days)	Runoff as a % of Precipitation	Augmented Precip. (15% incr)	New % of Rainfall as Runoff	Augmented Accum. Runoff above Baseflow	Actual Storm Season Runoff (AF)	Remainder of Year Runoff	Total Year Runoff (AF)	Augmented Storm Season Runoff (AF)	Augmented Total Year Runoff (AF)	Percent Increase
67-68	11/6/67	12/5/67	A	2.18	26.8	18.0	8.8	0.11	2.51	0.12	11.0	53.1			57.4		
"	12/6/67	1/4/68	B	0.95	44.4	21.0	23.4	0.68	1.09	0.72	28.5	87.9			98.0		
"	1/7/68	2/5/68	C	1.45	59.9	21.0	38.9	0.74	1.67	0.86	52.2	118.6			144.9		
"	2/6/68	3/6/68	D	0.88	79.0	30.0	49.0	1.53	1.01	1.76	64.6	156.4			187.3		
"	3/7/68	4/5/68	E	1.03	110.4	33.0	77.4	2.07	1.18	2.27	97.4	218.6			258.2		
				6.49					7.46			635	298	933	746	1,044	11.9
70-71	11/26/70	12/25/70	F	6.47	107.4	15.0	92.4	0.36	8.02	0.70	204.1	212.7			433.8		
"	1/1/71	1/30/71	G	0.80	61.6	30.0	31.6	1.09	0.92	1.22	40.8	122.0			140.2		
"	2/1/71	3/2/71	H	0.62	51.6	30.0	21.6	0.96	0.71	1.07	27.6	102.2			114.0		
"	3/3/71	4/1/71	I	0.66	51.3	27.0	24.3	1.01	0.76	1.14	31.5	101.6			115.8		
"	4/2/71	5/1/71	J	0.74	39.2	24.0	15.2	0.56	0.85	0.62	19.2	77.6			85.5		
				9.79					11.26			616	243	859	889	1,132	31.8
71-72	11/11/71	12/10/71	K	0.81	22.9	12.0	10.9	0.37	0.93	0.38	12.9	45.3			49.3		
"	12/11/71	1/9/72	L	5.59	82.6	21.0	61.6	0.30	6.43	0.46	107.6	163.5			254.6		
"	1/26/72	2/25/72	M	0.37	57.5	39.0	18.5	1.38	0.43	1.43	22.4	113.8			121.6		
				6.77					7.79			323	453	775	426	879	13.4
72-73	11/1/72	11/30/72	N	3.84	201.8	15.0	186.8	1.34	4.42	1.64	263.6	399.6			551.6		
"	12/1/72	12/30/72	O	1.22	73.6	33.0	40.6	0.92	1.40	1.00	50.9	145.7			166.1		
"	1/1/73	1/30/73	P	4.99	591.4	48.0	543.4	2.99	5.74	3.50	730.5	1,171.0			1,541.4		
"	2/1/73	3/2/73	Q	7.21	1,039.7	75.0	964.7	3.68	8.29	5.00	1,507.3	2,058.6			3,133.0		
"	3/3/73	4/1/73	R	3.48	742.2	150.0	592.2	4.68	4.00	5.60	814.5	1,469.6			1,909.7		
				20.74					23.85			5,245	375	5,620	7,302	7,677	36.6
73-74	11/12/73	12/9/73	S	3.45	48.4	21.0	27.4	0.22	3.97	0.24	34.6	95.8			110.1		
"	12/22/73	1/20/74	T	7.12	501.6	30.0	471.6	1.82	8.19	2.60	774.3	993.2			1,592.5		
"	2/12/74	3/14/74	U	2.51	233.2	60.0	173.2	1.90	2.89	2.38	250.1	461.7			614.0		
"	3/15/74	4/13/74	V	2.52	343.4	78.0	265.4	2.90	2.90	3.42	360.7	680.0			868.6		
				15.60					17.95			2,231	559	2,790	3,185	3,744	34.2
74-75	10/26/74	11/24/74	W	1.23	18.6	12.0	6.6	0.15	1.41	0.16	8.2	36.8			40.6		
"	12/3/74	1/1/75	X	5.12	101.4	15.0	86.4	0.46	5.89	0.55	117.8	200.8			262.9		
"	1/30/75	2/28/75	Y	4.23	295.9	42.0	253.9	1.65	4.86	2.00	353.5	585.9			783.1		
"	3/1/75	3/30/75	Z	5.29	489.3	57.0	432.3	2.25	6.08	2.80	619.1	968.8			1,338.7		
				15.87					18.24			1,792	488	2,280	2,425	2,913	27.8


San Antonio Creek
Runoff as a Percent of Rainfall
5.0
4.0
3.0
2.0
1.0
0
1
2
3
4
5
6
7
8
R
Q
V
P
Z
E
U
Y
T
D
M
N
I
G
H
O
C
B
J
K
X
L
F
W
A
S

Salsipuedes Creek

Rain Year	30 Day Period from	to	Alpha Code	Accum. Precip (in)	Accum. Runoff (cfs days)	Accum Base Flow (cfs days)	Accum. Runoff above Base flow	Runoff as % of Precip.	Augm. Precip. (15% incr)	New % of Rain as Runoff	Augmented Accum. Runoff above Base flow	Actual Storm Season Runoff (AF)	Remainder of Yr. Runoff	Total Year Runoff (AF)	Augmented Storm Season Runoff (AF)	Augmented Total Year Runoff (AF)	Percent Increase
1966-67	11/20/66	12/19/66	A	4.33	215.4	18.0	197.4	3.6	4.97	3.7	233.1	427.2			498.1		
"	1/21/67	2/19/67	B	5.93	2,042.9	39.0	2,003.9	26.7	6.81	28.7	2,477	4,052			4,990.5		
"	3/1/67	3/30/67	C	1.76	173.4	108.0	65.4	2.9	2.03	3.2	82.2	343.9			377.2		
"	3/31/67	4/29/67	D	7.01	466.4	114.0	352.4	4.0	8.06	5.4	551.1	925.1			1,319.2		
				19.03								5,748	962	6,710	7,185	8,147	21.4
1967-68	11/17/67	12/16/67	E	3.27	51.9	21.0	30.9	0.7	3.77	0.75	35.8	102.9			112.6		
"	12/18/67	1/16/68	F	1.64	54.5	30.0	24.5	1.2	1.89	1.3	31.1	108.1			121.3		
"	1/26/68	2/24/68	G	2.99	71.2	48.0	23.2	0.6	3.44	0.7	30.5	141.2			155.7		
"	3/6/68	4/4/68	H	3.42	94.4	15.0	79.4	1.8	3.94	2.2	109.7	187.2			247.2		
				11.32								539	238	777	637	875	12.6
1970-71	11/24/70	12/23/70	I	8.40	250.8	4.5	246.3	2.3	9.66	2.7	330.3	497.5			664.1		
"	12/26/70	1/24/71	J	1.20	93.8	72.0	21.8	1.4	1.38	1.5	26.2	186.0			194.8		
	2/17/71	3/18/71	K	1.04	70.9	48.0	22.9	1.7	1.19	1.8	27.2	140.6			149.1		
				10.64								824	356	1,180	1,008	1,364	15.6
1971-72	12/22/71	1/20/72	L	7.10	192.4	2.1	190.3	2.1	8.16	2.2	227.4	381.6	135	517	455.2	590	14.1
1972-73	11/10/72	12/9/72	M	9.32	89.8	1.8	88.0	0.7	10.72	1.2	162.9	178.1			326.6		
"	1/4/73	2/2/73	N	8.19	2,124.2	5.1	2,119.1	20.4	9.42	23.8	2,839.8	4,213.3			5,642.8		
"	2/3/73	3/4/73	O	9.94	3,665	219.0	3,446.0	27.4	11.43	34.7	5,023.9	7,269.4			10,399.1		
"	3/5/73	4/3/73	P	4.37	1,321	750.0	571.0	10.3	5.03	11.5	723.0	2,620.2			2,939.5		
				31.82								14,281	1,379	15,660	19,308	20,687	32.1
1973-74	11/12/73	12/11/73	Q	4.40	70.7	33.0	37.7	0.7	5.06	0.8	51.3	140.2			167.1		
"	12/22/73	1/20/74	R	9.69	1,327.7	48.0	1,279.7	10.4	11.14	13.4	1,890.9	2,633.5			3,845.8		
"	2/22/74	3/23/74	S	4.36	465.2	123.0	342.2	6.2	5.01	7.2	456.7	922.7			1,149.9		
"	3/24/74	4/22/74	T	3.78	270.4	186.0	84.4	1.8	4.34	2.7	148.6	536.3			663.6		
				22.23								4,233	1,087	5,320	5,826	6,913	29.9
1974-75	12/3/74	1/1/75	U	6.89	819.0	30.0	789.0	9.0	7.92	11.1	1,113.7	1,624.5			2,268.5		
	1/30/75	2/28/75	V	5.75	1,616	84.0	1,532.0	21.0	6.61	22.9	1,917.1	3,205.3			3,969.2		
	3/2/75	3/31/75	W	8.62	3,278	240.0	3,038	27.8	9.92	33.0	4,144.1	6,501.8			8,695.6		
	4/1/75	4/30/75	X	1.36	461.8	420.0	41.8	2.4	1.57	2.6	51.6	916.0			935.4		
				22.62								12,248	1,532	13,780	15,869	17,401	26.3



Salsipuedes Cr.
RUNOFF AS A PERCENT OF RAINFALL
Inches Precip. for 30-Day Periods
35
30
25
20
15
10
5
0
2
4
6
8
10
12
W
O
B
V
N
P
R
U
S
D
X
C
A
K.
T
H
I
J
F
L
G
E
Q
M

Surface Reservoir Yields

Calculation of yields for Cachuma, Jameson, and Gibraltar involved the drawing of mass curves showing the accumulated inflows minus evaporation, spills and releases over a period of time. The most critical dry period for each reservoir was then selected and new graphs were drawn showing just these periods. These graphs are shown on the following pages. In order to calculate the safe yield for each reservoir the point of spill was found just prior to the critical period. From this point a line can be drawn to a point at the end of the period determined by adding the usable capacity of the reservoir to the lowest point in the period. The slope of the resulting line represents the rate of withdrawal that could have occurred during the period, which would not have exceeded the usable capacity. This provides the safe yield figure. To find the effects of cloud seeding, inflows were augmented 20 to 30 percent, and new curves were drawn. The new point of spill was determined and the slope of the new safe yield line was determined. If inflows to the reservoirs are increased, then evaporation losses and downstream releases would also increase. In order to accurately account for these, an operational study, possibly with the aid of a computer, would be necessary. Since this is beyond the scope of this report, the Water Agency made estimates allowing 20 percent for increased evaporation lossess. It was assumed that the remaining increment would be divided equally between downstream releases and surface deliveries.

JAMESON INFLOW

[as per 68/C1 Ref. (13)]

Year End Sept. 30	Inflow to Jameson	Evap. -Rain	Releases + Spills	Net Inflow	Augm. 20% Net Inflow	Augm. 30% Net Inflow
1945-46	3.5	0.2	1.9	1.4	2.0	2.4
46-47	1.4	0.2	0.7	0.5	0.8	0.9
47-48	0.3	0.2	0.3	-0.2	-0.1	-0.1
48-49	0.3	0.2	0.3	-0.2	-0.1	-0.1
49-50	0.5	0.1	0.5	-0.1	0.0	0.0
1950-51	0.1	0.1	0.1	-0.1	-0.1	-0.1
51-52	11.6	0.0	5.6	6.0	8.3	9.5

Year	Accum. Net Inflow	Accum. 20% Net Inflow	Accum. 30% Net Inflow
1945-46	1.4	2.0	2.4
46-47	1.9	2.8	3.3
47-48	1.7	2.7	3.2
48-49	1.5	2.6	3.1
49-50	1.4	2.6	3.1
1950-51	1.3	2.5	3.0
51-52	7.3	10.8	12.5

Spill 1945-46 - March and April 1946 - net inflow to this point = 1.8

Critical dry period was May 1946 - January 1952

Length of period = 5 years 8 months = 5.67 years

JAMESON YIELD CALCULATIONS

to locate spill point (April-May 1946) on graph

	actual	+20%	+30%
inflow to this point	3.4	4.1	4.4
spills + release	-1.6	-1.6	-1.6
accum. net inflow (spill point)	1.8	2.5	2.8

assume 5,880 is usable storage -

accum. net inflow in 1951 = 1.3 + 5.88 = 7.18
minus spill point = 1.80
5.38

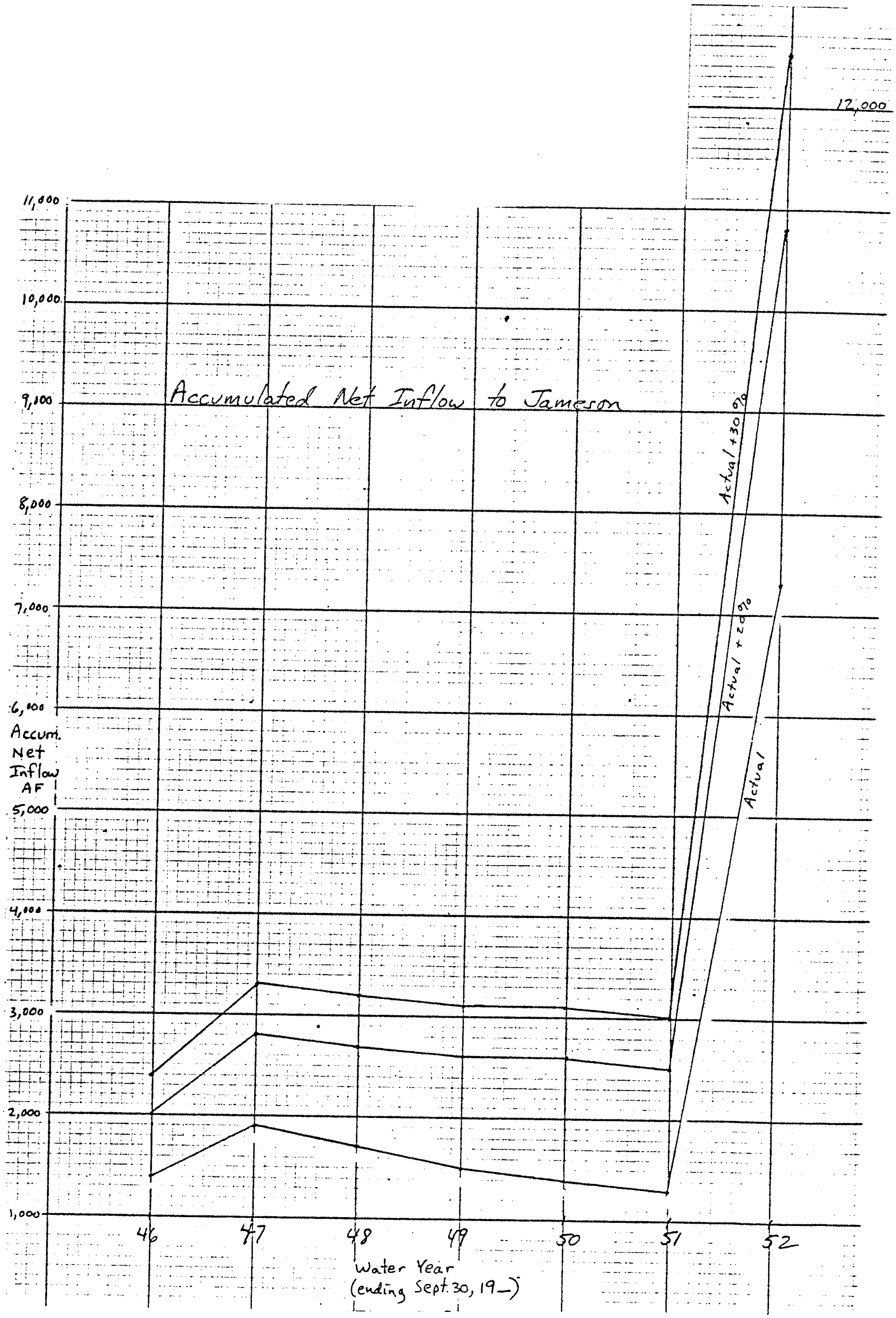
so safe yield under actual conditions = $\frac{5.38}{5.67 \text{ years}}$ = 950 AFY

for 20% increment -

accum. net inflow in 1951 = 2.5 + 5.88 = 8.38
minus spill point = 2.50
5.88 ÷ 5.67 = 1,040 AFY,
which is an increase of 90 AF

for 30% increment -

accum. net inflow in 1951 = 3.0 + 5.88 = 8.88
minus spill point = 2.80
6.08 ÷ 5.67 = 1,070 AFY
which is an increase of 120 AF


Accumulated Net Inflow to Jameson
Accum. Net Inflow AF
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,100
10,000
11,000
12,000
46
47
48
49
50
51
52
Water Year (ending Sept. 30, 19_)
Actual +30%
Actual +20%
Actual

GIBRALTAR INFLOW

[as per 68/C1 Ref. (13)]

Year End Sept. 30	Inflow to Gibral.	Evap. -Rain	Releases + Spills	Net Inflow	Augm. 20% Net Inflow	Augm. 30% Net Inflow
1946-47	11.1	1.3	5.7	4.1	6.3	7.4
47-48	0.4	0.5	0.7	- 0.8	- 0.7	- 0.7
48-49	1.5	0.1	0.8	0.6	0.9	1.1
49-50	3.1	0.1	0.8	2.2	2.8	3.1
1950-51	0.1	0.2	0.1	- 0.2	- 0.2	- 0.2
51-52	101.1	0.3	86.6	14.2	34.4	44.5

Year	Accum. Net Inflow	Aug. Accum. 20% Net Inflow	Aug. Accum. 30% Net Inflow
1946-47	4.1	6.3	7.4
47-48	3.3	5.6	6.7
48-49	3.9	6.5	7.8
49-50	6.1	9.3	10.9
1950-51	5.9	9.1	10.7
51-52	20.1	43.5	55.2

Gibraltar spilled in March 1947

Oct	0.0	0.1	0.0	20% Aug net inflow at spill = 5.6
Nov	2.2	-0.1	0.0	30% Aug net inflow at spill = 8.75
Dec	4.6	-0.1	2.0	
Jan	2.2	0.0	2.0	No inflow until December
Feb	0.8	0.1	0.5	So length dry period
Mar	0.7	0.0	0.4	Is 4 years 8 months = 4.67

GIBRALTAR YIELD CALCULATIONS

spill point for graph at end of March 1947

	actual	20% avg	30% avg
	5.6	7.7	8.75

assume usable capacity = 9,300 - 2,100 = 7,200

$$\begin{array}{r} 7.2 \\ +\ 5.9 \\ \hline 13.1 \end{array} \qquad \begin{array}{r} 13.1 \\ -\ 5.6 \\ \hline 7.5 \end{array} \qquad \frac{7.5}{4.67} = 1.630$$

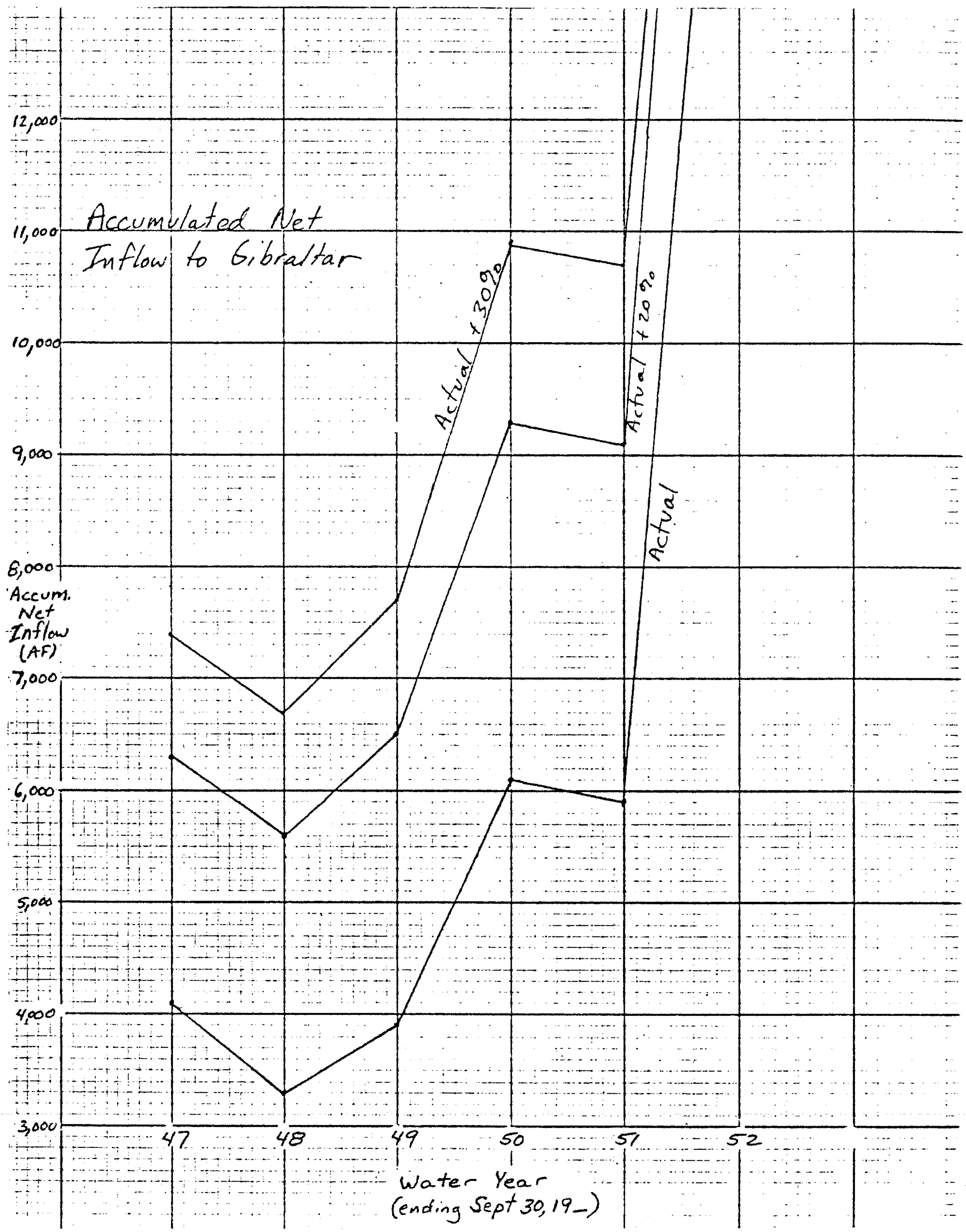
1,600 AF safe yield on actual inflow

20% augmentation -
low storage in 1951:

$$\begin{array}{rl} 9.1 & \\ +7.2 & = \text{usable capacity} \\ \hline 16.3 & \\ -7.7 & = \text{spill point on graph} \\ \hline 8.6 & \div\ 4.67 = 1{,}840 = \text{new safe yield which is an increase of 240 AFY} \end{array}$$

30% augmentation -
low storage in 1951:

$$\begin{array}{rl} 10.7 & \\ +7.2 & = \text{usable capacity} \\ \hline 17.9 & \\ -8.75 & = \text{spill point on graph} \\ \hline 9.15 & \div\ 4.67 = 1{,}960 = \text{new safe yield which is an increase of 360 AFY} \end{array}$$


Accumulated Net
Inflow to Gibraltar
12,000
11,000
10,000
9,000
8,000
Accum.
Net
Inflow
(AF)
7,000
6,000
5,000
4,000
3,000
Actual +30%
Actual +20%
Actual
47
48
49
50
51
52
Water Year
(ending Sept 30, 19_)

CACHUMA INFLOW

[as per 68/C1 Ref. (13)]

Year End Sept. 30	Inflow to Cachuma	Eva-poration	Prior Rights Releases	Net Inflow	Augm. 20% Net Inflow	Augm. 30% Net Inflow
1942-43	176.7	10.5	5.8	160.4	195.7	213.4
43-44	86.5	10.4	5.7	70.4	87.7	96.4
44-45	36.1	10.3	6.6	19.2	26.4	30.0
45-46	33.5	10.0	7.7	15.8	22.5	25.9
46-47	9.4	9.0	7.1	- 6.7	- 4.8	3.9
47-48	0.1	7.6	0.1	- 7.6	- 7.6	- 7.6
48-49	0.6	6.3	0.6	- 6.3	- 6.2	- 6.1
49-50	1.6	4.9	1.6	- 4.9	- 4.6	- 4.4
1950-51	0.0	3.0	0.0	- 3.0	- 3.0	- 3.0
51-52	182.9	9.0	8.1	165.8	202.4	220.7

Year	Accum. Net Inflow	Accum 20% Net Inflow	Accum. 30% Net Inflow
1942-43	160.4	195.7	213.4
43-44	230.8	283.4	309.8
44-45	250.0	309.8	339.8
45-46	265.8	332.3	365.7
46-47	259.1	327.4	369.6
47-48	251.5	319.9	362.0
48-49	245.2	313.7	355.9
49-50	240.3	309.1	351.5
1950-51	237.3	306.1	348.5
51-52	403.1	508.5	569.2

Spilled Feb, Mar, April 1944 - Reservoir full during May (EOM Stor 204.8)

CACHUMA YIELD CALCULATIONS

To find spill points on graph (May 1944)

	actual	20%	30%
monthly inflows to this point	84.4	101.3	109.7
evaporation + releases	-6.9	-6.9	-6.9
+ accum. net inflow to this point	160.4	+195.7	+213.4
	237.9	290.1	316.2

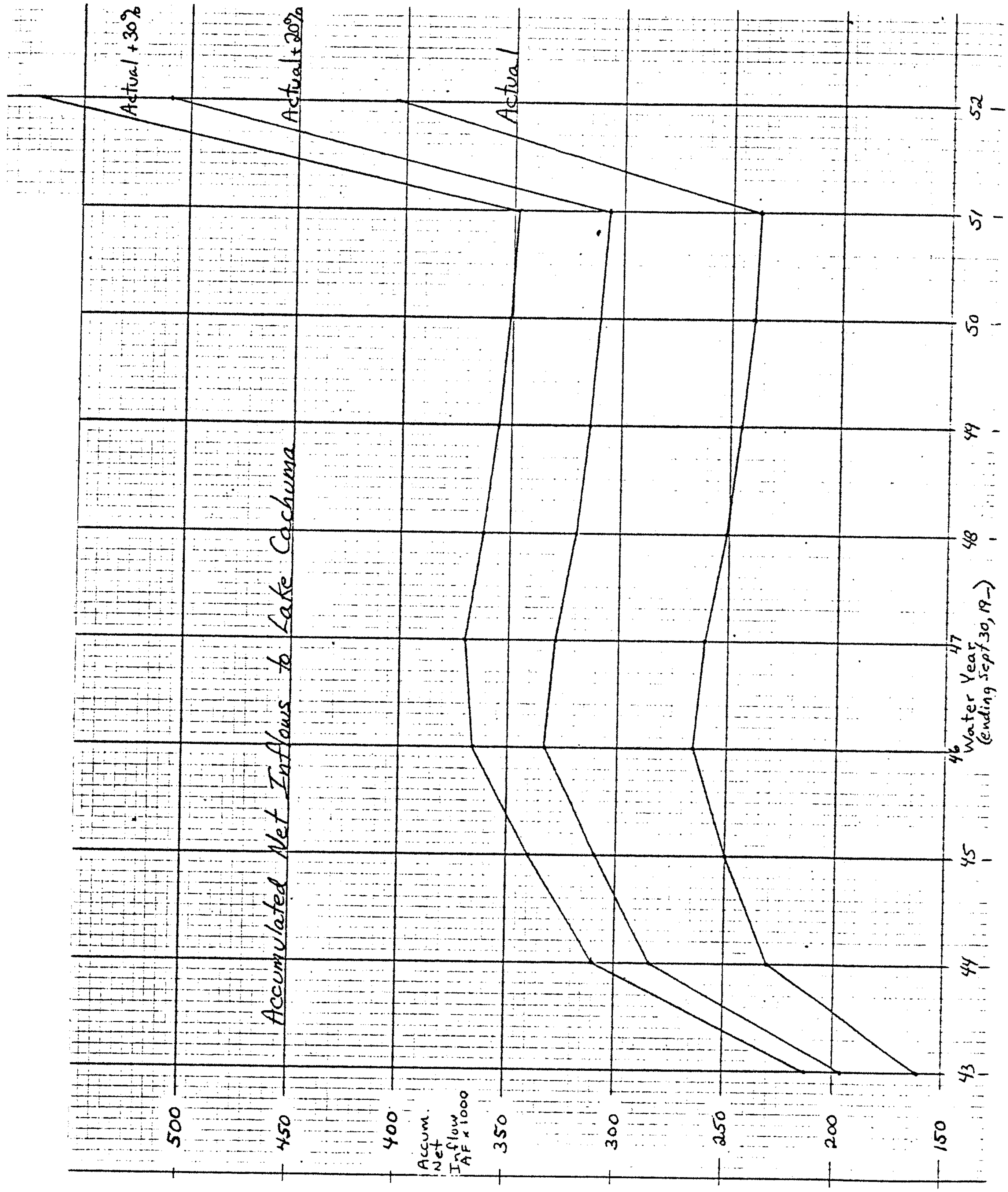
critical dry period May 1944 - Dec 1951 = 7 7/12 = 7.58 years

Assume usable cpcy = 188.7

low point in 1951: 237.2
+188.7 = usable capacity
426.0
-237.9 = spill point on graph
188.1 ÷ 7.58 = 24.8 KAF = actual safe yield

for 20% increment -
low point in 1951: 306.1
+188.7 = usable capacity
494.8
-290.1 = spill point on graph
204.7 ÷ 7.58 = 27.0 KAF = inc. of 2,200 AFY

for 30% increment -
low point in 1951: 348.5
+188.7 = usable capacity
537.2
-316.2 = spill point on graph
221.0 ÷ 7.58 = 29.2 KAF = inc. or 4,400 AFY


Accumulated Net Inflows to Lake Cachuma
Actual + 30%
Actual + 20%
Actual
Accum. Net Inflow AF x 1000
500
450
400
350
300
250
200
150
43
44
45
46
47
48
49
50
51
52
Water Year (ending Sept 30, 19_)

Rainfall Infiltration

The following tables display the calculation for increases to groundwater recharge by deep percolation of rainfall. The graphs shown in Figure IV-9 (p. IV-42) were programmed into a computer. Irrigated and non-irrigated recharge area were included as additional variables. Once set up, the program generated the infiltration for the year, given the rainfall. For rainfall under 10 inches, no infiltration occurred. After 30 inches of rainfall, no more infiltration was assumed to occur. For each basin, the program was run for a base period which included equal numbers of dry and wet years. To find increases due to weather modification, the rainfall amounts were increased 15 percent, and the program was run again. Allowance was made for flood years when seeding would most likely have been suspended.

SANTA MARIA

Year	S.M. rainfall	unaugmented infiltration	infiltration w/15% precip incr.	infiltration w/7.5% precip incr.
*1910-11	20.69	31,984	31,984	31,984
2	9.63	0	960	0
3	5.46	0	0	0
* 4	18.86	22,130	22,130	22,130
5	18.93	22,507	37,797	30,152
* 6	16.66	11,157	11,157	11,157
7	14.48	6,650	11,134	8,464
8	16.19	9,833	20,830	14,291
9	10.99	819	3,573	2,196
1920	9.60	0	902	0
1	11.04	402	3,669	2,286
2	16.89	11,777	25,102	18,286
3	12.43	3,225	6,340	4,782
4	6.27	0	0	0
5	15.07	7,635	13,894	9,862
6	10.05	0	1,767	507
7	15.61	8,538	17,238	11,497
8	15.36	8,120	15,690	10,740
9	10.75	418	3,112	1,765
1930	9.18	0	95	0
1	8.72	0	0	0
2	16.78	11,495	24,483	17,707
3	11.44	1,571	4,438	3,004
4	7.67	0	0	0
5	19.14	23,638	39,097	31,367
6	13.75	5,430	8,876	7,153
7	20.98	33,545	50,491	42,018
* 8	21.58	36,776	36,776	36,776
9	10.62	200	2,862	1,531
1940	16.09	9,551	20,210	13,713
* 1	30.64	85,561	85,561	85,561
2	17.04	12,330	26,093	19,212
3	17.26	13,515	27,455	20,485
4	14.56	6,783	11,394	8,608
5	11.31	1,353	4,188	2,771
6	11.08	969	3,746	2,357
7	9.42	0	556	0
8	8.20	0	0	0
9	9.17	0	76	0
1950	10.47	0	2,574	1,262
1	8.66	0	0	0
* 2	18.57	20,569	20,569	20,569
3	10.87	618	3,342	1,980
4	12.12	2,707	5,744	4,225
5	13.17	4,461	7,762	6,111
6	14.56	6,783	11,394	8,608
7	9.01	0	0	0
* 8	25.86	59,822	59,822	59,822
9	7.62	0	0	0
1960	11.33	1,387	4,226	2,806
1	7.11	0	0	0
* 2	16.39	10,396	10,396	10,396
3	11.30	1,337	4,167	2,753
4	7.81	0	0	0
5	11.62	1,871	4,783	3,327
6	9.13	0	0	0
Totals		498,361	708,458	594,221
Averages (56 yrs)		8,899	12,651	10,611

Irrigated Recharge area = 36,750 Non Irrigated recharge area = 47,750

* Cloud Seeding operations probably would have been suspended during these years due to potential [illegible]

SAN ANTONIO Infiltration

Year	Los Alamos Rain	unaugmented infiltration		augmented Infiltration (precip incr. 20%)	augmented Infiltration (precip incr. 10%)
* 1910-11	29.05	45,623		45,623	45,623
2	12.26	378		906	642
3	8.31	0		0	0
* 4	25.86	33,953		33,958	33,958
5	23.02	23,573	170,33	40,408	31,990
* 6	15.88	1,157		1,157	1,157
7	19.55	10,884		25,182	18,033
8	19.49	10,664		24,918	17,791
9	12.34	396		926	661
1920	11.42	198		689	443
1	11.67	252		753	503
2	18.22	6,020		19,345	12,683
3	13.23	587		1,156	872
4	5.38	0		0	0
5	13.13	566		1,130	848
6	12.15	355		877	616
7	17.58	3,680		16,537	10,109
8	14.98	963	17465	5,128	1,370
9	10.39	0		423	200
1930	10.55	11		464	238
1	9.64	0		230	22
2	17.83	4,594		17,634	11,114
3	11.60	237		735	486
4	8.86	0		28	0
5	18.08	5,509		18,731	12,120
6	13.43	630		1,239	919
7	21.51	18,051		33,782	25,917
* 8	19.71	11,469		11,469	11,469
9	12.72	477		1,024	751
1940	15.52	1,079	113799	7,498	1,823
* 1	35.21	68,148		68,148	68,148
2	17.73	4,229		17,195	10,712
3	16.37	1,331		11,228	5,242
merge 4	17.36	2,876		15,572	9,224
5	12.25	376		903	640
6	13.41	626		1,230	914
7	8.92	0		44	0
8	8.08	0		0	0
9	11.68	254		756	505
1950	12.43	415		950	682
1	10.20	0	23521	374	155
* 2	21.69	18,709		18,709	18,709
3	12.51	432		970	701
4	13.46	637		1,252	926
5	13.24	589		1,159	874
6	16.79	1,483		13,071	6,931
7	10.27	0		392	171
* 8	29.17	46,061		46,061	46,061
9	8.59	0		0	0
1960	12.91	518		1,073	796
1	7.20	0		0	0
* 2	23.27	24,487	7324	24,487	24,487
3	14.18	791		1,618	1,096
4	9.27	0		134	0
5	13.79	707		1,395	1,004
6	12.64	460		1,004	732
Totals	14.93	354,440		539,678	441,066
Average (56 yrs)		6,329		9,637	7,876
				52.3% incr	24.4%

* Years with floods – no seeding

Irrigated recharge area = 4,730

Non Irrig. " " = 61,270

July to June Water Year	unadjusted Rain Fall **	Carpinteria unaugmented Infiltration	Carpinteria 16% augmented (Precip) Infiltration	Goleta unaugmented Infiltration	Goleta 18% augmented (Precip) Infiltration
1910-1911 *	31.94	5731 ***	5732 ***	5769 ***	5768
2	16.35	833	1640	342	1350
3	12.78	300	605	127	255
4 *	31.52	5731 ***	5732 ***	5769 *** 23437	5768
5	21.46	2504 24802	3694	2244	3839
6 *	25.88	4036	4036	4069	4069
7	22.56	2885	4136	2698	4375
8	21.66	2574	3775	2327	3936
9	12.16	208	498	92	214
1920	14.68	583	1007	232	536
1	14.31	528	899	212	392
2	19.25	1738	2806	1332	2762
3	17.24	1060	1998	502	1783
4	6.36	Ø	Ø	Ø	Ø
5	12.26	222	515	98 9055	220
6	16.93	982	1873	396	1632
7	22.73	2944 13256	4205	2768	4457
8	13.48	404	726	166	300
9	14.54	563	966	225	468
1930	13.91	469	801	190	348
1	14.99	630	1098	250	687
2	22.13	2736	3964	2521	4165
3	8.64	Ø	Ø	Ø	Ø
4	13.43	397	718	163	297
5	21.12	2386	3558	2104	3673
6	18.21	1378	2388	902	2256
7	25.51	3908	5322	3916	5768
8 *	26.10	4112 [illegible]	4112	4160 21625	4160
9	13.35	385	704	158	292
1940	14.94	622	1083	247	663
1 *	45.21	5731 ***	5732 ***	5769 ***	5768
2	12.87	313	621	132	260
3	24.37	3513	4864	3445	5256
4	17.95	1288	2283	795	2129
5	15.23	666	1190	263	804
6	11.33	84	354	46	159
7	13.35	385	704	158	292
8	9.34	Ø	10	Ø	29
9	10.43	Ø	198	Ø	100
1950	13.15	355 11648	669	147 8925	279
1	11.29	78	347	44	157
2 *	31.20	5731 ***	5732 ***	5769 ***	5768
3	12.98	330	640	138	262
4	15.32	679	1226	268	848
5	17.07	1018	1929	432	1700
6	19.59	1856	2942	1472	2928
7	13.89	466	797	188	346
8 *	31.94	5731 ***	5732 ***	5769 ***	5768
9	9.06	Ø	Ø	Ø	11
1960	10.82	8 12629	266	18 11512	126
1	9.99	Ø	122	Ø	72
2 *	26.22	4154	4154	4209	4209
Totals		83,235	109,104	73043	101,707
Average (52 yrs)		1601 AFY	2,098 AFY	1405 AFY	1,956 AFY
		⇒ 31% increase		⇒ 39% increase	

* Cloud Seeding operations would probably have been suspended due to flood potential

** Values tabulated are for the Santa Barbara Station. The transfer factor used for the Carpinteria Basin is 0.975, for Goleta is 1.00

*** The cutoff infiltration (after Geotech) is about 15.9 inches for irrigated lands and 8.4 inches for non irrigated lands. In this case the applied water is 30.00 inches (30.77 inches at Santa Barbara For [illegible]

— LOMPOC INFILTRATION —

Year	Rain	Infiltration Plain	Infiltration Upland
1868	20.15	5,284	218
9	12.66	748	214
1870	8.06	0	Ø
1	8.06	0	Ø
2	15.11	1,597	457
3	8.63	0	Ø
4	12.66	748	214
5	14.10	1,247	357
6	19.14	4,395	4183
7	4.03	0	Ø
8	21.87	6,797	8603
9	9.35	0	Ø
1880	16.26	2,050	595
1	12.23	599	172
2	9.79	0	Ø
3	9.64	0	Ø
4	29.93	13,889	21650
5	10.79	100	29
6	17.41	2,873	1383
7	10.36	0	Ø
8	14.53	1,396	400
9	15.69	1,798	515
1890	26.48	10,853	16065
1	13.24	949	272
2	10.36	0	Ø
3	19.71	4,896	5106
4	7.63	0	Ø
5	13.67	1,098	314
6	11.08	201	58
7	14.53	1,396	400
8	4.89	0	Ø
9	10.50	0	Ø
1900	9.64	0	Ø
1	15.11	1,597	457
2	12.23	599	172
3	14.53	1,396	400
4	10.22	0	Ø
5	21.44	6,419	7907
6	18.42	3,761	3018
7	21.15	6,163	7437
8	14.25	1,299	372
9	25.47	9,965	14430
1910	16.40	2,161	619
1	25.63	10,105	14689
2	7.81	0	Ø
3	6.80	0	Ø
4	23.52	8,249	11274
5	24.83	9,401	13394
6	16.49	2,214	634
7	13.53	1,050	300
8	17.29	2,767	1188
9	12.71	766	219
1920	8.75	0	Ø
1	13.68	1,102	315
2	16.77	2,378	681
3	12.66	748	214
4	5.96	0	Ø
5	12.30	624	178
6	12.12	561	161
7	16.54	2,243	642
8	16.04	1,951	558
9	10.36	0	Ø
1930	9.18	0	Ø

Year	Rain	Infiltration Plain	Infiltration Upland
1	7.66	0	Ø
2	16.44	2,185	625
3	11.24	256	73
4	8.21	0	Ø
5	17.37	2,838	1318
6	11.13	218	62
7	20.46	5,556	6320
8	24.75	9,331	13265
9	12.34	637	182
1940	16.11	1,992	570
1	40.58	23,259	38891
2	18.53	3,858	3196
3	15.27	1,652	473
4	16.21	2,050	587
5	11.35	294	84
6	12.45	676	193
7	8.83	0	Ø
8	7.92	0	Ø
9	13.54	1,053	301
1950	9.70	0	Ø
1	9.18	0	Ø
2	21.12	6,137	7388
3	12.06	540	155
4	12.38	651	186
5	13.08	894	256
6	13.74	1,122	321
7	10.01	0	Ø
8	27.38	11,645	17,533
9	7.74	0	Ø
1960	8.69	0	Ø
1	8.16	0	Ø
2	24.85	9,419	13,427
3	12.81	800	229
4	9.99	0	Ø
5	14.17	1,271	364
6	12.43	669	191
7	15.10	1,594	456
8	8.08	0	Ø
9	24.16	8,812	12310
1970	10.24	0	Ø
1	9.21	0	Ø
2	6.75	0	Ø
3	21.95	6867	8732
4	15.78	1,829	524
5	16.68	2,325	665
6	8.63	0	Ø

1914-1962 avg. uplands (no irrigated acreage) = 2359AF

1914-1962 avg. uplands (2181 irrigated acreage = 2758 AFY

1868-1976 avg. (as above with irrigated acreage = 2522 AFY

1914-1962 (49 yr) Avg. Plain = 2,949

1868-1976 (avg) = 2,302 for Plain

	irrig. rech area	non-irrig rech.
Uplands	2,181	27,000
Plain	7,620	5,500

Note: For Plain, [illegible] of confined acreage is included in recharge area

LOMPOC AREA INFILTRATION

Year	Rain	Lompoc Plain augmented infiltration (precip incr. 19%)	Lompoc Uplands augmented infiltration (precip incr. 19%)
1913-14 *	23.52	8,249	11,274
5	24.83	13,552	21,031
6 *	16.49	2,214	634
7	13.53	1,987	569
8	17.29	5,658	6,506
9	12.71	1,602	459
1920	8.75	0	0
1	13.68	2,091	598
2	16.77	5,113	5,505
3	12.66	1,582	453
4	5.96	0	0
5	12.30	1,433	410
6	12.12	1,359	389
7	16.54	4,872	5,062
8	16.04	4,349	4,098
9	10.36	633	181
1930	9.18	147	42
1	7.66	0	0
2	16.44	4,768	4,869
3	11.24	996	285
4	8.21	0	0
5	17.37	5,741	6,661
6	11.13	951	272
7	20.46	8,977	12,613
8 *	24.75	9,331	13,265
9	12.34	1,450	415
1940	16.11	4,422	4,233
1 *	40.58	23,259	38,891
2	18.53	6,956	8,895
3	15.27	3,543	2,615
4	16.21	4,527	4,426
5	11.35	1,042	298
6	12.45	1,495	428
7	8.83	3	1
8	7.92	0	0
9	13.54	1,994	571
1950	9.70	361	103
1	9.18	147	42
2 *	21.12	6,137	7,388
3	12.06	1,334	382
4	12.38	1,466	420
5	13.08	1,755	502
6	13.74	2,133	610
7	10.01	489	140
8 *	27.39	11,645	17,522
9	7.74	0	0
1960	8.69	0	0
1	8.16	0	0
2 *	24.85	9,419	13,427
Totals		169,180	196,485
Average (49 yrs)		3,453	4,010

* Cloud Seeding operations probably would have been suspended in these years due to flood potential

Also, for the Plain 80% of the confined area is included in the recharge area:

irrigated area = 3,700 + (80%)(4,900) = 7,620
non irrig area = 2,700 + (80%)(3,500) = 5,500

For Uplands irrigated = 2,181 acres
non-irrig = 27,000 "

Santa Ynez Uplands (revised) Infiltration

Year	Los Alamos Rain	unaugmented infiltration	augmented infiltration 9.5% (low)	augmented infiltration 19% (high)
* 1910-11	- 29.05	64,432	64,432	64,432
2	12.26	523	784	1,051
3	8.31	0	0	0
* 4	- 25.86	51,685	51,685	51,685
5	23.02	37,145	48,341	59,819
* 6	15.88	1,464	1,464	1,464
7	19.55	19,380	28,888	38,637
8	19.49	19,073	28,552	38,270
9	12.34	541	803	1,072
1920	11.42	335	578	827
1	11.67	391	639	893
2	18.22	12,571	21,433	30,517
3	13.23	740	1,021	1,424
4	5.38	0	0	0
5	13.13	718	997	1,379
6	12.15	498	757	1,021
7	17.58	9,295	17,845	26,611
8	14.98	1,132	3,269	10,739
9	10.39	105	326	552
1930	10.55	141	365	595
1	9.64	0	142	352
2	17.83	10,574	19,246	28,137
3	11.60	375	622	875
4	8.86	0	0	144
5	18.08	11,854	20,648	29,663
6	13.43	785	1,070	1,514
7	21.51	29,414	39,876	50,601
* 8	19.71	20,199	20,199	20,199
9	12.72	626	896	1,195
1940	15.52	1,328	6,297	14,035
* 1	- 35.21	64,432	64,432	64,432
2	17.73	10,062	18,686	27,526
3	16.37	3,100	11,062	19,224
4	17.36	8,168	16,611	25,268
5	12.25	521	781	1,048
6	13.41	780	1,065	1,505
7	8.92	0	0	160
8	8.08	0	0	0
9	11.68	393	642	896
1950	12.43	561	825	1,096
1	10.20	62	279	501
* 2	21.69	30,336	30,336	30,336
3	12.51	579	845	1,117
4	13.46	792	1,078	1,528
5	13.24	742	1,024	1,429
6	16.79	5,250	13,416	21,788
7	10.27	78	296	520
* 8	- 29.17	64,432	64,432	64,432
9	8.59	0	0	72
1960	12.91	669	943	1,280
1	7.20	0	0	0
* 2	23.27	38,425	38,425	38,425
3	14.18	953	1,330	5,855
4	9.27	0	51	253
5	13.79	865	1,158	3,474
6	12.64	608	877	1,152
Totals		527,134	649,768	791,020
Average (56) yrs		9,413	11,603 (2,190)	14,125 (4,712)

Rain adj. factor = $\frac{15.8}{14.9}$

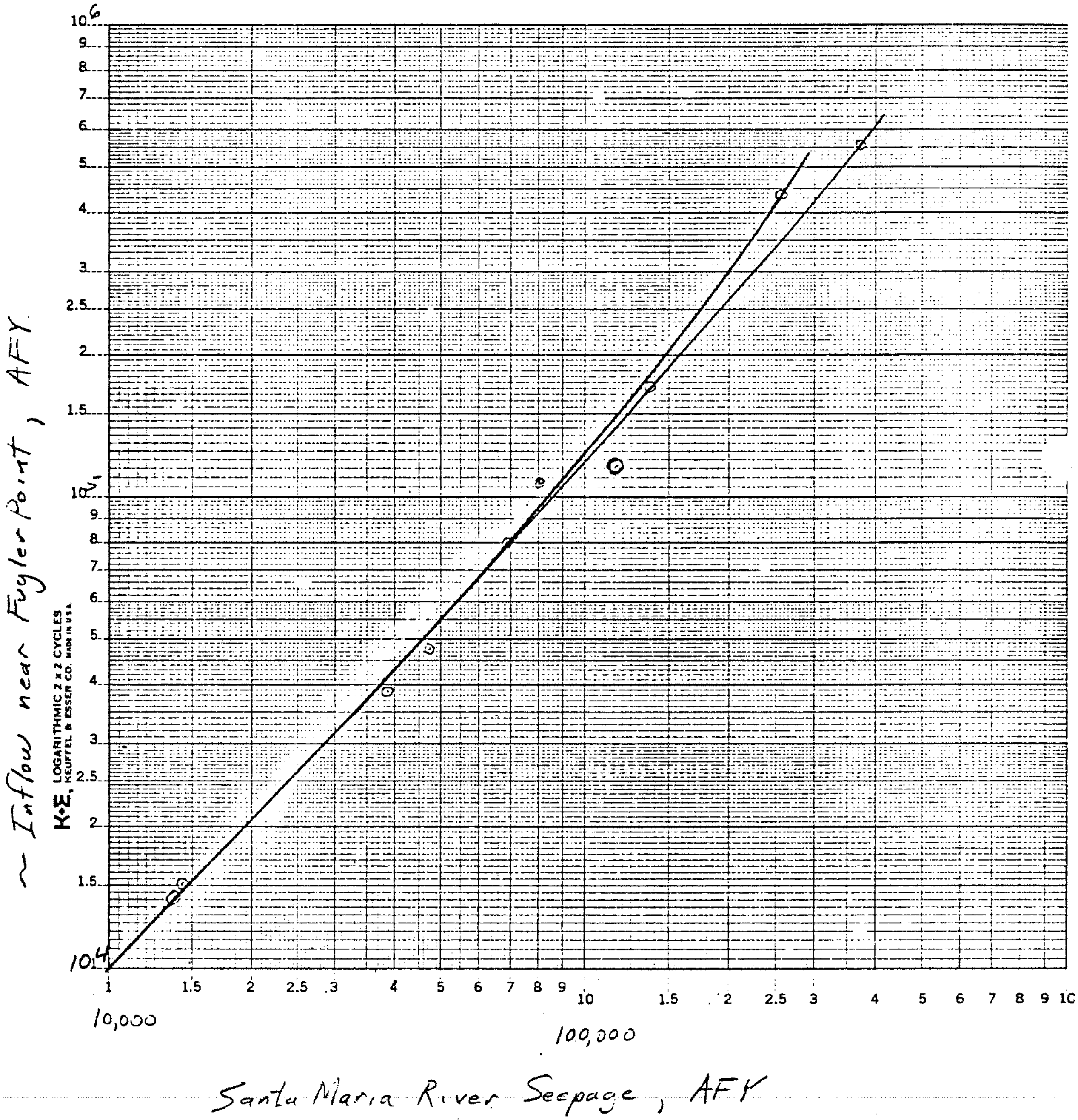
Recharge area: irrigated 4,650
non-irrig. 83,350

Cutoff at 30" precip

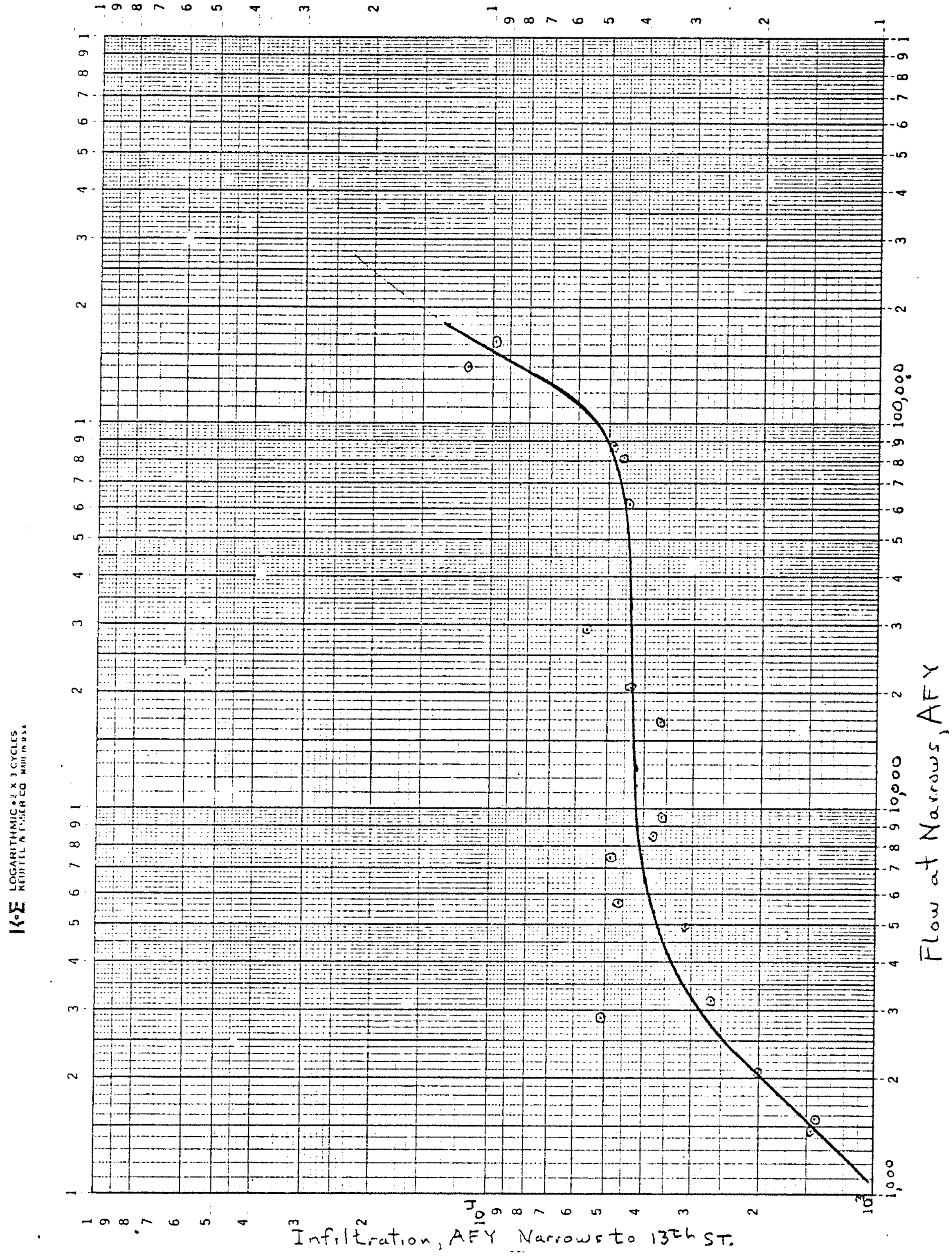
* Flood years - no cloud seeding

Stream Seepage

The following graphs show runoff versus seepage losses for the Santa Maria and the Santa Ynez Rivers. They were derived from USGS stream flow records. With the increase in runoff having been determined, incremental seepage losses were read from these graphs. Unfortunately, figures for other areas of the County could not be determined in this fashion due to the lack of suitable stream gage arrangements necessary for seepage loss calculations.



10^6
9
8
7
6
5
4
3
2.5
2
1.5
10^5
9
8
7
6
5
4
3
2.5
2
1.5
10^4
K·E LOGARITHMIC 2 x 2 CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.
~ Inflow near Fugler Point, AFY
1
1.5
2
2.5
3
4
5
6
7
8
9
10
1.5
2
2.5
3
4
5
6
7
8
9
10
10,000
100,000
Santa Maria River Seepage, AFY


Flow at Narrows, AFY
Infiltration, AFY Narrows to 13th ST.
100,000
10,000
1,000
10
K&E LOGARITHMIC 2 X 3 CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.

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