PRECIPITATION AUGMENTATION POTENTIAL FROM CONVECTION BAND CLOUD SEEDING IN SANTA BARBARA COUNTY

NAWC Report WM-87-7

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ABSTRACT

A statistical analysis of October through April precipitation within a portion of Santa Barbara County in California was made to determine how cloud seeding during this period might have augmented the natural precipitation.

The study covered a 61 year period (through 1980) beginning in 1920. The study covered a portion of the major watershed within the county that supplies most of the water to the City of Santa Barbara and other neighboring communities.

Winter storms were identified by weather type during the historical (non-seeded period), during seeded years in the 1950's and during a research period from 1968 through 1974. The storms identified by weather type during the research period were used to develop seed to no-seed ratios of precipitation amounts which fell during the convection band portion of the storms. These ratios were then applied to similar type storms during the historical period to approximate the augmented precipitation that would have been produced if the convection band portion of these storms had been seeded. These same ratios were also applied to the precipitation totals during the seeded storms of the 1950's and the research period.

Results of the statistical study indicate that if all the convection bands within all the storms in the 61 year period had been effectively seeded the amount of precipitation would have been increased by an estimated 21-22 percent over the totals that actually were observed. This would have represented increases of over 2 inches to over 15 inches of precipitation in the lowest to highest years. On average, these increase were between 3 to 7 inches in the lowest to highest water years.

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1.0 INTRODUCTION

Weather modification, in the form of cloud seeding to augment natural precipitation within winter storms, has been applied in either research or operational programs in Santa Barbara County during the majority of the winter seasons since 1950.

An operational program was begun within the County during the winter of 1950-51 and with the exception of the winters of 1953-54 and 1955-56 cloud seeding to augment winter precipitation continued through the decade of the 50's. The emphasis shifted from operations to research/operations with randomized seeding during the latter part with the winters of 1957, 1958, and 1959 ushering in the Santa Barbara I Cloud Seeding Research Project.

Following the 1959 winter season there was a hiatus in cloud seeding activities until the winter season of 1967-68 when cloud seeding activities were renewed within the County. From January 1968 and through the following six winter seasons (until April 1974) cloud seeding research was resumed. This project was known as the Santa Barbara II Cloud Seeding Research Project. Like the earlier research project, Santa Barbara II also incorporated randomized seeding, but unlike it's predecessor, which utilized ground based silver iodide seeding generators at generally low elevations (near sea-level), the primary seeding mode in Santa Barbara II was from high-output high elevation (4000 foot) silver iodide pyrotechnic flares which were burned at 15 minute intervals during the passage of organized trackable convection bands. In a later phase of the project aerial seeding utilizing a high output silver iodide-acetone seeding generator was also used as one of the seeding modes.

Research in the early 1960's (Elliott and Hovind, 1964) had indicated the presence of organized convection bands which were imbedded within winter storm systems moving into central and southern California. These convection bands contained stronger updrafts, higher cloud tops, abundant moisture, and a very high seeding potential. Furthermore, about one-half of the total storm precipitation was produced within the convection bands making them attractive seeding candidates.

Statistical results obtained during the Santa Barbara II project indicated that seeding convection bands was indeed 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 (Thompson et al., 1975). These increases covered sizable areas downwind from the point of seeding.

Following the end of the Santa Barbara II research project, cloud seeding activities in Santa Barbara County ceased until the end of the decade, with the exception of a short duration operational seeding project in January and February 1978. This seeding project was instituted by Santa Barbara County following the two drought years of 1976 and 1977. Heavy precipitation in January and early February led to a termination of the project because the watersheds were becoming saturated and further augmented precipitation was unnecessary.

In the decade of the 80's interest in cloud seeding within Santa Barbara County has resumed with operational seeding programs conducted during most of the winter seasons since 1981-82. With this renewed interest and an apparent realization that cloud seeding can be a viable approach to augmenting water supplies, North American Weather Consultants (NAWC) received a contract from the Santa Barbara County Flood Water Agency to conduct a study of cloud seeding potential in a climatological sense. This study was focused on the watershed above Lake Cachuma. The study's goal would be to document seeding increases if the seeding technique of seeding all convection bands during all seedable storms was applied. The results of this analysis could then be utilized by the Agency to estimate the additional runoff that would occur over the watershed from the augmented precipitation.

2.0 ANALYSIS APPROACH

The results from the Santa Barbara II Research Project (hereafter referred to as SBA II) suggested that concentrating on seeding the portion of winter storms that contained convection bands was likely to prove to be the most effective way to augment winter precipitation in Santa Barbara County (Brown **et al.**, 1974). Consequently, it was decided to utilize this seeding approach in the statistical analysis of the precipitation data available from the watershed area above Lake Cachuma.

Figure 2.1 is a map of the southeast portion of Santa Barbara County which contains the watershed that drains into Lake Cachuma. The portion of the watershed above Lake Cachuma, which covers approximately 475 square miles, is indicated on the figure by the dashed line along with the many creeks and small streams that converge to form the Santa Ynez River. The watershed is mostly mountainous rising eastward from Lake Cachuma (elevation 780 feet MSL) to a crest line over 5000 feet above MSL (some peaks are 6000 feet) along the eastern boundary of the watershed. The southern boundary of the watershed follows the crest of the coastal mountains just north of Santa Barbara and the other coastal cities along the south coast of the county. The crest line elevation on the southern boundary is between 3000 to 4000 feet with the terrain dropping to near 1000 feet MSL where the Santa Ynez River flows out of the mountains and into the valley above Lake Cachuma. The northern crest of the watershed runs east to west some 18 miles north of Santa Barbara with elevations generally near 6000 feet along the crest.

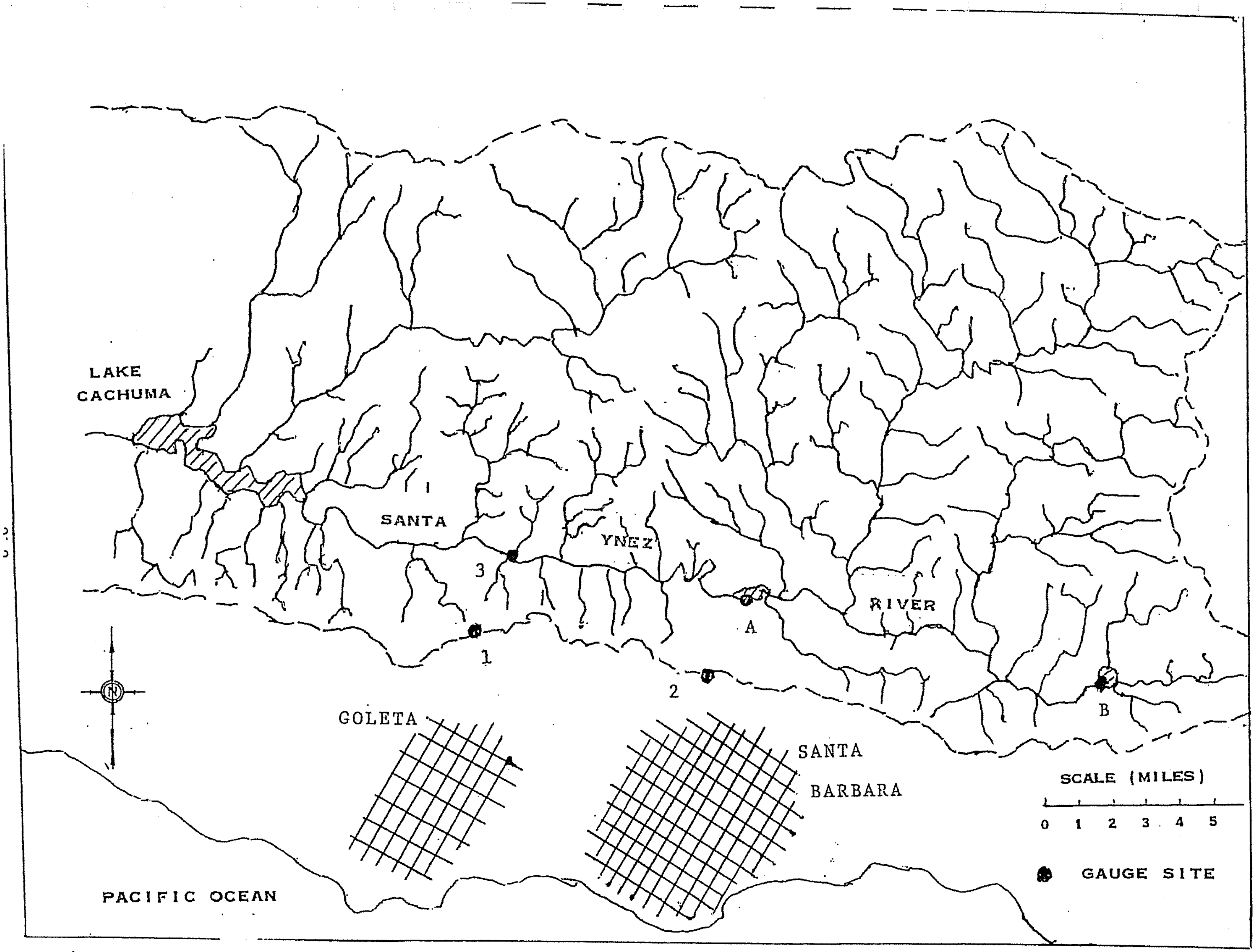

Figure 2.1 Map of watershed above Lake Cachuma in Santa Barbara County.

2.1 Data Selection

The approach that was adopted consisted of a two-step process. First, the percent of precipitation that was (on the average) observed to fall within convection bands during SBA II was determined. Second, this band precipitation percentage was applied to a historical precipitation period (when no seeding had been done) to determine the amount of precipitation that would have occurred if the Santa Barbara II seeding modes had been applied to the storms in the historical period.

Data that were supplied by the Santa Barbara County Water Agency consisted of monthly records showing daily precipitation amounts for six locations within the County. The period of record varied at each location with the longest record dating back to the 1919 water year. Only two of the six locations namely, Gibraltar Reservoir and Juncal Dam were within the watershed above Lake Cachuma, therefore, only those two sites were utilized in the analysis. The precipitation gauge site at Gibraltar Reservoir is indicated in Figure 2.1 by the small black circle labeled A, and the Juncal Dam precipitation gauge at Jameson Lake is the circle labeled B. The period of record from Gibraltar Reservoir dated back to the 1920 water year while the Juncal Dam record began in the 1926 water year. In this context, the term water year as used in this report is defined as the months of October through April, inclusive. The actual water year begins in September and goes through the following August. As a practical matter, very little precipitation falls in Santa Barbara County during any May to September period, therefore the October-April period in general, represents the water year. Over the years these months have received 97 to 98 percent of the annual total and contain all the synoptic storm systems that would contain convection bands affecting southern California.

For comparative purposes, and so that the maximum number of years of record could be used, the record at Juncal Dam was extended to include the water years from 1920 through 1925. This was done by calculating the precipitation amounts at Juncal Dam from regression equations relating Gibraltar Reservoir precipitation and Juncal Dam precipitation in the non-seeded water years between 1926 and 1980. This relationship was very good with a .9827 correlation coefficient(r) for the water year totals at the two sites. Individual storm precipitation totals for the storms that occurred during the 1920-25 water years were calculated from regression equations developed for the individual storm types that occurred during the six water years. This process and the storm typing that was adopted is explained more completely in subsequent sections. Suffice it to say that the calculated Juncal Dam precipitation compared favorably with Gibraltar Reservoir for the period in question.

Because it was desirable to include only the water years without cloud seeding, either operationally or for research, most of the water years of the 50's were excluded from the historical data sample. The exceptions were the water years of 1950, 1954, and 1956 when no seeding was conducted. Likewise, the period from 1968 through the 1974 water year was excluded. This was the SBA II research period. Following the end of SBA II, and through the 1980 water year (the last water year for which storm types were available), the only water year that was excluded because of seeding was 1978. In summary, the non-seeded water years in the data sample totaled 46: 1920-1950, 1954, 1956, 1960-67, 1975-77, and 1979-80. Section 4.9 contains a separate discussion on the seeded years.

2.2 Storm Typing

It was necessary to adopt an objective scheme to classify the storms in the historical not-seeded and SBA II research periods so that the percent of precipitation which occurred during each storm type during the research period could be applied to a similar type storm in computing the seeded increase during the historical period. Fortunately, such a scheme was in existence with a catalogue which typed weather systems back to 1920. This typing system, developed by a team of meteorologists at the California Institute of Technology (C.I.T. or more familiarly Cal Tech) during the World War II years, allows one to go back through time and recreate an approximate synoptic weather map for any 3-day period in the region of the eastern Pacific Ocean and western North America (Elliott, 1951).

2.2.1 Phases of a Weather Type.

The Cal Tech weather types possess both spatial and temporal extension, i.e., they are not designed for one spot, nor are they snapshot pictures of the synoptic situations. Experience has shown that the most practical spatial dimension for a weather type is a 45° longitude sector of the westerlies. Accordingly, the Pacific Ocean and western North America was divided into segments 15 degrees of longitude wide for each phase of the storm cycle. The East Pacific Zone (Zone 2) begins at the International Date Line (180 degrees) and extends eastward to 135 degrees W longitude where the North American Zone (Zone 3) begins. This in turn extends eastward to 90 degrees W longitude, etc. Within these zones each phase constitutes 15 degrees of longitude representing the approximate daily eastward movement of a synoptic cyclone (winter storm system) moving across the Pacific and North America. Specifically, phase 1 of Zone 3 begins at 135 degrees W longitude, phase 2 begins at 120 degrees, and phase 3 begins at 105 degrees. Weather types were developed for each sector separately on the basis of the mean steering pattern, storms tracks, large polar outbreaks, and other important mechanisms controlling the large features of the weather during the lifetime of the type.

On average, cyclone families are spaced about 45 degrees of longitude apart. Therefore, a given cyclone family will move through a sector in 3 days. The first day of the type occurs on the day the first cyclone family crosses the zone boundary from the west. The longitude of this boundary is the phase 1 position. Subsequent phase positions are fixed 15 degrees of longitude apart. This scheme is based upon the average 15 degree per day movement of cyclone families.

2.2.2 Weather Types

Approximately 15 weather types were developed to cover the synoptic situations affecting the eastern Pacific and North America. Basically, these consist of five or six major types and a number of related sub types. It is not the intent of this report to discuss the details of each weather type or the weather generally associated with it but some general knowledge of the typing scheme is useful for a better understanding of the methodology used in performing this statistical analysis.

Type A, AO - Prior conditions show a persistent deep low at about 50-55 degrees N and 170-180 degrees W. The peak of the warm sector breaks off and moves southeastward as a wave between Polar high pressure in Alaska and high pressure centered in the Pacific 800-1000 miles west of northern California. The A type generally produces only light amounts of precipitation in southern California. Type AO (where the low pressure system is moving toward southern California offshore) can produce copious amounts of precipitation if the upper low track has been offshore for a significant time allowing the system to acquire Pacific moisture.

Type B - Prior conditions show a northerly (above 50 N) zonal track into the Gulf of Alaska. The B type is nearest to a pure zonal type with the storm track around 55-60 N. High pressure is centered 1200-1500 miles west of central California. Storm fronts trail through southern California as the system moves eastward. The B type generally produces light to moderate precipitation amounts. There are several other B sub types but these generally do not produce stormy weather in southern California.

Types C, F - These are related types with split upper flow and a strong high centered over the Great Basin. With sub type Ch the Basin high is stronger and further north than with sub type Cl. the C types have a northerly storm track (above 50 N) entering British Columbia and a southerly storm track (between 30-35 N) entering southern California. In type F, the northern low splits in the Gulf of Alaska with one center moving into British Columbia and the other plunging southeastward off California with both centers passing around the Great Basin high. These types usually produce moderate to heavy amounts of precipitation in Southern California.

Type D - This type is characterized by a large saddle shaped high over the mid-Pacific and Alaska. Storms move from southwest to northeast into the Pacific Northwest with a weak high in the Great Basin. This weather type generally produces only light to moderate precipitation amounts in southern California.

Type E - The E types, of which there are several, are generally characterized by high pressure covering Alaska and the northwest portions of Canada with weak high pressure in the Pacific centered at low latitude (30 degrees N). The storm track is between these highs (generally 40-50 N) with storm systems (Lows) entering North America at these latitudes. The E types vary from E North (En) which has the northern most trajectory through E High (Eh), E Medium (Em), and E Low (El). The E types are the most frequent storm types in southern California and all of the sub types except (En) are capable of producing anywhere from light to heavy amounts of precipitation. A special case of an E is E Jetstream (Ej) sub-type, wherein a trailing frontal zone is maintained across Oregon or California under a strong west-southwest to east-northeast oriented jet-stream. This type can produce flood proportion precipitation as new frontal waves move northeastward across the region where the jet-stream is stationary.

2.2.3 Santa Barbara II Storm Typing

With this brief background, the storm periods which occurred during SBA II were identified and classified as to storm type from the existing catalogue of storm types. Then the precipitation amounts that were recorded as occurring within convection bands for all of the storm periods at the Gibraltar Reservoir and Juncal Dam sites were identified and tabulated as to whether they were in seeded or not-seeded bands along with the storm type in which they occurred. The daily storm total data for the Gibraltar Reservoir and Juncal Dam sites provided by the Agency were from the identical locations as the precipitation gauge locations used in the research project.

The results of these tabulations are shown in Table 2-1, which lists the number of storms for each storm type that occurred during SBA II, the number of seeded and not-seeded bands that occurred with each storm type, the median value of storm total for each type at each of the precipitation

Table 2-1

Santa Barbara II Research Precipitation Statistics

				< GIBRALTAR RESERVOIR >			< JUNCAL DAM >		
STORM TYPE	NO. OF STORMS	NO.OF SEEDED	CONV.BAND NOT SEED	MED STM PCPN-IN	PCPN IN BANDS-PCT	S/NS RATIO	MED STM PCPN-IN	PCPN IN BANDS-PCT	S/NS RATIO
A	18	23	21	1.35	59	1.31	1.49	63	1.27
B	8	6	6	0.65	72	1.31	0.48	70	1.22
C	7	13	9	2.09	47	1.23	2.18	52	1.28
D	11	7	8	0.39	62	1.16	0.51	65	1.15
E	36	45	44	0.95	44	1.64	1.13	44	1.63
TOTAL	80	94	88						
AVERAGE				1.09	57	1.33	1.16	59	1.31

sites (the median was used instead of the average because the average was typically top-heavy due to the affect from one or more abnormally heavy storms), the percent of the total storm precipitation that occurred within each convection band for each of the storm types, and the seed to no-seed ratio for each of the storm types at the precipitation gauge locations.

There were 80 storms during the research period in which 182 convection bands (of which 94 were seeded) were identified within the storms. The A and Ao types (of which there were 18 storms) were combined because the catalogue listed them that way. The relatively rare C and F types were combined for the same reason. The E sub-types were combined into one group to improve the sample size since, with the exception of En and Ej there is not a significant difference between these storm types as far as the synoptic pattern is concerned. Within the E type classification the 36 storms consisted of 14 classified as El, 17 Em types, 3 typed Eh, and one each for En and Ej.

2.3 SBA II Precipitation Statistics Procedures

The procedures used to determine the percent of precipitation which occurred within convection bands during SBA II and the resulting seed to no-seed ratio that was calculated for each storm type are described in the sections that follow.

2.3.1 Seed to No-Seed Ratios

Precipitation for each of the seeded and not-seeded convection bands that occurred during the project were totaled for each category in each of the storm types that were observed. These totals were then averaged to determine the average convection band precipitation observed to fall during both the seeded and not-seeded band periods for each of the five major storm types. The convection band seed to not-seed ratio for each storm type was then determined by dividing the average seeded band precipitation by the average not-seeded band precipitation. For example, at Gibraltar Reservoir there were 18 storm periods classified as storm type A or Ao. During these 18 storms there were 23 convection bands which were seeded and 21 convection bands which were not seeded. The precipitation in the 23 seeded bands averaged .699 inches while the 21 not-seeded bands had an average precipitation of .535 inches. Dividing the not seeded average into the seeded average produced a ratio of 1.31.

At Juncal Dam, for the same storm type with the same number of seeded and not-seeded convection bands, precipitation in the seeded bands averaged .838 inches while the precipitation in the not-seeded band category averaged .659 inches which produced a seed to no-seed ratio of 1.27. The seeding ratios shown in Table 2-1 for the other storm types were produced in a like manner. Juncal Dam is located about 10 miles east of Gibraltar Reservoir and at 2076 feet MSL is 525 feet higher than Gibraltar.

In spite of their semi-mountainous locations, these ratios were in relatively close agreement between the two precipitation gauge sites for the same storm type. However, the ratios at both sites differed considerably from one storm type to another suggesting that (at least on average) the physical composition of the storms (by type) affected the seedability of the storms. For example, the seed to no-seed ratios varied from a high of greater than 1.6 with the E type storms to a low of 1.15 with the D type storms indicating the E storms were considerably more affected by seeding than were the D storms. This could be because of differences in temperature ranges in the clouds within the two storm types or possibly the availability of more supercooled liquid water in one type than the other. These kinds of information were not investigated and are not readily available in a study of this kind utilizing historical data. Some of these differences in ratios might be attributed to the sample size with only 15 convection bands in the D storm sample versus 89 convection bands in the E storm sample. Likewise, there were only 12 bands in the B storm sample but the seed to no-seed ratios were somewhat higher than with the D storms. Although it is not shown in Table 2-1, the seed to no-seed ratios for the E storm sub types El and Em (the most common of the E types to affect southern California) were above 1.7 while the ratio for sub type Eh (which had a total of only four convection bands) was undetermined since there were no not-seeded convection bands in the sample. Obviously, the ratio with the Eh type storm would be lower than the other E type ratios since the combined ratio was slightly higher than 1.6, but it was still much greater than with the other storm types.

Seed to no-seed ratios for the A, B, and C storm types fell between the extremes of the E and D types and were all between 1.22 and 1.31. These ratios were very close to the average ratios for all the storm types which were 1.33 and 1.31 at Gibraltar Reservoir and Juncal Dam, respectively.

2.3.2 Percent of Precipitation by Storm Type

It was reasoned that the total precipitation (TP) that fell within a given storm consisted of precipitation produced by the storm lifting (LP), possibly some orographic storm component (OP) because of the mountainous terrain, and if organized convection existed, the precipitation (BP) that was within the organized convection band portion(s) of the storm, such that the storm total was

$$TP = LP + OP + BP \tag{1}$$

The non convective precipitation (LP) and (OP) can be represented by (SP) so that equation (1) can be written as

$$TP = SP + BP \tag{2}$$

where (BP) was the sum of the precipitation within all the convection bands occurring within the storm. For the storms within SBA II which contained seeded convection bands the seeded storm total (TPs) consisted of

$$TPs = SP + \sum_{n=0}^{N} Bs + \sum_{n=0}^{N} Bns \tag{3}$$

where (Σ Bs) and (Σ Bns) were the total precipitation within all the seeded convection bands and all the not-seeded convection bands, respectively. Therefore, the total precipitation produced within the seeded bands was

$$\sum_{n=0}^{N} Bs = TPs - SP - \sum_{n=0}^{N} Bns \tag{4}$$

where the left side of (4) contained the seeding effect within the seeded convection bands that occurred in each of the storm types. It should be recalled that the seed to no-seed ratio (R) was determined from the relationship

$$R = \frac{Bs}{Bns} \tag{5}$$

Where Bs and Bns were the average precipitation amounts within convection bands for each storm type, so that dividing the left side of equation (4) by the ratio (R) should produce an amount of "approximate natural" band precipitation in the observed seeded bands for each of the storm types.

This approximate "natural" band precipitation was then combined with the natural precipitation observed to fall in the not-seeded convection bands to estimate the total of "modified natural" convection band precipitation for all the convection bands of a given storm type. This "modified natural" band precipitation total was then divided by the sum of all the storm totals to estimate the amount of precipitation that occurred (on average) within the convection bands of a given storm type.

For example, at Gibraltar Reservoir in the A type storms, the 23 seeded convection bands totaled 16.08 inches of precipitation while the 21 not-seeded bands totaled 11.23 inches with a seed to no-seed ratio of 1.31. To remove the "seeding effect" the 16.08 inches was divided by 1.31 to give an approximate "natural" band total of 12.27 inches. This total was added to the 11.23 inches from the not-seeded bands to yield 23.50 inches of precipitation in all of the convection bands observed with the A (or Ao) type storms. The total precipitation attributed to the 18 A type storms at Gibraltar was 39.82 inches. Dividing this number into the total precipitation for all the convection bands revealed that 59 percent of the precipitation observed to fall in the A type storms fell within the convection bands.

Table 2-1 indicates that these values ranged from a low of 44 percent of storm precipitation in bands with all the E type storms (at both Gibraltar and Juncal Dam) to a high of about 70 percent at both sites with the B type storms. For the E sub type storms at Gibraltar, these individual percentages were over 55 percent for the Eh type (but with only 4 bands in 3 storms) to about 38 percent of the precipitation in bands with sub type Em, and 47 percent precipitation in bands for sub type El. The average amount of precipitation observed within all the convection bands at both precipitation sites was slightly less than 60 percent of the storm total precipitation.

In between these extremes, the percent of precipitation which was attributed to the convection bands in the A, C, and D type storms ranged from 47 and 52 percent for the C type storms at Gibraltar and Juncal, respectively, to near 60 percent in the A type storms, and slightly higher in the D storms at both sites. Average precipitation in band percentage for all storm types was 57 percent at Gibraltar and 59 percent at Juncal.

3.0 DATA ANALYSIS

With the data analysis procedure established the next step was to determine what the seeding effect would have been in each of the storms that occurred during the historical period selected for study. In actual practice this meant going through the daily precipitation totals, assigning each precipitation day to a storm type and totaling the precipitation on a storm-by-storm basis for each storm between October 1, and April 30 in each water year. Some months had many storms, as did some years while others had very few.

3.1 Determination of Storm Totals

Most of the time it was easy to define the storm precipitation total since the precipitation all fell within the same storm type classification. This was usually within a three day period although sometimes a storm type would repeat to extend over a much longer time period(as long as a week in some cases). Occasionally, it was more difficult to assign a storm total. An example was when a storm or series of storms extended over several days which embodied two different storm types. Even in these cases it was usually possible to see a trend in the daily precipitation with one day having the highest total of the group and the other days indicating less, suggesting the end of one storm and the beginning of another. In the few cases where the trend between storms was not clear the storm totals were subjectively assigned to one storm type or another but with the same days assigned to the same storms for each of the two precipitation sites.

This inability to accurately define all storm totals was not a serious flaw but it did tend to reduce the "observed" number of storms through the historical period. This was because there was a distinct tendency to call one long storm period (say, 5-7 days) simply one storm if the storm type catalogue did not change from one type to another during the period. In actual fact, there may have been two or three (or more) storms, i.e., frontal passages with clear breaks in the precipitation periods during the whole time period but without recording precipitation records there was no way to determine the actual distribution. This conservative approach has likely under-estimated the number of storms affecting the region during some of the water years but this would not have any pronounced effect on the calculated increase in precipitation or the percent increase due to seeding.

3.1.1 Calculation of Seeding Effect

Once the storm type had been assigned and the storm totals determined the remaining step was the calculation of the estimated seeding effect that would have occurred if the storm had actually been seeded in the manner utilized during SBA II. The best way to explain the procedure that was used is to use the actual data from a portion of a water year and describe the steps that occurred in calculating the estimated seeding effect. A portion of the precipitation record from Gibraltar Reservoir for the 1920 water year has been selected to do this.

The record showed there was one storm in October 1919 with a total of 0.30 inches recorded on the 24th. From the catalogue of storm types this fell within the period of a B type storm pattern over the eastern Pacific and western North America. Table 2-1 indicated that for Gibraltar Reservoir the percent of precipitation within bands for this type storm was 72 percent with a seed to no-seed ratio of 1.31. Multiplying the storm total (0.30 inches) by the percent of in-band precipitation (.72) provided an estimate that .216 inches of the storm total fell within one or more convection bands during the storm. The remainder of the storm total (0.084 inches) was estimated to be from clouds without any convection bands. Applying the seeding effect ratio (1.31) to the portion of the precipitation attributed to the convection bands gave an estimate of 0.282 inches that would have been produced within the convection bands if seeding had been done. The sum of the precipitation total in the "seeded" portion (0.282 inches) plus the unseeded storm precipitation (0.084 inches) was 0.366 inches (rounded off to 0.37 inches) compared to 0.30 inches actually recorded during the storm. In this case the estimated seeding increase (0.07 inches) amounted to a 23 percent increase in precipitation at the Gibraltar Reservoir site.

A more dramatic but by no means unusual storm occurred between December 3-6 of the same year when a total of 4.50 inches were recorded over the four days. Daily totals were 1.40, 1.00, 0.90, and 1.20 inches, respectively. This example is one of a moderately long storm period that may have actually contained more than one frontal passage, probably contained several convection bands, and likely could have been considered as more than one storm. However, since the storm catalogue indicated an E type storm pattern (actually E1) for nine days (from December 1-9) it was classified as only one E type storm. The estimated seeded increase from this "storm" was 1.27 inches (3.25 inches produced within the convection bands plus 1.98 inches which fell in the non banded portions of the storm). This increase was considerably greater in precipitation total than with the earlier B storm but the percent increase over the natural total with the E storm was only about five percent greater than the increase with the B storm.

Each storm period during the water year was treated in this same manner with the monthly natural and "seeded" precipitation totals tabulated and summed for the water year. Every precipitation period which indicated any amount of precipitation (0.01 inch or more) was processed even though the small amounts contributed very little to the seeding effect. This was done because inspection of the precipitation data from the two precipitation sites occasionally indicated that for a given storm period one of the sites might have shown a small precipitation amount, say around 0.01-0.05 inch, while the other site recorded 0.10 inch or more. It is questionable whether storms of this nature would have been seeded in actual fact but this procedure eliminated the need to establish a minimum cut-off point.

Infrequently, one precipitation site would indicate precipitation while the other site would not. If the indicated precipitation amount was small it was assumed that the data were accurate and the site indicating no precipitation had received a trace or less. In that case the storm type at the site reporting some precipitation was processed and the storm type counted. However, the storm type was not counted at the other site reporting no precipitation. This procedure is responsible for the fact that the data summaries indicate slightly different averages for the storm types in some cases. In a very few cases, one of the precipitation sites reported considerable precipitation for a storm period while the other site reported no precipitation. When this happened it was assumed the data were missing at the site reporting zero precipitation. In these cases the storm total at the missing data site was estimated by utilizing the precipitation relationship established between the two sites from the linear regression computations that were made for each of the storm types.

4.0 RESULTS

The results from this statistical approach in determining the estimated increase in precipitation amounts at Gibraltar Reservoir and Juncal Dam are given in the several tables and figures that follow in this section. These results assume that all possible convection bands that had occurred within all the storms passing through Santa Barbara County during the historical sample period had been seeded. In reality this is unrealistic as there would be a number of factors such as implimenting suspension criteria during certain water years, the ability to identify and react to each and every convection band that came along within every storm, the orientation and movement of the convection bands from the seeding platform to affect the desired watershed area, the seedability of all the storms, etc., that would likely make it impossible to have seeded all the seedable portions of every seedable storm. Nevertheless, it is probable that a significant portion of most of the storms included in the data set could have been effectively seeded to yield a significant increase in precipitation over the watershed.

4.1 Precipitation Statistics in the Historical Years

Table 4-1 contains a listing of the October-April precipitation statistics for the Gibraltar Reservoir gauge site between the water years of 1920 and 1980. This record covered 46 years with the years in which actual cloud seeding had taken place eliminated, as described in Section 2.1. Thus there are gaps in the water year listings after the 1950 water year, when seeding activities began in the County. The table is arranged by water year (column 1) starting in 1920. Column 2 contains the total precipitation (in inches) for the water year period between October and April, column 3 displays the total precipitation (in inches) that would have occurred if all the convection bands in all the storms had been seeded, column 4 has the calculated amount of precipitation (in inches) that seeding would have produced (the difference between columns 3 and 2), and column 5 shows the seasonal percent increase due to seeding.

The additional columns (6-11) in the table contain the number of storms by each storm type, and the total number of storms within each water year. A similar listing is displayed in Table 4-2 for the Juncal Dam site.

4.2 Natural and Seeded Precipitation

One of the points of interest in Table 4-1 is the comparison of the average and median precipitation values for the natural precipitation and the "seeded precipitation" columns. The average natural (non-seeded) precipitation at Gibraltar Reservoir for the 46 water years was nearly 24 inches (23.73 inches) but the median was less than 21 inches (20.44 inches). These same trends are reflected in the calculated seeded precipitation totals where the average was nearly 29 inches (28.89 inches) but the median was close to 25 inches (25.22 inches). The average annual increase in precipitation due to seeding was calculated to be over five inches (5.16 inches) but the median value was less than five inches (4.58 inches). These differences appear because of the large variability in precipitation total from one water year to another, with large standard deviations from year to year. This can be readily seen in Figure 4.1 which contains a plot of the natural seasonal precipitation (in inches) at Gibraltar Reservoir (top curve) and

Table 4-1

Gibraltar Reservoir Precipitation Statistics and Storm Types

GIBRALTAR RESERVOIR SELECTED WATER YEARS (OCTOBER-APRIL), 1920-1980

WATER YEAR	NATURAL PCPN-IN	SEEDED PCPN-IN	INCREASE (INCHES)	PERCENT INCREASE	CTT "A"	STORM "B"	TYPES "C"	(NO. OF "D"	STORMS) "E"	STORM TOTAL
1920	20.44	25.49	5.05	24.71	5	4	1	0	5	15
1921	18.75	22.96	4.21	22.45	7	3	1	0	9	20
1922	40.89	48.98	8.09	19.78	8	2	0	1	8	19
1923	22.24	26.75	4.51	20.28	3	6	2	1	8	20
1924	10.40	12.28	1.88	18.06	2	7	4	0	2	15
1925	14.86	17.67	2.81	18.91	4	5	1	1	8	19
1926	28.05	35.23	7.18	25.60	2	6	1	0	6	15
1927	28.55	36.33	7.78	27.25	3	4	1	0	10	18
1928	19.79	23.61	3.82	19.31	3	3	4	3	3	16
1929	19.42	24.44	5.02	25.85	4	0	0	0	7	11
1930	17.02	20.16	3.14	18.44	1	2	0	4	5	12
1931	13.95	16.19	2.24	16.06	1	1	7	1	3	13
1932	32.85	38.65	5.80	17.66	5	1	2	5	7	20
1933	15.96	19.08	3.12	19.55	5	2	1	0	4	12
1934	18.42	22.68	4.26	23.13	2	1	2	1	6	12
1935	29.46	36.20	6.74	22.88	5	1	4	1	12	23
1936	21.38	26.18	4.81	22.45	3	0	2	1	9	15
1937	36.14	43.81	7.66	21.20	9	3	1	1	10	24
1938	40.93	49.41	8.48	20.72	0	1	1	6	16	24
1939	19.81	23.08	3.27	16.51	8	0	2	0	4	14
1940	18.13	22.74	4.61	25.43	2	2	2	0	16	22
1941	66.64	81.47	14.83	22.25	2	0	7	0	14	23
1942	18.87	23.19	4.32	22.89	2	4	4	0	11	21
1943	37.71	46.25	8.54	22.65	5	0	4	1	8	18
1944	29.39	34.50	5.11	17.39	6	4	6	0	9	25
1945	21.07	26.39	5.32	25.25	6	2	0	0	7	15
1946	25.28	31.55	6.27	24.80	3	2	1	2	9	17
1947	18.58	22.35	3.77	20.29	4	2	4	0	9	19
1948	11.64	14.43	2.79	23.97	7	2	2	1	7	19
1949	13.67	15.63	1.96	14.34	6	1	9	0	5	21
1950	16.53	20.27	3.74	22.63	5	2	0	1	7	15
1954	20.44	24.96	4.52	22.11	4	1	1	3	8	17
1956	21.82	27.07	5.25	24.06	4	3	2	0	9	18
1960	14.97	18.11	3.16	21.19	4	6	1	0	6	17
1961	12.10	14.76	2.66	21.98	6	3	0	1	7	17
1962	36.15	45.23	9.08	25.12	5	6	0	2	6	19
1963	17.83	22.37	4.54	25.46	4	1	0	0	7	12
1964	14.62	18.06	3.44	23.53	5	1	1	0	8	15
1965	22.65	27.14	4.49	19.82	5	4	2	1	6	18
1966	29.70	34.38	4.68	15.76	5	2	0	3	2	12
1967	39.73	47.23	7.50	18.88	9	2	0	5	5	21
1975	27.54	33.41	5.87	21.31	2	6	1	1	7	17
1976	15.05	18.96	3.91	25.98	5	1	0	0	5	11
1977	10.09	12.64	2.55	25.27	2	5	0	1	3	11
1979	27.10	32.93	5.83	21.51	9	0	1	0	6	16
1980	34.87	43.71	8.84	25.35	4	5	3	1	6	19
TOTAL	1091.48	1328.93	237.45	999.99	201	119	88	49	335	792
AVERAGE	23.73	28.89	5.16	21.74	4.4	2.6	1.9	1.1	7.3	17.2
MEDIAN	20.44	25.22	4.58	22.18	4	2	1	1	7	17

Table 4-2

Juncal Dam Precipitation Statistics and Storm Types

JUNCAL DAM SELECTED WATER YEARS (OCTOBER-APRIL), 1920-1980

WATER YEAR	NATURAL PCPN-IN	SEEDED PCPN-IN	INCREASE (INCHES)	PERCENT INCREASE	CTT "A"	STORM "B"	TYPES "C"	(NO. OF STORMS) "D"	"E"	STORM TOTAL
1920	22.48	28.21	5.73	25.49	5	4	1	0	5	15
1921	19.77	24.03	4.26	21.55	7	3	1	0	9	20
1922	41.53	49.35	7.82	18.83	8	2	0	1	7	18
1923	24.53	29.67	5.14	20.95	3	5	2	1	8	19
1924	11.79	13.99	2.20	18.66	2	7	4	0	2	15
1925	15.78	18.67	2.89	18.31	4	5	1	1	8	19
1926	34.53	42.99	8.46	24.51	2	6	1	0	6	15
1927	34.20	42.76	8.56	25.03	3	3	1	0	9	16
1928	19.63	23.44	3.81	19.41	3	3	4	4	3	17
1929	19.48	24.21	4.73	24.28	4	0	0	0	7	11
1930	16.07	19.09	3.02	18.79	1	2	0	4	5	12
1931	17.35	20.53	3.18	18.33	1	1	7	1	4	14
1932	35.58	42.12	6.54	18.38	5	3	2	5	7	22
1933	16.79	20.04	3.25	19.36	5	2	1	0	5	13
1934	21.52	26.38	4.86	22.58	3	1	2	1	6	13
1935	29.94	36.74	6.80	22.71	6	1	3	1	12	23
1936	24.32	29.75	5.43	22.33	3	0	2	2	9	16
1937	40.35	48.58	8.23	20.39	8	3	1	1	10	23
1938	47.42	56.89	9.47	19.97	0	1	1	6	17	25
1939	19.08	22.54	3.46	18.13	10	0	2	0	6	18
1940	19.35	24.31	4.96	25.63	1	2	2	0	15	20
1941	66.26	81.74	15.48	23.36	4	0	7	0	14	25
1942	20.48	25.33	4.85	23.68	2	5	4	0	12	23
1943	40.68	50.32	9.64	23.69	5	0	4	1	8	18
1944	30.48	35.79	5.31	17.42	5	5	6	0	8	24
1945	24.97	31.16	6.19	24.79	7	2	0	0	9	18
1946	28.86	35.97	7.11	24.64	4	4	2	2	9	21
1947	24.03	28.99	4.96	20.64	4	2	4	0	9	19
1948	12.72	15.59	2.87	22.56	5	0	2	1	7	15
1949	13.77	16.11	2.34	16.99	7	1	9	0	4	21
1950	18.85	23.07	4.22	22.39	5	0	0	1	6	12
1954	25.33	30.78	5.45	21.52	3	1	1	2	8	15
1956	22.74	27.92	5.18	22.78	3	3	2	0	8	16
1960	15.50	18.46	2.96	19.10	4	6	1	0	6	17
1961	11.98	14.47	2.49	20.78	6	1	0	1	6	14
1962	43.62	54.53	10.91	25.01	5	5	0	2	5	17
1963	17.28	21.53	4.25	24.59	5	1	0	0	7	13
1964	17.61	21.54	3.93	22.32	5	1	1	0	8	15
1965	23.25	27.83	4.58	19.70	5	2	2	1	5	15
1966	31.74	36.58	4.84	15.25	4	2	0	2	2	10
1967	46.25	54.60	8.35	18.05	10	2	0	4	5	21
1975	31.31	37.89	6.58	21.02	3	6	1	1	7	18
1976	16.79	21.02	4.23	25.19	4	2	0	0	4	10
1977	10.83	13.45	2.62	24.19	2	4	0	1	3	10
1979	29.35	35.33	5.98	20.37	8	0	1	0	7	16
1980	39.14	48.97	9.83	25.11	3	4	3	0	6	16
TOTAL	1195.31	1453.26	257.95	988.76	202	113	88	47	333	783
AVERAGE	25.98	31.59	5.61	21.49	4.4	2.5	1.9	1.0	7.2	17.0
MEDIAN	23.00	28.06	4.96	21.54	4	2	1	1	7	16

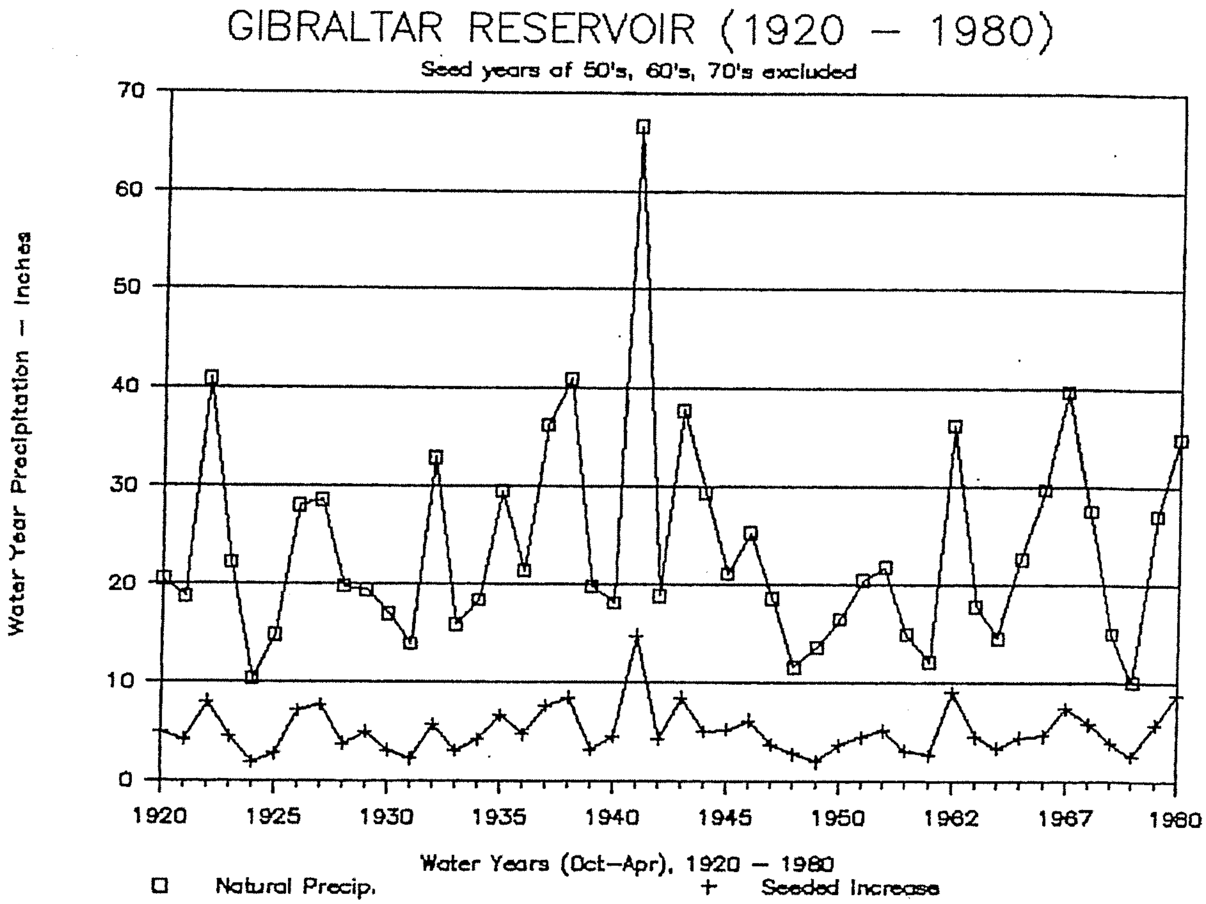

Figure 4.1 Natural Water Year Precipitation (inches) and "Seeded" Increase (inches) at Gibraltar Reservoir.

the calculated seeding increase[1] (in inches) for the same water years listed in Table 4-1. These plots are from columns 2 and 4, respectively, in Table 4-1.

As would be expected, similar results are also seen in the data covering the same 46 year period at the Juncal Dam location (Table 4-2). The difference between the average and the median for the natural precipitation which fell at Juncal during the historical period was nearly three inches (slightly less than at Gibraltar) while these differences were even greater (about 3.5 inches) for the calculated precipitation totals expected from seeding. The table indicates the median value of precipitation increase was 4.96 inches but the average was much higher at 5.61 inches. Figure 4.2 plots the data contained in columns 2 and 4 in Table 4-2 at Juncal Dam. The result is nearly a carbon copy of the plot of the data at Gibraltar (except for the small differences in annual total) with the same large differences in annual precipitation total evident at both locations.

Because of this large seasonal variability, the average values of these precipitation data appear to be less representative than the medians. Consequently, much of the discussion that follows pertains to the median values of precipitation rather than the averages.

4.3 Seeded Percent Increase

Perhaps the most interesting data in Table 4-1 and Table 4-2 are contained in column 5. This column lists the percent

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[1]Note: when the term seeding increase is used throughout the remainder of this report it should be understood that this is an estimated increase.

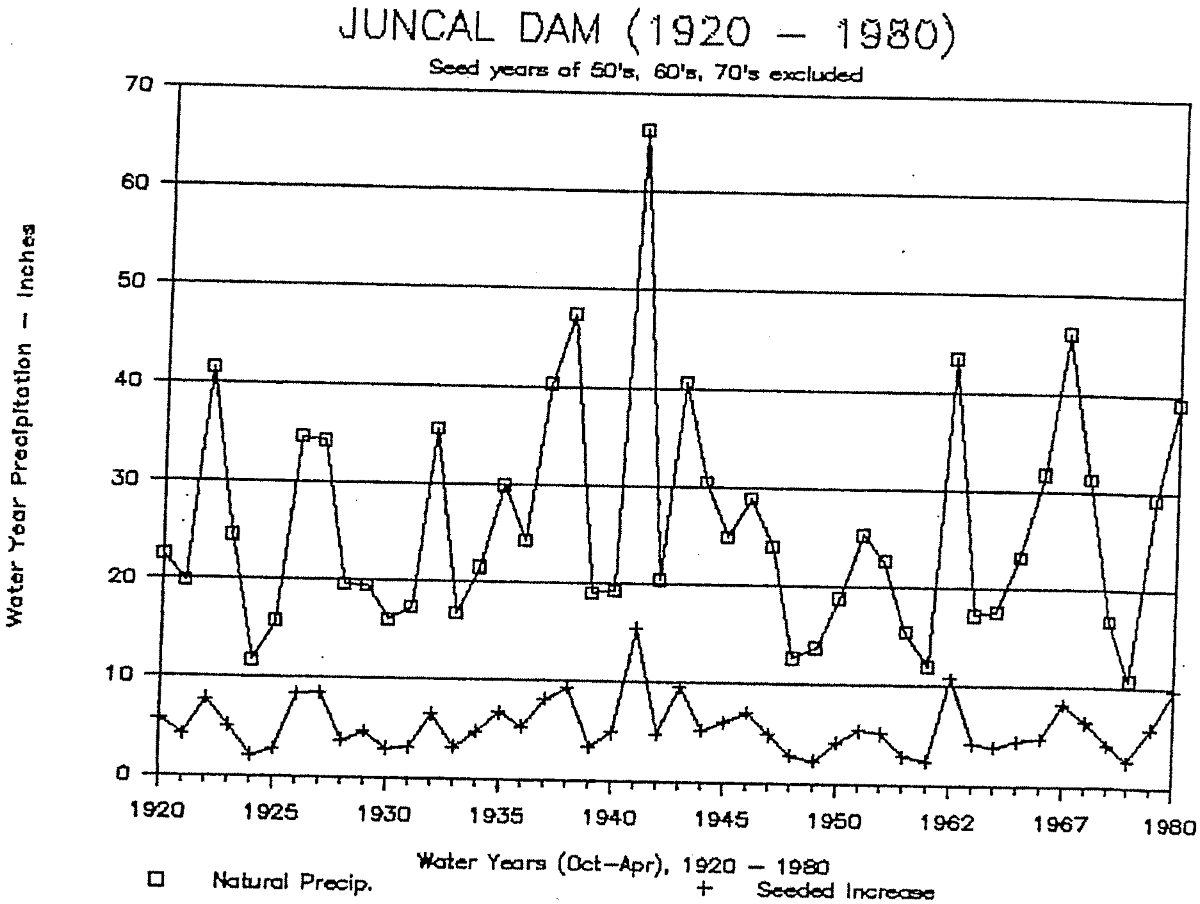

Figure 4.2 Natural Water Year Precipitation (inches) and "Seeded" Increase (inches) at Juncal Dam

increase in seasonal precipitation that would have been attained if all the convection bands in all the storms had actually been seeded. At Gibraltar this increase due to seeding averaged 21.7 percent with the median value even greater at 22.2 percent. These values were slightly higher than at Juncal Dam where both the average and median values of the percent increase due to seeding were 21.5 percent. The annual differences between the two sites was usually small (less than one percent) but differed (in both directions) by over two percent in a few years. Over the entire data sample the annual percent increase at Gibraltar was larger than at Juncal Dam in over twice as many of the years (31).

While the median and average percent increases were both about 22 percent these numbers varied considerably from one season to another with differences of six percent or more occurring frequently. At Gibraltar Reservoir, in the extreme cases, the difference between the indicated percent increase in 1948 and 1949 was 9.6 percent less, while at Juncal Dam the greatest yearly variation was 7.5 percent, between 1939 and 1940. Figure 4.3 contains plots of the data from column 5 and from column 4 from Table 4-1 at Gibraltar Reservoir. These are the percent increase due to seeding for each historical water year (top curve) and the seeded increase in inches (bottom curve) for the same water years. The bottom curve is the same data as contained in the bottom curve in Figure 4.1. Figure 4.4 contains the same data for Juncal Dam from columns 5 and 4 in Table 4-2.

The plots clearly illustrate the large seasonal variation in percent increase from year to year. The character of the top curves in these figures resembles the top curves in Figures 4.1 and 4.2, which are of the annual precipitation total,

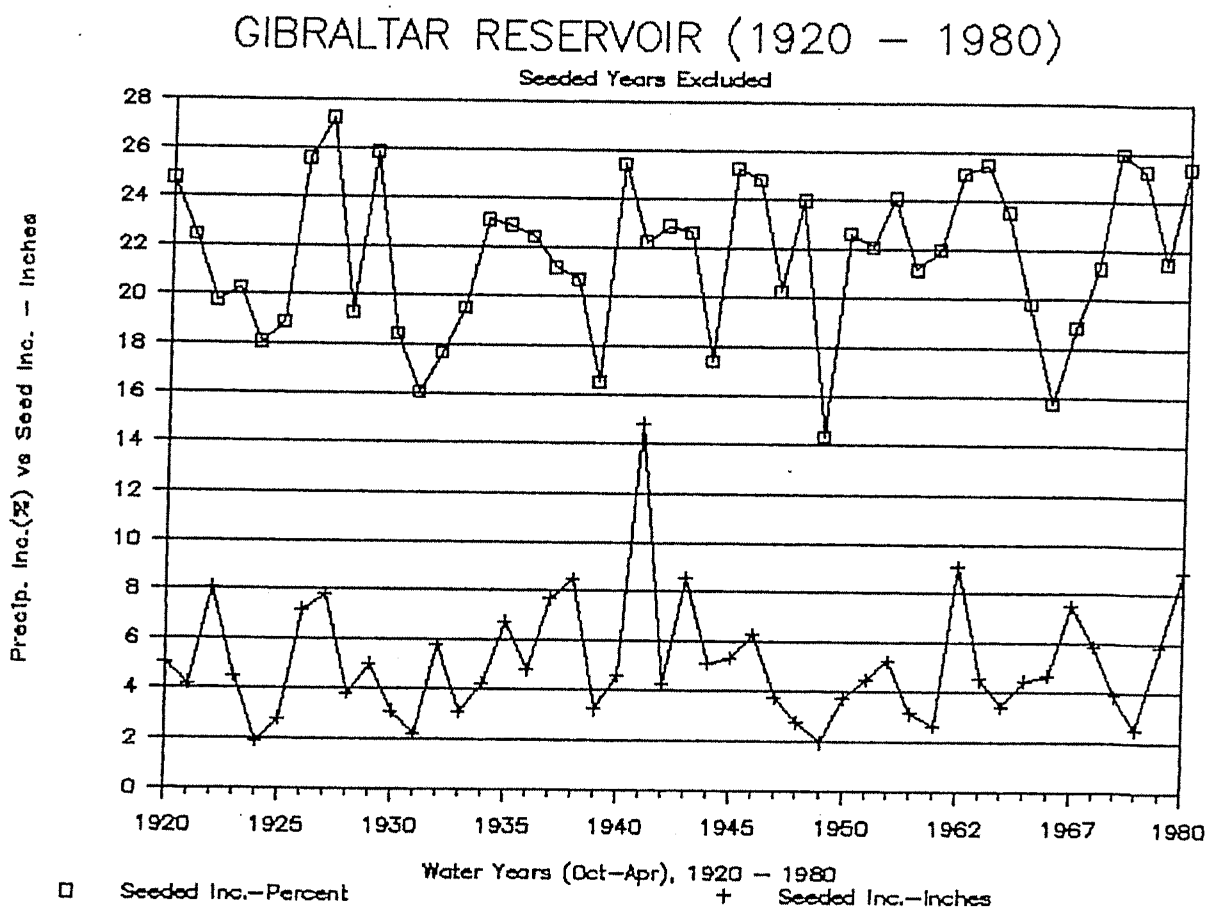

Figure 4.3 "Seeded" Increase (percent) and "Seeded" Increase (inches) by Water Year at Gibraltar Reservoir.

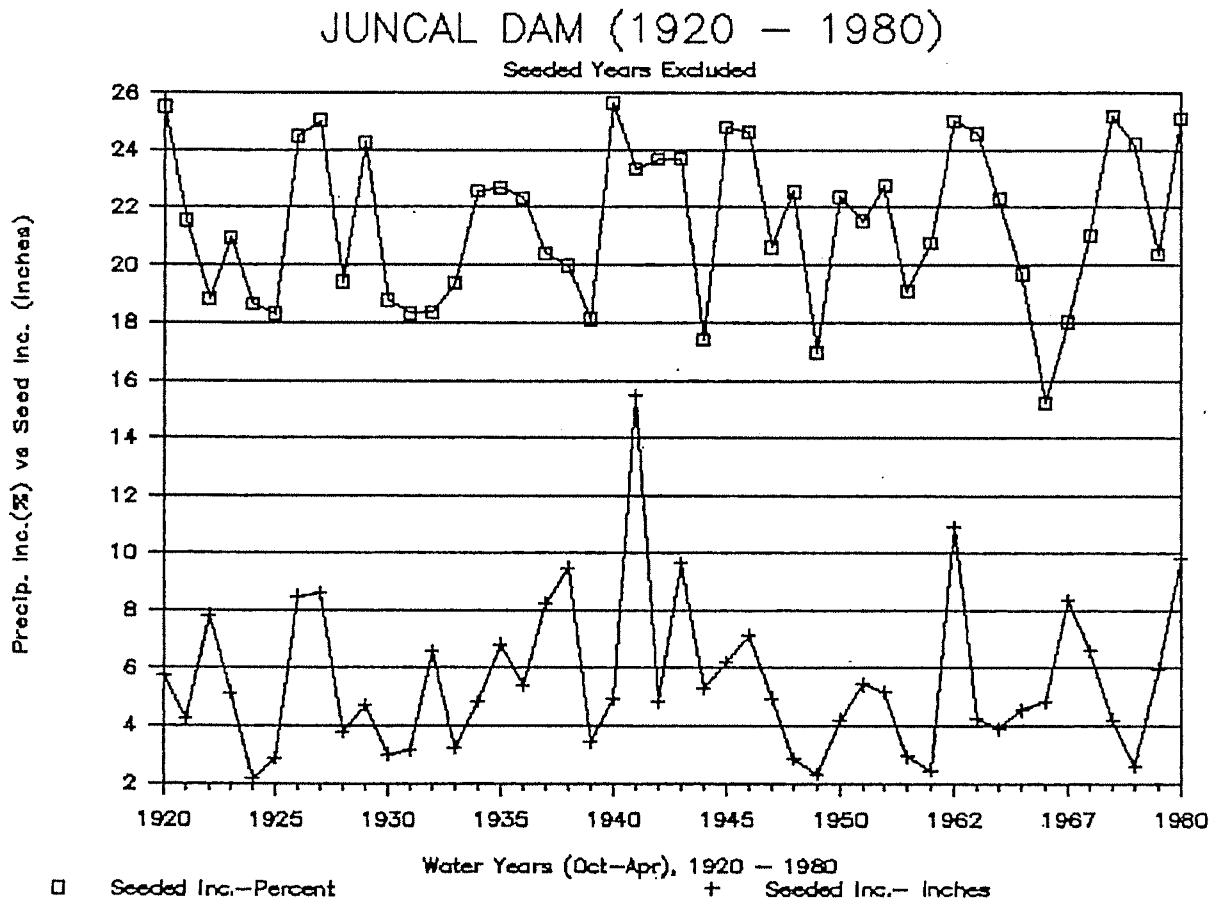

Figure 4.4 "Seeded" Increase (percent) and "Seeded" Increase (inches) by Water Year at Juncal Dam

with both sets of data showing large deviations from the mean. However, in the case of the percent increase plots these fluxuations were not because of any differences in annual precipitation totals from year to year. These yearly differences in estimated seeding percentage increase were, at least in part, due to the make-up of the storm types that affected the region from year to year. The years which contained a majority of the more seedable type storms, i.e., E, B, and A types, showed higher percent increases than the years that had fewer of these types. If these differing storm type years happened to occur next to each other, as in 1948 and 1949 and in 1939 and 1940, large season to season variations were likely to appear. For example, in 1948 there were 19 storm periods of which the A, B, and E storm types totaled 16 (84 percent). The seasonal natural precipitation total was low (only 11.64 inches) but the seeding increase was 24 percent. The following year (1949) produced more precipitation (13.67 inches) during 21 storms but the A, B, and E storm types made up only 12 (57 percent) of the total number of storms. The indicated increase due to seeding in this water year was only 14 percent because nine of the storms were of type C, which produced less seeding effect than the A, B, and E storm types.

4.4 Storm Type Distribution

Throughout the historical period, most of the years (29) had more E type storms than any other single type. When that happened at Gibraltar Reservoir the median percent increase during those years was 22.88 percent. This was 0.70 percent higher than the median for the 46 year sample. These 29 years included the year 1941, which received the most natural precipitation of any single year (66.64 inches) but they did not include the year 1977, which received the least precipitation

(10.09 inches). However, 1977, while being low in total precipitation had one of the higher percent increases (25.27 percent) of the whole sample. There were only three E type storms (27 percent of the seasonal total) in 1977 which suggests that E type storms are not necessary to produce significant seeding percent increases. Indeed, the year 1938 which had 16 E type storms (out of 24 seasonal storms) yielded an estimated 20.7 percent increase (over one percent below the median).

At both Gibraltar Reservoir and Juncal Dam, for the entire historical sample period, the average number of storms during the water year was 17 with the most being 25 and the least being 10. However, as mentioned previously these numbers are conservative because of the way storm periods were selected. The type E storms prevailed with both an average and median of seven storms per water year. This was about 40 percent of the seasonal distribution. The E type storms were followed in frequency by the A type storms (about 4-5 per season) with one or two of the B, C, and D type storms.

4.5 Monthly Precipitation Distribution

To learn more about the distribution of storm precipitation within the water years, the data in the historical period were rearranged to provide the monthly precipitation at the two precipitation gauge sites. These data are displayed in Table 4-3, for Gibraltar Reservoir, and in Table 4-4, for Juncal Dam. The tables are arranged to display the natural and seeded precipitation totals (in inches) for each of the months from October through April for each water year. Except for minor differences in monthly totals and the fact that the Juncal Dam precipitation totals average slightly more than those at Gibraltar Reservoir, the two data sets are

Table 4-3

Gibraltar Reservoir Precipitation Statistics By Month and Water Year

GIBRALTAR RESERVOIR MONTHLY PRECIPITATION (INCHES) OCTOBER- APRIL WATER YEAR

WATER YEAR	OCT NAT PCPN	OCT SEED INC	NOV NAT PCPN	NOV SEED INC	DEC NAT PCPN	DEC SEED INC	JAN NAT PCPN	JAN SEED INC	FEB NAT PCPN	FEB SEED INC	MAR NAT PCPN	MAR SEED INC	APR NAT PCPN	APR SEED INC	TOTAL NAT PCPN	TOTAL SEED INC	PERCENT INC
1920	0.30	0.06	0.00	0.00	4.50	1.27	0.46	0.09	7.74	2.03	6.24	1.39	1.20	0.21	20.44	5.05	24.71
1921	0.70	0.15	1.92	0.40	1.59	0.43	8.88	1.85	2.65	0.60	2.66	0.73	0.35	0.05	18.75	4.21	22.45
1922	0.50	0.09	0.07	0.02	17.21	3.19	7.66	1.66	8.98	1.35	6.02	1.69	0.45	0.09	40.89	8.09	19.78
1923	0.44	0.07	3.43	0.96	10.25	1.51	3.37	0.90	1.68	0.24	0.09	0.03	2.98	0.80	22.24	4.51	20.28
1924	1.10	0.12	0.10	0.02	0.27	0.06	1.00	0.21	0.10	0.02	6.95	1.32	0.88	0.13	10.40	1.88	18.08
1925	0.73	0.08	0.96	0.17	1.78	0.39	0.40	0.10	1.67	0.47	5.82	1.20	3.50	0.40	14.86	2.81	18.91
1926	1.17	0.29	1.77	0.23	2.18	0.61	3.67	1.00	6.79	1.58	0.37	0.07	12.10	3.40	28.05	7.18	25.60
1927	0.02	0.01	7.90	2.22	1.06	0.28	2.20	0.57	13.47	3.75	2.79	0.72	1.11	0.23	28.55	7.78	27.25
1928	4.13	0.61	1.15	0.12	4.49	0.79	0.10	0.02	5.83	1.64	3.81	0.61	0.28	0.03	19.79	3.82	19.31
1929	0.00	0.00	3.93	1.11	6.26	1.76	2.14	0.39	2.28	0.58	2.81	0.79	2.00	0.39	19.42	5.02	25.85
1930	0.00	0.00	0.00	0.00	0.00	0.00	7.24	1.03	0.91	0.25	8.44	1.76	0.43	0.10	17.02	3.14	18.44
1931	0.00	0.00	2.49	0.28	0.00	0.00	5.03	1.28	3.61	0.38	0.00	0.00	2.82	0.30	13.95	2.24	16.06
1932	0.00	0.00	5.42	0.81	11.28	2.84	4.94	0.91	10.80	1.16	0.11	0.03	0.30	0.05	32.85	5.80	17.66
1933	0.16	0.03	0.00	0.00	0.81	0.13	14.39	2.82	0.00	0.00	0.26	0.05	0.34	0.09	15.96	3.12	19.55
1934	0.48	0.05	0.00	0.00	8.96	2.13	4.67	1.32	4.09	0.70	0.22	0.06	0.00	0.00	18.42	4.26	23.13
1935	2.71	0.30	2.85	0.80	5.26	1.26	7.83	1.83	1.18	0.16	5.09	1.12	4.54	1.27	29.46	6.74	22.88
1936	0.44	0.05	0.77	0.10	1.98	0.58	0.35	0.09	14.02	2.98	2.79	0.72	1.03	0.29	21.38	4.81	22.45
1937	0.62	0.08	0.00	0.00	13.67	2.56	5.00	0.64	7.58	2.14	9.17	2.22	0.10	0.02	36.14	7.66	21.20
1938	0.17	0.05	0.04	0.01	5.20	1.40	2.32	0.50	15.62	1.90	15.99	4.16	1.59	0.46	40.93	8.48	20.72
1939	0.22	0.04	0.12	0.01	7.10	0.76	4.73	1.04	1.93	0.36	5.65	1.05	0.06	0.01	19.81	3.27	16.51
1940	0.11	0.03	0.17	0.04	2.36	0.63	7.03	1.70	5.52	1.39	1.51	0.43	1.43	0.39	18.13	4.61	25.43
1941	0.88	0.16	0.44	0.04	11.16	2.09	9.31	1.67	18.62	3.88	17.97	4.65	8.26	2.34	66.64	14.83	22.25
1942	1.11	0.15	0.75	0.21	8.07	2.02	1.44	0.20	1.01	0.29	2.27	0.39	4.22	1.06	18.87	4.32	22.89
1943	0.92	0.17	0.30	0.09	1.56	0.43	21.90	6.16	6.72	0.72	5.25	0.70	1.06	0.27	37.71	8.54	22.65
1944	0.55	0.19	0.19	0.02	6.76	0.78	2.83	0.61	15.03	2.59	2.20	0.41	1.83	0.51	29.39	5.11	17.39
1945	0.00	0.00	5.57	1.51	1.54	0.29	0.70	0.20	7.61	2.11	5.59	1.20	0.06	0.01	21.07	5.32	25.25
1946	1.97	0.53	0.64	0.09	9.86	2.59	0.41	0.11	2.80	0.50	9.60	2.45	0.00	0.00	25.28	6.27	24.80
1947	0.96	0.17	8.15	1.88	4.36	0.57	0.42	0.07	0.82	0.23	3.57	0.77	0.30	0.08	18.58	3.77	20.29
1948	0.04	0.01	0.02	0.01	0.48	0.09	0.00	0.00	2.73	0.50	5.23	1.45	3.14	0.73	11.64	2.79	23.97
1949	0.09	0.02	0.00	0.00	4.88	0.55	2.22	0.35	1.41	0.37	4.88	0.65	0.19	0.02	13.67	1.96	14.34
1950	0.02	0.01	2.53	0.72	4.62	0.84	4.16	0.97	2.38	0.66	1.42	0.40	1.40	0.14	16.53	3.74	22.63
1954	0.00	0.00	2.83	0.32	0.25	0.04	7.70	1.87	3.19	0.90	6.26	1.33	0.21	0.06	20.44	4.52	22.11
1956	0.00	0.00	1.63	0.33	8.66	2.40	5.48	1.47	0.99	0.19	0.00	0.00	5.06	0.86	21.82	5.25	24.06
1960	0.00	0.00	0.00	0.00	1.96	0.52	5.58	1.07	3.64	0.83	0.43	0.11	3.36	0.63	14.97	3.16	21.14
1961	0.09	0.02	7.37	1.39	0.63	0.18	2.67	0.74	0.02	0.00	0.85	0.20	0.47	0.13	12.10	2.66	21.98
1962	0.03	0.01	5.51	1.06	3.01	0.83	2.72	0.53	23.05	6.17	1.83	0.48	0.00	0.00	36.15	9.08	25.12
1963	0.30	0.07	0.00	0.00	0.30	0.09	2.11	0.59	6.75	1.91	5.25	1.20	3.12	0.68	17.83	4.54	25.46
1964	0.89	0.14	3.63	1.03	0.00	0.00	4.40	1.24	0.00	0.00	2.69	0.48	3.01	0.55	14.62	3.44	23.53
1965	1.15	0.21	4.18	0.60	5.21	1.32	0.93	0.28	0.37	0.11	0.79	0.14	10.02	1.83	22.65	4.49	19.82
1966	0.00	0.00	17.00	2.14	9.36	1.70	2.24	0.63	0.86	0.19	0.24	0.02	0.00	0.00	29.70	4.68	15.76
1967	0.04	0.01	7.48	1.33	9.38	1.56	8.22	2.31	0.60	0.17	5.54	0.55	8.47	1.57	39.73	7.50	18.88
1975	0.89	0.25	0.06	0.02	9.53	2.50	0.00	0.00	5.97	0.96	8.96	1.75	2.13	0.39	27.54	5.87	21.31
1976	0.40	0.10	0.44	0.13	0.22	0.06	0.00	0.00	10.93	3.06	1.98	0.36	1.08	0.20	15.05	3.91	25.98
1977	0.25	0.05	0.44	0.09	0.89	0.16	5.36	1.47	0.26	0.03	2.89	0.75	0.00	0.00	10.09	2.55	25.27
1979	0.00	0.00	2.76	0.51	2.51	0.45	8.49	1.94	6.08	1.63	7.26	1.30	0.00	0.00	27.10	5.83	21.51
1980	0.58	0.16	0.96	0.13	2.02	0.57	8.13	1.92	17.69	4.62	4.39	1.22	1.10	0.22	34.87	8.84	25.35
TOTAL	25.16	4.54	105.97	20.95	213.43	45.21	200.83	46.35	255.98	56.30	194.13	43.11	95.98	20.49	1091.48	237.45	999.99
AVERAGE	0.55	0.10	2.30	0.46	4.64	0.98	4.37	1.01	5.56	1.22	4.22	0.94	2.09	0.46	23.73	5.16	21.74
MEDIAN	0.30	0.05	0.86	0.18	4.42	0.62	3.52	0.82	3.10	0.68	3.23	0.72	1.07	0.22	20.44	4.58	22.18
MAX.	4.13	0.61	17.00	2.22	17.21	3.19	21.90	6.16	23.05	6.17	17.97	4.65	12.10	3.40	66.64	14.83	27.25
PCT INC		18.04		19.77		21.18		23.08		21.99		22.21		21.87			21.75

Table 4-4

Juncal Dam Precipitation Statistics By Month and Water Year

JUNCAL DAM MONTHLY PRECIPITATION (INCHES) OCTOBER - APRIL WATER YEAR

WATER YEAR	OCT NAT PCPN	OCT SEED INC	NOV NAT PCPN	NOV SEED INC	DEC NAT PCPN	DEC SEED INC	JAN NAT PCPN	JAN SEED INC	FEB NAT PCPN	FEB SEED INC	MAR NAT PCPN	MAR SEED INC	APR NAT PCPN	APR SEED INC	TOTAL NAT PCPN	TOTAL SEED INC	PERCENT INCR.
1920	0.35	0.05	0.00	0.00	5.02	1.39	0.55	0.09	8.69	2.12	6.51	1.85	1.36	0.23	22.48	5.73	25.49
1921	0.90	0.14	2.09	0.40	1.71	0.44	8.75	1.76	2.77	0.61	3.10	0.83	0.45	0.08	19.77	4.26	21.55
1922	0.58	0.09	0.08	0.01	16.16	2.78	7.79	1.61	9.43	1.33	6.71	1.85	0.78	0.15	41.53	7.82	18.83
1923	0.53	0.09	3.81	1.06	11.11	1.88	3.79	0.95	1.78	0.32	0.20	0.03	3.31	0.81	24.53	5.14	20.95
1924	1.25	0.18	0.12	0.02	0.32	0.05	1.21	0.19	0.12	0.02	7.72	1.58	1.05	0.16	11.79	2.20	18.66
1925	0.80	0.08	1.01	0.17	1.98	0.37	0.44	0.09	1.79	0.47	5.79	1.13	3.97	0.58	15.78	2.89	18.31
1926	1.66	0.33	1.62	0.26	2.56	0.75	4.16	1.08	8.99	1.84	0.34	0.05	15.20	4.15	34.53	8.46	24.51
1927	0.00	0.00	10.00	2.77	1.14	0.29	2.64	0.61	15.43	4.24	3.68	0.43	1.31	0.22	34.20	8.56	25.03
1928	2.22	0.34	1.57	0.15	5.55	0.93	0.04	0.01	5.91	1.64	4.07	0.72	0.27	0.02	19.63	3.81	19.41
1929	0.00	0.00	3.82	1.06	4.51	1.26	2.68	0.45	2.87	0.66	3.00	0.83	2.60	0.47	19.48	4.73	24.28
1930	0.00	0.00	0.00	0.00	0.00	0.00	7.40	1.12	1.20	0.34	7.12	1.48	0.35	0.08	16.07	3.02	18.79
1931	0.00	0.00	2.63	0.36	0.00	0.00	6.15	1.58	3.61	0.52	0.00	0.00	4.96	0.72	17.35	3.18	18.33
1932	0.01	0.00	6.48	0.93	12.12	3.05	4.49	0.75	11.74	1.67	0.15	0.04	0.59	0.10	35.58	6.54	18.38
1933	0.37	0.07	0.00	0.00	0.44	0.07	15.25	2.94	0.00	0.00	0.33	0.06	0.40	0.11	16.79	3.25	19.36
1934	0.64	0.06	0.03	0.00	11.15	2.57	5.11	1.41	4.39	0.77	0.20	0.05	0.00	0.00	21.52	4.86	22.58
1935	3.16	0.47	2.95	0.81	5.57	1.24	6.99	1.65	1.28	0.21	5.56	1.20	4.43	1.22	29.94	6.80	22.71
1936	0.32	0.03	0.97	0.15	2.18	0.61	0.30	0.08	16.64	3.53	2.95	0.76	0.96	0.27	24.32	5.43	22.33
1937	3.29	0.48	0.00	0.00	11.72	1.95	5.10	0.63	9.28	2.56	10.89	2.59	0.07	0.02	40.35	8.23	20.39
1938	0.15	0.04	0.05	0.02	6.16	1.54	2.75	0.53	18.94	2.44	17.58	4.40	1.79	0.50	47.42	9.47	19.97
1939	0.28	0.05	0.17	0.04	6.34	0.92	5.50	1.24	1.76	0.30	4.80	0.85	0.23	0.06	19.08	3.46	18.13
1940	0.17	0.03	0.07	0.01	2.00	0.48	6.58	1.67	6.83	1.73	2.36	0.66	1.34	0.38	19.35	4.96	25.63
1941	1.16	0.20	0.60	0.09	10.89	2.23	8.92	1.92	18.02	3.95	16.27	4.19	10.40	2.90	66.26	15.48	23.36
1942	0.74	0.12	0.85	0.24	8.78	2.35	1.15	0.22	1.23	0.34	1.98	0.33	5.75	1.25	20.48	4.85	23.68
1943	1.14	0.19	0.18	0.05	1.27	0.35	25.48	7.06	6.55	0.95	5.08	0.79	0.98	0.25	40.68	9.64	23.69
1944	0.62	0.16	0.12	0.02	8.46	1.23	2.25	0.40	15.09	2.66	2.22	0.37	1.72	0.47	30.48	5.31	17.42
1945	0.00	0.00	7.61	2.05	1.29	0.22	0.82	0.23	9.64	2.56	5.55	1.12	0.06	0.01	24.97	6.19	24.79
1946	2.18	0.53	0.73	0.09	11.13	3.03	0.37	0.10	3.32	0.56	11.11	2.80	0.02	0.00	28.86	7.11	24.64
1947	0.88	0.16	10.38	2.32	6.80	1.04	0.49	0.08	1.62	0.45	3.58	0.86	0.28	0.05	24.03	4.96	20.64
1948	0.06	0.01	0.00	0.00	0.65	0.12	0.00	0.00	3.34	0.57	5.11	1.37	3.56	0.80	12.72	2.87	22.56
1949	0.07	0.01	0.00	0.00	4.64	0.69	2.35	0.36	1.95	0.49	4.72	0.78	0.04	0.01	13.77	2.34	16.99
1950	0.00	0.00	3.42	0.95	4.56	0.77	4.92	1.08	3.12	0.87	1.51	0.42	1.32	0.13	18.85	4.22	22.39
1954	0.00	0.00	4.03	0.40	0.19	0.03	8.33	2.04	4.94	1.36	7.55	1.54	0.29	0.08	25.33	5.45	21.52
1956	0.00	0.00	1.64	0.29	6.85	1.82	6.61	1.80	1.08	0.18	0.00	0.00	6.56	1.09	22.74	5.18	22.78
1960	0.00	0.00	0.00	0.00	1.74	0.41	6.52	1.00	3.79	0.88	0.29	0.07	3.16	0.60	15.50	2.96	19.10
1961	0.04	0.01	7.49	1.36	0.83	0.22	2.29	0.63	0.00	0.00	0.79	0.12	0.54	0.15	11.98	2.49	20.78
1962	0.00	0.00	6.07	1.27	2.55	0.70	3.04	0.48	29.93	7.93	2.03	0.53	0.00	0.00	43.62	10.91	25.01
1963	0.26	0.04	0.00	0.00	0.17	0.05	2.19	0.61	6.76	1.87	4.79	1.04	3.11	0.64	17.28	4.25	24.59
1964	1.09	0.19	5.35	1.48	0.00	0.00	4.83	1.34	0.00	0.00	2.16	0.20	4.18	0.72	17.61	3.93	22.32
1965	1.10	0.19	3.82	0.60	6.85	1.76	0.80	0.21	0.31	0.08	0.92	0.13	9.45	1.61	23.25	4.58	19.70
1966	0.00	0.00	18.86	2.43	9.62	1.64	2.09	0.58	1.07	0.18	0.10	0.01	0.00	0.00	31.74	4.84	15.25
1967	0.10	0.02	7.23	1.17	12.45	2.01	9.40	2.59	0.71	0.20	6.06	0.59	10.30	1.77	46.25	8.35	18.05
1975	0.65	0.18	0.13	0.02	10.29	2.58	0.00	0.00	7.19	1.19	10.47	2.19	2.58	0.42	31.31	6.58	21.02
1976	0.33	0.06	0.10	0.03	0.29	0.08	0.00	0.00	12.47	3.45	2.28	0.38	1.32	0.23	16.79	4.23	25.19
1977	0.09	0.02	0.83	0.13	1.30	0.22	5.31	1.47	0.23	0.02	3.07	0.76	0.00	0.00	10.83	2.62	24.19
1979	0.00	0.00	3.41	0.59	3.05	0.52	7.52	1.58	6.84	1.80	8.53	1.49	0.00	0.00	29.35	5.98	20.37
1980	1.52	0.42	0.93	0.14	2.33	0.64	9.06	2.07	19.19	4.98	5.12	1.40	0.99	0.18	39.14	9.83	25.11
TOTAL	28.71	5.04	121.25	23.94	224.72	47.28	212.41	48.29	291.84	64.84	204.35	44.87	111.08	23.69	1195.31	257.94	988.76
AVERAGE	0.62	0.11	2.64	0.52	4.89	1.03	4.62	1.05	6.34	1.41	3.63	0.98	2.43	0.52	25.98	5.61	21.49
MEDIAN	0.32	0.05	0.99	0.16	3.78	0.78	3.98	0.69	4.00	0.82	3.88	0.76	1.18	0.22	23.00	4.96	21.54
MAX	3.29	0.53	18.86	2.77	16.16	3.05	25.48	7.06	29.93	7.93	17.28	4.40	15.20	4.15	66.26	15.48	25.63
PCT INC		17.55		19.74		21.00		22.73		22.22		21.96		21.17			21.58

much the same. Over the years, October received the least precipitation (median value about one-third inch at both sites), while at Gibraltar, December had the highest median (4.42 inches), and at Juncal Dam, January had the highest median (3.98 inches). At both sites, February had the highest average precipitation total but this was largely because of one month with a total over 20 inches and several other months with totals over 15 inches.

All the months except October and November indicated seeding effects greater than 20 percent but seeding effects appeared to be greatest during January with the percent increase at Gibraltar over 23 percent and nearly that at Juncal Dam. At Gibraltar, in any one water year, the greatest monthly seeding total that would have occurred would have been 6.17 inches during February, 1962, followed by 6.16 inches in January, 1943. Obviously, seeding in some of these very heavy precipitation events might not always be desirable. However, there were many months (particularly in October) where the seeding effects would have been zero because no precipitation fell. At Juncal Dam, the corresponding greatest seeded totals for the same months and years would have been 7.93 inches in February, 1962, and 7.06 inches in January, 1943, and like Gibraltar the Juncal site also experienced many months when zero precipitation was logged.

4.6 Partitioned Gibraltar Precipitation Data

In order to determine what the effects of seeding would have been if only certain groups of water years had been seeded, the Gibraltar Reservoir precipitation data were partitioned into three sets of nearly equal size, arranged from the water year that received the most natural precipitation to the one that received the least. The top group (called highest third) consisted of the 15 years that received the most precipitation, the next group (called middle third) consisted of the following 16 years, and the bottom group (called lowest third) was made up of the remaining 15 years that received the least precipitation.

4.6.1 Highest Third Years at Gibraltar

This group had annual precipitation totals which ranged from 66.64 inches to 27.54 inches. Table 4-5 lists the natural and seeded totals for each month of the water years that make up the group. As a group, the natural precipitation averaged 35.91 inches with a median of 34.87 inches. If all the bands within the storms in this group had been seeded the net increase due to seeding would have been 116.18 inches. This would have yielded an average of 7.7 inches per water year or a 21.6 percent increase over the not-seeded precipitation total. During the individual months, the one that received the greatest precipitation total was clearly February, which had a median of 9 inches. This month would also have produced an additional 1.58 inches of precipitation from seeding. There were only two years in this 15 year sample in which October precipitation total was zero, but even so, the median value of precipitation produced by seeding was only 0.09 inches. On the other hand, April, which had the second lowest monthly total in the group, and which also had two months with zero precipitation would have yielded a median seeded value of over a quarter of an inch.

The data for this group are plotted in Figure 4.5, which contains the average natural precipitation and the average seeded precipitation totals month by month. Figure 4.6 contains a plot of the median values of the same data.

Table 4-5

Gibraltar Reservoir Precipitation Statistics Partitioned By Natural Precipitation Highest Third Group

GIBRALTAR RESERVOIR MONTHLY PRECIPITATION (INCHES) OCTOBER- APRIL WATER YEAR, HIGHEST THIRD

WATER YEAR	OCT NAT PCPN	OCT SEED INC	NOV NAT PCPN	NOV SEED INC	DEC NAT PCPN	DEC SEED INC	JAN NAT PCPN	JAN SEED INC	FEB NAT PCPN	FEB SEED INC	MAR NAT PCPN	MAR SEED INC	APR NAT PCPN	APR SEED INC	TOTAL NAT PCPN	TOTAL SEED INC	PERCENT INCREASE
1941	0.88	0.16	0.44	0.04	11.16	2.09	9.31	1.67	18.62	3.88	17.97	4.65	8.26	2.34	66.64	14.83	22.25
1938	0.17	0.05	0.04	0.01	5.20	1.40	2.32	0.50	15.62	1.90	15.99	4.16	1.59	0.46	40.93	8.48	20.72
1922	0.50	0.09	0.07	0.02	17.21	3.19	7.66	1.66	8.98	1.35	6.02	1.69	0.45	0.09	40.89	8.09	19.78
1967	0.04	0.01	7.48	1.33	9.38	1.56	8.22	2.31	0.60	0.17	5.54	0.55	8.47	1.57	39.73	7.50	18.88
1943	0.92	0.17	0.30	0.09	1.56	0.43	21.90	6.16	6.72	0.72	5.25	0.70	1.06	0.27	37.71	8.54	22.65
1962	0.03	0.01	5.51	1.06	3.01	0.83	2.72	0.53	23.05	6.17	1.83	0.48	0.00	0.00	36.15	9.08	25.12
1937	0.62	0.08	0.00	0.00	13.67	2.56	5.00	0.64	7.58	2.14	9.17	2.22	0.10	0.02	36.14	7.66	21.20
1980	0.58	0.16	0.96	0.13	2.02	0.57	8.13	1.92	17.69	4.62	4.39	1.22	1.10	0.22	34.87	8.84	25.35
1932	0.00	0.00	5.42	0.81	11.28	2.84	4.94	0.91	10.80	1.16	0.11	0.03	0.30	0.05	32.85	5.80	17.66
1966	0.00	0.00	17.00	2.14	9.36	1.70	2.24	0.63	0.86	0.19	0.24	0.02	0.00	0.00	29.70	4.68	15.76
1935	2.71	0.30	2.85	0.80	5.26	1.26	7.83	1.83	1.18	0.16	5.09	1.12	4.54	1.27	29.46	6.74	22.88
1944	0.55	0.19	0.19	0.02	6.76	0.78	2.83	0.61	15.03	2.59	2.20	0.41	1.83	0.51	29.39	5.11	17.39
1927	0.02	0.01	7.90	2.22	1.06	0.28	2.20	0.57	13.47	3.75	2.79	0.72	1.11	0.23	28.55	7.78	27.25
1926	1.17	0.29	1.77	0.23	2.18	0.61	3.67	1.00	6.79	1.58	0.37	0.07	12.10	3.40	28.05	7.18	25.60
1975	0.89	0.25	0.06	0.02	9.53	2.50	0.00	0.00	5.97	0.96	8.96	1.75	2.13	0.39	27.54	5.87	21.31
TOTAL	9.08	1.77	49.99	8.92	108.64	22.60	88.97	20.94	152.96	31.34	85.92	19.79	43.04	10.82	538.60	116.18	323.80
AVERAGE	0.61	0.12	3.33	0.59	7.24	1.51	5.93	1.40	10.20	2.09	5.73	1.32	2.87	0.72	35.91	7.75	21.59
MEDIAN	0.55	0.09	0.96	0.13	6.76	1.40	4.94	0.91	8.98	1.58	5.09	0.72	1.11	0.27	34.87	7.66	21.31

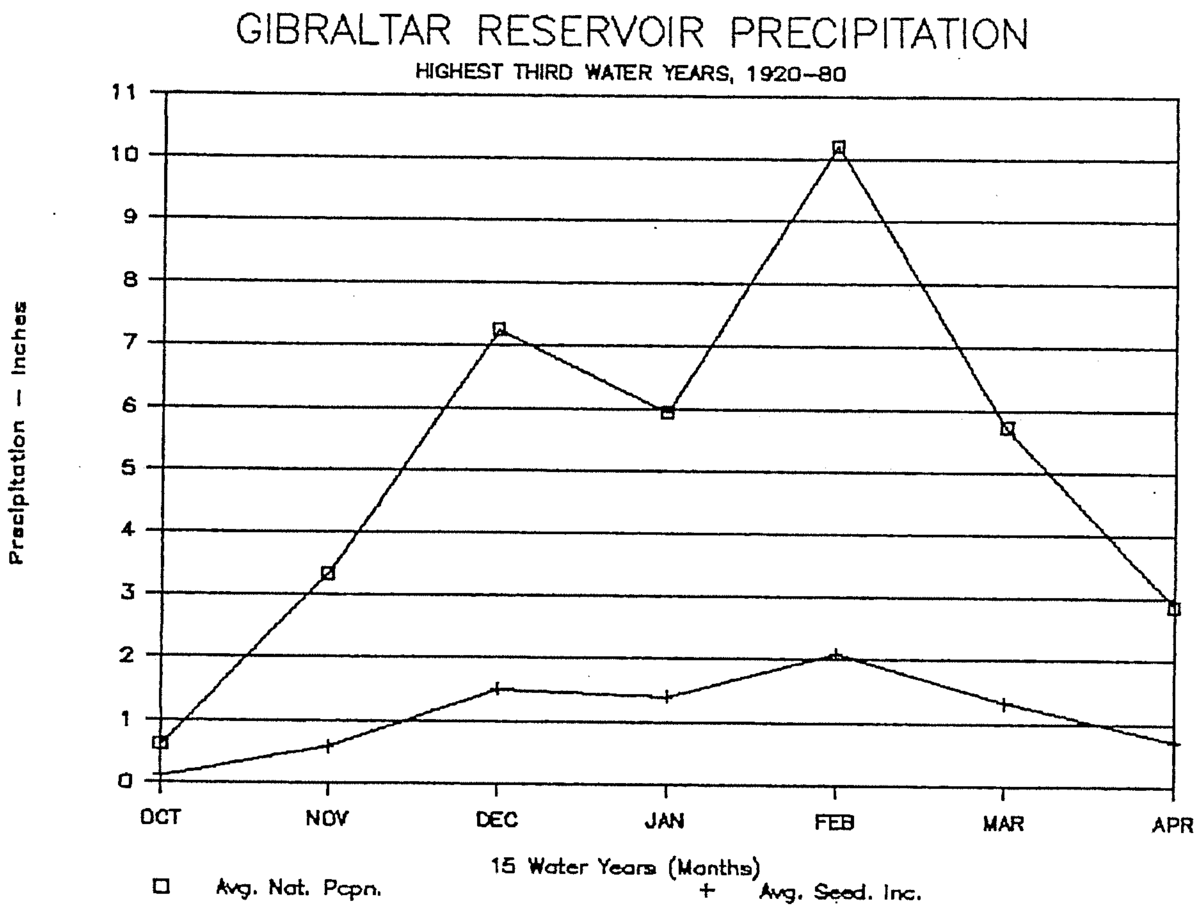

Figure 4.5 Average of Gibraltar Reservoir Natural Precipitation (inches) and "Seeded" Increase (inches) by month for Highest Third Group

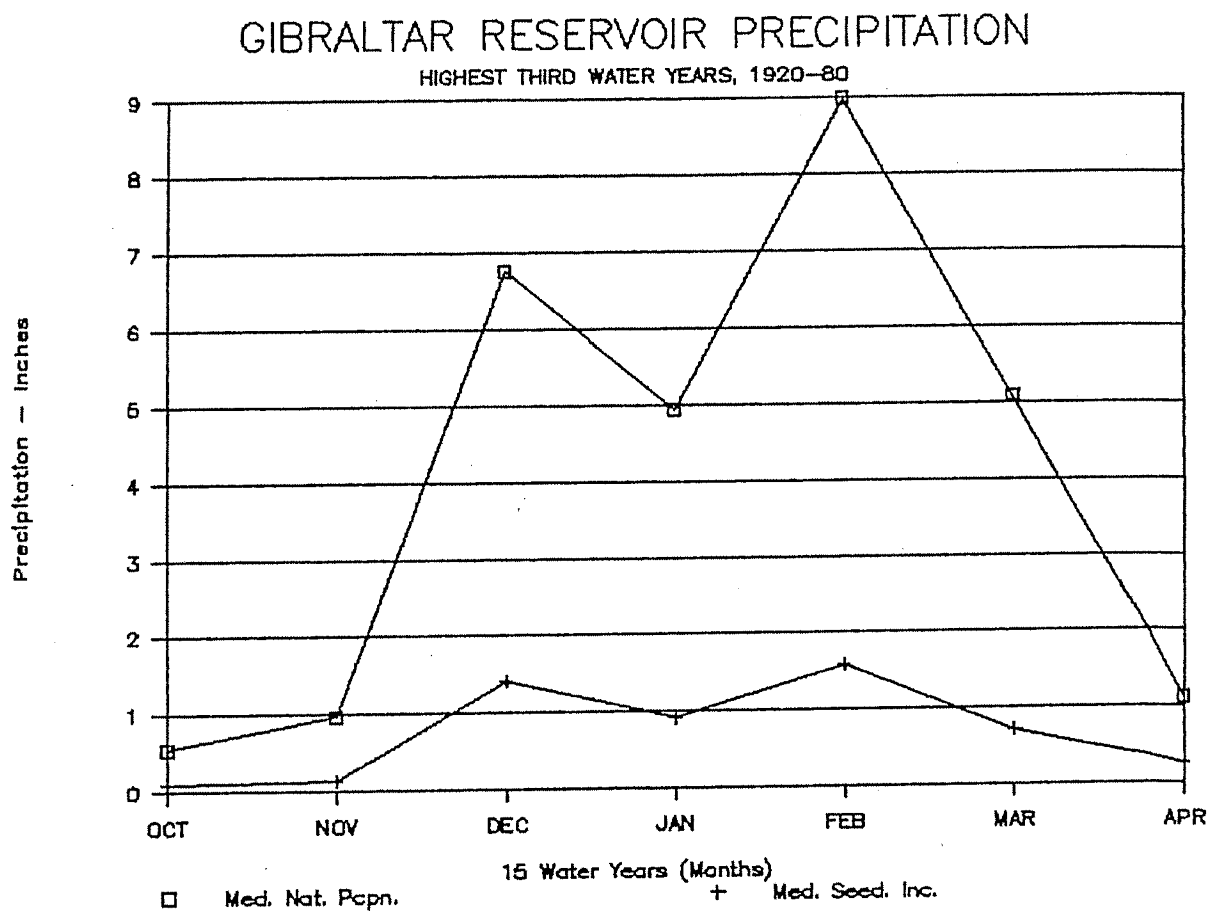

Figure 4.6 Median of Gibraltar Reservoir Natural Precipitation (inches) and "Seeded" Increase (inches) by month for Highest Third Group.

4.6.2 Middle Third Years at Gibraltar

The precipitation totals in this group, which spanned the average and median values for the whole historical sample, ranged from 27.10 inches to 18.42 inches. These data are shown in Table 4-6 and cover 16 water years (one more than the top and bottom groups because of the 46 year total). Natural precipitation in this group averaged 21.00 inches with a median of 20.44 inches. The average and median were both about 14-15 inches less than the average and median of the highest group. This difference was more than the amount of precipitation received over the whole water year in about a third of all the precipitation years in the entire sample suggesting that at least some of the data in the top group represent unusually large precipitation amounts compared to the rest of the data set. Seven of the 15 water years (nearly half of the group) in the top group had natural precipitation totals over 36 inches, which was 15 percent of the entire 46 year sample.

Estimated average and median values of seeded precipitation in the middle group would have been between 4.5-4.7 inches had all the convection bands been seeded. This would have represented a 22 percent increase over the natural precipitation in the group which would have been a slightly higher percentage than the increase due to seeding in the top group. December was clearly the wettest month for the years in the group with a median of 4.85 inches. This month would also have produced the greatest seeding increase (1.03 inches). March trailed December by about an inch and one half in precipitation total and the other months all had median values of less than three inches (although the averages were considerably higher). October natural precipitation was a poor seventh among the months again, although the median values between October and April

Table 4-6

Gibraltar Reservoir Precipitation Statistics Partitioned by Natural Precipitation
Middle Third Group

GIBRALTAR RESERVOIR MONTHLY PRECIPITATION (INCHES) OCTOBER- APRIL WATER YEAR, MIDDLE THIRD

WATER YEAR	OCT NAT PCPN	OCT SEED INC	NOV NAT PCPN	NOV SEED INC	DEC NAT PCPN	DEC SEED INC	JAN NAT PCPN	JAN SEED INC	FEB NAT PCPN	FEB SEED INC	MAR NAT PCPN	MAR SEED INC	APR NAT PCPN	APR SEED INC	TOTAL NAT PCPN	TOTAL SEED INC	PERCENT INC
1979	0.00	0.00	2.76	0.51	2.51	0.45	8.49	1.94	6.08	1.63	7.26	1.30	0.00	0.00	27.10	5.83	21.51
1946	1.97	0.53	0.64	0.09	9.86	2.59	0.41	0.11	2.80	0.50	9.60	2.45	0.00	0.00	25.28	6.27	24.80
1965	1.15	0.21	4.18	0.60	5.21	1.32	0.93	0.28	0.37	0.11	0.79	0.14	10.02	1.83	22.65	4.49	19.82
1923	0.44	0.07	3.43	0.96	10.25	1.51	3.37	0.90	1.68	0.24	0.09	0.03	2.98	0.80	22.24	4.51	20.28
1956	0.00	0.00	1.63	0.33	8.66	2.40	5.48	1.47	0.99	0.19	0.00	0.00	5.06	0.86	21.82	5.25	24.06
1936	0.44	0.05	0.77	0.10	1.98	0.58	0.35	0.09	14.02	2.98	2.79	0.72	1.03	0.29	21.38	4.81	22.45
1945	0.00	0.00	5.57	1.51	1.54	0.29	0.70	0.20	7.61	2.11	5.59	1.20	0.06	0.01	21.07	5.32	25.25
1920	0.30	0.06	0.00	0.00	4.50	1.27	0.46	0.09	7.74	2.03	6.24	1.39	1.20	0.21	20.44	5.05	24.71
1954	0.00	0.00	2.83	0.32	0.25	0.04	7.70	1.87	3.19	0.90	6.26	1.33	0.21	0.06	20.44	4.52	22.11
1939	0.22	0.04	0.12	0.01	7.10	0.76	4.73	1.04	1.93	0.36	5.65	1.05	0.06	0.01	19.81	3.27	16.51
1928	4.13	0.61	1.15	0.12	4.49	0.79	0.10	0.02	5.83	1.64	3.81	0.61	0.28	0.03	19.79	3.82	19.31
1929	0.00	0.00	3.93	1.11	6.26	1.76	2.14	0.39	2.28	0.58	2.81	0.79	2.00	0.39	19.42	5.02	25.85
1942	1.11	0.15	0.75	0.21	8.07	2.02	1.44	0.20	1.01	0.29	2.27	0.39	4.22	1.06	18.87	4.32	22.89
1921	0.70	0.15	1.92	0.40	1.59	0.43	8.88	1.85	2.65	0.60	2.66	0.73	0.35	0.05	18.75	4.21	22.45
1947	0.96	0.17	8.15	1.88	4.36	0.57	0.42	0.07	0.82	0.23	3.57	0.77	0.30	0.08	18.58	3.77	20.29
1934	0.48	0.05	0.00	0.00	8.96	2.13	4.67	1.32	4.09	0.70	0.22	0.06	0.00	0.00	18.42	4.26	23.13
TOTAL	11.90	2.09	37.83	8.15	85.59	18.91	50.27	11.84	63.09	15.09	59.61	12.96	27.77	5.68	336.06	74.72	155.42
AVERAGE	0.74	0.13	2.36	0.51	5.35	1.18	3.14	0.74	3.94	0.94	3.73	0.81	1.74	0.36	21.00	4.67	22.21
MEDIAN	0.44	0.06	1.77	0.32	4.85	1.03	1.79	0.34	2.72	0.59	3.15	0.75	0.33	0.07	20.44	4.51	22.67

were much closer than were the averages. Median values indicated seeding increases in October were very small (0.06 inch) and they were not much better in April (0.07 inch).

The plots of these data for the middle third group are displayed in Figure 4.7 (averages of natural precipitation and seeded increases) and Figure 4.8 (medians of natural precipitation and seeded increases) in the same format as with the highest third group.

4.6.3 Lowest Third Years at Gibraltar

Natural precipitation totals in this group included the 15 lowest total years in the entire 46 year sample. Precipitation totals in the group ranged from 18.13 inches to 10.09 inches. The data for the lowest third group are tabulated in Table 4-7. Natural precipitation was less than 15 inches for most of the years in the group, showing 14.44 inches on average with a 14.86 inch median. Calculated precipitation increases due to seeding were a little over three inches for the group (average 3.10 inches and median 3.12 inches) with the average percent increase for the group showing 21.4 percent and a median percent increase even higher (22.0 percent). This median value was slightly lower than the middle third group but higher than the top group while the average percent increase was about the same as in the other two groups. Thus, it would appear that even though the amount of precipitation produced from seeding in this group would be less than half of the amount from seeding the highest group, the percent increase would be at least the same.

Within the lowest third group, January was the wettest month (about four inches naturally) with nearly one inch of additional precipitation produced from seeding. That one inch

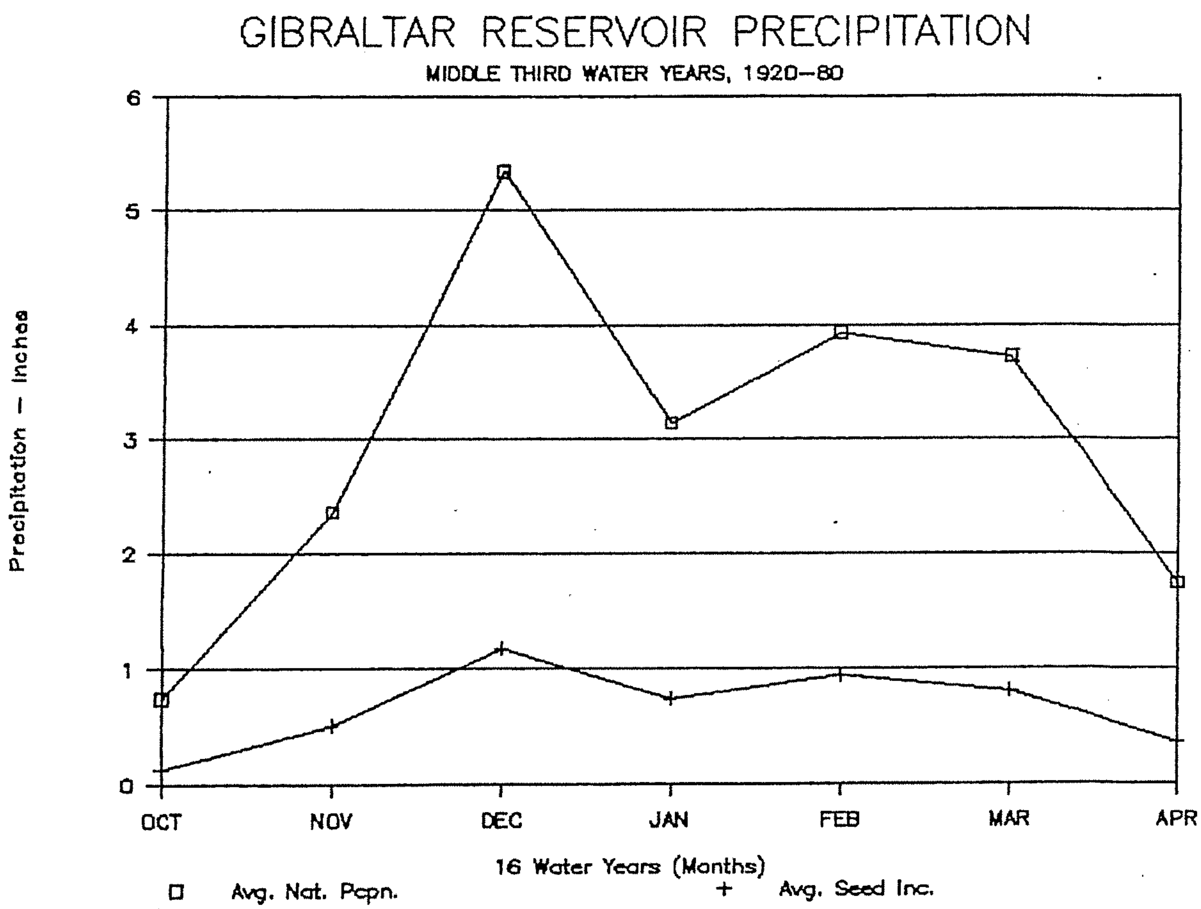

Figure 4.7 Average of Gibraltar Reservoir Natural Precipitation (inches) and "Seeded" Increase (inches) by month for Middle Third Group.

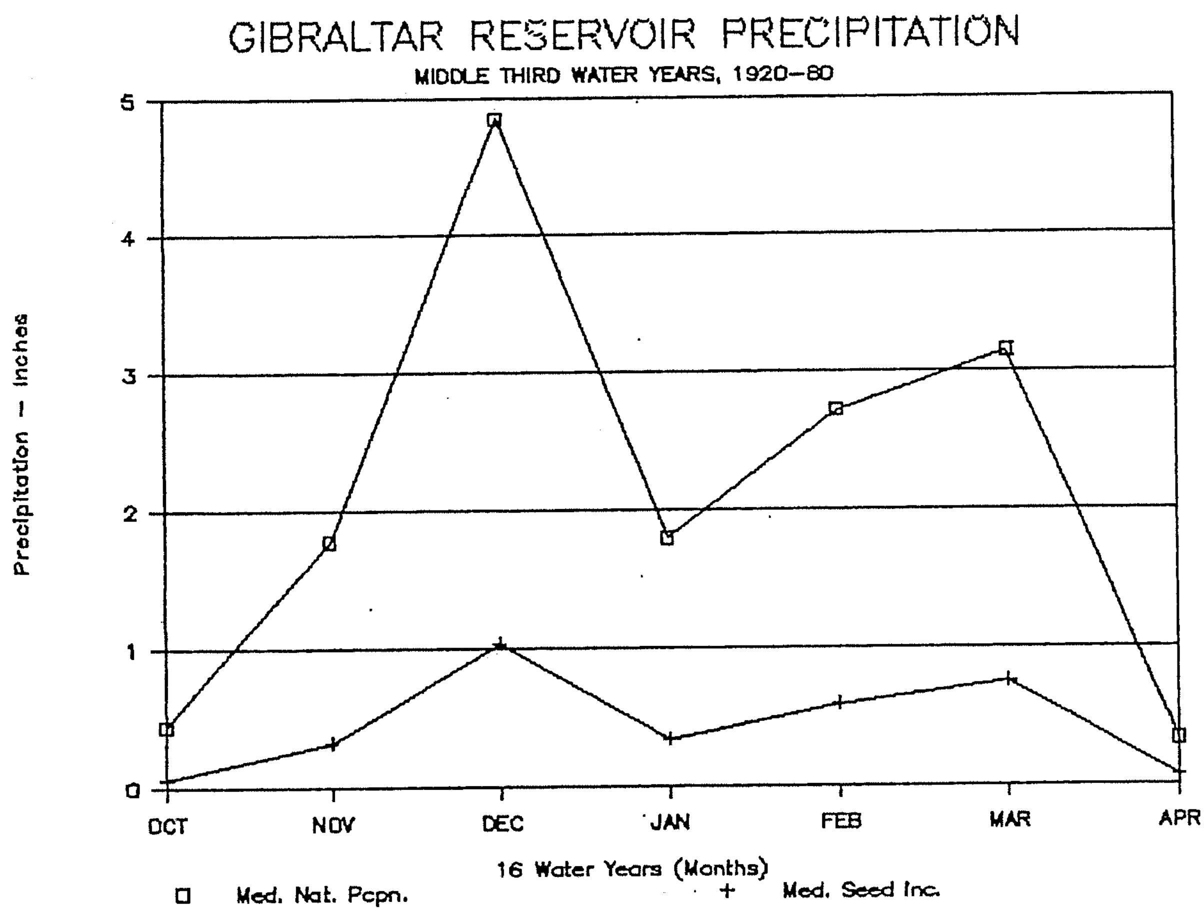

Figure 4.8 Median of Gibraltar Reservoir Natural Precipitation (inches) and "Seeded" Increase (inches) by month for Middle Third Group.

Table 4-7

Gibraltar Reservoir Precipitation Statistics Partitioned By
Natural Precipitation, Lowest Third Group

GIBRALTAR RESERVOIR MONTHLY PRECIPITATION (INCHES) OCTOBER- APRIL WATER YEAR, LOWEST THIRD

WATER YEAR	OCT NAT PCPN	OCT SEED INC	NOV NAT PCPN	NOV SEED INC	DEC NAT PCPN	DEC SEED INC	JAN NAT PCPN	JAN SEED INC	FEB NAT PCPN	FEB SEED INC	MAR NAT PCPN	MAR SEED INC	APR NAT PCPN	APR SEED INC	TOTAL NAT PCPN	TOTAL SEED INC	PERCENT INC.
1940	0.11	0.03	0.17	0.04	2.36	0.63	7.03	1.70	5.52	1.39	1.51	0.43	1.43	0.39	18.13	4.61	25.43
1963	0.30	0.07	0.00	0.00	0.30	0.09	2.11	0.59	6.75	1.91	5.25	1.20	3.12	0.68	17.83	4.54	25.46
1930	0.00	0.00	0.00	0.00	0.00	0.00	7.24	1.03	0.91	0.25	8.44	1.76	0.43	0.10	17.02	3.14	18.44
1950	0.02	0.01	2.53	0.72	4.62	0.84	4.16	0.97	2.38	0.66	1.42	0.40	1.40	0.14	16.53	3.74	22.63
1933	0.16	0.03	0.00	0.00	0.81	0.13	14.39	2.82	0.00	0.00	0.26	0.05	0.34	0.09	15.96	3.12	19.55
1976	0.40	0.10	0.44	0.13	0.22	0.06	0.00	0.00	10.93	3.06	1.98	0.36	1.08	0.20	15.05	3.91	25.98
1960	0.00	0.00	0.00	0.00	1.96	0.52	5.58	1.07	3.64	0.83	0.43	0.11	3.36	0.63	14.97	3.16	21.14
1925	0.73	0.08	0.96	0.17	1.78	0.39	0.40	0.10	1.67	0.47	5.82	1.20	3.50	0.40	14.86	2.81	18.91
1964	0.89	0.14	3.63	1.03	0.00	0.00	4.40	1.24	0.00	0.00	2.69	0.48	3.01	0.55	14.62	3.44	23.53
1931	0.00	0.00	2.49	0.28	0.00	0.00	5.03	1.28	3.61	0.38	0.00	0.00	2.82	0.30	13.95	2.24	16.06
1949	0.09	0.02	0.00	0.00	4.88	0.55	2.22	0.35	1.41	0.37	4.88	0.65	0.19	0.02	13.67	1.96	14.34
1961	0.09	0.02	7.37	1.39	0.63	0.18	2.67	0.74	0.02	0.00	0.85	0.20	0.47	0.13	12.10	2.66	21.98
1948	0.04	0.01	0.02	0.01	0.48	0.09	0.00	0.00	2.73	0.50	5.23	1.45	3.14	0.73	11.64	2.79	23.97
1924	1.10	0.12	0.10	0.02	0.27	0.06	1.00	0.21	0.10	0.02	6.95	1.32	0.88	0.13	10.40	1.88	18.08
1977	0.25	0.05	0.44	0.09	0.89	0.16	5.36	1.47	0.26	0.03	2.89	0.75	0.00	0.00	10.09	2.55	25.27
TOTAL	4.18	0.68	18.15	3.88	19.20	3.70	61.59	13.57	39.93	9.87	48.60	10.36	25.17	4.49	216.53	46.55	320.7
AVERAGE	0.28	0.05	1.21	0.26	1.28	0.25	4.11	0.90	2.66	0.66	3.24	0.69	1.68	0.30	14.44	3.10	21.3
MEDIAN	0.09	0.03	0.17	0.04	0.63	0.13	4.16	0.97	1.67	0.38	2.69	0.48	1.40	0.20	14.86	3.12	21.9

represented nearly one-third of the total for the water year. indicating that the yield from seeding during most of the other six months would have been considerably less. Specifically, seeding during the months of October, November, December, and April would have produced a total of less than one-half inch of additional precipitation (0.40 inch) during each of these months. Figure 4.9 contains the monthly averages for the data in the group plotted in the same format as the other two groups and Figure 4.10 shows the data plots for the medians of the monthly natural and seeded precipitation.

4.7 Seeding Percent Increase by Group

The percent increase data from Tables 4-5, 4-6, and 4-7 have been combined by each month of the water year with each of the groups (highest, middle, lowest third) and an all-groups category. These are displayed in Figure 4.11 as a summary graph for the seeding effects estimated to be produced by convection band seeding. It is clear from the graph that the marginal seeding months in regard to percent increase are October and April, although the highest-third precipitation group had the greatest percent increase of any single group in April. However, in most of the water years these months had seeding increases that were less than 20 percent. Probably more importantly, as seen in the sections above, the amount of precipitation produced from seeding in these months is estimated to be relatively small. Most of the groups in November and December averaged estimated seeding increases of 20 percent or better with indicated seeding precipitation amounts still relatively small in November but increasing considerably to median precipitation values over one-half inch in December. The groups during January, February, and March had seeding

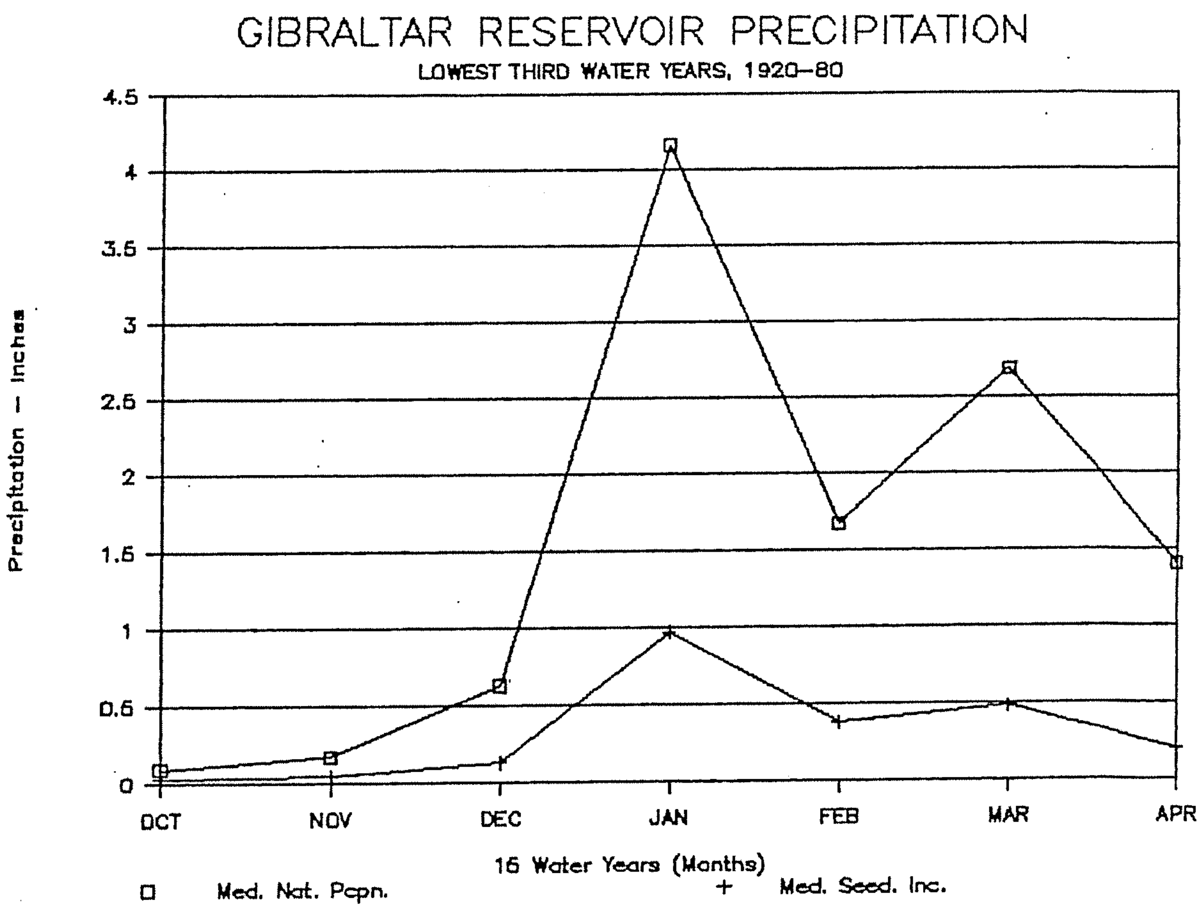

Figure 4.9 Average of Gibraltar Reservoir Natural Precipitation (inches) and "Seeded" Increase (inches) by month for Lowest Third Group

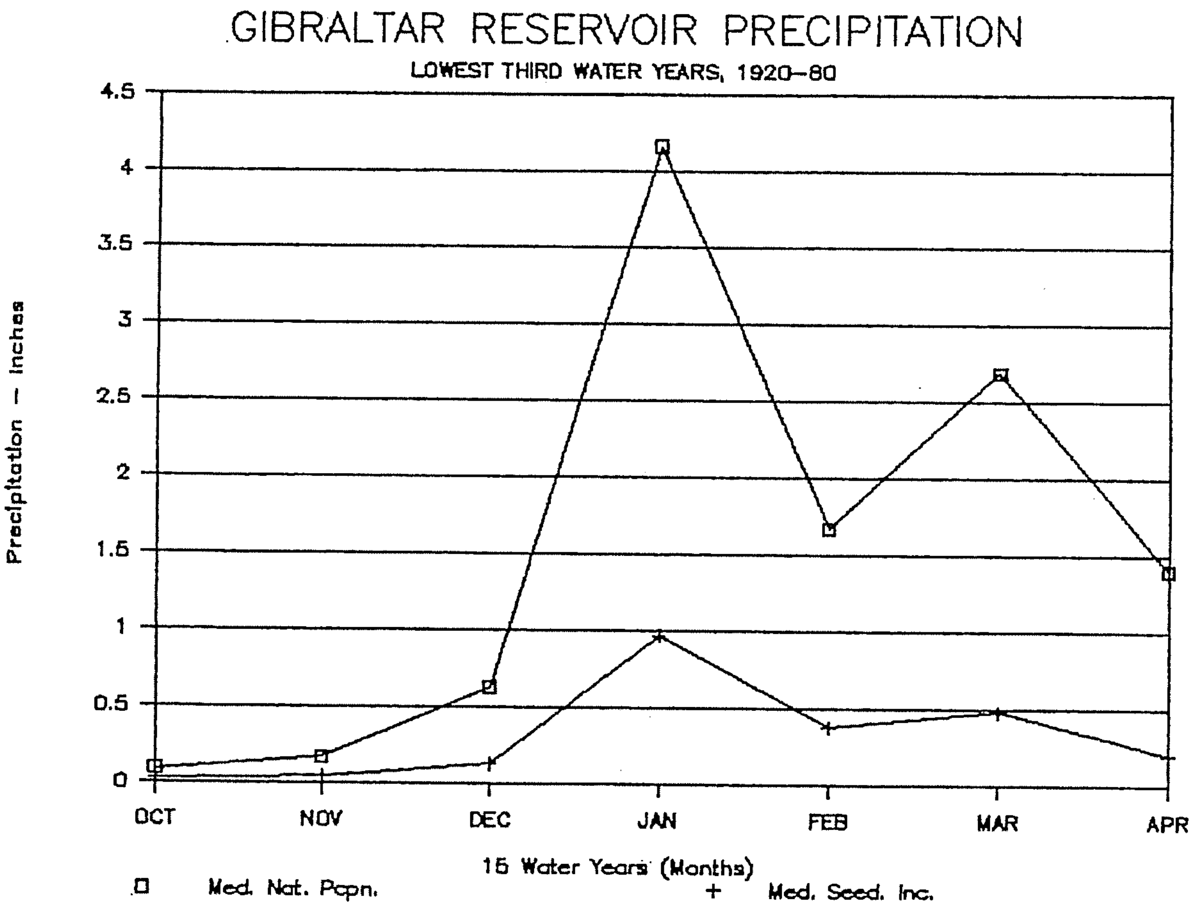

Figure 4.10 Median of Gibraltar Reservoir Natural Precipitation (inches) and "Seeded" Increase (inches) by month for Lowest Third Group.

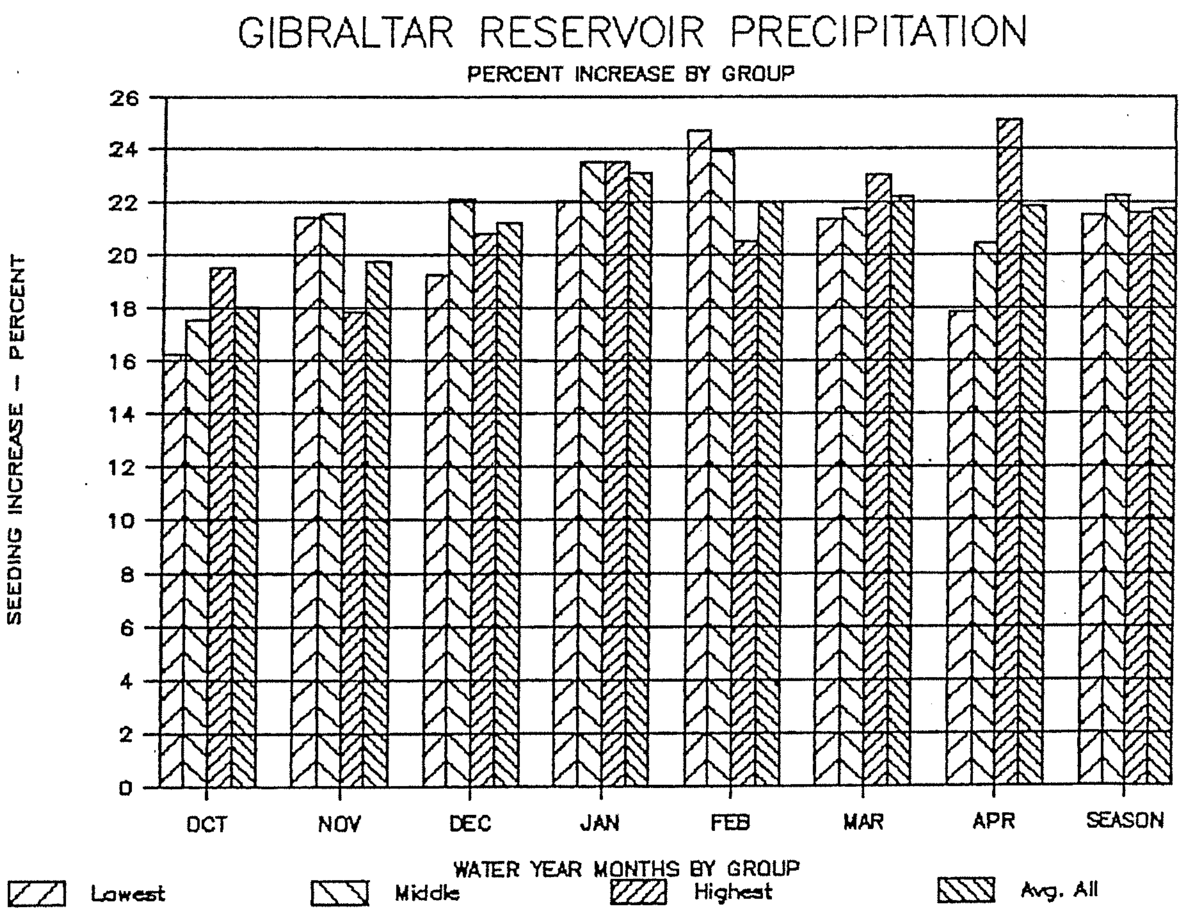

Figure 4.11 Estimated "Seeded" Precipitation Increase (percent) by Group at Gibraltar Reservoir

increase percentage averages over 22 percent and median precipitation increases over one-half inch.

4.8 Other Possible Precipitation Sites

To improve the areal coverage of the calculated effects of seeding over the watershed, it would have been desirable to have been able to calculate precipitation increases from seeding at several precipitation gauge sites instead of just at Gibraltar Reservoir and Juncal Dam. However, long period precipitation records did not exist at any other gauge sites within the watershed.

The Agency did provide some precipitation data from three other gauge sites within the watershed but for a much shorter period of record from the early 1970's until the mid 1980's. These gauge locations were at San Marcos Pass Summit (elevation 2499 feet), on the southern boundary of the watershed about seven miles west-southwest of Gibraltar Reservoir, at the Graham Ranch (elevation 3500 feet), which is also near the southern boundary of the watershed about two miles southwest of Gibraltar Reservoir and one mile east of La Cumbre Peak (which is on the watershed boundary), and at the Los Prietos Ranger Station (elevation 1030 feet), which lies within the watershed about seven miles west-northwest of Gibraltar Reservoir and about 10 miles southeastward from Lake Cachuma.

The locations of these precipitation gauges are identified on Figure 2.1 by the numbers 1, 2, and 3, for the gauges at San Marcos Pass Summit, Graham Ranch, and the Los Prietos Ranger Station, respectively.

These gauge sites are all located within about seven miles of Gibraltar Reservoir, but at different elevations. Because they are relatively close, it was thought that if a good precipitation relationship were to exist between Gibraltar and these other sites for the storm types, these gauge locations could provide additional insight as to the areal precipitation amount and percent increases distributions.

A linear regression analysis was applied to these three gauge sites using the precipitation data at the sites and Gibraltar Reservoir for each of the five storm types that occurred during the non-seeded storm periods from the 1975 to 1980 water years. The results of this analysis listing the coefficient of the predictor station (Gibraltar), the y-axis intercept, and the correlation coefficient (r) are displayed in Table 4-8. It would have been preferable to have had more storm precipitation pairs for the type C and D storms but these storm types are relatively rare during most water years. The results of the regression analysis appear to be quite good, suggesting that the storm precipitation amount at Gibraltar would generally be a reasonable predictor for precipitation totals at the other sites. The correlation coefficients were mostly greater than .90, meaning that at least 80 percent of the variance would be accounted for in these cases. Two of the correlation coefficients were not that good (in the B type storms at Graham Ranch and Los Prietos R.S.), which would indicate storm precipitation calculations at these sites with B type storms might not be as reliable as with the other types.

Even though long period historical data does not exist for these sites, using this approach would make it possible to approximate the storm precipitation at the gauge sites

Table 4-8

Linear Regression Results From
Gibraltar Reservoir Precipitation

	San Marcos Pass				Graham Ranch				Los Prietos R.S.			
Storm Type	N	Coeff	Int	(r)	(N)	Coeff	Int	(r)	(N)	Coeff	Int	(r)
A	36	1.14	.18	.966	37	1.06	.26	.950	34	0.97	-.01	.967
B	16	1.07	.18	.965	21	0.95	.18	.730	20	0.73	.60	.872
C	8	1.13	.21	.993	8	1.17	.14	.998	8	0.89	-.08	.997
D	7	1.08	.18	.976	7	1.37	.02	.996	7	0.99	-.03	.998
E	46	1.04	.40	.972	47	.99	.42	.971	48	0.74	.18	.985

N = Number of Storms

Coeff = Coefficient of Predictor Gauge (Gibraltar Reservoir)

Int = Intercept of Y Axis

r = Correlation Coefficient

from the Gibraltar precipitation total for each of the storms during the historical data sample period. According to the regression equations, for every 0.01 inch of natural precipitation observed at Gibraltar Reservoir some calculated amount would be expected to be observed at each of the other gauges, which might or might not differ from one storm type to another. Specifically, for an inch of precipitation recorded at Gibraltar Reservoir, one would expect that 1.32 inches would be observed at San Marcos Pass Summit with an A type storm. These calculated storm totals for an inch of precipitation at Gibraltar are shown in Table 4-9 for each of the five general storm types at the three gauge sites. The table indicates that while individual storm totals are different at the San Marcos Pass Summit and Graham Ranch sites, the average for all storms would be about the same and would be nearly a third of an inch greater than at Gibraltar Reservoir. On the other hand, the Los Prietos Ranger Station site would average about 12 percent less than Gibraltar and would receive less precipitation than Gibraltar with most of the storm types.

If one were to assume that the percent of precipitation within convection bands and the seed to no-seed ratios would be about the same at these gauge sites as they are at Gibraltar Reservoir (a reasonable assumption since these parameters at Gibraltar Reservoir and Juncal Dam do not differ greatly for storm type), it would be possible to calculate the approximate additional precipitation total from seeding that would have occurred at these locations during the historical period.

As an example of this approach, this was done for the 1928 water year. This year, which was randomly selected, produced 19.79 inches of natural precipitation at Gibraltar Reservoir. This total was about an inch below the median value of 20.76

Table 4-9

Approximate Precipitation Distribution Per Inch
At Gibraltar Reservoir

STORM TYPE	San Marcos	Graham Ranch	Los Prietos R.S.
A	1.32	1.32	0.86
B	1.25	1.13	0.83
C	1.34	1.31	0.81
D	1.26	1.39	0.96
E	1.44	1.41	0.92
AVG.	1.32	1.31	0.88

inches and several inches below the 23.90 inch average for the entire 46 year period. There were 16 storm periods observed at Gibraltar during the water year with the storm types about equally distributed. There were three storms each of types A, B, D, and E, and four storms of type C. Calculated seeded precipitation at Gibraltar Reservoir was 3.82 inches for the water year, which gave a seeding increase over the natural precipitation of 19.31 percent.

Using the data from Table 2-1 for Gibraltar Reservoir and the regression data from Table 4-8 to calculate the natural precipitation at San Marcos Pass Summit, Graham Ranch, and Los Prietos R. S. produced the following estimates at these sites for the 1928 water year.

At San Marcos Pass Summit, the calculated natural precipitation would have been 24.78 inches. This would have been 4.99 inches or about 25 percent more than was observed at Gibraltar. The calculated increase due to seeding would have been 4.82 inches (one inch more than Gibraltar), which would have given a seeding increase of 19.45 percent.

The Graham Ranch site would have received about 24.58 inches naturally (4.79 inches or about 24 percent more than Gibraltar received), which when seeded would have produced an additional 4.62 inches during the water year. This would have been an increase of 18.80 percent over the non-seeded total.

At the Los Prietos Ranger Station, using this technique, the calculated natural precipitation total would have been 16.84 inches (2.95 inches or 15 percent less than Gibraltar).

Seeding would have produced 3.13 inches of additional water for an 18.59 percent increase.

In summary, for the 1928 water year at the five stations (including Juncal Dam), these calculated precipitation amounts due to seeding would have been 3.13 inches at Los Prietos R.S., 4.82 inches at San Marcos Pass, 3.82 inches at Gibraltar Reservoir, 4.62 inches at Graham Ranch, and 3.81 inches at Juncal Dam. This would have averaged 4.04 inches of additional water within the approximately 50 square mile watershed area bounded by these gauges. It is not known whether the area within these gauges is unique or whether other areas of similar size within the watershed would have produced similar precipitation amounts. Local terrain and exposure affects the amount of natural precipitation and these same factors may influence seeding results as well.

4.9 Precipitation Statistics in the Seeded Years

While it was considered necessary to separate those years in which no seeding had been conducted (the 46 year historical period) from the seeded years in order to develop the seeding ratios, it was also desirable to examine the 15 years in which seeding did take place. This is because it is important to determine whether, either collectively or individually, the storm types and precipitation during the seeded years were nonrepresentative of the historical period. Since the seeding ratios were developed within a portion of the seeded years, it would be essential that these seeded years not be significantly different than the historical period. In addition, it is also desirable to be able to examine the whole data sample to assess what the effects of seeding might have been over the entire 61 year period.

The data for Gibraltar Reservoir and Juncal Dam for the 15 seeded years are presented in Tables 4-10 and 4-11, respectively. These tables are in the same format as Tables 4-1 and 4-2, which covered the historical years for the two precipitation sites. They include the natural (non-seeded) precipitation (in inches), and the calculated (estimated) total due to seeding for the seven months of the water year, the calculated increase due to seeding, the percent increase due to seeding, and a listing of the number of storms by storm type. The tables also include averages and median values of these parameters.

4.9.1 Elimination of Seeding Effect in Seeded Years

Seeding was not conducted on every storm during the seeded period and if the storm, or any portion of it, was not seeded it was treated the same as in the historical period. That is, depending on the storm type observed, a seeding effect was calculated from the seeding ratio and band precipitation percentage and added to the storm total. However, in the case of the storms which were seeded it was assumed a seeding effect was included in the observed precipitation total and this effect was eliminated by reducing the precipitation total according to the storm type seeding ratio statistics (Table 2-1).

For example, at Gibraltar Reservoir for an A type storm which had been seeded, the reported storm total was 1.45 inches. Eliminating the seeding effect from 59 percent of the storm, which was presumed to contain the seeded convection bands, gave an "unseeded" (or natural) storm total of 1.23 inches. In another case, at Juncal Dam an E type storm, which was seeded, totaled 1.30 inches. In this type storm, on average only 44 percent of the storm contains convection bands but seeding produces a significant effect (seed/no-seed ratio 1.63). The "unseeded" precipitation which would have occurred without seeding was calculated to be 1.02 inches.

Precipitation totals were examined storm-by-storm by checking the seeding logs for each of the storm periods within the seeded years and modified by either adding or subtracting the appropriate amount of precipitation according to the seeding ratio statistics.

4.9.2 Representativeness of Seeded Years

Examination of Tables 4-10 and 4-11 for Gibraltar and Juncal, respectively, in the seeded years indicate the data are in good agreement with each other. Average and median values of storms (by type) are very close and average and median percent increases due to seeding are also within one percent agreement. Juncal Dam averaged more "natural" and "seeded" precipitation than did Gibraltar, but the median values were very close. Juncal Dam usually received more precipitation during the water year but with some exceptions (notably the 1952, 1958, 1959, 1969, and 1973 water years) these differences were generally less than two inches.

Moreover, when the data in Tables 4-10 and 4-11 are compared to the data for the historical years (Tables 4-1 and 4-2) they are in good agreement suggesting the seeded storm years are not uniquely different from the historical period. The biggest difference between the two data samples is in the greater number of storms in the seeded years period (median of 20 vs 17). This difference is simply because it was easier to define the storm periods during the seeded years where the seeding logs indicated a clearer separation of one storm

Table 4-10

Gibraltar Reservoir Precipitation Statistics
and Storm Types for 15 Seeded Years (1951-78)

GIBRALTAR RESERVOIR SEEDED WATER YEARS (OCTOBER-APRIL), 1951-1978

WATER YEAR	NATURAL PCPN-IN	SEEDED PCPN-IN	INCREASE (INCHES)	PERCENT INCREASE	CIT "A"	STORM "B"	TYPES "C"	(NO. OF "D"	STORMS) "E"	STORM TOTAL
1951	10.04	12.27	2.23	22.21	4	6	2	2	6	20
1952	44.67	54.82	10.15	22.72	10	6	2	2	8	28
1953	14.11	17.24	3.13	22.18	4	3	2	0	9	18
1955	19.33	22.51	3.18	16.45	7	3	3	1	4	18
1957	15.22	18.00	2.78	18.27	3	2	6	3	5	19
1958	45.51	57.29	11.78	25.88	11	1	1	1	19	33
1959	15.71	18.14	2.43	15.47	5	1	0	2	3	11
1968	13.65	16.68	3.03	22.20	5	5	0	1	6	17
1969	53.60	66.49	12.89	24.05	5	9	1	2	15	32
1970	15.26	18.01	2.75	18.02	3	2	4	0	13	22
1971	19.71	23.49	3.78	19.18	6	8	0	2	4	20
1972	15.43	17.28	1.85	11.99	3	4	3	4	1	15
1973	34.01	42.35	8.34	24.52	8	3	2	2	14	29
1974	24.02	28.52	4.50	18.73	4	6	6	2	8	26
1978	53.26	63.72	10.46	19.64	4	2	4	0	13	23
TOTAL	393.53	476.81	83.28	301.51	82	61	36	24	128	331
AVERAGE	26.24	31.79	5.55	20.10	5.5	4.1	2.4	1.6	8.5	22.1
MEDIAN	19.33	22.51	3.18	19.64	5	3	2	2	8	20

Table 4-11

Juncal Dam Precipitation Statistics and Storm Types for 15 Seeded Years (1951-78)

JUNCAL DAM SEEDED WATER YEARS (OCTOBER-APRIL), 1951-1978

WATER YEAR	NATURAL PCPN-IN	SEEDED PCPN-IN	INCREASE (INCHES)	PERCENT INCREASE	CIT "A"	STORM "B"	TYPES "C"	(NO. OF "D"	STORMS) "E"	STORM TOTAL
1951	9.66	11.39	1.73	17.91	4	6	3	2	6	21
1952	48.09	59.26	11.17	23.23	10	6	2	2	8	28
1953	15.01	18.17	3.16	21.05	5	4	2	0	8	19
1955	18.94	22.18	3.24	17.11	6	3	3	1	4	17
1957	15.92	18.92	3.00	18.84	3	2	5	3	5	18
1958	51.44	64.51	13.07	25.41	9	2	0	1	19	31
1959	19.75	22.90	3.15	15.95	5	1	0	2	3	11
1968	15.13	18.15	3.02	19.96	5	5	0	1	5	16
1969	72.89	89.81	16.92	23.21	5	5	1	2	13	26
1970	15.52	18.55	3.03	19.52	2	0	4	0	11	17
1971	20.97	24.81	3.84	18.31	6	8	0	2	4	20
1972	17.09	19.11	2.02	11.82	3	4	3	5	1	16
1973	39.63	48.97	9.34	23.57	7	1	2	2	12	24
1974	26.21	31.53	5.32	20.30	4	3	5	2	7	21
1978	54.10	66.02	11.92	22.03	4	2	5	0	13	24
TOTAL	440.35	534.28	93.93	298.22	78	52	35	25	119	309
AVERAGE	29.36	35.62	6.26	19.88	5.2	3.5	2.3	1.7	7.9	20.6
MEDIAN	19.75	22.90	3.24	19.96	5	3	2	2	7	20

from another. In the historical years, looking only at daily precipitation data, if there was precipitation reported on consecutive days the tendency was to consider these days as one storm as long as the storm type catalogue did not change. Aside from that, the trend of the storm types during the seeded years was identical to that of the historical period. The E type storms were most prevalent followed in order by the A, B, C, and D types. Considering the better resolution of storm frequency from the seeded period it is likely that the seeded period more accurately represents the annual distribution of storms by type than does the historical period.

Both the "seeded" and "natural" precipitation totals averaged greater during the seeded period but the median values were slightly less than during the historical period. The indicated percent increase due to seeding was actually less during the seeded period with median values over two percent lower than in the historical period.

The monthly breakdown of the precipitation statistics for the seeded water years are presented in Tables 4-12 and 4-13 for the Gibraltar Reservoir and Juncal Dam sites, respectively. These are in the same format as Tables 4-3 and 4-4 during the historical period.

The wettest months in both the seeded and historical periods were December, January, and February. However, in the seeded water years January was the wettest followed by February while in the historical period February was the wettest followed by December. In both the seeded and historical water years March was the fourth wettest month followed by November, April and October. No actual cloud seeding was ever done during October in the seeded sample so the natural precipitation

Table 4-12

Gibraltar Reservoir Precipitation Statistics By Month and Water Year, 15 Seeded Years (1951-78)

GIBRALTAR RESERVOIR MONTHLY PRECIPITATION (INCHES) OCTOBER- APRIL WATER YEAR SEEDED YEARS

WATER YEAR	OCT NAT PCPN	OCT SEED INC	NOV NAT PCPN	NOV SEED INC	DEC NAT PCPN	DEC SEED INC	JAN NAT PCPN	JAN SEED INC	FEB NAT PCPN	FEB SEED INC	MAR NAT PCPN	MAR SEED INC	APR NAT PCPN	APR SEED INC	TOTAL NAT PCPN	TOTAL SEED INC	PERCENT INCR
1951	1.48	0.40	2.28	0.62	0.64	0.17	1.86	0.41	1.14	0.21	1.34	0.22	1.30	0.20	10.04	2.23	22.21
1952	1.11	0.25	3.35	0.15	4.65	1.17	23.00	6.39	0.18	0.03	10.65	1.90	1.73	0.26	44.67	10.15	22.72
1953	0.08	0.01	4.85	0.89	6.91	1.70	1.05	0.28	0.00	0.00	0.15	0.04	1.07	0.21	14.11	3.13	22.18
1955	0.00	0.00	3.28	0.44	3.17	0.72	5.81	1.01	2.51	0.18	0.63	0.12	3.93	0.71	19.33	3.18	16.45
1957	0.08	0.02	0.00	0.00	0.38	0.10	7.29	1.43	3.70	0.78	0.50	0.10	3.27	0.35	15.22	2.78	18.27
1958	2.01	0.49	0.84	0.15	9.94	2.80	2.83	0.79	10.83	2.89	8.56	2.04	10.50	2.62	45.51	11.78	25.88
1959	0.00	0.00	0.13	0.03	0.05	0.02	4.89	0.89	10.07	1.39	0.00	0.00	0.57	0.10	15.71	2.43	15.47
1968	0.00	0.00	5.09	1.05	1.51	0.28	1.85	0.40	1.03	0.29	2.75	0.76	1.42	0.25	13.65	3.03	22.20
1969	1.19	0.23	0.85	0.24	1.91	0.53	29.17	7.92	16.10	3.14	1.88	0.28	2.50	0.55	53.60	12.89	24.05
1970	0.00	0.00	2.34	0.41	0.31	0.09	3.54	0.99	3.14	0.61	5.93	0.65	0.00	0.00	15.26	2.75	18.02
1971	0.08	0.02	8.20	1.53	7.58	1.45	1.08	0.10	1.28	0.36	0.66	0.14	0.83	0.18	19.71	3.78	19.18
1972	0.47	0.10	1.09	0.30	13.14	1.34	0.19	0.02	0.30	0.03	0.00	0.00	0.24	0.06	15.43	1.85	11.99
1973	0.55	0.14	8.24	2.10	1.03	0.07	7.71	2.16	12.59	3.15	3.89	0.72	0.00	0.00	34.01	8.34	24.52
1974	0.70	0.17	4.97	1.34	0.52	0.08	11.84	1.47	0.05	0.01	5.18	1.27	0.76	0.16	24.02	4.50	18.73
1978	0.00	0.00	0.14	0.03	9.23	1.23	9.67	2.27	11.95	3.36	18.03	2.76	4.24	0.81	53.26	10.46	19.64
TOTAL	7.75	1.83	45.65	9.28	60.97	11.75	111.78	26.53	74.87	16.43	60.15	11.00	32.36	6.46	393.53	83.28	301.51
AVERAGE	0.52	0.12	3.04	0.62	4.06	0.78	7.45	1.77	4.99	1.10	4.01	0.73	2.16	0.43	26.24	5.55	20.10
MEDIAN	0.08	0.02	2.34	0.41	1.91	0.53	4.89	0.99	2.51	0.36	1.88	0.28	1.30	0.21	19.33	3.18	19.64
MAX.	2.01	0.49	8.24	2.10	13.14	2.80	29.17	7.92	16.10	3.36	18.03	2.76	10.50	2.62	53.60	12.89	25.88
PCT INC		23.61		20.33		19.27		23.73		21.94		18.29		19.96			21.16

Table 4-13

Juncal Dam Precipitation Statistics By Month and Water Year, 15 Seeded Years (1951-78)

JUNCAL DAM MONTHLY PRECIPITATION (INCHES) OCTOBER - APRIL WATER YEAR SEEDED YEARS

WATER YEAR	OCT NAT PCPN	OCT SEED INC	NOV NAT PCPN	NOV SEED INC	DEC NAT PCPN	DEC SEED INC	JAN NAT PCPN	JAN SEED INC	FEB NAT PCPN	FEB SEED INC	MAR NAT PCPN	MAR SEED INC	APR NAT PCPN	APR SEED INC	TOTAL NAT PCPN	TOTAL SEED INC	PERCENT INC
1951	1.30	0.35	2.14	0.36	0.45	0.13	2.20	0.35	1.45	0.22	0.54	0.09	1.58	0.23	9.66	1.73	17.91
1952	1.42	0.22	3.41	0.35	4.49	1.10	26.13	7.13	0.29	0.05	10.21	2.01	2.14	0.31	48.09	11.17	23.23
1953	0.03	0.00	5.67	0.97	7.11	1.70	0.96	0.22	0.03	0.00	0.27	0.06	0.94	0.21	15.01	3.16	21.05
1955	0.00	0.00	2.70	0.47	3.31	0.69	5.73	0.96	2.95	0.37	0.60	0.10	3.65	0.65	18.94	3.24	17.11
1957	0.05	0.02	0.00	0.00	0.62	0.17	7.60	1.62	3.64	0.74	0.33	0.07	3.68	0.38	15.92	3.00	18.84
1958	2.67	0.57	1.12	0.18	12.15	3.37	3.34	0.94	11.41	3.01	9.47	2.20	11.28	2.80	51.44	13.07	25.41
1959	0.00	0.00	0.07	0.01	0.03	0.01	5.55	0.95	12.31	1.88	0.00	0.00	1.79	0.30	19.75	3.15	15.95
1968	0.00	0.00	5.54	0.91	1.41	0.25	2.26	0.40	1.19	0.32	3.15	0.87	1.58	0.27	15.13	3.02	19.96
1969	1.29	0.20	0.77	0.21	1.99	0.56	41.31	11.20	22.83	4.01	1.95	0.29	2.75	0.42	72.89	16.92	23.21
1970	0.00	0.00	2.55	0.43	0.18	0.05	3.21	0.89	3.13	0.69	6.45	0.97	0.00	0.00	15.52	3.03	19.52
1971	0.00	0.00	8.98	1.58	7.00	1.25	1.29	0.13	2.31	0.65	0.71	0.11	0.68	0.12	20.97	3.84	18.31
1972	0.78	0.11	11.12	0.31	14.38	1.46	0.30	0.05	0.30	0.05	0.00	0.00	0.21	0.04	17.09	2.02	11.82
1973	0.29	0.05	7.98	1.53	1.00	0.11	8.07	2.26	17.77	4.62	4.52	0.77	0.00	0.00	39.63	9.34	23.57
1974	0.88	0.22	5.34	1.42	0.26	0.03	13.24	2.11	0.00	0.00	6.10	1.47	0.39	0.07	26.21	5.32	20.30
1978	0.00	0.00	0.09	0.02	9.67	1.57	10.08	2.82	13.97	3.90	17.15	3.05	3.14	0.56	54.10	11.92	22.03
TOTAL	8.71	1.74	57.48	8.75	64.05	12.45	131.27	32.03	93.58	20.51	61.45	12.06	33.81	6.36	440.35	93.93	298.22
AVERAGE	0.58	0.12	3.83	0.58	4.27	0.83	8.75	2.14	6.24	1.37	4.10	0.80	2.25	0.42	29.36	6.26	19.88
MEDIAN	0.05	0.02	2.70	0.36	1.99	0.56	5.55	0.95	2.95	0.65	1.95	0.29	1.58	0.27	19.75	3.24	19.96
MAX.	2.67	0.57	11.12	1.58	14.38	3.37	41.31	11.20	22.83	4.62	17.15	3.05	11.28	2.80	72.89	16.92	25.41
PCT INC		19.98		15.22		19.44		24.40		21.92		19.63		18.81			21.33

total was the actual observed total. In both sample periods January appeared to contain the most seedable storms with the highest percent increase indicated during this month while the other months varied as to seedability.

At Gibraltar, the greatest monthly seeding total that would have been achieved had all the storms been seeded would have been 7.92 inches in January, 1969. This would have increased the January total to 37.09 inches compared to the 31.18 inches actually observed. There were seven storm periods in this month but only three of them were seeded. Seeding was suspended toward the end of the month due to exceptionally heavy precipitation and stream runoff. The calculated "natural" precipitation total for this month was 29.17 inches which meant that only 2.01 inches of the 7.92 inches due to seeding (25 percent of the calculated increase) were produced in these three storms. Similarly, February, 1958 was also a wet month in which 13.35 inches of precipitation were recorded at Gibraltar Reservoir. However, during this month there were six storm periods and five of these were seeded with 2.89 inches of additional precipitation produced by the seeding. If all the storms had been seeded in the month the calculated total would have been 13.72 inches. After removal of the seeding effects the natural precipitation that would have fallen during the month was calculated to be 10.83 inches. This meant that seeding actually produced a 23 percent increase in the monthly total which accounted for 87 percent of the calculated excess if all the storms had been seeded.

However, just as in the historical sample which had many months when no precipitation was observed there were several months (particularly in October and April) in the seeded years when no precipitation was observed. From November through

March though these zero precipitation months were fewer in number than in the historical years.

4.10 Precipitation Statistics in the 61 Year Sample

The precipitation statistics for all 61 of the water years from 1920 through 1980 are summarized for Gibraltar Reservoir and Juncal Dam in Table 4-14. These data were obtained by combining the summary rows at the bottom of Tables 4-1, 4-2, 4-10, and 4-11.

At Gibraltar Reservoir, the October-April period for the 61 water years averaged 24.3 inches of natural precipitation. If all the storms had been seeded an average of about five inches (5.3 inches) additional precipitation would have fallen in a typical water year. This total represents a 21 percent increase over the precipitation that would have fallen naturally. Median values, which are probably more representative, were lower with a natural precipitation total at 21 inches and a 4.5 inch increase due to seeding. This was a 22 percent increase over the natural unseeded total. Approximately 19 storms would have occurred per water year with over two-thirds of them (68 percent) consisting of the more seedable E and A type storms.

Data for Juncal Dam are similar with natural precipitation averaging nearly 27 inches (26.8 inches) per water year and with seeding producing nearly six inches of additional water (5.8 inches) in a typical year. Median values were again lower with 23 inches produced naturally and about five additional inches due to seeding. Both the average and median values of precipitation increase represent a 21 percent increase over the natural precipitation accumulations. Like Gibraltar

Table 4-14

Summary of Precipitation Statistics and Storm Types for Gibraltar Reservoir and Juncal Dam, 61 Water Years (October - April) From 1920-1980

GIBRALTAR RESERVOIR

	NATURAL PCPN-IN	SEEDED PCPN-IN	INCREASE (INCHES)	PERCENT INCREASE	CIT "A"	STORM "B"	TYPES "C"	(NO. OF "D"	STORMS) "E"	STORM TOTAL
TOTAL	1485.01	1805.74	320.73	1301.50	283	180	124	73	463	1123
AVERAGE	24.34	29.60	5.26	21.34	4.6	3.0	2.0	1.2	7.6	18.4
MEDIAN	21.07	26.18	4.54	22.20	5	3	2	1	8	19

JUNCAL DAM

	NATURAL PCPN-IN	SEEDED PCPN-IN	INCREASE (INCHES)	PERCENT INCREASE	CIT "A"	STORM "B"	TYPES "C"	(NO. OF "D"	STORMS) "E"	STORM TOTAL
TOTAL	1635.66	1987.54	351.88	1286.98	280	165	123	72	452	1092
AVERAGE	26.81	32.58	5.77	21.10	4.6	2.7	2.0	1.2	7.4	17.9
MEDIAN	23.25	27.92	4.96	21.05	5	2	2	1	7	18

Reservoir, the Juncal Dam site would also experience 18 storm periods during the typical water year.

The monthly distribution is summarized for the 61 water years at the two sites in Table 4-15. At Gibraltar Reservoir, all the months except October would have experienced increases in precipitation of 20 percent or more had all the storms been seeded. Juncal Dam was similar except October and November seeding increases would have been closer to 18 percent. Both the average and median seeding increases would have been greater than 0.50 inches at Gibraltar Reservoir and at Juncal Dam from December through March in a typical year.

Table 4-15

Summary of Precipitation Statistics by Month for Gibraltar Reservoir and Juncal Dam, 61 Water Years, 1920-1980

GIBRALTAR RESERVOIR	OCT NAT PCPN	OCT SEED INC	NOV NAT PCPN	NOV SEED INC	DEC NAT PCPN	DEC SEED INC	JAN NAT PCPN	JAN SEED INC	FEB NAT PCPN	FEB SEED INC	MAR NAT PCPN	MAR SEED INC	APR NAT PCPN	APR SEED INC	TOTAL NAT PCPN	TOTAL SEED INC	PERCENT INCR
TOTAL	32.91	6.37	151.62	30.23	274.40	56.98	312.61	72.88	330.85	72.73	254.28	54.11	128.34	27.45	1485.01	320.73	1301.50
AVERAGE	0.54	0.10	2.49	0.50	4.50	0.93	5.12	1.19	5.42	1.19	4.17	0.89	2.10	0.45	24.34	5.26	21.34
MEDIAN	0.30	0.05	1.09	0.21	2.51	0.58	4.16	0.90	2.80	0.60	2.89	0.65	1.11	0.21	21.07	4.50	22.20
MAX.	4.13	0.61	17.00	2.22	17.21	3.19	29.17	7.92	23.05	6.17	17.97	4.65	12.10	3.40	66.64	14.83	27.25
PCT INC		19.36		19.94		20.77		23.31		21.98		21.28		21.39			21.60

JUNCAL DAM	OCT NAT PCPN	OCT SEED INC	NOV NAT PCPN	NOV SEED INC	DEC NAT PCPN	DEC SEED INC	JAN NAT PCPN	JAN SEED INC	FEB NAT PCPN	FEB SEED INC	MAR NAT PCPN	MAR SEED INC	APR NAT PCPN	APR SEED INC	TOTAL NAT PCPN	TOTAL SEED INC	PERCENT INCR.
TOTAL	37.42	6.78	178.73	32.69	288.77	59.73	343.68	80.32	385.42	85.35	265.80	56.93	144.89	30.05	1635.66	351.87	1286.98
AVERAGE	0.61	0.11	2.93	0.54	4.73	0.98	5.63	1.32	6.32	1.40	4.36	0.93	2.38	0.49	26.81	5.77	21.10
MEDIAN	0.28	0.05	1.12	0.29	3.05	0.69	4.16	0.94	3.34	0.69	3.10	0.76	1.32	0.23	23.25	4.85	21.05
MAX.	3.29	0.57	18.86	2.77	16.16	3.37	41.31	11.20	29.93	7.93	17.28	4.40	15.20	4.15	72.89	16.92	25.63
PCT INC		18.12		18.29		20.68		23.37		22.14		21.42		20.74			21.51

5.0 CONCLUSIONS

This climatological study was undertaken with the goal of producing statistics that would enable the Santa Barbara County Water Agency to estimate the additional runoff from winter storms affecting the County if the storms had been seeded. The seeding mode adopted for the study was the one that had been used with success during the cloud seeding research project (SBA II) undertaken during the 1968 to 1974 water years. This earlier research demonstrated that "convection bands" embedded in naturally occurring winter storms responded positively to silver iodide seeding.

This climatological study indicated that seeding increases greater than 20 percent at Gibraltar Reservoir and Juncal Dam would have been achieved during most of the years in the historical period when cloud seeding was not conducted if cloud seeding had been undertaken. Both average and median seeding increases were 20 percent during the 15 water years when cloud seeding was conducted over the watershed. Seeding increases in inches of water are dependent upon the amount of natural precipitation that would be available for treatment, with more precipitation produced during the wetter years. Increases of three inches or more would be likely during the dryer years with increases of over seven inches probable during the wetter years. Seeding increases are considerably dependent upon the character of the storms and this may be reflected in the storm type.

Over the 61 water years the study suggested that in a typical year 18-19 storm periods would occur over the watershed with the majority of the storm periods consisting of seedable segments. In a typical year between 4.50 and 5.75 inches of additional water could be expected from cloud seeding in the Gibraltar Reservoir and Juncal Dam locations of the watershed. Additional watershed areas would experience greater or lesser amounts depending on exposure and local terrain influences.

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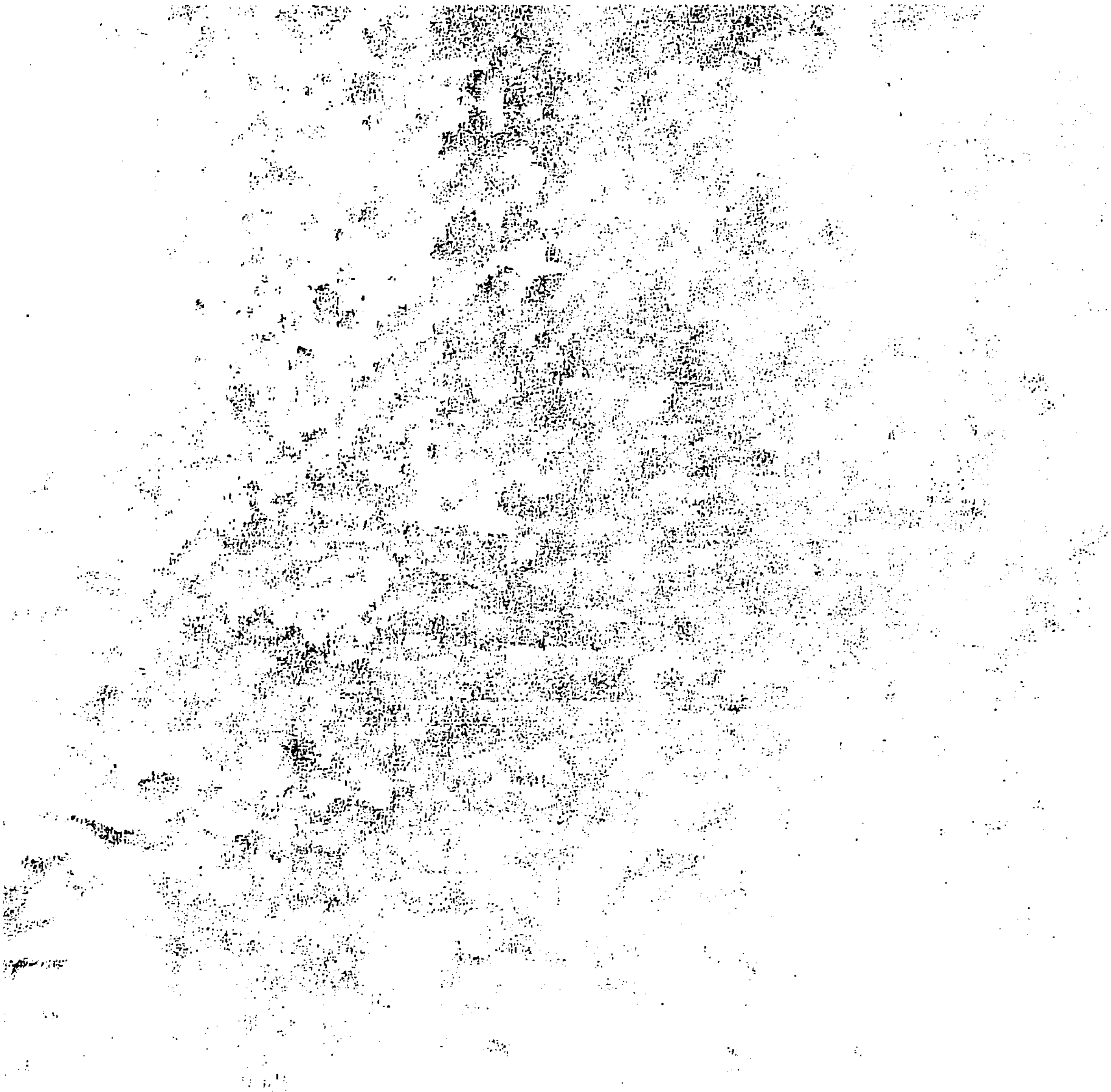

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