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Southern California Severe Thunderstorm Event and a First Look at Precipitation Data From the San Diego-Miramar WSR-88D

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ABSTRACT

On Friday, May 24, 1996, a late season upper level closed low positioned itself over southern Nevada and provided the environment required for widespread precipitation throughout the four-state areas of Nevada, Utah, Arizona, and California. In southern California, showers and thunderstorms developed and moved into northern San Diego County early Friday morning. These thunderstorms produced significant lightning, hail, and rainfall. A severe thunderstorm produced hail in the Fallbrook area that resembled a blanket of snow. Rainfall produced street flooding and slippery road conditions which resulted in numerous accidents.

This was the first event to occur after the installation and acceptance of the WSR-88D Doppler radar in San Diego. The WSR-88D was an extremely useful observing tool that enabled the NWSO San Diego forecasters to issue timely and accurate warnings. This paper summarizes the synoptic and mesoscale features present during the life of this brief but rather significant event, and highlights some of the new WSR-88D algorithms used by the NWSO San Diego meteorologist and hydrometeorologist technician staff. The occurrence of a significant hail event was also reviewed for its potential contamination and subsequent impacts on the precipitation algorithms.

INTRODUCTION

Previous authors (Cayan and Riddle, 1992) have noted that winter storms vary considerably in frequency, intensity, and trajectory. It is during the winter months that the jet stream is most favorably poised to trigger precipitation that water management officials are highly dependent on. Generally after the winter months, conditions become fairly dry throughout Southern California with only occasional thunderstorms developing when enough moisture becomes available either from decaying tropical systems, or from moisture that is imported from northern Mexico or Arizona. Climatology shows that during the entire month of May, precipitation averages 1.4 inches in Los Angeles and only 0.30 inches in San Diego. As indicated by these totals, significant precipitation occurrences during the end of May are not too common.

The precipitation and severe thunderstorm event that occurred on Friday, May 24, 1996, produced heavy rainfall in the northwest portion of San Diego County. This event was beneficial in replenishing the fresh water supply, but disrupted daily activities throughout the Fallbrook, Oceanside, Escondido, areas of southern California. Population figures show that approximately 2,688,000 people live in San Diego County. The late May event affected residents in the north and central sections of the county - specifically the 37,500 people living in Fallbrook, 142,000 in Oceanside, and 115,500 in Escondido.

The event produced significant precipitation with rainfall totals of nearly 2 inches in a 3-4 hour period over the normally dry sections of the mountainous terrain. The heaviest rainfall was centered over the Fallbrook area, which is located at an elevation of approximately 675 feet. A well-defined precipitation gradient verified that orographical effects were present, with vorticity moving across the area acting as the main trigger. It is likely that hail contamination over the Fallbrook to Escondido area resulted in significant overestimation by the San Diego WSR-88D. It should also be noted that other factors that cause radar precipitation overestimation or underestimation include radar siting, the precipitation algorithm, and the precipitation mechanism operating within the cloud system (Reynolds, 1995).

DATA SOURCES

National Center for Environmental Prediction (NCEP) products were used as the principal synoptic guidance. While the traditional model guidance was used, this office has access to the high resolution meso Eta 29Km model data from NCEP. Computer generated soundings for San Diego Miramar (NKX) and Vandenburg AFB (VBG), and time section wind profiles for those two stations are also available. High resolution, digital Geostationary Operational Environmental Satellite (GOES-9) data are available to the San Diego NWSO through the RAMM Advanced Meteorological Satellite Demonstration and Interpretation System (RAMSDIS).

The rainfall network used consisted of data received on the Hydro-Meteorological (HydroMet) Computer from the ALERT systems located throughout San Diego County. The San Diego County Flood Control is primarily responsible for maintaining the integrity of the gages which provide valuable data to the San Diego NWSO. Attachment 1 provides a map of San Diego County with important rivers, dams, and major cities for reference.

The WSR-88D located at Miramar (KNKX) in San Diego was installed on December 29, 1995 and accepted on March 15, 1996. The two months following the acceptance were relatively dry with only light rainfall events occurring on several occasions. Therefore, this was the first time the Doppler radar was able to observe a significant event. Data was archived on SCSI tape since the other archive devices were not operating at the time. This provided the NWSO San Diego forecasters an opportunity to play back the event and make hard copies of the WSR-88D products which were used to make initial evaluations of utility of the Doppler data in San Diego.

SYNOPSIS

Each model run leading up to the May 24, 1996 severe thunderstorm event in northwest San Diego County indicated an unseasonably cold closed low dropping south over the west coast. While model runs several days before the event had limited moisture, later model runs shifted the center of the upper low slightly west with more "over-the-water" trajectories into San Diego. All model outputs indicated the low would "bottom out" over Southern California.

The models valid on the morning of the event (1200Z ETA and RFS) indicated that a strong 500 mb short wave would move through San Diego during the day with heights lowering to 5580 m. PCGRIDDS also showed a strong Q-vector divergence/convergence couplet associated with the short wave moving through the area. In addition, both models had the left-front quadrant of a cyclonically curved jet maximum over San Diego between 1200Z-0000Z on the 24th. All of these factors pointed toward synoptic scale forcing with strong vertical motions. However, all models indicated a short lived event with strong downward vertical motion moving into the area by the afternoon.

The 1200Z Miramar sounding (NKX) was stable early in the morning of May 24. The scenario quickly changed 4-6 hours after the 1200Z sounding with rapid cooling aloft creating explosive destabilization as a pool of cold air at 700 mb (-4 to -5 degrees Celsius) moved directly over San Diego. Rapid destabilization occurred in 12 hours as the K-index from the NKX sounding went from 0 at 1200Z on May 24th to 30 by 0000Z on May 25.

Both the 1200Z ETA and RFS indicated only lifted indices in the 0 to minus 1 range over San Diego for May 24. The 1200Z Eta indicated the K-index would be in the mid-20s while the 1200Z RFS indicated the K-index would be in the low-30s over the area during the day on the 24th of May. This is not extremely unstable, but this event would occur between the traditional 12 hour model output steps.

Neither model advected in large amounts of moisture. The Eta had no rain for San Diego and the RFS only had rainfall totals of less than a tenth of an inch anywhere in the county. The models were a great help on the synoptic scale indicating generally strong upward forcing and general destabilization. This is typical of NCEP model performance over the west coast. Since few observations exist over the eastern Pacific, the models are usually initialized with a poor vertical distribution of moisture. This was clearly an event when the WSR-88D, satellite, and spotters would be the most help in making the short-term forecast.

SEVERE THUNDERSTORM EVENT

At around 1630Z a thunderstorm began to form over northwest San Diego County and split into two storms. GOES-9 satellite imagery on RAMSDIS showed a thunderstorm had formed northwest of Fallbrook (subsequently referred to Storm One) and another was just to the east over the foothills of the nearby mountains (Storm Two). Storm Two progressed slowly southeast along the NW-SE foothills with an apparent outflow boundary spreading out to its south and west. The extreme west end of this boundary interacted with Storm One causing rapid development by 1800Z - 1900Z (with associated colder tops on the IR imagery). This occurred at about the same time of maximum vertical motion and cold air aloft. Storm One followed the outflow from Storm Two SSE and continued to slowly decrease in intensity from 2000Z - 2100Z and dissipated over west central San Diego County.

Using the KNKX WSR-88D, Special Weather Statements were issued from 1645Z through 1830Z highlighting the heavy rain, possible small stream flooding, lightning danger and small hail. At about 1730Z reports of heavy rain and small hail were received from Valley Center (east of Fallbrook, near Storm Two). Shortly after the high reflectivities and VIL were seen on the KNKX WSR-88D near Fallbrook, a telephone call made to the spotter at the Fallbrook Fire Department at about 1900Z provided a report of one-inch diameter hail piling up three inches deep on the ground (from Storm One). A Severe Thunderstorm/ Flash Flood Warning was issued immediately for northwest San Diego County. While no subsequent "ground truth" reports of severe weather were received, based on the WSR-88D and satellite data, it was likely that severe thunderstorm conditions existed for about another hour.

Reports of flooding on the I-15 freeway in northwest San Diego County during the valid time period of the warning were received and verified the existence of a severe thunderstorm with possible heavy rain. Later reports indicated that traffic lanes were flooded by rain water that pooled due to drains clogged by hail and debris. The Fallbrook Fire Department reported the largest rainfall total for the event with 1.84 inches.

The following are descriptions of some of the WSR-88D data received and used during this event to issue the appropriate products, and after the event to analyze with more precision the areas where the rainfall was heaviest.

BASE REFLECTIVITY (R)

On Friday, May 24, 1996, the convective complex was well into its formative stage. By 1701Z, the Miramar WSR-88D lower elevation angles (0.5 degree and 2.4 degree) were indicating numerous areas where the reflectivity of the storms was 35-45 dBZ between Fallbrook and Escondido. At the same time, reflectivity pockets of 56 dBZ and 58 dBZ were found embedded within this same area.

Throughout the next 3 hours, the convection oscillated with the maximum reflectivity value of the storms reaching into the 60 dBZ to 67 dBZ range in the Fallbrook area on several occasions. Maximum tops for these storms were generally in the 25,000-30,000 ft. range.

Figure 1 shows a four quadrant base reflectivity 0.5 elevation angle history of the initial heavy rainfall and hail event that moved across Fallbrook. The existence of the two distinct storms which were discussed earlier are seen as individual maximums in these series of radar reflectivity products.

Several guidelines are available to determine the intensity of the storms. For the default WSR-88D Z-R relationship of $Z = 300R^{1.4}$, it has been shown that the values in Table 1 apply.

TABLE 1 ..... Z - R RELATIONSHIPS		
dBZ Value	Echo Intensity	WSR-88D Rainfall Rates for Z-R Relationship using $Z= 300 R^{1.4}$
20 - 29	light	0.02 inch / hr.
30 - 40	moderate	0.09 inch / hr.
41 - 46	strong	0.48 inch / hr.
46 - 50	Very Strong	2.00 - 2.49 inch / hr.
50 - 57	Intense	2.50 - 5.70 inch / hr.
57 +	Extreme	> 5.7 inch / hr
Note that normally any value above 55 is suspect due to presence of hail which produces contamination of the precipitation algorithm.		

In comparing these values, it is readily evident that for the May 24, 1996 event, the WSR-88D indicated the existence of intense convective activity where the values of the reflectivity exceeded 50 dBZ. In this case, the radar was also above the extreme intensity threshold repeatedly throughout the initial 3 hours of the event.

COMPOSITE REFLECTIVITY (CR)

The intense thunderstorms that were occurring over the north-central sections of San Diego County were quickly located using the composite reflectivity data. An area of reflectivity values greater than 60 dBZ was found on all volume scans beginning with 1730Z and continuing through 2008Z. The highest value of 67 dBZ occurred over Fallbrook at 1747Z and again at 1835Z. The higher reflectivity values persisted between the Fallbrook and Escondido area as thunderstorms continued to reform after the mature storms moved southeast.

Figure 2 provides a quick look at the volume scan at 1835Z where the maximum composite reflectivity value of 67 dBZ was clearly evident in the vicinity of Fallbrook.

VERTICALLY INTEGRATED LIQUID (VIL)

The maximum VIL of 43 Kg/m^2 occurred at 1823Z just west of Fallbrook. Although this value does not approach the estimated VIL values of 55 Kg/m^2 needed for large hail in the Midwest for the month of May, it represents a high value for southern California.

A paper presented at the first WSR-88D Users' Conference (Wofford, 1994) indicated that in a severe thunderstorm which produced small hail in south-central California, the highest VILs were on the order of 10 to 20 kg/m^2. VILs are highly dependent on the structure of the storm and its environment. The VIL threshold for severe weather can vary remarkably from one event to another. VILs should be used cautiously during severe storm events.

Figure 3 shows the four panels during which the VIL exceeded 40 kg/m^2 during the May 24 event. The VIL exceeded 40 kg/m^2 shortly after 1800Z, dropped slightly below for a few volume scans, but then reached a maximum at 1823Z, and maintained those values for the next two volume scans. After the value of 41 kg/m^2 at 1835Z, the values of the VILs persisted in the 30s until 1910Z.

STORM TOTAL PRECIPITATION (STP)

There have been many papers written that provide evidence that the precipitation algorithm can be contaminated by hail or mixed state hydrometers. Meteorologists need to account for the existence of frozen precipitation to determine if the radars values as provided in the precipitation products are overestimated or underestimated. In the case where the radar has hail contamination over the northern sector and none over the remainder of the area, the challenge to discriminate between the different outputs becomes more complex. Such was the case on May 24, 1996, where the higher VIL values between Fallbrook and Escondido pointed toward the existence of a hail event, while farther south only rain was occurring.

Since Fallbrook is approximately 30nm from the RDA site, it can be assumed that the Z value used to estimate R in the Z-R relationship is derived from the lowest part of the thunderstorm. The May 24, 1996 event provided the NWSO San Diego office with the opportunity to compare rainfall data recorded at ALERT and cooperative observer rain gages with the values which the WSR-88D algorithms provided to the forecasters.

Table 2 shows some of the heavier rainfall totals that were recorded at some of the ALERT stations in San Diego County. Additional observations are also included from cooperative observations. By using the actual ground truth data and applying the data generated by the WSR-88D in the final Storm Total Precipitation (STP) product, it was readily evident that the value of the radar data can also be used in improving an isohyetal analysis of storm precipitation.

Table 2. May 24 (8:00 am - 4:00 pm) rainfall (inches)				
Site #	Name	TOTAL	WSR-88D	Comparisons
139	Sandia Creek Rd.	0.04 in.	0.10	Radar overestimated
35	Fallbrook	0.91 in	3.50	Radar overestimated
Co-op	Fallbrook F.S.	1.84 in.	2.50	Radar overestimated
81	Rincon Springs F.S.	0.04 in.	0.50	Radar overestimated
83	Valley Center	0.24 in.	0.50	Radar overestimated
37	Lake Wohlford	0.79 in.	0.70	Radar underestimated
Co-op	Escondido Wild Animal Park	0.62 in.	0.80	Radar overestimated
41	Ramona	0.35 in.	0.30	Radar underestimated
Co-op	Ramona	0.72 in.	0.50	Radar underestimated
42	Barona	0.20 in.	0.20	Radar and gage equal
53	Santa Ysabel	0.24 in.	0.20	Radar underestimated
26	Santee	0.04 in.	0.00	Radar underestimated
Co-op	Poway	0.65 in.	1.60	Radar overestimated
3962	Sutherland Res.	0.24 in.	0.30	Radar overestimated

Note that the WSR-88D precipitation in this case provided anywhere from 48 percent to 67 percent above the actual recorded amounts over most sites where hail was also occurring. More representative comparisons occurred over the southern areas where hail contamination was not likely.

Figure 4 is the Storm Total Precipitation (STP) data compared to the rainfall values received from the ALERT and cooperative observer network and arrive at a representative isohyetal analysis. Note that the higher values were concentrated in the vicinity where Storm One and Storm Two were the most intense. It is also the area where orographical effects likely enhanced vertical motion. The heavier rainfall was recorded over the northwest part of San Diego County where values provided by the precipitation algorithms showed a trend for occurrence of significant rainfall. Thus, the WSR-88D STP data are shown as being very beneficial in providing a good estimate of not only the areas where the heaviest rain is occurring, but also on the extent of the activity. By using the background map in Attachment 1, the forecaster is able to provide the proper hydrometeorological products and services to emergency managers in the affected areas.

The isohyetal analysis in Fig. 5 is a comparison between one which was done without the benefit of additional radar precipitation data and one enhanced with the final storm precipitation product. With the use of the radar, a more precise analysis was performed. These data will be a tremendous benefit for historical reference on storms that impact southern California.

CONCLUDING REMARKS

This was the first significant weather event observed with the San Diego WSR-88D. The KNKX Doppler radar was a tremendous help in locating the precise location of strong thunderstorms, heavy rain, and hail using reflectivity and VIL products.

As shown, without the use of the Doppler radar, the isohyetal analysis using only ground truth data can be very misleading. With the help of the precipitation products generated by the WSR-88D, the isohyetal analysis is more representative of the extent of where rainfall occurred.

The radar provided qualitative information on where the heaviest rain was occurring. Rainfall totals on precipitation products were fairly representative in the areas without hail, and where hail was reported.

"Hail contamination" likely contributed to artificially high rainfall estimates by the algorithms. However, with the combination of satellite data and spotters, the KNKX WSR-88D proved to be an invaluable tool during this severe weather event.

For heavy rainfall, the composite reflectivity provides a quick and easy way of locating the most likely areas of increase convection. Meteorologists then focus on that area to obtain additional ground information for possible issuance of advisory and warning products. It is definitely a very exciting time for all meteorologists receiving WSR-88D data in the Western Region. Collaborative efforts are currently planned with the San Diego Flood Control managers to look at flash flood events, and how best to utilize Doppler capabilities to optimize warnings.

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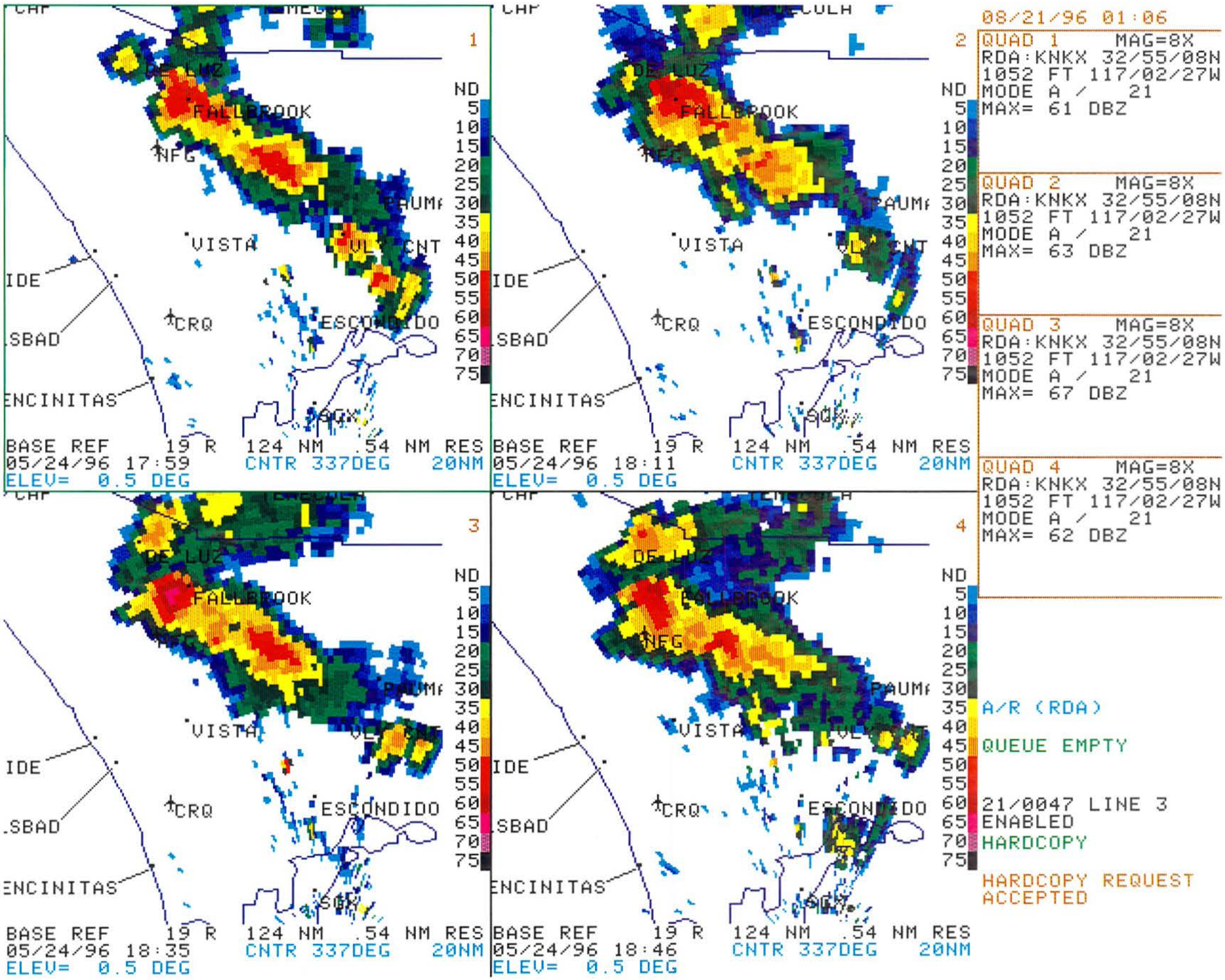

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1052 FT 117/02/27W
MODE A / 21
MAX= 61 DBZ
QUAD 2 MAG=8X
RDA:KNKX 32/55/08N
1052 FT 117/02/27W
MODE A / 21
MAX= 63 DBZ
QUAD 3 MAG=8X
RDA:KNKX 32/55/08N
1052 FT 117/02/27W
MODE A / 21
MAX= 67 DBZ
QUAD 4 MAG=8X
RDA:KNKX 32/55/08N
1052 FT 117/02/27W
MODE A / 21
MAX= 62 DBZ
A/R (RDA)
QUEUE EMPTY
21/0047 LINE 3
ENABLED
HARDCOPY
HARDCOPY REQUEST
ACCEPTED
DE LUZ
FALLBROOK
NFG
VISTA
PAUMA
ESCONDIDO
CRQ
ENCINITAS
ND 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
BASE REF 19 R 124 NM .54 NM RES
05/24/96 17:59 CNTR 337DEG 20NM
ELEV= 0.5 DEG
BASE REF 19 R 124 NM .54 NM RES
05/24/96 18:11 CNTR 337DEG 20NM
ELEV= 0.5 DEG
BASE REF 19 R 124 NM .54 NM RES
05/24/96 18:35 CNTR 337DEG 20NM
ELEV= 0.5 DEG
BASE REF 19 R 124 NM .54 NM RES
05/24/96 18:46 CNTR 337DEG 20NM
ELEV= 0.5 DEG

FIGURE 1

STM ID	AZ RAN		TVS	MESO	HAIL	DBZM HGT		VLOW	STM TOP	FCST MVMT		MW VOL
17	340	27	NO	NO	PRO	66	2.0	20	19.63	300	9	1328
12	83	15	NO	NO	NEG	54	10.0	17	15.21	304	9	213
18	56	11	NO	NO	NEG	50	17.4	29	17.41	300	9	105
R	54	17	NO	NO	NEG	47	7.9	18	11.60	294	13	84

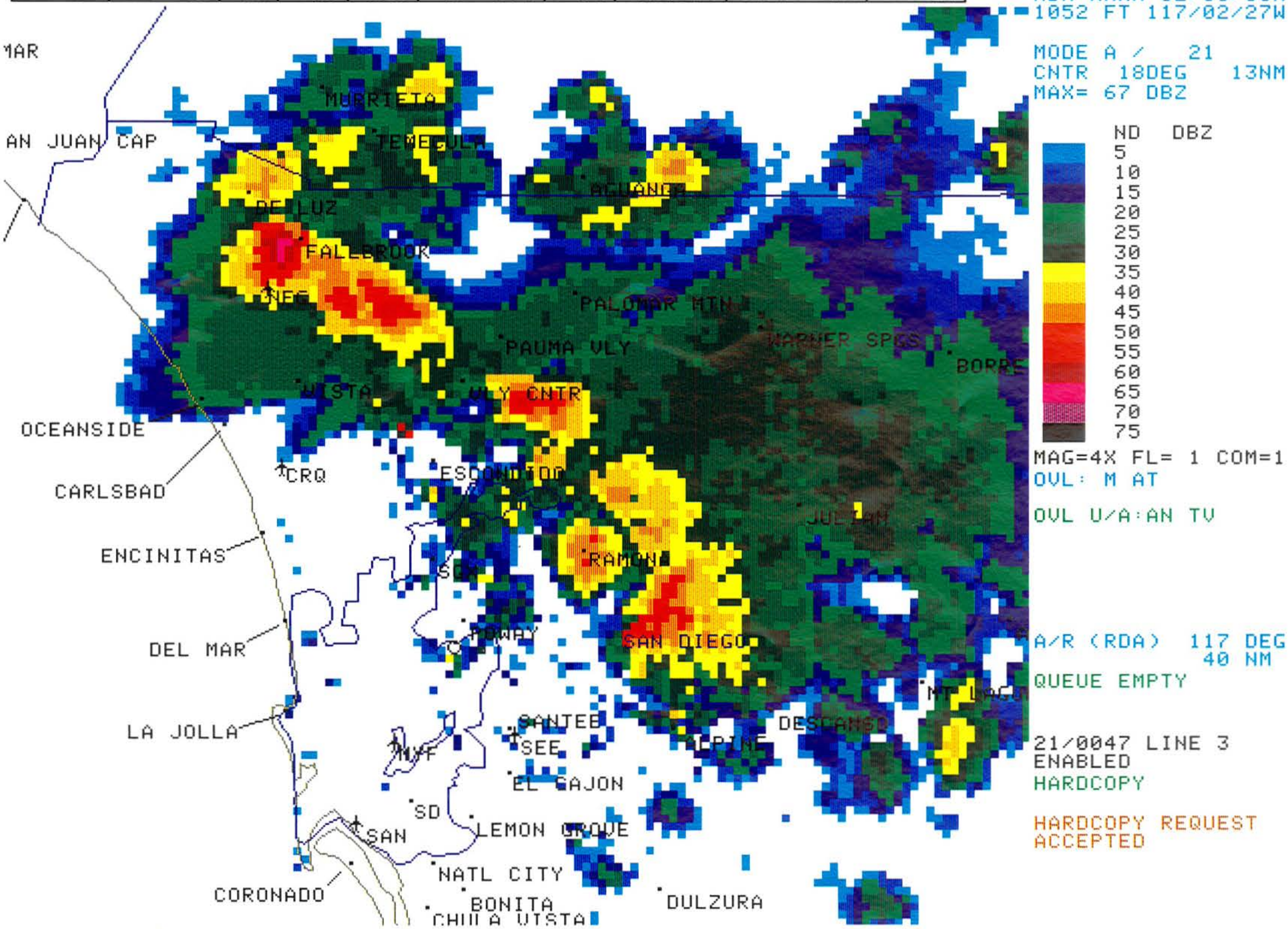
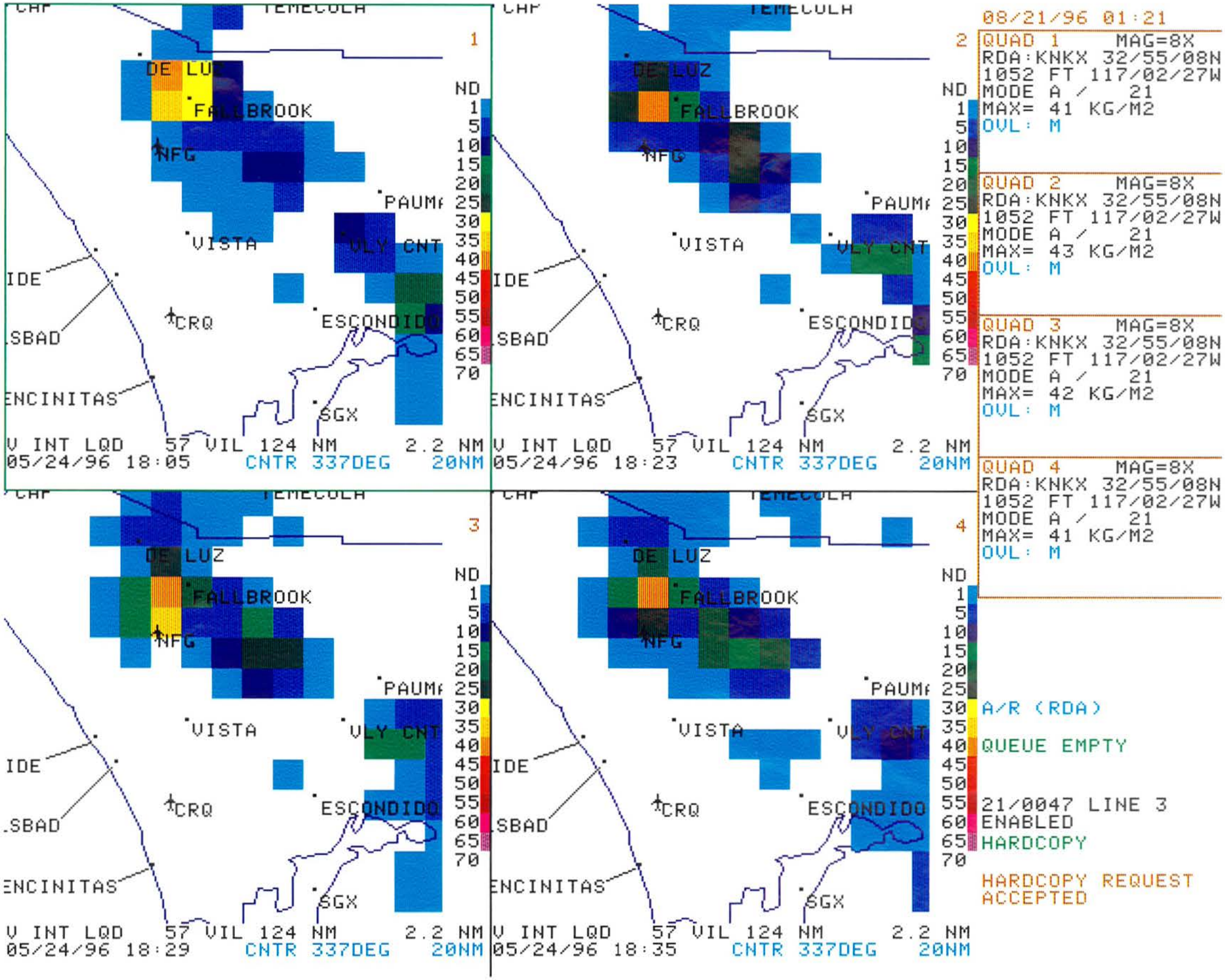


FIGURE 2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MODE A / 21
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OVL: M
QUAD 2 MAG=8X
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1052 FT 117/02/27W
MODE A / 21
MAX= 43 KG/M2
OVL: M
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OVL: M
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1052 FT 117/02/27W
MODE A / 21
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OVL: M
A/R (RDA)
QUEUE EMPTY
21/0047 LINE 3
ENABLED
HARDCOPY
HARDCOPY REQUEST
ACCEPTED
ND 1 5 10 15 20 25 30 35 40 45 50 55 60 65 70
TEMECULA
DE LUZ
FALLBROOK
NFG
PAUMA
VISTA
VLY CNT
IDE
CRQ
ESCONDIDO
SBAD
ENCINITAS
SGX
V INT LQD 57 VIL 124 NM 2.2 NM
05/24/96 18:05 CNTR 337DEG 20NM
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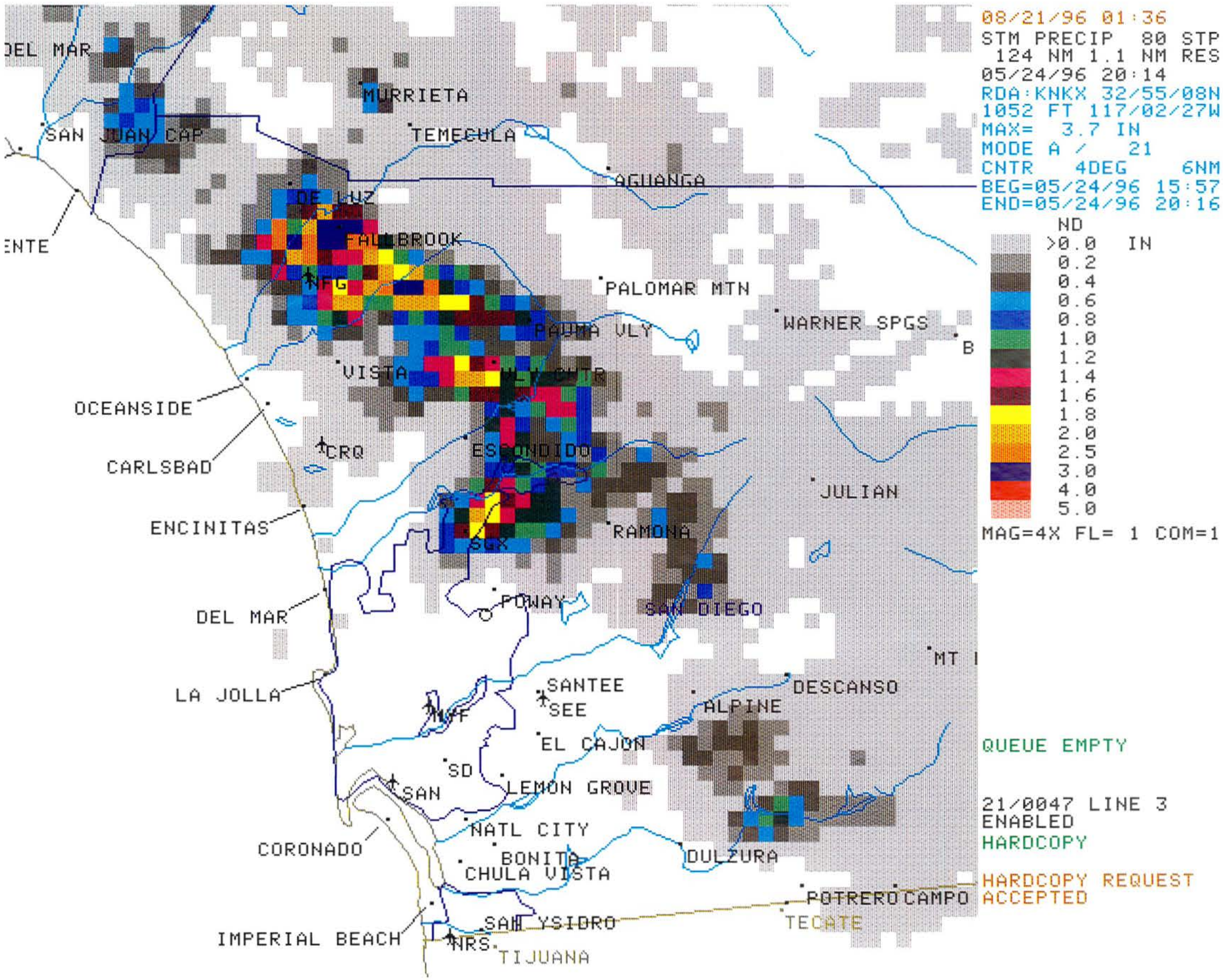
FIGURE 3



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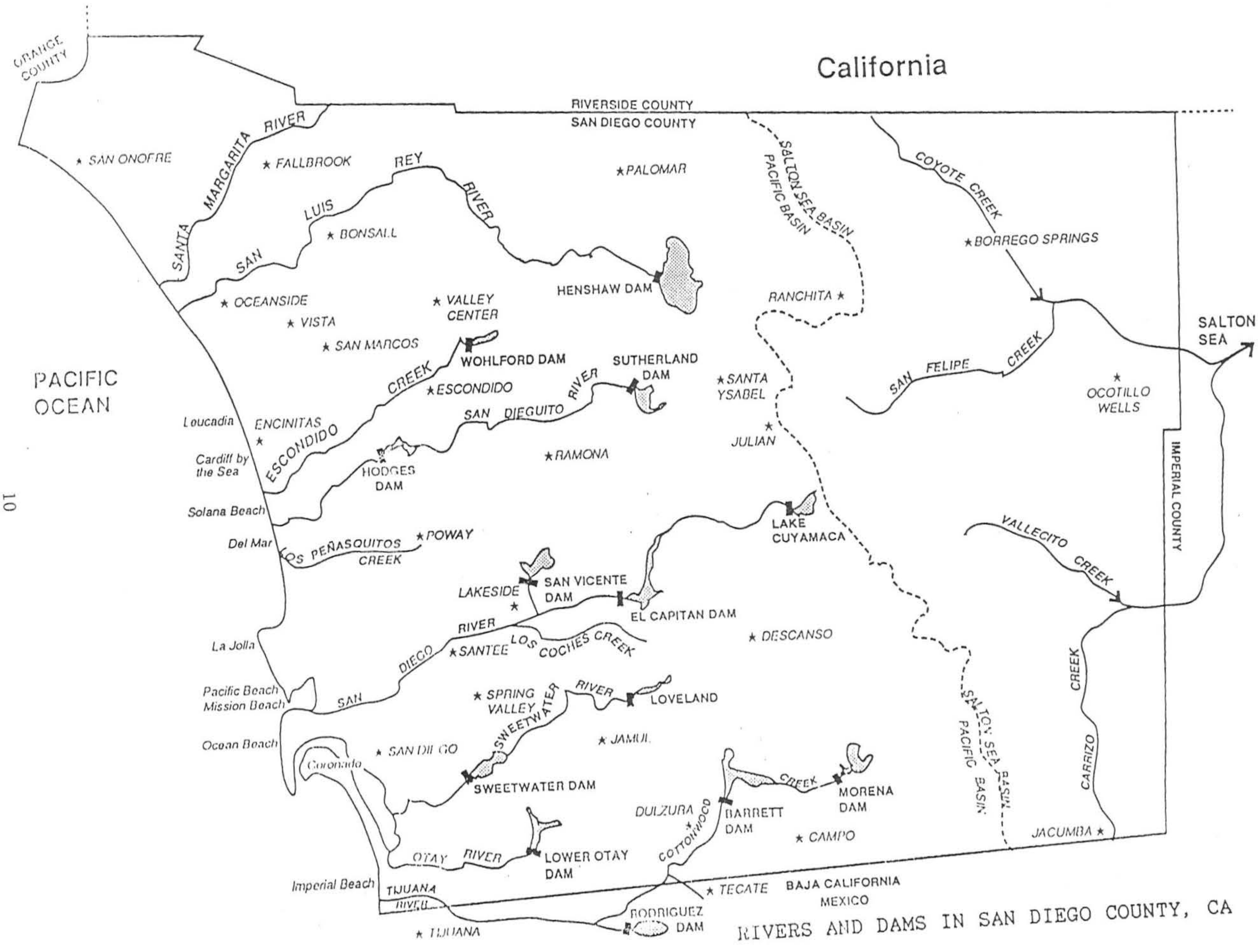
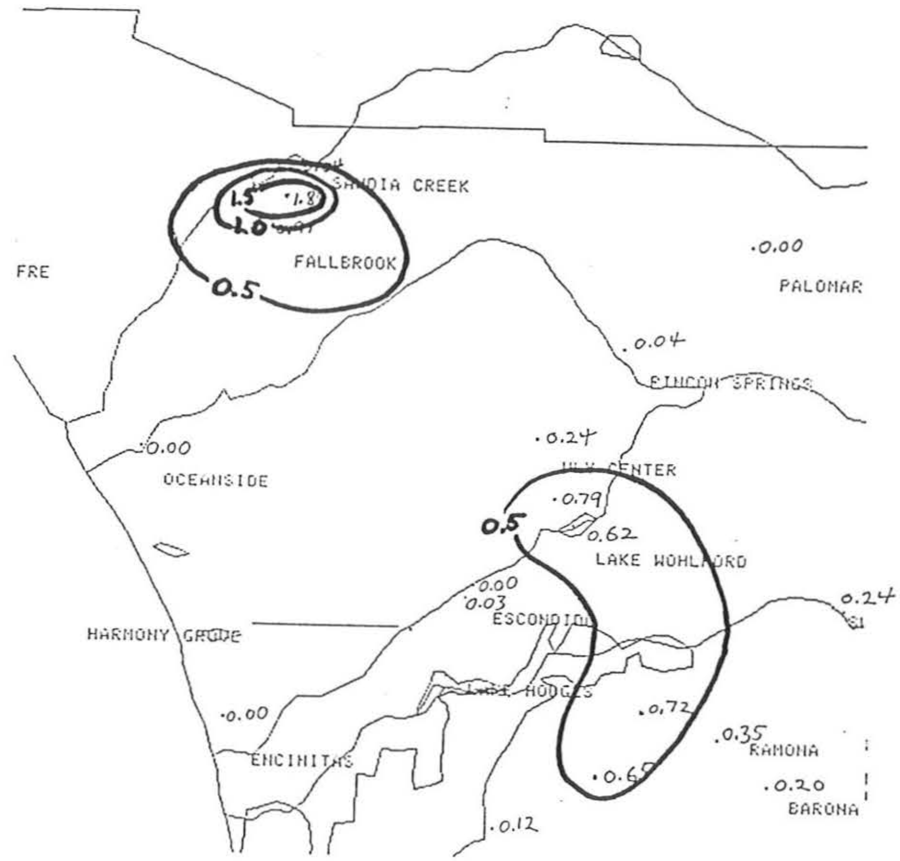
MAX= 3.7 IN
MODE A / 21
CNTR 4DEG 6NM
BEG=05/24/96 15:57
END=05/24/96 20:16
ND
>0.0 IN
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.5
3.0
4.0
5.0
MAG=4X FL= 1 COM=1
QUEUE EMPTY
21/0047 LINE 3
ENABLED
HARDCOPY
HARDCOPY REQUEST
ACCEPTED
DEL MAR
SAN JUAN CAP
MURRIETA
TEMECULA
AGUANGA
DE LUZ
FALLBROOK
NFG
PALOMAR MTN
WARNER SPGS
PAUMA VLY
VISTA
VLY CNTR
OCEANSIDE
CARLSBAD
CRQ
ESCONDIDO
JULIAN
ENCINITAS
RAMONA
SGX
DEL MAR
POWAY
SAN DIEGO
LA JOLLA
SANTEE
SEE
DESCANSO
ALPINE
NKX
EL CAJON
SD
SAN
LEMON GROVE
CORONADO
NATL CITY
BONITA
CHULA VISTA
DULZURA
POTRERO
CAMPO
TECATE
IMPERIAL BEACH
SAN YSIDRO
NRS
TIJUANA

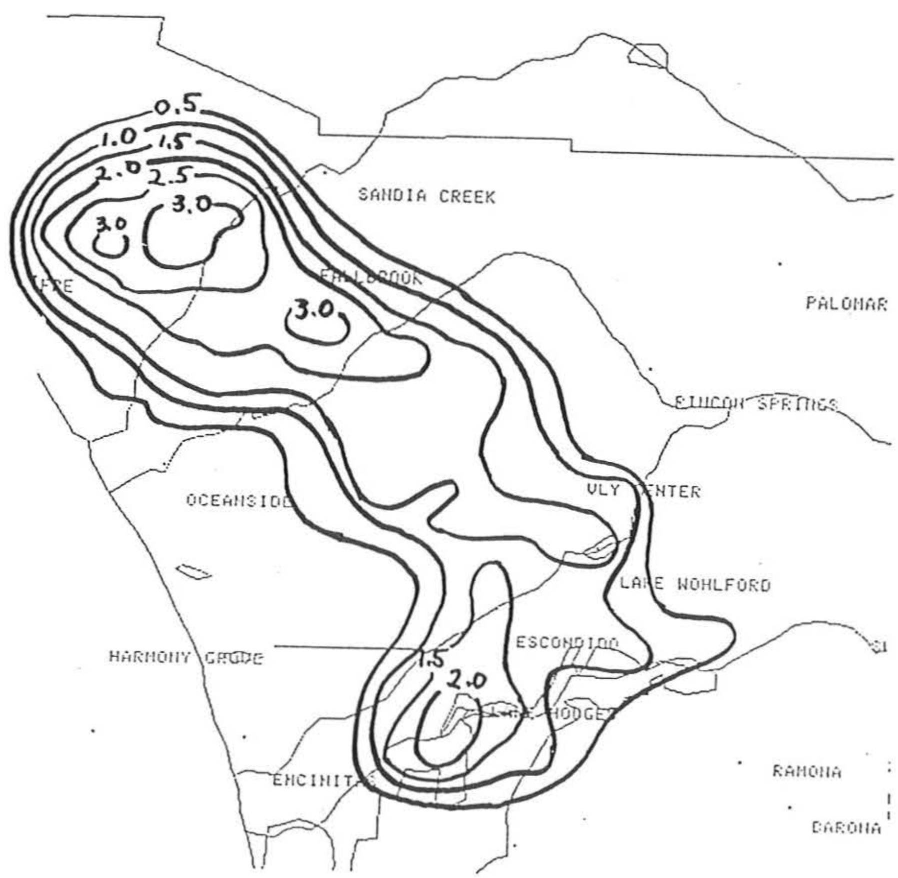
FIGURE 4



RIVERS AND DAMS IN SAN DIEGO COUNTY, CA



ISOHYETAL ANALYSIS USING RAIN GAGE DATA
0.5 INCH INTERVALS



ISOHYETAL ANALYSIS USING RADAR DATA
0.5 INCH INTERVALS

FIGURE 5