TABLE OF CONTENTS

LIST OF FIGURES

Figure

LIST OF TABLES

Table

INTRODUCTION

Research into rainfall enhancement in Texas expanded rapidly during the 1970's with the Texas High Plains Cooperative Program (HIPLEX), designed to investigate precipitation processes in summertime convective storms over West Texas. Although unable to be carried through to its intended experimental phase, valuable knowledge was obtained. It was concluded that the developing thunderstorm was much more amenable to efforts to increase natural rainfall than is the much less complex single cumulus cloud. Although scientific verification of a seeding effect would be more difficult in the multiple-cell thunderstorm, this convective system was proposed as the experimental unit for a future field experiment.

The Southwest Cooperative Program (SWCP) was initiated in 1983 as a focused application of knowledge gained during HIPLEX. The SWCP has been a joint research effort between the States of Texas and Oklahoma, and has been supported by the Bureau of Reclamation of the U. S. Department of the Interior. The goal of the SWCP has been to develop a scientifically sound and socially acceptable technology for the enhancement of summertime rainfall over the Texas-Oklahoma region. The 1986 and 1987 field projects constituted the first phase of efforts designed to lead to the successful achievement of that goal. The SWCP Texas field experiments were conducted in an area centered between Big Spring and San Angelo. Increases in rainfall were sought through seeding individual convective cells in vigorous growth regions of thunderstorms within the target area, working in direct cooperation with two operational seeding programs in the area. Significant accomplishments of the

SWCP include the following:

1. The research and operational programs collaborated most successfully. Each program was able to assist the other without compromising its objectives.

2. Water levels in lakes and reservoirs rose steadily during the program. Although large-scale weather patterns were largely responsible for the above normal rainfall, it is likely that the seeding programs contributed to the increased water supply.

3. Analysis of aircraft and radar data confirmed that the planned method of selection and treatment of targets had been successfully implemented. Further analysis of radar data indicated that increases in the growth of seeded cells provided the potential for up to 100% increases in radar-estimated rainfall.

Texas Tech University has been deeply involved in efforts to develop methods of increasing rainfall, from the first days of HIPLEX to the present. Following our data-gathering efforts in HIPLEX, we performed the analyses which led to the selection of the multiple-cell thunderstorm as the experimental unit for a future field experiment. We have been assigned co-responsibility for development of the design and the execution of the SWCP field operations of 1986 and 1987. Unfortunately, funding shortages have not allowed a continuation of the field experiments.

This study was undertaken in order to relate the findings of radar analyses to actual measurements of rainfall at the ground. A primary objective was to establish whether the radar-derived increases in rainfall were realized at the ground.

DATA

The two data sources available for this study were: (1) digitized radar measurements gathered by the 5-cm Skywater SWR-75 weather radar provided by the Bureau of Reclamation, and (2) rainfall measurements gathered by the recording raingage

network provided by the Colorado River Municipal Water District. The target area of the Southwest Cooperative Program research effort (SWCP) and the commercial seeding programs of the Colorado River Municipal Water District (CRMWD) and the City of San Angelo (SJT) are shown in Figure 1. The SWR-75 radar recorded data between the outer 100-km radius circle and the inner 40-km radius circle, within which it was judged that acceptable coverage of tall convective cells could not be obtained. Also shown in shading is the region covered by the CRMWD raingage network.

For the 1987 SWCP field project, the Skywater radar was moved from the center of the target area and located at the Howard County Industrial Park northeast of Big Spring in order to better cover convective systems advecting across the target area. In addition, the 40-km inner circle deployed in 1986 was reduced to a 30-km circle in order to increase the fraction of the target area capable of producing radar data. The target areas employed in 1987 are shown in Figure 2.

RESULTS

A summary of the randomized cases obtained by the Southwest Cooperative Program during the two years of field experimentation is presented in Table 1. A total of twenty six experimental units were selected, of which twelve were seeded and fourteen were treated as control units.

The locations of the initial treatment of the eleven experimental units of 1986 and the fifteen experimental units of 1987 are plotted as a single set, shown in Figure 3.

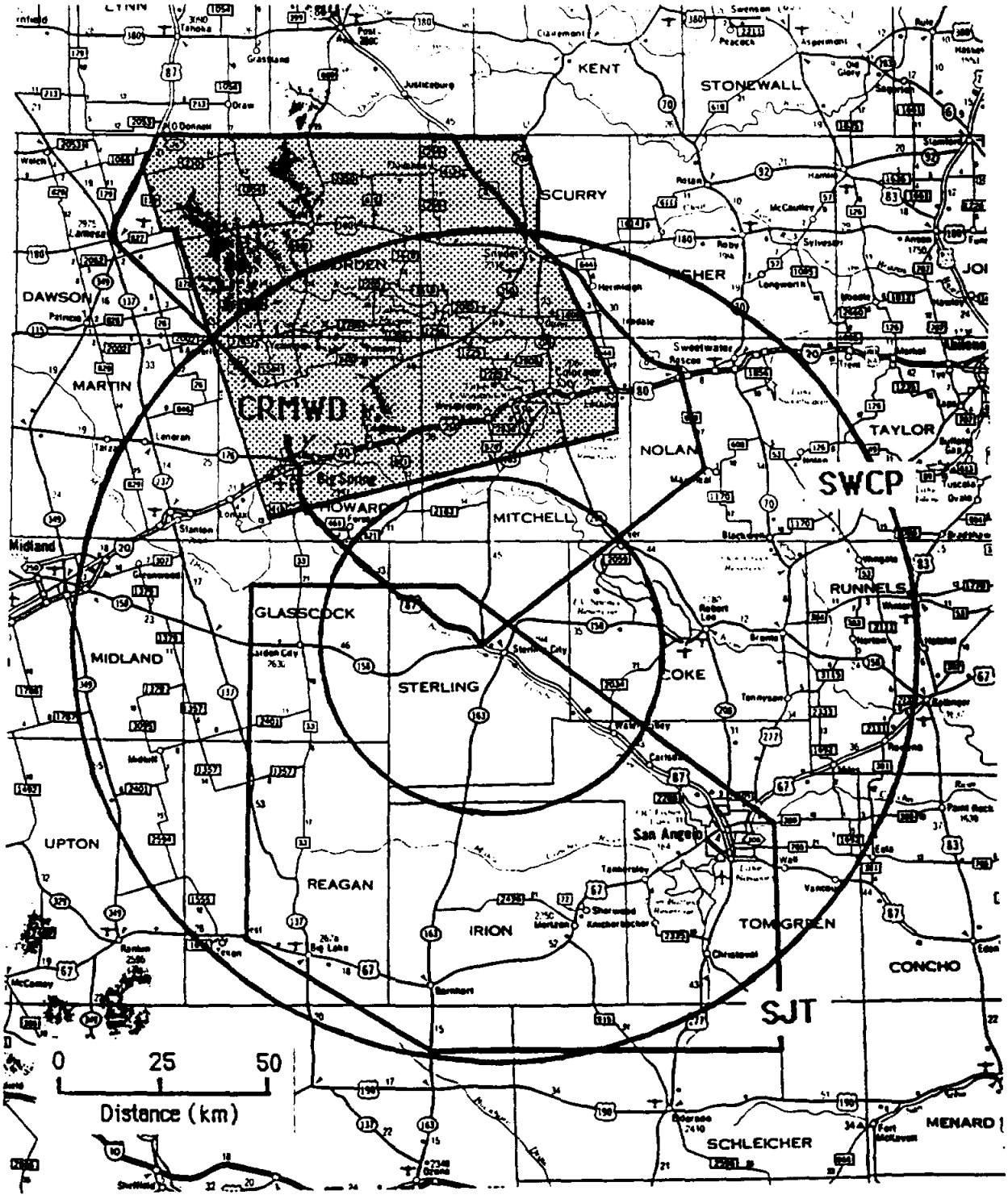

Figure 1. The 1986 target areas of the Southwest Cooperative Program (SWCP), the Colorado River Municipal Water District (CRMWD) and the City of San Angelo (SJT) cloud seeding programs. Also shown in shading is the region covered by the CRMWD recording raingage network.

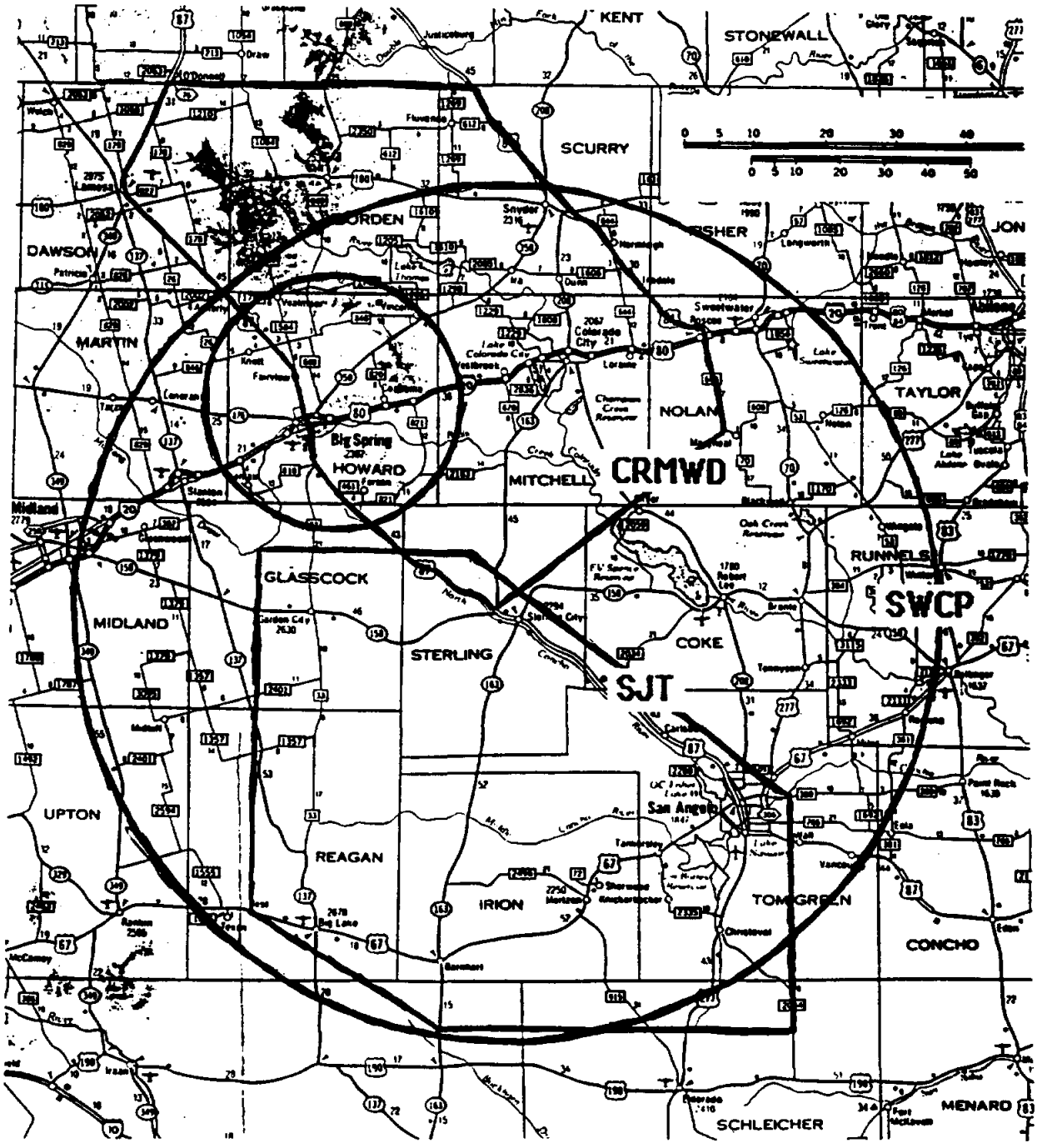

Figure 2. The 1987 target areas of the Southwest Cooperative Program (SWCP), the Colorado River Municipal Water District (CRMWD) and the City of San Angelo (SJT) cloud seeding programs.

TABLE 1

Summary of Southwest Cooperative Program
Randomized Cases

Date	Case	Treatment
29 May 1986	1	Control
29 May 1986	2	Seed
17 Jun 1986	3	Seed
18 Jun 1986	4	Seed
19 Jun 1986	5	Control
20 Jun 1986	6	Seed
23 Jun 1986	7	Control
11 Jul 1986	8	Control
20 Jul 1986	9	Control
20 Jul 1986	10	Seed
21 Jul 1986	11	Control
07 Jun 1987	1	Seed
07 Jun 1987	2	Control
12 Jun 1987	3	Control
13 Jul 1987	4	Seed
10 Aug 1987	5	Seed
11 Aug 1987	6	Control
11 Aug 1987	7	Seed
11 Aug 1987	8	Seed
12 Aug 1987	9	Control
12 Aug 1987	10	Control
13 Aug 1987	11	Control
13 Aug 1987	12	Seed
14 Aug 1987	13	Seed
14 Aug 1987	14	Control
15 Aug 1987	15	Control

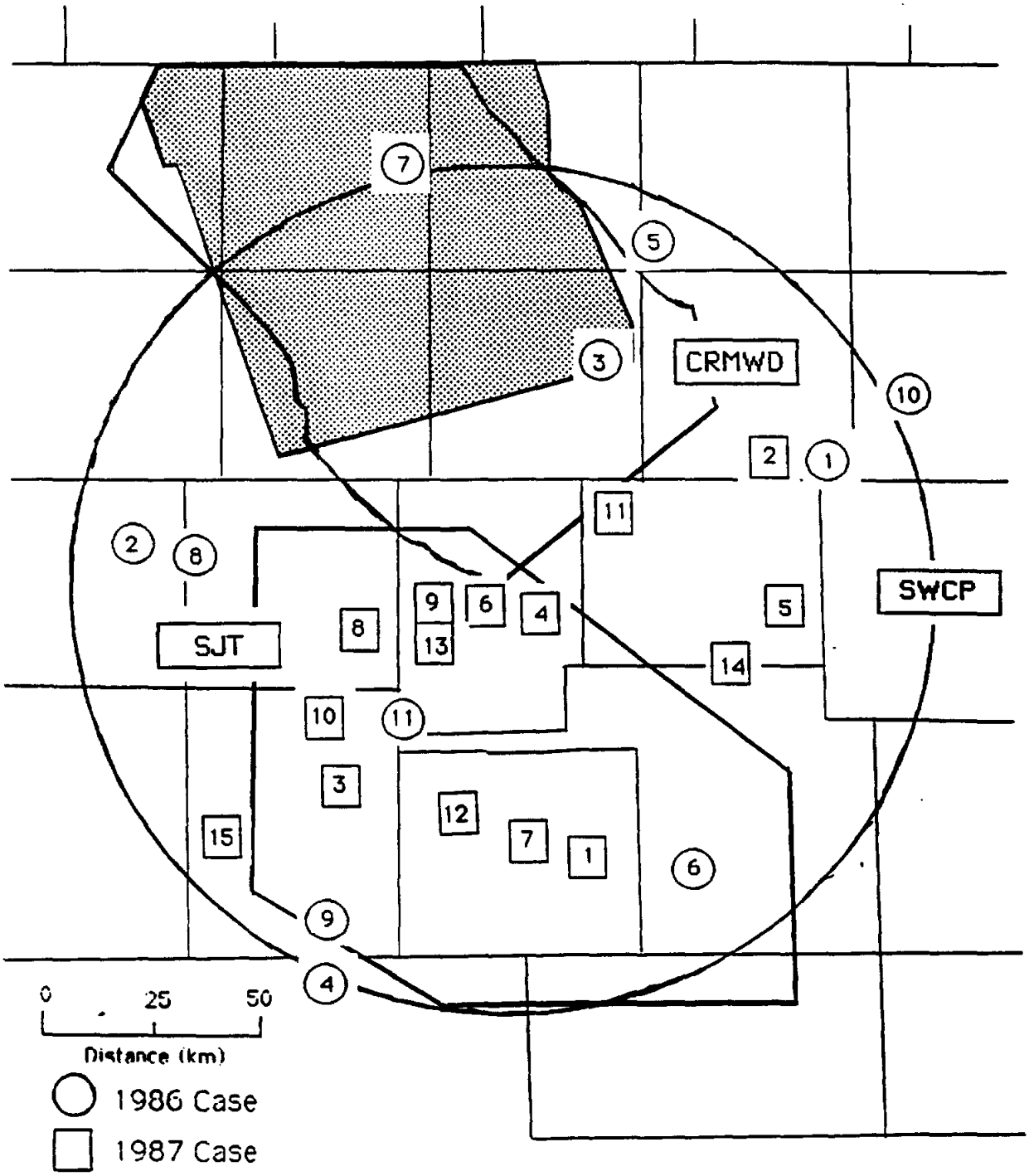

Figure 3. The target areas of the SWCP, CRMWD and SJT cloud seeding programs, along with the region covered by the CRMWD raingage network (shaded). The locations of the initial treatment of the 1986 and 1987 experimental units are denoted by numbers.

The boundaries of the SWCP, Colorado River Municipal Water District (CRMWD) and City of San Angelo (SJT) operational areas are also shown in Figure 3 along with the area covered by the CRMWD raingage network. Of the eleven cases obtained in 1986, only two were located within the CRMWD raingage network. It should be noted that only the 17 June case was seeded, while the 23 June case was a control case. None of the fifteen 1987 cases were located within the CRMWD raingage network.

The raingage data for 17 June 1986 were checked and it found that none of the raingages in the region of the network identified with Case 3 recorded any rainfall on that date. Therefore, it was impossible to investigate further the only experimental unit seeded over even a portion of the raingage network, and it was concluded that the primary objective of the study could not be attained.

A secondary objective of this study was established to investigate the other seeding events which had occurred during the 1986 and 1987 SWCP field projects. A summary of the non-randomized seedings performed by the Southwest Cooperative Program during the two years of field experimentation is presented in Table 2. Seeding events are identified by number with a certain date, and are further subdivided when the location of individual seedings differ significantly on a given date (i.e., 4a, 4b and 4c on 14 May 1986). The locations of the non-randomized seedings during 1986 and 1987 are plotted as a single set, shown in Figure 4. Only two seedings occurred over the Colorado River Municipal Water District: on 24 May and 3 July 1986.

TABLE 2

Summary of Southwest Cooperative Program
Non-randomized Seedings

Date	Event
29 Apr 1986	1
7 May 1986	2
9 May 1986	3
14 May 1986	4a
14 May 1986	4b
14 May 1986	4c
24 May 1986	5
31 May 1986	6
2 Jun 1986	7a
2 Jun 1986	7b
2 Jun 1986	7c
2 Jun 1986	7d
2 Jun 1986	7e
18 Jun 1986	8
19 Jun 1986	9a
19 Jun 1986	9b
21 Jun 1986	10a
21 Jun 1986	10b
21 Jun 1986	10c
3 Jul 1986	11
10 Jul 1986	12
11 Jul 1986	13a
11 Jul 1986	13b
11 Jul 1986	13c
19 May 1987	1a
19 May 1987	1b
28 May 1987	2
29 May 1987	3
8 Jun 1987	4a
8 Jun 1987	4b
12 Jun 1987	5
5 Jun 1987	5

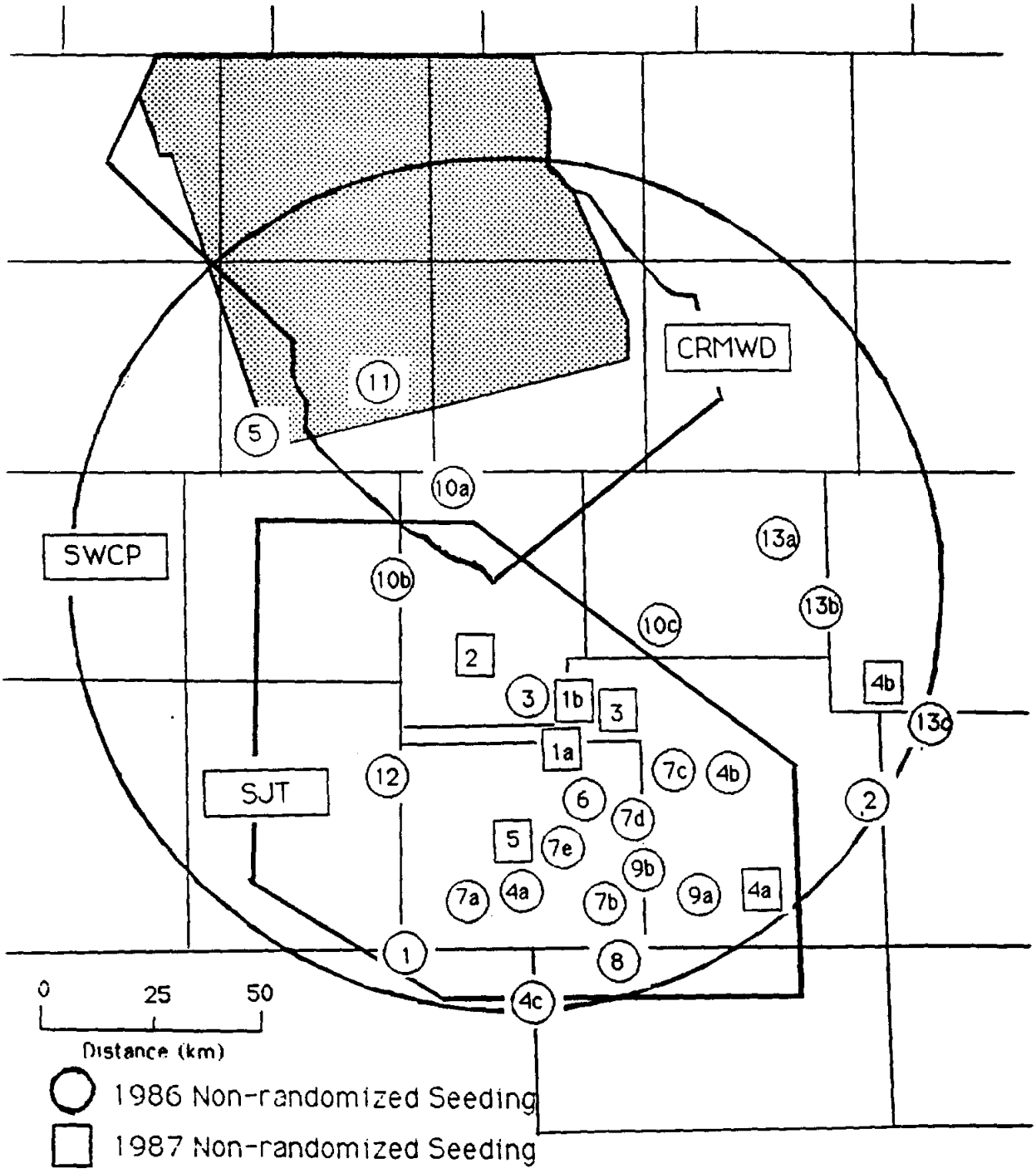

Figure 4. The target areas of the SWCP, CRMWD and SJT cloud seeding programs, along with the region covered by the CRMWD raingage network (shaded). The locations of non-randomized seedings in 1986 and 1987 are denoted by numbers.

The seeding on 24 May 1986 took place during the early portion of what became a widespread precipitation event. Two flares were dispersed into each of two convective towers as the cloud system underwent a very rapid development, and further seeding became impractical because of the extremely vigorous nature of the cells in the cloud system. The storm produced precipitation in every raingage in the network, one of the most extensive precipitation events recorded during the two field seasons. Eventually, a severe weather alert was issued in the area, and all aircraft operations were terminated. It is believed that any correlations of rainfall in the network with the seeding would be meaningless in view of the very vigorous nature of the natural storm system, and no further analysis has been performed.

Two convective cells were seeded on 3 July 1986. However, no precipitation was recorded in any of the raingages in the vicinity of the seeding events, and analysis of the situation was not possible.

Because of the inability to obtain the desired cases having matched sets of radar and raingage data, neither the primary objective nor the secondary objective of this study has been achieved.

RECOMMENDATIONS

Two recommendations are offered.

1. It is still felt that the planned objective of this study is worth pursuing. It is recommended that further field experiments be conducted with the specific intent to select experimental units over the Colorado River Municipal Water District raingage network.

2. Studies of the effect of the environment between cloud base and the ground

upon the depletion of rainfall should be conducted. It is believed that such an investigation will improve our understanding of the magnitude of the evaporative loss of rainfall produced within convective storms.