A Cloud Seeding Program to Enhance Hydroelectric Power Production from the El Cajon Drainage, Honduras

by

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TRC North American Weather Consultants (TRC NAWC) has contracted with Empresa Nacional De Energia Electrica (ENEE) to conduct cloud seeding programs in Honduras. Programs have been conducted over the El Cajon and Lake Yojoa drainage basins during portions of the 1993, 1994, 1995 and 1997 rainy seasons. The goal of this program has been to augment the amount of natural precipitation that falls in these drainages which will then augment the amount of inflow into the El Cajon Reservoir. This supplemental water can then be released to generate additional hydroelectric power.

Evaluations of the 1993, 1994 and 1995 cloud seeding programs indicated a 9 to 15 percent increase in precipitation attributed to the cloud seeding program. The June through October 1995 program indicated a 13 percent increase. Certain assumptions were made in order to estimate the additional runoff into El Cajon Reservoir due to the 1995 cloud seeding program. This estimate was 366,876,000 m^3.

Calculations of the cost of the program versus the value of the additional inflow from the 1995 program were performed using certain assumptions. The resultant benefit to cost ratio was calculated to be 23.5/1.

1.0 INTRODUCTION

Central American countries are heavily dependent upon hydroelectric facilities for the generation of electricity. In most of these countries the hydroelectric power production provides a majority and in some cases a large majority of the power consumed in these countries. During the 1991 rainy season and through most of the 1992 and 1993 rainy seasons, drought conditions persisted over most of Central America. This drought may have been related to an El Niño - Southern Oscillation event. The drought significantly impacted reservoir storage and as a consequence hydroelectric power production.

As a consequence, TRC North American Weather Consultants (TRC NAWC) was contacted by Empresa Electrica and the Instituto Nacional De Electrificacion (INDE) in the fall of 1991 to determine the potential of applying cloud seeding technology to offset some of the impacts of the drought in the Chixoy Drainage basin, Guatemala. A brief cloud seeding program was conducted in the fall of 1991 and a more extensive program was conducted in the summer of 1992. Adequate rainfall returned to Guatemala in the summer of 1993 and therefore no program was conducted. An emergency program was conducted in 1994. The estimated increases in precipitation in the 1992 program conducted over the Chixoy Drainage basin was 17 percent. Officials of the Empresa Nacional De Energia Electrica (ENEE) in Honduras expressed an interest in the program being conducted in Guatemala. As a consequence a program was designed and conducted for the El Cajon reservoir area in Honduras for three months during the summer of 1993. With the apparent success of this program, similar programs were conducted in the 1994, 1995 and 1997 rainy seasons. The remainder of this paper describes the programs that have been conducted in Honduras.

2.0 HONDURAS PROGRAM DESIGN

The primary seeding mode consisted of an aircraft seeding platform. Cessna 340A pressurized, twin-engine aircraft equipped with GPS navigation capabilities have been used in conducting this program. Both acetone-silver iodide generators and droppable silver iodide flare racks were utilized. Figures 1 and 2 provide photographs of this equipment. The flare racks were used in an attempt to achieve a dynamic seeding response in cumulus clouds based upon the Florida Area Cumulus Experiment (FACE) design (Simpson, 1980) and more recently the Southwest Cooperative Research Program and the Texas Experiment in Augmenting Rainfall through Cloud Seeding (Woodley, **et al.**, 1996). TRC NAWC has applied this approach in the performance of other summertime cloud seeding programs (Griffith, and Brown, 1976; Griffith, 1982; Griffith, 1987), (Solak, **et al.**, 1994), and (Griffith, **et al.**, 1995). Silver iodide flares were dropped into towering cumulus clouds reaching the -5°C level (approximately 5.5 km) utilizing this approach. The acetone-silver iodide generators were used in more stratiform cloud situations in an attempt to achieve a static seeding response. Several ground based silver iodide generators were also used on the program. Aerial seeding operations were only conducted in daytime hours. Ground generators were used in both daytime and nighttime seeding opportunities. A dedicated 5 cm weather radar served as an operations center for this program. The radar and aircraft operated from San Pedro Sula in support of the El Cajon Reservoir program (Figure 3). In the first two seasons of the program, weather information was supplied to the project from TRC NAWC's

Figure 1 Droppable Silver Iodide Flare Rack

Figure 2 Acetone-Silver Iodide Generator and Droppable Silver Iodide Flare Rack

office in Salt Lake City, Utah, USA via computer modem. An on-site capability was added in 1994 which provided near real-time weather satellite photographs over Central America and the Caribbean. A personal computer was added to the 1997 program to provide Internet access to acquire a variety of weather products.

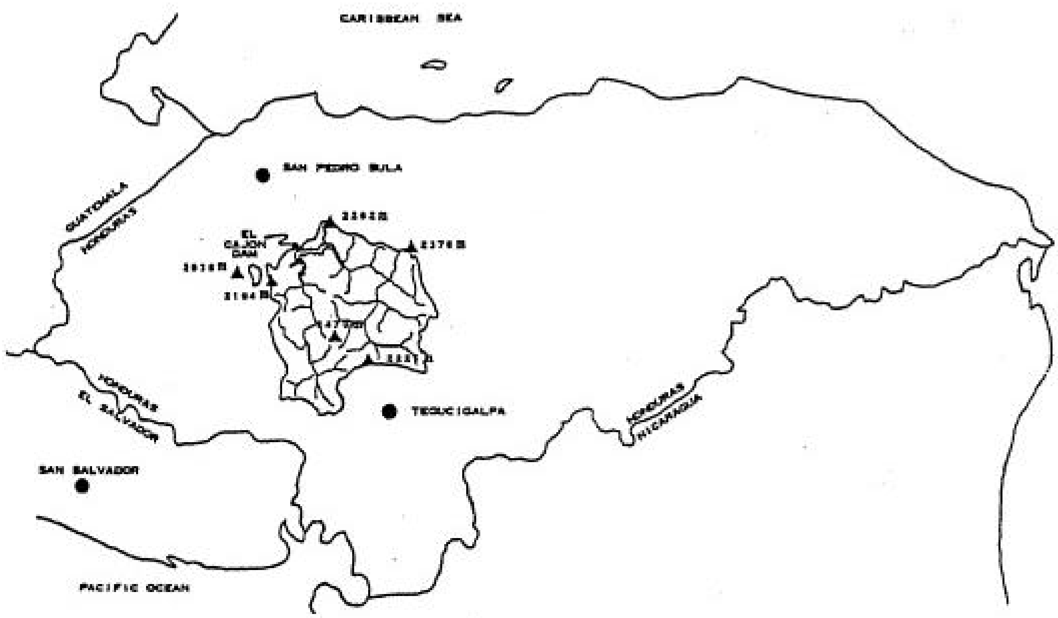


Figure 3 El Cajon Drainage Area, Honduras

3.0 OPERATIONS

The four programs in Honduras operated from August 24 to November 23, 1993; June 24 to November 11, 1994; June 1 to October 28, 1995, and August 25 to October 31, 1997. Tables 1 through 3 summarize the seeding activity for the first three seasons of operations. Seeding in the first two seasons was conducted primarily in the northern part of the El Cajon drainage. Seeding opportunities in 1995 were more wide spread throughout the drainage. Since the seeding aircraft was based in San Pedro Sula and the reservoirs are located in the northwest portion of the watershed, there was a natural tendency to conduct seeding operations in the northern part of the drainage.

Table 1

Monthly Activity Summary, 1993

Month	Seed Days	Aircraft Seeding (days)	Aircraft Seeding (Hours)	Ground Seeding (days)	Ground Seeding (Hours)
September	13	9	11.5	10	56.0
October	17	8	15.0	16	162.5

Table 2

Monthly Activity Summary, 1994

Month	Seed Days	Aircraft Seeding (days)	Aircraft Seeding (Hours)	Ground Seeding (days)	Ground Seeding (Hours)
June	1	1	1.8	1	9.0
July	12	9	23.3	9	97.1
August	18	14	35.8	13	135.7
September	18	14	23.5	13	144.0
October	15	10	10.1	9	34.9
November	7	5	7.7	5	22.5

Table 3

Monthly Activity Summary, 1995

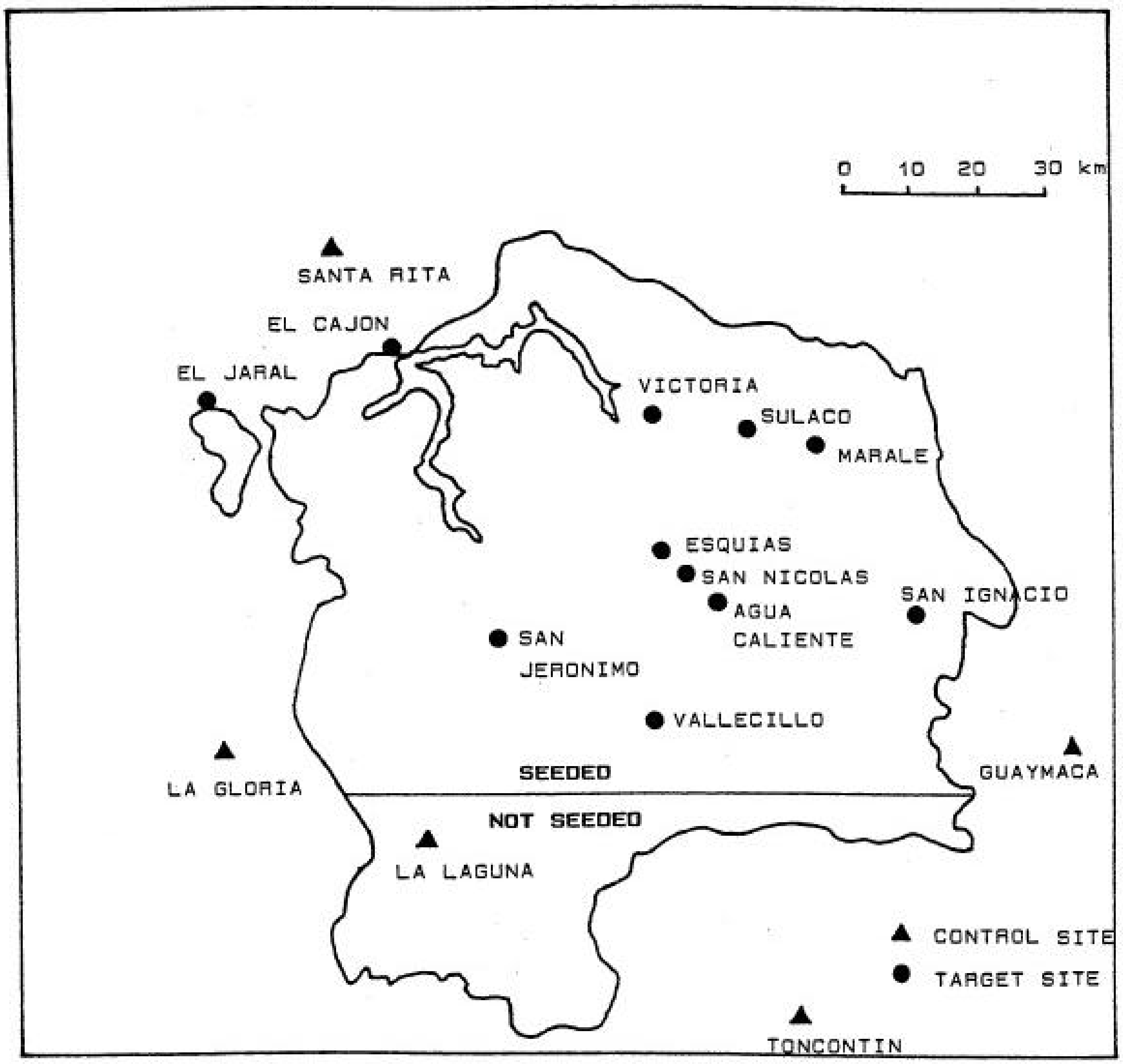
Month	Seed Days	Aircraft Seeding (days)	Aircraft Seeding (Hours)	Ground Seeding (days)	Ground Seeding (Hours)
June	20	13	27.9	18	694
July	23	9	20.8	27	998
August	30	13	30.5	29	1213
September	24	10	23.0	20	494
October	14	8	22.3	15	195

4.0 RESULTS

The results of the cloud seeding programs have been investigated utilizing a target/control evaluation technique. In this technique, precipitation data are collected from the target and nearby areas. Data are acquired from a historical period before any cloud seeding has been conducted. A linear regression equation is then developed which relates the precipitation in the target and nearby “control areas”.

ENEE personnel provided monthly precipitation data for the El Cajon drainage and surrounding areas. This data set covered the period from 1974 to 1992. Different regression equations were developed from this data set covering different operational periods (i.e. July-September, August-September) and utilizing different stations as “controls”. In the first two seasons of seeding, most of the seeding activities occurred over the northern half of the target area. Operations in 1995 covered approximately the northern three-fourths of the drainage. Figure 4 provides the precipitation stations used in the 1995 evaluations.

The regression equations developed from the historical periods were used to predict the amount of natural precipitation that would have occurred in the target area during the seeded seasons. These predicted amounts were then compared to the actual amounts to determine if there were any differences. Comparisons were made by dividing average observed precipitation in the target area by the predicted precipitation.



(Horizontal line through El Cajon Drainage indicates the approximate separation between the seeded and not seeded areas).

Figure 4 Locations of Target and Control Precipitation Gauges used in the 1995 Evaluation.

Table 4 provides the results of these evaluations for the three seeded seasons of 1993, 1994 and 1995. The calculated increases range from 9 to 15 percent and the difference in average precipitation ranges from 57 to 158 mm. These results are similar to programs conducted by TRC NAWC in other areas.

Table 4

Results of Target/Control Evaluations

Period	Regression Equation (1)	Correlation Coefficient (r)	Seeded Predicted (2)	Difference between Seeded and Predicted (mm)
September - October, 1993	yc = 143.75 + .75 (x)	.83	1.15	57
July - October, 1994	yc = 656.11 + .75 (x)	.82	1.09	91
June - October, 1995	yc = 552.9 + .75 (x)	.73	1.13	158

Notes: (1) Where: yc = calculated average target area precipitation.
x = average control area precipitation.
(2) Where: Seeded is the actual average target area precipitation. Predicted is the predicted average target area precipitation from the regression equation.

A hypothetical analysis of the potential benefit/cost ratio of this program can provide some interesting information. The 13 percent increase in precipitation for the 1995 season was equivalent to 158 mm of additional precipitation distributed over three-fourths of the El Cajon drainage area. This area is approximately 6,450 km^2. It is assumed that there is a 36 percent efficiency between precipitation and runoff in the El Cajon drainage for the June through October period:

$$6{,}450 \text{ km}^2 \times 10^6 \text{m}^2 \times \frac{158 \text{ mm}}{1000 \text{ mm/m}} \times .36 = 366{,}876{,}000 \text{ m}^3$$

ENEE has calculated that this amount of additional water would produce approximately 124,644,120 kilowatt hours of electricity at a value of $0.07541/kwh or a gross value of $9,400,009. Dividing this value by the cost of program results in a benefit/cost ratio of 23.5/1.

5.0 DISCUSSION

There are a number of potential advantages in utilizing cloud seeding to augment hydroelectric production in Central America including:

The benefit/cost ratios are typically in the 10/1 to 20/1 range.

No additional capital improvements are required.

Cloud seeding programs can be started and stopped quickly without any long-term commitment.

There are normally additional benefits in terms of increased water supplies to downstream water users.

Water used to produce hydroelectric power is reusable and is also less expensive than thermal power

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