AN OPERATIONAL DROUGHT RELIEF PROGRAM CONDUCTED IN JAMAICA DURING THE SUMMER OF 1975

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INTRODUCTION

Rainfall experienced in Jamaica during the period from January through March 1975 was substantially below normal. Domestic water supplies for the city of Kingston correspondingly dropped to seriously low levels by mid-April 1975. The Water Commission, which has jurisdiction over the water supplies for Kingston, decided to initiate a precipitation enhancement program to begin during the latter part of April. This decision was approved by the Jamaican government, even though no weather modification program had ever been attempted in Jamaica.

The Water Commission approached several commercial weather modification firms in the United States about developing a viable seeding project. North American Weather Consultants, Inc., of Goleta, California, was awarded the contract to perform this work. Two meteorologists were subsequently dispatched to Kingston, arriving in mid-April. Immediate preparations were begun to bring the project up to an operational status. The first seeding was accomplished on April 24, 1975, and operations continued during the months of May through September.

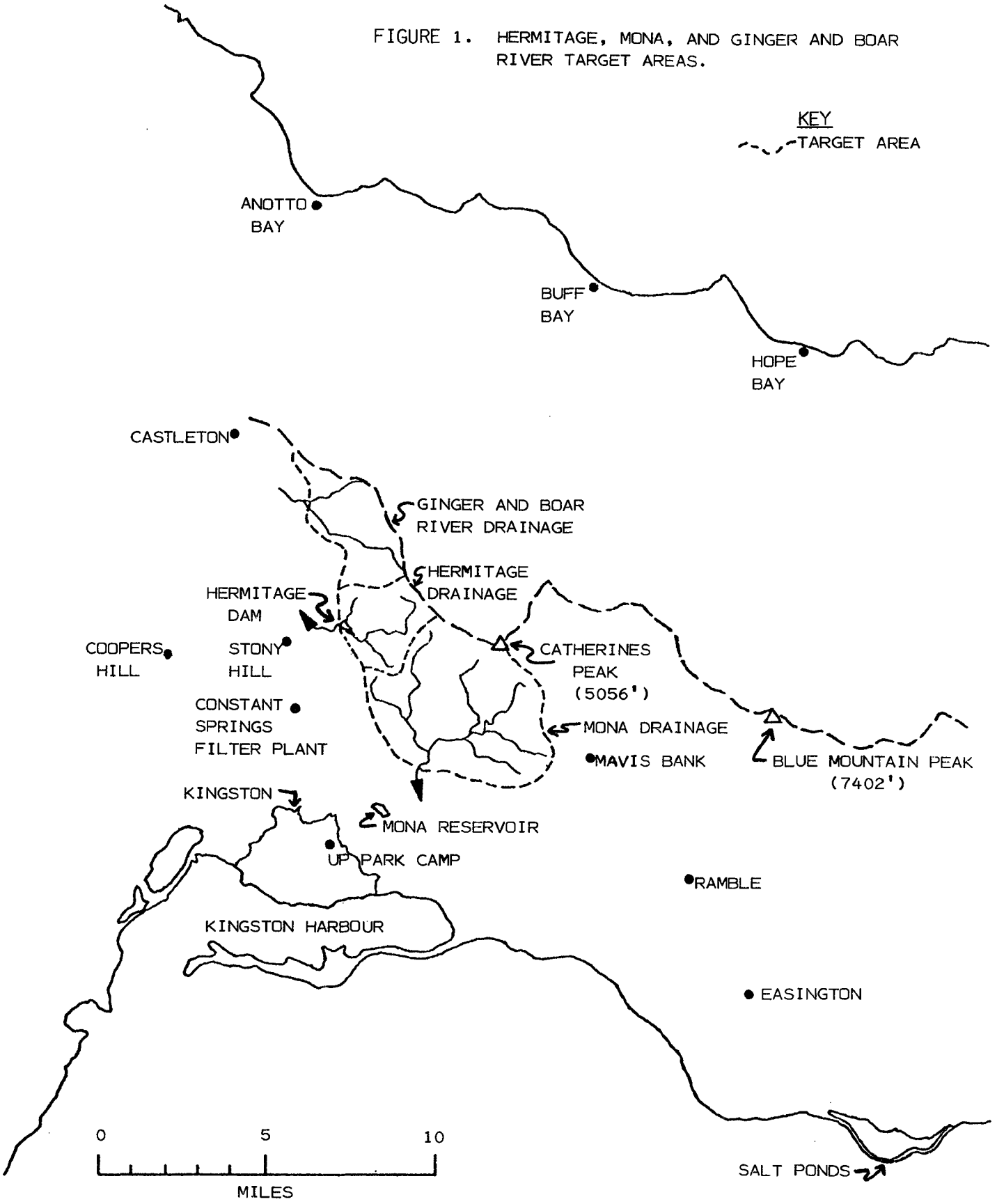
PROJECT DESIGN

The seeding techniques used in this project were based on both research and operational programs conducted in similar tropical locations (i.e., Florida and the Philippines) where significant results had been achieved (Simpson, et.al., 1971) (St. Amand and Elliott, 1972). The technique adopted consisted of penetrating cumulus clouds with tops extending through the freezing level and dropping silver iodide pyrotechnic flares into updraft regions. The project was designed to avoid seeding on any occasion when flooding was considered a definite possibility based on meteorological forecasts and knowledge of historical weather patterns related to flooding situations.

PROJECT ORGANIZATION

The project was organized utilizing existing facilities in Jamaica whenever possible. A De Havilland Twin Otter aircraft and crew, were furnished by the Jamaica Defence Force (JDF) for the seeding flights. The Meteorological Service of Jamaica provided weather forecasts and observations including information obtained by the radar facility at Coopers Hill (a Mitsubishi 10 c.m. weather radar). Figure 1 provides a map of the two primary target areas (Hermitage and Mona watersheds) and also shows the

FIGURE 1. HERMITAGE, MONA, AND GINGER AND BOAR RIVER TARGET AREAS.



location of the Coopers Hill radar. The Hermitage target area included parts of the Ginger and Boar River drainages since water from these areas is diverted to the Constant Springs Filter Plant for use in Kingston. The total target area was quite small being on the order of only 30 square miles.

A meteorologist was provided by North American Weather Consultants to fly with the aircraft to make the seeding decisions and to provide coordination of the project. Overall supervision of the project was accomplished by various representatives of the Water Commission.

PROJECT OPERATIONS

A typical day consisted of obtaining a weather forecast for cumulus development from the Meteorological Service by mid-morning. The project meteorologist, pilot, and co-pilot were placed on standby at JDF's Up Park Camp Facility (see Figure 1) if the forecast appeared favorable. Once suitable clouds began to develop near the target area, as determined by the radar and/or visual observations, the Twin Otter took off and climbed to the -2^{o} to -5^{o} Celsius level (usually 15,000 - 17,000 feet MSL). Actively growing cumulus towers were then selected for seeding which were either just east of the target area or over the target area due to the prevailing easterly trade winds and resultant westward movement of clouds. These clouds were penetrated and silver iodide pyrotechnics were dropped into the updraft regions. Updrafts of at least an indicated 500 fpm were considered necessary with updrafts of 1000 to 15000 fpm deemed desirable. The pyrotechnics were ignited upon ejection from a special rack (mounted on the belly of the Twin Otter) and burned for 30 to 45 seconds. The pyrotechnics contained either 40 or 50 grams of silver iodide (i.e., about one-tenth of a pound). All suitable clouds in the area were treated including new towers that appeared on the sides of developing thunderstorms. The Twin Otter then returned to Up Park Camp. Seeding logs were completed for each flight using information that had been recorded by the meteorologist on a voice tape recorder during the flight.

Table 1 summarizes the project operations for the months of May through August, 1975. Only very limited seeding operations were conducted during the months of April and September, and they have therefore been excluded from this summary. Several opportunities were missed during the May - August period as a result of conflicting requirements for use of the Twin Otter and/or the result of no pilot being available. The latter problem was related to the limited number of JDF pilots qualified to fly the Twin Otter.

From data given in Table 1 it can be estimated that approximately 30% of the days with suitable clouds (i.e., those that reach above the freezing level) over or near the target area were not seeded due to either the aircraft or a qualified pilot being unavailable. The optimum seeding potential for this area is therefore higher than that indicated in the subsequent evaluation of attainments for this operational demonstration project.

Table 1

Flights May - August, 1975

Month	Flights	Pyrotechnics Used	Missed Opportunities
May	12	76	4
June	8	102	3
July	6	75	6
August	14	149	3
Total	40	402	16
Average	10	100	4

Several observations gathered during this seeding project are worthy of note. These observations apply generally to the Hermitage and Mona target areas, but several also apply to Jamaica in its entirety. The observations fall naturally into: 1) observations relative to forecasting days with suitable clouds (and times of development); and 2) observations from actual flights.

Forecasting Cumulus Development

1. Suitable clouds (those reaching through the freezing level) generally did not develop in eastern Jamaica when winds were in excess of 25 knots in the lower levels from 3000 to 8000 feet MSL which then decreased in velocity in the region from 10,000 to 20,000 feet MSL. Atmospheric visibility was usually reduced by haze under these conditions.

2. On days when moderate to large sized cumulus clouds developed over the ocean in the morning there was generally active cumulus development over the island in the afternoon.

3. The best seeding response was associated with days when an organized synoptic feature was in the vicinity of Jamaica. The best conditions seemed to occur when an upper-level trough (at the 200 and 300 mb level) was located just east of Jamaica. Sometimes these troughs would remain quasi-stationary for several days producing extended rainy periods.

4. There were many days of active cumulus development over the western and central regions of Jamaica without corresponding developments over the eastern region. This seemed to be especially true when an upper-level trough was located just west of Jamaica.

5. On most days the vertical wind field exhibited either little or no wind shear or else a reverse shear condition with relatively strong low-level winds and lighter winds aloft. Seeding effects appeared to be better on days of the former type.

6. The period of best cumulus cloud development occurred almost without exception between 1200-1600 (daylight savings time). Consequently, almost all seeding flights were conducted during this period. The lighter the upper-level winds, the earlier the maximum development period occurred.

7. Cumulus clouds generally moved from east to west in agreement with the winds in the 8,000 to 10,000 foot layer. This appeared to hold true even on days when middle-level winds were out of the south or southwest (usually related to an upper-level trough west of Jamaica).

8. Days when active cumulus clouds formed without a synoptic system nearby usually occurred when the lower and middle-level winds were light, the 700 mb temperature - dew point spread was less than $10^{o}C$, and the atmosphere was unstable or conditionally unstable.

9. There were visual indications of periods of active cumulus development followed by periods of retardation of growth. Such cycles tended to persist for 1/2 to 1-1/2 hours each.

10. On days with limited moisture (i.e., temperature - dew point spread at 700 mb greater than $10^{o}C$) but otherwise favorable conditions, a few large cells developed. Turbulence in clouds tended to be greater on these days and there was frequently considerable lightning in the larger cells.

Flights

1. The flights were from 1-2 hours in duration with normal take-off times between 1300 and 1400 (daylight savings time).

2. Flights were generally smooth except during actual cloud penetrations. During penetrations, some indicated updrafts were encountered to 3000 fpm and downdrafts to 1000 fpm. Occasional sharp jolts were experienced with momentary weightless conditions causing unsecured items to rise inside the cabin. A maximum positive acceleration of 2 g's and a maximum negative acceleration of 1 g were indicated on the accelerometer.

3. Some moderate to heavy icing was encountered in clouds as well as some pea-sized graupel. No hail was encountered at normal flight levels in the types of clouds that were seeded. Ice build-up on the aircraft was dissipated rapidly by descending to a flight level above freezing.

4. Pileus cap clouds were occasionally observed on the tops of rapidly growing cumulus clouds. There were strong updrafts and high seeding potentials associated with cumulus clouds of this type.

5. Updrafts were from 1/2 to 3/4 the diameter of the cumulus clouds depending on the stage of development. Very actively growing clouds were found to be almost all updraft while dissipating cells often contained no updraft at all.

EVALUATIONS

Two types of evaluations were conducted for this seeding project. Due to the operational nature of the project and the resulting lack of randomized seeding decisions, the evaluations performed were of a qualitative nature. The two types consisted of the construction of percent of average maps and the computation of predicted precipitation amounts from target-control relationships.

The percent of average analyses were performed by North American Weather Consultants using climatological data supplied by the Jamaican Meteorological Service and included calculations for all long-term precipitation reporting stations in the eastern part of Jamaica. Percent of average maps were prepared for each of the four months of May - August, 1975, and for the four months combined. These maps are reproduced in Figures 2 - 6. A general pattern is evident in these figures with the highest precipitation anomalies occurring in or near the target area with lower values throughout the remainder of eastern Jamaica. Although these figures are not conclusive in establishing that this high anomaly is the result, or partially the result of seeding, they do lend considerable support to this conclusion since the same general pattern is repeated for each of the four months. These apparent positive seeding effects are quite good, especially when it is considered that these four months were in the middle of an extended Caribbean - wide drought period of marked severity. Even so, precipitation was only slightly below normal in the target area (i.e., Hermitage Dam was 80% of average for the period).

A graph was prepared of the daily storage amounts for Hermitage and Mona Reservoirs for the May through early September period (Figure 7). Also plotted on this graph is the average weighted daily rainfall amounts for four stations: Hermitage Dam (3.98), Langley (3.80), Hardwar Gap (3.00), and Gordon Town (13.92), all of which are located in or near the target area. The weighted factors, given in parentheses, were developed by the Meteorological Service. From this graph it can be seen that there were three major periods of seeding with coincident or subsequent increase in storage - May 21-25, June 2-6, and August 24-31. Approximate increases in storage for Hermitage were 50, 75, and 130 million gallons, respectively, during these periods. These amounts are conservative estimates since the amount of storage for Hermitage was calculated from measurements of the water level below the crest of the spillway. These measurements were related to storage values on the basis of a survey of

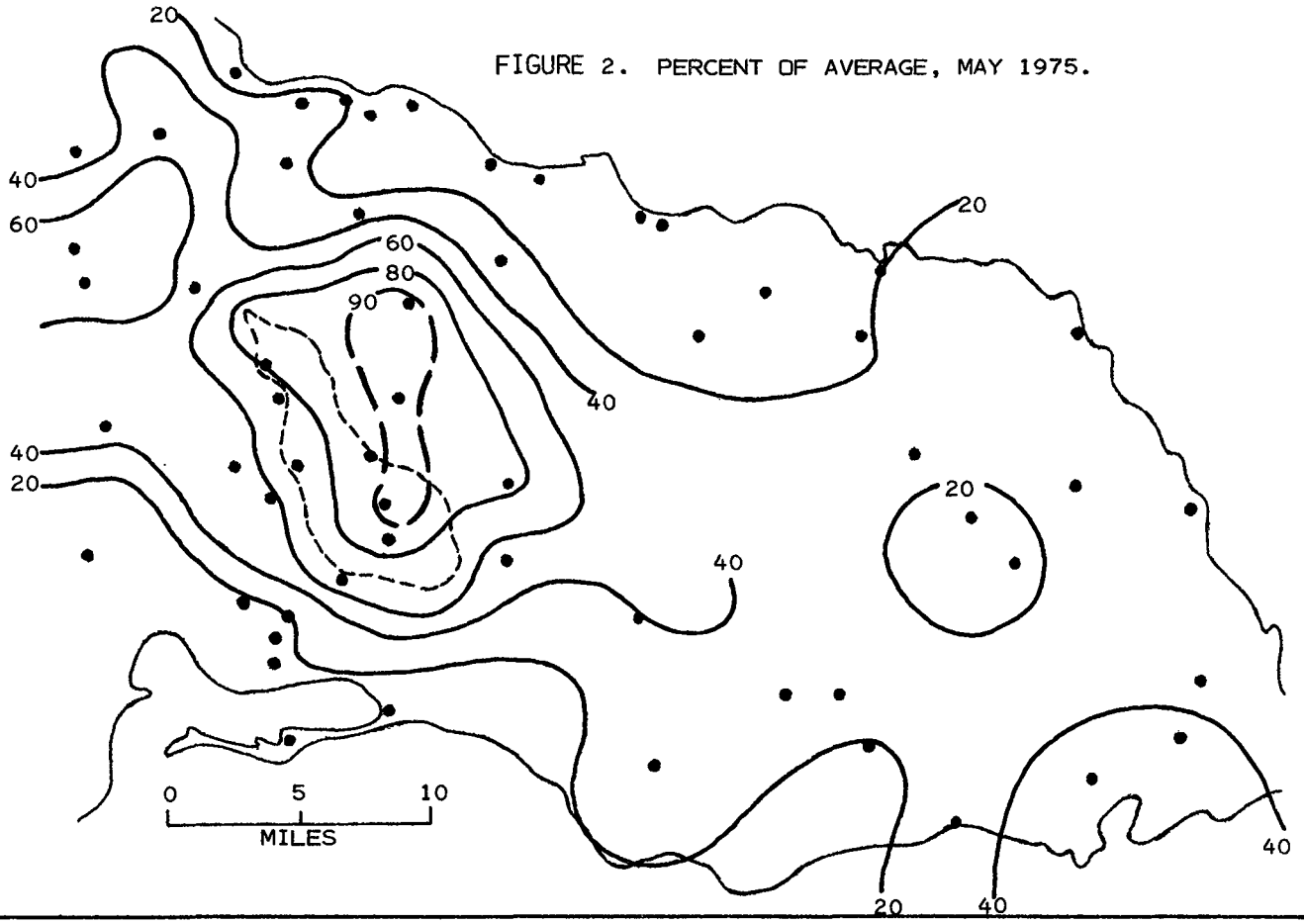


FIGURE 2. PERCENT OF AVERAGE, MAY 1975.

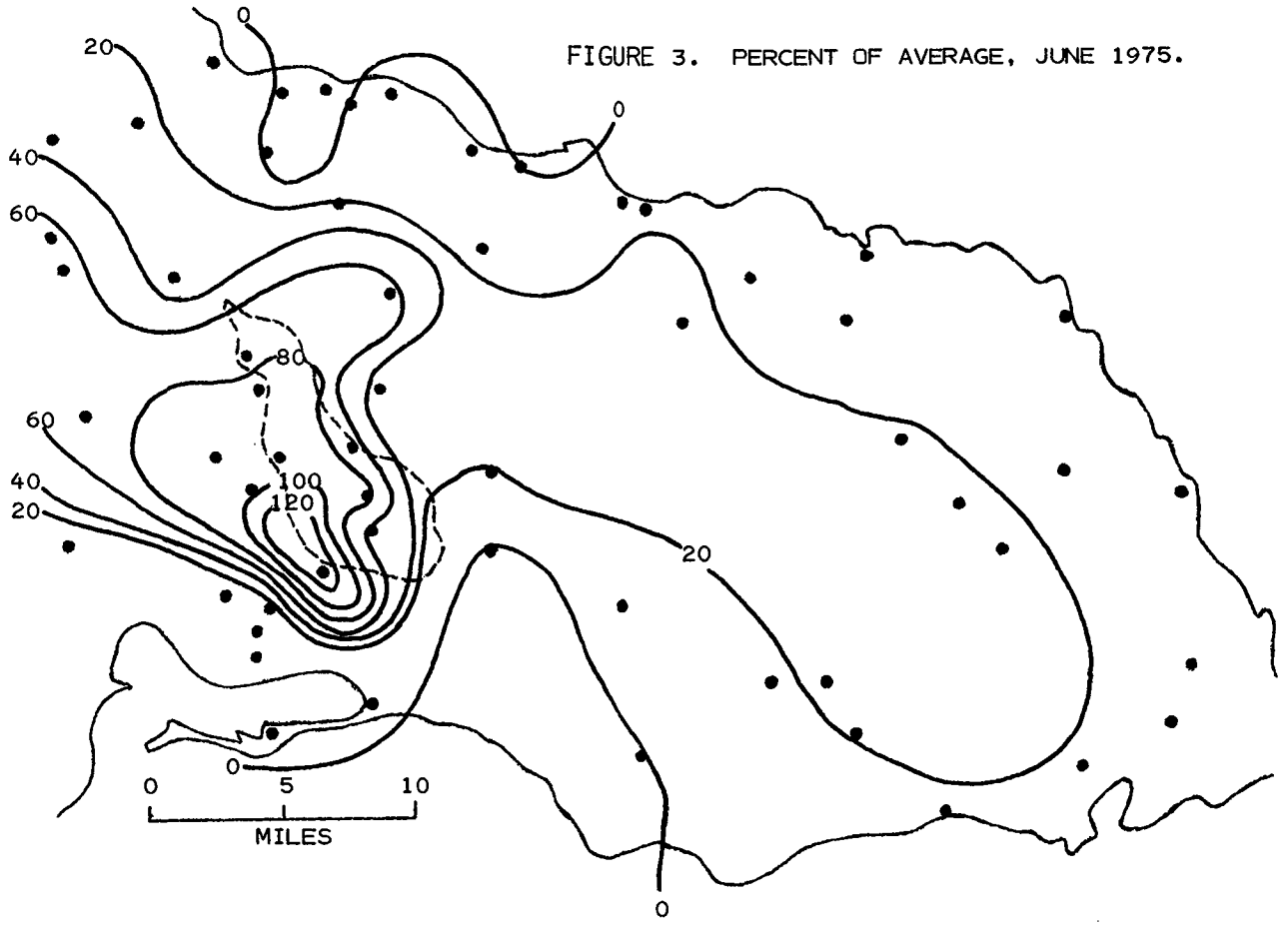


FIGURE 3. PERCENT OF AVERAGE, JUNE 1975.

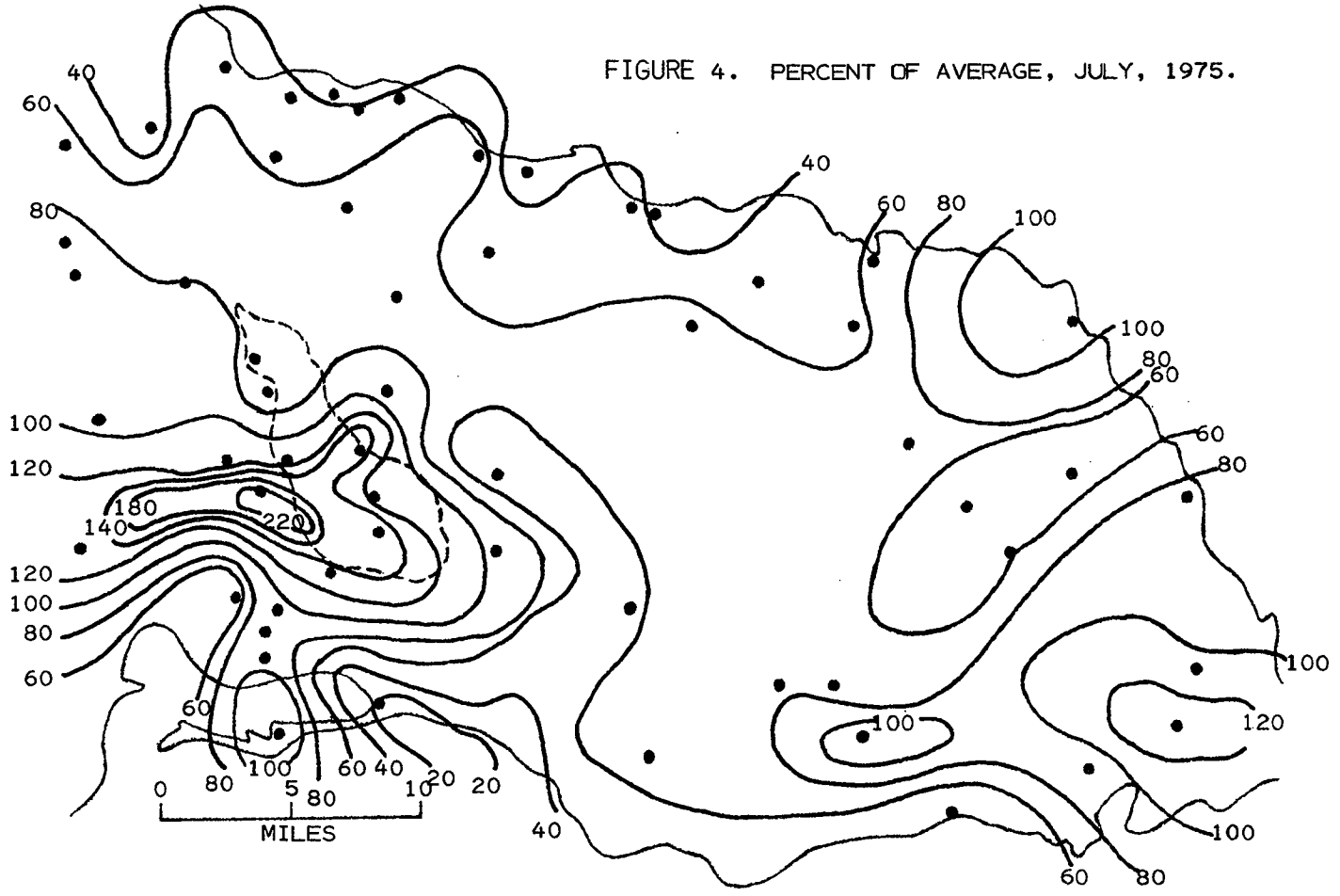


FIGURE 4. PERCENT OF AVERAGE, JULY, 1975.

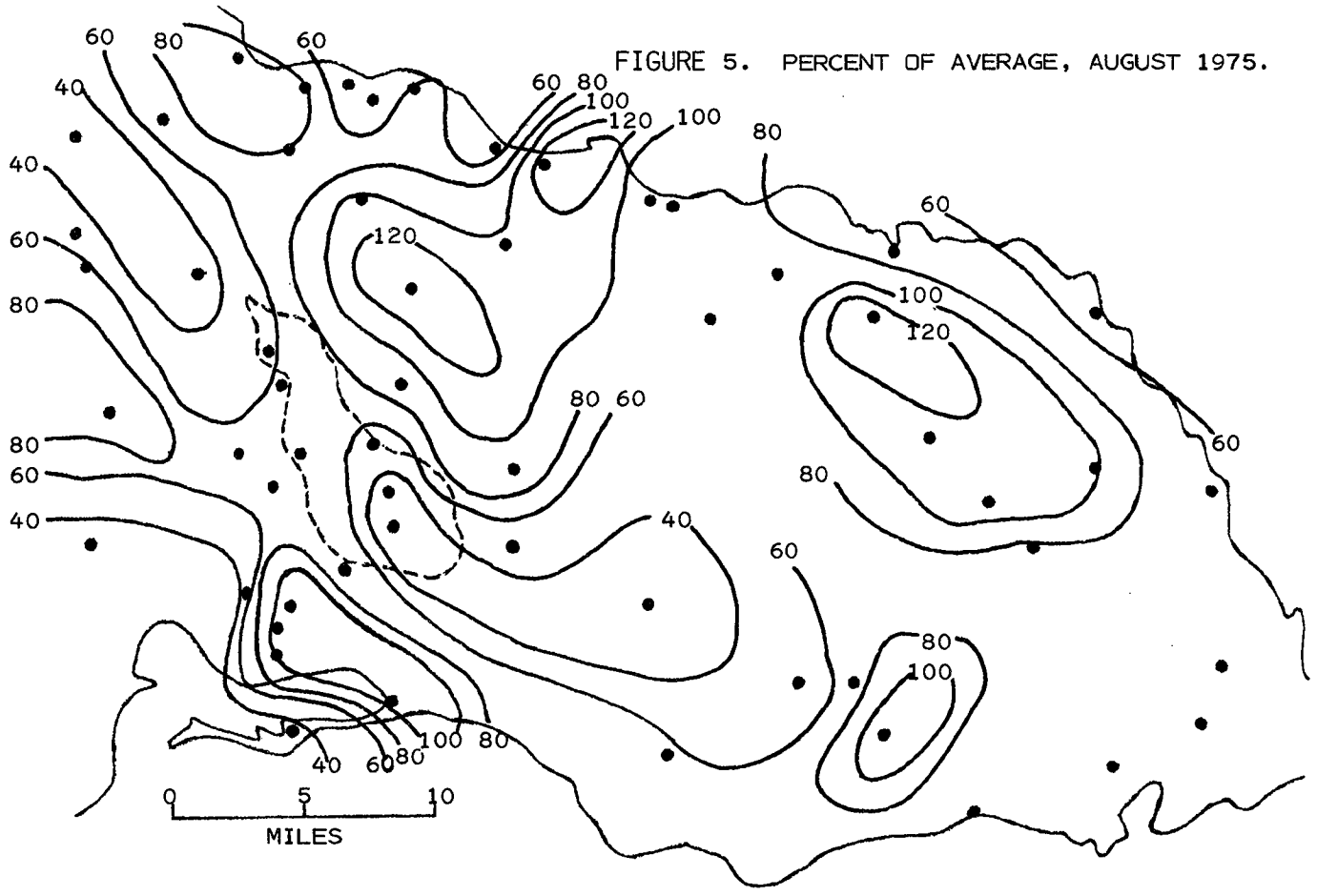


FIGURE 5. PERCENT OF AVERAGE, AUGUST 1975.

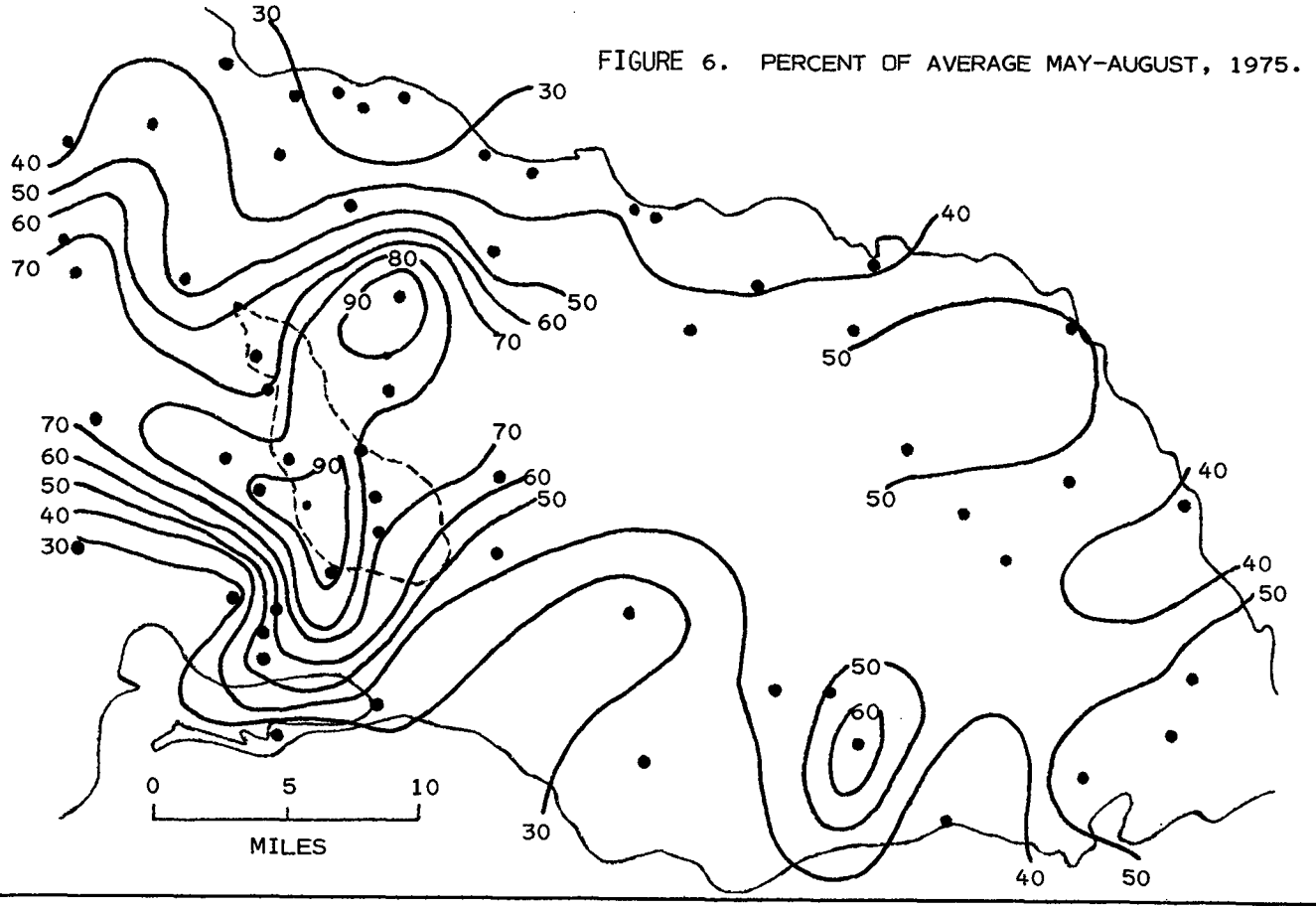
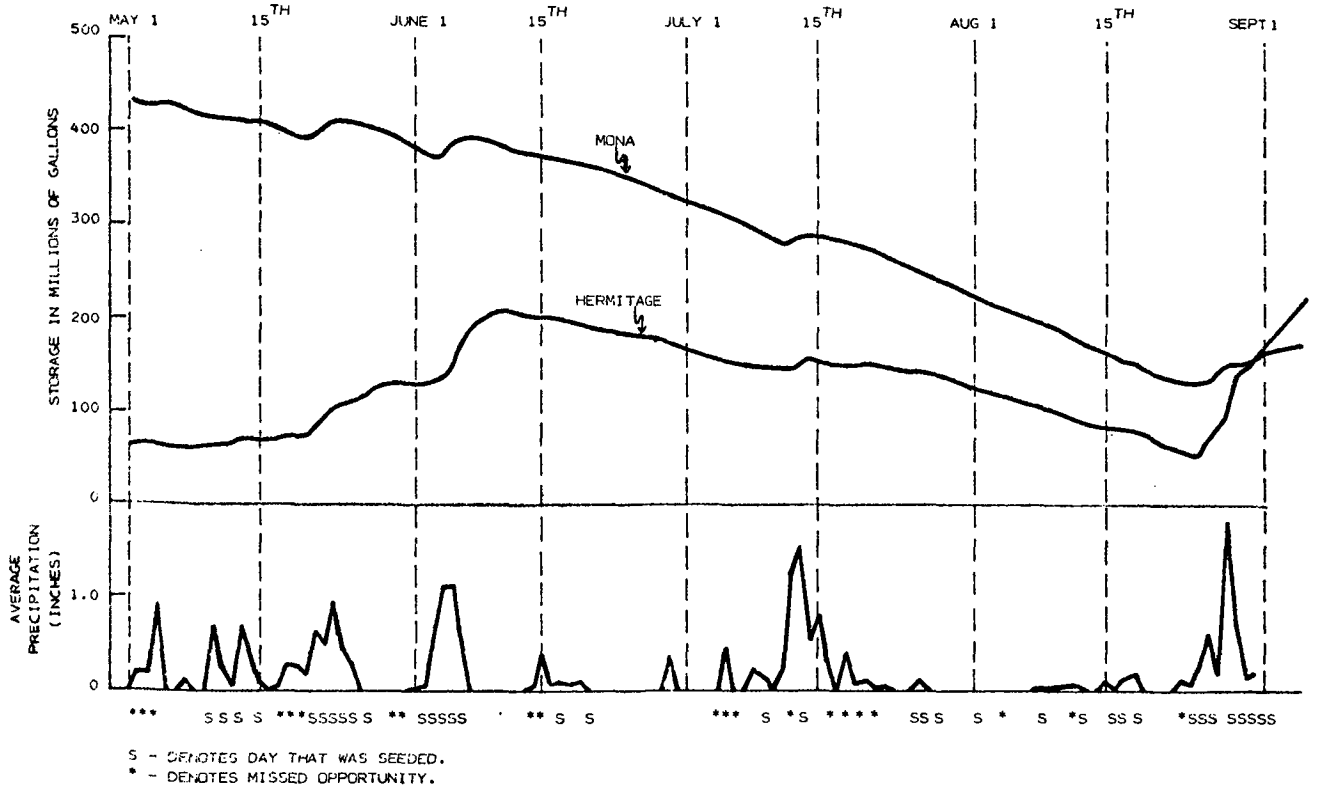


FIGURE 6. PERCENT OF AVERAGE MAY-AUGUST, 1975.

FIGURE 7. STORAGE IN HERMITAGE AND MONA RESERVOIRS VERSUS AVERAGE PRECIPITATION.



the ground contours below this height. A new survey has not been conducted for Hermitage since the removal of a sizeable quantity of silt during the early summer of 1975 (estimates of the increase in storage as a result of the desilting were placed at 80 million gallons). Consequently, the amount of storage was underestimated whenever the water level rose above the area that had been desilted. Corresponding increases in storage for Mona Reservoir for the three periods were approximately 20, 25, and 40 million gallons. Although the two watersheds are adjacent to each other, the Mona drainage appeared to respond to a lesser degree to the amount of precipitation that fell than did the Hermitage drainage.

A second evaluation of the project was performed by the Meteorological Service of Jamaica. This evaluation was based on the development of monthly target and control relationships using available precipitation data from previous years when no seeding had taken place. These relationships were then used to predict the expected target area precipitation for the four months of May - August and compared to the actual rainfall amounts to estimate the effects of seeding. The resulting conclusion was that the rainfall had been increased in the target area by an estimated 26%.

Using this percent increase, an estimate was made of the additional inflow produced (excluding base flows of the rivers) for the four months. The calculated increases were 125 and 40 million gallons of water for Hermitage and Mona, respectively. It was also indicated that this was a conservative estimate since ground water recharge and evaporation losses were not considered. In addition, no allowance was made for the underestimate of the amount of storage in Hermitage Reservoir discussed previously. To place these figures in context, it should be noted that storage in Hermitage Reservoir stood at under 60 million gallons in late April and again in late August, despite the indicated additional inflows of 125 million gallons within that period attributed to cloud seeding. The severity of the domestic water supply situation can thus be appreciated.

An evaluation of the direct costs of the project versus the indicated increase in runoff provided an estimate of 37 cents per 1000 gallons of water available for distribution. It was recognized that in actuality, there wre additional benefits to agriculture both within and outside the specified target area, especially when the small size of the target area was considered. If these benefits are considered in conjunction with the difference in storage amounts in Hermitage Dam, ground water recharge, and evaporation losses, then the benefit to cost ratio would rise substantially.

Another form of evaluation of a subjective nature was the observations of the flight crews and observers that were involved in the seeding flights. On many occasions seeded clouds were observed to grow rapidly, and subsequently, produce significant rainfall shortly after seeding. Penetrations of cumulus towers previously seeded were often more turbulent with significant increases in the amount of ice particles within the cloud. On a few days it appeared that seeding was instrumental in causing adjacent cumulus cells to join or merge.

CONCLUSIONS

A limited scope precipitation enhancement program conducted for the Kingston Corporate Area of Jamaica during the summer of 1975, appears to have been successful. Due to the high variability of natural rainfall amounts, the exact attainments of the program cannot be accurately specified. Qualitative evaluations based on percent of average precipitation lend strong support to the conclusion that there was a positive seeding effect in the target area. Semi-quantitative target and control evaluations performed by the Meteorological Service of Jamaica indicated increases in precipitation in the two target areas of approximately 26 percent. A corresponding increase in runoff of 165 million gallons was estimated to have resulted from the four month project. Attributing all direct costs of the project to this estimated increase in runoff indicates the cost of additional deliverable water to have been 37 cents per 1000 gallons.

REFERENCES

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