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VERIFICATION OF RAINFALL ESTIMATES: AN ANALYSIS OF ACTIVATION PATTERNS OF ADSID AND ACOUSID SEISMIC AND ACOUSTIC INTRUSION SENSORS TO DETERMINE RAINFALL RATES

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A test was conducted at Eglin AFB, Florida in the Fall of 1972 to verify rainfall rates as determined from the activation patterns of seismic and acoustic intrusion sensors. Sensor activations were recorded, analyzed, and compared with rainfall rates as determined from recording rain gauges collocated with the sensor strings. Useful comparison data were obtained on nine tests, as definite sensor activation patterns were correlated with various rainfall rates. Scatter diagrams were prepared and analyzed to summarize the sensor activation/rainfall rate comparison.

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PREFACE

The authors express their appreciation to the following personnel for assistance in conducting the rainfall tests: Captains Kenneth Smidy and Edward Keppel, Det 10 Staff Meteorologists; TSgt Robert Booth and the entire maintenance section of Det 10; Mr Bill Relph and Mr James Pippin, ADTC/TGYN Project Engineers; and Maj James Shunk, Air Weather Service/DNT. During the reporting stage of the tests, Capt John Moore, Det 10 Staff Meteorologist, and Mr Dave Nichols, ADTC/TSGW, provided additional assistance.

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VERIFICATION OF RAINFALL ESTIMATES

INTRODUCTION

During the 1971 and 1972 southwest monsoon seasons in Southeast Asia (SEA), the 1st Weather Group (1 WG) at Tan Son Nhut AB, Vietnam, made estimates of rainfall for the Ho Chi Minh Trail by analyzing the activation patterns from IGLOO WHITE seismic sensor strings. The data were collected at the Infiltration Surveillance Center and relayed to 7th Air Force (7 AF). These sensor-derived rainfall data soon became the primary source of rainfall knowledge for Laos because of the lack of other near real-time information. Rainfall estimates for the major pass areas and "choke-points" in the enemy's logistic network were of value to 7 AF in anticipating vehicular traffic levels.

The greatest limitation of the weather data secured from the sensors was the lack of verification of the rainfall estimates from independent sources. There was no question that the sensors activated for rainfall, and this fact allowed the tracking of rainshowers and thunderstorms across the sensor field and permitted the mapping of the spatial extent of rainfall areas. Even the relative change in a storm's intensity with time was detected by analyzing the sensor activation patterns. However, there was no way to verify the accuracy of the estimates of rainfall amounts. As the sensor weather data program was underway in a combat environment, a verification effort was impossible to undertake because of the lack of test equipment and available manpower, and the inaccessibility of the area of concern.

In a 9 December 1971 letter to 1st Weather Wing (1 WW), the 7 AF Staff Weather Officer Analysis Team (SWOAT) stated the need for a calibration test and recommended that the tests be performed at a CONUS location. The 1 WW endorsed the request in a forwarding letter to Air Weather Service (AWS), while HQ PACAF in a separate letter outlined the value of the rainfall data obtained from the sensors in SEA and recommended that calibration testing be performed at Eglin AFB, Florida. After HQ AWS contacted the Directorate of Sensor Matters (AFXOB) at HQ USAF, the Sensor Evaluation Group at Eglin, and Detachment 10, 6th Weather Wing at Eglin, it was determined that the tests were indeed feasible. HQ MAC provided the funds required for reimbursable test expenses, while Detachment 10 obtained four recording rain gauges from the US Geological Survey and AWS provided wind measuring sets. The Armament Development and Test Center (ADTC), Eglin AFB, provided the sensors, an instrumentation van to receive the sensor signals, computer reduction of the sensor data, and personnel to perform all functions necessary to collect the sensor data.

TEST EQUIPMENT AND LOCATIONS

Sensors

Description - The three types of sensors used in this test were the ADSID III, the ACOUSID III, and the COMMIKE III.

The ADSID III (Air-Delivered Seismic Intrusion Detector) is a purely seismic detector that was designed to detect ground vibrations created by moving vehicles or personnel. ADSID III is activated automatically whenever seismic disturbances exceed the sensitivity level of the sensor. The sensitivity level is a function of the gain setting of the geophone, and must be selected before the sensor is implanted.

The ACOUSID III (ACOUstic and Seismic Intrusion Detector) is a seismic sensor with a commandable acoustic interrogation capability. Thus, when the sensor is activated seismically by some disturbing element, a command can be sent to activate a microphone. The sensor will then transmit an audio record for 19 seconds. In this way, not only can the activations be confirmed, but some target discrimination can be performed. Interrogations of the sensor's status, as well as changes in gain setting, can be accomplished by radio command.

The COMMIKE III (COMmand microphone (MIKE)) is a passive, commandable acoustic sensor. This sensor is also air-delivered; however, a parachute is added to retard its fall speed as well as to aid emplacement in the upper foliage of trees. Because of its sensitive microphone and tree emplacement capability, this sensor is used to confirm the location of suspected enemy truck parks and staging areas and to monitor activities in those areas. The COMMIKE III relays acoustic information only upon command.

Emplacement - Thirty-six of these sensors from the IGLOO WHITE inventory were hand-emplaced in four strings in the west test area of Eglin AFB. Each sensor string consisted of alternately spaced ADSID III and ACOUSID III sensors, with one COMMIKE III sensor at the midpoint of the string. Sensors in each string were emplaced 100 meters apart and each parallel string was separated by approximately 1.0 kilometer (Figure 1). Data for the tests were collected at the "Blue Goose" instrumentation van, located at the west site. On 10 November 1972, the three strings of sensors east of the Blue Goose were removed as they were located in one of the deer hunting areas. For the remainder of the test, data were gathered from the west string only (Figure 2). The sensors were originally planted in the four strings to cover a large area and to detect rainfall in areas with different types of foliage. Pictures of the various foliage and the Blue Goose are shown in Figure 3.

Meteorological Equipment

Rain Gauges - Four recording rain gauges were obtained from the U.S. Geological Survey. Two were Stevens Recorders, Model #A35, and two were Water Level Recorders, Julien P. Friez and Sons, Co, Model #FA3. All four gauges used weight-driven chart paper drives. The rainfall was collected in a 12-inch diameter funnel which flowed into a 4-inch diameter holding tube. A float inside the tube was connected to a perforated steel tape which passed over a sprocket to a small counter-weight. As the water level in the tube rose, the float would rise causing the recording pen to move across the chart paper. The stands for the gauges were constructed by maintenance personnel of Det 10, 6 WW. Gear modifications

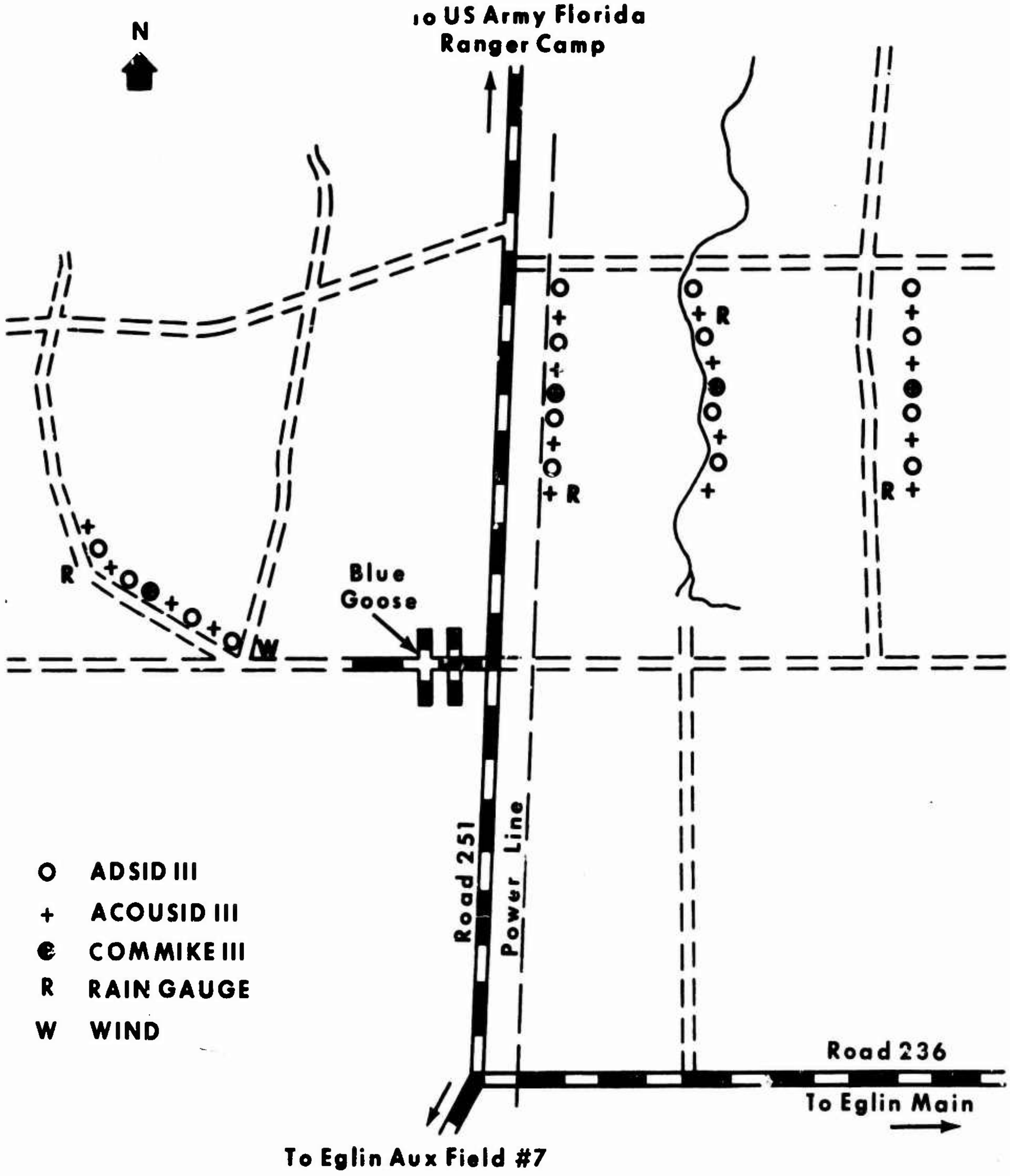

Fig 1. Location of four sensor strings with meteorological instruments.

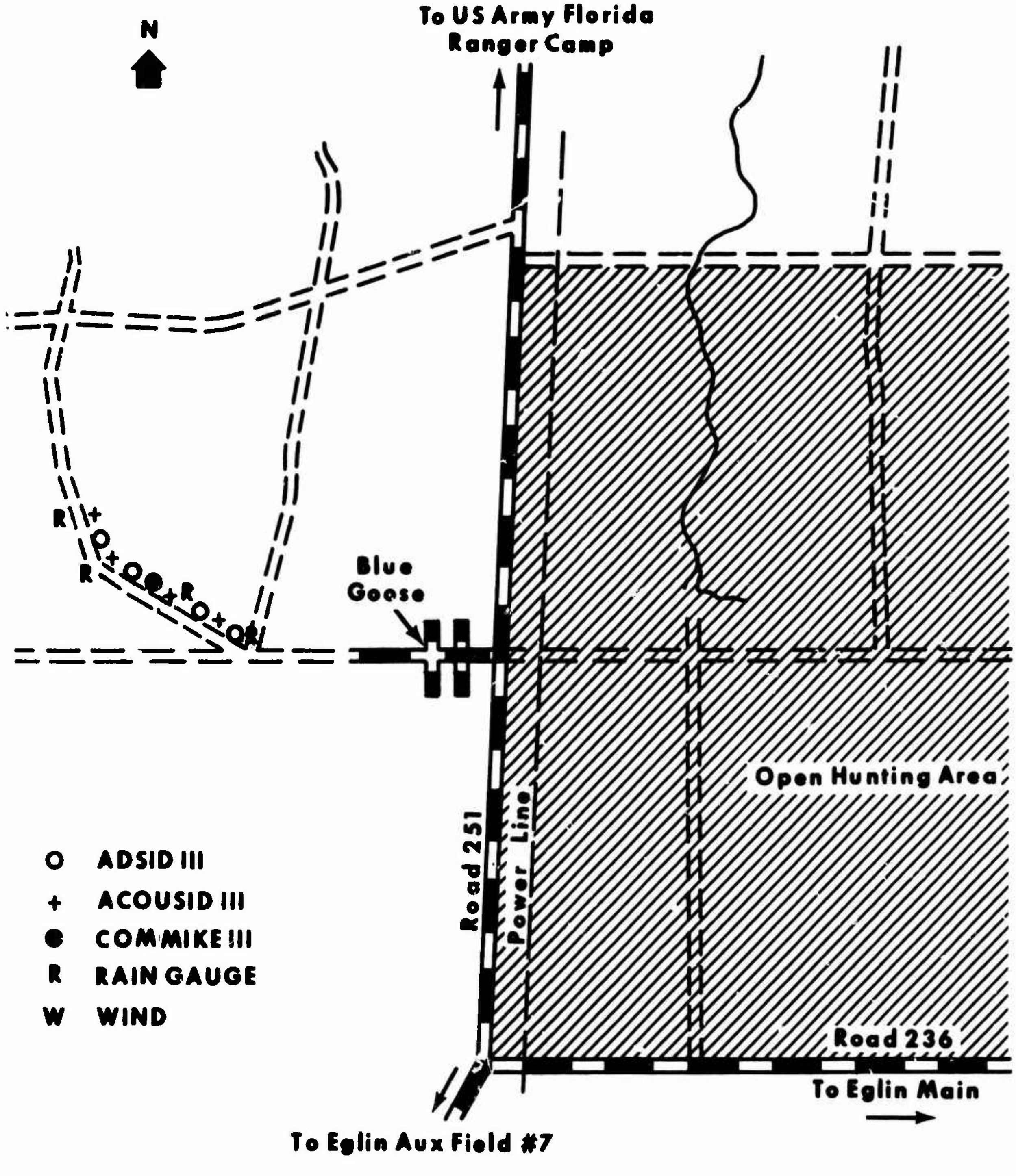

Fig 2. Location of single sensor string with meteorological instruments (after 10 Nov).

were made to increase the paper advance rate, and 4-inch holding tubes were constructed to replace the original 12-inch tubes. This expanded the time and rainfall scales for more accurate calculations of the rainfall rate. The rain gauges were originally placed at opposite ends of the sensor strings (Figure 1). On 10 November 1972, all four gauges were moved to the western sensor string (Figure 2) for the remainder of the test.

Wind Sets - A TMQ-15 Wind Measuring Set and Easterline Angus recorders were obtained from AWS resources. This was placed on the southern end of the western sensor string because that was the only location where 115-volt power for the recorder could be supplied. Pictures of the various gauges, their sites, and the TMQ-15 are shown in Figure 4.

CONDUCTING THE TESTS

Personnel from the Staff Meteorology Office, Det 10, 6 WW, were responsible for conducting the rainfall verification tests. When rainfall appeared imminent, they notified Wolfcall (the ADTC range test controller) who then coordinated the test times with the range contractor, whose personnel manned the "Blue Goose" instrumentation van. The Blue Goose had to be manned in order to collect any sensor data. Diesel-powered generators were used for power because of the high frequency of power outage in the area due to lightning strikes. Starting the generator and checkout of equipment required about a half hour before any data could be collected.

Several problems were encountered during this test. One problem concerned manning the Blue Goose after normal duty hours and on weekends. A long lead time forecast of rainshower activity over the sensor strings was not required during normal duty hours, since the contractor personnel were either working at the Blue Goose or at West Control, 3 miles away. However, most of the precipitation occurred during evenings and on weekends, so rainshower activity had to be forecast accurately with enough lead time to provide for manning of the Blue Goose. The AN/FPS-77 weather radar proved an invaluable tool in forecasting the shower activity. Another problem was the uncooperative weather during the early weeks of the test. During September, the precipitation was primarily in the form of light rainshowers, which moved rapidly with short average life times of 30 minutes. This was followed by more than 20 consecutive days in October with no precipitation. Finally, in November and December, there were several predictable squall lines which moved through the area and provided the basis for some useful data.

COLLECTION OF RAW DATA

The sensor data were collected at the Blue Goose in the following manner: The radio receivers fed the information to an instrumentation interface unit, which converted the signals into the proper format for the various recording instruments. All seismic activations and responses to commands were recorded on digital tape and an X-T (distance-time) plotter. Acoustic returns could be monitored real time with a speaker. All data received were recorded on an FR 1300 fourteen-track tape recorder

Fig 3. Types of foliage in sensor areas (upper left, east string; upper right, creek string; lower left, west string) and Blue Goose instrumentation van.

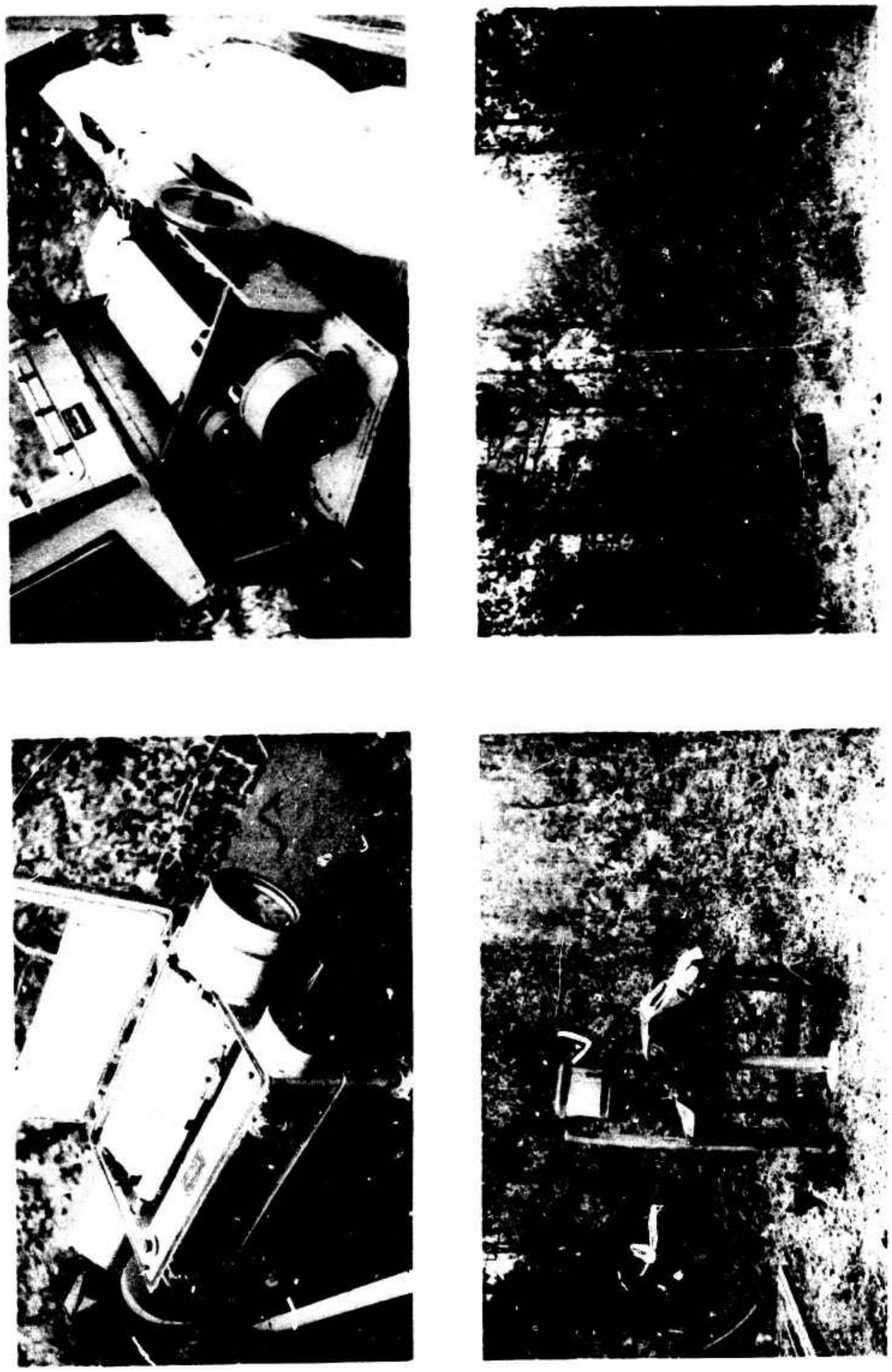

Fig 4. Meteorological instruments. Upper left, Friez water level recorder; upper right, Stevens recorder; lower left, complete rain collection device; lower right, TMQ-15 wind set and recorder.

to facilitate recovery of any data required. All data were time-tagged, with accuracy measured in thousandths of seconds.

The rainfall data were acquired in a less sophisticated fashion. Every three days, or after a rainstorm of any intensity, staffmet personnel drove out to the test area. Due to the rough terrain and sand roads, a 4-wheel drive vehicle was required, and an average trip took three hours. If no rain had fallen, time checks were written on the rain gauge charts, and the clock weights re-wound. If some precipitation had been recorded, the charts were removed, the collecting tubes emptied, and the recorders reset. Time checks were entered on the strip charts before they were removed and when the recorders were restarted. The amount of rainfall was also measured in the collecting tubes and entered on the charts as a cross check. The recorders and tables were covered with plastic material to insure that no spurious rainfall ran into the collecting tubes.

The TMQ-15 wind recorder ran continuously, and the data were removed only when the strip chart needed replacement.

DATA ANALYSIS

Rainfall Times

In order to compute rainfall rates, it was necessary to determine the rate of chart advance in the recorders. The gear ratio selected should have driven the chart one small division per 15 minutes. However, we discovered considerable variation from machine to machine and even from time to time. Therefore, it was necessary to calculate chart speed on each record by dividing total elapsed time by the number of divisions covered. If a recorder stopped, the chart speed could not be determined definitely. Normally, the rate from the previous record was used in these cases. After chart rate was established, the times of onset and cessation of rain were determined.

Initial Comparison

The initial comparison between the sensor and rainfall data was to see if the sensors had been monitored while it was raining and had collected any usable data. Table 1 is a summary of that comparison:

Date	Mission Number	Times of Sensor Data	Times of Rainfall data	Wind Data	Further Analysis
21 Sep	4708	2133Z-2235Z	2200Z	---	No
22 Sep	5704	1835Z-2030Z	1920Z	---	No
25 Sep	1704	1929Z-2230Z	1930Z-2135Z	---	Yes
26 Sep	2707	1000Z-1648Z	None	---	No
23 Oct	1703	1526Z-1940Z	1526Z-1840Z	Yes	Yes
26 Oct	4706	2338Z-0431Z	2300Z-0330Z	---	Yes
27 Oct	5705	1211Z-1906Z	0500Z-1240Z	Yes	Yes
7 Nov	2706	2001Z-2155Z	2015Z-2035Z	---	Yes
10 Nov	5705	2109Z-2345Z	2115Z-2345Z	---	Yes
13 Nov	1703	1804Z-0138Z	1900Z-0138Z	---	Yes
25 Nov	6702	1408Z-1550Z	1408Z-1550Z	---	Yes
4 Dec	1704	1909Z-2231Z	1909Z-2215Z	---	Yes
5 Dec	2705	2118Z-2400Z	2130Z-2400Z	Yes	Yes
6 Dec	3707	1626Z-2201Z	1626Z-2103Z	---	Yes

Table 1. Summary of Sensor vs Rainfall Data for Further Analysis

Of the fourteen tests attempted, eleven warranted further evaluation. The three that were disregarded had no measurable rain, and the sensor returns were almost nonexistent.

Rainfall Rates

The next step was to compute the rainfall rates. This was done by noting the times when the rainfall rates changed (when the slope of the trace changed), calculating the time intervals, and measuring the horizontal distances the pen traveled within the intervals. (Figure 5 is an example of the record from the Stevens recorders.) The rates were then converted to inches per hour. After examining the variety of calculated rainfall rates, the following classifications were established for the purpose of discussion: light rain, less than 0.25 inches/hour; moderate rain, 0.25 to 1.0 inches/hour; and heavy rain, more than 1.0 inch/hour.

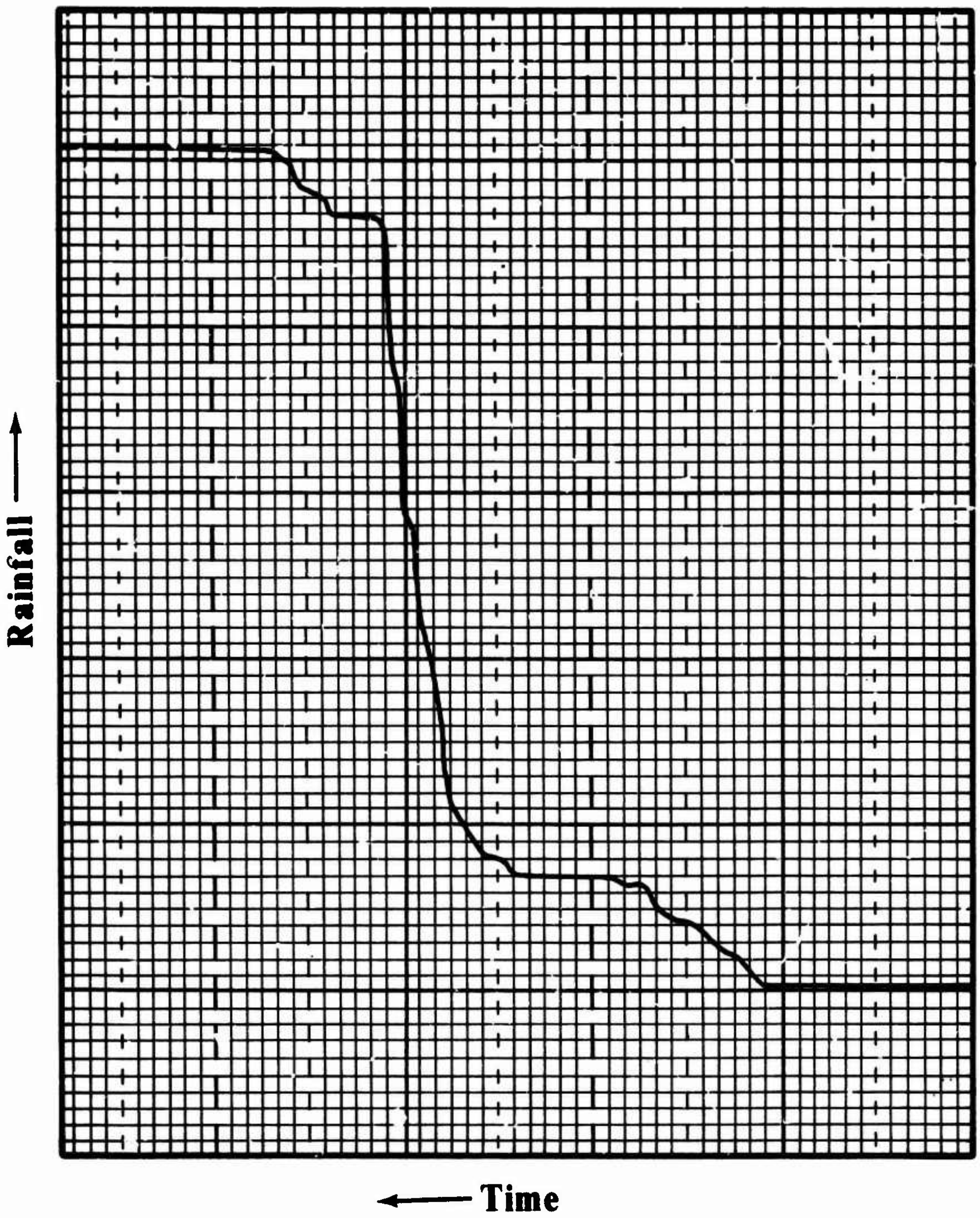

Fig 5. Example of Stevens recorder chart. One small time division equals 15 minutes, 7.5 small rainfall divisions equals 0.1 inch.

It became obvious at this time that the collection of accurate rainfall data would not be an easy task. Many problems were encountered such as clocks stopping, paper jamming, pen drive tapes slipping on the sprockets, pens not working, weights being stolen, and foreign material in the collecting funnel. Once the data were plotted, some timing errors were observed that could not be easily resolved. For example, a well defined line of thunderstorms moved through the test area over all four rain gauges. The rainfall data should have shown temporal continuity. However, ten to thirty minute variations were observed. Therefore, the timing of the rainfall turned out to be fairly subjective.

Wind Data

Wind data were only available on three tests. The TMQ-15 was not received prior to starting the test. Several days of data were missed due to paper jams in the recorder. Timing, however, seemed quite precise. Location of the wind set was a problem because we wanted it collocated with a sensor string; however, all of the sensors were in areas of tall pine trees. We selected a site with as much exposure as we could find, but the 10-foot mast placed the anemometer only above the smallest shrubs. Wind direction was not observed, because it would not relate to wind-caused seismic movement. Observed speeds were much below those observed at Eglin main base in storm situations. Available wind records were examined to determine whether winds caused seismic returns, especially when seismic returns could not be associated with rainfall.

Sensor Data - Seismic Returns

The seismic data obtained from the ADSIDs and ACOUSIDs were available in four formats. First, the X-T plot indicated each sensor activation, including the response to command of the ACOUSIDs (Figure 6). The operators also hand-scribed comments about weather at the Blue Goose site, as well as start and stop times of the audio commands. The other three formats were printouts from the CDC 6600 computer. One format (type 1 message) was one-minute summaries of the seismic activations from each sensor (Figure 7). Another format (all message types) was a similar minute-by-minute summary, but included the responses to command signals from the Blue Goose. The last format was a listing of all the signals recorded, with time to the millisecond (Figure 8).

Comparison of Rainfall and Seismic Sensor Data

Once all the rainfall had been analyzed and the data printouts obtained, the major task of comparing the rainfall rates to the seismic activations began. The eleven tests that appeared promising were individually analyzed. Three facts became obvious immediately: sensors activated for weather other than rain; the maximum activation rate was higher than the expected six times per minute; and sensors with identical gain settings could still have different sensitivity.

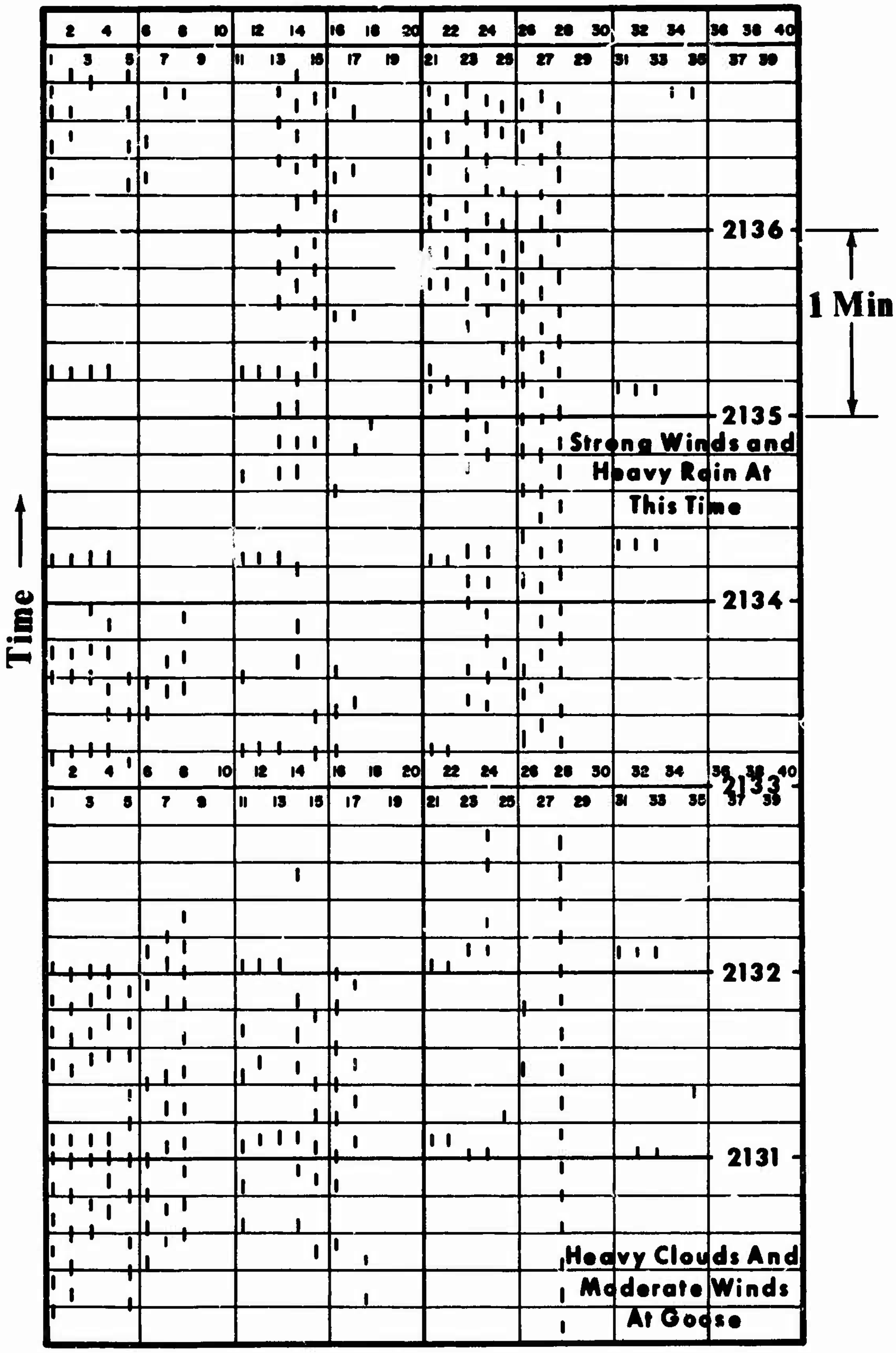

Fig 6. Example of X-T plot with operators' remarks.

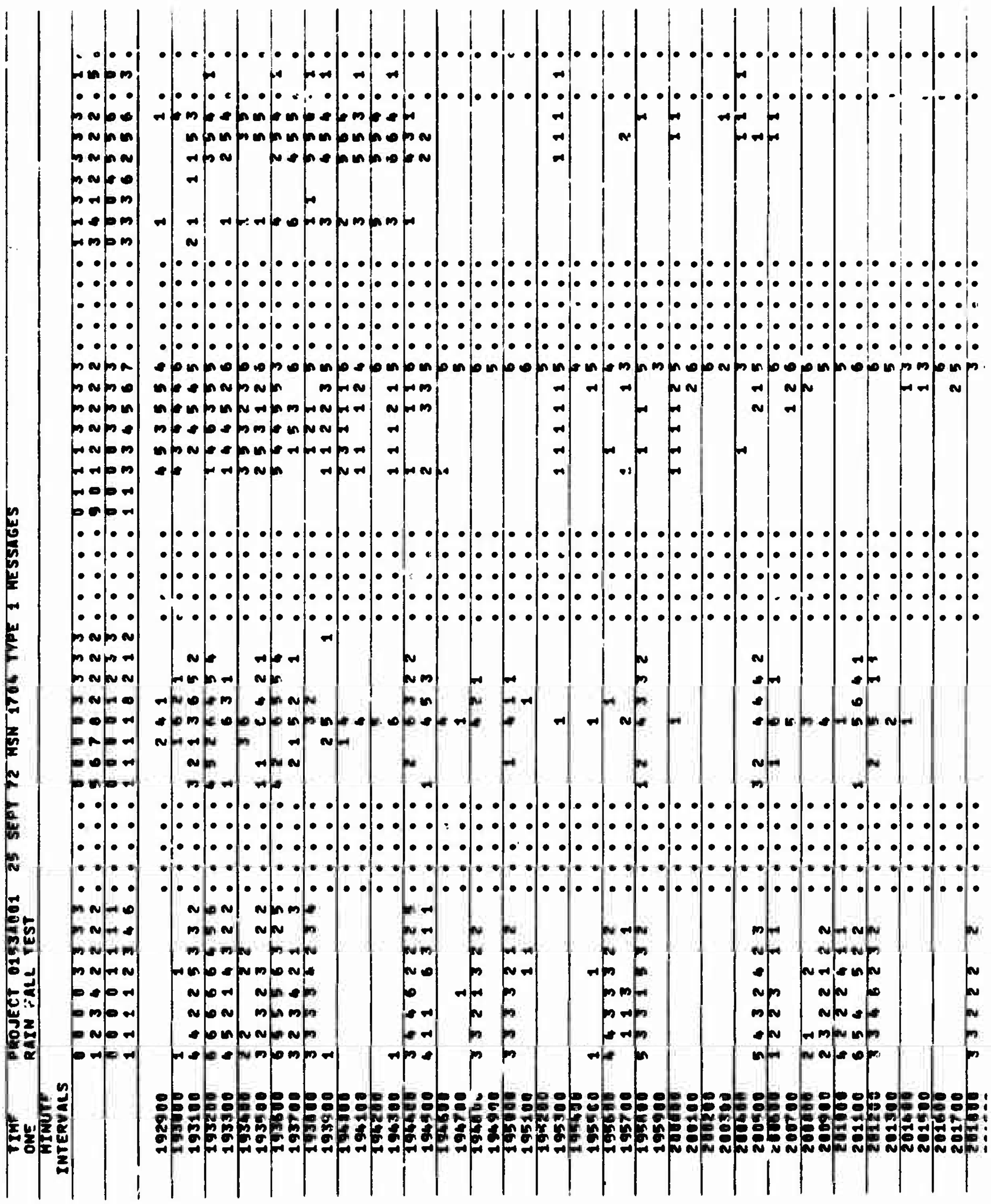

Fig 7. Example of type 1 message printout.

BLUE GOOSE
(PHASE 3)

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TIME HR MN SC	STATION	COMMAND	CHANNEL GP CH	TONE CODE	MESSAGE TYPE	RESPONSE	PARITY	MANUAL DATA	FILE	RAW DATA
19 28 13.745	9			1	28	RT	3		1	11312404672124232501
19 28 14.255	7			1	28	RT	3		1	07312405022524232501
19 28 14.256	1			1	28	RT	3		1	01312405022544232501
19 28 14.258	5			1	28	RT	3		1	05312405022604232501
19 28 14.259	2			1	28	RT	3		1	02312405022624232501
19 28 14.259	6			1	28	RT	3		1	06312405022624232501
19 28 14.260	32			1	28	RT	3		1	40312405023004232501
19 28 14.260	4			1	28	RT	3		1	04312405023004232501
19 28 14.261	3			1	28	RT	3		1	03312405023024232501
19 28 14.262	8			1	28	RT	5		1	10312405023044252501
19 28 14.262	9			1	28	RT	3		1	11312405023044232501
19 28 14.628	32			36	1				1	40312405061200571301
19 28 14.869	32			35	1				1	40312405103221331201
19 28 16.253	7			1	1				1	07312405422460612501
19 28 17.608	11			3	1				1	13312405660201252701
19 28 17.629	12			3	1				1	14312405661221042701
19 28 20.559	32			37	1				1	40312410052620631501
19 28 20.844	14			3	1				1	16312410102101662701
19 28 21.042	32			66	1				1	40312410202041871401
19 28 21.354	8			1	1				1	10312410232500062501
19 28 25.501	32			36	1				1	40312411250028651301
19 28 25.827	7			1	1				1	07312411301160352501
19 28 26.192	32			35	1				1	40312411414441001201
19 28 27.710	12			3	1				1	14312411670401302701
19 28 28.384	11			3	1				1	13312412034101212701
19 28 30.303	32			34	1				1	40312414030061251101
19 28 30.830	32			37	1				1	40312414161400341501
19 28 31.421	8			1	1				1	10312414241020122501
19 28 36.857	32			36	1				1	40312415402560451301
19 28 37.317	32			35	1				1	40312415630561111201
19 28 38.831	12			3	1				1	14312416001421102701
19 28 40.467	32			34	1				1	40312420043161201101
19 28 41.864	32			37	1				1	40312420203100041501
19 28 43.780	11			3	1				1	13312420474001022701
19 28 44.009	32			18	1				1	40312421000221615001
19 28 46.395	8			1	1				1	10312421434520262501
19 28 46.665	32			36	1				1	40312421463120461301
19 28 48.360	32			3[illegible]	1				1	40312422033001371201
19 28 48.849	12			[illegible]	1				1	14312422102221172701
19 28 50.471	32			34	1				1	40312424043421371101
19 28 51.457	32			37	1				1	40312424242560321501
19 28 54.729	11			3	1				1	13312425071221212701
19 28 58.335	32			36	1				1	40312426031520551301
19 28 58.787	12			3	1				1	14312426074161002701
19 28 59.118	8			1	1				1	10312426210500232501
19 28 59.748	32			35	1				1	40312426272201221201
19 29 1.746	32			37	1				1	40312440272140141501
19 29 4.893	11			3	1				1	13312441004461102701
19 29 8.484	12			3	1				1	14312442044101262701

Fig 8. Example of digital dump, giving time and content of all sensor signals.

The seismic sensors activated for traffic, rain, thunder, and possibly wind. One sensor string was only 100 meters from a paved road, and oriented parallel to the road. Traffic could be detected very well from the sensor returns (Figure 9). By examining the X-T plot, even the speed of the vehicles could be calculated. Analysis of rainfall data from this string was usually unfruitful because of these high traffic levels. At times, traffic would also cause activations on the second string east of the road. At other times, three strings were affected at the same time by what was suspected to be aircraft traffic. Thunder at times caused activations over the entire sensor field. On several days, the rainfall pattern was difficult to recognize on the seismic returns due to frequent activations from thunder. We suspected that some periods of otherwise unexplained activations were caused by wind, either directly by moving the sensor antennas or indirectly by tree movement. However, wind data were insufficient to establish any relationships.

We understood at the outset that the seismic sensors could transmit once every 10 seconds, giving a maximum activation rate of six per minute. However, we occasionally observed reports of seven activations per minute, and on 25 November one sensor transmitted seven times per minute for seventeen consecutive minutes. The ADTC Sensor Lab verified that the specifications for the inhibit circuit, which controls the activation interval, is 10 ± 2 seconds on the ADSID III and ACOUSID III. The control in this circuit is a resistance-capacitance (R-C) network. If seismic movements of sufficient intensity and frequency are reported by the sensor's geophone and build up a certain level of charge in other circuit elements, the sensor will transmit an "activation," provided the time constant of the R-C network is exceeded. Thus, during times of high levels of seismic movement, the sensor can transmit every time this time constant is exceeded. We observed this "saturation" to occur frequently during heavy rainfall. The time constant varied from 8.5 to 11.0 seconds on different sensors, but remained essentially the same for each sensor from day to day.

Activation and saturation levels are highly dependent on gain setting. Gain setting affects the level of seismic activity required to trigger the geophone. For a given level of seismic activity, increased gain setting results in more frequent triggering of the geophone. For each output from the geophone, a certain amount of charge builds up in another circuit element. This charge, however, has a certain decay rate. Outputs from the geophone must occur frequently enough to overcome this decay rate and build up the required level of charge before the sensor will transmit any activations. The higher the seismic level, the more frequent the outputs from the geophone and the more rapid the charge buildup to the critical level. Thus, higher gain settings not only lower the threshold level of seismic activity required for activation, but also lower the level of activity required for saturation. The sensors in each string were set at the same gain setting, two strings on gain 3 and two on gain 4. However, there was still a wide variation in the sensitivity of the various sensors in a string. This was especially noticeable during periods of light rainfall. After 10 November, when all four rain gauges were moved to the one sensor string, we were able to determine with some certainty that these

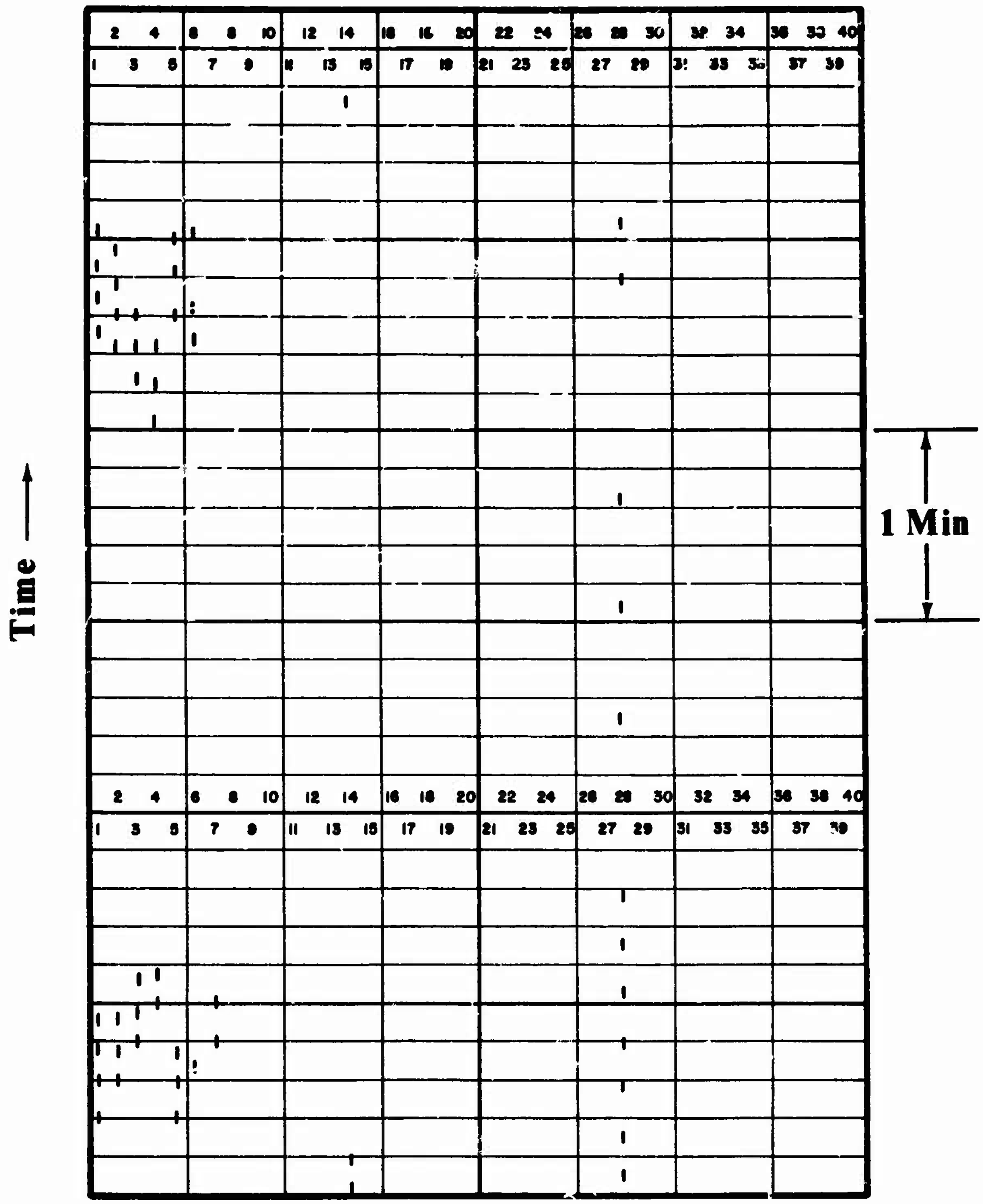

Fig 9. Example of activations caused by vehicular traffic. Channels 1, 2, 3, and 4 are ACOUSIDs (200 m. apart) and 5, 6, 7, and 8 are ADSIDs (200 m. apart) in the power line string. The two groups of activations are from traffic moving north and south on the highway. The heavy time divisions are approximately one minute.

variations were due to sensor sensitivity rather than to variations in rainfall along the string.

The seismic data from the ACOUSIDs for all tests before 25 November were not used in the comparisons, since during part or all of the rainfall periods the ACOUSIDs were being commanded for acoustic returns, and seismic activations are not transmitted during the acoustic transmission cycle.

Individual Comparison Results - Following is a discussion of the data collected for each test day and the comparison of the rainfall and sensor data, with a quantitative summary of the comparisons.

DATE: 25 September 1972

SENSORS: Two main periods of activations occurred from 1929Z to 1945Z and 2130Z to 2145Z. The sensor string nearest the highway activated at various levels every few minutes for traffic. ADSID #37 activated almost continuously and #32 activated only five times during the entire test. Both were disregarded. The operators added many valuable comments on the X-T plot regarding rain and wind. Both periods of heavy rain were preceded by strong winds. Data were acquired from 1929Z to 2230Z.

RAINFALL: Most of the rainfall occurred in the form of two showers, at about 1930Z and 2130Z. The first shower nearly missed the two eastern gauges, moving from SSE. The second shower was recorded on all gauges. The pen drive slipped on Gauge #2. However, the data for the first shower appeared reasonable. An obstruction in the collecting funnel on gauge #4 slowed the flow of water, so rates were unusable.

COMPARISONS/CONCLUSIONS: Rainfall times correlated well with maximum sensor activations. During the first shower, with rainfall rate 1.25"/hour, the three ADSIDs evaluated (gain 4) approached saturation for about a minute. The rate during the heaviest part of the second shower was about 3"/hour on both #1 and #3 gauges. ADSID #18 (gain 3) saturated at 10.0 second intervals for two minutes. ADSIDs #34 and #36 (both Gain 4) saturated for 8 and 6 minutes, at 9.5 and 10.1 second intervals, respectively. Comparisons listed below are averages over the entire period of the showers for all of the sensors considered.

GAIN 3		GAIN 4	
RAINFALL RATE (inches/hour)	SENSOR COUNT	RAINFALL RATE (inches/hour)	SENSOR COUNT
2.0	4.2	2.0	5.5
		1.25	4.8
		0.46	3.7

DATE: 23 October 1972

SENSORS: Seven ADSIDs were inoperative. The returns from the other ADSIDs were in 5 to 15 minute blocks, many of them uncorrelated in time, plus scattered low counts throughout the test period. Data period 1526Z - 2244Z.

RAINFALL/WIND: Rainfall occurred in the test area from approximately 1040Z to 1840Z. Most of the heavier precipitation occurred during the sensor data period. The rainfall was generally light to moderate with brief heavy showers. The rainfall records looked very good, but timing was a problem. Number two gauge exhibited extremely rapid chart speed. Gusty winds(up to 25 kts) were recorded between 1315Z and 1855Z.

COMPARISONS/CONCLUSIONS: Since time correlation was difficult and the heavier showers appeared to be brief and localized, each rain gauge record was compared only to returns from the adjacent sensor string and, in one instance, to one sensor. No activations could be attributed to wind. The activation rates from the ADSIDs set on gain 3 were much lower than the rate from those set on gain 4. Therefore, results are compiled separately. Activations from the sensor string nearest the road showed a high rate of vehicular traffic, making rainfall difficult to discern. The 0.5 and 0.67 inches/hour rates are not instantaneous rates, but are results of smoothing through a period of rapidly fluctuating rainfall. During a period of 1.5 inches/hour rainfall, two ADSIDs on gain 4 appeared to saturate briefly.

GAIN 3		GAIN 4	
RAINFALL RATE (inches/hour)	SENSOR COUNT	RAINFALL RATE (inches/hour)	SENSOR COUNT
2.0	2.8	1.5	5.7
1.3	1.8	1.3	5.2
1.0	1.6	0.5	3.8
1.0	1.4	0.5	3.3
0.67	1.9	0.5	2.9
0.20	0.0		

DATE: 26 October 1972

SENSORS: The sensor string nearest the highway had numerous brief periods of activations and one nine-minute period with counts up to six per minute. The other strings had very sporadic activations throughout the period. Period of data: 2338Z to 27/0431Z.

RAINFALL: Light rain (less than 0.05"/hr) began at about 2300Z and continued until about 27/0330Z. Brief moderate showers with rates up to 0.5"/hr occurred near 27/0200Z and 0300Z.

COMPARISONS/CONCLUSIONS: All of the activations on the sensor string near the road and the next string to the east appeared to be caused by traffic. These were all set at gain 3. The moderate showers that occurred along these two strings were too brief for an accurate calculation of rainfall rates, but they were about 0.3"/hr. No activations could be attributed to these showers. On the eastern-most string (gain 4) these showers triggered a two-minute period of activations which average 1.3 counts. The one shower with 0.5"/hr rate appeared to occur only on the northwest end of the western string, where the last three ADSIDs were inoperative, and therefore triggered no activations. The light continuous rain caused no activations on the gain 3 sensors and only isolated activations on the gain 4 sensors.

GAIN 3		GAIN 4	
RAINFALL RATE (inches/hour)	SENSOR COUNT	RAINFALL RATE (inches/hour)	SENSOR COUNT
0.3	0.0	0.3	1.3
0.05	0.0	0.05	0.0

DATE: 27 October 1972

SENSORS: Period of the data was 1211Z to 1414Z, 1535Z to 1552Z, and 1832Z to 1907Z. High activation levels were occurring at the beginning of the test and continued until 1300Z. Eight ADSIDs were out of commission. Operator remarks on the X-T plot gave changes in intensity of rainfall at the Blue Goose, which correlated very well with the sensor activations.

RAINFALL/WIND: Rain had begun near 0500Z, consisting of several periods of relatively light rain. Heavy showers began at about 0900Z. By 1000Z, the two rain gauges with the higher rate of pen travel had malfunctioned: the pen arms had travelled all the way across the paper and failed to reverse. By 1240Z the other two gauges had overflowed. Total rainfall amount was over three inches. Rates exceeded four inches per hour in the heavier showers. Wind gusts to 37 knots accompanied the heavy rain.

COMPARISONS/CONCLUSIONS: Due to the limited period of time that both the sensors and rain gauges were operating and the timing difficulties on the rain records, no comparisons could be made. However, it appeared reasonably certain that the sensors were operating during one period of 4"/hr rainfall. Activations during that period were analyzed for saturation. ADSIDs #34 and #35, gain 4, saturated at 9.7 and 11.0 seconds. ADSID #22, gain 3, saturated at 10.3 seconds; but ADSID #31, also gain 3, did not saturate at all.

DATE: 7 November 1972

SENSORS: Five ADSIDs were not operational. The three strings east of the highway had sporadic activations throughout the period. The string to the west had a 20-minute period of activations near the beginning of the test and only isolated activations thereafter. Data times were 2002Z - 2156Z.

RAINFALL: Approximately twenty minutes of light rain occurred at gauges #2 and #4 during the test period. Brief light showers occurred at all gauges before and after the test period. Total accumulation was 1/16 inch.

COMPARISONS/CONCLUSIONS: The two ADSIDs operating in the string nearest the highway had activations averaging 1.5 and 1.0 counts per minute during the rain period. However, some traffic is evident on the X-T plot during the period, and the strings to the east also experienced activations at the same times, where no rainfall was recorded. Therefore, we concluded that a comparison of these activations to rainfall rate would be invalid. Another period of activations on the eastern-most string, which lasted for 22 minutes, did not correspond to rainfall or other sensor activations. The area east of the highway was to be opened for hunting on 11 November. Possibly a large part of the activations on the three eastern strings were caused by hunters reconnoitering the area. The string west of the Goose (gain 1) had a period of activations which correspond well with the rainfall times and rates.

RAINFALL RATES (inches/hour)	SENSOR COUNTS
0.14	2.8
0.05	0.9

DATE: 10 November 1972

SENSORS: This was the first test day with only one sensor string. All ADSIDs were operating. The periods of activation corresponded fairly well, but the levels of sensitivity varied considerably. All were on gain setting 4. Operator remarks on the X-T plot described rain intensities at the Goose, including "plenty lightning and thunder" at the beginning of the test. Test period: 2109Z - 2345Z.

RAINFALL: All four gauges showed the same rainfall pattern: Approximately 6 minutes of moderate rain, 10 minutes of light rain, 10 minutes of heavy rain, 25 minutes of no rain, and then 20 minutes of moderate rain. There was a time discrepancy of about 10 to 12 minutes between the gauges, so some adjustment was made. The time discrepancy could not be attributed to the movement of the storm, since the gauges were now all along one sensor string. The total rainfall was about 0.7 inch and occurred from 2130Z to 2300Z.

COMPARISONS/CONCLUSIONS: This test was the best in the series for comparison of rainfall and sensor data. The times compared favorably, showers were of sufficient duration to make accurate analyses, and several different rates occurred. Due to the apparently different levels of sensitivity of the ADSIDs, activation levels were computed separately. During the period of light rain following the first shower, considerable thunder occurred, activating the sensors. Therefore, no comparison was made for that period. Also, the series of smaller showers near the end of the rain period varied in intensity from one end of the string to the other, so the rate computed from the nearest rain gauge was used in the comparison. During the first shower (1.3 inch/hr), ADSIDs #66, #55, and #52 saturated, but #46 did not. During the heavy shower (2.5 inch/hr), all ADSIDs saturated. The time interval was 10.5 seconds for #66, 10.4 for #55, 10.9 for #52, and 10.6 for #46.

RAINFALL RATES (inches/hour)	SENSOR COUNTS				AVERAGE
	#66	#55	#52	#46	
2.5	5.7	5.4	5.4	5.3	5.5
1.3	5.7	5.6	5.6	3.4	5.1
0.13	0.8	2.6			1.7
0.1			3.0		3.0
0.04				0.0	0.0

DATE: 13 November 1972

SENSORS: ADSID #46 was inoperative. A high level of activations occurred from 1812Z to 1935Z and 2024Z to 14/0034Z. The level of activations among sensors varied considerably at several times during the test. Operator remarks on the X-T plot were very helpful in determining times of start and stop and change of intensity of rainfall, as well as occurrence of wind and thunder. Period of test: 13/1804Z - 14/0137Z.

RAINFALL: The first period of rain was from 1805Z to 1930Z, with rates up to 1 inch/hr. The second period, with maximum rate up to 4 inch/hr, began at 13/2150Z and ended at 14/0030Z. There was generally good agreement in times and rates between the gauges. Number 1 gauge was inoperative and #2 malfunctioned between 2300Z and 0000Z. Total accumulation varied from 1-1/8 inch to 1-7/16 inch.

COMPARISONS/CONCLUSIONS: Evaluation of the data was extremely difficult. Activation levels were unexplainably high during the first four hours. Wind and thunder may have been responsible. The first rainfall period was only recognizable on ADSID #52, but activation levels were too high, especially at the end of the rainfall period. During the second rainfall period, ADSIDs #55 and #52 activated at the 5.5 level, regardless of rainfall intensity, throughout and even for some time following the rainfall period. A reasonable comparison was obtainable from ADSID #66, however, which is listed below. All three ADSIDs saturated during the period when the rainfall rate was slightly over 1 inch/hr. The minimum interval was 10.6 seconds for #66, 10.5 for #55, and 10.9 for #52. All sensors were set on gain 4.

RAINFALL RATES (inches/hour)	SENSOR COUNTS
4.0	5.8
2.0	5.8
1.0	5.6
1.0	5.2
0.5	5.5
0.2	3.9
0.1	3.9
0.05	1.4

DATE: 25 November 1972

SENSORS: During this test and for the remainder of the test series, the ACOUSIDs were not commanded for acoustic data. Therefore, they were acting essentially as ADSIDs. This was also the test that prompted our investigation of minimum activation times and saturation by heavy rain. ACOUSID #970 responded seven times per minute for 17 consecutive minutes. Counts were generally one or two per minute higher from it than from the neighboring ADSID. ADSIDs #55 and #52 activated almost continuously throughout the test and their data were disregarded. ACOUSID #1564 was inoperative and ACOUSID #1450 had slipped to gain 3. A significant difference in activation levels from the usable sensors was apparent in the data, but all showed the same general pattern of starts and stops. The period of data was 1408Z - 1550Z.

RAINFALL: Due to malfunctions, data were available from only two gauges. Even then, the amount of rainfall measured in the collecting tube on gauge #2 was 1-1/4 inch, but the chart indicated less than an inch. By comparing the chart to that from gauge #1, it was determined that the perforated steel tape which drives the pen arm mechanism had slipped during the heaviest rain, and therefore data after that point were unusable. The chart speed calculations for gauge #1 indicated unusually rapid chart speed, but this was not borne out in comparison with the chart from gauge #2. The general pattern of rainfall had to be adjusted to a best fit with the sensor activations and the operators' remarks. About 1/3 inch of rain had fallen before the sensor test began, and light rain was falling as the test began. The rainfall during the test consisted of one 25-minute period of heavy rain (1.6 inch/hr) and several periods of moderate rain. Light rain was still falling at the conclusion of the test.

COMPARISONS/CONCLUSIONS: A reasonable fit was found in the sensor and rainfall data. However, the activation levels from the various sensors varied considerably, as the figures below indicate. All four of the gain 4 sensors considered in the analysis saturated during the 1.6 inch/hr rainfall. The time interval was 8.6 seconds for ACOUSID #970, 10.7 for ADSID #66, 9.1 for ACOUSID #1396, and 10.7 for ADSID #46.

RAINFALL RATES (inches/hour)	SENSOR COUNTS					AVERAGES - GAIN 4	
	#970	#66	#1396	#46	#1450 (gain 3)	ACOUSID	ADSID
1.6	6.9	5.4	5.6	5.5	1.0	6.3	5.5
1.0	6.7	5.3	3.7	5.0	0.0	5.2	5.2
0.5	5.9	2.7	1.0	3.0	0.0	3.5	2.9
0.5	6.0	2.7	1.0	3.0	0.0	3.5	2.9
0.4	4.2	3.3	0.5	2.5	0.1	2.4	2.9
0.3	3.9	2.7	0.9	2.0	0.0	2.4	2.4
0.1	1.0	0.0	0.0	0.0	0.0	0.5	0.0
0.1	0.8	0.0	0.0	0.0	0.0	0.4	0.0

DATE: 4 December 1972

SENSORS: ADSID #52 had numerous activations during the entire test while the other sensors had only isolated returns.

RAINFALL: Only one of the four rain gauges measured the light rain (less than 0.12 inch/hr) that fell during this entire test.

COMPARISONS/CONCLUSIONS: For the light rainfall observed, ADSID #52 reflected the start and stop times very well (within 2 minutes). However, the counts/minute were quite unreasonable, especially since no other sensors were activated. It was possible that the gain on this particular sensor had slipped. The rainfall rate of 0.12 inch/hr produced activations of 4.7 counts/minute. Because of the inconsistencies these data were not included in the summary.

DATE: 5 December 1972

SENSORS: ADSID #52 had a much higher level of activations than the other sensors during the more quiet periods, and its data were not considered in the analysis. The type one computer output showed several counts of 8, 9, and 11 per minute for ACOUSID #970 which were not borne out on the X-T plot. The overall activation pattern showed two brief periods of high activations at the beginning of the test followed by an hour and 20 minutes of low levels, 40 minutes of high levels, and finally 30 minutes of low levels. Operator's comments on the X-T plot gave a good description of the changes in rainfall intensity, thunder, and wind. Period of data was 05/2118Z - 06/0000Z.

RAINFALL/WIND: A brief shower(1 inch/hr) at the beginning of the test was followed by 90 minutes of variable, mostly light, rain, 30 minutes of heavy rain (up to 4 inches/hr), and finally 45 minutes of lighter showers. Accumulation during the test period was one inch. Three hours later, another period of heavy rain brought the evening's total rainfall to 2.9 inches. Wind was light except for a period of gusts up to 32 knots near 2300Z. The rain gauge records had time discrepancies of up to 25 minutes. One gauge had unusually slow chart speed and another malfunctioned during the heavy rain period.

COMPARISONS/CONCLUSIONS: A good fit between the rainfall pattern and sensor activation levels was found. However, the sensitivity of the individual sensors varied considerably, especially for the lower rainfall rates. The excessive activation rate indicated for ACOUSID #970 was due to activations of another sensor nearby which was on the same frequency and had been implanted for surveillance of the closed hunting area. This sensor was set at a lower gain setting, and its activations were only received during the heaviest rainfall. After examining the digital dump for activation times, it was decided that all of the excessive counts for ACOUSID #970 could be changed to 7 counts per minute. All sensors saturated for rainfall of 2 inches/hr or higher, with the following minimum interval: 8.5 seconds for ACOUSID #970, 10.6 for ADSID #66, 9.5 for ACOUSID #1564, 10.6 for ADSID #55, 8.8 for ACOUSID #1450, 9.1 for ACOUSID #1396, and 10.7 for ADSID #46. In the summary below, most of the sensors show a higher count rate for the 4 inch/hr rainfall than for the 2 inch/hr rainfall, which seems to contradict the finding that all sensors were saturated at 2 inches/hr. The 4 inches/hr rainfall lasted only 3 or 4 minutes. The timing of the activations within the one minute summaries can lead to different counts during such short periods.

RAINFALL RATES	SENSOR COUNTS							AVERAGES	
(inches/hour)	#970	#66	#1564	#55	#1450	#1396	#46	ACOUSID	ADSID
4.0	7.0	5.5	6.5	5.5	7.0	6.5	5.8	6.8	5.6
2.0	6.9	5.5	6.3	5.6	6.7	6.3	5.4	6.6	5.5
1.0	6.9	4.8	6.1	5.5	6.6	5.8	4.8	6.4	5.0
0.7	5.5	4.3	3.6	5.5	6.3	3.4	4.5	4.7	4.8
0.5	4.7	3.4	3.0	4.0	3.3	1.4	1.2	3.1	2.9
0.125	3.9	2.6	1.8	4.2	2.0	1.0	1.0	2.2	2.6
0.05	1.9	0.0	0.6	2.0	0.7	0.2	0.3	0.9	1.1

DATE: 6 December 1972

SENSORS: Two periods of activations occurred, 1633Z to 1711Z and 2039Z to 2100Z. In both instances, ADSID #52 continued transmitting for 15 to 25 minutes after all other sensors had stopped; therefore, its activations could not be used in the analysis. ACOUSID #790 had been removed and taken to the lab for frequency change due to the presence of another sensor in the area on the same frequency. It was given a radio frequency code of 1390, and then reimplanted during the first period of activations of the test. Period of data was 1626Z - 2201Z.

RAINFALL: Moderate rain fell between 1620Z and 1711Z and between 2032Z and 2115Z. The first period was characterized by moderate showers (0.5 inch/hr) interspersed with brief periods of light rain. The second period of rain was somewhat lighter (0.33 inch/hr) and steadier, tapering off gradually at the end. Total accumulation was 3/8 inch. The pattern, except for timing problems, compared favorably from gauge to gauge. Data were available from three gauges.

COMPARISON/CONCLUSIONS: Activations during the first rainfall period clearly depicted the showery nature of the precipitation. Since the individual showers were very brief, the rainfall rates used for comparison were averages rather than instantaneous rates. Considerable variation in sensor count rates occurred even though all sensors were at gain 4. The second period of rainfall presented an interesting case. The rate was high enough that a response should have been expected from all sensors. Yet only ADSIDs #52 and #55 started transmitting when the rain began. Number 55 stopped at the end of the rainfall, but #52 continued on for 25 minutes. The other sensors activated either for only the heaviest portion of the rainfall or not at all. Operator's comments on the X-T plot only referred to light rain during this period, when in fact, rates were as high as .5 inch/hr during part of the period. It was possible that drop size during this period was small, leading to the indications of light rain and low activation rates.

RAINFALL RATES (inches/hour)	SENSOR COUNTS							AVERAGES	
	#1390	#66	#1564	#55	#1450	#1396	#46	ACOUSID	ADSID
0.5	---	4.1	3.8	5.4	5.2	2.3	3.1	3.8	4.2
0.33	1.6	0.5	0.0	4.4	0.6	0.0	0.3	0.5	2.1
0.17	---	2.5	2.0	4.2	3.3	2.0	2.2	2.4	3.0

Combined Comparison Results - Obviously, the size of the data sample and the range of sensitivities of the various sensors do not warrant a sophisticated statistical analysis of the comparisons. Examination of the daily test results indicated that the data should be separated into three categories for analysis: the ADSID and ACOUSID gain 4 data, and all the gain 3 data. The reason for separating the ACOUSID and ADSID data is the apparently shorter response time and therefore higher activation levels of the ACOUSIDs during heavy rainfall. This separation of the data did reduce the size of each sample, but was determined to be necessary. Compilations of average and individual sensor counts were not "pure" data, because the number of sensors for which a comparison was available was different from day to day, and individual sensor rates were not computed for the days through 7 November. Graphs of sensor count vs rainfall rate were plotted, with separate graphs for individual sensor counts and average counts for the gain 4 data (Figures 10 through 14). Some adjustment was made for the heavier rainfall rates to account for the findings previously discussed on saturation rates. Various tables were also prepared, listing and averaging all rainfall rates observed within specified increments of sensor count, and for sensor counts computed within specified increments of rainfall rate, but these did not appear as instructive as the graphs. The large degree of data scatter for the lower rainfall rates may be attributed to several causes. First, the sensors have varying degrees of sensitivity, especially for these lower rates. Second, on the "average" graphs, the averages are for different sensors and different numbers of sensors in each case. Third, other effects, such as thunder, traffic, and wind, were present in varying degrees on different days. Fourth, the rainfall and sensor count rates computed were, because of the showery nature of the precipitation, not instantaneous rates, but rather averages of varying rates over a period of time. Finally, drop sizes may have been different for a given rate, causing different activation rates. Nevertheless, we believe that these graphs, especially the "average" graphs, can be used with a reasonable degree of assurance in analyzing sensor activation levels for rainfall rates.

Sensor Data - Acoustic Returns

All data received from the sensors were recorded on 14-track magnetic tape by the FR 1300 recorders. During the period 21 September - 13 November, the ACOUSIDs were commanded for acoustic data for various intervals. (After 13 November, we determined that continuous seismic monitoring was more valuable, since we were then operating with only one sensor string.) The written comments on the X-T plots indicated when acoustic data were being recorded. A total of 39 reels of tape were used on these tests.

With assistance from personnel of the Audio Distribution System of the "Music Box" Facility at Eglin AFB, selected portions of these magnetic tapes were replayed. An H. P. Sanborn 3900 tape recorder was used, and a time hack (accurate to one second) was displayed on a digital clock for reference to other data.

During the earlier portion of the test, ACOUSIDs were commanded about once a minute. Upon command, the sensor would transmit audio for 19 seconds, then

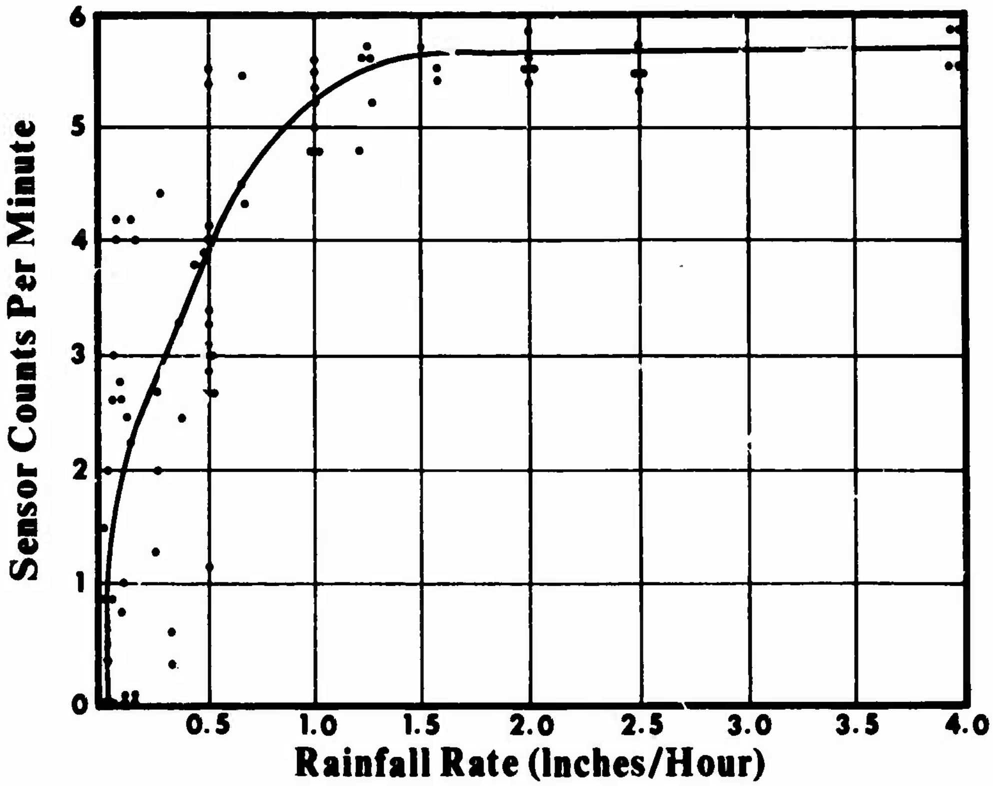

Fig 10. Individual gain 4 ADSID activation rate vs rainfall rate.

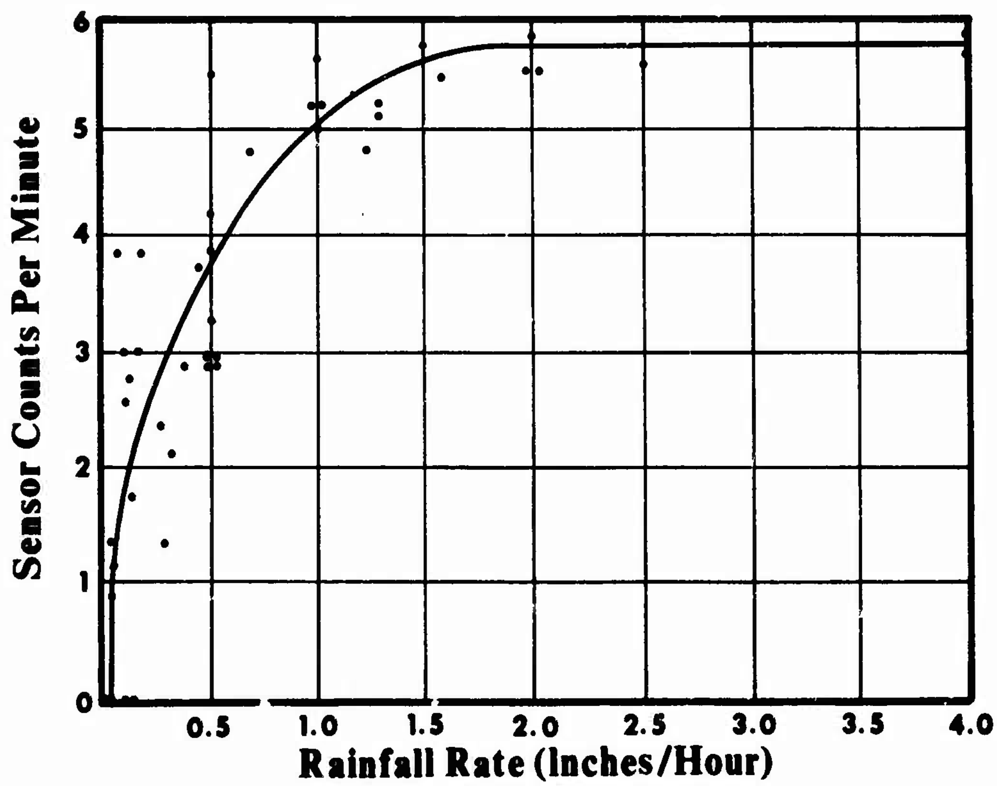

Fig 11. Average gain 4 ADSID activation rate vs rainfall rate.

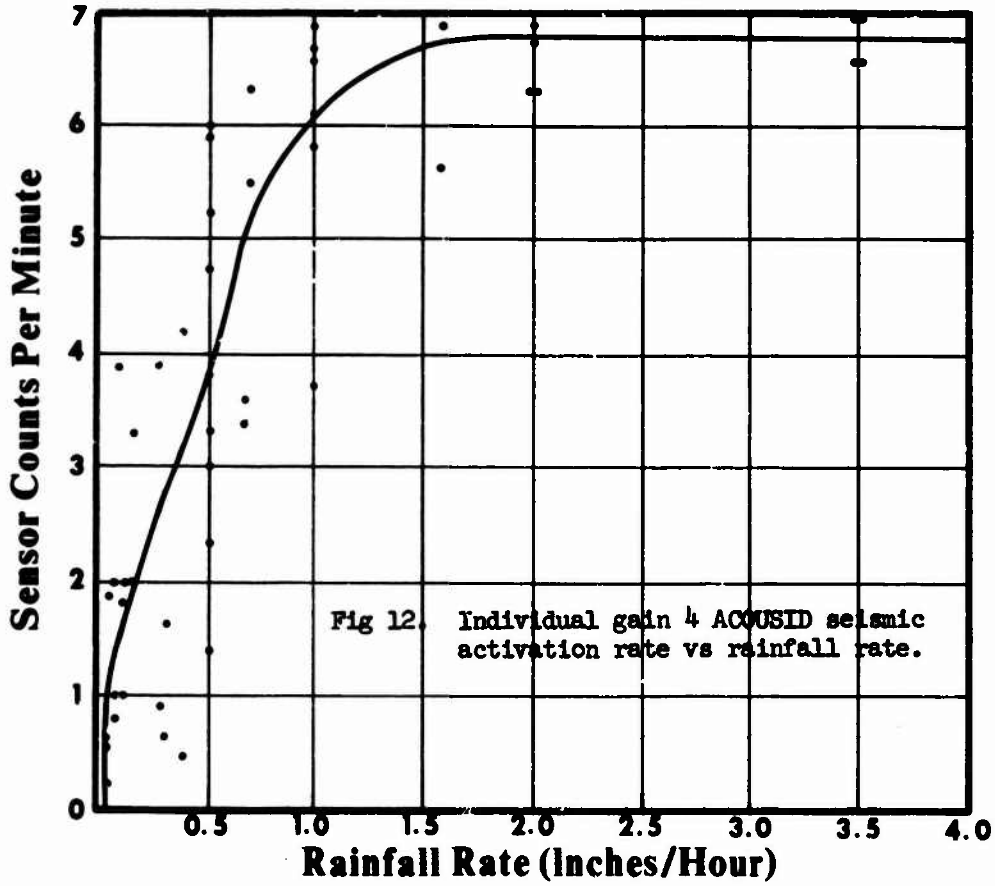

Fig 12. Individual gain 4 ACOUSID seismic activation rate vs rainfall rate.

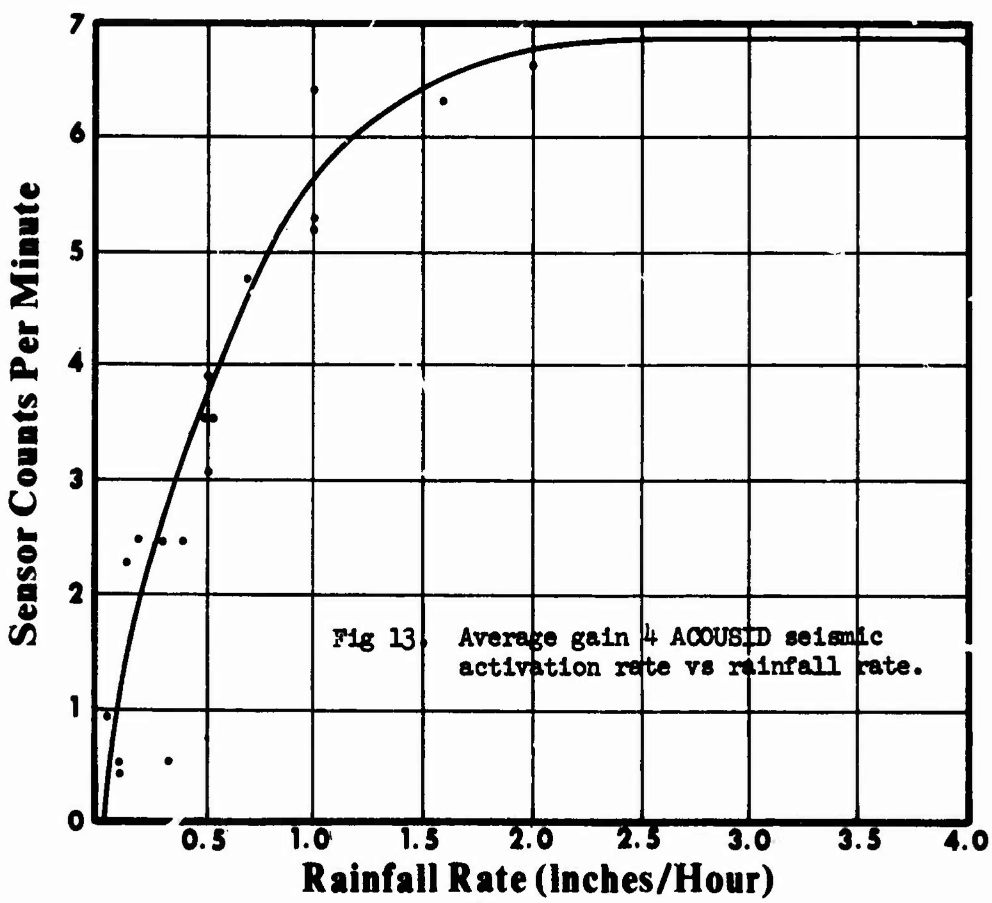

Fig 13. Average gain 4 ACOUSID seismic activation rate vs rainfall rate.

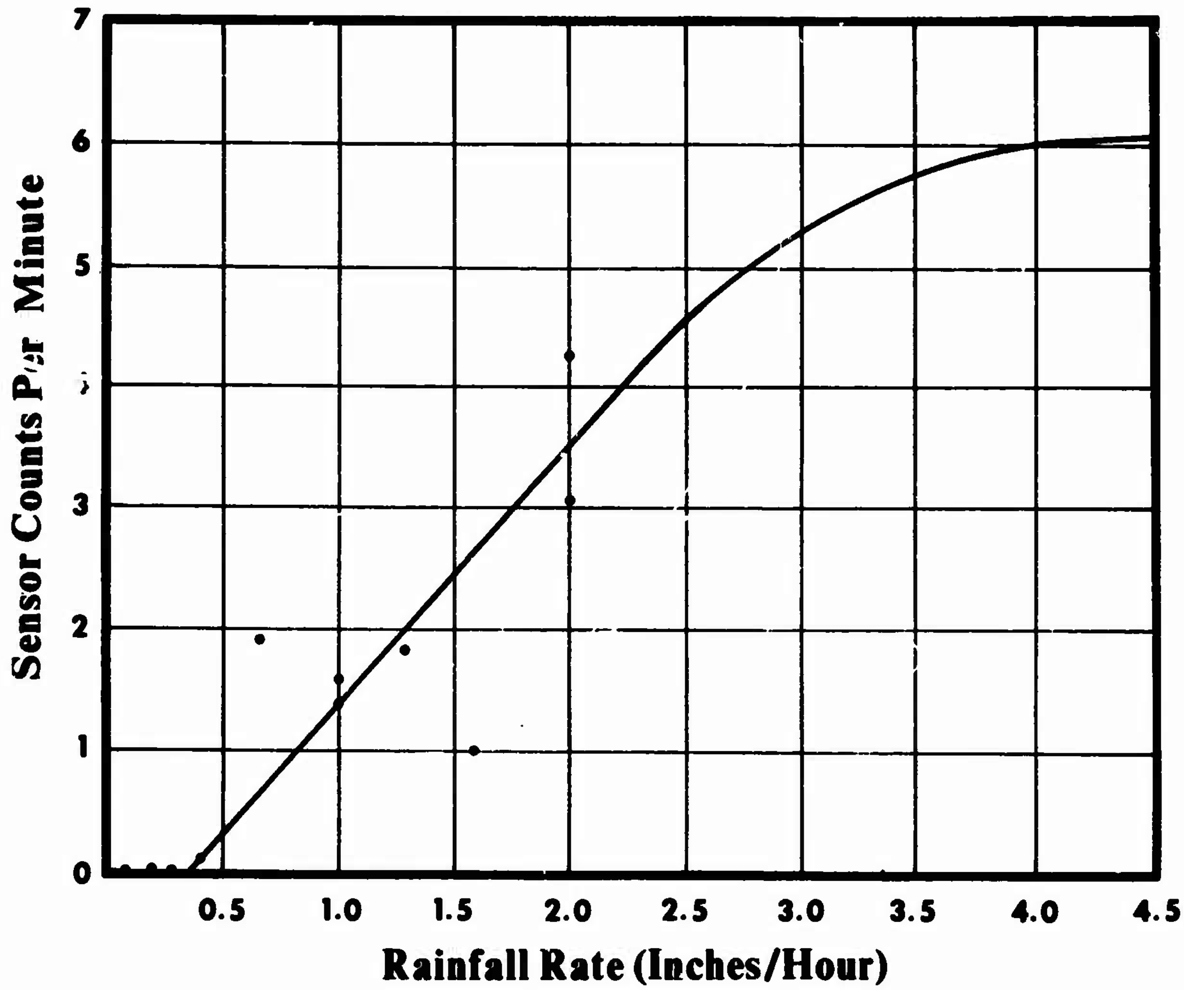

Fig 14. All gain 3 seismic activations vs rainfall rate.

TIME	COMMENTS
2120Z	Start acoustic portion
2121	Very light rain
2121:05	Thunder
2122	Increase to mod rain
2123:25	Thunder
2125	Slight decrease in rain
2127	More decrease
2128:50	Thunder
2129:26	Thunder
2130	Rain decreasing more
2130:28	Thunder
2131	Lots of thunder
2132	Light rain
2132:25	Lots cf thunder
2133:43	Thunder
2134	Very light rain
2135:05	Thunder
2135	Light rain
2137:05	Thunder
2139:33	Increase in rain to mod
2140:25	Thunder
2142:05	Now mod+ rain
2142:45	Heavy rain!
2144	Slight decrease
2145	Heavy to mod+ rain
2146:18	Thunder
2147	To mod, then heavy, then mod; up and down.
2152	Decrease to light rain, then very light rain.

TIME	COMMENTS
2120Z	Start sensor-maybe light rain
2121	Thunder
2122	Light to mod rain
2123	Mod rain
2123:21	Thunder
2126	Rain decrease to light
2127:24	Little thunder
2129:25	Good thunder
2130	Light rain
2131	Thunder - lots
2132	More thunder
2133	Rain almost stopped
2134	Thunder
2135:05	Good thunder
2137	Almost nothing
2140	Increase in rain-light to mod
2140:30	Good Thunder
2141	Down to light rain
2142	Up to mod rain
2143	Heavy rain!
2144	Down to mod+ rain
2146:05	Thunder
2147	Slight dropoff in rain to mod
2149	Slight, then big increase in rain
2151	Down, then up, then down
2152	Light to very light. One short burst up, then down again.

Fig 15. Comparison of acoustic data received from two ACOUSIDs on 10 Nov 1972.

it would be off until commanded again. The noise level during these "silent periods" was so much greater than the actual audio that it became very difficult trying to evaluate the short periods of audio. However, on 26 September, 10 November, and 13 November, the audio commands were sent automatically every twenty seconds. Except for a loud beep every twenty seconds, the returns were continuous audio. Listening to these tapes was not only easier, but also very enlightening. On 26 September, the ADSIDs had been reporting some activations, yet no rain was in the area. By listening to the acoustic data, we could hear some traffic, both air and ground, occasional thunder, and some birds in the background. Nearby thunder completely saturated the ACOUSID response. On 10 November, there were over thirty minutes of continuous audio during a large thunderstorm with various rainfall rates. Figure 15 is a log of the data heard from two of the ACOUSIDs. On 13 November, there were numerous short sections of continuous audio, but the rainfall was not as variable. We had hoped to determine from the audio reports the reason for the high level of seismic activations in the absence of rainfall. Considerable thunder was heard throughout the period. Wind could not be detected in the audio signal. Only two ACOUSIDs were transmitting during the first rainfall period. The sounds from the two were similar, except that one was more sensitive. During the second rainfall period, one ACOUSID failed while the other was operating intermittently. Considerable thunder was still heard during the usable audio periods. We listened to the channel which recorded the COMMIKE signal on several of the tapes. We heard nothing but noise on any of the samples checked.

It was apparent from listening to the ACOUSIDs and from the logs that rainfall rates at the different sensors within a string changed at about the same time. This contrasted sharply to the 10 to 15 minute variations between the much more primitive rain gauge indications. Also, the changes in rain intensity heard in the audio signal corresponded very well in time to the changes in level of seismic activations. This was valuable in analyzing the data for 10 November, when seismic activation levels remained high during light or no rain periods because of thunder. We could see no way of quantitatively adjusting the seismic count during rainfall periods for activations caused by other phenomena, such as thunder, so these periods were excluded in the comparisons.

A video display of the audio returns for selected test periods was made on an H. P. Sanborn 7702 strip chart recorder for ACOUSIDs #970 and #1564 on 10 November. A portion from #970 is shown in Figure 16. A time hack was placed on the chart every minute. By comparing the width of the trace, one can readily see the changes in rainfall intensity. Also evident on the chart are the 19-second "beeps" and the response from thunder. Thunder caused the recorder pens to impact on both ends of the scale, frequently damaging the pens. By reducing the gain on the recorder, the responses from thunder could be kept within range, but the rainfall detail was lost. These strip charts were useful as an aid in separating the seismic activations due to thunder from those caused by rainfall. However, if the activations which occurred from thunder were removed from the seismic count, it still could not be determined whether rainfall would have triggered the

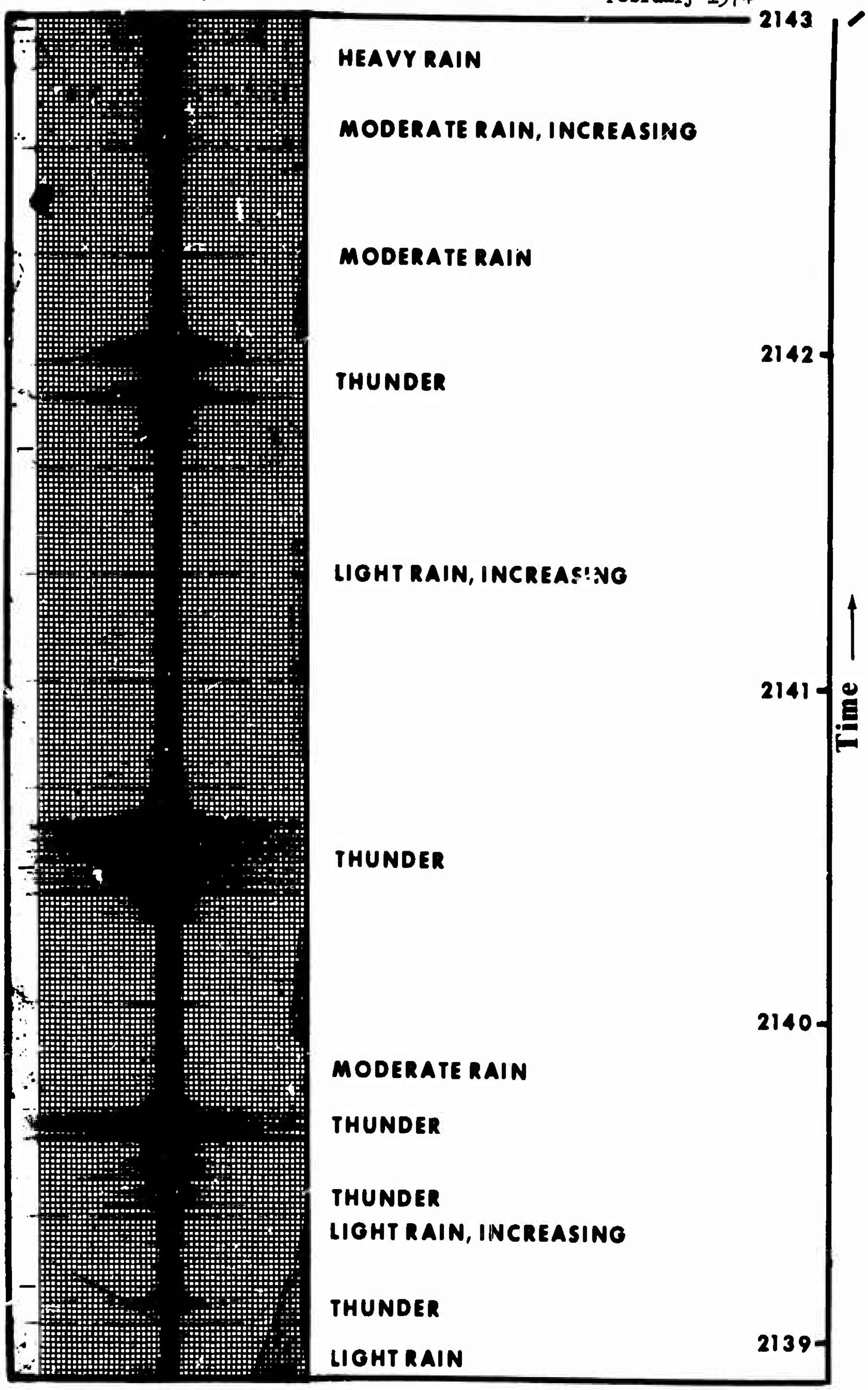

Fig 16. Visual display of portion of acoustic data from 10 Nov 72.

ADSID during the same response period. Selected portions of the acoustic data were recorded on a 1/4 inch magnetic tape at $7\frac{1}{2}$ IPS. The same signal was recorded on two channels.

After 25 November, no acoustic data were collected, because we had sufficient audio data for reproduction purposes and wanted to test the ACOUSIDs in the pure seismic role. No seismic data could be obtained for the ACOUSIDs while they were in continuous audio command. During the earlier parts of the test series, when the ACOUSIDs were commanded once per minute, the seismic count could not be used in analysis because of the 19-second period of each minute when counts were not available. In an operational situation, when weather personnel were monitoring the sensor operation in real time, the audio command would probably be used as a brief check on the seismic returns, without significantly affecting the value of the seismic data.

CONCLUSIONS

1. Seismic activation rates from intrusion sensors can be used to infer rainfall rates with some degree of confidence.

2. Sensors "saturate," that is, activate at a maximum rate when certain rainfall rates are exceeded.

3. There is a lower threshold value of rainfall rates below which sensors do not activate.

4. Gain settings strongly affect the sensor activation rates in rainfall, the lower threshold, and the rainfall rate at which they saturate.

5. Sensors with the same gain setting have different sensitivities to rainfall, especially for lower rainfall rates.

6. Acoustic sensor returns are invaluable aids in interpreting seismic returns.

7. Insufficient data were collected to determine the effects of different types of vegetation on rainfall sensor activations.

8. Seismic sensors are very responsive to thunder, especially nearby thunder. No definite conclusions could be reached on the effect of wind.

9. If seismic sensors are to be used to obtain estimates of intense rainfall, gain settings of 4 and 3 should be used to increase the spectrum of rainfall rates which can be inferred.

10. Because of the data processing capability needed for recovery of rainfall estimates, the use of intrusion sensors to obtain rainfall estimates should be done in conjunction with routine sensor intelligence operations.

RECOMMENDATIONS

1. Although noise levels may obscure the rainfall returns, it would be worthwhile to evaluate sensors with gain settings of 5 and 6 to more accurately estimate lower rainfall rates.

2. If more accurate rainfall comparisons are needed, a controlled experiment with a wider variety of rainfall rates, less variability of rainfall rate occurrences, and accurate rainfall rate and drop size measurements is recommended.

3. Before any operational program of sensor rainfall analysis is begun, the sensors to be used must be evaluated carefully because of variations in sensor types and modifications in design and capabilities.