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FORECASTING FLOODS IN HAWAII (EXCLUDING HAWAII ISLAND)

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noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / National Weather Service

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No. 5 A Computer Method to Generate and Plot Streamlines. Roger A. Davis. February 1969. (PB-183-622)

No. 6 Verification of an Objective Method to Forecast Frontal Passages in the Hawaiian Islands. E. M. Carlstead. September 1969.

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- Continued on inside back cover -

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TABLE OF CONTENTS

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I. SEVERE WEATHER EVENTS IN HAWAII

As background for forecasting Hawaiian floods, severe weather events listed in Storm Data are summarized. Table 1 (Annual Frequencies of Severe Weather Events for 1965-1975) and Figure 1 (Yearly Occurrencies of Severe Weather Events for 1965-1975) show: (1) Funnel clouds are the most frequent event with an annual median of nine. However, most of these funnels do not reach the ground and waterspout-tornado damages are not common. The reason for the greater number of funnel clouds after 1970 is better recording of the reports after 1970. (2) Floods, with an annual median of four, is the next frequent event; 1965, 1967, and 1968 were the peak flood years and the first two years--1965 and 1967--recorded more than twice the number of other years, excluding 1968. (3) All high seas incidents may not have been recorded in the earlier years and the annual median is only one. (4) High wind, with an annual median of two, has not occurred as often in the last three years as in the past. (5) Lightning and hail damages are rare events.

Table 2 (Monthly Frequencies of Severe Weather Events for 1965-1975) and Figure 2 (Monthly Occurrencies of Severe Weather Events for 1965-1975) show: (1) A definite seasonal variation of the events--winter (October through April) being the active season. (2) In general, there are three peaks in severe weather events--January, April, and November. (3) Southern Hemisphere storm-caused southerly swells striking Hawaii and swells from tropical cyclones account for high seas occurrencies in June, July, and August.

II. OBJECTIVE OF STUDY

"Flash flooding is the most frequent and serious weather-related threat to life and property in Hawaii. The objective of the flash flood warning service is to provide threatened areas with as much alerting and warning time as possible." This quote, taken from the Regional Operations Manual Letter P-20-75 (E-13), National Weather Service Pacific Region, describes the aim of this paper.

With continued growth of Hawaii, past intense rains that were not damaging in sparsely populated areas could cause a disaster today because of the widespread urbanization of residential and tourist areas, especially on Oahu. There is now, more than ever, the need to meet the objective of the Hawaii flood warning program.

III. METEOROLOGICAL AND HYDROLOGICAL STUDIES IN HAWAII

Meteorological aspects of Hawaiian weather have been studied, especially in the late 1940's and early 1950's, by various researchers in the program sponsored by the U. S. Weather Bureau, Pineapple Research Institute, Hawaiian Sugar Planters' Association and, more recently, by University of Hawaii researchers. The Water Resources Research Center at the University of Hawaii has published, within the past 10 years, some excellent Hawaii flood hydrology studies by the University of Hawaii scientists. The list of the publications is in the Reference section at the end of this paper.

Except for an excellent objective method by David Smith (based on previous work by I-Pai Wu) relating the half-hour rainfall amounts and duration to flooding or no flooding on Oahu drainage basins, no other useful flood forecasting method has been proposed to date. The reasons for the lack of any comprehensive flood forecasting study are the difficulty of the problem and the lack of verifying and supporting data prior to about 1965.

IV. THE PROBLEM

A flood is not a flood until it happens. This is the crux of the forecast problem. The possibility of heavy rain quite frequently poses a threat to Hawaii but in most cases the expected downpour does not materialize or is not as heavy as anticipated. However, when the heavy intense rain occurs, the lead time to onset of flooding after the intense rain begins is very short--typically an hour to upwards of four hours in almost all basins in Hawaii. How can one forecast these "short-fused," highly localized, events? This is the challenge.

V. RECENT FORECAST AIDS

More tools are now available: Hourly satellite pictures from the Satellite Field Service Station (SFSS) at Honolulu International Airport; telemetered rain gages on all islands, especially concentrated on Oahu; better and more timely radar reports from Kokee and Mt. Kaala National Guard radar units; improved computer forecasts for the Hawaiian area from FWC, Pearl Harbor; and better critical weather observations by the radio operators in the Oahu Civil Defense system.

VI. SCOPE OF STUDY

The floods from 1965 to the present (October 1976) were studied and the 11 most severe floods in respect to fatalities, monetary loss and areal extent were selected for detailed investigation. Observations of lightning and thunderstorms and short period intense rainfall were related to most floods since 1965. Data were insufficient for these studies prior to 1965. Hawaii Island floods were not included because of the different nature of the storms on that island; these floods may be analyzed at a later date.

VII. DATA SUMMARIZATION

A. Location Number (Table 3, column 1). The location numbers were used to identify the 11 floods in Figure 3.

B. Year-Month-Day (Table 3, column 2). The severe floods average one a year but 1965 and 1968 experienced more than one, while 1966, 1970, 1972 and 1973 had none. These serious floods occurred during the winter months--late November through early May.

C. Location (Table 3, column 3). Most of the floods were localized as seen in Figure 3, which outlines the flood areas. There is a good relationship between the location of flooding and the low level (surface to 5,000 feet) easterlies and the deep (surface to 35,000 feet) southwesterlies. On Oahu, low level easterlies were associated with the five floods over the windward side and area just leeward of the Koolaus, while deep southwesterlies preceded the flooding at Makaha and leeward southeast Oahu, both normally the dry areas of the island. A similar relationship occurred on Maui where windward Hana's flood occurred with low level easterlies and the flood in the central valley, normally a dry area, was preceded by deep southwesterlies. This relationship suggests that flooding in the normally dry leeward areas of the islands is preceded by deep southwesterlies, while windward and lee areas close to the windward mountain have flooding preceded by low level easterlies.

The floods in the normally dry leeward areas are caused by thunderstorms embedded in the deep southwesterlies moving inland in a line, dumping copious rain in several hours.

The floods on the windward side and just to the lee of the windward mountains are more difficult to explain. The hypothesis is that low level easterlies aid in the ascent of moist air up the windward mountain slopes into the thunderstorm that move in or develop over the mountain so there is a continuous supply of moisture from below which may result in "anchoring" the thunderstorm cells over the mountain long enough to dump intense rain for the few hours necessary for flooding.

The two Kauai floods were not localized as on Oahu and Maui and were associated with southerly component low level wind flow. The somewhat conical shape of the island and its northernmost location in the island chain may be the reasons for the greater areal extent of the flooding on Kauai.

D. Damage and Deaths (Table 3, column 4). Damages ranged from $310,000 to $3,300,000 (mean near $1,000,000) with the greater damages occurring on Oahu where most of the population lives. Except for the first Keapuka, Oahu, flood on February 4, 1965 and flood of April 19, 1974 on Kauai and Oahu where two and five fatalities occurred, respectively, there were no other fatalities.

E. Flood Time (Table 3, column 5). Except for the second Keapuka flood on February 1, 1969 and the January 31, 1975 Kauai flood which both began near noon, all of the other nine floods began during hours of darkness. This is not mere coincidence. The hypothesis is that thunderstorms that move inland or develop over land at night are aided by radiational cooling of their tops for stronger convective activity which results in heavier and longer rain downpour than in thunderstorms unaided by nighttime radiational cooling. Thus, the severest floods start at night. This fact should be be considered in planning for effective dissemination of flood WATCHES and WARNINGS.

F. Lightning and Thunderstorm Observations at Honolulu International Airport (Table 3, column 6). In the seven Oahu floods, except the second Keapuka flood that began near noon on February 1, 1969, lightning preceded flooding by about six hours, on the average. This compares to thunderstorm observations with an average lead time of about five hours in four out of the seven Oahu floods. This suggests that lightning and thunder observations are good indicators of impending flooding and also that lightning may be a better indicator than thunder because most of the floods occur during darkness when it is easier to see lightning than hear thunder.

The average of six days of observed thunderstorms per year (excluding thunderstorms on the second and consecutive following days and summer daytime thunderstorms) at Honolulu International Airport during 1965-October 1976 related to the average of two floods per year on Oahu. Out of a total of 76 thunderstorm days in this period, 14 were associated with flooding on Oahu. This implies a probability of about 20% flooding on Oahu with occurrence of thunderstorm at the airport.

All of the above relationships suggest that observations of lightning and thunder moving inland or over land are valid criteria for issuing flood WATCHES.

G. Stream Gages (Table 3, column 7). Stream height and discharge in most cases were at maximums for each of the 11 floods.

H. Lihue Soundings (Figure 4). The following were noted in the soundings taken at Lihue, Kauai, about five to 19 hours (median 12 hours) prior to the 11 floods:

1. Low level easterlies (surface to at least 5,000 feet) were present in six out of the 11 cases.

2. Deep southwesterlies occurred in three other cases.

3. Except for the February 1/12Z 1969 sounding, all soundings indicated a trough to the west of Lihue at some level in the layer between 700 mb and 250 mb.

4. The temperature and height were generally colder and lower in the layer between 700 mb and 250 mb. Table 4 presents the summarization of the freezing level, stability index and the temperature and the height of the 700 mb, 500 mb, and 300 mb levels.

I. Rainfall Intensity (Table 5). Rainfall data were available for all floods except the Keapuka flood of February 4, 1965. Rainfall charts recorded the intensity at or near each flood site. The hourly rainfall prior to and after onset of flooding and the total storm rainfall are presented. Because the time of onset of flooding is not exactly known and some of the gages are not located upstream of the flood, rainfall to two hours after the noted flood time is considered flood-causing. In nine flood cases with continuous rainfall data, the following were noted:

1. Rainfall near one inch/hour fell seven to two hours before noted flood time with the median three hours prior to flooding.

2. Rainfall near two inches/hour fell four to one hour before noted flood time with the median two hours prior to flooding.

3. Flood-causing rainfall ranged from four to 13 inches in the period four hours prior to and two hours after noted flood time.

4. Total storm rainfall ranged from 5.9 to 22.1 inches with a median of 15.75 inches.

From the above, the following can be concluded: (1) Intense rain is a necessary prerequisite for flooding, (2) lead time is very short between beginning of intense rain and flooding, and (3) total storm rainfall is great.

VIII. FLOOD PRONE AREAS (FIGURES 5 AND 6).

Flood prone areas on Kauai, Oahu and Maui, taken from U. S. Geological Survey's quadrangle maps, are localized in the coastal drainage basins of each island and are only a small percent of the total land area.

IX. TELEMETERED RAIN GAGES (FIGURES 5 AND 6).

Telemetered rain gages are located on each island with the majority concentrated on Oahu.

X. RAINFALL AMOUNTS OF 5-YEAR FLOOD (80% PROBABILITY) (TABLE 6).

The rainfall amounts for the first 1/2 hour, first one hour and first two hours related to the 5-year flood (80% probability) were taken from the frequency analysis of annual peak discharge in the papers by Wu and Smith. For the 15 streams on Oahu, the median critical rainfall amount for the first 1/2 hour is 1.3 inches, first one hour is 1.8 inches, and first two hours is 2.8 inches.

To test these critical rainfall values, the maximum precipitation of 1/2, one, and two hours for the period 1950-1970 at Honolulu International Airport was reviewed. There were only 10 days with 1/2, one, or two hours rainfall that equalled or exceeded the critical values. Thunderstorms were observed on nine out of these 10 days and seven floods (six major and one minor) occurred on these 10 intense thunderstorm rain days.

XI. EXAMPLE IN ISSUING ALERT, WATCH, AND WARNING.

To help the reader visualize the procedure and available tools employed in issuing timely ALERT, WATCH and WARNING as objectively as possible, the sequence of events associated with the April 19, 1974 Haleiwa and Moanalua, Oahu, flood is presented. The flood began about 9:00 a.m. on Oahu.

A. Satellite picture about 24 hours before flood (Figure 7). Overcast clouds with possible embedded thunderstorms are seen over large areas west of Oahu. Presence of thunderstorms is not certain so no ALERT issued to State and County Civil Defense agencies and WSOs. Called Kokee radar unit and asked for radar report for area west and northwest of Kauai. NESS forecaster asked to determine whether thunderstorms exist in overcast cirrus.

B. FWC Pearl's 500-mb 36-hour prognosis about 24 hours before flood. Closed low center in trough is forecast to be over Hawaii.

C. 500-mb map about 18 hours before flood (Figure 8). Deep trough just west of islands is a good clue for possible heavy rain in the state.

D. Other maps about 18 hours before flood. Surface and 700-mb maps show normal trade wind flow. The 250-mb map shows shallow trough west of islands.

E. Lihue's sounding about 18 hours before flood. Freezing level lowered to 11,800 feet and 700-mb and 500-mb temperatures and heights are also lowering. A 500-mb trough is located west of Lihue.

F. Kokee radar report about 15 hours before flood. Isolated buildups (tops unknown, movement unknown) 100 miles northwest of Kauai. Hourly radar reports requested from Mt. Kaala and Kokee radar units. Flood ALERT for State called to Civil Defense agencies and WSOs.

G. Satellite picture about 12 hours before flood (Figure 9). Line of thunderstorms is seen just northwest of Kauai. WATCH issued for Kauai after Kokee radar and Kauai radio operators (critical weather observers) confirm thunderstorms within 50 miles of Kauai. Equipment operator requested to query telemetered rain gages on Kauai hourly.

H. Lightning and thunder reported on Oahu about 10 hours before flood. Radio operators report lightning and thunder approaching Oahu from north. WATCH issued for Oahu. Equipment operator requested to query telemetered rain gages on Oahu hourly.

I. Kokee radar report about five hours before flood (Figure 10). Three lines of thunderstorms are seen over Kauai, in Kauai Channel and just north of Oahu moving toward the south. Flood WARNING issued for Kauai.

J. About four hours before flood. Heavy thunderstorm rain at Kokee radar site reported by radio operator and telemetered rain gage at Powerhouse Wainiha, Kauai, recorded .45 inch in 1/2 hour.

K. About three hours before flood. Mt. Kaala radar reports thunderstorms over northern Oahu and telemetered rain gage at Opaeula, Oahu, recorded 1.85 inches in an hour. Flood WARNING issued for Oahu.

XII. SUMMARY OF STUDY.

A. There is, on the average, one severe localized flood a year. They occur mainly on Oahu, at night, from late November through early May.

B. Flood damage averages about $1 million and damage amounts are increasing yearly mainly because of more property construction and inflation. Fatalities are not common.

C. A 500-mb trough is usually present west of the islands before flooding.

D. On Oahu and Maui, flood associated with low level easterlies occurred on windward side or just lee of windward mountain while flood preceded by deep southwesterlies occurred in the normally dry leeward area.

E. On Kauai, flooding is not as localized as on Oahu and Maui.

F. Lightning and thunder observations are good indicators of possible flooding. There is about a 20% probability of flooding after lightning or thunder is observed over land--especially at night.

G. In the severe floods of this study, the rainfall for 1/2, one, and two hours prior to flooding exceeded the critical rainfall values of 1.3, 1.8, and 2.8 inches, respectively.

H. Time is very short between beginning of intense rain and onset of flooding--usually from one to four hours.

I. An objective flood forecast method is needed.

XIII. AN OBJECTIVE FLOOD FORECASTING METHOD.

The conditions in the check lists for issuing ALERT, WATCH, WARNING and DRAINAGE STATEMENT which follow were selected from this study. Conditions identified by an asterisk (*) are necessary prerequisites for flooding and are more important than the other conditions.

CHECKLIST FOR ISSUING FLOOD ALERT, WATCH, WARNING AND DRAINAGE STATEMENT FOR KAUAI, OAHU, MAUI, MOLOKAI AND LANAI

I. Issue ALERT 24 to 12 hours before flood, if most or all of the following are met. (place most emphasis on factors marked with *)

			YES	NO
1. October through April.				
2. 700-250 mb maps: low or upper trough within 300 miles west of State and moving towards State.				
3. Latest Lihue's rawindsonde report: values are approaching those listed below:	TEMP	HEIGHT		
700 mb	3C	3100m		
500 mb	-11C	5770m		
300 mb	-37C	9500m		
Freezing level lowering to 12,000 feet.				
Inversion high, weak or not present.				
4. FWC's 500 mb 36-hour prog: low or trough closer to State.				
*5. Satellite pictures: extensive area of overcast clouds with possible embedded thunderstorms within 100 miles NW, W, or SW of State moving toward State.				
*6. Radar reports: line or area of thunderstorms within 100 miles NW, W, SW of State moving towards State.				

* most important factor.

ALERT criteria met:____________________
(month/year)

Offices called: State Civil Defense_______________
(date/time)

Oahu Civil Defense__________ (date/time)

WSO Lihue (ask them to pass to Kauai CD)__________ (date/time)

WSO Kahului (ask them to pass to Maui CD)__________ (date/time)

WSO Hilo (ask them to pass to Hawaii CD)__________ (date/time)

II. Issue WATCH 18 to 6 hours before flood, if most or all of the following criteria are met. (place most emphasis on factors marked *)

			YES	NO
1. ALERT: all or most of its criteria are met.				
2. Latest lihue's rawindsonde report: values are approaching those listed below:	TEMP	HEIGHT		
700 mb	3C	3100m		
500 mb	-11C	5770m		
300 mb	-37C	9500m		
Freezing level lowering to 12,000 feet.				
Inversion high, weak, or not present.				
3. 500 mb, layer 700-250 mb: trough or low west or over State.				
4. FWC's 500 mb 36-hour prog: low or trough very close or over State.				
*5. Satellite picture: extensive area of overcast clouds with embedded thunderstorms within 50 miles NW, W, SW of State moving toward State.				
*6. Radar reports: line or area of thunderstorms within 50 miles NW, W, SW of State moving towards State.				
*7. Pireps: line or area of thunderstorms within 50 miles NW,W, SW of State.				
*8. Observer reports: lightning or thunder.				

* most important factor.

WATCH criteria met:____________________
(month/year date/time)

III. Issue WARNING 4 to 0 hours before flood, if most or all of the following criteria are met. (place most emphasis on factors marked *)

			YES	NO
1. ALERT: all or most of its criteria met.				
2. WATCH: all or most of its criterai met.				
3. Latest Lihue's rawindsonde report: values are approaching those listed below:	TEMP	HEIGHT		
700 mb	3C	3100m		
500 mb	-11C	5770m		
300 mb	-37C	9500m		
Freezing level lowering to 12,000 feet.				
Inversion high, weak, or not present.				
4. 500 mb or layer 700-250 mb: low or trough west or very close or over State.				
5. FWC's 500 mb 36-hour prog: low or trough very close or over State.				
*6. Satellite picture: extensive area of overcast clouds with embedded thunderstorms over State.				
*7. Radar report: thunderstorms over State.				
*8. Station report: thunderstorm.				
*9. Pirep: thunderstorm over State.				
*10. Police, Civil Defense, observer: thunderstorm, intense rain.				
*11. Telemetered rain gage: amount approaching 1 inch in 1st ½ hr or approaching 2 inches in 1st hour.				
*12. Flash flood reported.				

* most important factor.

WARNING criteria met:________________________
(month/year date/time)

IV. Issue DRAINAGE FLOOD STATEMENT 4 to 0 hours before minor street or low-lying area flooding

	YES	NO
1. month: any month but mainly October through April.		
2. 700-250 mb layer: low or trough very close to State.		
3. Satellite picture: extensive area of overcast clouds over State or island.		
4. Station report: overcast layered clouds, no lightning or thunder, steady rain.		
5. Radar report: area of overcast clouds with isolated buildups but no thunderstorms.		
*6. Police, Civil Defense, observers, public: steady rain and minor street or area flooding.		
7. Telemetered rain gage: steady rain less than 1 inch in an hour and not approaching flash flood criteria.		

* most important factor.

DRAINAGE FLOOD STATEMENT criteria met: ______________________
(month/year day/time)

Table 1. Annual Frequencies of Severe Weather Events for 1965-1975

	Minimum	Median	Maximum
*Funnel clouds	3	9	31
Flood	1	4	11
Strong winds	0	2	6
*High seas	0	1	13
Lightning, hail	0	1	3

*Funnel cloud: funnel aloft, waterspout, tornado, dust devil

*High seas: surf, swell, wave, surge

Table 2. Monthly Frequencies of Severe Weather Events for 1965-1975

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Funnel cloud	Minimum	0	0	0	0	0	0	0	0	0	0	0	0
	Median	0	0	0	2	1	0	0	0	1	1	1	1
	Maximum	7	4	5	5	6	3	2	2	3	4	3	4
Flood	Minimum	0	0	0	0	0	0	0	0	0	0	0	0
	Median	0	0	0	0	0	0	0	0	0	0	1	0
	Maximum	3	2	2	4	2	0	1	1	1	2	2	2
Strong winds	Minimum	0	0	0	0	0	0	0	0	0	0	0	0
	Median	0	0	0	0	0	0	0	0	0	0	0	0
	Maximum	2	1	0	1	0	0	0	0	0	0	2	3
High seas	Minimum	0	0	0	0	0	0	0	0	0	0	0	0
	Median	0	0	0	0	0	0	0	0	0	0	0	0
	Maximum	1	2	1	2	1	1	2	2	0	1	5	1
Lightning, hail	Minimum	0	0	0	0	0	0	0	0	0	0	0	0
	Median	0	0	0	0	0	0	0	0	0	0	0	0
	Maximum	1	1	1	1	0	0	1	0	1	2	3	0

Table 3. Data Summarization

1 Location Number	2 Yr Mo Day	3 Location	4 Damage/Death	5 Flood Time	6 Lightning/Thunder (time)		7 Stream Gage Location	yr began	peak ht (ft) rank p. discharge (CFS)
1	65 Feb 4	Keapuka, Oahu	$1 mil/2	4/3AM	3/1025PM	4/615AM	Kamooalii	1958	8.48' 2nd 6,190CFS 2nd
2	65 May 2	Kahaluu, Oahu	$1 mil/0	2/8AM	1/655PM	2/1016AM	Ahuimanu	1963	11.64' 3rd 6,610CFS 3rd
3	67 Dec 18	SE Oahu	$.9 mil/0	18/3AM	17/855PM	17/1034PM	Wailupe Gulch	1958	5.72' 2nd 3,600CFS 1st
4	68 Jan 5	Pearl City, Oahu	$1.2 mil/o	5/330AM	4/701PM	4/850PM	Waiawa	1953	20.56' 1st 23.400CFS1st
5	68 Apr 15	Hana, Maui	$.31 mil/0	15/10PM	none	none	Kawaipapa Gulch	1965	10.35' 1st 13,400CFS1st
6	68 Nov 30	Kauai	$.4 mil/0	30/1130PM	none	none	Kapaa	1962	17.08' 1st 12,800CFS1st
7	69 Feb 1	Keapuka, Oahu	$.436mil/0	1/1230PM	none	none	Kamooalii	1958	10.16' 1st 12,000CFS1st
8	71 Jan 28	Central Maui	$.591mil/0	28/7AM	27/1130PM	28/156AM	Kulanihako Gulch	1963	9.4' 1st 4,460CFS 1st
9	74 Apr 19	Haleiwa,Moana-lua, Oahu.Kauai	$3.3mil/5	19/9AM	18/1115PM	18/1115PM	Helemano	1968	22.5' 1st 18,200CFS1st
10	75 Jan 31	Kauai	$.531mil/0	31/1PM	31/909AM	none	S. Fork Wailua	1914	20.21' 2nd 42,500CFS3rd
11	76 Feb 7	Makaha, Oahu	$.782mil/0	7/7AM	7/355AM	none	Makaha	1966	16.4' 1st 4,310CFS 1st

Table 4. Summarization of Lihue's Soundings

	Minimum	Median	Maximum
Freezing Level (ft)	8400	11900	13800
Total Total Index	38	42	52
700 mb Temp (°C)	-4.7	3.4	8.0
HT (m)	3009	3113	3145
500 mb Temp (°C)	-18.4	-11.5	-8.2
HT (m)	5667	5776	5833
300 mb Temp (°C)	-43.2	-36.6	-34.7
HT (m)	9302	9499	9578

Table 5. Hourly Rainfall (inches) Before and After Flood Time

Yr Mo Day	Gage Location	8-7	7-6	6-5	5-4	4-3	3-2	2-1	1-0	Flood Time	0-1	1-2	2-3	Total Storm Rainfall
		Hourly Interval												
65 May 2	Waiahole							1.75		8AM	2.75	4.25		——
67 Dec 18	Kaalakei						.80	1.95	1.70	3AM	2.00	.85	.90	8.20
68 Jan 5	Pearl City Terrace		.95	1.15	.64	0	0	2.20	1.80	3:30AM				6.75
68 Apr 15	Hana			.25	.15	.20	.95	1.15	2.30	10PM	3.90	.40	1.70 overflow	17.57overflow
68 Nov 30	Kapaa Stables	.50	.20	0	.25	.85	1.70	2.20	1 overflow	11:30PM				15.75overflow
69 Feb 1	Kamooalii Stream	.5	.4	.3	.2	.8	.4	2.4	3.0	1PM	2.0	4.5	.8	16.0
71 Jan 28	Kihei				.36	.09	.45	.90	1.85	7AM	1.65	.60		5.90
74 Apr 19	Helemano Intake					2.35	1.95	2.40	4 overflow	9AM				22.10
75 Jan 31	Kilauea				.26	.30	.38	.93	2.98	1PM	1.35	.67		7.00
76 Feb 7	Makaha Stream			.8	1.2	.6	.4	.2	2.0	7AM	2.2	.2	.4	18.0

Table 6. Rainfall Amounts of 5-Year Flood (80% probability)

Stream	First ½ Hour	First 1 Hour	First 2 Hours
1. Kamananui	1.5 inches	2.1 inches	3.4 inches
2. Opaeula	1.3	1.8	3.0
3. Makaha	.7	1.0	2.1
4. Punaluu	1.3	1.8	3.0
5. N. Fork Kaukonahua	1.7	2.7	4.2
6. Waihee	.8	1.3	2.4
7. Ahuimanu	1.0	1.4	2.4
8. Haiku	1.7	2.2	3.8
9. Wailupe	1.1	1.4	2.6
10. Waiomao	.6	1.1	2.0
11. Nuuanu	1.1	1.6	2.6
12. Kalihi	1.5	2.2	3.8
13. Moanalua	1.3	1.9	3.4
14. Halawa	1.2	1.7	2.8
15. Waimalu	1.4	1.9	3.2

Figure 1. Yearly Occurrences of Severe Weather Events for 1965-1975

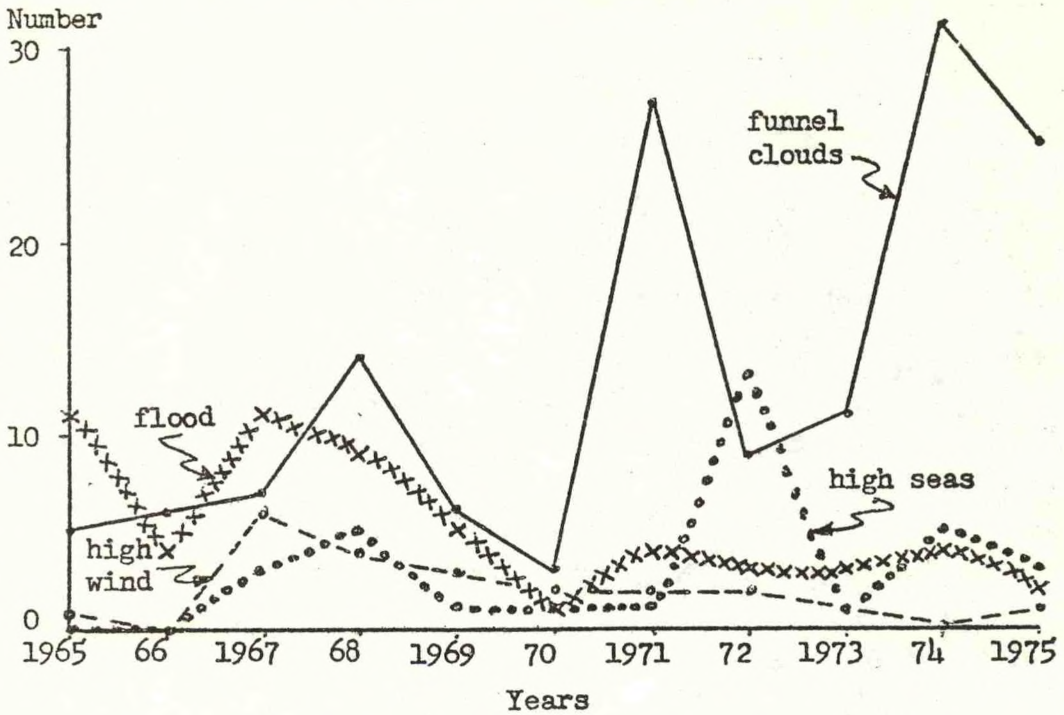


Figure 2. Monthly Occurrences of Severe Weather Events for 1965-1975

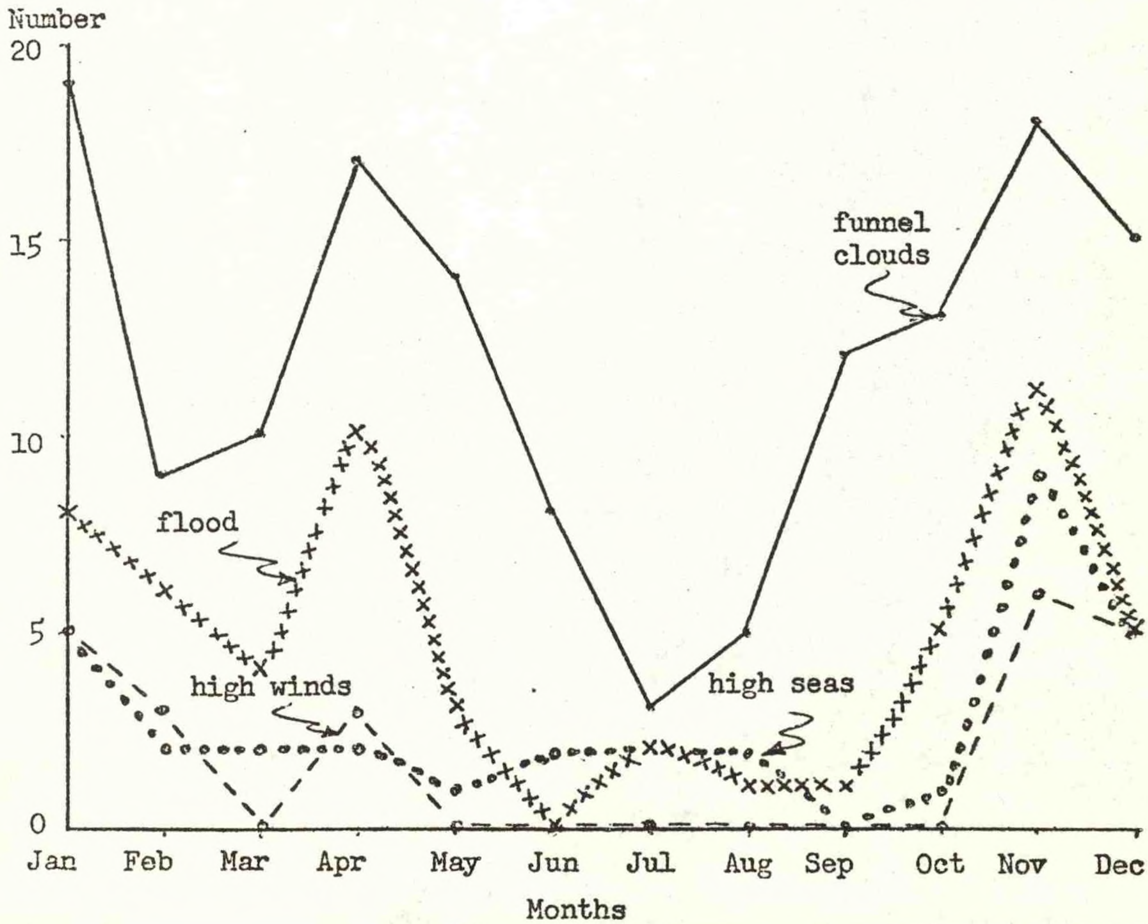


Figure 3. Location and Location Numbers of Floods

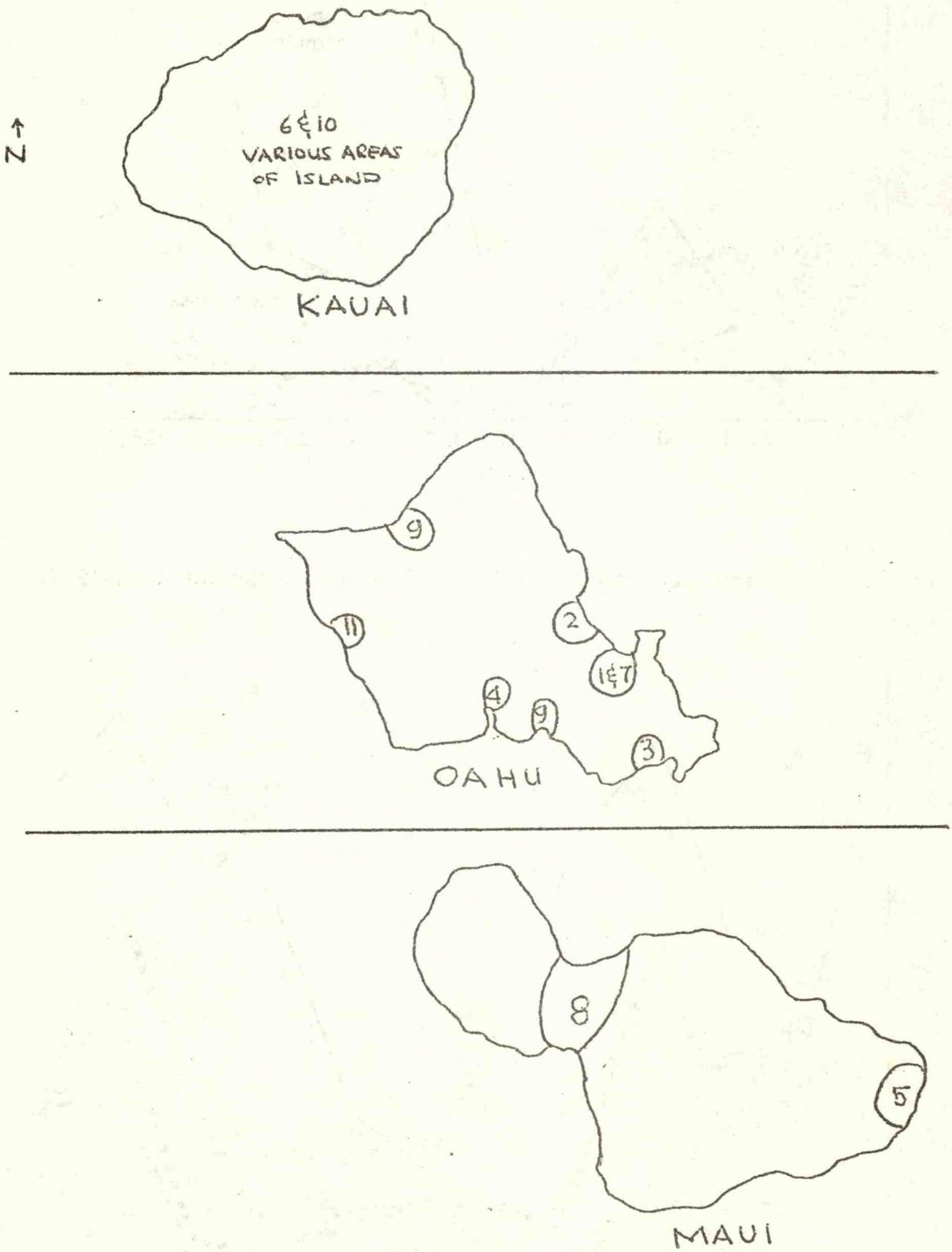


Figure 4. Lihue's Sounding Prior to Flooding.

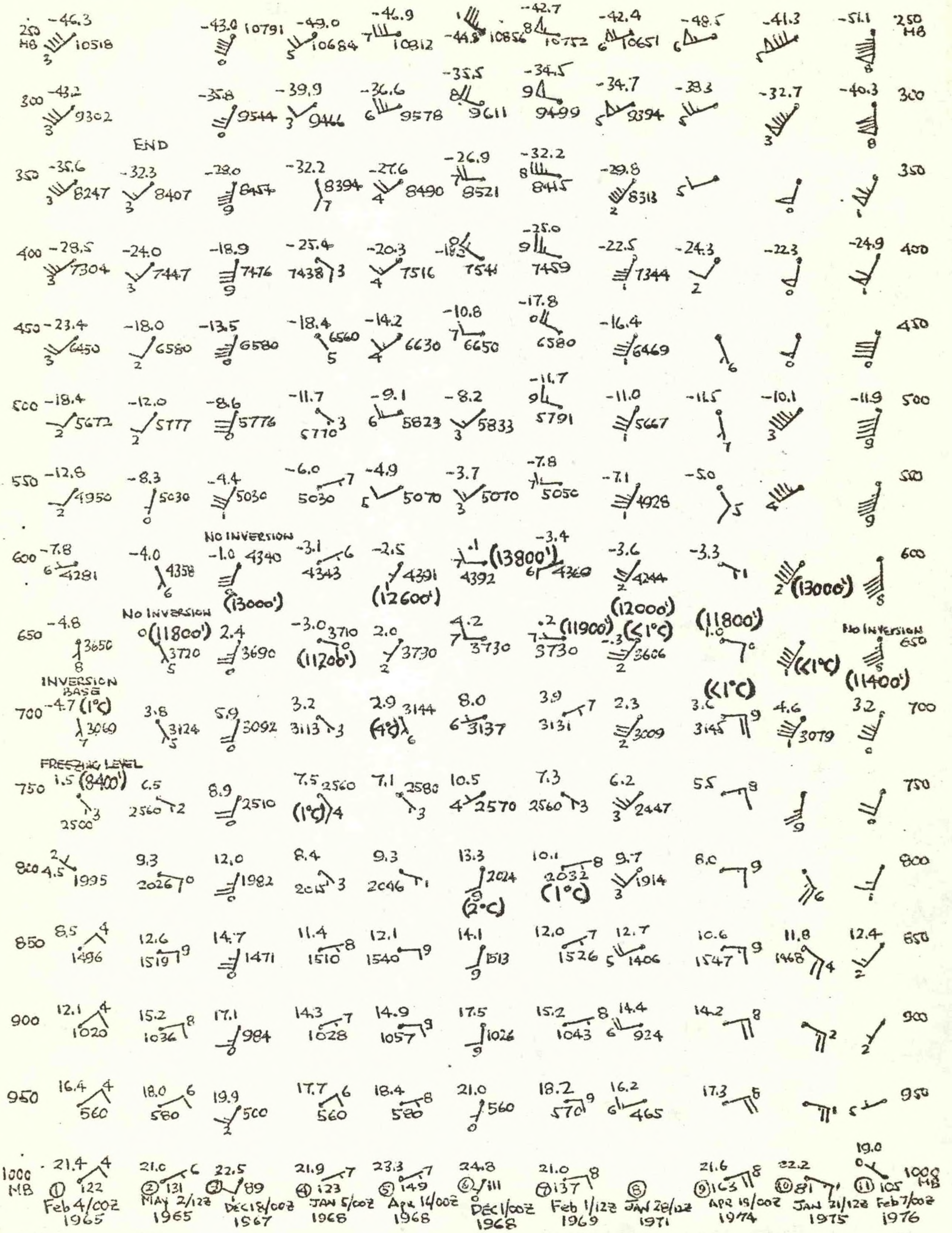


Figure 5. Flood Prone Areas, Telemetered Rain Gages, and Stream Locations on Oahu

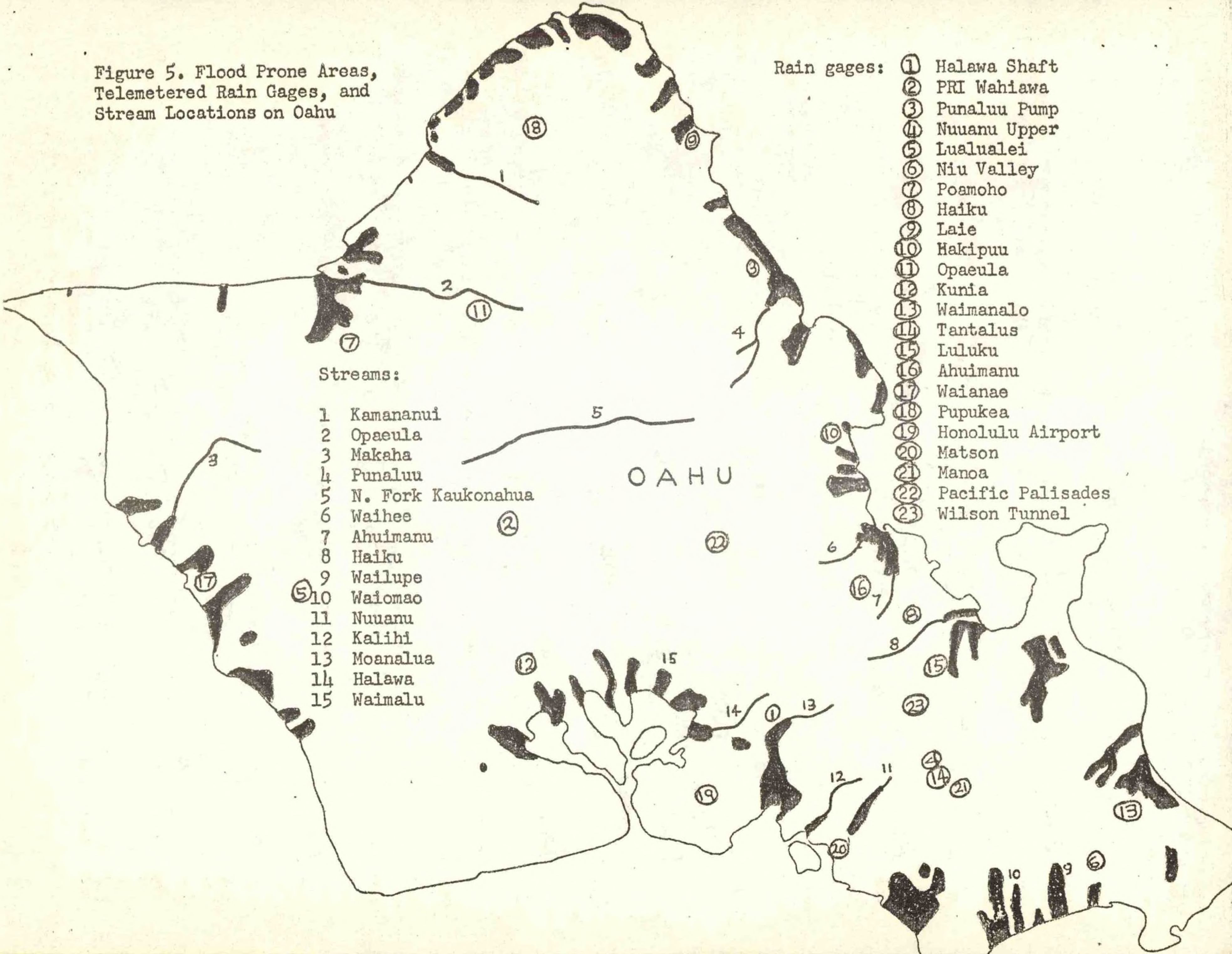
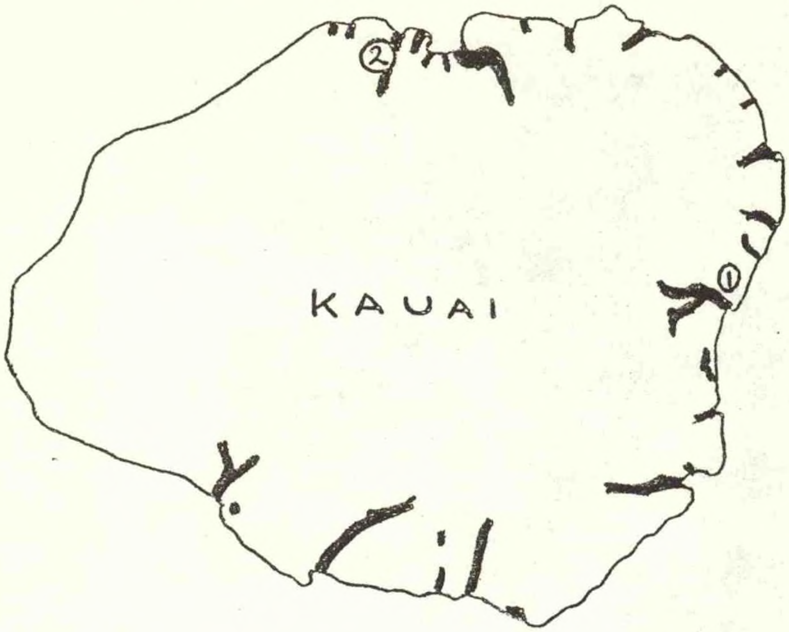


Figure 6. Flood Prone Areas and Telemetered Rain Gage Locations on Kauai and Maui



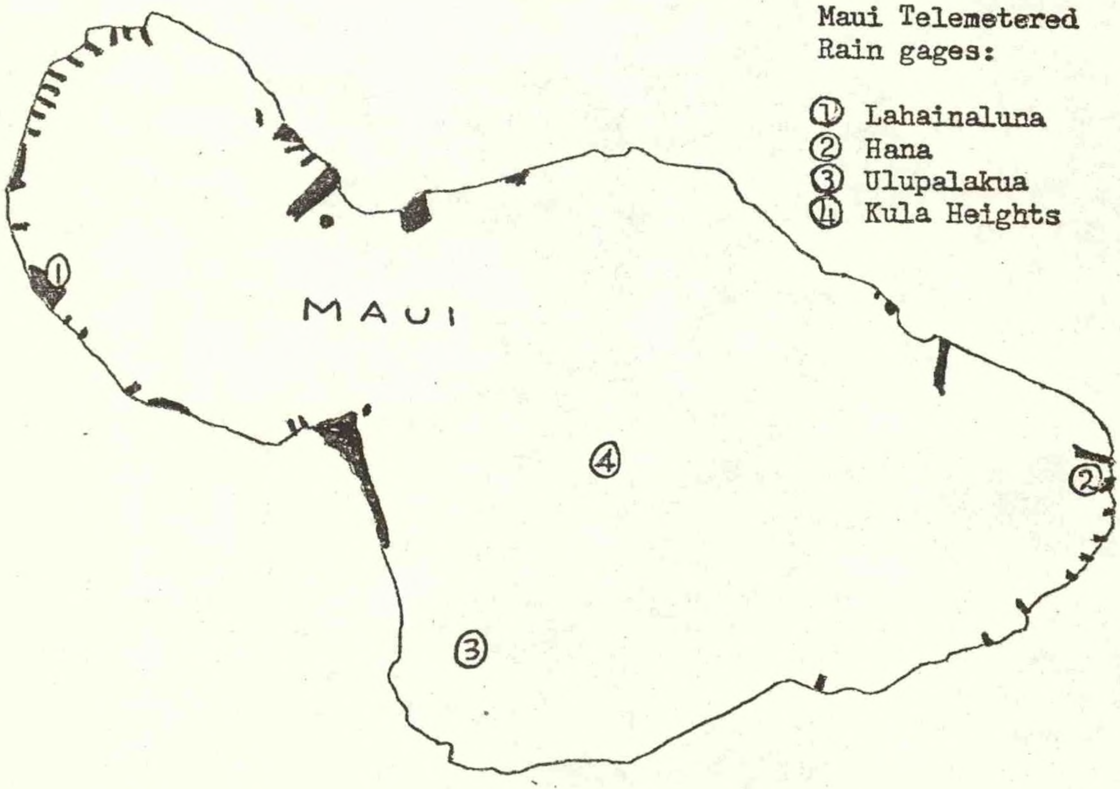


Figure 7. Satellite Picture About 24 Hours Before Flood

April 18, 1974
9:53 A. M.
Weather satellite
infrared picture

Figure 8. 500 MB Trough West of Hawaii

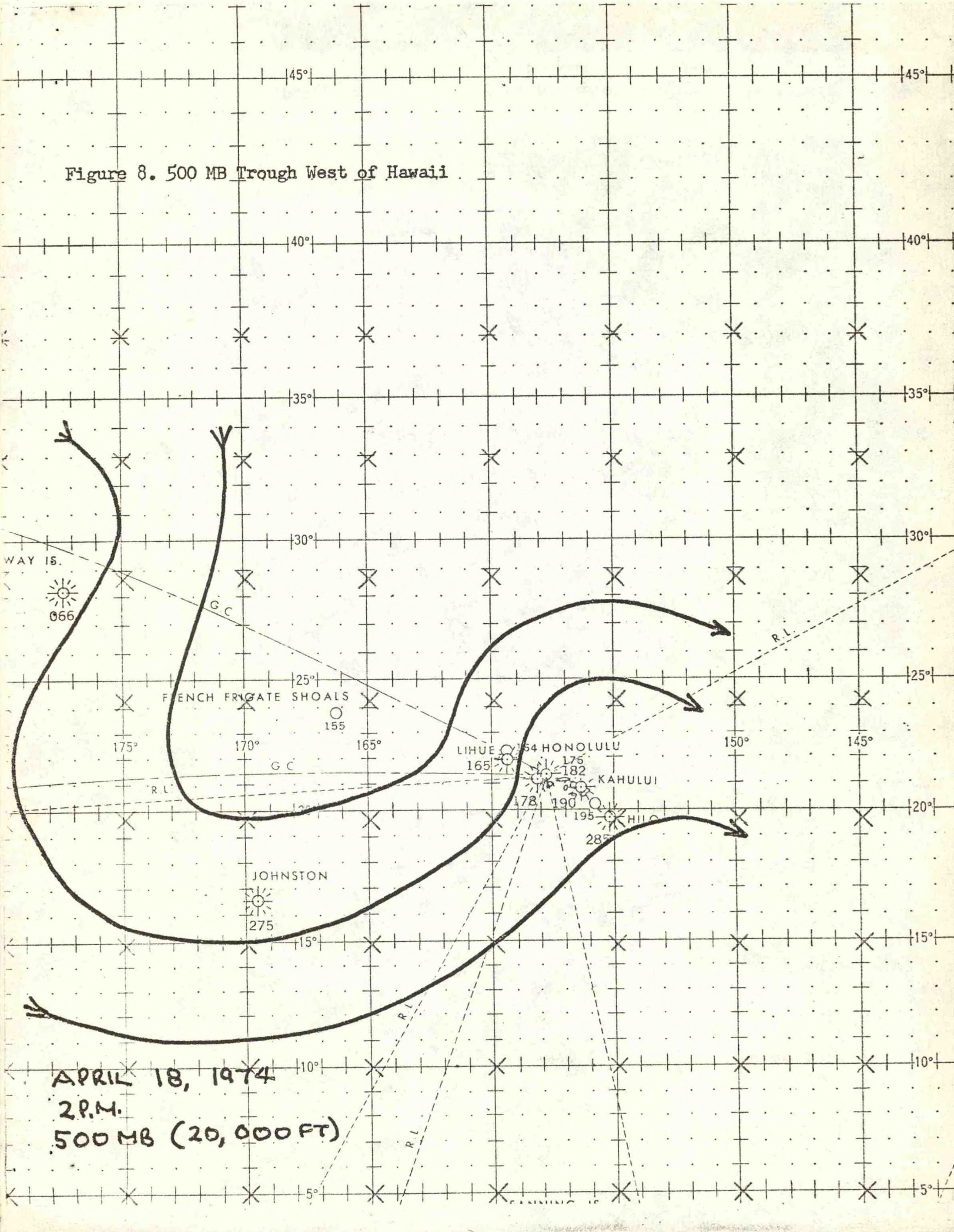
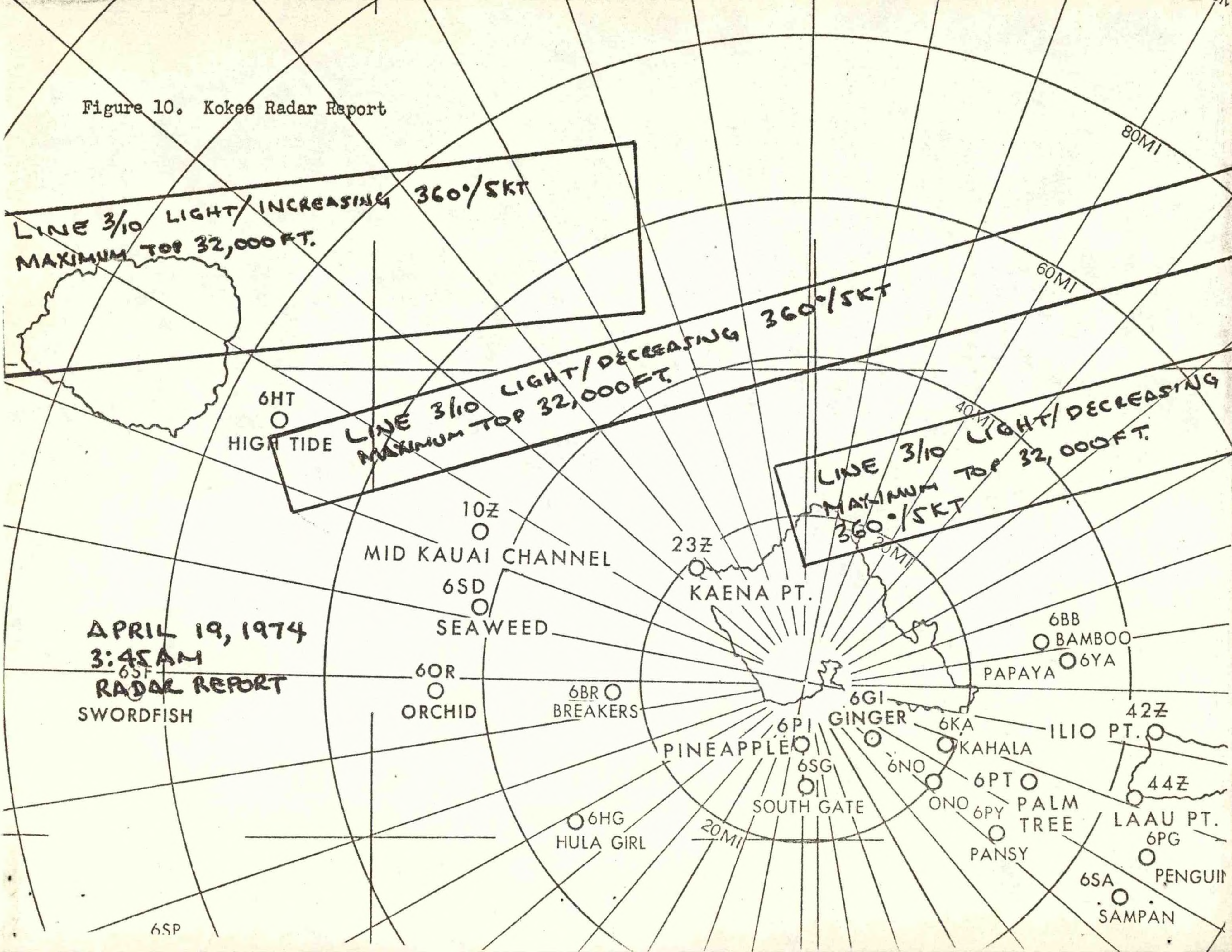


Figure 9. Satellite Picture About 12 Hours Before Flood

April 18, 1974
8:35 P. M.
Infrared satellite
picture

Figure 10. Kokee Radar Report



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