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EVALUATION OF THE STREAMFLOW-DATA PROGRAM IN HAWAII

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ABSTRACT

Streamflow data for Hawaii are evaluated and guidelines for planning future data programs are provided. Evaluation involved (1) definition of long-term goals of the data-collection program in quantitative form, (2) examination and analysis of all available data to determine which goals have been achieved, and (3) consideration of alternative programs and techniques to overcome shortcomings in the present network and to increase benefits from future programs.

INTRODUCTION

The stream-gaging program of the U.S. Geological Survey in Hawaii began in 1909 under an agreement with the Territory of Hawaii, but the initial investigation included the compilation of some records collected earlier by interested private parties. The early programs were aimed primarily at obtaining reliable information about the existing water supply, both developed and undeveloped, for agricultural needs. Consequently, much effort was expended in measuring the flow in the many diversion ditches used for the irrigation of rice, taro, and sugarcane.

As needs for information about duties of water were met, emphasis changed to information on flow of streams in general; and coverage was widened to include streams in remote areas where development was foreseen. At times groups of stations were established to meet specific needs of cooperating agencies. Examples are the stations that were installed to measure springflow along the shores of Pearl Harbor, Oahu, and the stations on the northern slopes of the Kohala Mountains, Hawaii, to investigate the feasibility of extending an existing irrigation water-supply system.

At the end of the 1971 water year, there were 150 gaging stations in operation in Hawaii on streams and ditches, and records were available for many other stations that had been operated in the past. Cooperative funds were provided by several agencies of the State and Federal governments and by county and local agencies. Thirteen stations were supported by Federal funds.

As population increased and shifted toward urban areas, information on flood discharges became more and more important. In 1957, a network of 24 crest-stage stations was established on Oahu, in cooperation with the City and County of Honolulu. This network on Oahu has been enlarged subsequently, and the crest-stage gage network has been extended to other islands, in cooperation with the State of Hawaii and with other Federal agencies. In 1971, there were 93 crest-stage stations in operation; 11 on Kauai, 36 on Oahu, 10 on Molokai, 21 on Maui, and 15 on Hawaii.

Some low-flow partial-record stations were started in 1960, and in 1971, there were 20 such stations in operation. In addition, streamflow measurements were made at 14 miscellaneous sites.

The increasing cost of operation, the constraint on funds and manpower, and the need for a greater variety of hydrologic information, make it imperative that there be a systematic evaluation of the surface-water program to determine how best to apply the available funds and manpower to serve local, State and Federal interests. The purpose of this study is to evaluate the present streamflow-data program and to use this evaluation in the design of a program for the future that will most efficiently produce the types of information needed.

The concepts and procedures used in this study are presented in detail by Carter and Benson (1970), and are summarized only briefly in this report. The basic steps are (1) definition of the long-term goals of the streamflow-data program in quantitative form, (2) examination and analysis of all available data to determine which goals have already been met, (3) consideration of alternative means of meeting the remaining objectives, and (4) proposal of a program of data collection and analysis to improve the present network and to increase benefits from future programs.

This report was prepared by the Hawaii District of the U.S. Geological Survey, under the direction of Willis L. Burnham, District Chief. Assistance from Howard F. Matthai, of the Western Region is acknowledged.

SURFACE-WATER HYDROLOGY OF HAWAII

The variability of streamflow in Hawaii reflects the extreme variability of rainfall. While small in area, the State of Hawaii has a range in rainfall that is greater than that of any other state of the nation. Mean annual rainfall in the Islands ranges from 6.5 inches at Kawaihae, Hawaii to about 460 inches at Mt. Waialeale on Kauai, possibly the wettest site in the world. On each of the major islands, average rainfall ranges from less than 18 inches to more than 250 inches per year.

This extreme range is the result of orographic effects resulting from mountains on each island that deflect upward the incoming moisture-laden trade winds. The lifting causes the moisture to condense and precipitate, primarily upon the windward slopes of the mountains. Consequently, the unit discharges (discharge per unit area) of streams on the windward side of each island are generally larger than those on the leeward side.

As in most tropical regions, rainfall is highly variable from one year to another. This variability is illustrated by the lowest annual rainfall of 72 inches and highest annual rainfall of 207 inches at Hilo, Hawaii, 10 and 46 inches at Honolulu, Oahu, and 5 and 48 inches at Mana, Kauai.

Rainfall intensities are also extreme in the Islands as illustrated by the following examples: 6 inches in 30 minutes, 12 inches in 1 hour, 38 inches in 24 hours at Kilauea, Kauai, in January 1956; and 15.2 inches in 3 hours at the rain gage in Moanalua Valley, Oahu, in November 1931. Intensities of 12 inches or more in 24 hours are not unusual.

While, in general, rainfall is heavier during the winter months than in the summer months (the Kona area, on the western slopes of Hualalai and Mauna Loa on the island of Hawaii is the most notable exception), storms and floods can occur in any month of the year.

Streamflow reflects also differences in geology. Perennial streams are found where the terrain has become relatively impervious due to weathering. They are also found below springs which act as drains for ground water fed by percolation into pervious surfaces and confined by dikes or other geologic features. The presence of dikes that extend across two or more stream valleys often leads to apparently unbalanced water budgets for the individual streams. The stream valley that has been eroded most deeply drains a disproportionately large amount of the water stored behind the dikes, and in effect, decreases the base flow of neighboring streams. A tunnel drilled into a dike complex to develop water may similarly reduce the base flow of streams in neighboring valleys, as well as that of the stream within the valley in which it is located (Hirashima, 1963).

In areas of relatively fresh lava where there are no confining features, rain disappears into the ground and except during extremely heavy rains, channels are dry throughout their length.

CONCEPTS USED IN THIS STUDY

The principal concept of this study is that streamflow information may be needed at any point on any stream in Hawaii and that the program must be designed to accommodate this need. This information can be provided by a combination of data collection and hydrologic studies that generalize the information obtained at gaging sites.

Another important concept is that the goals of the program, including accuracy goals, should be specifically identified. This permits evaluation of existing data to determine which goals have been accomplished and how the program should be modified in an attempt to accomplish the remaining goals.

The procedures used in this study are those that have been adopted for use throughout the U.S. Geological Survey and are presented with reference to the general framework shown in table 1. Streamflow data are classified into four types:

(1) Data for current use.
(2) Data for planning and design.
(3) Data to define long-term trends.
(4) Data on the stream environment.

In similar studies for other States, streamflow data for planning and design were also classified as those for natural-flow streams or regulated streams; and each classification was further subdivided into those for principal or minor streams. The latter subdivision was made on the basis of drainage-area size, generally at 500 square miles.

In Hawaii, the idea of a division between principal and minor-stream streams based on drainage-area size is not realistic. Therefore, several streams have been classified as principal streams (see page 16) and the remaining streams as minor streams.

The criteria for each of the four types of data and the methods for obtaining the data are described in the following sections.

Table 1. Framework for design of data-collection program

Type of data	Current use	Planning and Design		Long-term trends	Stream environment
		Natural flow			
		Minor streams	Principal streams		
Goals	To provide current data on streamflow needed for day-by-day decisions on water management as required.	To provide information on statistical characteristics of flow at any site on any stream to the specified accuracy.		To provide a long-term data base of homogeneous records on natural-flow streams.	To describe the hydrologic environment of stream channels and drainage basins.
Accuracy goal	As required	Equivalent to 10 years of record	Equivalent to 25 years of record	Highest obtainable	As required
Approach	Operate gaging stations as required to provide specific information needed.	Relate flow characteristics to drainage basin characteristics using data for gaged basins.	Operate gaging stations to obtain 25 years of record (or the equivalent by correlation) at a network of points on principal streams; interpolate between points.	Operate a number of carefully selected gaging stations indefinitely.	Observe and publish information on stream environment.
Evaluate available data	Identify stations where data are used currently and code the specific use of data.	Develop relationship for each flow characteristic and compare standard error with accuracy goal. Evaluate sample.	Lay out network of points on principal streams and compare data available at these points with goal.	Select one or two stations in each principal island to operate indefinitely for this purpose.	Evaluate information available in relation to goals.
Design future program	Identify goals that have not been attained. Consider alternate means of attaining goals. Identify elements of future program.				

Data for Current Use

Streamflow data for current use are needed at many sites for the management of water, the assessment of current water availability, the management of water quality, the forecast of water hazards, and the surveillance necessary to comply with legal requirements. This classification represents the need for information on the actual flow at any moment or during any specific day, week, month, or year. The user's interest is in flows as they occur, as well as in the historical record.

Data for current use are obtained by operating gaging stations to meet the specific requirements of the water-management systems. These gaging stations are considered separately because (1) justification for them can be related to specific needs, (2) the data obtained from them may have little or no transfer value in a hydrologic sense, and (3) their locations and periods of operation and the accuracy requirements of the data obtained may be specified by the user, who usually provides the financing required.

This part of the program is not subject to design but changes in response to specific needs for data in water management.

Data for Planning and Design

Designers and planners of water-related facilities increasingly use the statistical characteristics of streamflow rather than flow at specific times. The probability that the historical sequence of flow observed at a given site will occur again is remote, and predictions of future flows needed in design and planning must consider all probable flows and sequences of flow. This information enables prediction of future streamflows, not in terms of specific events, but in terms of probability of occurrence over a span of years. For example, many highway bridges are designed on the basis of the flood that will be exceeded once in 50 years on the average; storage reservoirs can be designed on the basis of the probability of deficiency of storage for a given draft rate; the water available for irrigation, dilution of waste, or other purposes may be stated in terms of the mean flow or probability of flow magnitudes for periods of a year, season, month, week, or day.

A long record of streamflow is the best basis for defining statistical characteristics. Although it is not feasible to collect a long, continuous record at every site where data are needed, a number of such stations are required to provide information that can be transferred by statistical analogy to ungaged sites or to sites where a small amount of streamflow data is available.

Streamflow information on natural streams may be transferred by regression methods that relate flow characteristics to basin characteristics such as drainage area, topography and climate; by relating a short record to a long one; or by interpolating between gaged points on a stream channel.

For regulated streams, a systems approach provides the most meaningful information and usually involves additional and detailed information on the water-management scheme that has been imposed on the stream. Only those regulated streams where streamflow could be adjusted to natural conditions were used in the analysis.

Accuracy Goals

In using past hydrologic experience to appraise the probability of future occurrences, some error must be tolerated. Statistical techniques are based on the assumption that data are random. Natural streamflow, while not truly random, varies greatly in time and space; therefore, it is treated as random events and statistical techniques are applied. Estimates of the magnitude and frequency of occurrence of events of interest to the designer are made from the historical streamflow data, and the probable accuracy of the estimates can be appraised.

The principal measure of the accuracy with which a particular streamflow characteristic can be determined is the statistical measure of error, "standard error of estimate," expressed in this report as a percentage of the average value of the characteristic. The standard error is the estimated limit above and below the average within which about 67 percent (two of three) of future values of the characteristic are expected to fall. Conversely, there is one chance in three that future values will differ from the average by more than one standard error.

In general, the longer the record, the more reliable are the estimates of probable future occurrences. However, even with a long record, say 50 to 100 years or more, it is not possible to determine flow characteristics with great precision. The accuracy goals proposed in this report are based on the accuracy that can be obtained from a selected number of years of record. The goals are expressed in terms of the standard error and are computed from a theoretical relation of standard error to variability index and number of years of record (Hardison, 1969). The standard error of a streamflow characteristic decreases with years of available record, but at a decreasing rate (fig. 1). The incremental economic value of additional years of record beyond a reasonable limit in planning and design of projects is under continuing study, but usable guidelines are not presently available.

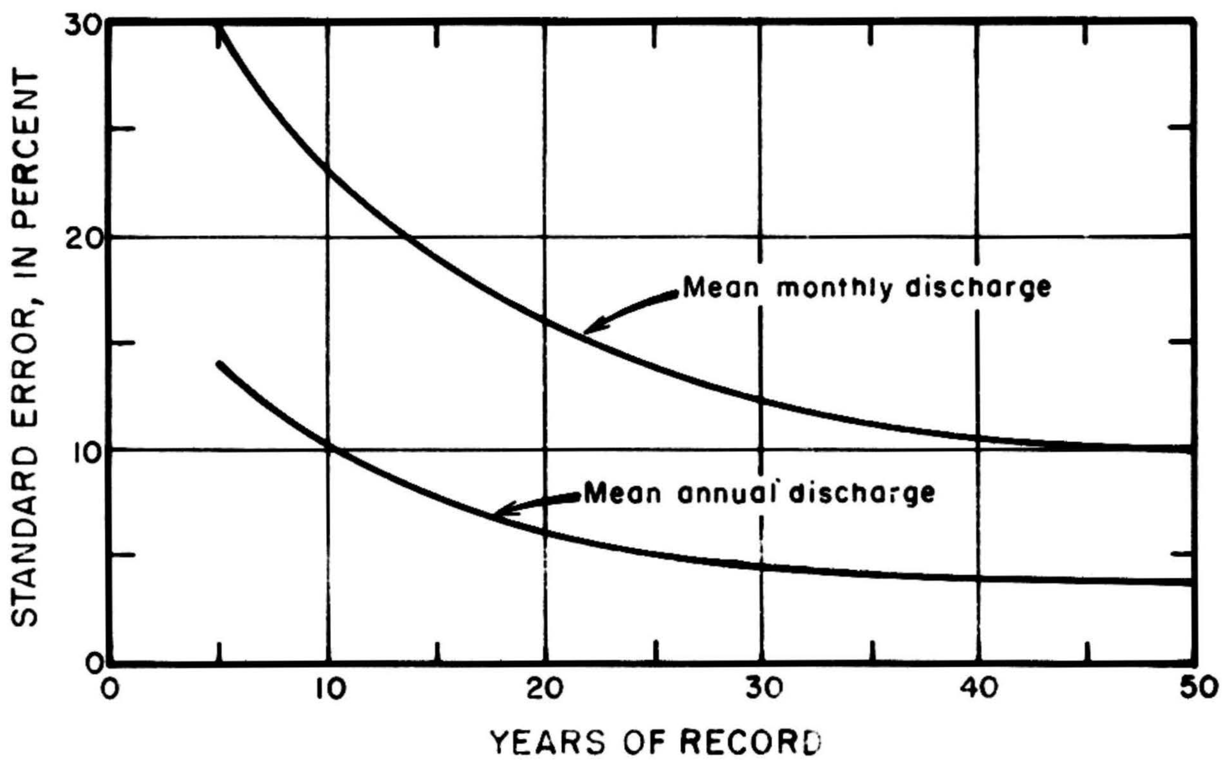

Figure 1.—Theoretical relation of standard error of estimate to length of record

The accuracy goals proposed in this report are expressed as the accuracy equivalent to an arbitrary number of years of record. For principal streams, the accuracy is that which would be equivalent to accuracy obtained from 25 years of record; for other streams, that which would be equivalent to accuracy obtained from 10 years of record.

At sites on natural-flow streams where streamflow records are not available, the desired streamflow characteristics may be estimated by means of the relation between the streamflow parameter and the characteristics of the drainage basin. This relation is obtained by multiple regression analysis, a statistical method of handling sample data that can relate a streamflow characteristic to the topographic and climatic characteristics that affect streamflow. This analysis produces a regression equation that can be used to compute the flow characteristic at any point on natural streams in a homogeneous region. The standard error of a regression equation provides a measure of the accuracy of an estimate made from the equation for an ungaged site. That error may be compared with the error associated with the accuracy goal associated with the same characteristic to determine whether the accuracy objective has been met.

Data to Define Long-Term Trends

A long continuous series of consistent observations of streamflow (1) defines long-term hydrologic trends and (2) provides a reference or comparative base for noting changes in the flow regime of streams affected by increased regulation. Past records are used to estimate future flow characteristics, and it is assumed that the observed record is a representative sample of long-term flows. To affirm this assumption, or to better define the ways in which flow characteristics change with time, selected gaging stations should be operated indefinitely on streams in basins that have undergone no significant manmade changes and are expected to remain unchanged in the future.

Data on Stream Environment

Stream discharge and water use are intimately related to the environment in which the water occurs. Environmental data include a wide variety of water-related information other than stream discharge. These data are useful in hydrologic studies and in planning, designing, and operating systems for controlling water or pollution. For example, (1) data on the geometry of stream channels are useful in appraising the use of a stream for recreation or in determining its capacity to assimilate waste, (2) flood-profile data are useful in determining areas subject to inundation, and (3) data on aquifer characteristics are valuable in hydrologic studies of the variability of low flow and in planning the conjunctive use of surface water and ground water.

GOALS OF THE HAWAII STREAMFLOW-DATA PROGRAM

The objective of the Hawaii streamflow-data program is to provide the type of information needed at any point on any stream to an acceptable accuracy.

Data for Current Use

The program goal for this type of data is to provide the particular information needed for specific sites for current use. Because demands often change, this part of the program cannot be designed in advance. Accuracy goals at a given site depend on the requirements of the data user, and can be met by intensive observation or by more sophisticated instrumentation as needed.

Data for Planning and Design

The program goal for planning and design data is to define selected flow characteristics within the accuracy provided by 10 years of record for most streams and by 25 years of record for the principal streams. This definition applies to all streams, those with natural flow and those that are affected by regulation and diversions. The equivalent of 10 or 25 years of record is considered reasonable because the accuracy of streamflow characteristics is dependent upon time-sampling errors and space-sampling errors. Generally, the latter are greater than the former.

The accuracy goals equivalent to 10 and 25 years of record for selected streamflow characteristics in Hawaii were calculated using methods described by Hardison (1969) and are tabulated below.

Accuracy of statistical characteristics of streamflow in Hawaii

Streamflow characteristic	Standard error, in percent, for indicated length of record			
	Windward area		Leeward area	
	10 years	25 years	10 years	25 years
Mean annual flow	9	6	11	6
Mean monthly flow (average)	19	13	25	17
2-year flood	15	9	19	12
50-year flood	50	25	60	38
2-year 7-day high flow	9	6	13	8
50-year 7-day high flow	40	25	40	25
2-year 7-day low flow	9	6	12	8
20-year 7-day low flow	25	14	27	17

Data to Define Long-Term Trends

The goal for this type of data is to operate indefinitely a small network of stations on streams that are expected to be relatively free from manmade changes. Stations should be on streams that are located in basins that differ in physical characteristics.

Data on Stream Environment

Environmental data describe the flow and the stream channel in terms that will be valuable in (1) planning the use of the stream for any purpose, such as recreation, waste disposal, and conjunctive surface water-ground water supply and (2) minimizing damage from flood events. The long-range goals for this type of data are given below.

1. Hydrometric surveys of stream-aquifer systems.
2. Definition of flood profiles along stream channels.
3. Identification of limits of areas inundated for floods of different frequencies.
4. Reconnaissance surveys of streamflow and stream channel parameters that are related to the use of the stream for recreation, including fishing. These parameters may include velocities, depths, bank vegetation, bed material, water temperature, water quality, and accessibility.
5. Research studies of the effect on streamflow of manmade changes in the environment.

EVALUATION OF EXISTING DATA IN HAWAII

In this evaluation, all available data are considered and analyzed in relation to program objectives. A separate evaluation is made for each of the four types of data.

Data for Current Use

About 89 percent of the gaging stations in Hawaii (including ditch stations) are operated to provide data for current use. It is assumed that the need for this type of data is being met, and that this part of the program can be modified as requirements change. A summary of the 133 stations (including ditches) to provide this type of data is listed below.

Use of data	Number of stations
1. Assessment	62
2. Operation or management	59
3. Water quality	9
4. Compact or legal	41
5. Research or special studies	56

Stream-gaging stations that are operated to satisfy the need for current-purpose data are listed in table A-1 and are coded according to the specific use of data.

Data for Planning and Design

The statistical characteristics of streamflow can be defined by gaging, analytical methods of generalization, systems studies, or any combination of the three. The following evaluation of this type of data follows the framework shown in table 1.

One purpose of the evaluation is to determine how accurately selected statistical characteristics of streamflow can be defined by regionalization of the natural-flow data now available.

The most effective method of regionalization presently known is the technique of multiple regression wherein streamflow characteristics are related to basin and climatic characteristics which affect streamflow.

Once the regression equations and their constants are defined, streamflow characteristics for a specific site in a given basin can be approximated by substituting the appropriate values of the independent variables in the formulas.

The 75 streamflow records used in the analyses are those having 10 or more years of mostly unregulated flow, or flow that can be adjusted to natural conditions. Records were not adjusted to a base period. Not all flow characteristics were defined for each station. Probable recurrence intervals for streamflow characteristics were not computed for periods greater than twice the length of record available.

Streamflow Characteristics

Streamflow characteristics analyzed in this study represent the full range of flow and are defined as follows:

1. Flood-peak characteristics are represented by discharges at recurrence intervals of 2, 5, 10, 25, and 50 years (Q_2, Q_5, Q_{10}, Q_{25}, and Q_{50}). These were determined from frequency curves computed by the Log-Pearson Type III method described by the Water Resources Council (1967).

2. Mean-flow characteristics are described by the mean of the annual means q_a, and by the mean of record for each calendar month, q_n where the subscript "n" refers to the numerical order of the month beginning with January as 1.

3. Flow-variability characteristics are represented by the standard deviations of the annual and monthly means. The symbols used are, respectively, SD_a and SD_n, where the subscript "n" refers to the numerical order of months with January as 1.

4. Flood-volume characteristics are represented by the annual maximum 1-day and 7-day mean flow at 2- and 50-year recurrence intervals ($V_{1,2}$, $V_{1,50}$, $V_{7,2}$, and $V_{7,50}$). These were determined from high-flow frequency curves using the Log-Pearson Type III method.

5. Low-flow characteristics are the annual minimum 7-day and 30-day mean flows at 2- and 20-year recurrence intervals ($M_{7,2}$, $M_{7,20}$, $M_{30,2}$, and $M_{30,20}$). These were computed from low-flow frequency curves.

Drainage-Basin Characteristics

Drainage-basin characteristics defined for this study are:

1. Drainage area, A, in square miles.

2. Main-channel length, L, in miles, from the gaging station to the basin divide, as measured on topographic maps with scale of 1:24,000.

3. Mean basin elevation, E, in feet above mean sea level, measured on 1:24,000 maps by laying a grid over the map, determining the elevation at each grid intersection, and averaging these elevations. The grid spacing was selected to give at least 25 intersections within the basin boundary.

4. Range in elevation, R, in feet, determined by subtracting the elevation of the gaging station from the elevation of the highest point in the basin.

5. Percentage of gentle slope, G, the percentage of surface area in the basin with slope less than an arbitrary limit of 30 percent.

6. Area of swamp, S_t, expressed as a percentage of the drainage area plus 1 percent.

7. Vegetative cover, F, expressed as the percentage of the drainage area covered by forests plus 1 percent, as shown on 1:24,000 topographic maps.

8. Mean annual precipitation, P, in inches, determined from isohyetal map prepared by the U.S. National Weather Service.

9. Precipitation intensity, $I_{24,2}$, defined as the maximum 24-hour rainfall having a recurrence interval of 2 years. These values were determined from U.S. Weather Bureau publication (1962).

Values of the above basin characteristics for each of the 75 gaging stations used in the regression analysis are listed in table A-2.

Regression Analysis

Each of the streamflow characteristics was related to the basin and climatic characteristics in equations developed by using multiple-regression methods. The equation has the form

$$Y = a\ A^b\ L^c\ E^d\ .\ .\ .$$

where Y is a streamflow characteristic and A, L, E, etc., are basin characteristics. The constants, a, b, c, d, etc. are determined by standard multiple-regression procedures.

All the basin characteristics were used initially in each regression. A high-speed digital computer was used to calculate the regression equation, the standard error of estimate, and the significance of each basin parameter. Automatically, then, the computer repeated the calculations, omitting the least significant basin parameter in each calculation until only the most significant parameter remained.

After the relations for a given streamflow characteristic were computed, the entire computation process was repeated relating another streamflow characteristic to the same set of basin characteristics.

The first regression equations were computed on a statewide basis for eleven selected characteristics (Q_2, Q_{50}, q_a, SD_a, q_{10}, q_2, q_8, SD_2, SD_{10}, $V_{7,2}$ and $M_{7,2}$), which were chosen as representative characteristics. The residuals, defined as the percentage deviation of the simulated characteristics from the observed characteristics at each station, were computed and plotted on a map of Hawaii. While no great differences were found, there was an indication that for most of the characteristics tested, stations in windward areas differed from those in leeward areas. Consequently, the regression equations were developed separately for the two areas, and the results showed improved standard errors of estimate with the exception of certain minimum-flow characteristics ($M_{7,20}$, and $M_{30,20}$) for stations in the leeward area.

Results of the regression computations for the 37 streamflow characteristics are shown in tables A-3 and A-4. The basin characteristics specified for each equation are only those found to be statistically significant at least at the 5-percent level. The standard error of estimate for each equation is also given. For example, the equation for the mean annual flow in the windward area is:

$$q_a = 0.0150\ A^{.949}\ P^{.588}\ I_{24,2}{}^{.850}$$

and the standard error of estimate is 34 percent.

The standard errors of the regression equations listed in tables A-3 and A-4 exceed those set as goals and listed in the table on page 10 in nearly all cases. The exceptions are the goals for the 50-year flood for 10 years of record in leeward areas and the goals for the 50-year 7-day high flow for 10 years of record in both leeward and windward areas, all three of which were just barely met. None of the goals equivalent to 25 years of record were achieved.

Among the reasons that so few goals were met using this analytical approach are: (1) the basin characteristics used may not describe the conditions adequately. For example, there is no acceptable procedure for describing, with numbers, geology or differences in geology and its effect on streamflow. (2) More detailed areal definition of annual precipitation and rainfall intensities may be necessary. And (3) the regression model used may not be the most representative of local conditions. The scope of this study precluded the development of more data or detailed evaluation of applicability of other models.

A higher accuracy was chosen for streams on which costly existing and possible additional developments justify better streamflow information. Streams selected and classified as principal streams in table A-1 are:

Kauai: Waimea River, Hanapepe River, Wailua River, and Hanalei River.

Oahu: Kaukonahua Stream, Waikele Stream, Kamooalii Stream, and Punaluu Stream.

Molokai: Halawa Stream.

Maui: Palikea Stream, Wailuaiki Stream, Nailiilihaele Stream, and Honokohau Stream.

Hawaii: Wailuku River and Honokane Nui Stream.

Evaluation of Regulated-Stream Systems

Owing to generally unfavorable conditions, steep channel slopes, narrow stream valleys, and very permeable channel bottoms, very few large on-stream reservoirs have been built to store surface water in Hawaii. Regulation in the sense of controlling the amount of flow in streams is limited to assuring that minimum water rights downstream of diversions are maintained.

However, extensive irrigation systems have been constructed on each of the major islands. Most of these systems collect the low-to-medium flows of many minor streams and, in some cases, high-level ground water in the wetter sections of the island and transmit the water across long distances for use in the drier, more sunny sections. Although the total amounts exported from the rainy sections are usually measured, few of the diversions from each individual stream are measured continuously.

Other systems range from one with a single ditch-single diversion to multiple ditch-multiple diversion systems not involving long distance inter-basin transmissions.

A systems approach utilizing a mathematical model may be used to define flow characteristics for different amounts of diversion or for natural conditions, but this would call for a major effort. Therefore, the present evaluation is limited to identifying streams affected by diversions or regulation.

Streams on which there are significant diversions:

Kauai: All perennial streams, Waimea River to Hanalei River.

Oahu: All perennial streams, except those between Waimalu and Kalihi Streams, Manoa, Palolo, Kaneohe, Kaluanui, and Kamananui Streams.

Molokai: Kawela Gulch and Waikolu Stream.

Maui: All perennial streams in areas other than the southeastern section; the only regulated stream in the southeastern section is Wailua Stream.

Hawaii: All perennial streams, except some along the Hamakua coast north of Hilo and streams between Waimanu and Waikaloa Streams in the Kohala mountains.

Data to Define Long-Term Trends

At present, one streamflow station, 167170.00 Honolii Stream near Papaikou, Hawaii, is designated as a long-term trend or benchmark station for indefinite operation. Several others are being designated as long-term trend stations to provide areal coverage of the State and to sample basins that differ in physical characteristics.

Data on Stream Environment

Many environmental factors were determined for the drainage areas of the 75 gaging stations for the present study and are tabulated in table A-2.

Detailed channel surveys have been made at many sites in connection with indirect measurements of peak flows for large floods and in connection with model studies made to develop the stage-discharge relation at gaging stations.

Flood-inundation maps have been drawn for several areas and published as Hydrologic Atlases; much data on stream-channel dimensions were obtained during the preparation of these maps.

THE PROPOSED PROGRAM

The information developed in different segments of this study has been merged to plan a streamflow-information program that will approach the optimum network of stations and yield additional knowledge about streams and streamflow. For the optimum program, a balance must be maintained between data collection and data analysis. Continuous interaction between the two is needed not only to gain a better understanding of the hydrologic system, but also to guide future evaluation of the program in meeting ever-changing needs and in adapting to changing technology.

Data Collection

Data for Current Use

Operation of the 93 stations identified as current-purpose streamflow stations in table A-1 should be continued as long as specific needs remain. Needs will be assessed continuously, and the data collection network will be modified by establishing or discontinuing stations as needs change. The data requirements for each site will be examined to determine whether a continuous record of discharge is needed or whether measurement of specific-flow characteristics, such as peak flow or instantaneous flow, will suffice.

Data for Planning and Design

The objective of providing the necessary information on any stream in Hawaii has been only partially attained. This evaluation has indicated the need for continued operation of certain stations to obtain continuous-record or partial-record data. The need for some additional gaging stations is also apparent.

Low-flow characteristics, especially, cannot be estimated reliably by the regression methods used. However, base-flow discharge measurements at many ungaged sites are available, and low-flow characteristics at many of these sites may be defined by correlation with concurrent flow at nearby gaging stations. Base-flow measurements should be obtained at many other ungaged sites, along with concurrent flow data at suitable continuous-record index stations where similar hydrologic conditions exist.

Flood-peak characteristics at recurrence intervals of 100 years are often estimated for project design. Although the objectives include only the 50-year flood, it would be desirable to collect 50 years of flood-peak data at selected sites to define the 100-year flood. This can be met most economically by operation of crest-stage gages. Continuous-record stations that have been operated long enough to determine other streamflow characteristics should be considered for conversion to partial-record operation to help meet this need.

Collection of hydrologic data for planning and design purposes appears desirable for several areas in this State. Stations are proposed for the following streams:

Kauai: Kalihiwai River near Kalihiwai
Manoa Stream near Haena

Oahu: Kawa Stream near Kaneohe

Molokai: Waialua Stream near Waialua

Maui: Kukuiula Gulch near Kipahulu
Wailua Stream near Kipahulu
Makapipi Stream at Nahiku (low level)
Waiokamilo Stream near Wailua (above lower diversion)

Hawaii: Kolekole Stream near Honomu
Umauma Stream near Hakalau

Regulated-flow streams

The analysis of any specific regulated stream basin is beyond the scope of this investigation; therefore, recommendations for data collection are of a general nature.

Measurements of principal diversions from streams should be continued to supplement records of streamflow, as well as to provide information useful in investigations involving surface-water, ground-water, and quality-of-water studies that can be anticipated for the future.

Data to Define Long-Term Trends

In addition to continuing the operation of the one station presently designated as a long-term station, Honolii Stream near Papaikou, Hawaii, several others are so designated from the present network. The additional stations were selected to provide a long-term sample reflecting areal coverage of the Islands. Many of the selected stations have been operated for considerable periods of time.

Kauai

160190 Waialae Stream at altitude 3,820 ft, near Waimea
160680 East Branch North Fork Wailua River near Lihue
160975 Halaulani Stream at altitude 400 ft, near Kilauea
161080 Wainiha River near Hanalei

Oahu

162000 North Fork Kaukonahua Stream above Right Branch, near Wahiawa
162116 Makaha Stream near Makaha
162260 North Halawa Stream near Aiea
162290 Kalihi Stream near Honolulu
163030.03 { 163020 Punaluu ditch near Punaluu
163030 Punaluu Stream near Punaluu }

Molokai

164000 Halawa Stream near Halawa
164114 Kakaako Gulch near Mauna Loa
164140 Kaunakakai Gulch at Kaunakakai

Maui

165080 Hanawi Stream near Nahiku
165700 Nailiilihaele Stream near Huelo
166200 Honokohau Stream near Honokohau

Hawaii

167200 Kawainui Stream near Kamuela
167592 Right Branch Waiaha Stream near Holualoa
167640 Hilea Gulch tributary near Honuapo

Several stations should be reestablished and designated long-term stations, either at their original sites or at more representative sites.

Kauai

Kamooloa Stream near Koloa (above diversions)

Maui

Oheo Gulch near Kipahulu
Waihee River near Wailuku (above diversions)
Ukumehame Stream near Olowalu

The stations designated for indefinite operation in Hawaii are coded with a "B" in column 1 of table A-1.

Summary of Data Collection

In table A-1 the types of data collected at each station in the current network are indicated. According to the criteria used in this report, some stations have sufficient length of record for hydrologic data purposes; however, many of these stations provide current information for other purposes.

Although the gaging-station program does not require radical revision, certain modifications are desirable. Deficiencies in the streamflow program have been identified, and specific recommendations for collection of data have been made. The proposed streamflow stations are listed in table A-1. The economic advantage of operating partial-record stations, to provide needed flow data at stations where a continuous record is not needed, has been considered. Stations no longer needed for the purpose indicated are identified by parentheses in column 6 of table A-1. The locations of gaging stations in the current network and locations of proposed stations are shown in figures 2 through 6.

Frequent appraisal of the data-collection network is recommended, so that it can be revised in light of the changing needs for current purpose data, and to determine how the network should be adjusted to improve the hydrologic data and to increase benefits.

Data Analysis

The proposed program of data analysis for Hawaii streams can be considered in two categories--analyses based on data now available and analyses that require additional or specialized data.

Streamflow information collected to date supplies the basic data for analyses that can aid in the design of water projects and in water management. Analytical studies of this type are justified when the need becomes apparent and the necessary data are available; some such studies should be updated periodically to include recent streamflow information. The analysis of streamflow characteristics by regression techniques used in the preparation of this report may provide a basis for designing future regionalization studies. Data analyses and appropriate reports should be scheduled in future programs as finances permit. These include the following:

1. Analysis of the magnitude and frequency of peak flows in Hawaii. As more data are collected at the many recently installed stations, greater confidence can be placed upon estimates of flood magnitude and frequency.

2. Analysis of the magnitude and frequency of annual maximum average flows for selected periods of time.

3. Analysis of low-flow characteristics of selected streams.

The second type of data analysis, wherein additional or specialized data are required, include:

1. Definition of flood profiles for floods of different frequencies.

2. Effects of urbanization on flood runoff and water quality.

3. Hydrometric surveys of stream-aquifer systems.

    a) Traverses of stream channels to determine locations of inflow from springs and seeps, and of outflow because of streambank or stream-bottom infiltration.

    b) Effects of development on surface- and ground-water systems.

4. Relation of stream-channel geometry to flow characteristics, such as mean annual flows and peak flows.

5. Derivation of low-flow characteristics for ungaged streams from correlation of base-flow measurements at the ungaged streams and concurrent flows at nearby gaged streams.

These are only a few of the data analyses and hydrologic studies that should be made in Hawaii. Changing needs for streamflow information and changes in water-related technology must be reevaluated frequently.

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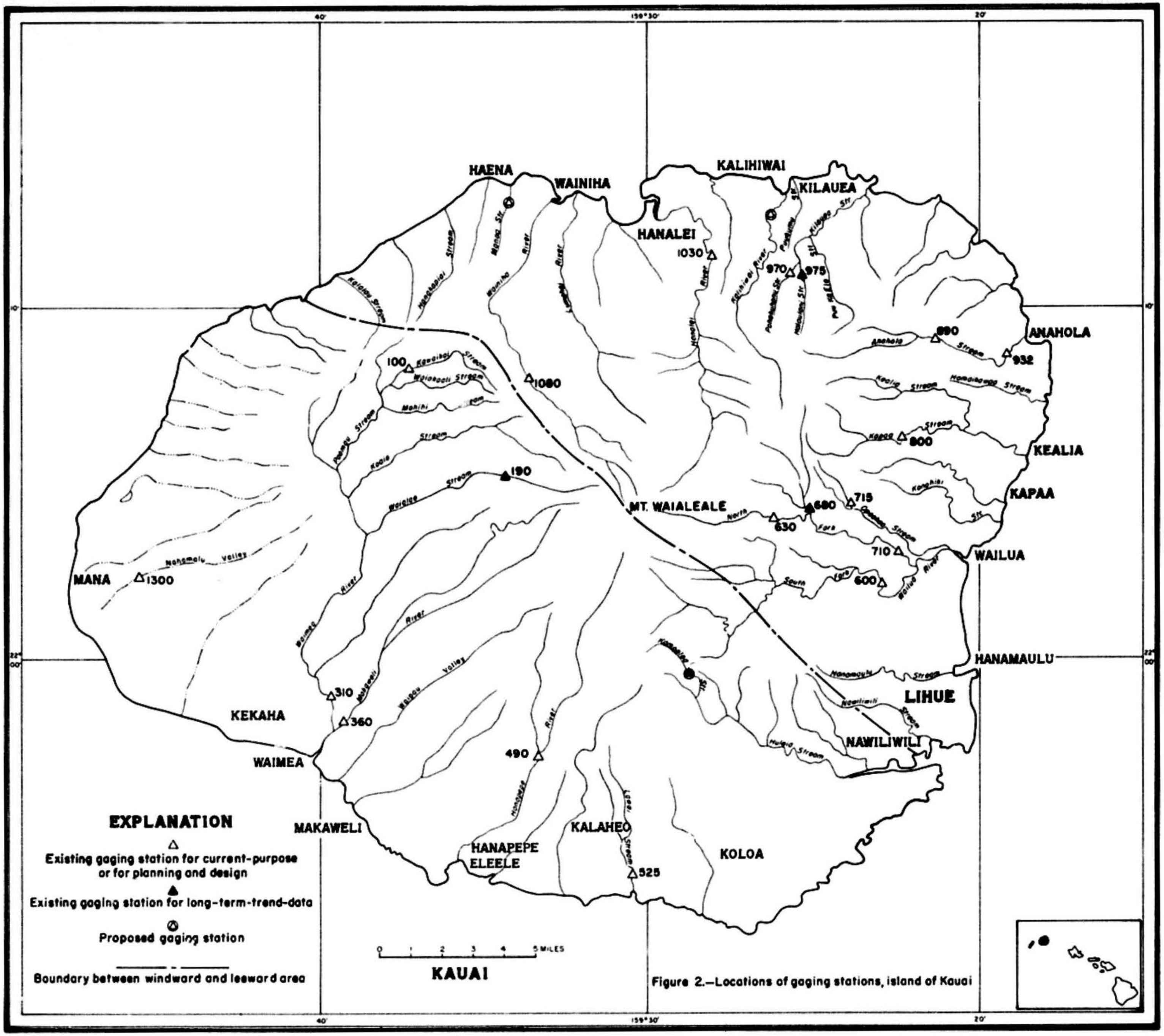

Figure 2.—Locations of gaging stations, island of Kauai

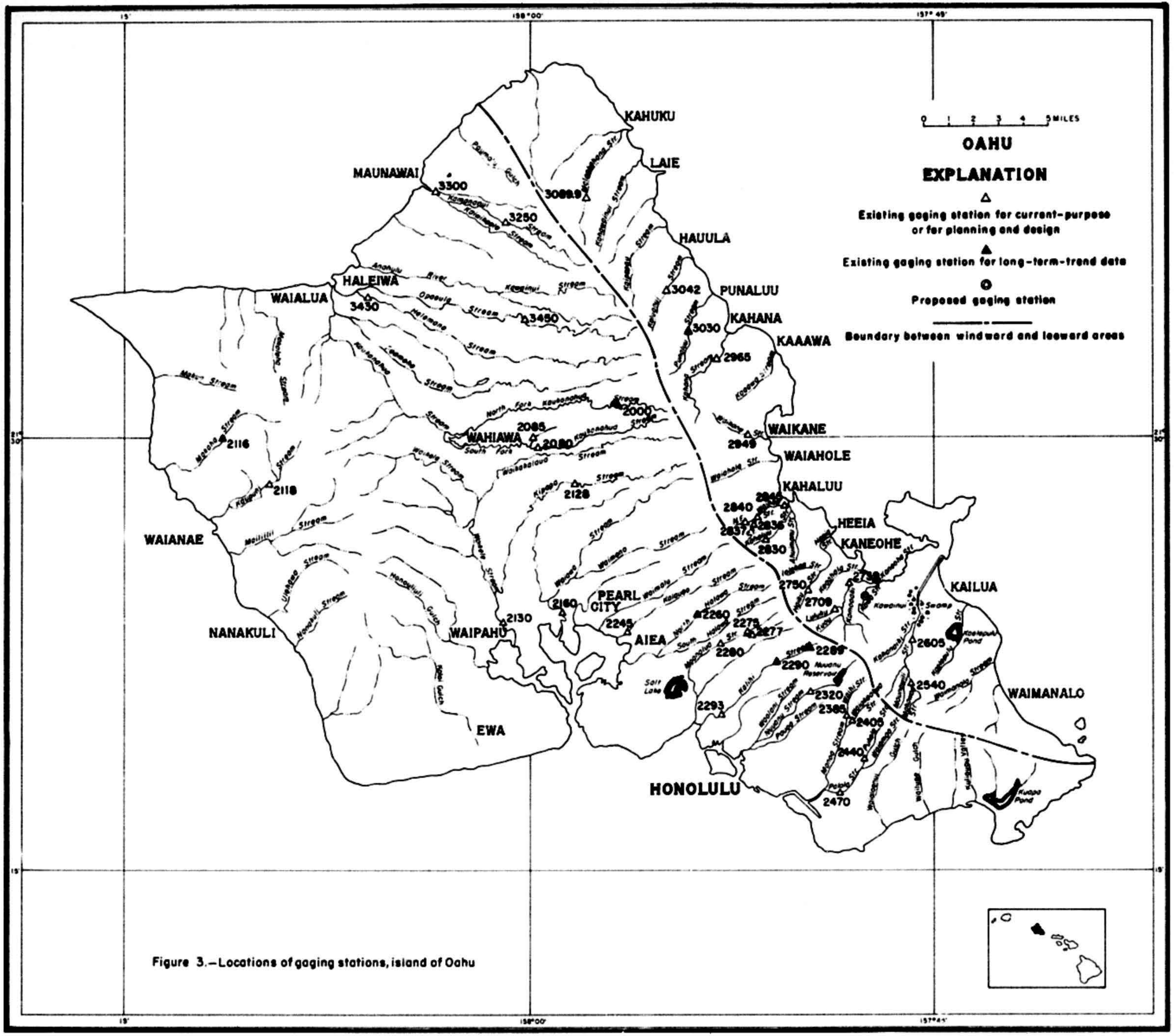

Figure 3.—Locations of gaging stations, island of Oahu

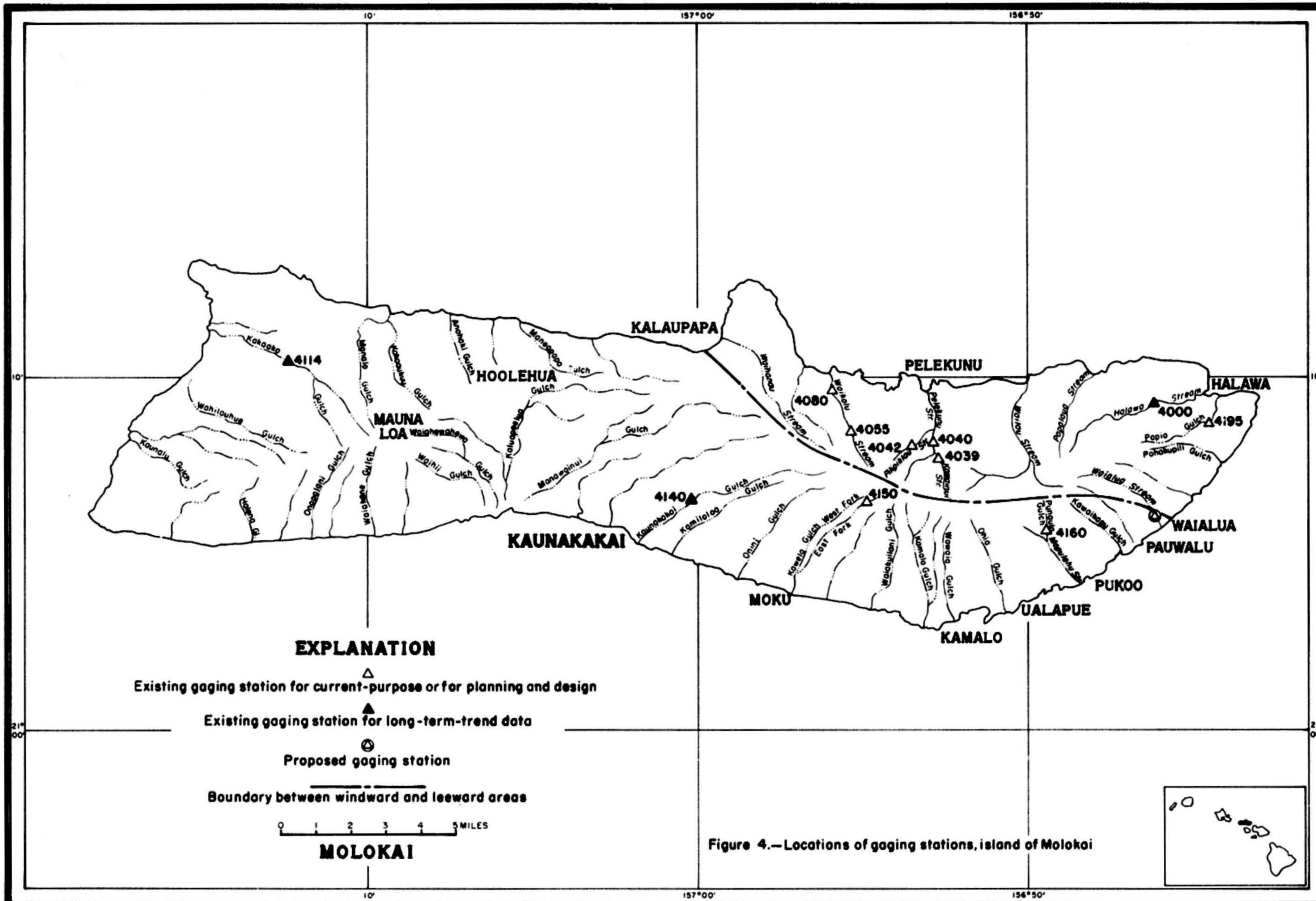

Figure 4.—Locations of gaging stations, island of Molokai

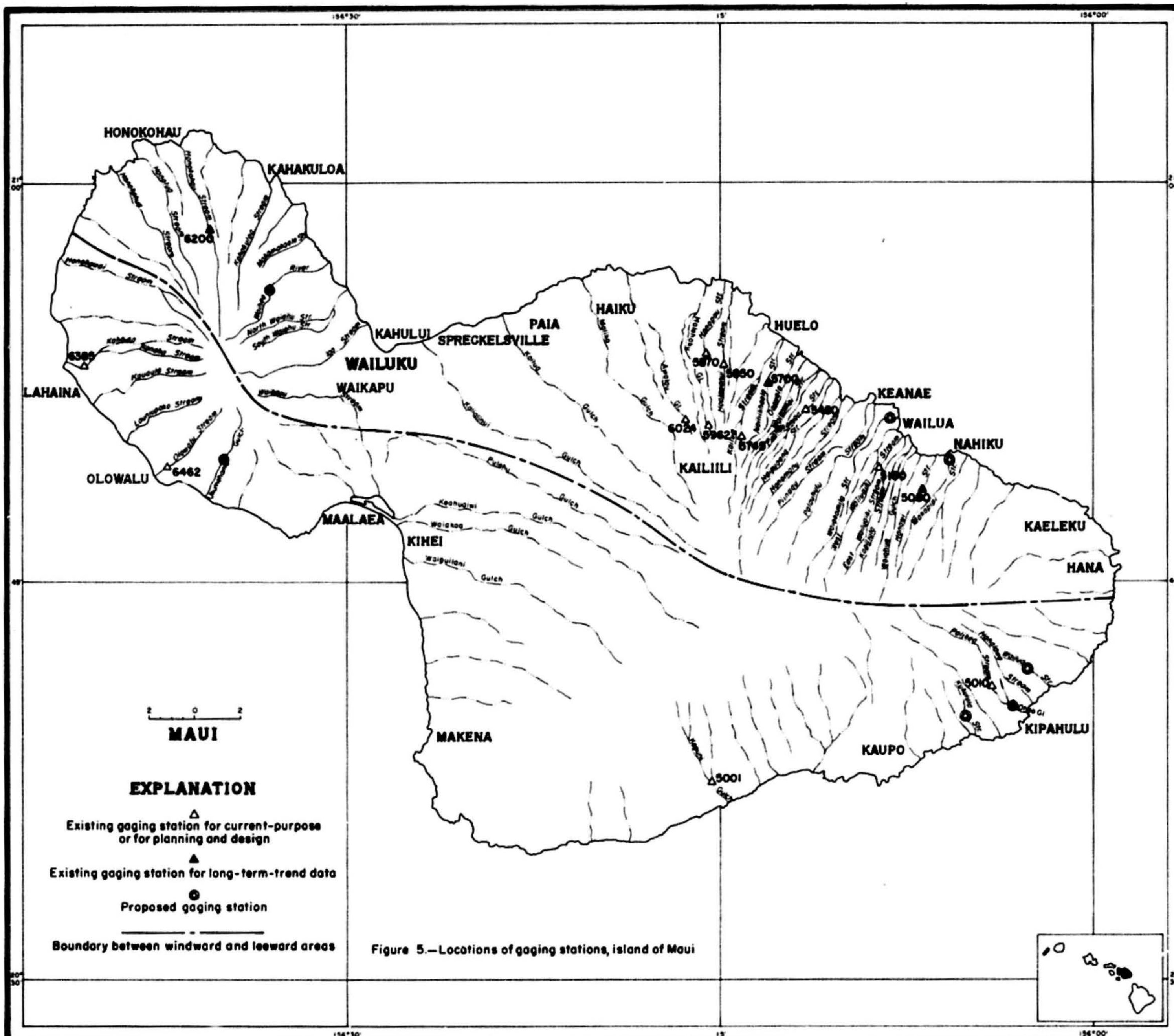

Figure 5.—Locations of gaging stations, island of Maui

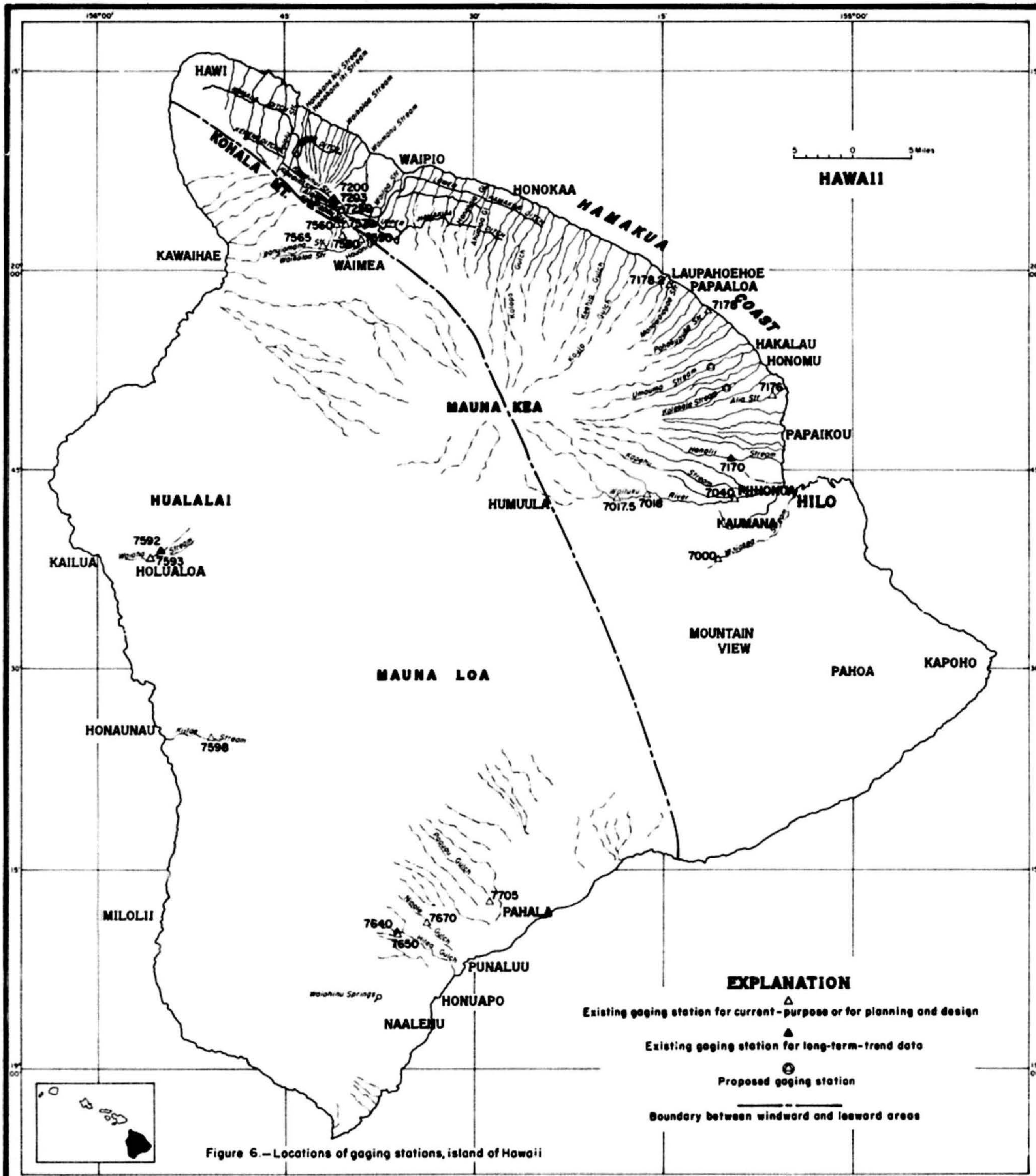

Figure 6.—Locations of gaging stations, island of Hawaii

APPENDIX

Table A-1.--Classification of existing streamflow stations and those proposed for the network

Column 1: B, benchmark or long-term-trend station.

Column 2: C, current-purpose station.

Columns 3-5: Purposes for which current-purpose station is operated; 1, assessment; 2, operation; 3, forecasting; 4, disposal; 5, water quality; 6, compact or legal; 7, research or special studies.

Column 6: P, principal-stream station; H, hydrologic station to meet objective of defining regional streamflow characteristics except when classified as P; R, regulated-stream station which provides data required for a systems analysis of regulated flow; ( ), station is no longer required for the purpose indicated.

Column 7: Effect of regulation or diversion on low and monthly flow; --, no appreciable effect; 1, no appreciable effect on daily flow (diurnal fluctuation only); 2, no appreciable effect on weekly flows; 3, monthly flow not affected by more than 10 percent of natural conditions; 4, monthly flow affected, but published data available to adjust to natural conditions with an error of less than 10 percent; 5, effect of regulation has not been evaluated; 6, effect on daily flow is more than 10 percent; 7, effect on weekly flow is more than 10 percent; 8, monthly flow affected by more than 10 percent and data not available to adjust to natural conditions with an error of less than 10 percent; 9, effect varies by month or season.

Column 8: Effect of regulation on peak flow; --, no appreciable effect; 1, annual peak flow affected by less than 10 percent; 2, annual peak flow affected by more than 10 percent; 3, annual peak flow affected by an undetermined amount.

Column 9: Financing of station; 1, U.S. Geological Survey; 2, cooperative program; 3, other Federal agency; 4, combination of 1 and 2; 5, combination of 1 and 3; 6, combination of 2 and 3; 7, combination of 1, 2, and 3.

Station number	Station name	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
16-0100	Kawaikoi Stream near Waimea		C	1			H	--	--	2
16-0190	Waialae Stream at altitude 3,820 ft, near Waimea	B	C	1			H	--	--	1
16-0310	Waimea River near Waimea		C	1	7		P	8	1	2
16-0360	Makaweli River near Waimea		C	1	7			8	1	2
16-0490	Hanapepe River below Manuahi Stream, near Eleele		C	1	6		P	8	1	2
16-0525	Lawai Stream near Koloa		C	7			H	9	1	2
	Kamooloa Stream near Koloa	B								
16-0600	South Fork Wailua River near Lihue		C	6	1		P	4	1	2
16-0630	North Fork Wailua River at altitude 650 ft, near Lihue		C	6	1	2	P	4	1	2
16-0680	East Branch of North Fork Wailua River near Lihue	B	C	6	2	1	H	--	--	2
16-0710	North Fork Wailua River near Kapaa		C	7	1		P	4	1	3
16-0715	Left Branch Opaekaa Stream near Kapaa						H	--	--	2
16-0800	Kapaa Stream at Kapahi ditch intake, near Kapaa		C	6	1	2		5	1	2
16-0890	Anahola Stream near Kealia		C	6	2	1		5	1	2
16-0932	Anahola Stream at Anahola		C	7	1			8	1	3
16-0970	Pohakuhonu Stream near Kilauea		C	1	2			8	1	2
16-0975	Halaulani Stream at altitude 400 ft, near Kilauea	B					H	--	--	2
	Kalihiwai River near Kilauea						H			
16-1030	Hanalei River near Hanalei		C	7	1		P	4	1	3
16-1080	Wainiha River near Hanalei	B					H	--	--	2
	Manoa Stream near Haena						H			
16-1300	Mahomalu Valley near Mana		C	7			(H)	--	--	2
16-2000	North Fork Kaukonahua Stream above Right Branch, near Wahiawa	B					H	--	--	2
16-2080	South Fork Kaukonahua Stream at East Pump Reservoir, near Wahiawa		C	1	6		P	5	1	2
16-2085	Right Branch of South Fork Kaukonahua Stream near Wahiawa		C	1	6		P	8	3	2
16-2116	Makaha Stream near Makaha	B					H	--	--	2
16-2118	Kaupuni Stream at altitude 374 ft, near Waianae		C	7				5	1	2
16-2128	Kipapa Stream near Wahiawa		C	7			H	--	--	2
16-2130	Waikele Stream at Waipahu		C	7	5		P	8	1	2
16-2160	Waiawa Stream near Pearl City		C	7	5	1		8	1	2
16-2245	Kalauao Stream at Moanalua Road, at Aiea		C	7				5	--	2
16-2260	North Halawa Stream near Aiea	B					(H)	--	--	2
16-2275	Moanalua Stream near Kaneohe		C	7	5	1	H	--	--	2
16-2277	Moanalua Stream tributary near Kaneohe		C	7	5	1	H	--	--	2
16-2280	Moanalua Stream near Honolulu		C	7	5	1	H	--	--	2
16-2289	Kalihi Stream near Kaneohe		C	7	1		(H)	--	--	2
16-2290	Kalihi Stream near Honolulu	B					H	2	--	1
16-2293	Kalihi Stream at Kalihi		C	7	1		H	2	--	6
16-2320	Nuuanu Stream below reservoir 2 wasteway, near Honolulu		C	1	7			8	3	2
16-2385	Waihi Stream at Honolulu		C	1			H	--	--	2
16-2405	Waiakeakua Stream at Honolulu		C	1			H	3	--	2
16-2440	Pukele Stream near Honolulu		C	1			H	--	--	2
16-2470	Palolo Stream near Honolulu		C	7			H	--	--	3
16-2540	Makawao Stream near Kailua		C	7			(H)	3	--	2
16-2605	Maunawili Stream at Highway 61, near Kailua		C	7	5		(H)	3	--	2
	Kawa Stream near Kaneohe						H			
16-2709	Luluku Stream at altitude 220 ft, near Kaneohe		C	7				3	--	2
16-2739	Kamooalii Stream at Kaneohe		C	7	5		P	1	--	6
16-2750	Haiku Stream near Heeia		C	7	1	2	H	3	--	2
16-2830	Kahaluu Stream near Heeia		C	1	7		(H)	5	--	2

Table A-1.--Classification of existing streamflow stations and those proposed for the network--Continued

Station number	Station name	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
16-2836	South Fork Waihee Stream near Heeia		C	7	1			5	--	2
16-2837	North Fork Waihee Stream near Heeia		C	7	1		H	--	--	2
16-2840	Waihee Stream near Heeia		C	7	1			5	--	2
16-2845	Waihee Stream at Kahaluu		C	5	7			8	1	2
16-2949	Waikane Stream at altitude 75 ft, at Waikane		C	7	1		H	3	--	2
16-2965	Kahana Stream at altitude 30 ft, near Kahana		C	7	1		H	3	--	2
16-3030	Punaluu Stream near Punaluu	B					P	4	--	2
16-3042	Kaluanui Stream near Punaluu		C	7			H	--	--	2
16-3089.9	Malaekahana Stream near Laie						(H)	--	--	2
16-3250	Kamananui Stream at Pupukea Military Road, near Maunawai		C	1			H	--	--	2
16-3300	Kamananui Stream at Maunawai						H	--	--	2
16-3430	Helemano Stream at Haleiwa		C	7				8	--	3
16-3450	Opaeula Stream near Wahiawa						H	--	--	2
16-4000	Halawa Stream near Halawa	B					P	--	--	2
16-4039	Kawainui Stream near Pelekunu		C	7			H	--	--	2
16-4040	Pelekunu Stream near Pelekunu		C	7			H	--	--	2
16-4042	Pilipililau Stream near Pelekunu		C	7			H	--	--	2
16-4055	Waikolu Stream at altitude 900 ft, near Kalaupapa		C	7	1			4	--	2
16-4080	Waikolu Stream below pipeline crossing, near Kalaupapa		C	1				4	--	2
16-4114	Kakaako Gulch near Mauna Loa	B	C	7				--	--	2
16-4140	Kaunakakai Gulch at Kaunakakai	B	C	1			H	--	--	3
16-4150	East Fork Kawela Gulch near Kamalo		C	1				8	1	2
16-4160	Punaula Gulch near Pukoo		C	1			H	--	--	2
	Waialua Stream near Waialua						H			
16-4195	Papio Gulch at Halawa		C	7	1			8	--	2
16-5001	Kepuni Gulch near Kahikinui House		C					--	--	2
	Kukuiula Stream near Kipahulu						H			
16-5010	Palikea Stream below diversion dam, near Kipahulu						H	--	--	2
	Oheo Gulch near Kipahulu	B								
	Wailua Stream near Kipahulu						H			
	Makapipi Stream near Nahiku						H			
16-5080	Hanawi Stream near Nahiku	B	C	2	6	1	H	--	--	2
16-5180	West Wailuaiki Stream near Keanae		C	2	1	6	H	--	--	2
	Waiakamilo Stream near Wailua						H			
16-5450	Puohokamoa Stream above Spreckels ditch, near Huelo		C	2	1	6	(H)	1	--	2
16-5700	Nailiilihaele Stream near Huelo	B	C	2	1	6	H	--	--	2
16-5745	Kailua Stream near Kailiili		C	7	1			--	--	2
16-5850	Hoolawanui Stream near Huelo		C	2	1	6	(H)	--	--	2
16-5870	Honopou Stream near Huelo		C	2	1	6	H	--	--	2
16-5962	Halehaku Gulch near Kailiili		C	2	6			--	--	2
16-6024	Awalau Gulch at Kailiili		C	2	6			8	3	2
	Waihee River near Wailuku	B								
16-6200	Honokohau Stream near Honokohau	B					P	--	--	2
16-6385	Kahoma Stream at Lahaina		C	7				8	1	3
16-6462	Olowalu Stream at Olowalu		C	7				8	1	2
	Ukumehame Stream near Olowalu	B								
16-7000	Waiakea Stream near Mountain View						H	--	--	2
16-7017.5	Wailuku River near Humuula		C	1			P	--	--	2
16-7018	Wailuku River near Kaumana		C	1			P	--	--	2
16-7040	Wailuku River at Piihonua		C	1			P	8	--	2
16-7170	Honolii Stream near Papaikou	B					H	--	--	1
16-7176	Alia Stream near Hilo		C	7				8	1	2
	Kolekole Stream near Honomu						H			
	Umauma Stream near Hakalau						H			
16-7178	Pohakupuka Stream near Papaaloa		C	7				8	1	2
16-7178.2	Manowaiopae Stream near Laupahoehoe		C	7				8	1	2
16-7200	Kawainui Stream near Kamuela	B	C	2			H	--	--	2
16-7203	Kawaiki Stream near Kamuela		C	2			H	--	--	2
16-7250	Alakahi Stream near Kamuela		C	2			H	--	--	2
16-7560	Kohakohau Stream near Kamuela		C	2	1			5	--	2
16-7565	Keanuiomano Stream near Kamuela		C	2	7		H	5	--	2
16-7570	Waikoloa Stream near Kamuela		C	1	7		(H)	--	--	2
16-7580	Waikoloa Stream at Marine Dam, near Kamuela		C	1	7		H	5	--	2
16-7590	Hauani Gulch near Kamuela		C	1	7			5	--	2
16-7592	Right Branch Waiaha Stream near Holualoa	B	C	1			H	--	--	2
16-7593	Waiaha Stream at Luawai, near Holualoa		C	7				5	2	2
16-7598	Kiilae Stream near Honaunau		C	1	7		H	--	--	2
16-7640	Hilea Gulch tributary near Honuapo	B	C	1			H	--	--	2
16-7650	Hilea Gulch tributary No. 2 near Honuapo		C	1			H	--	--	2
16-7670	Ninole Gulch near Punaluu		C	1	7		H	--	--	2
16-7705	Paauau Gulch at Pahala		C	7	1			5	1	2

Table A-2.--Basin characteristics for gaging stations used in regression analysis

Station number	Drainage area A	Stream length L	Elevation E	Range in elevation R	Gentle slope G	Vegetative cover F	Areas of swamp S_t	Precipitation P	Precipitation intensity $I_{24,2}$
16-0100	4.1	6.41	3,845	860	48	58	42	146	8.5
16-0130*	1.6	4.42	3,915	820	33	72	28	135	8.6
16-0170*	3.33	4.69	4,250	730	83	18	82	148	9.3
16-0190	2.5	4.35	4,355	890	69	31	69	157	9.3
16-0490	18.8	9.14	2,020	4,220	5	95	0	162	7.4
16-0680	6.2	4.30	1,390	2,650	34	100	0	151	9.4
16-0975	1.1	2.14	1,110	2,210	59	82	8	150	9.1
16-1010*	7.4	4.55	3,150	4,420	19.5	98	.5	271	10.7
16-1050*	1.5	2.88	2,220	3,860	13	100	0	165	10.7
16-1060*	5.93	3.81	2,275	3,840	13	100	0	262	10.5
16-1080	10.2	6.95	3,210	4,240	30	73	27	247	10.2
16-1150*	2.6	3.51	2,990	3,800	2	100	0	123	8.8
16-1160*	1.1	2.92	3,445	3,580	5	100	0	107	8.2
16-1170*	1.6	1.40	2,890	3,300	12	99	0	96	7.7
16-2000	1.38	4.65	1,750	1,490	4	100	0	241	10.0
16-2010*	1.2	4.50	1,700	1,240	3	100	0	241	10.0
16-2060*	1.93	5.47	1,650	960	7	100	0	222	10.0
16-2110*	1.79	6.10	1,700	1,410	24	100	0	185	9.9
16-2128	4.29	8.51	1,515	1,890	11	96	0	174	8.5
16-2230*	6.07	9.57	1,000	2,320	22	90	0	110	6.7
16-2245	2.59	7.95	1,020	2,730	28	89	0	95	7.3
16-2260	3.45	4.82	1,410	2,240	14	100	0	111	7.7
16-2280	2.73	4.10	1,215	2,140	23	99	0	121	7.4
16-2290	2.61	2.72	1,130	2,200	38	100	0	122	7.0
16-2385	1.14	2.05	1,305	2,810	32	99	0	150	8.0
16-2405	1.06	1.61	1,240	2,000	15	99	0	145	8.0
16-2440	1.18	2.35	1,180	1,850	20	86	0	120	7.8
16-2460*	1.04	2.41	1,230	1,830	15	94	6	110	7.6
16-2750	.97	1.04	1,210	1,610	37	96	0	100	6.3
16-2780*	.29	.65	1,440	2,380	10	100	0	98	6.0
16-2840	.93	1.04	1,080	2,050	30	100	0	140	7.2
16-3030	2.78	3.02	1,160	2,530	31	100	0	222	7.4
16-4000	4.62	4.60	2,270	3,410	58	100	0	92	7.0
16-4020*	4.38	3.22	2,250	3,760	11	100	0	194	8.0
16-4030*	1.41	1.39	1,820	2,800	17	100	0	179	8.0
16-4040	2.62	1.95	2,420	3,950	1	100	0	110	7.2
16-4050*	1.09	1.54	2,150	4,110	1	100	0	145	8.0
16-4080	3.68	4.06	2,670	4,050	24	100	0	77	6.4
16-4140	6.57	9.33	2,310	3,940	60	39	0	47	5.3
16-4160	.24	1.0	2,320	1,850	62	100	0	125	7.4
16-5010	6.29	6.14	4,320	6,010	39	99	0	140	8.0
16-5020*	.43	2.08	2,470	2,940	40	82	0	140	7.4
16-5080	3.49	5.85	4,630	6,620	64	88	0	190	9.8
16-5100*	.69	2.02	2,100	1,330	100	100	0	325	10.6
16-5150*	.32	3.85	2,490	2,960	100	100	0	285	12.0
16-5160*	4.31	6.30	4,600	6,790	45	75	0	165	9.8
16-5170*	3.11	5.80	4,340	6,970	60	83	1	225	9.9
16-5180	3.66	6.28	4,795	7,360	54	81	0	190	9.7
16-5190*	1.93	6.13	4,650	6,210	41	83	0	200	9.7
16-5200*	.51	2.45	2,115	1,600	78	100	0	340	12.0
16-5240*	2.54	5.35	5,425	5,380	67	100	0	135	9.8
16-5270*	3.17	6.70	4,810	6,550	67	100	0	150	10.6
16-5360*	1.16	5.75	3,610	4,570	73	100	0	280	10.8
16-5450	2.35	6.15	3,100	4,300	57	100	0	290	11.8
16-5550*	3.92	9.90	5,420	8,030	67	49	0	110	9.9
16-5570*	.47	1.93	1,900	1,270	62	100	0	275	11.9
16-5650*	.64	3.01	2,125	1,890	71	100	0	350	11.7
16-5660*	.22	1.40	1,665	860	65	100	0	285	10.2
16-5700	3.49	7.73	3,400	5,660	85	94	0	300	10.6
16-5740*	.8	2.4	3,850	1,890	99	100	0	220	10.0
16-5770*	2.49	5.83	3,170	3,720	83	100	0	260	10.7
16-5850	1.34	4.55	2,350	2,300	95	100	0	215	10.2
16-5860*	.55	2.30	1,815	2,200	98	100	0	215	10.1
16-5870	.64	2.00	1,790	1,050	67	100	0	175	9.9
16-6170*	.4	1.55	2,180	1,500	28	99	0	210	7.5
16-6180*	3.47	4.70	2,285	4,100	27	92	8	220	8.2
16-6200	4.11	5.75	3,190	4,820	5	99	1	150	10.6
16-6360*	1.51	3.65	3,350	4,620	20	100	0	106	6.5
16-7370*	.58	2.91	3,735	1,800	86	100	0	200	8.0
16-7390*	.62	3.15	3,150	2,190	69	100	0	200	8.0
16-7400*	.13	.78	2,340	800	69	100	0	200	8.0
16-7410*	.32	1.78	2,565	1,530	78	100	0	200	8.0
16-7420*	.21	1.50	2,585	1,240	76	100	0	200	8.0
16-7560	2.51	4.57	4,505	2,040	78	100	0	127	6.2
16-7570	.78	1.82	3,870	720	95	100	0	123	6.4

* Discontinued station.

Table A-3.--Summary of regression equations, windward areas

$$\left[Y = aA^{b_1} L^{b_2} E^{b_3} R^{b_4} G^{b_5} F^{b_6} S_t^{b_7} P^{b_8} I_{24,2}^{b_9} \right]$$

Flow characteristic Y	Regression constant a	Exponent of basin characteristic									Standard error of estimate (percent)
		Drainage area b_1	Stream length b_2	Elevation b_3	Range in elevation b_4	Gentle slope b_5	Vegetative cover b_6	Areas of swamp b_7	Precipitation b_8	Precipitation intensity b_9	
Q_2	1.34×10^{1}	0.870							0.763		55
Q_5	5.83×10^{4}	.824	0.538	-0.564*							51
Q_{10}	8.00×10^{4}	.851	.433*		-0.537*						51
Q_{25}	2.05×10^{3}	.775									58
Q_{50}	2.47×10^{3}	.762									63
q_a	1.50×10^{-2}	.949							.588	0.850*	34
SD_a	5.50×10^{-1}	.750								1.278	36
q_{10}	1.03	1.024		-.325*					.851		36
q_{11}	2.16×10^{-1}	1.004		-.286*					.458*	1.327	34
q_{12}	1.07×10^{-2}	.965							.497*	1.030*	36
q_1	1.76	1.011		-.294*						1.829	38
q_2	2.74×10^{-2}	1.001							.490*	1.353	34
q_3	6.18×10^{-1}	.925							.839		34
q_4	1.77×10^{-2}	.913							.577	1.091*	35
q_5	1.32×10^{-1}	.985		-.407					.478*	1.436	37
q_6	1.14	1.015		-.373*					.873		44
q_7	2.17×10^{-2}	.955							.982		45
q_8	2.62×10^{-2}	.958							1.035		40
q_9	1.33	1.010		-.532					.529*	1.286*	39
SD_{10}	2.76×10^{-2}	.606	0.592						.825		27
SD_{11}	8.71×10^{-1}	.892							1.798		41
SD_{12}	2.44×10^{-3}	.838	.365*							2.149	39
SD_1	3.08×10^{-2}	1.020						-0.353		2.464	45
SD_2	2.26×10^{-3}	.955						-.275		3.313	41
SD_3	1.44×10^{-4}	.730		0.644					.868		42
SD_4	1.35×10^{-2}	.746	.424						.809		39
SD_5	1.93	.758	.492*	-.543				-.180*		2.185	34
SD_6	3.44×10^{-2}	.763								2.171	45
SD_7	4.10×10^{-2}	.791								2.284	40
SD_8	3.83×10^{-2}	.594	.704			-0.138*		-.198*	.968		37
SD_9	3.53×10^{-3}	.847								3.129	38
$V_{1,2}$	1.09	.868								2.207	36
$V_{7,2}$	3.84×10^{-1}	.839								2.400	36
$V_{1,50}$	3.77×10^{3}	.865					-1.208*	-.242*	.647		38
$V_{7,50}$	1.58×10^{-2}	.773		.542					.700		39
$M_{7,2}$	5.38×10^{3}	1.184		-1.517		-.296*			.882*		81
$M_{30,2}$	4.36×10^{2}	1.146		-1.183		-.225*			.892		73
$M_{7,20}$	1.91×10^{4}	1.236		-1.781		-.442			1.012*		114
$M_{30,20}$	2.51×10^{3}	1.187		-1.496		-.382			.997*		102

* Significant at 0.05 level, all others significant at 0.01 level.

Table A-4.--Summary of regression equations, leeward areas

$$\left[Y = aA^{b_1} L^{b_2} E^{b_3} R^{b_4} G^{b_5} F^{b_6} S_t^{b_7} P^{b_8} I_{24,2}^{b_9} \right]$$

Flow characteristic Y	Regression constant a	Exponent of basin characteristic									Standard error of estimate (percent)
		Drainage area b_1	Stream length b_2	Elevation b_3	Range in elevation b_4	Gentle slope b_5	Vegetative cover b_6	Areas of swamp b_7	Precipitation b_8	Precipitation intensity b_9	
Q_2	1.33×10^{-2}	0.884				0.306*			1.640		42
Q_5	3.41×10^{-1}	.892				.317*			1.460		47
Q_{10}	2.40×10^{-1}	.891				.321*			1.436		50
Q_{25}	2.10	.965		-0.611*		.593			1.918		49
Q_{50}	2.85	.970		-.693*		.629			1.992		52
q_a	6.93×10^{-8}	.746		1.057	0.154				2.783	-1.588*	28
SD_a	1.39×10^{-6}	1.124	-0.332*	.621					1.587		20
q_{10}	2.44×10^{-9}	.754		.724	.192	.238*			3.433	-1.923*	31
q_{11}	3.86×10^{-7}	.799		.940	.149				1.756		25
q_{12}	3.18×10^{-8}	.811		1.258	.134				1.729		28
q_1	9.95×10^{-8}	1.140	-.594*	1.285	.127*				2.013		33
q_2	1.21×10^{-7}	.813		.787	.150*			0.177*	3.099	-3.311*	34
q_3	1.42×10^{-8}	.801		1.033	.201				1.801		23
q_4	1.26×10^{-9}	.702		1.023	.120*				2.367		35
q_5	1.36×10^{-8}	.785				.377*			3.384		56
q_6	8.51×10^{-11}	1.222	-1.324	1.165					3.769		60
q_7	1.24×10^{-10}	.614		.882					4.473	-3.124*	57
q_8	1.62×10^{-9}	.673		.829					4.235	-3.290	44
q_9	5.38×10^{-10}	1.249	-1.197	.958					3.518		49
SD_{10}	5.40×10^{-5}	.956				.336			2.179		35
SD_{11}	7.10×10^{-4}	1.016			.092*	.278			1.128		22
SD_{12}	2.69×10^{-7}	1.203	-.347*	.905	.119	.169*			1.686		20
SD_1	3.48×10^{-8}	1.426	-.869*	1.182					2.138		59
SD_2	2.45×10^{-6}	.997		.697					1.735		50
SD_3	5.10×10^{-6}	.926		.722	.233				1.507		29
SD_4	2.13×10^{-7}	.902		.753	.116*				1.886		28
SD_5	7.83×10^{-6}	1.003				.278*			2.796		42
SD_6	1.70×10^{-11}	1.230	-.975	1.150			0.582		2.770		32
SD_7	4.38×10^{-7}	.787		.568					3.225	-1.993*	35
SD_8	3.44×10^{-7}	.895		.543			.690*	.255	2.783	-2.380*	32
SD_9	3.53×10^{-8}	1.399	-1.029*	.603*					2.940		61
$V_{1,2}$	3.30×10^{-3}	.946		.554					1.239		30
$V_{7,2}$	2.36×10^{-5}	.967		.732	.086*				1.472		25
$V_{1,50}$	1.54×10^{-4}	1.107		.432*		.252*			1.799		34
$V_{7,50}$	3.40×10^{-4}	.974		.735					1.419		35
$M_{7,2}$	6.17×10^{-9}							.859	10.302	-15.622	238
$M_{30,2}$	6.86×10^{-10}							.788	10.326	-14.149	226
$M_{7,20}$	1.66×10^{-13}				.967*			1.305	11.645	-19.248	546
$M_{30,20}$	1.06×10^{-7}						-3.020*		11.162	-14.278	360

* Significant at 0.05 level, all others significant at 0.01 level.