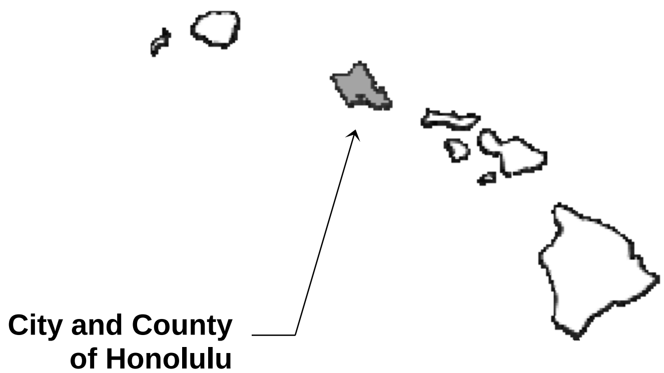
FLOOD INSURANCE STUDY

VOLUME 1 OF 4

CITY AND COUNTY OF HONOLULU, HAWAII



Community Name	Community Number
CITY AND COUNTY OF HONOLULU	150001

REVISED
November 5, 2014

Federal Emergency Management Agency
FLOOD INSURANCE STUDY NUMBER
15003CV001C

NOTICE TO
FLOOD INSURANCE STUDY USERS

Communities participating in the National Flood Insurance Program have established repositories of flood hazard data for floodplain management and flood insurance purposes. This Flood Insurance Study (FIS) may not contain all data available within the repository. It is advisable to contact the community repository for any additional data.

Part or all of this FIS may be revised and republished at any time. In addition, part of this FIS may be revised by the Letter of Map Revision process, which does not involve republication or redistribution of the FIS. It is, therefore, the responsibility of the user to consult with community officials and to check the community repository to obtain the most current FIS components.

This FIS report was revised on the Revised FIS Dates shown below. Users should refer to Section 10.0, Revisions Description, for further information. Section 10.0 is intended to present the most up-to-date information for specific portions of the FIS report. Therefore, users of this FIS report should be aware that the information presented in Section 10.0 supersedes information in Sections 1.0 through 9.0 of this FIS report.

Initial FIS Effective Date: November 20, 2000

Revised FIS Dates: September 30, 2004
June 2, 2005 (Flood Insurance Rate Maps only)
January 19, 2011
November 5, 2014 – To change special flood hazard areas, to change base flood elevations, to add new detailed study areas, and to reflect updated topographic information.

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FLOOD INSURANCE STUDY
CITY AND COUNTY OF HONOLULU, HAWAII

1.0 INTRODUCTION

1.1 Purpose of Study

This Flood Insurance Study (FIS) revises and updates information on the existence and severity of flood hazards in the geographic area of the City and County of Honolulu, Hawaii.

This FIS aids in the administration of the National Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973. This study has developed flood risk data for various areas of the county that will be used to establish actuarial flood insurance rates. This information will also be used by Honolulu to update existing floodplain regulations as part of the Regular Phase of the National Flood Insurance Program (NFIP), and will also be used by local and regional planners to further promote sound land use and floodplain development. Minimum floodplain management requirements for participation in the NFIP are set forth in the Code of Federal Regulations at 44 CFR, 60.3.

In some States or communities, floodplain management criteria or regulations may exist that are more restrictive or comprehensive than the minimum Federal requirements. In such cases, the more restrictive criteria take precedence and the State (or other jurisdictional agency) will be able to explain them.

1.2 Authority and Acknowledgments

The sources of authority for this FIS are the National Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973.

The hydrologic and hydraulic analyses for the original FIS were performed by the R. M. Towill Corporation, under subcontract to the Pacific Ocean Division, U.S. Army Corps of Engineers (USACE), for the Federal Emergency Management Agency (FEMA), under Interagency Agreement No. IAA-H-10-77, Project Order No. 19. That work was completed in August 1976 for riverine flooding and October 1979 for tsunami flooding.

The hydrologic and hydraulic analyses for the McCully Area and the Moiliili Area were performed by M&E Pacific, Inc., under subcontract to the USACE, for FEMA, under Inter-Agency Agreement No. (DACW) 84-77-C-0069, Work Order No. 2, Part 2. Those analyses were completed in February 1979.

The hydrologic and hydraulic analyses for Moanalua and Kahauiki Streams were prepared at the request of the U.S. Army Support Command, Hawaii, Directorates of Facilities Engineering and of Housing, through the USACE. That work was completed in 1982.

The hydrologic and hydraulic analyses for additional streams were performed by the R. M. Towill Corporation, for FEMA, under Contract No. EMW-83-C1186. Streams that were included in that portion of this study, whose work was completed in April 1985, are as follows:

Ahuimanu Stream	Makaleha Stream
Aiea Stream	Malaekahana Stream (revised November 5, 2014)
Haiamoa Stream	Nuuanu Stream
Honouliuli Stream	Unnamed Stream
Kaalaea Stream	Waihee Stream
Kahaluu Stream	Waikele Stream
Kalauao Stream	Waolani Stream
Kalihi Stream	
Kawainui Stream	

The hydrologic and hydraulic analyses for other additional streams in this study were performed by the R. M. Towill Corporation for FEMA, under Contract No. EMW-86-C-2228. That work was completed in March 1989 for riverine flooding in the areas of the following streams:

Kaelepulu Stream Tributary	Ulehawa Stream
Kaloi Gulch	Waikakalaua Stream
Nanakuli Stream	Wailele Stream Right and Left Overbanks
North Halawa Stream	

The hydrologic and hydraulic analyses for Kamanaiki Stream and the portions of Kalihi Stream above North School Street were performed by the R. M. Towill Corporation for FEMA, under Contract No. EMW-88-C-2606. That work was completed in May 1989.

The hydrologic and hydraulic analyses in the September 30, 1995, restudy for Kapakahi Stream #2, Makaha Stream, West Makaha Stream, and Wailani Drainage Canal were performed by R. M. Towill. The work was compiled in July 1993. Additional description of this revision to the original FIS is included in Section 10.

The November 20, 2000, revision converted the FIRM for the City and County of Honolulu, Hawaii, to countywide digital format. It also incorporated hydrologic and hydraulic analyses for Waiawa Stream, overflow area of Waiawa Stream, Panakauahi Gulch, Moanalua Stream, and Manaiki Stream were performed by the R. M. Towill Corporation for FEMA under Contract No. EMW-93-C-4221. That work was completed in May 1997. The information prepared by R. M. Towill Corporation was modified by Michael Baker Jr., Inc., to conform to current

FEMA standards. The modifications were completed in August 1999. Additional description of this revision to the original FIS is included in Section 10.

The September 30, 2004, countywide revision had base map information shown on the FIRM that was provided in digital format by the City and County of Honolulu Department of Planning and Permitting, Honolulu Land Information System (HoLIS). Imagery was derived from U.S. Geological Survey (USGS) Digital Orthophoto Quadrangles produced at a scale of 1:12,000 from photography dated 2001 or later, except on panels 0090, 0105, 0195, 0351, 0352, 0353, 0354, and 0370 where this imagery was not available; therefore, Digital Line Graphs submitted by the County of Honolulu were used. Street centerlines and surface water features were compiled at a scale of 1:4,800 from orthophotography dated 2001.

The January 19, 2011 revision was performed to incorporate new ortho-imagery available for portions of City and County of Honolulu from mosaicked 2-foot ground resolution satellite imagery that meets 1:12,000 scale horizontal accuracy standards provided by DigitalGlobe and the United State Department of Agriculture Natural Resources Conservation Service. This information was collected between April 2005 and July 2006. This revision also included new detailed coastal hurricane storm surge and wave height analysis and approximate analyses of "behind levee" flooding. That work was performed by the RMTC/URS a Joint Venture for FEMA Region IX under Contract No. EM-2003 CO -0046.

This revision (November 5, 2014) to the FIS report was originally planned for BakerAECOM to perform a “with and without levee analysis’ for levee systems along Keaahala and Waialae-nui Streams. During the project coordination meeting held with the County on August 24, 2010, the County contended that levees do not exist along Keaahala Stream. A field investigation conducted in December of 2010 confirmed Keaahala Stream does not have any levees. A separate field investigation also confirmed that levees do not exist along Waialae-Nui Stream. Therefore, this study was modified such that new detailed studies (hydrologic and hydraulic) on these reaches were performed as a result of this new information. BakerAECOM also performed, as part of this revised FIS, Independent QA/QC and subsequent mapping incorporation of the Kaiwainui Marsh Flood Control Project study and the Keaaulu Gulch and Malaekahana Stream studies performed by the USACE. The USACE studies included both hydrologic and hydraulic analyses. Finally, BakerAECOM also performed new hydrologic and hydraulic analyses for approximately 5 stream miles of previous Zone A flood zones and replaced with Zone AE. These previous Zone A streams include Wailele Stream, Kaupuni Stream, Mailiili Channel, Maili Channel, Waimalu Stream, Oneawa Channel (scoped as Kawainui Canal and part of the USACE Kawainui Marsh Flood Control Project study), JCIP Drainage Canal (scoped as Drainage Canal), Halawa Stream, and Waimanalo: Stream A. This work was perfomed by BakerAECOM under contract HSFEHQ-09-D-0368. Additional description of this revision is included in Section 10.

1.3 Coordination

Consultation Coordination Officer's (CCO) meetings may be held for each community described in this countywide FIS. An initial CCO meeting is typically held with representatives of FEMA, the community, and the study contractor to explain the nature and purpose of the FIS and to identify the streams to be studied by detailed methods. A final CCO meeting is typically held with representatives of FEMA, the community, and the study contractor to review the results of the study.

The USACE, the USGS, and the Soil Conservation Service (SCS) supplied information for the Septemeber 30, 2004 and January 19, 2011 studies. The USACE, the City and County of Honolulu, the USGS, and the SCS supplied information for the November 5, 2014, study.

The date of the initial and final CCO meetings held for City and County of Honolulu are shown in Table 1, "Initial and Final CCO Meetings."

Table 1: Initial and Final CCO Meetings

	For FIS Date	Initial	Intermediate	Final
City and County of Honolulu	September 3, 1980	March 1, 1976	February 23, 1977	October 12, 1977
	January 6, 1983	*	*	*
	September 4, 1987	April 26, 1983	*	March 8, 1985
	September 28, 1990	*	*	February 28, 1990
	September 30, 1995	*	*	August 4, 1994
	November 20, 2000	*	*	September 22, 1999
	September 30, 2004	September 16, 2003	*	May 2004
	January 19, 2011	June 12, 2008	*	August 27, 2009
	November 5, 2014	August 24, 2010	*	November 5, 2014

*Data not available

2.0 AREA STUDIED

2.1 Scope of Study

This FIS covers the Island of Oahu, which is incorporated as the City and County of Honolulu, Hawaii.

The areas studied by detailed methods were selected with priority given to all known flood hazard areas and areas of projected development and proposed construction.

Table 2: Flooding Sources Studied by Detailed Methods

Aina Haina Area
Kului Stream
Wailupe Stream

Hauula-Punaluu Area
Hanahimoa Stream
Kaipapau Stream
Kaluanui Stream
Punaluu Stream
Wailele Stream
Waipilopilo Stream

Heeia Area
Heeia Stream

Kaaawa Area
Kaaawa Stream

Waialae-Kahala Area
Kapakahi Stream
Kapakahi Stream #2
Waialae-Iki Stream
Waialae-Nui Stream
Waialae Major Drain
Wailani Drainage Canal

Waialua-Haleiwa Area
Anahulu River
Helemano Stream
Kaukonahua Stream
Kiikii Stream
Opaeula Stream
Poamoho Stream
Paukauila Stream

Kahana Area
Kahana Stream

Kahuku Area
Hoolapa Stream
Kalaeokahipa Stream
Ohia Stream
Ohia Stream (East)

Kailua-Lanikai Area
Kaelepulu Stream

Kalihi-Moanalua Area
Kahauiki Stream
Kalihi Stream
Kamanaiki Stream
Moanalua Stream (Lower)
Moanalua Stream (Upper)

Lualualei Valley Area
Maili Channel
Mailiili Channel

McCully Area
Makiki Stream

Moiliili Area
Manoa Stream
Manoa-Palolo Drainage Canal
Palolo Stream

Nanakuli Area
Nanakuli Stream
Ulehawa Stream

Table 2: Flooding Sources Studied by Detailed Methods
(continued)

<u>Sunset Beach Area</u>	<u>Other Areas</u>
Pahipahialua Stream	Ahuimanu Stream
Paumalu Stream	Ahuimanu Stream Tributary
	Aiea Stream
<u>Waianae Valley Area</u>	Haiamoa Stream
Kaupuni Stream	Halawa Stream
	Honouliuli Stream
<u>Waikane-Waiahole Area</u>	JCIP Drainage Canal
Waiahole Stream	Kaalaea Stream
Waikane Stream	Kahaluu Stream
	Kalauao Stream
<u>Waikiki Area</u>	Kaloi Gulch
Ala Wai Canal	Kawainui Stream
	Kea'aulu Gulch
<u>Waimanalo Area</u>	Malaekahana Stream
Inoaole Stream	Malaleha Stream
Stream A	Manaiki Stream
Stream B	North Halawa Stream
Stream C	Nuuanu Stream
Stream D	Overflow area of Waiawa Stream
Waimanalo Stream	Oneawa Channel
	Parakauahi Gulch
<u>Waimea Area</u>	Unnamed Stream
Waimea River	Waiawa Stream
	Waihee Stream
<u>Kaneohe Area</u>	Waihee Stream Tributary
Kawa Stream	Waikele Stream
Keaahala Stream	Waikakalaua Stream
Tributary to Kawa Stream	Waimalu Stream
	Waolani Stream
<u>Makaha Area</u>	
East Makaha Stream	
Makaha Stream	
West Makaha Stream	

The entire coastline of the Island of Oahu was studied by detailed methods. The methodology employed to delineate inundation limits of tsunami of the selected recurrence intervals was agreed upon at the Tsunami Conference held on February 23, 1977.

A hurricane storm surge and wave height hazard using detailed methods was studied on the Island of Oahu from Kaena Point east to Kawaihoa Point. That work was completed in 2008.

The areas studied by detailed methods were selected with priority given to all known flood hazard areas and areas of projected development and proposed construction.

Some streams on the Island of Oahu, including portions of detailed-study streams, were also studied by approximate methods. Approximate analyses were used to study those areas having a low development potential or minimal flood hazards, as could be ascertained at the initiation of the study. Streams studied by approximate methods were not included in the analysis where the 1-percent annual chance flood event floodplain permanently narrows to less than 200 feet. The scope and methods of study were proposed to, and agreed upon by, FEMA and the City and County of Honolulu.

2.2 Community Description

The State of Hawaii legally consists of 132 islands with a total land area of 6,425 square miles. However, approximately 99.9 percent of this area (6,421.6 square miles) is contained within eight major islands. The eight major islands, their land areas, and their jurisdictional Counties are as follows:

Island	Land Area (Sq. Miles)	County
Hawaii	4,037.0	Hawaii
Maui	728.2	Maui
Oahu	592.7	Honolulu
Kauai	548.7	Kauai
Molokai	260.9	Maui
Lanai	139.5	Maui
Niihau (Privately Owned)	69.6	Kauai
Kahoolawe	45.0	Maui

The State of Hawaii is unique among all states in that it has only two levels of government: state and county. There are no smaller municipalities under the county level and no school districts.

The City and County of Honolulu is the capital of the State of Hawaii and its center of business. The resident population at the time of the 2007 census was 905,601.

The Island of Oahu, which is entirely within the City and County of Honolulu, has an extreme length of 44 miles, an extreme width of 30 miles and an extreme elevation of 4,020 feet (Mount Kaala). It has 209 miles of tidal shoreline and 79 percent of the land area is within 5 miles of the coastline. Approximately 45.3 percent of the land area is below an elevation of 500 feet and approximately 4.6

percent is above an elevation of 2,000 feet. The slopes of the land area are as follows:

42.5 percent of the land at slopes less than 10 percent
12.0 percent of the land at slopes 10 to 19 percent
45.5 percent of the land at slopes steeper than 20 percent

Approximately two-thirds of the land area is planned for agriculture (27.99 percent) and open space (40.68 percent). Urban areas, which include residential and nonresidential areas, constitute 17.11 percent, and the remaining 14.22 percent is under military jurisdiction.

The climate in Hawaii is comfortable year-round with little variation throughout the year. At the Honolulu International Airport, the average temperature for the coolest month is 72.4 degrees Fahrenheit (°F) and 79.4°F for the warmest month. Average annual precipitation at the airport is 21.89 inches.

A description of the areas studied by detailed methods follows.

Kahuku Area – Hoolapa, Kalaeokahipa, Ohia, and Ohia (East) Streams

The Kahuku study area is located on the north shore coastal plain and drains a portion of the northern slopes of the Koolau Mountains. Elevations in the study area range from sea level on the coastal plain to about 1,860 feet above sea level at the upper limits. There are three distinct intermittent gulches: Ohia, Kalaeokahipa, and Hoolapa, draining an area of about 7.6 square miles. The approximate 3.2 square miles of low-lying floodplain between the Kamehameha Highway and the coastline are primarily used for the cultivation of sugar cane. Approximately 20 percent of the area can be classified as swamp. An abandoned military airfield is also located in the northern section of the study area.

Hauula-Punaluu Area – Kaipapau, Waipilopilo, Hanahimoa, Kaluanui, Punaluu, and Wailele Streams

This study area includes an approximate 4.3-mile stretch of the narrow windward coastal plain bordered by Kahana Valley to the south and Laie to the north. Runoff originates in the upper Koolau Mountain Range and descends the steep slopes in deep, narrow ravines. The southern half of the Hauula-Punaluu study area is drained by Punaluu and Kaluanui Streams (an approximate 6.02 and 3.21 square miles of drainage area, respectively). Lesser streams, Hanahimoa and Kaipapau (an approximate 1.57 and 2.18 square miles of drainage area, respectively), in addition to Waipilopilo and Wailele, drain the northern half of the study area. An interconnected canal system drains the sugarcane fields along the coast. This system outlets through box culverts under the Kamehameha Highway. Nearly 75 percent of this study area is in a forest reserve, with the remaining land used for grazing, agriculture, and single-family residences. Mean annual rainfall is 80 inches.

Kahana Area – Kahana Stream

The Kahana Stream, with a drainage area of approximately 7.4 square miles, is located in the northeastern section of Oahu and flows northeasterly from its origin in the Koolau Mountains to its outlet at Kahana Bay.

Kaaawa Area – Kaaawa Stream

The Kaaawa Stream floodplain is on the east coast of Oahu, approximately 25 road miles north of downtown Honolulu. The Kaaawa and Makaha Streams drain an area of approximately 4.0 square miles. The upper half of the drainage basin is land dedicated as public watershed and forest reserve. The floodplain of approximately 200 acres is a low coastal plain. The floodplain forms the base of the triangular contributing area, the apex of which is approximately 2.5 miles from the base at an elevation of 1,012 feet (Local Tidal Datum). This area is characterized by the slopes of the Koolau Mountains. The Kaaawa floodplain is primarily residential in nature. The economy of this rural community is centered around agricultural activity, primarily truck farming, and the waterfront recreational facilities of the three public parks along the coast. In addition, many residents commute to jobs outside Kaaawa.

Waikane-Waiahole Area – Waikane and Waiahole Streams

The Waikane Stream drainage basin is located on the northeastern side of the Island of Oahu. The basin is irregular in shape and covers an area of approximately 3.6 square miles. Waikane Stream originates at an elevation of about 2,400 feet above sea level near the top of the Koolau Mountain Range and flows easterly for about 3.1 miles before discharging into the Pacific Ocean at Kaneohe Bay. The floodplain extends approximately 0.75 mile inland from Kaneohe Bay and is relatively flat. The upper drainage basin rises gradually from the floodplain to steep slopes sharply incised by erosion and covered by dense foliage. Waikane Stream is a perennial stream. The floodplain is used for agricultural purposes.

The Waiahole Stream drainage basin is situated between the Kaalaea and Waikane drainage basins on the northeastern side of Oahu. This somewhat fan-shaped basin covers approximately 3.91 square miles. Waiahole Stream begins near the 2,500-foot elevation, flows easterly through a sparsely populated and cultivated floodplain, and discharges into Kaneohe Bay.

The mean annual rainfall over the Waikane and Waiahole drainage basin is approximately 80 inches, ranging from 50 inches along the coastline to 200 inches at the higher elevations. Approximately 70 percent of the rainfall occurs between November and April.

Heeia Area – Heeia Stream

The Heeia drainage basin is on the northeastern side of the Island of Oahu. This irregularly shaped basin is approximately 3.6 square miles in area and extends approximately 3.2 miles from the ocean to the 2,826-foot (Local Tidal Datum) summit of the Koolau Mountains. The basin is hilly and rugged in the upper sections and terminates in a flat valley near the ocean. Three perennial streams, Heeia and its tributaries Haiku and Lolekaa, drain the area, and the storm runoff from these streams flows northeasterly.

The relatively high rainfall and moderate temperatures are conducive to dense plant growth. Grass, shrubs, and trees pervade the entire basin area. Approximately 40 percent of the upper basin is in a forest reserve and generally remains in its natural condition.

The approximately one square mile of low-lying floodplain between Kahakili and the Kamehameha Highway is used primarily for cattle grazing. Approximately 50 percent of the floodplain can be classified as swamp.

Kaneohe Area – Keaahala, Kaneohe, Kamooalii, Kawa and Tributary to Kawa Streams

The Kaneohe area is on the windward side of the Island of Oahu, approximately 10 miles north of downtown Honolulu. The area is bounded on the west by the Koolau Range, on the south by the Kaneohe (Halekou) volcanic cone, and on the north and east by Kaneohe Bay. A flat coastal plain extends inland from Kaneohe Bay for approximately 1.7 miles. Gently sloping land rises above the plain and continues to the foot of the Koolau Range. The Town of Kaneohe, which is within the central section of the area, is a major commercial center on windward Oahu.

Waimanalo Area – Waimanalo Stream, Waimanalo Streams A, B, C, and D, and Inoaole Stream

The Waimanalo area is located on the windward side of the island, approximately 13 miles northeast of downtown Honolulu. The area is within a valley bounded by the Koolau Range on the south, Aniani Nui Ridge including Keolu Hills on the west and north, and Waimanalo Bay on the east. The basin covers an area of approximately 10.9 square miles. The valley consists of a flat coastal plain along its mouth At Pacific Ocean, gently rising lands within its interior section, and steep mountain slopes along its edges. Residential and scattered commercial developments are located along the southern parts of the flat coastal plain of the valley and within Waimanalo Town located in the lower central part of the valley. Bellows Air Force Base, an inactive airfield, and Olomana Golf Course occupy the northern parts of the flat coastal plain of the valley. The upper interior section of the valley is devoted to agriculture.

<u>Aina Haina Area</u> – Wailupe and Kului Streams

The Wailupe Stream basin lies on the leeward slopes of the Koolau Mountains in southeastern Oahu. The rectangular basin has an area of approximately 3.2 square miles and is bounded by the coastal shoreline, Hawaii-Loa Ridge, Koolau Ridge, and Wiliwilinui Ridge. The upper two miles of the basin are relatively steep and rise to a maximum elevation of 2,600 feet (Local Tidal Datum). This portion of the basin is a forest reserve area and remains in its natural condition. The lower 1.5 miles are flatter and remains in its natural condition. The lower 1.5 miles are flatter and include the residential community of Aina Haina on the valley floor and along the coastline.

<u>Waialae-Kahala Area</u> – Waialae-Iki, Kapakahi #1, Waialae-Nui Streams and Waialae Major Drain

The Waialae-Kahala area is located in southeastern Oahu, within the metropolitan area of Honolulu. Waialae-Nui Stream has a drainage area of approximately 1.75 square miles; it flows into Kapakahi Stream #1 below the Kalanianaole Highway. Kapakahi Stream #1 has a drainage area of approximately 1.3 square miles above the confluence, and approximately 3.18 square miles at its mouth. The Waialae Major Drain, constructed by the City and County of Honolulu, is a concrete-lined open channel extending from the ocean to the Kalanianaole Highway. An underground box culvert is used upstream of the highway. At its mouth, the drain has a drainage area of approximately 2.1 square miles, and at its inlet section above the highway, approximately 0.8 square mile. Areas mainly residential in nature that drain into the Waialae-Kahala area include Diamond Head, Kaimuki, Wilhelmina Rise, Maunalani Heights, Waialae-Nui, and Ainakoa. Mean annual precipitation is about 35 inches.

<u>Kalihi-Moanalua Area</u> – Kalihi, Kamanaiki, Lower and Upper Moanalua and Kahauiki Streams

The Kalihi-Moanalua area is located on the southern coast of Oahu and has two major streams, Kalihi and Moanalua, which contribute to flood problems. The Kalihi Stream drainage basin lies within the City of Honolulu and extends about 6.1 miles from Keehi Lagoon to the leeward slopes of the Ko'olau Mountain Range, with elevations from sea level to approximately 2,650 feet (Local Tidal Datum), and drains an area of approximately 6.7 square miles. The floodplain, a low coastal area which extends about 1.0 mile inland from Keehi Lagoon, is relatively flat. The upper drainage basin rises gradually from the floodplain area to steep slopes sharply incised by erosion and covered by dense foliage. Kalihi Stream and its tributary, Kamanaiki Stream, are deep and steep in the upper area, and shallow and wide in the lower coastal area. The coastal area is densely populated and includes residential, commercial, and light- to heavy-industrial development. Moanalua Stream drains an area of approximately 9.8 square miles and is located on the western edge of the City of Honolulu. The drainage basin is an elongated rectangle, approximately 6.3 miles long, which varies in width from approximately 0.6 to 1.8 miles. The basin extends from the Ko'olau Mountains, at an elevation of over 2,000 feet (Local Tidal Datum) to the Pacific Ocean at Keehi Lagoon. Moanalua Stream has its origin and primary course in a sharply defined valley lying to the northwest of Moanalua Road. Manaiki Stream, a small tributary, meets Moanalua Stream above the Moanalua Road bridge, and the combined stream winds through the narrow, flat coastal plain until it joins Kahauiki Stream and outlets into the Keehi Lagoon. Within the coastal area there is an industrial area on the west bank of Moanalua Stream and a military reservation on the east bank.

<u>Makaha Area</u> – East and West Makaha Streams

The Makaha area is located on the western (leeward) coast of the Island of Oahu and is approximately 25 miles northwest of central Honolulu. The Makaha Stream Basin has a drainage area of approximately 9.2 square miles. Elevations in the basin range from sea level along the coast to over 4,000 feet at the summit of Mount Kaala. Average annual precipitation varies with topography in the basin, averaging 20 inches in the lower reaches to over 75 inches in the headwaters. There are three area streams that discharge into the ocean: Makaha Stream, which flows southwesterly, and two minor streams located north and south of Makaha Stream.

<u>Waialua-Haleiwa Area</u> – Kiikii, Kaukonahua, Poamoho, Paukauila, Helemano, and Opaeula Streams and the Anahulu River

The Waialua-Haleiwa study area along the northwestern coast of the Island of Oahu contains an area of approximately 96.5 square miles. Mean annual precipitation ranges from 30 inches in the coastal area to over 250 inches in the Koolau Mountains. Waialua and Haleiwa are adjoining communities located 30 road miles northwest of downtown Honolulu. Waialua is primarily a sugar plantation town. Haleiwa evolved from an old Hawaiian settlement to its present-day status as a residential, agricultural, and business community. Business activity consists mainly of service and retail establishments which are located in the older section along Kamehameha Highway. Sugarcane fields and small truck farms predominate in the floodplain. Public beaches, beach parks, and a small boat harbor provide most of the residential activities in the area. Within the study area are located the three major streams—Anahulu River, Paukauila Stream, and Kiikii Stream. These three watercourses emerge at Kaiaka and Waialua Bays—Kiikii and Paukauila Streams discharge into Kaiaka Bay and Anahulu River discharges into Waialua Bay. Helemano and Opaeula Streams are tributaries to Paukauila Stream and Poamoho and Kaukonahua Streams are tributaries to Kiikii Stream.

Waimea Area – Waimea River

The Waimea Valley drainage basin is on the northwestern side of the Island of Oahu. The elliptical basin is approximately 13.4 square miles in area and extends approximately 10.5 miles from the ocean to the 2,266-foot (Local Tidal Datum) summit of the Koolau Mountains. The topography is generally hilly and rugged in the upper sections and terminates in a small flat valley near the ocean. The Waimea River and three perennial streams—Elahala, Kamananui, and Kaiwikoele—drain the area, and the storm runoff from these streams flows in a westerly direction.

The relatively high rainfall and moderate temperatures are conducive to heavy vegetation. Grass, shrubs, and trees pervade the entire basin area. Approximately two-thirds of the upper basin is in a forest reserve area and generally remains in its natural condition. Economic activity in the area is centered around tourism, particularly excursion trips to Waimea Falls.

Sunset Beach Area – Paumalu and Pahipahialua Streams

The drainage areas of the Paumalu (approximately 3.0 square miles) and Pahipahialua (approximately 1.3 square miles) Streams are located in the northeastern section of the Island of Oahu. These streams flow northeasterly and discharge into the Pacific Ocean.

Waianae Valley Area – Kaupuni Stream

The drainage area of Kaupuni Stream (approximately 14.0 square miles) is located in the southeastern section of the Island of Oahu, approximately 25 miles northwest of central Honolulu; and directly adjacent to the Makaha area described above, and west of the Lualualei Valley. Kaupuni Stream flows to the southwest and discharges into the Pacific Ocean. The stream consists largely of concrete engineered channel, carrying drainage from the surrounding, largely residential, developments, as well as draining the mountainous terrain found in the upstream end of the drainage area. Elevations extend from sea level up to approximately 3,900 feet within the Waianae mountain range.

Kailua-Lanikai Area – Kaelepulu Stream

The Kailua-Lanikai area is located on the windward side of the Island of Oahu, approximately 11 miles northeast of downtown Honolulu. The Kailua area, located on a relatively flat coastal plain off Kailua Bay, consists of a central commercial section with surrounding residential development, while the Lanikai area, located on a narrow strip of land along the seaward slope of Kaiwa Ridge, consists primarily of residential development. A levee and channel to convey floodflows from Kawainui Swamp is located northwest of Kailua Town and extends to Kailua Bay. Local interests have improved the channel of Kaelepulu

Stream from a point just upstream of its mouth to Kaelepulu Pond within the Enchanted Lake development, which was constructed on the swampland surrounding Kaelepulu Pond.

<u>Lualualei Valley Area</u> – Maili and Mailiili Channels

The drainage areas of the Maili (approximately 2.7 square miles) and Mailiili (approximately 15.8 square miles) Channels are located in the southeastern section of the Island of Oahu, approximately 25 miles northwest of central Honolulu. These streams flow south and southwesterly and discharge into the Pacific Ocean. Both channels are concrete engineered channels, carrying drainage from the surrounding, largely residential, developments as well as draining the more undeveloped farmlands within the valley and the mountainous terrain in the upstream portions of their respective drainage areas (particularly the drainage area of Mailiili Channel where elevations reach as high as 2,600 feet within the Waianae mountain range).

<u>McCully Area</u> – Makiki Stream

The McCully drainage basin is located on the southeastern portion of Oahu, with Punchbowl Crater, Mt. Tantalus, and Round Top defining the upper boundary and Wilder Avenue, Kalakaua Avenue, Manoa Road, and McCully Street defining the lower limits. The irregularly shaped basin includes approximately 2.5 square miles of land area and varies from a forested, unpopulated upper zone to a fully developed residential zone.

Makiki Stream is the primary watercourse in the McCully area. With its headwaters at Mt. Tantalus, Makiki Stream traverses approximately 3.5 miles to its outlet at the Ala Wai Canal. The several streams within the area eventually feed into Makiki Stream, the most notable being Kahana Stream for which a manmade ditch, Makiki Ditch, was constructed.

<u>Moiliili Area</u> – Manoa Stream, Manoa-Palolo Drainage Canal, Palolo Stream

The Moiliili drainage basin is situated immediately east of the McCully drainage area. With Mt. Tantalus, Mt. Olympus, and the Koolau Mountain Range as the upper boundary, the drainage basin begins in the Honolulu Watershed Forest Reserve in the Manoa and Palolo Valleys. Within Manoa Valley, several streams in the forest reserve are tributaries of Manoa Stream. For Palolo Valley, Pukele and Waiomao Streams drain the entire valley, with both streams converging into Palolo Stream. Palolo Stream outlets from Palolo Valley into Manoa Stream at a point approximately 800 feet upstream from the King Street bridge, where the combined watershed for the Manoa-Palolo drainage basin is approximately 10.4 square miles. Below the King Street Bridge, the combined waterway is known as the ManoaPabolo Drainage Canal, which feeds into the Ala Wai Canal.

The Moiliili area is densely populated. Above Moiliili, in both the Manoa and Palolo Valleys, land use is residential, and in the upper valleys, preservation of the natural environment is observed.

Waikiki Area – Ala Wai Canal

South of the McCully and Moiliili areas is the Waikiki area. Unlike the other detailed areas, Waikiki is characterized by high-density, high-rise, and commercial developments. Waikiki is a resort community that is bounded by the Honolulu Zoo on the east, the Pacific Ocean on the south and west, and by the entire length of the Ala Wai Canal on the north. The ground is essentially level for the entire area, with only minimum slopes At Pacific Ocean front.

The Ala Wai Canal is a manmade estuary that collects and transmits flows from the Pabolo, Manoa, and Makiki Valleys directly to the ocean instead of flowing through Waikiki. Thus, Waikiki, which was originally marshland, was able to develop into its present status as a resort community.

Nanakuli Area – Nanakuli and Ulehawa Streams

The Nanakuli and Ulehawa Stream watersheds are located on southwest Oahu on the leeward side of the Waianae Mountain Range. Both of these streams empty into the Pacific Ocean at the Town of Nanakuli, located along the coast between Kahe Point and the Town of Waianae. The two watersheds have similar land uses: The lower areas contain residential and commercial developments; the interior valley areas support mostly diversified farms and scattered residential units; the upper watershed areas are undeveloped.

Other Areas

Nuuanu and Waolani Streams

Nuuanu Valley is located on the leeward side of the Koolau Mountain Range and is almost directly northeast of downtown Honolulu. Its main watercourse is Nuuanu Stream while Waolani Stream is a tributary of Nuuanu Stream. The watershed contains a well-developed commercial and residential portion of Honolulu in the lower elevations near the ocean. The mid-elevation areas are partially utilized for residential uses and a golf course. The remainder is set aside as conservation land. The upper portions are zoned for conservation although a major highway, the Pali Highway, traverses the Nuuanu Valley and the Koolau Mountain Range to the windward side of the island, connecting Kailua with Honolulu.

Aiea and Kalauao Streams

The Aiea Stream and Kalauao Stream watersheds lie adjacent to each other approximately seven miles northwest of downtown Honolulu. Almost all of the usable land in the lower- and mid-elevation areas are developed with single- and multi-family residences, in conjunction with commercial and public service facilities. The Kalauao watershed includes a golf course and a major shopping center. The upper portions of both watersheds are zoned for conservation.

Waikele Stream

The Waikele Stream watershed is located in the central portion of Oahu and extends to the upper elevations of both the Koolau and Wainae Mountain Ranges. Most of the lower- and mid-elevation areas are developed with single- and multi-family residences. Along with the commercial and public service facilities, the watershed includes military reservations, golf courses, and a sugar plantation. The upper portions of the watershed are set aside for conservation. Waikele Stream discharges into the West Loch of Pearl Harbor.

Honouliuli Stream

The Honouliuli Stream watershed is adjacent to the portion of the Waikele Stream watershed that extends to the headwaters of the Waianae Mountain Range. Honouliuli Stream also discharges into the West Loch of Pearl Harbor. The lands in the lower areas are not fully developed. There is some single-family residential development although most of the developed land is being used for agricultural purposes, as are the mid-elevation areas. The upper areas are set aside for conservation.

Makaleha and Unnamed Streams

The Makaleha Stream and Unnamed Stream watersheds are located on the northwest side of the island. These watersheds extend to the headwaters of the Waianae Mountain Range. The lower areas are primarily developed for agriculture, although there are single-family residences near the ocean.

The Unnamed Stream passes Waialua and contains residential development in the lower areas of its watershed. The upper watershed areas are set aside as conservation land.

Malaekahana Stream and Kea’alu Gulch

The Malaekahana Stream and Kea’alu Gulch watersheds extend to the upper elevations of the northwestern end of the Koolau Mountain Range, on the northern side of Oahu. The watershed collects water from the windward side of the most northerly portion of the Koolau Mountain Range. The lower areas consist of single-family residential and agricultural use. The mid-elevations are used for agriculture or set aside for conservation while the upper elevations are completely set aside for conservation.

James Campbell Industrial Park (JCIP) Drainage Canal

The drainage area of the JCIP Drainage Canal (approximately 2.8 square miles) is located in the southern section of the Island of Oahu near Barbers Point, approximately 19 miles west of central Honolulu and directly east of Barbers Point Naval Airstation. The canal flows south and discharges into the Pacific Ocean. The studied canal is a concrete engineered channel, carrying drainage from the surrounding, largely industrial, developments in the lower and middle portions of the drainage area; as well as draining the residential and forest areas found in the upper portion of the drainage area. Elevations range from as low as sea level to approximately 650 feet.

Kaalaea, Haiamoa, Waihee, Kahaluu, and Ahuimanu Streams

These five watersheds are located on the western side of Kaneohe Bay. Four of the five streams, Kaalaea being the exception, are the main watercourses for the Kahaluu watershed. Kaalaea Stream is in a separate area, although the watersheds are parallel. The five stream watersheds are fairly similar. All have single-family residences in the lower- and mid-elevation areas with a few commercial establishments near the highway. Most of the single-family residences in the mid-elevation areas are above the stream elevations. The flat, low-lying areas next to the stream are in cultivation. The Ahuimanu and Kahaluu Stream watersheds have more development for single-family residential purposes as well as the attendant commercial and public-service facilities. The upper areas of all the watersheds are set aside for conservation.

Kawainui Stream and Oneawa Channel

The Kawainui Stream watershed is located in Kailua on the windward side of the island. This watershed is essentially flat. The major watercourses, Kaelepulu Stream and Kawainui Canal, carry drainage from the Koolau Mountain Range away from the study area. Kawainui Stream is a tributary of Kaelepulu Stream. The land is almost completely developed for residential or commercial uses. Swampland adjacent to the stream has not been developed. The Oneawa Channel (sometimes referred to as Kawainui Channel) is a portion of the overall Kawainui Marsh Flood Control Project, carrying flood flows from the marsh to the Pacific Ocean along the north side of Kailua.

Kaloi Gulch

The Kaloi Gulch watershed is located on the leeward side of the Waianae Mountain Range, on southern Oahu. The portion under study is near the Town of

Ewa and the so called "Ewa Plain." Waipahu, the nearest urban center, is located approximately 2 miles to the northeast, and the Barbers Point Naval Air Station is located roughly 0.5 mile to the southwest.

Land use in the lower to middle portion of the watershed is active with sugar cane cultivation. There are several residential developments along the east side of Kaloi Gulch between Renton and Waimanalo Roads. The upper portion of the watershed above the H-1 Freeway is undeveloped.

Waikakalaua Stream

The Waikakalaua Stream watershed is located in Central Oahu, on the leeward slopes of the Koolau Mountains. Waikakalaua Stream is a tributary to the Waikele stream with the point of confluence located just downstream of the Kamehameha Highway.

The study area for Waikakalaua Stream is located in the lower part of the watershed and covers a portion of Mililani Town. The study area begins just upstream of the confluence with Waikele Stream. The land is primarily in single-family residential use with some commercial activity. The middle portion is mostly in pineapple agriculture. Undeveloped land held in forest reserves is found in the middle to upper portions of the watershed.

North Halawa/Halawa Stream

The Halawa watershed (approximately 19.3 square miles) is located on the leeward side of the Koolau Mountains, on the western fringe of the City of Honolulu. The stream system is comprised of two main tributaries: North Halawa Stream and South Halawa Stream, which combine to form Halawa Stream downstream of the confluence of these two tributaris. The Halawa Stream system empties into Pearl Harbor.

The land use in the lower portion of the Halawa watershed is mostly industrial. In the middle to upper areas, the land is mostly undeveloped forest reserve with some residential development, with the far upper areas completely undeveloped forest reserve.

Waiawa Stream, Overflow area of Waiawa Stream, Panakauahi Gulch, Manaiki, and Moanalua Stream

Moanalua and Manaiki Streams are located on the southeast coast of the island of Oahu, lying in a valley on the leeward slopes o fthe Ko'olau Mountain Range. The entire drainage area is located within the District of Honolulu. It is approximately four to five miles west of downtown Honolulu. The basin is roughtly rectangular in shape, 6.0 miles long and 1.7 miles wide, and drains an area of 10 square miles. The area is drained by the Moanalua Stream and its two major tributaries, Manaiki Stream and Kahauiki Stream. Moanalua Valley is largely residential, with many houses lining the banks of Moanalua and Manaiki Streams. Moanalua Elementary School, Moanaulua Intermediate School, and Moanalua Gardes all lay between Moanalua and Manaiki Streams.

The Waiawa Stream watershed occupies an anrea of 27.3 square miles, extending from the Ko'olau Mountain Range to Pearl Harbor. Approximately 1,000 feet upstream of the Kamehameha Highway crossing, Waiawa Stream converges with the Panakauahi Gulch. Leeward Community College lies on the right overbank of Waiawa Stream just below the H-1 Freeway. Watercress farms occupy a low-lying plain on the right overbank of Waiawa Stream below Leeward Community College. An abandoned sewage treatment plant occupies the right overbank upstream of the mouth of the stream. U.S. Naval Reservation property lines the left overbank of Waiawa Stream.

Waimalu Stream

The Waimalu watershed (approximately 14.5 square miles) is located on the leeward side of the Koolau Mountains, on the western fringe of the City of Honolulu, just northwest along the coastline of Pearl Harbor from Halawa Stream. Waimalu Stream flows south and empties into Pearl Harbor.

The land use in the lower portion of the Waimalu watershed is mostly industrial. In the middle to upper areas, the land is mostly undeveloped forest reserve with some residential development, with the far upper areas completely undeveloped forest reserve.

2.3 Principal Flood Problems

The Island of Oahu is subject to flooding from stream overflow, tsunamis, and hurricanes. In some areas along the coast, all three types of flooding may occur. Tsunamis, which are a series of waves generated by submarine earth movements, travel at high velocities and have had a devastating effect on the developed areas of Hawaii. Sources of these tsunamis are varied and are located in North and South America, the Aleutian Islands, Japan, Kamchatka, the islands lying between the Philippines and Samoa, and even Hawaii itself. Within the Hawaiian Islands, the City of Hilo on Hawaii has been most severely damaged from tsunami impacts. Based on 1970 figures, Hilo had suffered losses of $62 million over the previous 50 years.

Although historical records show that hurricane landfall is infrequent, hurricane-induced storm surge and waves pose a flooding threat to the island. Review of hurricane storm-tracks from 1949 to 2008 indicate that only 14 storms Category 1 or higher have come within a 200 nautical mile radius of the Hawaiian Islands as shown in Figure 1, "Hurricane Tracklines." The Island of Oahu has significant exposure to hurricane induced storm surge, with extensive low-lying areas located on the south shore. The Island of Oahu has not experienced direct hurricane landfall, but has been impacted from hurricane-generated wind and waves. Three hurricanes have made landfall or had notable impacts to the Hawaiian archipelago.

While the specific cause of tsunami and hurricane related flooding can be attributed to a single factor, the cause of flooding as a result of stream overflow may be due to various reasons. Possible flood causes include: debris-clogged streams, flash floods, undefined streamflow patterns, isolated depressions in topography, inadequate drainage facilities, and changed drainage conditions because of development.

Flooding for the Island of Oahu is attributable to fast-moving surface runoff from steep mountain slopes discharging onto low, flat, coastal plains. This condition causes stormwater from the highlands to overtop lowland streams and flood areas adjacent to the streams. Most flood problems on the island occur in the low-lying areas, which have largely been developed with inadequate or nonexistent flood-control measures and storm drainage systems.

Excessive surface water from overland flow frequently causes flooding in poorly drained areas. Many of these problems are found in developed areas where the natural drainage patterns have been altered during development. Other factors which contribute to this type of flooding are insufficient or excessive land slopes and poor soil conditions.

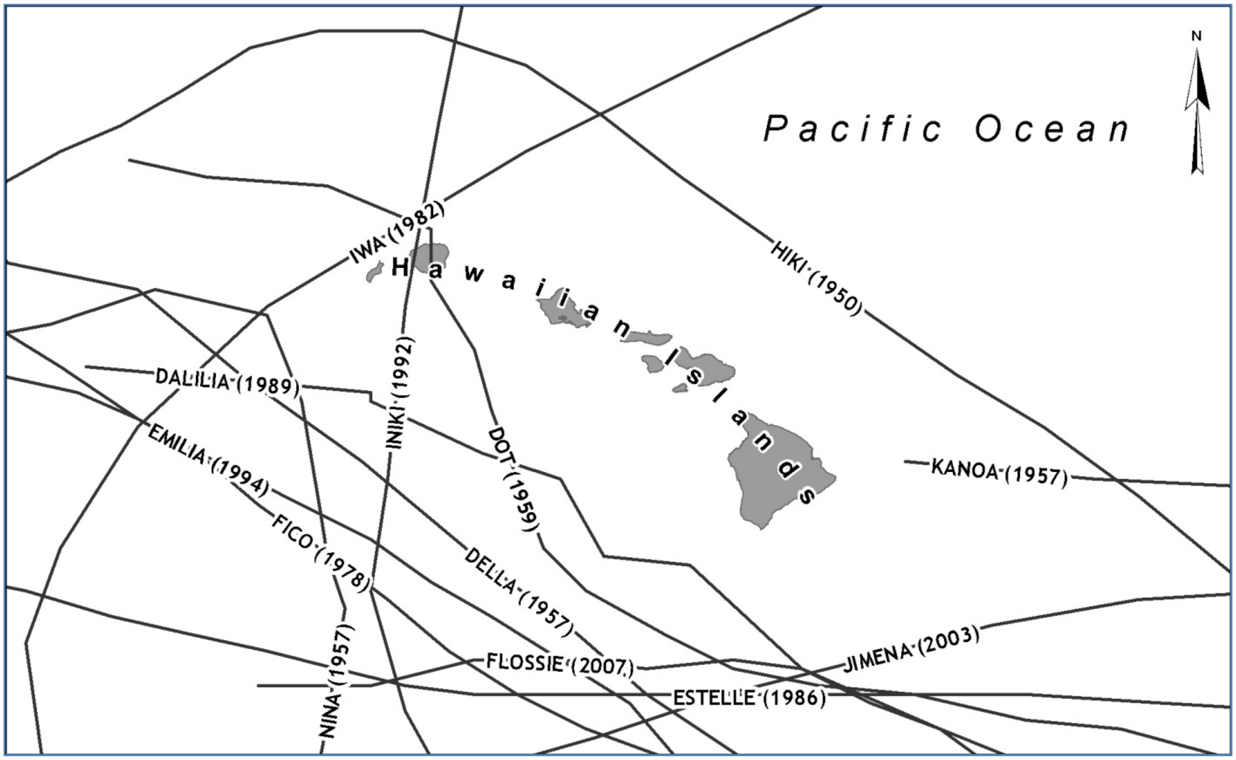


Figure 1: Hurricane tracklines within a 200 nautical mile radius of the Hawaiian Islands (1949-2008)

Flood problems for those areas that have been studied by detailed methods are described below.

<u>Kahuku Area</u> – Hoolapa, Kalaeokahipa, Ohia, and Ohia (East) Streams

The flooding in this area results primarily from ponding in the flat, low-lying area seaward of Kamehameha Highway. This low-lying area, which measures approximately 3.2 square miles, and is used primarily for growing sugarcane, does not have an adequate drainage system to convey floodwater to the ocean. The flooding problem is compounded by the formation of sand dunes at the outlets which prevent floodwater from discharging into the ocean. From the stream gaging station record of Oio Stream near Kahuku, the largest recorded flood occurred on April 15, 1963. No estimate of damage from this flood is available. Tsunami hazard in this area is severe. Historical data on the tsunami shoreline elevations indicate heights of 20 to 25 feet above sea level.

<u>Hauula-Punaluu Area</u> – Kaipapau, Waipilopilo, Hanahimoa, Kaluanui, Punaluu, and Wailele Streams

Flooding in this area is caused by ponding of the low-lying areas inland of Kamehameha Highway and by the inadequate capacities of streams in this area.

The records of the three stream gaging stations in this area, which date back to 1954, indicate that the largest recorded flood in this area occurred on July 17, 1974; Punaluu Stream (Stream Gaging Station 3030) had a peak discharge of 5,700 cubic feet per second (cfs) and Kaluanui Stream (Stream Gaging Station 3042) had a peak discharge of 2,000 cfs.

The most severe coastal flooding in the Hauula-Punaluu study area has been caused by tsunami, with storm surf causing only minor damage. The two most severe known tsunami occurred in 1946 and 1957, with maximum observed elevations of 12 feet above sea level at Punaluu Beach Park and 13 feet above sea level at Hauula, respectively.

A major storm event in December 2008 resulting in both State and Federal disaster declarations. Heavy flooding in the Wailele Stream area resulted in residential damages estimated at $2,000,000, $1,500,000 in damage to Brigham Young University Hawaii facilities, and $600,000 in damage to the Polynesian Cultural Center.

<u>Kahana Area</u> – Kahana Stream

Kahana Valley is under the jurisdiction of the State of Hawaii, Department of Land and Natural Resources and will eventually be developed into a State Park. Presently, the land is leased for agricultural and residential purposes. There is no significant development in this basin. The few residences in this basin are located generally above the valley floor and are free from flooding during large floods. The road serving the residents of the upper valley is flooded during large floods, however, it generally does not remain impassable for any long period. Flooding on Kahana Stream is at the lower reaches, generally from the mouth to approximately 1.5 mile upstream. Flooding at the mouth is caused by sand dunes obstructing bridges. Further upstream, flooding occurs in the overbank due to the inadequate capacity of the existing natural channel section to convey the flow.

<u>Kaaawa Area</u> – Kaaawa Stream

The principal flooding problem in this area is the ponding of flood-water inland of Kamehameha Highway and the inadequate capacity of Kaaawa Stream to convey the larger floods. The approximate ponding limits for the April 15, 1953, flood were established from interviews with residents of that area and outlined for a portion of the Kaaawa area in the Floodplain Information Report (USACE, 1969) for Kaaawa.

The tsunami of April 1, 1946, was the most destructive ever to hit the Kaaawa area. It was generated by an earthquake in the East Aleutian Islands. The highest wave, estimated at 17 feet, had a measured runup to the 11.8-foot elevation along the coastal plain between Swanzy Beach Park and Kaaawa Park. This was the most severely damaged area of the floodplain. Several homes in this area and

Army barracks on the present Swanzy Beach Park site were either severely damaged or demolished. These structures and a seawall which extended a short distance south from the Army barracks diminished the force of the wave on structures further inland. However, unprotected inland homes south of the seawall were flooded by the incoming wave.

In addition to riverine flooding and tsunami inundation in the coastal area of the Kaaawa floodplain, storm surf flooding occasionally occurs in low-lying areas on the inland side of Kamehameha Highway.

<u>Waikane-Waiahole Area</u> – Waikane and Waiahole Streams

The flooding in this area is primarily caused by the inadequate channel capacities of the three main streams and the backwater caused by the bridges and culverts at Kamehameha Highway. A major part of the inundated area is the low-lying area inland of Kamehameha Highway between Waikane and Waiahole Streams. This area receives floodflows generated within its own basin and from the overbank flows of the other streams. Flows in excess of the culvert capacities often backup and overtop Kamehameha Highway. Historic floods in this area were determined from a stream gage on Waikane Stream installed in December 1959. There were 15 annual peak discharges recorded ranging from 292 cfs to 8,800 cfs, the latter occurring on February 4, 1965. Other major floods in excess of 4,000 cfs occurred on February 1, 1969 (4,020 cfs), and on March 15, 1963 (4,560 cfs). A report entitled "Floods in Waiahole-Waikane Area, Oahu, Hawaii," prepared by the USGS (USGS, 1974) in cooperation with the Hawaii State Department of Land and Natural Resources, indicated that the floods of May 2, 1965 (3,300 cfs, Waiahole Stream Gaging Station 2949), and November 12-14, 1965 (3,230 cfs, Waiahole Stream Gaging Station 2949), caused approximately 0.76 square mile of inundation of this area.

<u>Heeia Area</u> – Heeia Stream

Heeia Stream is confined to a narrow valley until it reaches the floodplain at an elevation of approximately 40 feet. The basin topography and existing drainageway capacities are such that flooding in the Heeia area is restricted almost entirely to the low-lying area between elevation 40 feet and Kamehameha Highway. During moderate to high peak discharges, floodwater overtops the banks, inundating the low-lying swamp. Erosion and sedimentation also compound the flood problem.

The impact of floods of high peak discharges originating from the mountains on the floodplain below the Kahekili Highway is reduced by the Kahekili Highway embankment. This embankment acts as a detention dam with a controlled outlet. There is no major tsunami flooding problem in the Heeia area as a result of the protection afforded by the configuration of the Kaneohe Bay estuary.

Discharge records for Haiku and Lolekaa Streams date back to 1915 and 1941, respectively. The largest flood of record for Haiku Stream occurred in May 1965, with an estimated discharge of 5,740 cfs at the USGS Gage No. 2750 (drainage area of 0.97 square mile). The largest flood of record for Lolekaa Stream occurred on the same date with an estimated discharge of 797 cfs at the USGS Gage No. 2780 (drainage area of 0.29 square mile). This represents unit runoff of approximately 5,920 and 2,500 cfs per square mile for the respective drainage areas. Numerous floods have occurred since 1890; however, they were not documented.

<u>Kaneohe Area</u> – Keaahala, Kaneohe, Kamooalii, Kawa and Tributary to Kawa Streams

The principal flood problems in this area are caused by the inadequate capacities of these five streams which were apparent during the storms of February and November 1965 and February 1969. The February 4, 1965, storm claimed 2 lives and severely damaged approximately 30 homes in the Keapuka Subdivision.

This catastrophe occurred when Kamooalii Stream overtopped its banks upstream of the Luluku Street crossing. The February 1, 1969, storm again caused damage to homes in this area; fortunately no lives were lost. Other areas flooded in this storm were the Kapunahala Subdivision, lower reaches of Kaneohe Stream, View Golf Course, and the Kahaluu Valley floodplain. Flooding in the Keapuka Subdivision was attributed to debris obstructing the opening of the Luluku Street bridge. The Kapunahala Subdivision was unexpectedly flooded by floodflows from another area. The floodwater from Keaahala Stream was unable to pass under Kahekili Highway due to culvert obstruction and, therefore, flowed southerly on Kahekili Highway and into the Kapunahala Subdivision. Other areas were flooded by the inadequate capacity of the stream to convey the floodflow.

The low-lying area of the coastal Kaneohe area has experienced a large number of stream floods (over 20 since 1936). More recent storm events occurred during the December 2008 storm event, and another on June 4, 2011.

<u>Waimanalo Area</u> – Waimanalo Stream, Waimanalo Streams A, B, C, and D, and Inoaole Stream

Flooding in this area is caused by inadequate channel capacities and resultant lowland ponding. There are two stream gaging stations within this study area; one on Waimanalo Stream upstream of Kalanianaole Highway, installed in 1963, and the other on Inoaole Stream upstream of Hihimanu Street, installed in 1958. Data from these gaging stations indicate occurrences of large floods in March 1963, November 1965, December 1967, and November 1970.

Records of historical tsunami occurrence within the Waimanalo Bay area indicate that they have had little effect on developments along the seaward portion of the

Waimanalo area. This is because the land along the shoreline rises abruptly to elevations of 10 to 15 feet above sea level. This is higher than the wave height of the tsunami of 1946 (record elevation) which had wave heights of 8.0 feet off the shoreline of Waimanalo Bay.

The December 2008 major storm event resulted in large amounts of rainfall in the Waimanalo area (estimated 5.6 inches in 12-hour period) and some reports of flooding.

Aina Haina Area – Wailupe and Kului Streams

The principal flood problem in this area is the inadequate channel capacity of Wailupe Stream and sheetflow flooding of an adjacent lowland residential area. Two floods large enough to cause overbank flooding have occurred since the installation of a stream gaging station on Wailupe Stream at the Ani Street Bridge. The first, occurring in March 1958, was estimated at 2,170 cfs; the second, in December 1967, was estimated at 3,600 cfs. Kului Stream, which is a tributary to Wailupe Stream, also causes flooding near its confluence with Wailupe Stream due to the inadequate capacity of the Hind Iuka Drive culvert.

Waialae-Kahala Area – Waialae-Iki, Kapakahi #1, Waialae-Nui Streams and Waialae Major Drain

This area is a totally developed residential area and the principal flood problem results from the inadequate capacities of the major drains to convey the floodwater from large storms. This area suffered its most severe flooding on March 5, 1958, from a storm which produced 12.5 inches of rainfall in 7.5 hours. Other storms, which caused various degrees of flooding, occurred on November 1954, February 1955, March 1955, January 1957, and on December 1967. Waialae-Nui Stream, which traverses the eastern limits of the residential area, also causes flooding during the occurrence of large floods.

Kalihi-Moanalua Area – Kalihi, Kamanaiki, Lower and Upper Moanalua and Kahauiki Streams

The principal cause of flooding of the lower reaches of Kalihi and Moanalua Streams are the restricted capacities of the numerous bridges at the mouths of the streams. The flood problems in both the Kalihi and Kamanaiki Streams are a result of limited stream channel capacities and debris which constricts flows at numerous bridge crossings. Within the study reach, Kalihi Stream flows through a relatively deep channel section and flooding primarily occurs at the bridges. The Kamanaiki Stream floods more often due to its having a shallower channel with many irregular sections, sharp bends, and abrupt transitions. Both streams have heavy vegetation and tree growth along the banks, especially in the upper reaches.

On November 18, 1930, 23.5 inches of rain fell over Kalihi Valley. Storm flows, which were blocked just upstream of School Street, suddenly penetrated the debris obstruction and caused extensive damage to the areas below. The discharge recorded at USGS Stream Gage 2290 was 12,400 cfs.

Many walls have been built on private property along the stream. The lower portion between King Street and the H-1 Freeway is walled on both sides, although the channel itself is not lined. Vegetation abounds in the streambed or on its banks. This vegetation may cause flooding by catching debris and forming a barrier to floodflows.

The seaward portion of the coastal plain in the lower area is subject to tsunami inundation; however, such flooding is considered minor when compared to that which would occur from storm runoff, since the area is well protected from tsunami inundation by the broad coastal reef extending seaward from the Keehi Lagoon area.

Since 1915, the largest recorded floods were (USGS Gage 2990):

January 16, 1921 – 6,340 cfs
December 30, 1923 – 6,070 cfs
October 15, 1924 – 5,830 cfs
November 18, 1930 – 12,400 cfs
February 28, 1932 – 6,510 cfs
November 23, 1982 – 5,120 cfs

Makaha Area – East and West Makaha Streams

Makaha Stream presently consists of three separate channels referred to as East Makaha Stream, West Makaha Stream and Makaha Stream. Historical flooding from these streams resulted from the inadequate capacities to convey the storm runoff. The largest flood known to have occurred since 1953 occurred on November 24, 1954. The peak discharge was estimated to be 1,700 cfs at Stream Gaging Station No. 2116. Less severe floods occurred in March 1962, December 1964, and November 1965.

The tsunami of April 1, 1946, which resulted from a strong earthquake in the Aleutian Islands, had the severest effect in the Makaha coastal areas. The maximum wave runup elevation was approximately 22 feet, resulting in flooding of areas approximately 500 feet inland.

Waialua-Haleiwa Area – Kiikii, Kaukonahua, Poamoho, Paukauila, Helemano, and Opaeula Streams and the Anahulu River

The most recent flood in this area, which claimed three lives and caused considerable damage, occurred on April 19, 1974. At the Helemano Stream gaging station (Stream Gaging Station No. 3430) a record discharge of 18,200 cfs was estimated. Record discharges turned in for three other gaging stations in this area are as follows: 16,300 cfs for Anahulu River near Hakilua (Stream Gaging Station No. 3500), and 6,940 cfs for Poamoho Stream at Waialua (Stream Gaging Station No. 2112). Other large floods in this area occurred on February 28, 1932 (record rainfall flood), February 1935, March and October 1939, February 1956, February 1969 and July 1974.

Waimea Area – Waimea River

The flooding in this area is attributed to the inadequate capacity of the watercourse and the obstruction of floodflows by two bridges across the stream. The flooding problem is further aggravated by sand dunes at the outlet, obstructing flow into the ocean, and the deposition of debris in the lower watercourse from erosion in the upper reaches where the velocities are higher. The largest recorded flood at a stream gaging station on the upstream reach occurred on April 19, 1974, and had an estimated discharge of 5,610 cfs. No major flood damage was reported in the study area. Other large floods recorded at the gaging station since 1958 occurred in March 1962, April 1963, February 1965, March 1968, and February 1969.

Sunset Beach Area – Paumalu and Pahipahialua Streams

The principal flood problem in this area is the lack of defined streams with capacity adequate to convey storm runoff to the ocean. Flooding in the highlands is caused by overland flow, which results from inadequate capacity of existing streams or the lack of streams. In the lowlands, the problem results from the poor drainage systems and local depressions. This area has been flooded on numerous occasions. The largest known flood, according to the Flood Plain Information report (USACE, 1968) for this area, occurred on March 13-14, 1962. Rainfall of

8.33 inches in a 24-hour period caused a wall of water to dump tons of mud, boulders, and other debris across Kamehameha Highway. The USGS estimated a peak flow of 4,000 cfs in this area. Other large floods in this area occurred in February 1956, January 1957, April 1963, and November 1965. A stream gaging station was installed on Paumalu Gulch at Sunset Beach (Stream Gaging Station No. 3180) in 1968, and the largest flood recorded occurred on April 19, 1974, with a peak discharge of 982 cfs. Other large floods occurred in March 1968 and January 1971.

Waianae Valley Area – Kaupuni Stream

Principal flood problems in this area are similar to those found in the adjacent Lualualei Valley and Makaha Areas. While Kaupuni Stream is an engineered flood control channel, local drainage systems are subject to flooding during heavy storm events and the coastal area has historically been impacted by tsunami and hurricane flooding events. Two recent storms, hurricanes Iwa (1982) and Iniki (1992) generated damaging high waves, and storm surges produced coastal flooding to an elevation of 11ft above msl and higher. The tsunami of April 1, 1946, which resulted from a strong earthquake in the Aleutian Islands, impacted the Waiamae area with a maximum wave runup elevation of approximately 12 feet. A tsunami in 1957 produced recorded flood inundation heights of approximately 14 feet.

The largest flood known to have occurred since 1961 occurred in January 1982. The peak discharge was estimated to be 3,300 cfs at USGS Stream Gaging Station No. 1800. A large storm in November 1996 also caused extensive flooding in this area as well as the adjacent Lualualei Valley area. The December 2008 major storm event reportedly produced very large rainfall amounts over short periods of time (estimated 7.2 – 8.1 inches over a 12-hour period). Heavy winds at Waianae boat harbor and extensive flooding (up to chest high) in Wainanae were reported.

Kailua-Lanikai Area – Kaelepulu Stream

The flooding in this area is caused by backwater from Kaelepulu Stream. The outlet of Kaelepulu Stream is often obstructed by sand dunes which cause backup of the floodflow until the sand plug is breached. Flooding of the Coconut Grove Subdivision of Kailua results from the inadequacy of the existing storm drains in that area and from the tailwater from Kaelepulu Stream. A storm drain system currently being constructed will alleviate flooding from lesser floods; however, for floods of the 50-year or greater recurrence interval flooding in this area would occur because of backwater from Kaelepulu Stream, which is the outlet channel for the Coconut Grove drainage system.

Lualualei Valley Area – Maili and Mailiili Channels

The principal flooding problems in the area can be generally characterized as caused by exceedance of the local drainage system capacity. Heavy rains on November 11, 13, and 14 of 1996 resulted in extensive flooding in the leeward and central portions of Oahu. In the Lualualei Valley, rainfall runoff sheet flowed from the steep faces of the surrounding mountains and across the moderately sloping open lands of the valley, and collected on the valley floor. Homes and portions of area roadways were inundated for up to seven days. A 2001 United States Army Corps of Engineers study attributed flooding problems to the absence of a storm drainage system within agricultural areas, and partially blocked existing culverst and other drainage structures in residential areas, due to their poor maintenance.

The December 2008 major storm event led to reports of flooding in these same low-lying areas. Also, approximately $8,000,000 in damage to mostly coastal areas was reported due to a small tsunami in March 2011.

<u>McCully Area</u> – Makiki Stream

Makiki Stream between King Street and the Ala Wai Canal runs a length of 3,080 feet. Within this study limit, previous flooding has occurred at two specific locations. At the Philip Street Bridge, the bend in the stream has resulted in water overshooting into the street, causing traffic disruption and some property damage. The second location of flooding is in the block bordered by Fern, Nanea, Malanai, and Hauoli Streets. At this low point, flooding approximately 1.5 feet in depth has caused property damage and traffic congestion.

<u>Moiliili Area</u> – Manoa Stream, Manoa-Palolo Drainage Canal, Palolo Stream

For Manoa Stream, there have been two known deaths due to flooding, the first during the flood of December 3, 1918, and the second during the flood of December 3, 1950. Despite these two recorded casualties, additional flood damage information is unavailable. Principal flood problems associated with Manoa Stream are due to inadequate capacities at several locations, especially at the numerous bridge crossings (twelve). At the higher areas, from Paradise Park to Manoa Elementary School, the steep, sloping channel results in shallow, rapid, supercritical flows and minimal flooding. In the lower portion, the flatter terrain causes higher-level, slower-moving, subcritical flows which, when coupled with several bridge constrictions, do create a greater flooding potential. The Woodlawn area is particularly susceptible to flooding.

For the Manoa-Palolo Drainage Canal and Palolo Stream, no direct flood hazard is apparent. The unlined and overgrown condition of the banks create the potential for overgrowth-related flooding; hence, the entire Manoa-Palolo Drainage Canal and the unlined segment of Palolo Stream were studied in detail.

<u>Waikiki Area</u> – Ala Wai Canal

The flooding problem associated with the Ala Wai Canal is that of overtopping into the Waikiki district. During the November 1965 and December 1967 storms, the Ala Wai Canal overflowed at the confluence of Manoa-Palolo Drainage Canal. Nearly 2-foot-deep stormwaters overflowed across Ala Wai Boulevard into the adjacent hotel and apartment basements and parking lots.

The Ala Wai Canal was originally constructed in the 1920s to create and protect the Waikiki district. Initially dredged to elevation of -25 feet, the capacity of the watercourse was expected to discharge floodwaters from the entire Makiki, Manoa, and Palolo drainage basins. With the increased urbanization within the drainage area, siltage, and additional drainage from Waikiki itself, the canal can no longer convey floodflows, and flooding into Waikiki has occurred.

Nanakuli Area – Nanakuli and Ulehawa Streams

The Nanakuli Stream floodplain is very broad in the lower reaches and is able to contain most floods. Backwater from the 1% annual chance flood event will collect behind the Farrington Highway Bridge. Downstream, a walk bridge and an abandoned railroad bridge further restrict the flows. Localized flooding in the downstream area is primarily due to a sand bar at the stream mouth. This sand bar builds up over time from the surf and, unless cleared regularly, causes a severe obstruction to flow. Between 1968 and 1985, the largest floods recorded were:

January 3, 1969 – 2,070 cfs
February 7, 1976 – 3,300 cfs
October 31, 1982 – 2,470 cfs

The Ulehawa Stream faced regular flooding problems near Farrington Highway. In January 1957, a severe southerly storm (known as a "Kona Storm") occurred over the Waianae and Nanakuli area. Damages sustained in the vicinity of Maili, Moiliili, and Ulehawa Streams totaled over $350,000 and involved residential and farm losses.

Other Areas

Nuuanu and Waolani Streams

The portions of Nuuanu and Waolani Streams in the study area are not channelized with concrete, unlike the channelized lower portions of Nuuanu Stream outside the study area. The area is thus prone to flooding and erosion problems during large storms. During Hurricane Kolohe in 1972, Nuuanu Stream overflowed its banks and bank erosion occurred. Similar events have also been recorded for Waolani Stream. Certain portions of the two streams in the study area have private walls to keep out floodwater. The extensive vegetation in and on the banks of the two streams is a flood hazard. The vegetation may catch debris and constrict flow or it may become uprooted and cause flooding by collecting and blocking floodflows at manmade structures such as bridges.

Aiea and Kalauao Streams

The existing Aiea Flood Control Channel has alleviated flooding problems below Moanalua Road. The area above Moanalua Road is still prone to flooding, mainly from storm runoff that cannot be conveyed by the stream channel or the H-1 culvert. The same is true to Kalauao Stream which cannot carry the storm runoff downstream to the ocean within its defined channels. The bridge structures and utility crossings near the stream outlet also add to the flooding problem by catching debris and restricting flow. Both streams have vegetation growth which may create obstructions to floodflows.

Waikele Stream

The Waikele Stream watershed is very large and receives a large portion of the storm runoff on the island. Compounding the rainfall flooding problem are inadequate bridge openings as well as manmade and natural streamcourses that cannot convey the storm runoff within their defined channels. During large storms the stream floods what is now the Waipahu Cultural Garden Park area, depositing silt which further decreases stream capacity. Flooding problems were severe enough for the City and County of Honolulu to divert the stream away from Waipahu Town.

Honouliuli Stream

Flooding reports are received every year for some portion of the Honouliuli Stream study area. The stream has a very flat slope and has a winding course through the lower plain. Thus, there are many sites where debris can collect and cause the floodwater to overflow the streambanks.

Makaleha and Unnamed Streams

These two streams do not have the capacity to transmit storm runoff down to the ocean. Inadequate manmade structures at road crossings, especially Farrington Highway, and the flat topography near the ocean also serve to promote the flooding problems. During Hurricane Kolohe in 1972, the portion of Farrington Highway that crosses the two streams was impassable due to flooding.

Malaekahana Stream and Kea'aulu Gulch

Malaekahana Stream does not have the capacity to transmit storm runoff downstream to the ocean. Kea'aulu Gulch contributes additional flows to Malaekahana Stream at their confluence upstream of the Kamehameha Highway crossing. The bridge on Kamehameha Highway cannot convey flows under the highway, thus causing the storm waters to flood the area upstream of the highway, until the water is high enough to flow over the highway.

James Campbell Industrial Park (JCIP) Drainage Canal

Stream flooding risk in this area of Oahu, near Barbers Point, is considered moderate to low due to the arid climate of the region; particularly when compared to the other areas of Oahu. Historically, the coast has been impacted by tsunamis and hurricanes, with the 1946 Alaskan earthquake tsunami generating 12 foot high waves at Barbers Point and incurring damages during both Hurricane Iniki (1992) and Iwa (1982).

Kaalaea, Haiamoa, Waihee, Kahaluu, and Ahuimanu Streams

Flooding in this area can be severe, causing loss of life, crop and property damage, and soil erosion. The natural channels have low capacities due to vegetation and the topography. Thus, the streambanks are overtopped by large storms. Until recently, the area near the outlet of Kahaluu Stream had chronic flooding problems. A multi-use flood-protection and recreational project has helped to relieve this problem. There are other areas of chronic flooding such as the inadequate culvert bridge on Waihee Stream at Ahilama Road.

Kawainui Stream and Oneawa Channel

The flat topography of the study area is the main cause of the flooding problems along Kawainui Stream. The tailwater effect from Kaelepulu Canal also helps to promote the overtopping of streambanks. There are also two bridges on Kawainui Stream that tend to restrict the flow of storm runoff along Kawainui Stream to Kaelepulu Canal. There area is also moderately exposed to tsunami hazards, recording wave runup elevations of approximately 6 feet as a result of the 1946 tsunami, for example.

The Oneawa Channel was constructed as part of the Kawainui Marsh Levee Flood Control project and conveys flood waters from behind the Marsh levee to the Pacific Ocean. Historic floods in the Kawainui marsh and its uplands led to construction of the flood control project and subsequent large storm events, such as those that occurred in January 1988, led to further improvement of the project in order to reduce the flood risk to the Kailua area.

Kaloi Gulch

The study reach for Kaloi Gulch is situated on a gently sloping plain and is subjected to shallow sheet flooding. The stream is perched slightly higher than the overbanks and is characteristic of irrigation ditches in the area. The flow is contained within the channel by berms along both banks and flows which escape the channel are usually not able to return. No records of significant flood damage were uncovered during the literature search for Kaloi Gulch. Between 1968 and 1985, the largest floods to occur were:

February 1, 1969 – peak flow of 645 cfs
January 8, 1989 – 724 cfs

These flows were recorded at gage 16212450.

Waikakalaua Stream

Waikakalaua Stream meanders and cuts through a relatively deep gulch. The threat of flooding is limited to the area within the gulch where residential developments have encroached onto the floodplain. Numerous footbridges and bridge crossings for the Waipio Acres Access Road present significant restrictions to floodflows. Adverse horizontal bends, unstable streambanks, and debris accumulation aggravate the situation and render portions of residential developments prone to inundation. In the past, flood damage as the result of intense rainfall has not been significant due to the relatively low population density and an upstream irrigation storage system. However, the area has undergone considerable growth and the threat of flood damage has increased. Between 1958 and 1985, the largest floods to occur were:

April 15, 1963 – 4,820 cfs
November 14, 1965 – 2,460 cfs
April 19, 1974 – 3,130 cfs
October 18, 1981 – 2,780 cfs

These flows were recorded at gage 1212700, located just upstream of the confluence with Waikele Stream.

North Halawa\Halawa Stream

Within the North Halawa study reach, flooding potential is very limited. The existing channel is relatively deep and flooding is limited to a few developments which have encroached on the lower portion of the stream. Just below the study limit, two flood-prone areas have been identified: 1) Just above the confluence of North and South Halawa Streams; 2) an area between Salt Lake Boulevard and Kamehameha Highway. Flooding in these areas would result from storms exceeding a recurrence interval of 50 years. Since 1930, the largest recorded floods were:

November 18, 1930 – 6,540 cfs
February 28, 1932 – 6,650 cfs
May 14, 1963 – 5,620 cfs
March 18, 1980 – 5,470 cfs

The Halawa Stream reach was impacted by October 28, 1981 with an estimated $1,000,000 in damages; and the December 2008 major storm events, with large amounts of rainfall recorded in the upstream Koolua Mountains.

Waiawa Stream, Overflow area of Waiawa Stream, Panakauahi Gulch, Manaiki, and Moanalua Stream

The construction of Moanalua Road required a realignment of Moanalua Stream, resulting in a 90-degree change in direction of main flow. The existing channel capacity for both Moanalua and Manaiki Streams are inadequate, as are the road crossings. These factors, along with the peculiar bend at Moanalua Road are the primary causes of flooding in Moanalua and Manaiki Streams. Backwater resulting primarily from downstream conditions causes a high tailwater condition at Moanalua Road, adding to the flooding problem. The Moanalua Gardens Park Bridge crossing at Moanalua Stream cannot convey the 1-percent annual chance (100-year) flow and stream flow overtops this bridge.

The existing access road crossing along Manaiki Stream consists of two 36-inch culverts which do not have adequate capacity. Stream flow backs up at the crossing and overtops the road. The Mahiole Street crossing at Manaiki Stream is also inadequate and stream flow overtops the bridge.

The flood problems for Waiawa Stream are the result of limited stream channel capacity, inadequate road crossings, and low-lying coastal plains. Waiawa Stream has a history of flooding below Kamahameha Highway. The additional discharge from the Panakauahi Gulch contributes to this flooding. During past severe storms, debris has piled up at the Kamehameha Highway and Farmington Highway crossings and stream flow overtops the road. During heavy rainfall, the low-lying area below Leeward Community College becomes inundated, flooding the watercress farms.

The flooding problem in the Panakauahi Gulch is primarily a result of limited stream channel capacities and inadequate road crossing. At the Cane Haul Road crossing, the upstream ends of the culverts are blocked with sediment, allowing no flow to pass through. Therefore, the flood waters back up at the culverts and overtop the road.

In 1953, a recording gage was installed on Waiawa Stream near the town-bound Farrington Highway Bridge. On October 27-28, 1981, heavy rainfall caused record stream flows in Waiawa Stream. USGS stream gage station #16216000 measured a peak discharge of 27,900 cubic feet per second (cfs).

Waimalu Stream

As described in the section above, which discusses several other previously detailed study streams surrounding the Pearl Harbor area, principal flooding problems tend to be the result of limited stream channel capacity, inadequate road crossing, and low-lying coastal plains. The stream also crosses below the Kamehameha Highway, an area susceptible to flooding problems. Heavy silting of the channel bottom, along with debris in the channel are also contributors to flooding during heavy rainfall events.

Hurricanes

Hurricane Dot made landfall on the Island of Kauai on August 6, 1959, as a Category 3 storm. Sustained winds of 81 mph, with wind gusts of 103 mph, were recorded at Kilauea Light, and damaged vegetation indicated that winds may have exceeded 125 mph in some locations (National Weather Service, 1959). A peak storm surge of 2.6 feet was recorded in Nawiliwili Harbor on the island of Kauai. On the Island of Oahu, damage was limited to rain-induced flooding and localized wind damage. The Island of Hawaii experienced local flooding related to torrential rainfall in addition to minor wave damage near South Point and along the Kona Coast (National Weather Service, 1959).

Hurricane Iwa caused severe wind damage to the Island of Kauai and notable wave damages to the southwest facing coasts of all islands. Although it did not make direct landfall on any of the Hawaiian Islands, Hurricane Iwa passed to the north of the Island of Kauai as a Category 1 hurricane on November 11, 1982. The south shore of Kauai and the Waianae coast of Oahu experienced sever wave damage. Total damages from the storm were estimated at $250 million, in 1982 dollars (National Weather Service, 1982).

The storm-of-record for the Hawaiian Islands is Hurricane Iniki. Hurricane Iniki made landfall on the Island of Kauai on September 11, 1992, as a Category 4 storm with maximum sustained winds over land at 140 mph with gusts as high as 175 mph. Extensive wind, wave and surge damage occurred along the south coast of Kauai, damaging or destroying 14,350 homes (National Weather Service, 1992). A peak surge of 4.1 feet (Local Tidal Datum) was observed by a water level station in Nawiliwili Harbor on the Island of Kauai.

2.4 Flood Protection Measures

Flood-control improvements in the City and County of Honolulu have been constructed by the Federal and State governments. FEMA specifies that all levees must have a minimum of 3-foot freeboard against 1-percent annual chance flood event to be considered a safe flood protection structure and meet all the requirements of 44 CFR 65.10. A detailed description of the flood-control improvements for each area studied by detailed methods follows:

<u>Kahuku Area</u> – Hoolapa, Kalaeokahipa, Ohia, and Ohia (East) Streams

There are no existing flood-control structures in this area capable of conveying large floods. No flood-control improvements are planned for the future.

Hauula-Punaluu Area – Kaipapau, Waipilopilo, Hanahimoa, Kaluanui, Punaluu, and Wailele Streams

The USACE constructed a flood-control project which proposes a levee system to protect the Town of Laie from flooding from Laie-Wai (Kahawainui) Stream. There are berms along both banks of the Wailele Stream in the middle portion of the study reach. These berms provide limited protection but are not considered sound flood control structures. A USACE Wailele Flood Control project is currently in its feasibility stage.

There are presently no flood-control improvements in this area capable of conveying the larger floods.

Kahana Area – Kahana Stream

There are no existing flood-control improvements in this valley for controlling large floods. The general plan for developing this valley is the creation of a state park with the stream remaining in its natural state.

Kaaawa Area – Kaaawa Stream

The only existing flood-protection structures within this study reach are the drainage culverts and bridges which convey floodwater under Kamehameha Highway. The low-lying areas are also protected from high surf by a seawall in the vicinity of Swanzy Beach Park. No additional flood-control structures are planned at this time.

Waikane-Waiahole Area – Waikane and Waiahole Streams

Aside from the three bridges for the main watercourses and three additional culverts under Kamehameha Highway, there are no flood-control structures to convey large floods in this area. There are no flood-control improvements presently planned.

Heeia Area – Heeia Stream

Except for a short reach of concrete-lined trapezoidal channel in the upper reaches and the culverts under Kahekili Highway, there are no improvements along Heeia Stream for flood-control purposes.

Kaneohe Area – Keaahala, Kaneohe, Kamooalii, Kawa and Tributary to Kawa Streams

This area has some existing flood-control measures with more major flood-control measures planned for the very near future. Keaahala Stream is partly improved, from its mouth at Kaneohe Bay to Wailele Road. Proposed improvements along both banks will keep the base flood within the banks of the existing channel. From Wailele Road to 300 feet upstream of Kamehameha Highway, the city has constructed a flood-control channel.

Kaneohe Stream and its major tributaries, Anolani Stream and Kamooalii Stream, are improved throughout most of their lengths. In addition, a flood-control dam has been constructed at the headwaters of Kamooalii Stream. As a result of these projects, the channel of these streams will convey the 1% annual chance flood event flows.

Kawa Stream is unimproved throughout most of its reach. From its mouth to Kaneohe Bay Drive, the channel is unimproved. Upstream of Kaneohe Bay Drive the stream is partially improved; the invert is unlined and the walls are lined. Near the upstream limit of study, the channel is a concrete rectangular channel that was recently constructed as part of the residential development of that area. The Tributary to Kawa Stream also has lined channel banks.

<u>Waimanalo Area</u> – Waimanalo Stream, Waimanalo Streams A, B, C, and D, and Inoaole Stream

There are existing flood-control structures within this area. Stream A, upstream of Kalanianaole Highway, is an improved channel that extends approximately 1,400 feet upstream. Two other streams which have had flood improvements completed are the Waimanalo Stream, from 300 feet downstream to 600 feet upstream of Highway 72, and the Unnamed Stream that flows into the ocean south of Waimanalo Park. The remaining streams in the study areas are unimproved and currently not scheduled to be improved.

<u>Aina Haina Area</u> – Wailupe and Kului Streams

Wailupe Stream was improved approximately 25 years ago. The walls have since deteriorated and the channel section can no longer contain the 1% annual chance flood event. There are no current plans for channel improvements within the study reach.

<u>Waialae-Kahala Area</u> – Waialae-Iki, Kapakahi #1, Waialae-Nui Streams and Waialae Major Drain

Most of the reaches studied in this area are improved channels or partially improved. Kapakahi Stream #1 from its mouth At Pacific Ocean to Kalanianaole Highway is partially improved by a concrete wall along its banks for a segment of its length and the remainder is unimproved. Waialae-Nui Stream from its confluence with Kapakahi Stream #1 to Kalanianaole Highway is unimproved. Both streams are improved channels upstream of Kalanianaole Highway. The drain through the residential area is an improved channel, however, it is inadequate to convey large floodflows.

Kalihi-Moanalua Area – Kalihi, Kamanaiki, Lower and Upper Moanalua and Kahauiki Streams

There are reaches within the study area that were improved in conjunction with construction in this area. The reaches on Moanalua Stream that have channel improvements are from Moanalua Park Bridge to just upstream of Janet White Road and from the Golf Course Bridge to the upstream side of the Ala Aolani Street bridge at its uppermost crossing of Moanalua Stream. Major channel improvements for Moanalua Stream and Kalihi Stream were incorporated into the H-1 Freeway construction in this area. Also, the numerous bridges restricting the flow near the mouth of the streams were replaced. The portion of the study area between King Street and the H-1 Freeway also has cement-rubble-masonry stream channel walls. Upstream of the freeway there are stream channel walls built on private property on some portions of the stream. The next drainage structure is at the end of the study area, at the School Street Bridge.

Makaha Area – East and West Makaha Streams

There currently are no flood-control improvements capable of containing the larger floods in this area.

Waialua-Haleiwa Area – Kiikii, Kaukonahua, Poamoho, Paukauila, Helemano, and Opaeula Streams and the Anahulu River

There are presently no flood-control improvements in this area capable of containing the larger floods. A feasibility study for flood-control improvements is currently in progress for this area. The city also has completed dredging of Paukauila Stream to alleviate the flooding in this area.

Waimea Area – Waimea River

There is a levee along the north bank of Waimea River which provides protection to Kamehameha Highway. There are no other flood-control improvements capable of containing the larger floods.

Sunset Beach Area – Paumalu and Pahipahialua Streams

There currently are no flood-control improvements capable of containing the larger floods in this area.

Waianae Valley Area – Kaupuni Stream

The studied Kaupuni Stream reach is an improved concrete-lined channel designed to convey flood flows from the area to the Pacific Ocean. A previous USACE project, the Waianae small boat harbor, was completed in January 1979 in Waianae town near Kaupuni Stream.

Kailua-Lanikai Area – Kaelepulu Stream

Widening of Kaelepulu Stream by dredging was completed. This flood-control method lessens the impact of flooding on the surrounding area. A storm drainage system currently being constructed in the Coconut Grove area would alleviate flooding from lesser floods.

Lualualei Valley Area – Maili and Mailiili Channels

The studied Maili and Mailiili Channels are improved concrete-lined channels designed to convey flood flows from their respective drainage areas to the Pacific Ocean. Previous drainage projects include construction of the Lualualei Reservoir and construction of bridges in the 1960s and 1970s as part of flood control projects at that time. There are numerous planned projects and studies for the area intended to improve and assess drainage in the area, including a concrete repair project along Maili Channel which was put out for construction bids in February 2012. Plans to implement the recommendations put forth in a USACE flood study issued in 2001 are still underway, having slowed presumably due to funding issues. Recommendations in the study primarily center around establishment and improvement of the local drainage system in order to more effective convey storm runoff to the Maili and Mailiili flood conveyance channels, and to establish improved maintenance of the overall system, existing and proposed.

McCully Area – Makiki Stream

Makiki Stream was originally improved in 1930 for flood protection, with the entire length from King Street to the Ala Wai Canal channelized with cement-rubblemasonry walls on both banks. Other existing improvements included 250 feet of culvert downstream of the Fern Street bridge. No construction projects are currently scheduled.

Moiliili Area – Manoa Stream, Manoa-Palolo Drainage Canal, Palolo Stream

The waterways for Manoa and Palolo Streams and the Manoa-Palolo Drainage Canal have been constructed and improved for flood protection. The 1.3-mile Manoa-Palolo Drainage Canal was constructed in 1935 to provide a direct outlet to the Ala Wai Canal for the combined flows from Manoa and Palolo Streams. Its present capacity is less than the projected 10-year frequency flood. Also, between 1951 and 1960, approximately 1,000 feet of Manoa Stream and 9,000 feet of Palolo Stream were improved by the City and County of Honolulu.

Waikiki Area – Ala Wai Canal

In the Waikiki area, flood protection historically has been provided by dredging the Ala Wai Canal. In 1966, the City and County of Honolulu dredged to elevation -6.0 feet (Local Tidal Datum) for 1,500 feet of the length of the canal. Recently, the canal has been dredged by the State of Hawaii, Department of Land and Natural Resources. Dredging was to elevation -10.0 feet (Local Tidal Datum) for approximately 3,000 feet of the length of the canal between McCully Bridge and the confluence of the Manoa-Palolo and Ala Wai Canals. The dredged capacity of the canal is approximately 13,000 cfs, or equivalent to approximately a 10% annual chance flood event.

Nanakuli Area – Nanakuli and Ulehawa Streams

There are no flood protection measures for Nanakuli Stream. An approximately 2,000-foot-long segment of the Ulehawa Stream from the stream mouth has been improved with a trapezoidal channel. The channel, built in the 1960s, was excavated in coral and the banks were lined with concrete. The lining ends at the lower limit of this FIS. The capacity of this channel is 6,600 cfs. There are no other flood-protection measures for this area.

Other Areas

Nuuanu and Waolani Streams

The lower portion of Nuuanu Stream, from the ocean to the beginning of the study area, has been improved for flood protection. Upstream of the School Street Bridge, where the study area begins, the stream is unlined except for some areas where stream channel walls have been built on private property. The only flood-control structures in the study area on Nuuanu Stream occur at bridges on Kuakini Street and Nuuanu Avenue. Waolani Stream has much more extensive privately constructed channel walls. Some residences are built adjacent to the stream. There are cement-rubble-masonry walls, although there is a section of reinforced concrete wall upstream of the Kuakini Street Bridge. There are two bridges in the study area, at Kuakini Street and Judd Street.

Aiea and Kalauao Streams

The portion of Aiea Stream between the Pacific Ocean and Moanalua Road has been improved for flood protection. Over half of the portion between Moanalua Road and the H-2 Freeway has also been improved. Upstream of the freeway, there are no flood-control structures except for the bridge on Anounou Street and privately constructed channel walls. The outlet of Kalauao Stream has been channelized with earth banks from the Pacific Ocean to Kamehameha Highway. There are drainage structures at the bridges for Kamehameha Highway, Kihale Place, Moanalua Road, and a dirt road at the end of Koauka Street. The study area ends at the outlet for the H-1 Freeway culvert.

Waikele Stream

The lower portion of Waikele Stream has been extended by siltation and a dense mangrove cover. Thus, the outlet of the stream is now well beyond the old railroad bridge where the earthen-bank channel ends. Most of the lower area of Waikele Stream between the old railroad bridge and Farrington Highway has been lined with a trapezoidal concrete channel. This channel was built in 1960 after the State of Hawaii diverted Waikele Stream away from Waipahu Town to its present course. Thus, only the largest of storms will cause Waikele Stream to threaten Waipahu Town. The land in the floodplain upstream of Farrington Highway was a flood hazard area and is now a City Park. Another flood-control structure is located at the Waipahu Street Bridge. The study area terminates at the H-2 Freeway Bridge where a culvert bridge was built for a sugar plantation road.

Honouliuli Stream

Honouliuli Stream has no flood-protection improvements other than the bridges on Fort Weaver Road and the bridge on the Old Fort Weaver Road. There are some smaller bridges for the sugar plantation and for local residents. A few cementrubble-masonry walls have been constructed on private property for flood protection.

Makaleha and Unnamed Streams

There are no flood-protection improvements for these streams other than the bridge crossings on Farrington Highway, Waialua Beach Road, and Pouiki Street for Unnamed Stream and the bridge crossings on Farrington Highway, on a local road for the Dillingham Ranch and on a sugar plantation road for Makaleha Stream.

Malaekahana Stream and Kea’aulu Gulch

There are no flood-protection improvements on Malaekahana Stream or Kea’aulu Gulch other than the bridge on Kamehameha Highway and privately owned earthen walls on the streambanks to protect the agricultural lands that border the streams in the floodplain.

James Campbell Industrial Park (JCIP) Drainage Canal

The studied channel reach is an improved concrete-lined channel designed to convey flood flows from the surrounding drainage area to the Pacific Ocean.

Kaalaea, Haiamoa, Waihee, Kahaluu and Ahuimanu Streams

Kaalaea Stream has no flood-protection improvements other than bridges on Kamehameha Highway and Pulama Road. Haiamoa Stream has no flood-protection improvements other than bridges on Kamehameha Highway and Ahilama Road. Waihee Stream discharges into a flood-protection lagoon that also receives flow from Kahaluu Stream. A culvert bridge on Ahilama Road is the only other flood-control structure on Waihee Stream. Kahaluu and Ahuimanu Streams have had flood-protection channels constructed or have channels planned for construction in the near future. Flood-protection improvements are not planned for the higher section of the Kahaluu Stream Study area.

Kawainui Stream and Oneawa Channel

Kawainui Stream has been separated from Kawainui Marsh by an earth berm and the Oneawa Channel (Kawainui) Canal conveys floodflows from the Kawainui Swamp. Oneawa Channel is a part of the Kawainui Marsh Flood Control project. This flood control project was originally constructed in 1966 to protect the Kailua community from floodwater from the marsh. Vegetation in the marsh caused overtopping of the project during the January 1988 storm, and as a result the levee height was raised and concrete floodwall installed in 1997. There are no other flood-protection structures on Kawainui Stream except for the Kailua Road Bridge, and two bridges on Kahahiaka and Kaawakea Roads. A new bridge on Hamakua Drive is now under construction.

Kaloi Gulch

There are no flood protection measures on Kaloi Gulch.

Waikakalaua Stream

A short stretch of Waikakalaua Stream has been lined with gunite just upstream of the Kamehameha Highway Bridge. The lining is applied only in the lower portion of the channel. There are several vehicle bridges, and numerous footbridges for crossing of the channel.

North Halawa/Halawa Stream

The lower portion of North Halawa Stream was improved with a rectangular concrete-lined channel as part of the Moanalua Road and H-3 Freeway projects. In addition, most of the developments have constructed walls on the upper channel slopes for protection from extreme flooding conditions. Similarly, along the Halawa Stream study reach, the stream was improved with a rectangular concrete-lined channel designed to convey flood flows to its outlet at Pearl Harbor.

Waiawa Stream, Overflow area of Waiawa Stream, Panakauahi Gulch, Manaiki, and Moanalua Stream

There are existing channel and bridge improvements along Moanalua and Manaiki Streams. The channel from the Moanalua Gardens Park Bridge to approximately 400 feet upstream of the Jarrett White Road Bridge is lined with concrete. The Manaiki Stream banks are revetted for a distance of 200 feet above Moanalua Road. The channel for Manaiki Stream, from the Pineapple Place crossing to 200 feet above the Mahiole Street crossing, is concrete lined. The Moanalua Road crossing has also been enlarged. Although channel improvements have been made, the flooding problems of Moanalua and Manaiki Streams still exist.

The flood control measures along Waiawa Streams focus mainly on the lower reaches of the streams. A levee has been built along the east overbank of Waiawa Stream near the Lehau Avenue area. However, this levee does not provide adequate freeboard for the 1-percent annual chance flood. Another levee has been constructed on the west overbank of Waiawa Stream, protecting the abandoned sewage treatment plant. This levee also does not provide adequate freeboard for the 1-percent annual chance flood. There are no flood control measures along Panakauahi Gulch.

Both Waiawa Stream and Panakauahi Gulch are unlined. There are many bridge crossings through the study reaches. In the upstream reaches of Waiawa Stream and the Panakauahi Gulch, there are pipe culverts at the road crossings with large concrete bridges. The downstream reaches of Waiawa Stream have pipe crossings and footbridges.

Waimalu Stream

The studied channel reach is an improved concrete-lined channel designed to convey flood flows from the surrounding drainage area to Pearl Harbor. A channel dredging project, intended to remove significant sediment buildup from the Waimalu channel bottom, was put out for construction bids in April 2012.

3.0 ENGINEERING METHODS

For the flooding sources studied in detail in the county, standard hydrologic and hydraulic study methods were used to determine the flood hazard data required for this FIS. Flood events of a magnitude which are expected to be equaled or exceeded once on the average during any 10-, 25-, 50-, 100-, or 500-year period (recurrence interval) have been selected as having special significance for floodplain management and for flood insurance rates. These events, commonly termed the 10-, 25-, 50-, 100-, and 500-year floods, have a 10-, 2-, 4-, 1-, and 0.2-percent chance, respectively, of being equaled or exceeded during any year. Although the recurrence interval represents the long term average period between floods of a specific magnitude, rare floods could occur at short intervals or even within the same year. The risk of experiencing a rare flood increases when periods greater than 1 year are considered. For example, the risk of having a flood which equals or exceeds the 100-year flood (1-percent chance of annual exceedence) in any 50-year period is approximately 40 percent (4 in 10), and, for any 90-year period, the risk increases to approximately 60 percent (6 in 10). The analyses reported herein reflect flooding potentials based on conditions existing in the county at the time of completion of this FIS. Maps and flood elevations will be amended periodically to reflect future changes.

3.1 Hydrologic Analyses

Hydrologic analyses were carried out to establish the peak discharge-frequency relationships for the flooding sources studied in detail affecting the county.

The hydrologic analyses for the detailed-study areas were all based upon hydrologic data and frequency curves previously established for the study area. The sources of the hydrologic data for all of the detailed-study areas and unusual hydrologic techniques which may have been applied in their evaluation are as follows:

<u>Kahuku Area</u> – Hoolapa, Kalaeokahipa, Ohia, and Ohia (East) Streams

The hydrologic data used in the analysis of streams studied by detailed methods in this area were updated from a previous flood frequency report prepared by the USACE (USACE, 1971).

The lowlands below Kamehameha Highway have no well-defined drainageway to convey the larger floods to the ocean. A ponding condition is thus created by the nature of the topography and the sand dunes which tend to impound the water in the lowlands. Therefore, to evaluate the extent of flooding in this area, the hydrographs for the various frequency floods were routed through this low area to obtain the ponding elevation.

The frequency-discharge/drainage area relationships for the streams studied by detailed methods are shown in Figure 2.

<u>Hauula-Punaluu Area</u> – Kaipapau, Waipilopilo, Hanahimoa, Kaluanui, Punaluu, and Wailele Streams

The discharges for the detailed-study streams, with the exception of Wailele Stream, were updated from a regional flood frequency report developed by the USACE (U.S. Department of Agriculture, 1973). The frequency-discharge/drainage-area relationships for the streams studied by detailed methods are shown in Figure 3.

The 100-year discharge for Wailele Stream (downstream) was computed in accordance with the procedures contained in the USGS Report WRI 80-45 (U.S. Department of the Interior, 1979).

The portion of upper Wailele Stream restudied for the November 5, 2014 study was analyzed using the Regional Regression equations described in Section 10.

<u>Kahana Area</u> – Kahana Stream

The hydrologic data used in evaluating this stream were obtained from a letter report prepared by the USACE (USACE, 1973). The frequency-discharge/drainage-area relationship for Kahana Stream is shown in Figure 4.

<u>Kaaawa Area</u> – Kaaawa Stream

The hydrologic data used in this study were updated from the USACE Floodplain Information Report on Kaaawa Stream (USACE, 1969). The frequency-discharge/drainage-area relationship for Kaaawa Stream is shown in Figure 5.

<u>Waikane-Waiahole Area</u> – Waikane and Waiahole Streams

The hydrologic data used in this study were updated from a regional flood frequency report developed by the USACE (U.S. Department of Agriculture, 1973). The hydrologic data for the unnamed ditch were revised by the USACE for this study. The frequency-discharge/drainage-area relationships for the streams studied by detailed methods are shown in Figure 6.

<u>Heeia Area</u> – Heeia Stream

The hydrologic data used in the analysis of Heeia Stream were updated from a previous report by the USACE (U.S. Department of Agriculture, 1973). The frequency-discharge/drainage-area relationship for Heeia Stream is shown in Figure 7.

<u>Kaneohe Area</u> – Keaahala, Kaneohe, Kamooalii, Kawa and Tributary to Kawa Streams

For the streams studied by detailed methods in this area (other than Keaahala Stream, updated in Section 10 below), the hydrologic data were updated from a previous FIS (U.S. Department of Housing and Urban Development, 1971). The frequency-discharge/drainage-area relationships for these streams are shown in Figures 7 and 8.

Keaahala Stream hydrology, restudied for the November 5, 2014 study, is described in Section 10.

Kailua-Lanikai Area – Kaelepulu Stream

The hydrologic data used in the analysis of Kaelepulu Stream were updated from a previous FIS developed for the Federal Insurance Administration (FIA) (U.S. Department of Housing and Urban Development, 1971). The frequency-discharge/drainage-area relationship for this stream is shown in Figure 9.

Waimanalo Area – Waimanalo Stream, Waimanalo Streams A, B, C, and D, and Inoaole Stream

The hydrologic data for the analyses of the streams studied by detailed methods (except for Waimanalo: Stream A, updated in Section 10 below) were updated from a previous FIS developed for the FIA (U.S. Department of Housing and Urban Development, 1971). There is a low-lying area upstream of Highway 22 that impounds a large portion of the flood flows. Therefore, the floodflows were routed through this area. The frequency-discharge/drainage-area relationships for the streams studied in detail in this area are shown in Figure 10.

Waimanalo: Stream A hydrology, restudied for the November 5, 2014 study, is described in Section 10.

Aina Haina Area – Wailupe and Kului Streams

The hydrologic data for the analysis of Wailupe Stream and Kului Stream were updated from a previous report by the USACE (USACE, 1971). The frequency-discharge/drainage-area relationship for Wailupe Stream is shown in Figure 11.

Waialae-Kahala Area – Waialae-Iki, Kapakahi #1, Waialae-Nui Streams and Waialae Major Drain

The hydrologic data used for this area (other than Waialae-Nui Stream, updated in Section 10 below) were updated from a previous report developed by the USACE (USACE, 1972). The frequency-discharge/drainage-area relationships for streams in this area are shown in Figures 12, 13, and 14.

Waialae-Nui Stream hydrology, restudied for the November 5, 2014 study, is described in Section 10.

Kalihi-Moanalua Area – Kalihi, Kamanaiki, Lower and Upper Moanalua and Kahauiki Streams

The hydrologic data used in this study were developed by the USACE, and were in part updated from previous reports by the USACE (USACE, 1972). The frequencydischarge/drainage-area relationships for the streams studied by detailed methods are shown in Figure 15.

The hydrologic analysis was limited to the determination of the 1-percent annual chance flood flows for Kalihi and Kamanaiki Streams upstream of North School Street. The flow frequencies were based on a statistical analysis of USGS gage data, performed in accordance with the procedures given in Bulletin No. 17B (Water Resources Council, 1981). A generalized skew coefficient of -0.05 was used (for Hawaii).

For Kalihi Stream, the length of record is 73 years and the drainage area is 2.61 square miles at USGS Gaging Station No. 16229000.

At the confluence of Kamanaiki and Kalihi Streams, the length of record is 28 years and the drainage area is 5.18 square miles at USGS Gaging Station No. 16229300.

For the lower reaches of Moanalua and Kahauiki Streams, hydrologic data from 27 gages were used. Frequency curves for the 27 stations were calculated following procedures from "Guidelines for Determining Flood Flow Frequency" (Water Resources Council, 1977). 50-percent annual chance flood event were plotted against their respective drainage areas, and flows for desired areas were selected from this curve. Frequency-discharge curves were based on the log-Pearson Type III distribution with standard deviation of 0.33 and skew coefficient of -0.2.

<u>Makaha Area</u> – East and West Makaha Streams and Makaha Stream

The hydrologic data used for East Makaha and West Makaha Streams were updated from a previous report developed by the USACE (USACE, 1972). The frequencydischarge/drainage area relationships for these streams are shown in Figure 16.

Revised Makaha Stream and East and West Makaha Streams hydrology is described in Section 10.

<u>Waialua-Haleiwa Area</u> – Kiikii, Kaukonahua, Poamoho, Paukauila, Helemano, and Opaeula Streams and the Anahulu River

The hydrologic data used for the analyses of streams in this study area were updated from previous USACE reports (U.S. Department of Housing and Urban Development, 1971; USACE, 1970). The frequency-discharge/drainage-area relationships for the streams studied by detailed methods are shown in Figure 17.

<u>Waimea Area</u> – Waimea River

The hydrologic data used in the analysis of the Waimea River were updated from a previous report prepared by the USACE (USACE, 1972). The frequency-discharge/drainage-area relationship for the Waimea River is shown in Figure 18.

Sunset Beach Area – Paumalu and Pahipahialua Streams

The hydrologic data used in the analyses of streams studied by detailed methods in this area were updated from a previous report prepared by the USACE (USACE, 1968). The frequency-discharge/drainage-area curves for these streams are shown in Figure 18.

Waianae Valley Area – Kaupuni Stream

Kaupuni Stream hydrology is described in Section 10.

Lualualei Valley Area – Maili and Mailiili Channels

Maili and Mailiili Channel hydrology is described in Section 10.

McCully Area – Makiki Stream

For Makiki Stream, regression equations developed by the USGS were used to obtain peak discharges for the 10-, 2-, and 1-percent annual chance flooding events (U.S. Department of the Interior, 1976). Since no equation for a 0.2-percent annual chance flood was determined by the USGS study, a regression equation for this event was developed utilizing the same basic data and regression techniques as applied by the USGS. The regression equations used are as follows:

$$Q_{10} = 5.75\ (DA)^{0.82}(FC)^{1.20}$$

$$Q_{50} = 17.1\ (DA)^{0.80}(FC)^{1.09}$$

$$Q_{100} = 25.4\ (DA)^{0.79}(FC)^{1.05}$$

$$Q_{500} = 49.9\ (DA)^{0.78}(FC)^{1.00}$$

where DA is the area of the drainage basin in square miles and FC is the ratio of the drainage area covered by forests and vegetation to the total drainage area in percent.

The computed peak discharges for Makiki Stream within the study limits were reduced to reflect present conditions upstream of the detailed-study limit, where restricted channel capacity causes a diversion of flow away from the Makiki Channel. Kahana Stream, a tributary to Makiki Stream, overflows between Mott-Smith Drive and Liholiho Street, where the channel capacity is approximately 360 cfs due to the discharge resulting from the other tributary areas. The frequency-discharge/drainage-area relationship for Makiki Stream is shown in Figure 19.

Moiliili Area – Manoa Stream, Manoa-Palolo Drainage Canal, Palolo Stream

For Manoa Stream and the Manoa-Palolo Drainage Canal, the SCS hydrograph method of analysis was used to determine peak discharges for floods of the selected recurrence intervals (U.S. Department of Agriculture, 1972). Due to the high proportion of urbanized area within the drainage basin, the regression equations developed by the USGS were not appropriate, as evidenced by discharges computed for areas with no forest cover. Results of the SCS method compared favorably against a regional flood-frequency analysis performed by the USACE using gaging station records from drainage basins with urbanized areas. The SCS method resulted in slightly higher peak discharges, which are probably due to the higher proportion of urbanized area within the Manoa Stream drainage basin as compared to the basins of the gaged stations whose records were used in the USACE analysis.

The frequency-discharge relationships for Manoa Stream and Manoa-Palolo Drainage Canal are shown in Figures 20 and 21, respectively.

For Palolo Stream, discharges were based on a statistical analysis of discharge records covering a 25-year period at USGS Gaging Station No. 1,624.70. The analysis was performed by the USACE and followed the standard log-Pearson Type III method as outlined by the Water Resources Council (Water Resources Council, 1977). The frequency-discharge/drainage-area relationship for Palolo Stream is shown in Figure 19.

Waikiki Area – Ala Wai Canal

For the Ala Wai Canal, the SCS hydrograph method of analysis was used to determine peak discharges for floods of the selected recurrence intervals (U.S. Department of Agriculture, 1972). Due to the high proportion of urbanized areas within the drainage basin, the regression equations developed by the USGS were not appropriate, as evidenced by discharges computed for areas with no forest cover. Results of the SCS method compared favorably with a regional flood-frequency analysis performed by the USACE using gaging station records from drainage basins with urbanized areas. The SCS method resulted in slightly higher peak discharges, which are probably due to the higher proportion of urbanized area within the Ala Wai drainage basin as compared to basins of the gaged stations whose records were used in the USACE analysis. The frequency-discharge/drainage-area relationships for Ala Wai Canal are shown in Figure 22.

Nanakuli Area – Nanakuli and Ulehawa Streams

For Nanakuli Stream, the 1-percent annual chance discharge was determined from statistical analysis of 18 years of data from USGS Gaging Station No. 16212300. The drainage area on this stream is 3.98 square miles. Calculation of 1-percent annual chance flood magnitudes from gaged data were made in accordance with procedures contained in Bulletin No. 17B (Water Resources Council, 1981). A generalized skew coefficient of -0.05 (for Hawaiian Islands) was used.

For Ulehawa Stream, the 1-percent annual chance discharge was computed in accordance with the procedures outlined in the USGS report WRI 80-45 (U.S. Department of the Interior, 1979).

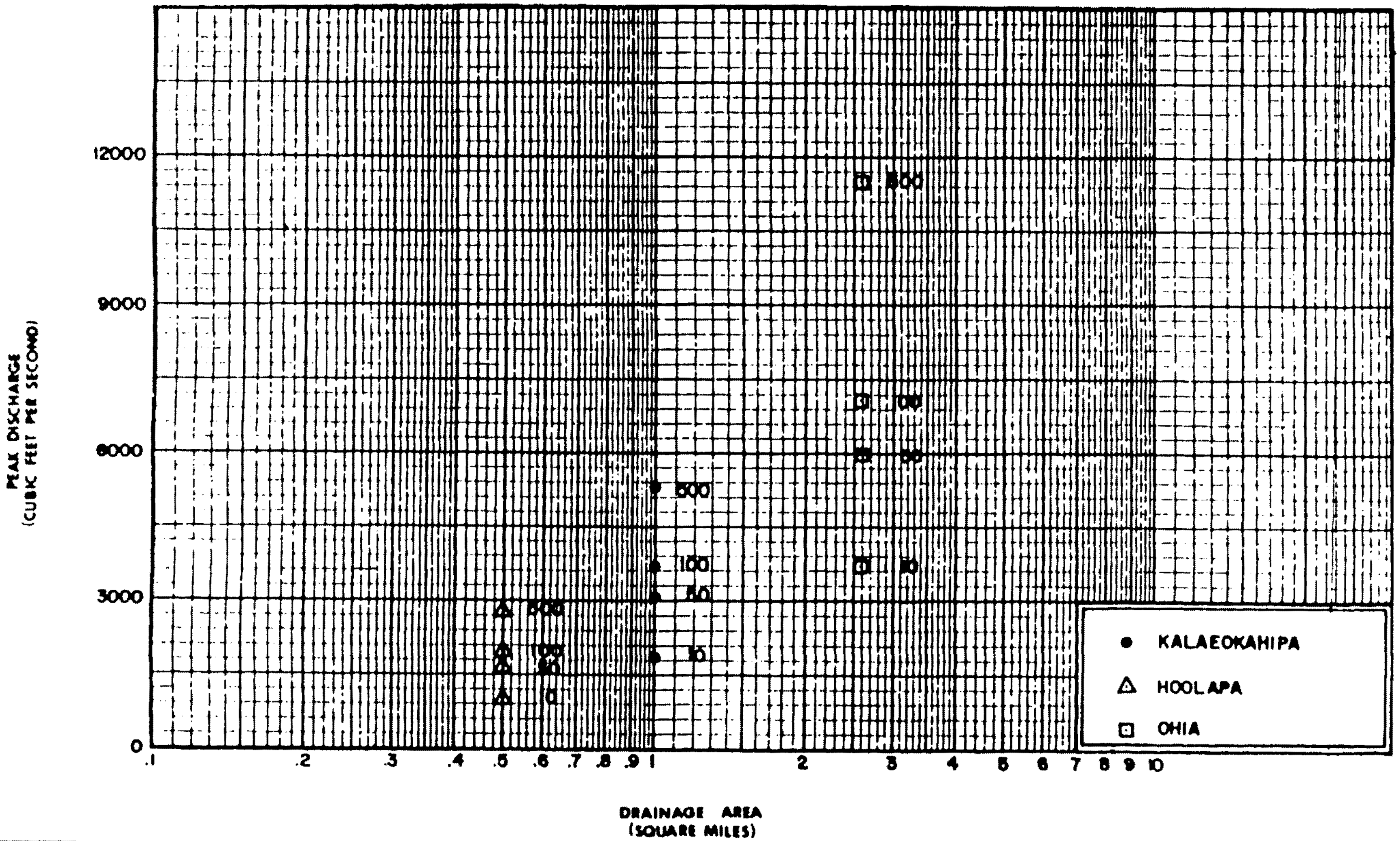


FIGURE 2

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY AND COUNTY OF HONOLULU, HI

FREQUENCY-DISCHARGE, DRAINAGE AREA CURVES

KAHUKU STREAMS

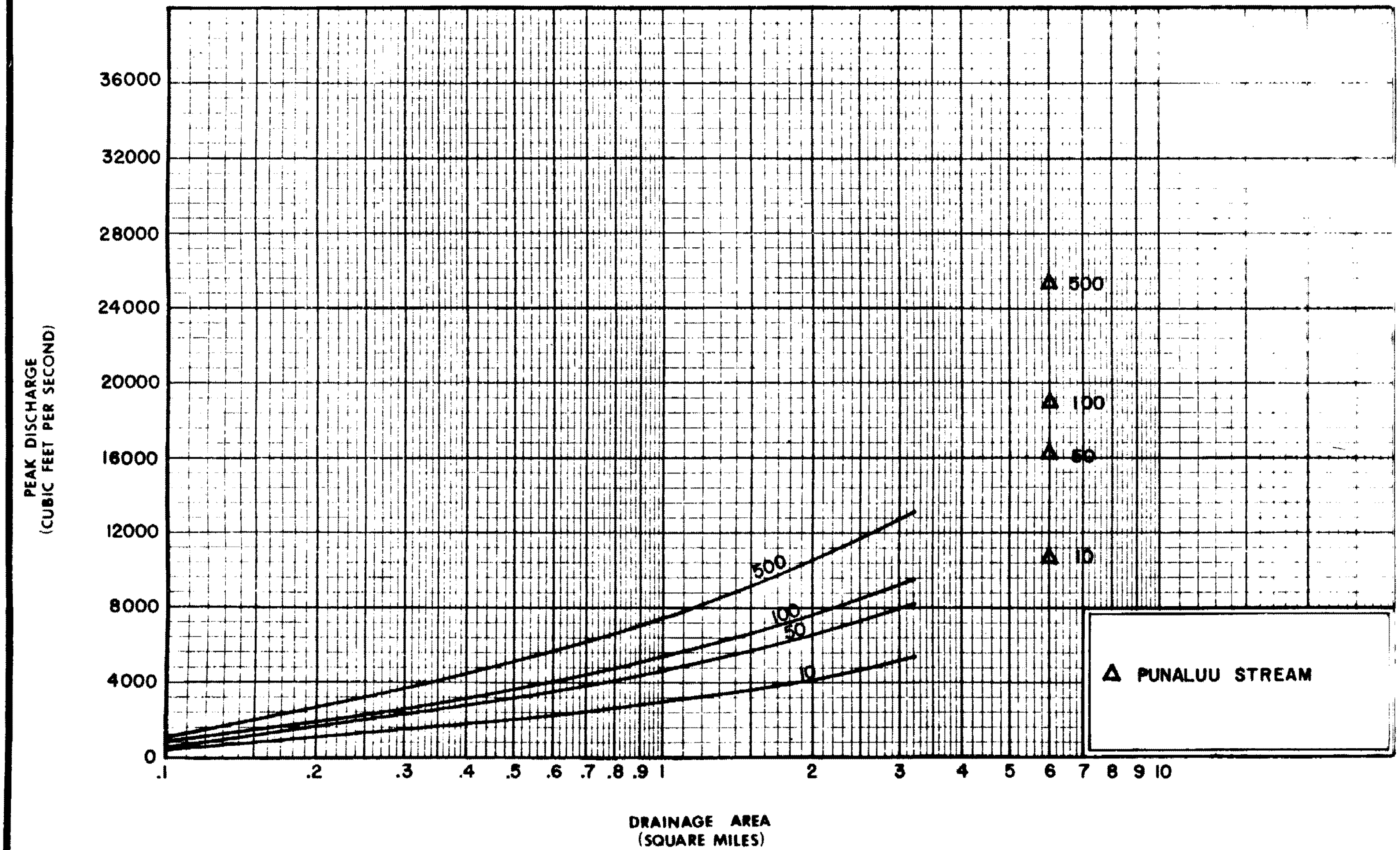


FIGURE 3

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY AND COUNTY OF HONOLULU, HI

FREQUENCY-DISCHARGE, DRAINAGE AREA CURVES

HAUULA-PUNALUU STREAMS NEAR LAIE

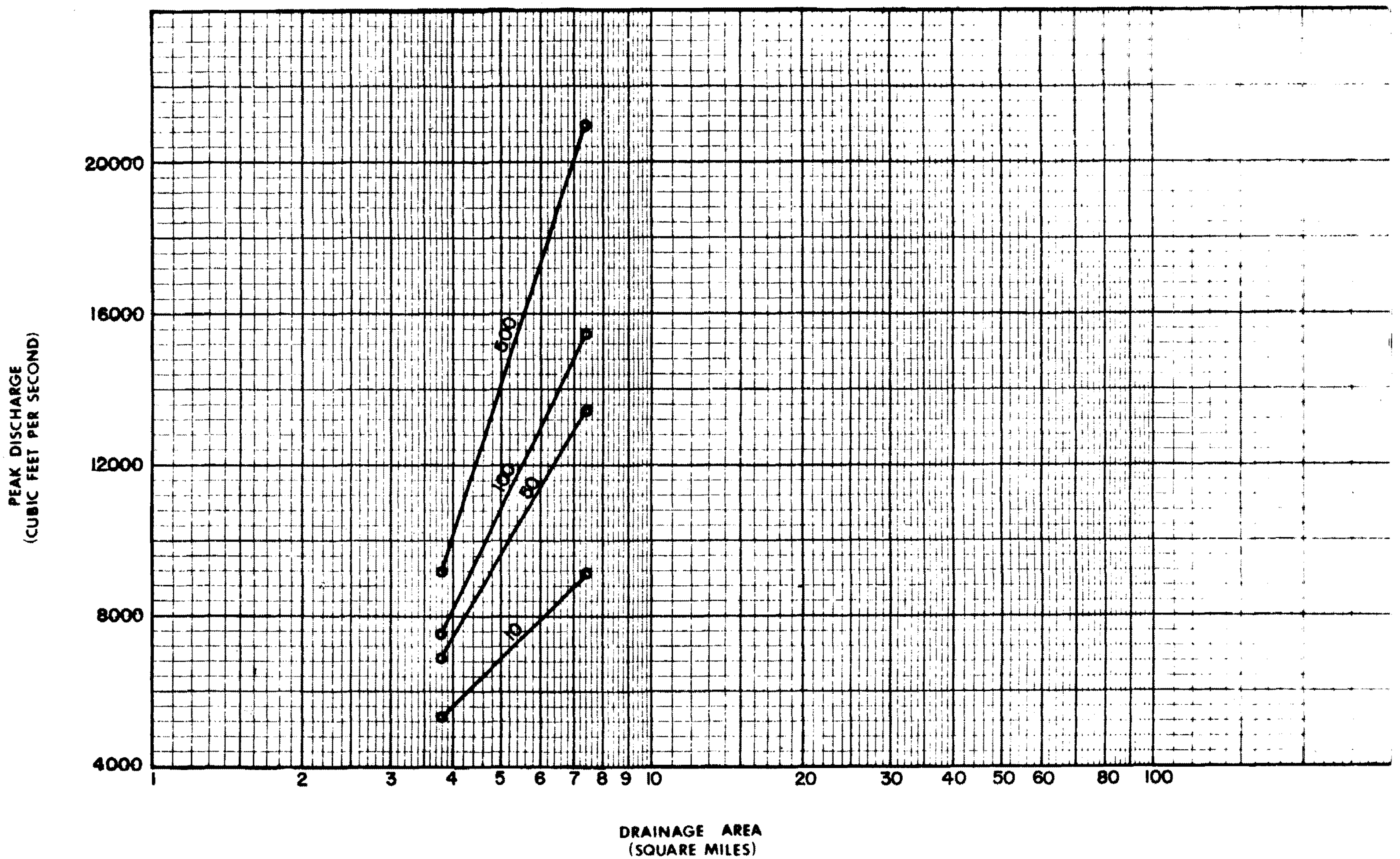


FIGURE 4

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY AND COUNTY OF HONOLULU, HI

FREQUENCY-DISCHARGE DRAINAGE AREA CURVES

KAHANA STREAM

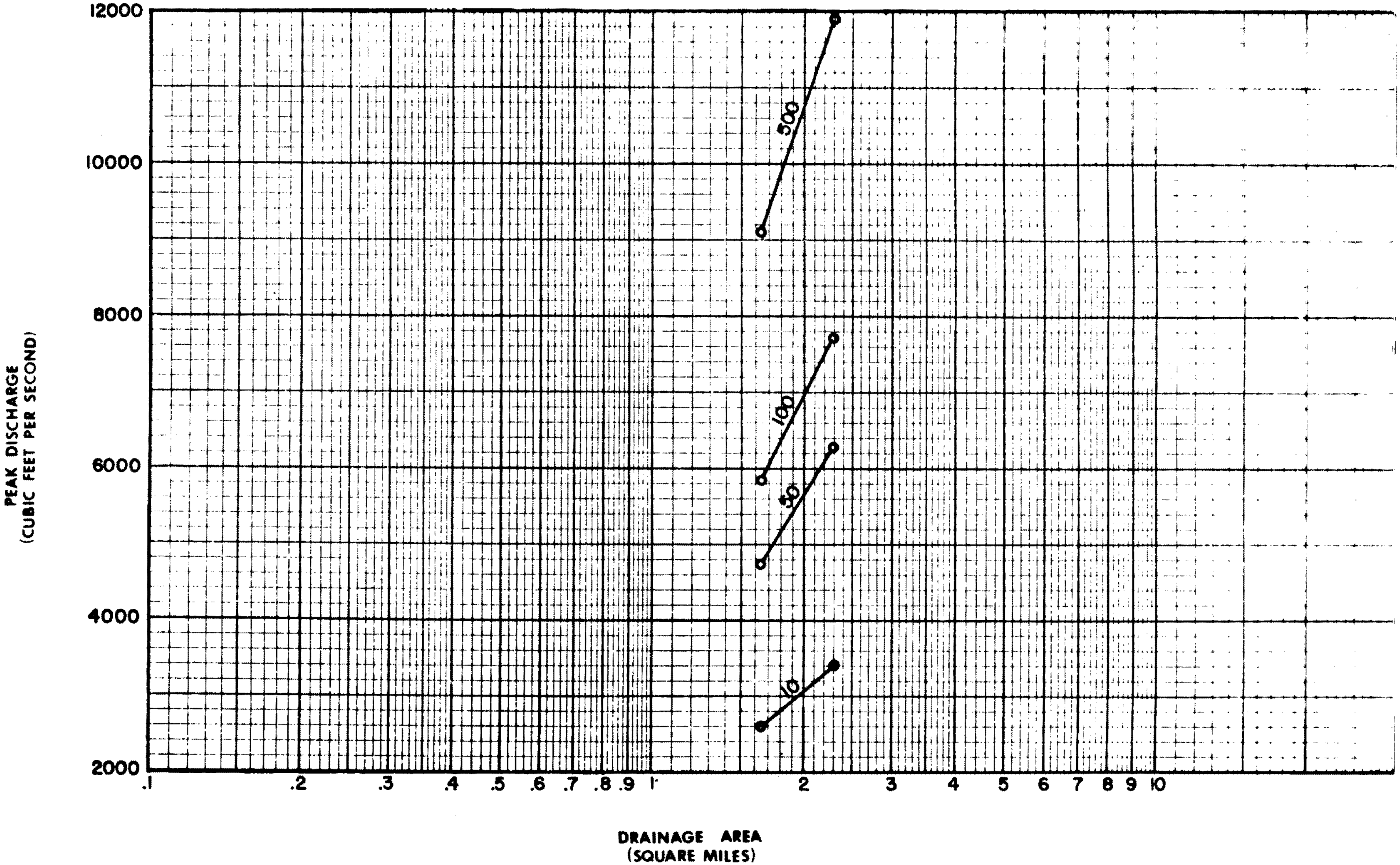


FIGURE 5

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY AND COUNTY OF HONOLULU, HI

FREQUENCY-DISCHARGE, DRAINAGE AREA CURVES

KAAAWA STREAM

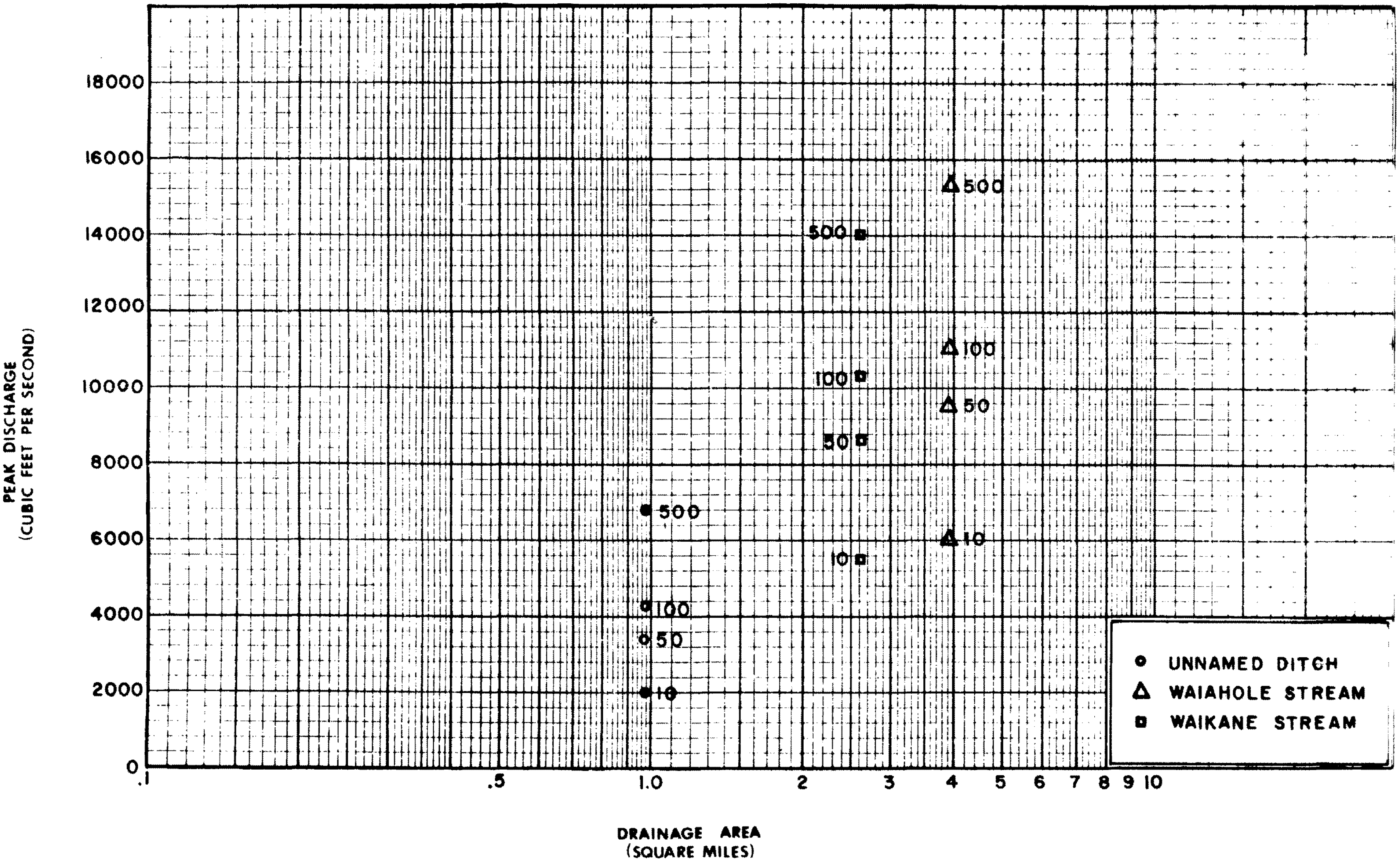


FIGURE 6

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY AND COUNTY OF HONOLULU, HI

FREQUENCY-DISCHARGE, DRAINAGE AREA CURVES

WAIKANE & WAIAHOLE STREAMS

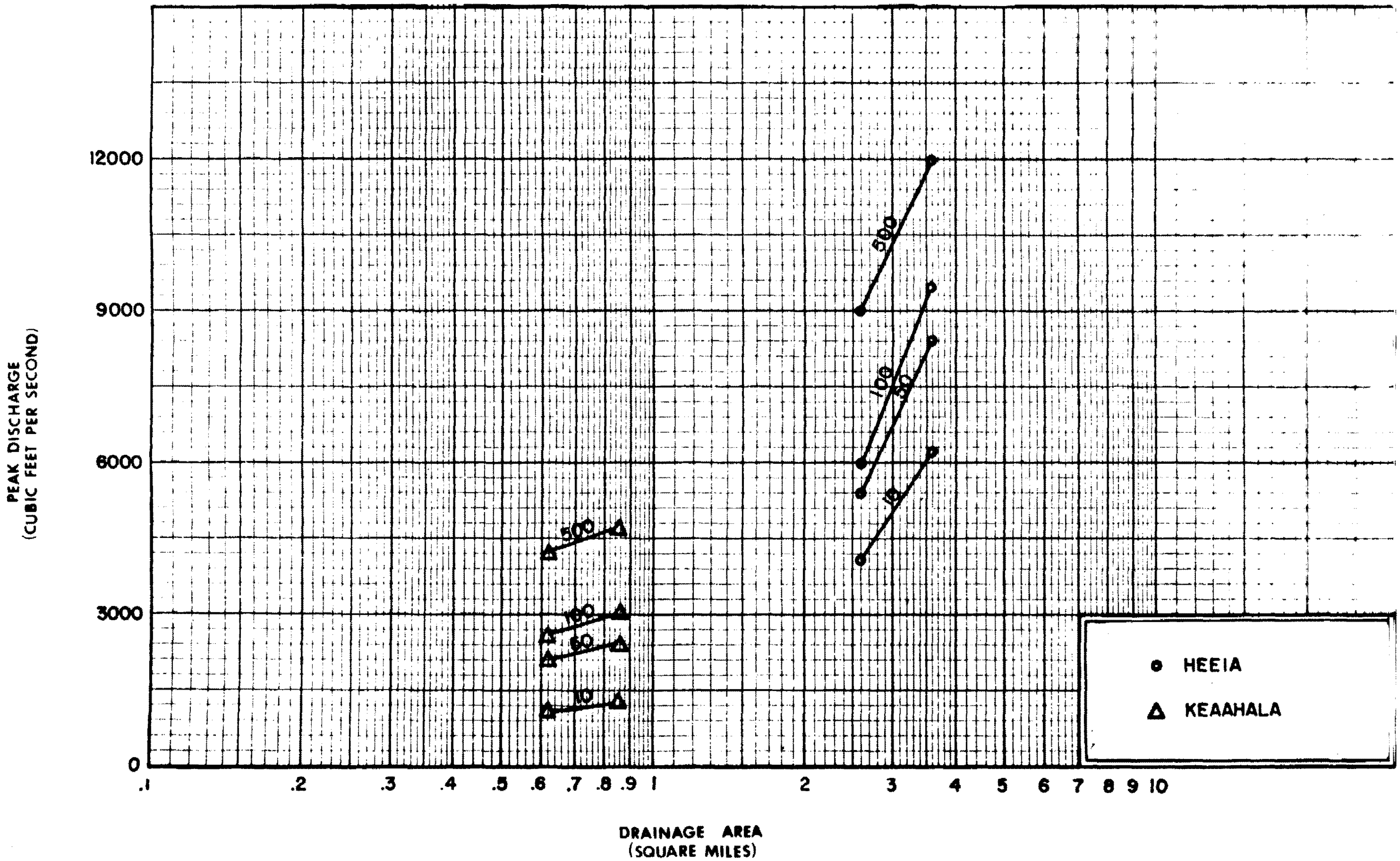


FIGURE 7

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY AND COUNTY OF HONOLULU, HI

FREQUENCY-DISCHARGE, DRAINAGE AREA CURVES

KEAAHALA & HEEIA STREAMS

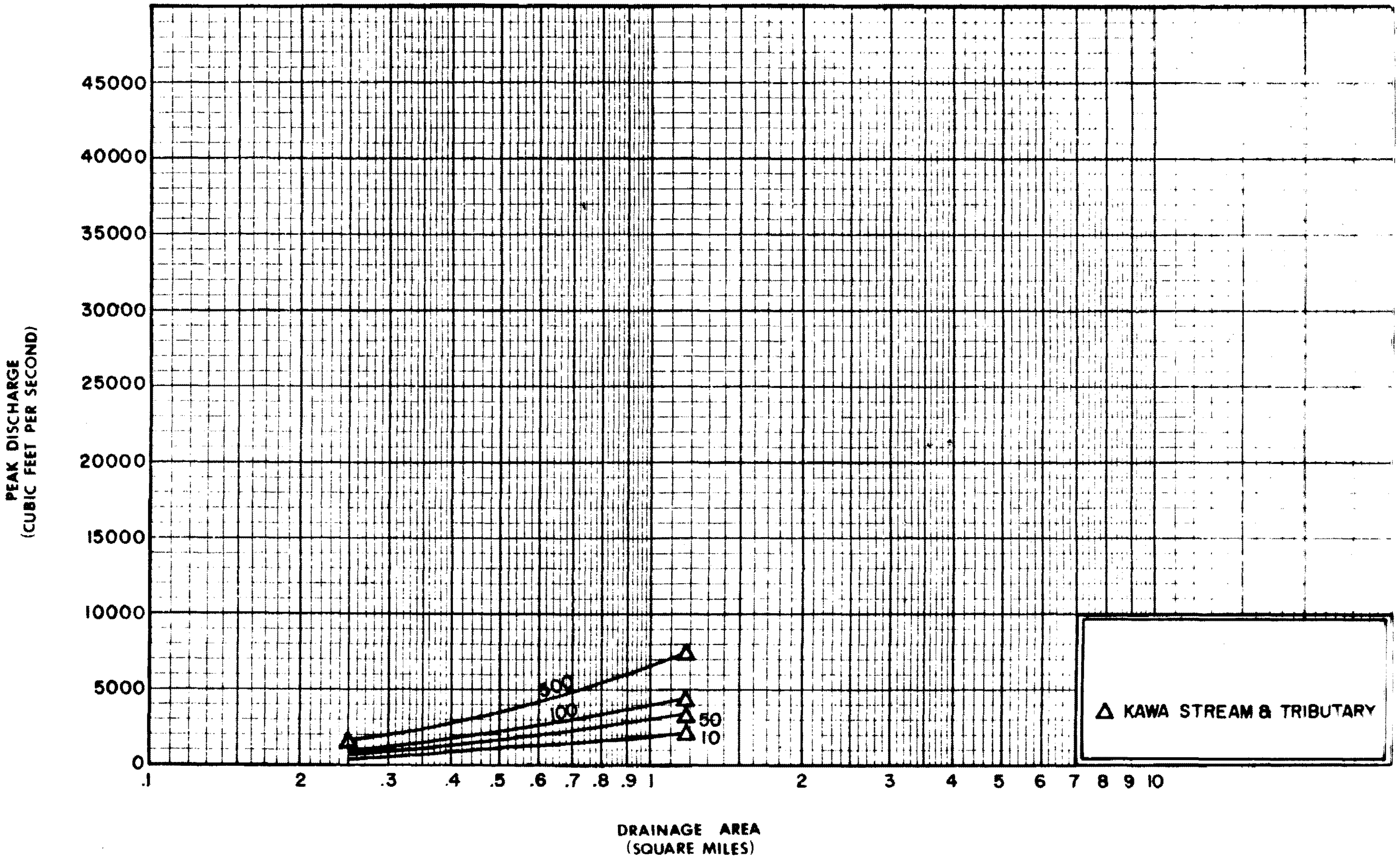


FIGURE 8

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY AND COUNTY OF HONOLULU, HI

FREQUENCY-DISCHARGE, DRAINAGE AREA CURVES

KAWA STREAM

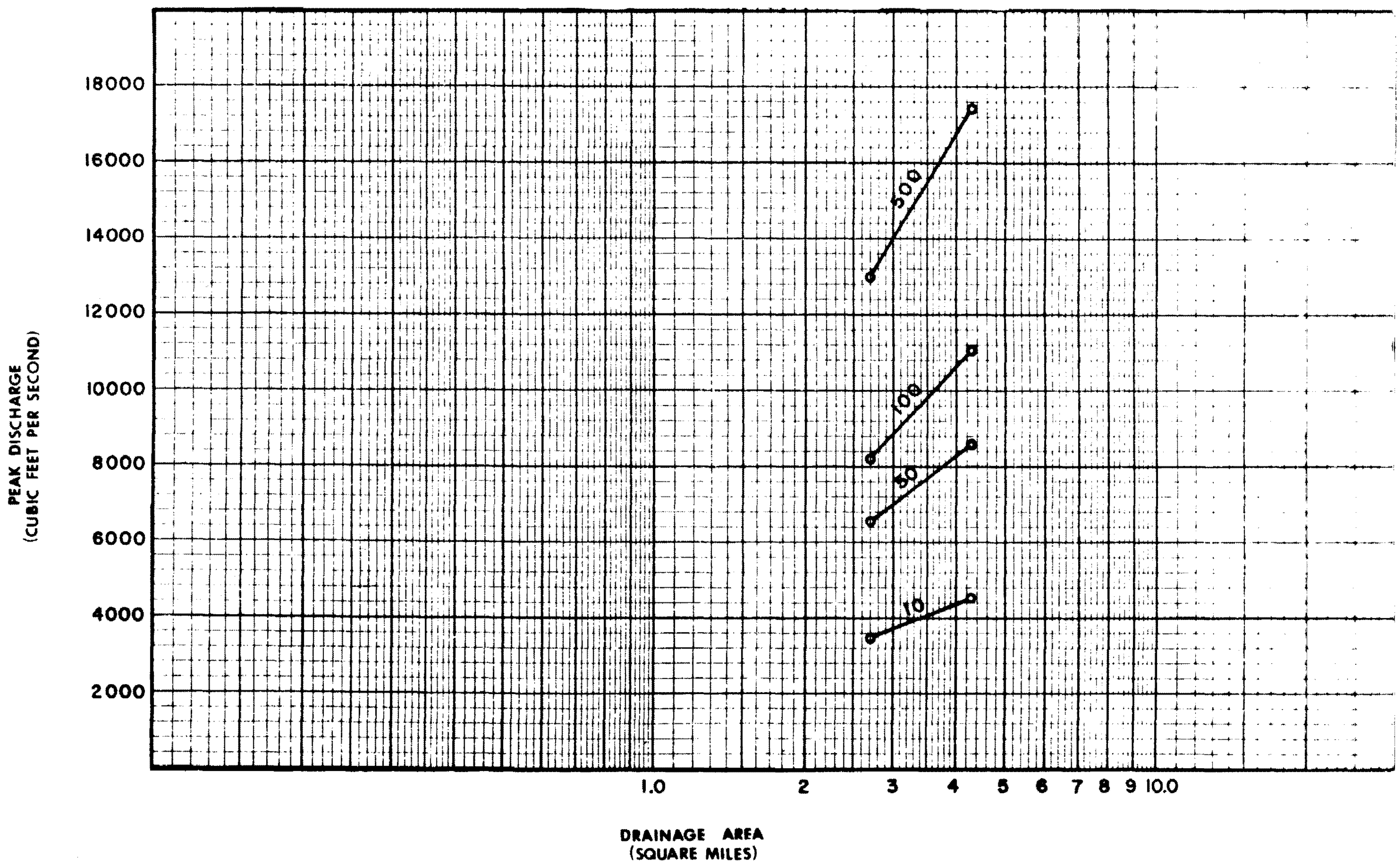


FIGURE 9

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY AND COUNTY OF HONOLULU, HI

FREQUENCY-DISCHARGE, DRAINAGE AREA CURVES

KAELEPULU STREAM

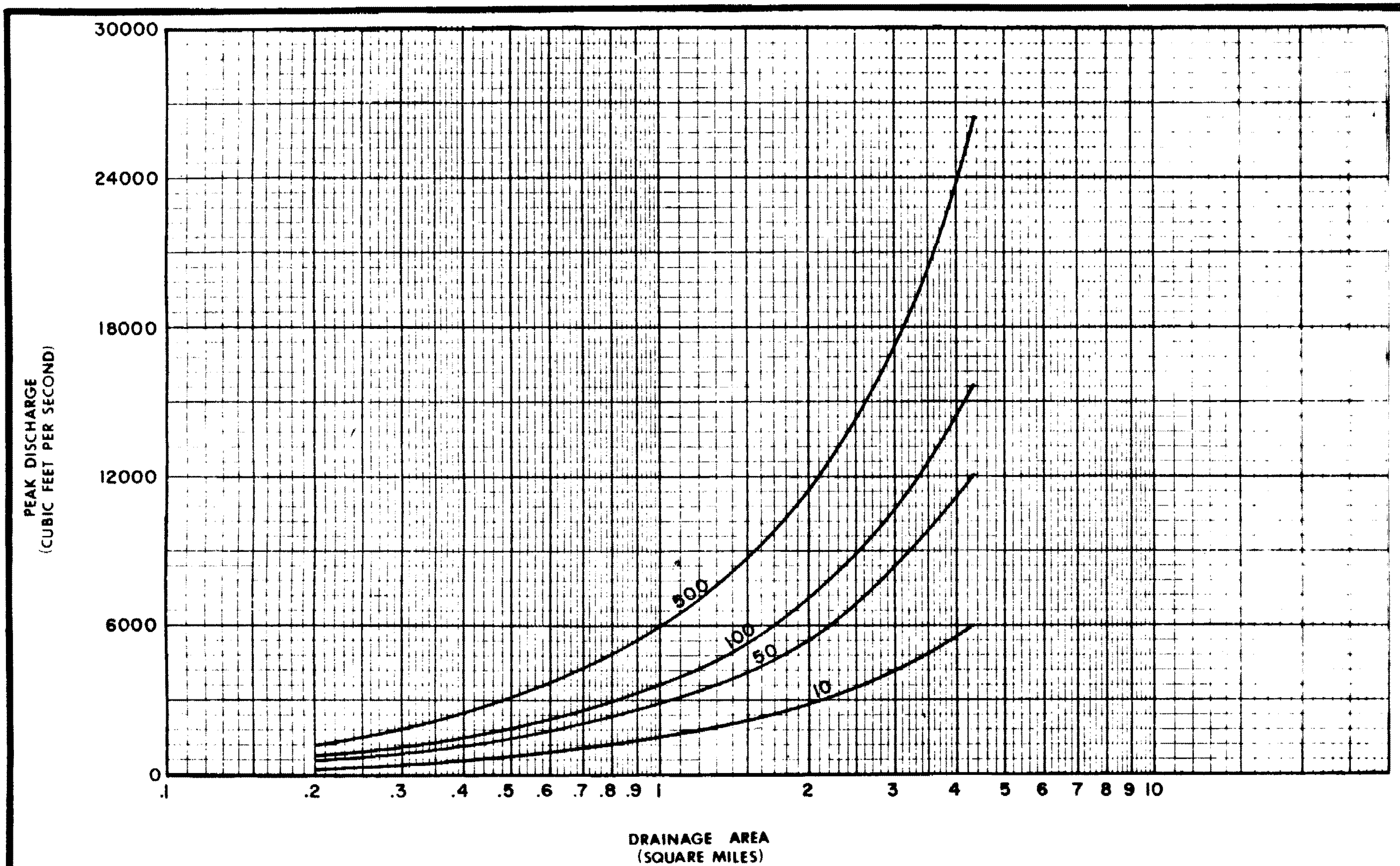


FIGURE 10

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY AND COUNTY OF HONOLULU, HI

FREQUENCY-DISCHARGE, DRAINAGE AREA CURVES

WAIMANALO STREAMS

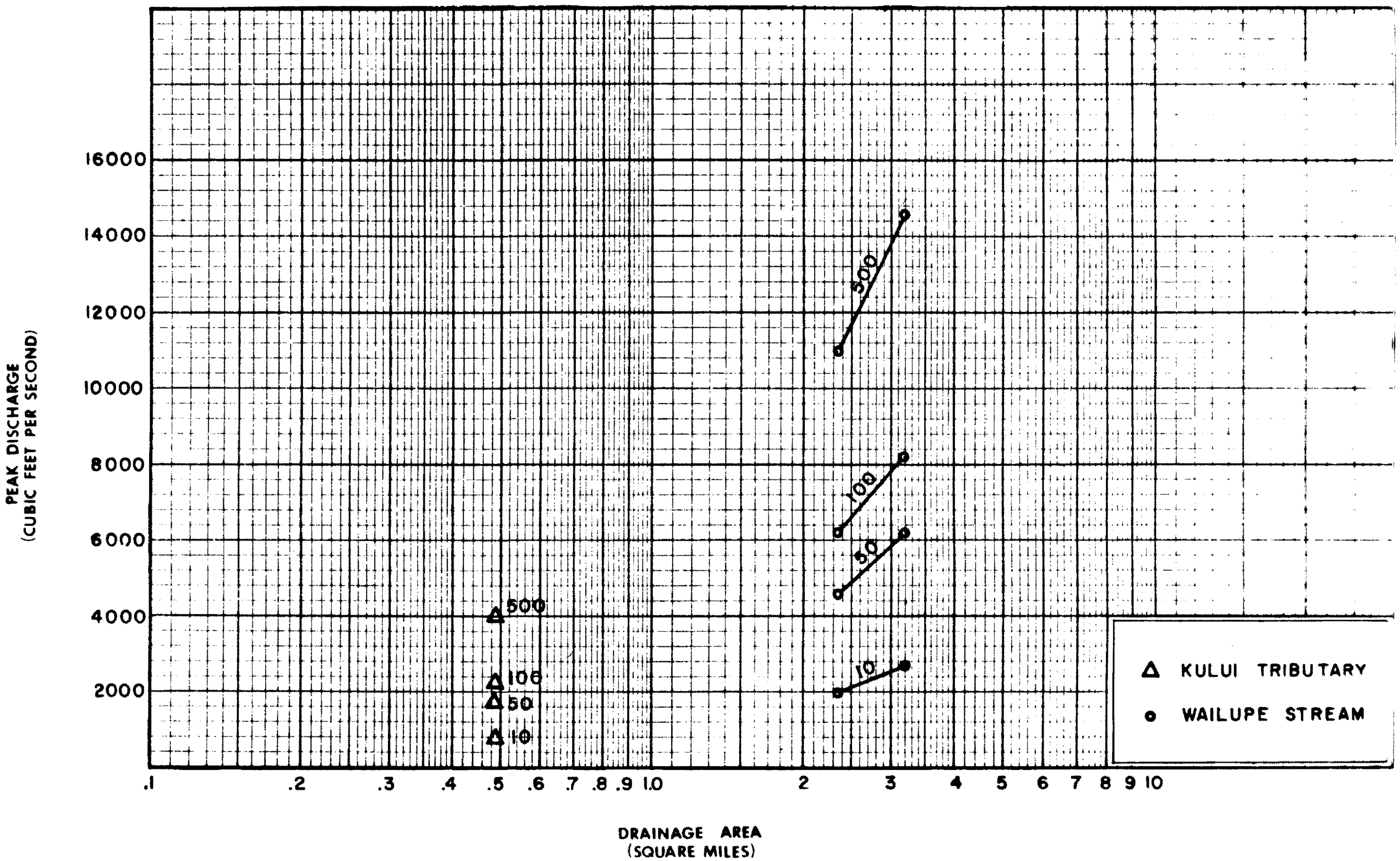


FIGURE 11

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY AND COUNTY OF HONOLULU, HI

FREQUENCY-DISCHARGE, DRAINAGE AREA CURVES

WAILUPE STREAM & KULUI TRIBUTARY

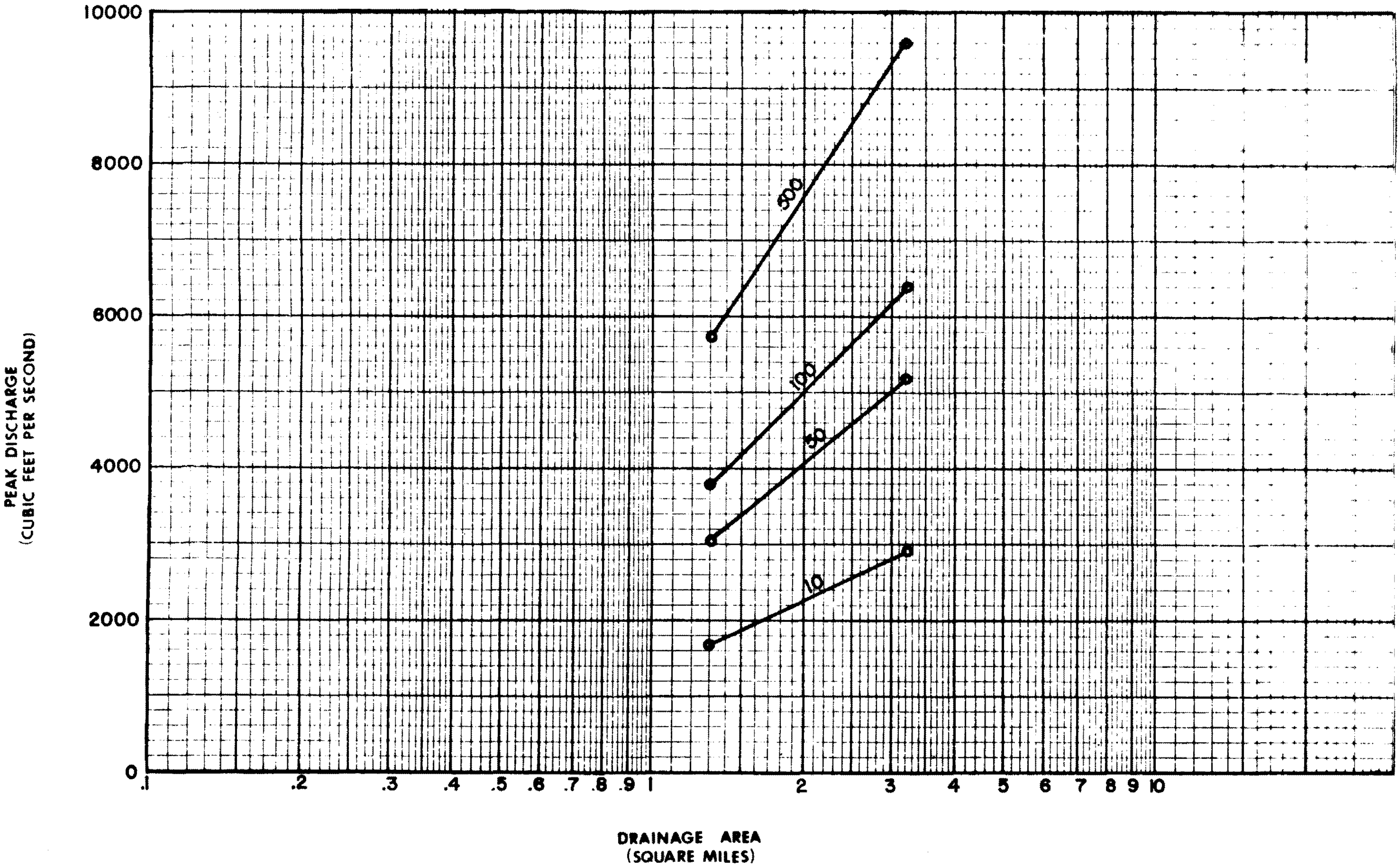


FIGURE 12

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY AND COUNTY OF HONOLULU, HI

FREQUENCY-DISCHARGE, DRAINAGE AREA CURVES

KAPAKAHI STREAM # 1

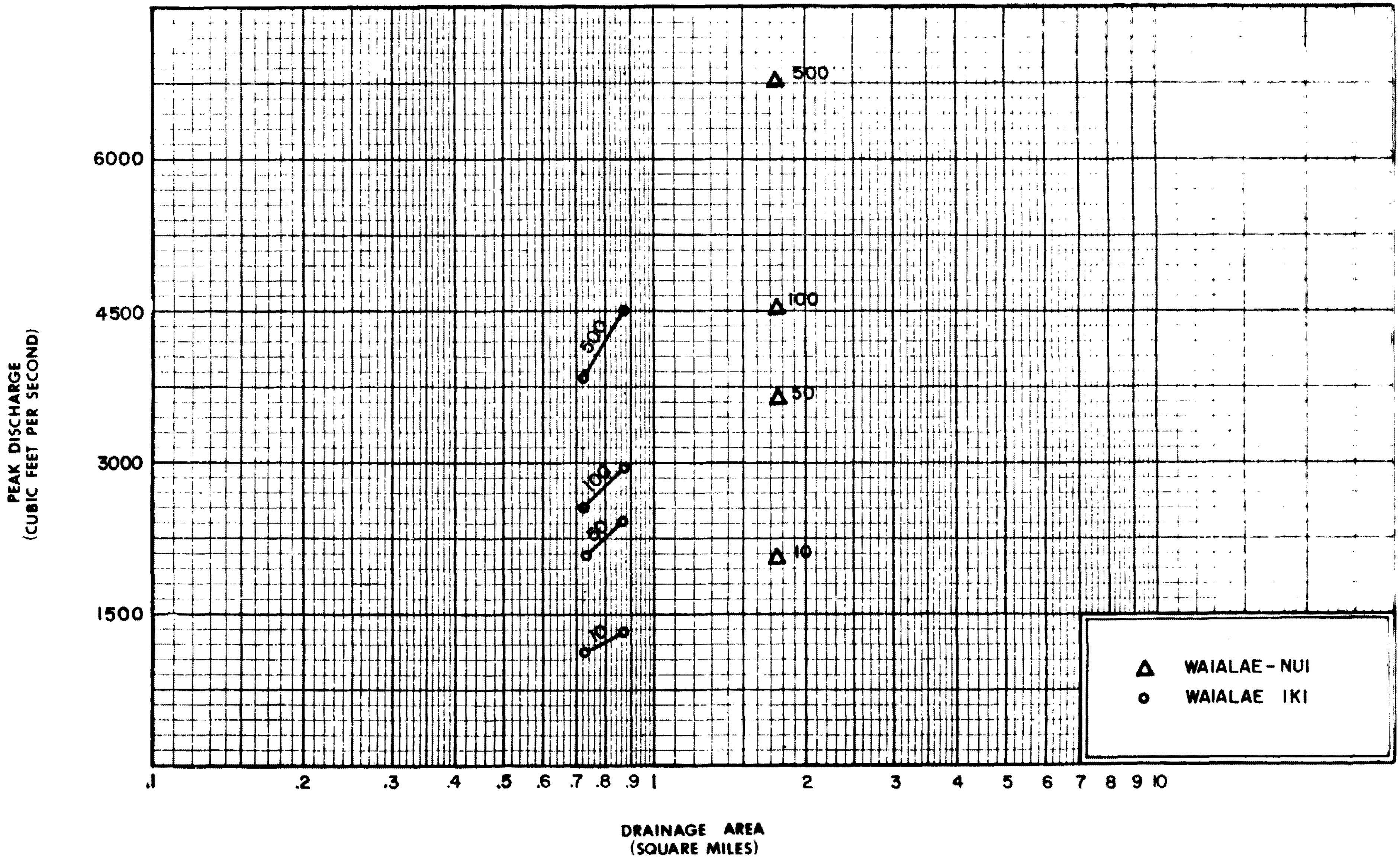


FIGURE 13

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY AND COUNTY OF HONOLULU, HI

FREQUENCY-DISCHARGE, DRAINAGE AREA CURVES

WAIALAE IKI & WAIALAE NUI STREAMS

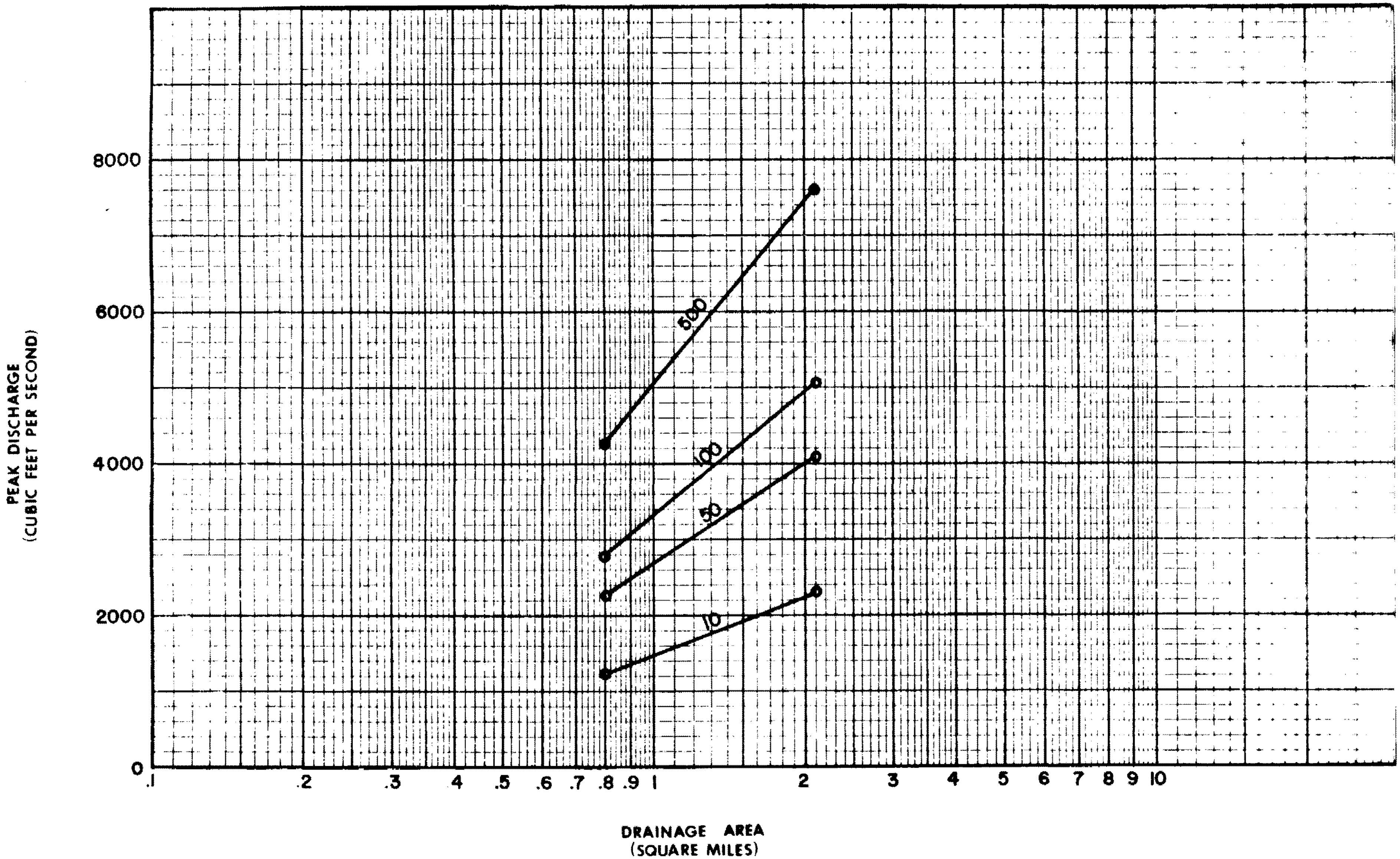


FIGURE 14

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY AND COUNTY OF HONOLULU, HI

FREQUENCY-DISCHARGE, DRAINAGE AREA CURVES

WAIALAE MAJOR DRAIN

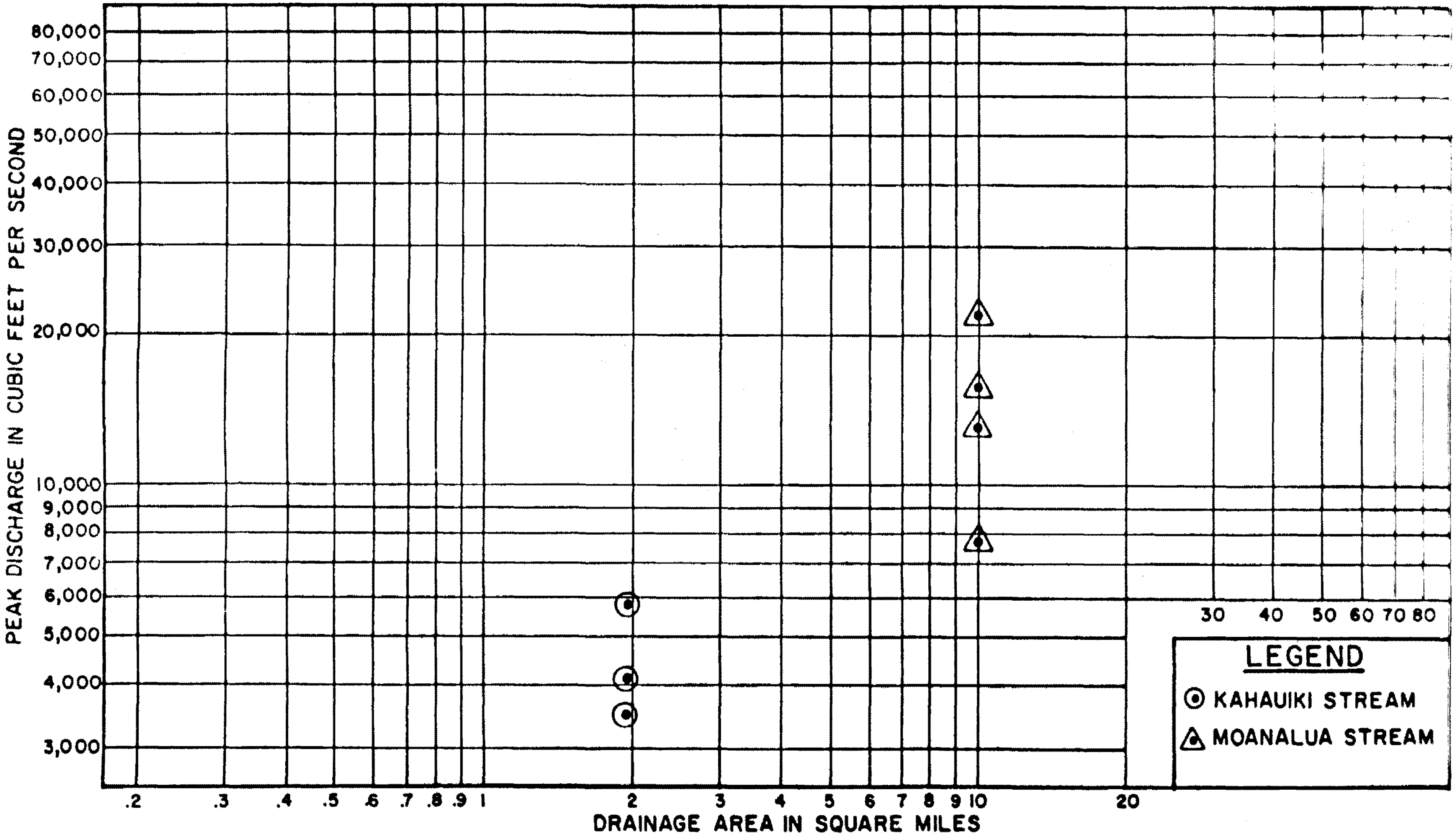


FIGURE 15

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY AND COUNTY OF HONOLULU, HI

FREQUENCY-DISCHARGE VS. DRAINAGE AREA

MOANALUA AND KAHAUIKI STREAMS

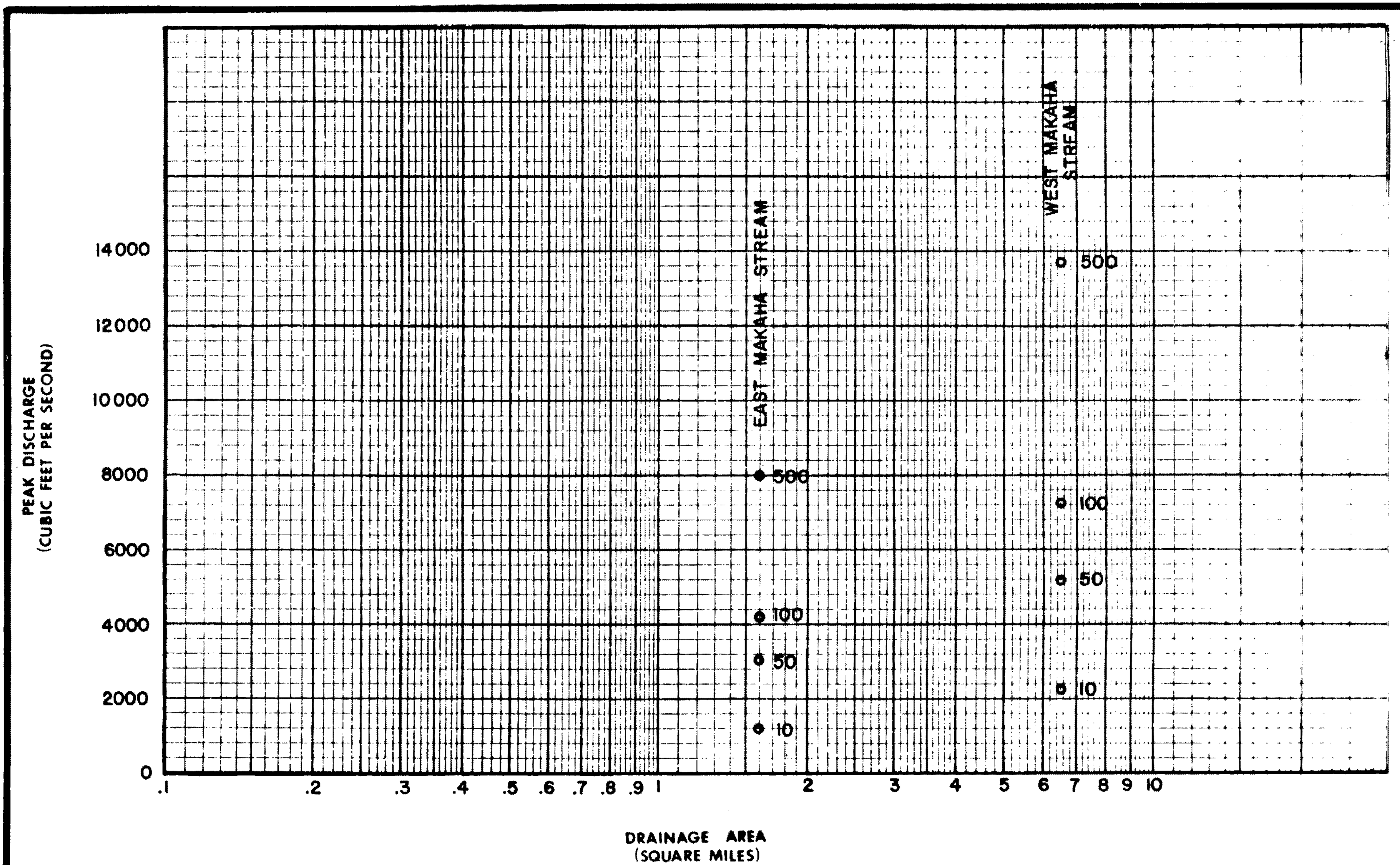


FIGURE 16

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY AND COUNTY OF HONOLULU, HI

FREQUENCY-DISCHARGE, DRAINAGE AREA CURVES

MAKAHA STREAMS

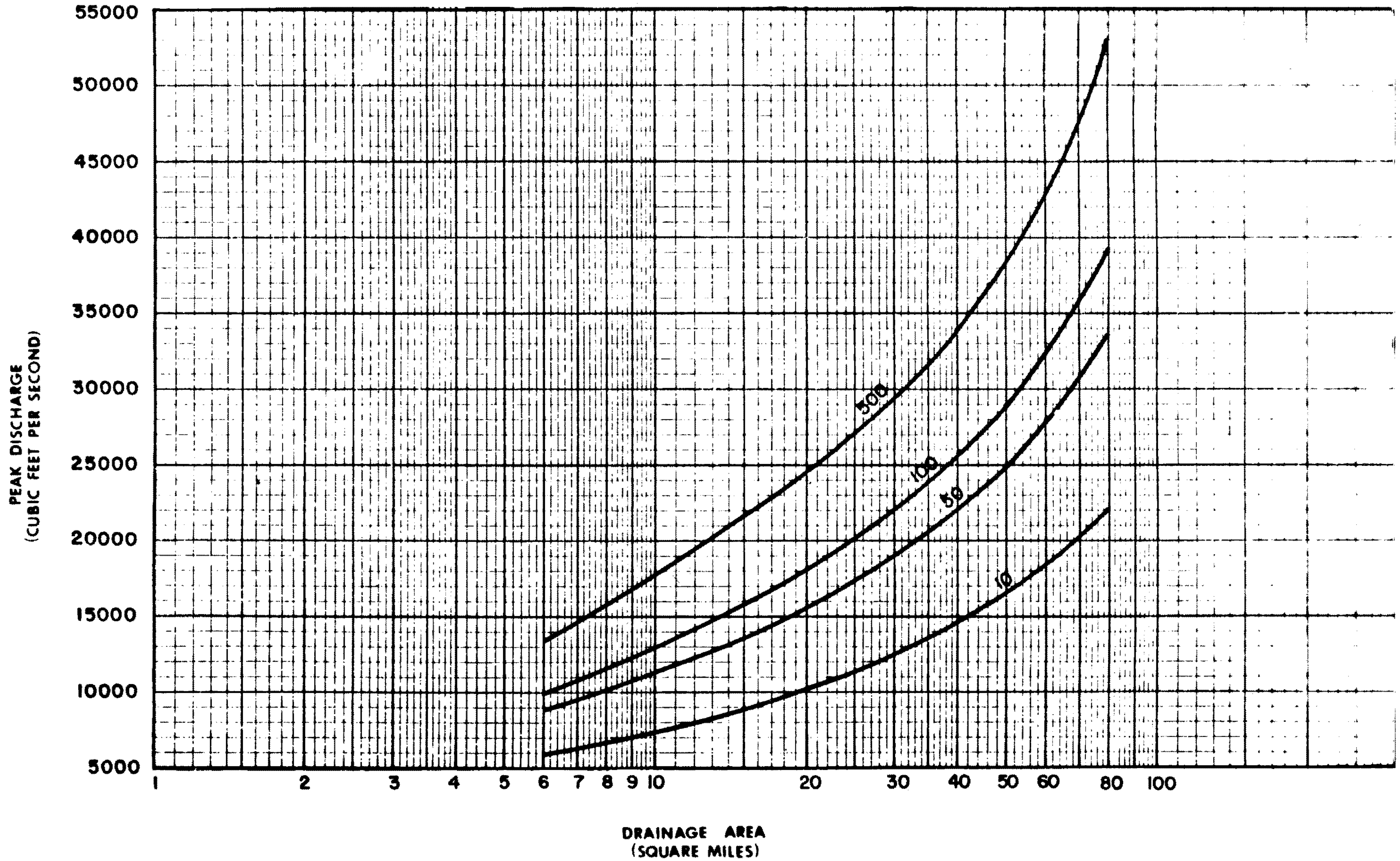


FIGURE 17

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY AND COUNTY OF HONOLULU, HI

FREQUENCY-DISCHARGE, DRAINAGE AREA CURVES

WAIALUA - HALEIWA STREAMS

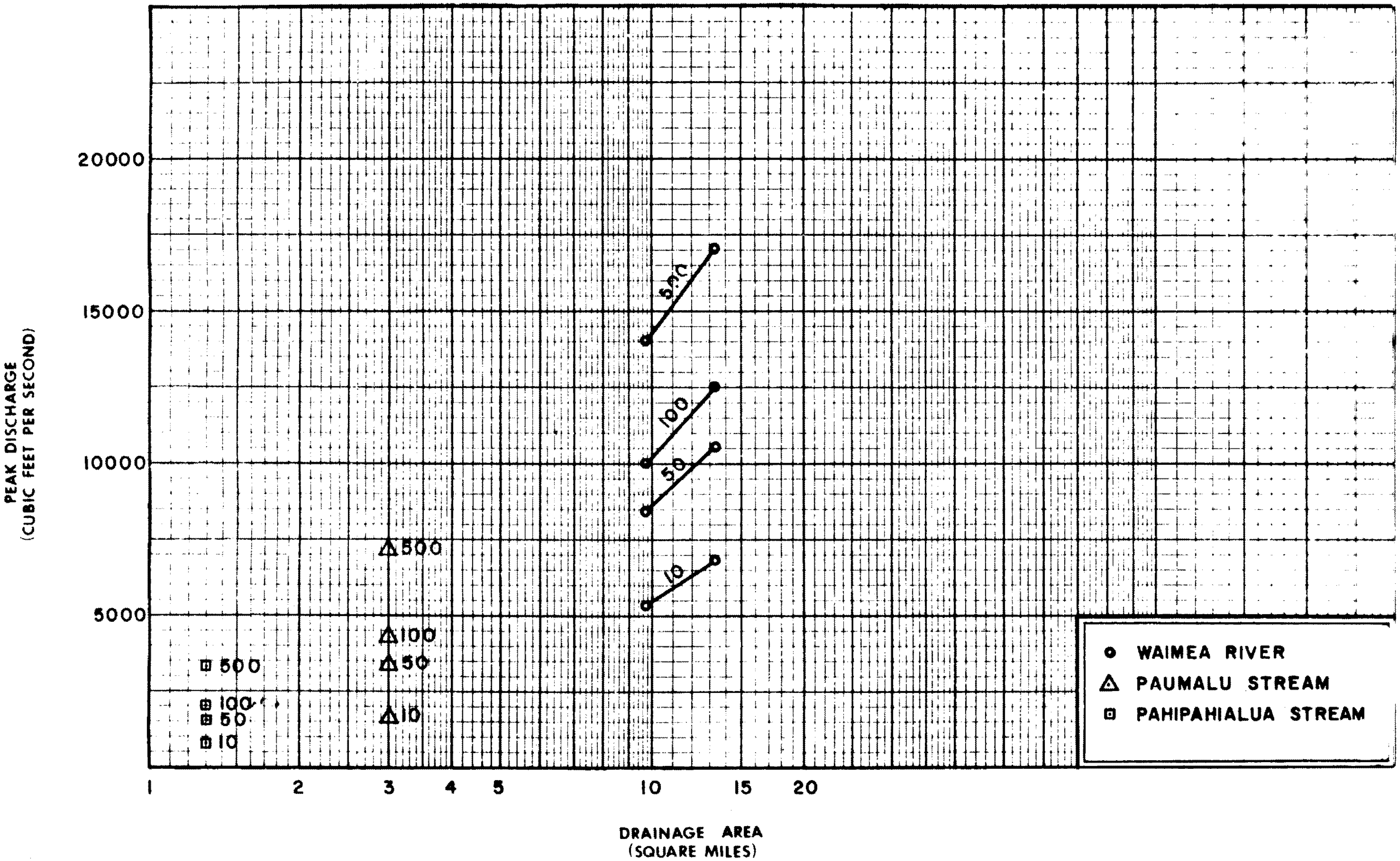


FIGURE 18

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY AND COUNTY OF HONOLULU, HI

FREQUENCY-DISCHARGE, DRAINAGE AREA CURVES

WAIMEA RIVER, PAUMALU & PAHIPAHIALUA STREAMS

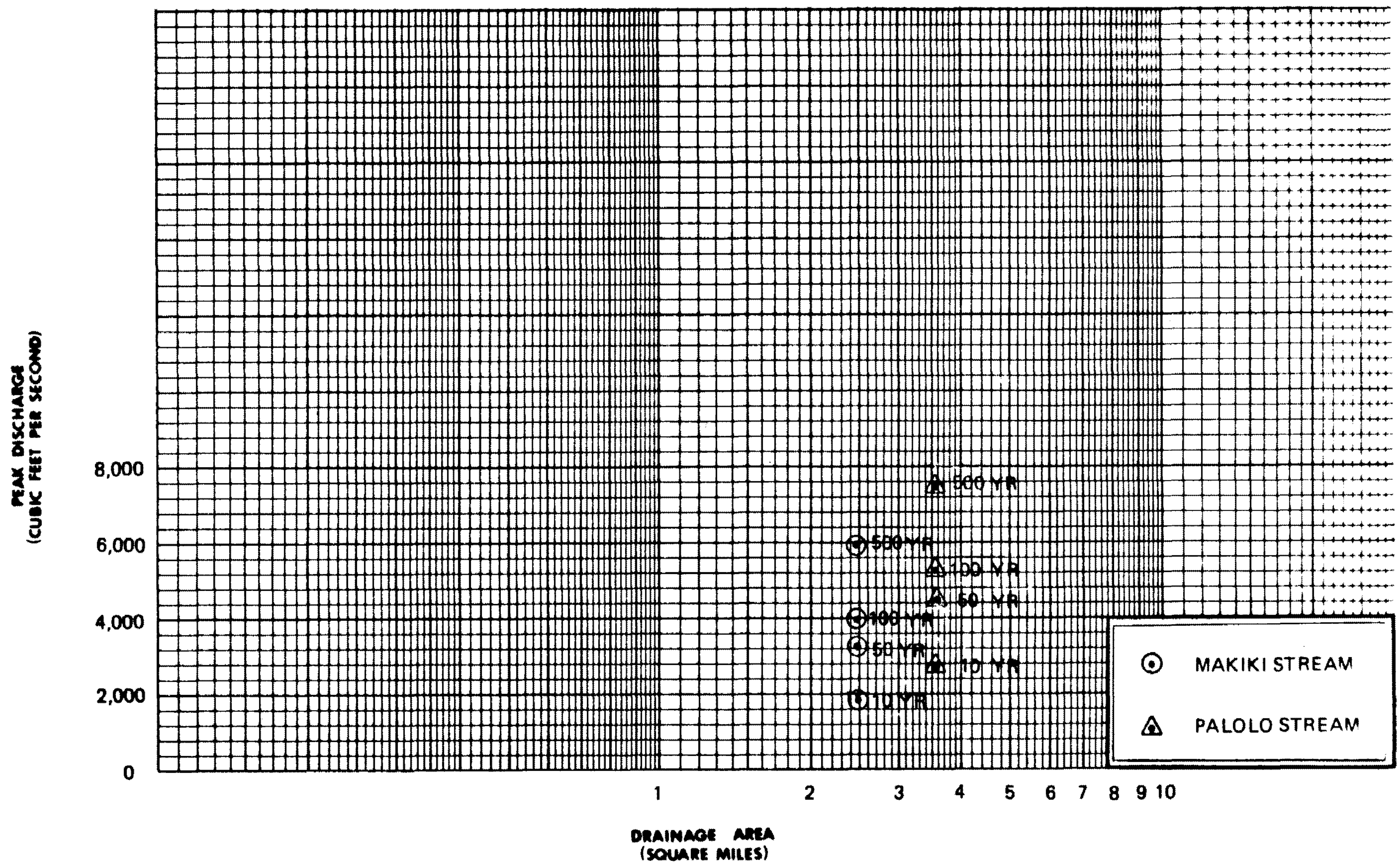


FIGURE 19

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY AND COUNTY OF HONOLULU, HI

FREQUENCY-DISCHARGE, DRAINAGE AREA CURVES

MAKIKI STREAM AND PALOLO STREAM

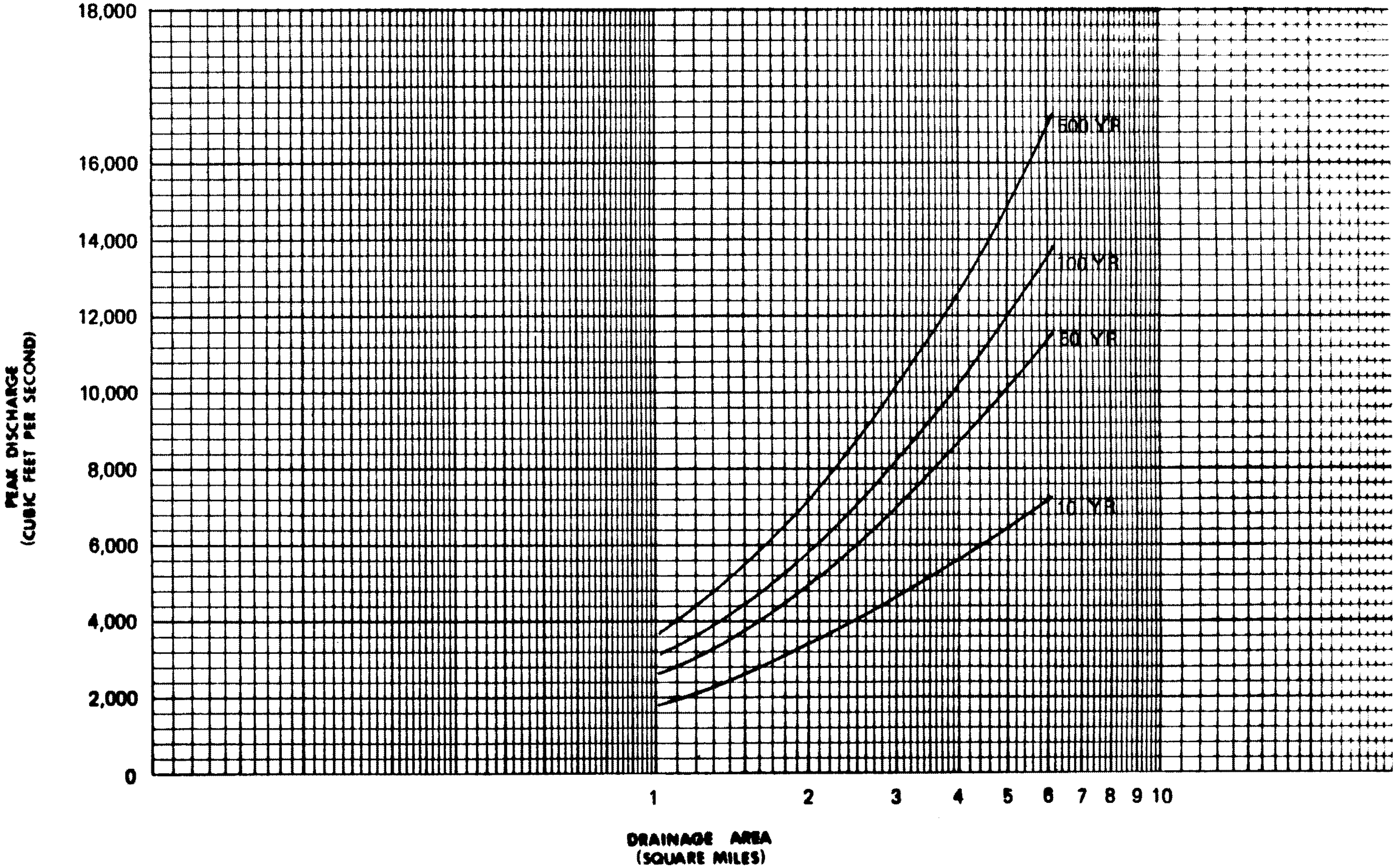


FIGURE 20	FEDERAL EMERGENCY MANAGEMENT AGENCY CITY AND COUNTY OF HONOLULU, HI	FREQUENCY-DISCHARGE, DRAINAGE AREA CURVES MANOA STREAM

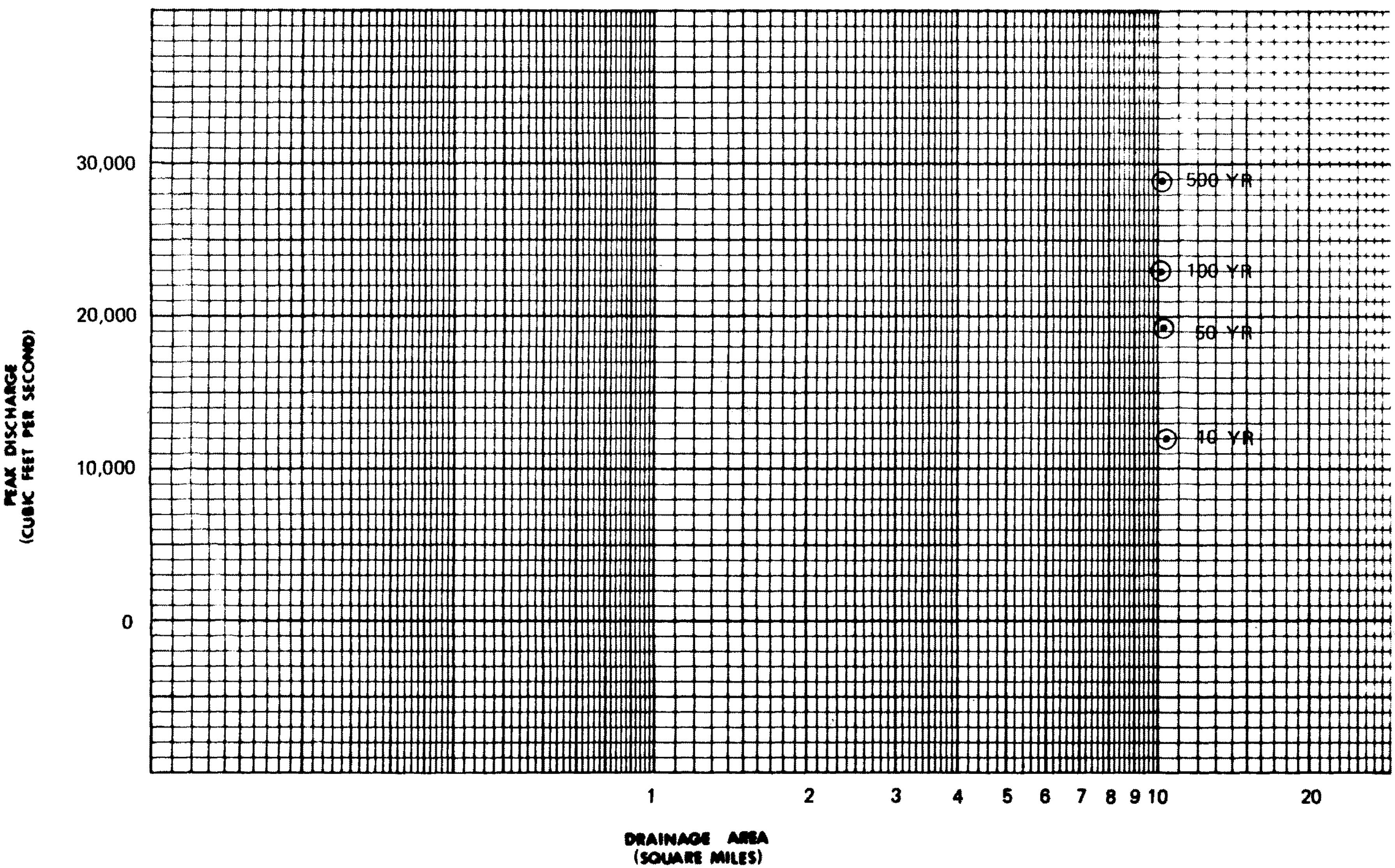


FIGURE 21

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY AND COUNTY OF HONOLULU, HI

FREQUENCY-DISCHARGE, DRAINAGE AREA CURVES

MANOA - PALOLO DRAINAGE CANAL

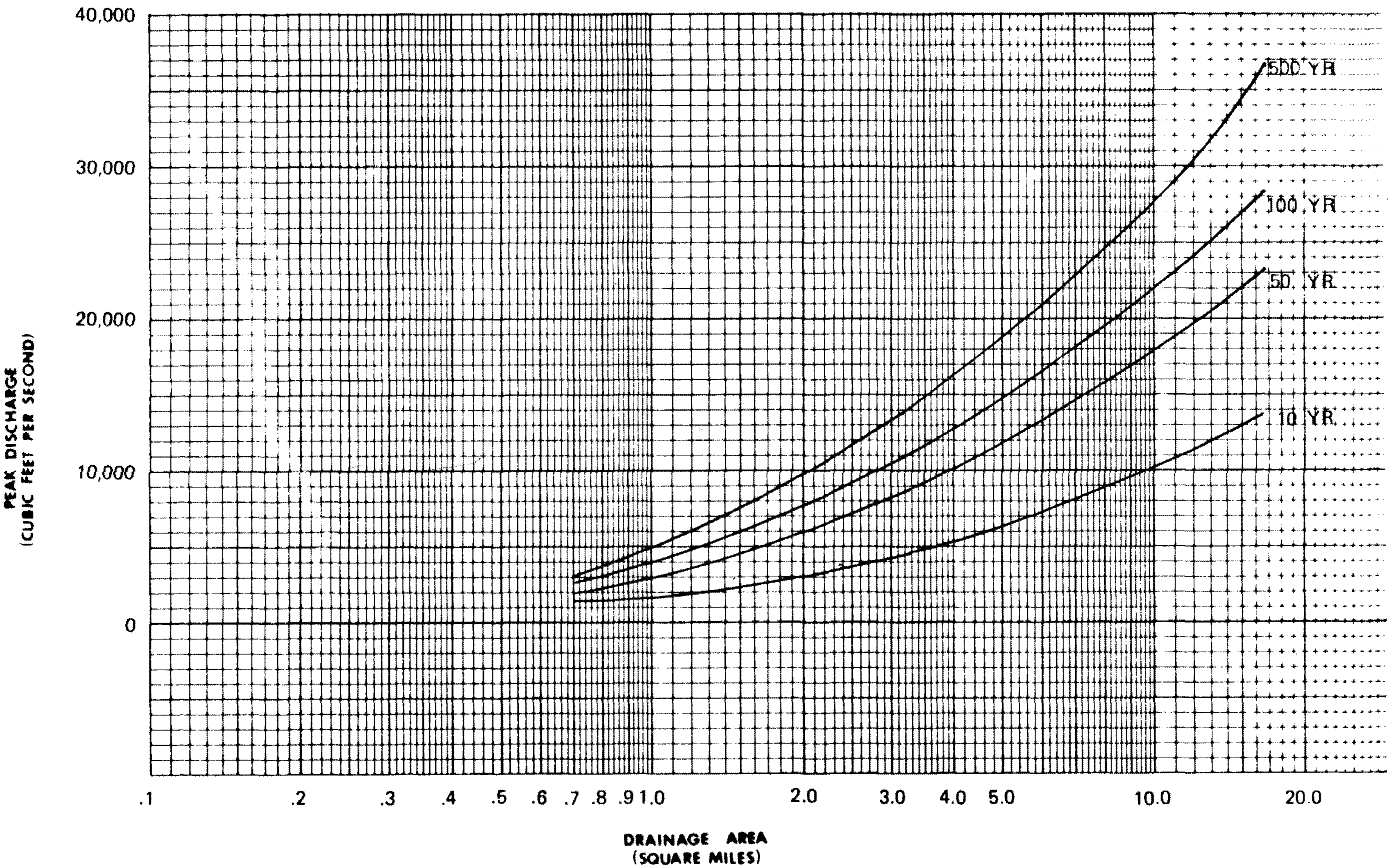


FIGURE 22

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY AND COUNTY OF HONOLULU, HI

FREQUENCY-DISCHARGE, DRAINAGE AREA CURVES

ALA WAI CANAL

Other Areas

Nuuanu and Waolani Streams

Nuuanu Stream and Waolani Stream discharges were based on a statistical analysis of discharge records covering a 67-year period and a 24-year period, respectively. Nuuanu Stream discharges were based on measurements from USGS Gaging Station No. 16232000 on Nuuanu Stream below Reservoir 2 Wasteway. Waolani Stream discharges were based on measurements from USGS Gaging Station No. 16235400 on Waolani Stream. The analysis of stream discharges was performed using the standard log-Pearson Type III method as outlined by the Water Resources Council (Water Resources Council, 1977). An analysis using the logarithm of the ratio of discharge (Q) versus drainage area (DA), log (Q/DA), and logarithm of the drainage area, log (DA), for gaged watersheds in the general vicinity of the Nuuanu and Waolani Streams was done to determine a transfer equation. The transfer equation is needed to calculate the discharge at locations along the streams other than at the gaged location.

Aiea and Kalauao Streams

Aiea Stream discharges were based on a statistical report (WRI 80-45) done by the USGS which developed regression equations for the 10-, 2-, and 1-percent annual chance flooding events using data from 74 gaging stations (U.S. Department of the Interior, 1979). The 0.2-percent annual chance discharge was determined from the plot of the 10-, 2-, and 1-percent annual chance flooding events on a log-probability graph. The USGS regression equation also provided a means of calculating the flows at different locations within the Aiea Stream watershed. Kalauao Stream discharges were based on statistical analysis of discharge records covering a 25-year period and measurements from USGS Gaging Station No. 16224500 on Kalauao Stream at Moanalua Road, at Aiea. For Kalauao Stream, the analysis of stream discharges was performed using the standard log-Pearson Type III method as outlined by the Water Resources Council (Water Resources Council, 1977).

Waikele Stream

Waikele Stream discharges were based on a statistical analysis of discharge records covering a 31-year period and measurements from USGS Gaging Station No. 16213000 on Waikele Stream at Waiahu. For Waikele Stream, the analysis of stream discharges was performed using the standard log-Pearson Type III method as outlined by the Water Resources Council (Water Resources Council, 1977).

Honouliuli Stream

Honouliuli Stream discharges were based on a statistical analysis of discharge records covering a 23-year period and measurements from USGS Gaging Station

No. 16212500 on Honouliuli Stream near Waipahu. The analysis of stream discharges was performed using the standard log-Pearson Type III method as outlined by the Water Resources Council (Water Resources Council, 1977).

Makaleha and Unnamed Streams

Makaleha Stream discharges were based on statistical analysis of discharge records covering a 24-year period and measurements from USGS Gaging Station No. 16310501 on Malaekahana Stream at altitude 30 feet, near Kahuku. The analysis of stream discharges was performed using the standard log-Pearson Type III method as outlined by the Water Resources Council (Water Resources Council, 1977). For the Unnamed Stream, discharges were based on a statistical study (WRI 80-45) done by the USGS (U.S. Department of the Interior, 1979).

Malaekahana Stream and Kea’aulu Gulch

The hydrologic estimates for Malaekahana Stream (restudied for the November 5, 2014 study) and Kea’aulu Gulch are described in Section 10.

James Campbell Industrial Park Drainage Canal

JCIP Drainage Canal hydrology is described in Section 10.

Halawa Stream

Halawa Stream hydrology is described in Section 10.

Waimalu Stream

Waimalu Stream hydrology is described in Section 10.

Kaalaea, Haiamoa, Waihee, Kahaluu, and Ahuimanu Streams

For Kaalaea and Haiamoa Streams, the discharges were based on a statistical study (WRI 80-45) done by the USGS (U.S. Department of the Interior, 1979). For Waihee, Kahaluu and Ahuimanu Streams, discharges were based on a statistical analysis of discharge records covering periods of 44, 34, and 20 years, respectively. Waihee Stream discharges were based on measurements from USGS Gaging Station No. 16284000 on Waihee Stream near Heeia. Kahaluu Stream discharges were based on measurements from USGS Gaging Station No. 16283000 on Kahaluu Stream. Ahuimanu Stream discharges were based on measurements from USGS Gaging Station No. 16283480 on Ahuimanu Stream near Kahaluu. For Waihee, Kahaluu, and Ahuimanu Streams, the analyses of stream discharges were performed using the standard log-Pearson Type III method as outlined by the Water Resources Council (Water Resources Council, 1977).

Kawainui Stream and Oneawa Channel

For Kawainui Stream, discharges were based on the SCS TR-55 method for determining 10-, 2-, and 1-percent annual chance discharges (U.S. Department of Agriculture, 1975). The 0.2-percent annual chance discharge was determined from the plot of the 10-, 2-, and 1-percent annual chance discharge on a log-probability graph. The TR-55 method was used because the Kawainui watershed is essentially flat and is not typical of the watersheds used in the USGS WRI 80-45 report (U. S. Department of the Interior, 1979).

The hydrologic analysis for Oneawa Channel is described in Section 10.

Kaloi Gulch, Waikakalaua Stream, and North Halawa Stream

The Kaloi Gulch Tributary, located near Honouliuli, has a drainage area of 1.70 square miles. The 1-percent annual chance discharge was determined from statistical analysis of 18 years of record at USGS Gaging Station No. 16212450.

For Waikakalaua Stream, located at Wahiawa, the 1-percent annual chance discharge was determined from statistical analysis of 28 years of record taken from USGS Gaging Station No. 16212700. The drainage area on Waikakalaua Stream is 6.96 square miles.

North Halawa Stream, located near Aiea, has a drainage area of 3.45 square miles. The 1-percent annual chance discharge was determined from statistical analysis of 36 years of record at USGS Gaging Station No. 16226000.

Calculation of 1-percent annual chance flood magnitudes from gaged data for all three streams were made in accordance with procedures contained in Bulletin No. 17B (Water Resources Council, 1981). A generalized skew coefficient of -0.05 (for Hawaiian Islands) was used.

Peak discharge-drainage area relationships for the following streams are shown in Table 3: Summary of Discharges:

Ahuimanu Stream
Aiea Stream
Haiamoa Stream
Halawa Stream
Honouliuli Stream
JCIP Drainage Canal
Kaalaea Stream
Kahaluu Stream
Kalauao Stream
Kalihi Stream
Kaupuni Stream
Mailiili Channel
Makaleha Stream
Malaekahana Stream
Nuuanu Stream
Oneawa Channel
Unnamed Stream
Unnamed Tributary to Keaahala Stream
Waialae-Nui Stream
Waihee Stream
Waikele Stream

Kawainui Stream	Wailele Stream
Keaahala Stream	Waimalu Stream
Keaaulu Gulch	Waimanalo: Stream A
Maili Channel	Waolani Stream

For the following streams, which were studied in part or entirely by approximate methods, the 1-percent annual chance discharges were updated from previous studies on the appropriate study areas:

Kaelepulu Stream Tributary	Ulehawa Stream
Kaloi Gulch	Waikakalaua Stream
Nanakuli Stream	
North Halawa Stream	

Table 3: Summary of Discharges

Flooding Source and Location	Drainage Area (sq. miles)	Peak Discharges (cubic feet per second) 10-Percent	4-Percent	2-Percent	1-Percent	0.2-Percent
AHUIMANU STREAM						
Upstream of confluence of Kahaluu Stream	2.45	5,860	---[1]	12,000	15,300	25,000
At confluence with tributary	1.06	3,200	---[1]	6,540	8,350	13,600
AHUIMANU STREAM TRIBUTARY						
Upstream of confluence of Main Branch	0.42	1,620	---[1]	3,320	4,240	6,900
Near Hui Nene Street	0.33	1,370	---[1]	2,800	3,580	5,820
AIEA STREAM						
At Moanalua Road	1.38	1,140	---[1]	2,130	2,660	4,030
Near Aiea Heights	1.05	910	---[1]	1,710	2,140	3,100
HAHAKEA GULCH						
At mouth	4.0	1,800	---[1]	3,600	4,600	7,500
HAIAMOA STREAM						
At Pacific Ocean	0.56	1,280	---[1]	2,530	3,230	5,100
Upstream of Ahilama Road	0.22	640	---[1]	1,270	1,640	2,550
HALAWA STREAM						
1,700 feet Upstream of Kam-Highway	9.62	4,057	5,693	7,128	8,738	13,209
HONOULIULI STREAM						
At Pacific Ocean	12.13	3,180	---[1]	6,430	8,030	12,170
Downstream of Farrington Highway	11.03	3,060	---[1]	6,190	7,730	11,710
JCIP DRAINAGE CANAL						
500 feet Upstream of Olai St	2.83	826	1,490	2,175	3,049	5,938
KAALAEA STREAM						
At Pacific Ocean	1.56	2,690	---[1]	5,230	6,610	10,500
Upstream of Pulama Road	0.97	1,890	---[1]	3,700	4,700	7,500

[1]Not computed

Table 3: Summary of Discharges (continued)

Flooding Source and Location	Drainage Area (sq. miles)	Peak Discharges (cubic feet per second) 10-Percent	4-Percent	2-Percent	1-Percent	0.2-Percent
KAELEPULU STREAM						
Downstream limit of study	0.176	---[1]	---[1]	---[1]	1,404	---[1]
Upstream limit of study	0.128	---[1]	---[1]	---[1]	1,120	---[1]
KAHALUU STREAM						
Upstream of confluence of Ahuimanu Stream	1.36	1,220	---[1]	2,630	3,530	6,550
At Melekula Road	1.01	980	---[1]	2,110	2,830	5,220
KALAEOKAHIPA STREAM						
At Kamehameha Highway	1.15	410	---[1]	1,380	4,500	---[1]
KALAUAO STREAM						
At Pacific Ocean	2.65	1,860	---[1]	2,990	3,540	4,960
Downstream of H-1 Freeway	2.53	1,780	---[1]	2,870	3,400	4,760
KALIHI STREAM						
Downstream limit of study	5.18	---[1]	---[1]	---[1]	16,880	---[1]
Upstream limit of study	2.61	---[1]	---[1]	---[1]	10,683	---[1]
KALOI GULCH						
Downstream limit of study	5.805	---[1]	---[1]	---[1]	2,425	---[1]
Upstream limit of study	5.223	---[1]	---[1]	---[1]	2,359	---[1]
KAMANAIKI STREAM						
Downstream limit of study	0.85	---[1]	---[1]	---[1]	4,944	---[1]
Upstream limit of study	0.64	---[1]	---[1]	---[1]	4,069	---[1]
KAPAKAHI STREAM						
Downstream limit of study	0.329	---[1]	---[1]	---[1]	12,712[2]	---[1]
Upstream limit of study	0.109	---[1]	---[1]	---[1]	11,971[3]	---[1]
KAUPUNI STREAM						
Just Upstream of confluence with East Makaha Stream	5.31	1,959	3,178	4,333	5,714	9,846
At Plantation Road	8.75	2,435	4,040	5,587	7,453	13,137

[1]Not computed
[2]Includes overflow from Waikele Stream and split flow from Wailani Drainage Canal
[3]Includes overflow from Waikele Stream

Table 3: Summary of Discharges (continued)

Flooding Source and Location	Drainage Area (sq. miles)	Peak Discharges (cubic feet per second) 10-Percent	4-Percent	2-Percent	1-Percent	0.2-Percent
KAWAINUI STREAM						
At confluence with Kaelepulu Stream	0.96	1,150	---[1]	1,850	2,150	3,150
Upstream of Pali Highway	0.41	450	---[1]	720	840	1,230
KEAAHALA STREAM						
Upstream of confluence with Unnamed Tributary to Keaahala Stream	0.34	680	---[1]	1,220	1,500	2,250
825 feet Downstream of Kahekili Highway	0.50	1,292	1,694	2,030	2,367	3,195
At mouth	1.18	2,003	2,680	3,197	3,714	4,937
KEAAULU GULCH						
At confluence with Malaekahana Stream	1.39	968	1,653	2,327	3,156	5,811
MAKAHA STREAM AND WEST MAKAHA STREAM						
Downstream limit of study	7.034	---[1]	---[1]	---[1]	11,561	---[1]
Upstream limit of study	5.250	---[1]	---[1]	---[1]	7,388	---[1]
MAKALEHA STREAM						
At Pacific Ocean	6.44	2,120	---[1]	4,240	5,410	8,880
Upstream of Farrington Highway	4.23	1,640	---[1]	3,280	4,180	6,860
MAILI CHANNEL						
At Kulaaupuni Street	2.70	800	1,444	2,107	2,956	5,760
MAILIILI CHANNEL						
1,450 feet Upstream of Paakea Road	15.82	3,182	5,410	7,597	10,265	18,544
MALAEKAHANA STREAM						
At Pacific Ocean	6.51	4,467	7,340	10,202	13,702	25,031
Upstream of agricultural area	4.55	3,326	5,641	7,277	9,531	16,289
MANAIKI STREAM						
Approximately 250 feet upstream of Mahole Street	2.01	---[1]	---[1]	---[1]	4,900	6,080

[1]Not computed

Table 3: Summary of Discharges (continued)

Flooding Source and Location	Drainage Area (sq. miles)	Peak Discharges (cubic feet per second) 10-Percent	4-Percent	2-Percent	1-Percent	0.2-Percent
MOANALUA STREAM						
Approximately 250 feet downstream of Moanalua Road	7.87	---[1]	---[1]	---[1]	13,500	18,200
Approximately 180 feet upstream of Jarrett White Road	5.03	---[1]	---[1]	---[1]	9,700	12,700
NANAKULI STREAM						
Downstream limit of study	4.106	---[1]	---[1]	---[1]	7,554	---[1]
Upstream limit of study	3.518	---[1]	---[1]	---[1]	7,256	---[1]
NORTH HALAWA STREAM						
Downstream limit of study	4.197	---[1]	---[1]	---[1]	9,916	---[1]
Upstream limit of study	3.956	---[1]	---[1]	---[1]	9,794	---[1]
NUUANU STREAM						
At H-1 Freeway	4.48	3,070	---[1]	6,310	8,040	12,900
Downstream of Pali Highway	4.27	2,950	---[1]	6,060	7,720	12,400
OHIA STREAM						
At Kamehameha Highway	2.41	985	---[1]	1,870	8,900	---[1]
Approximately 500 feet upstream of Kamehameha Highway	2.41	---[1]	---[1]	---[1]	4,875[2]	---[1]
OHIA STREAM (EAST)						
At Kamehameha Highway	0.46	---[1]	---[1]	---[1]	5,925[3]	---[1]
Approximately 1,200 feet upstream of Kamehameha Highway	0.46	345	---[1]	1,720	1,900	---[1]
ONEAWA CHANNEL[4]						
At confluence with Kawainui Marsh	10.62	4,910	5,623	6,782	8,127	7,432

[1]Not computed [2]Excludes overflow into Ohia Stream (East)
[3]Includes overflow from Ohia Stream
[4]Represents max flow through unsteady flow modeled reach

Table 3: Summary of Discharges (continued)

Flooding Source and Location	Drainage Area (sq. miles)	Peak Discharges (cubic feet per second) 10-Percent	4-Percent	2-Percent	1-Percent	0.2-Percent
PANAIKAUAHI GULCH						
At confluence with Waiawa Stream	8.39	---[1]	---[1]	---[1]	14,200	18,300
Approximately 800 feet upstream of Cane Haul Road	7.88	---[1]	---[1]	---[1]	13,500	17,400
ULEHAWA STREAM						
Downstream limit of study	3.521	---[1]	---[1]	---[1]	3,785	---[1]
Upstream limit of study	1.941	---[1]	---[1]	---[1]	2,436	---[1]
UNNAMED STREAM						
At Pacific Ocean	3.32	1,340	---[1]	3,160	4,300	7,750
Upstream of Farrington Highway	1.97	940	---[1]	2,200	2,920	5,250
UNNAMED TRIBUTARY TO KEAAHALA STREAM						
At confluence with Keaahala Stream	0.20	450	---[1]	810	1,000	1,530
WAIALAE-NUI STREAM						
At confluence with Kapakahi	1.67	1,741	2,429	2,982	3,542	5,088
WAIAWA STREAM						
At mouth	27.34	---[1]	---[1]	---[1]	34,000	43,800
Approximately 4,380 feet upstream of confluence of Panakauahi Gulch	16.08	---[1]	---[1]	---[1]	23,000	29,650
WAIHEE STREAM						
At Kahaluu Lagoon	2.31	2,380	---[1]	4,740	6,070	10,030
Upstream of agricultural area near end of Waihee Road	0.88	1,180	---[1]	2,350	2,990	4,980
WAIHEE STREAM TRIBUTARY						
Upstream of confluence of Main Branch	0.24	470	---[1]	930	1,180	1,970
At Ahilama Road	0.19	390	---[1]	790	1,000	1,670

[1]Not computed

Table 3: Summary of Discharges (continued)

Flooding Source and Location	Drainage Area (sq. miles)	Peak Discharges (cubic feet per second)				
		10-Percent	4-Percent	2-Percent	1-Percent	0.2-Percent
WAIKAKALAUA STREAM						
Downstream limit of study	4.580	---[1]	---[1]	---[1]	5,591	---[1]
Upstream limit of study	4.184	---[1]	---[1]	---[1]	5,486	---[1]
WAIKELE STREAM						
At Pacific Ocean	45.79	10,620	---[1]	21,000	26,400	41,400
Downstream of H-1 Freeway	44.91	10,450	---[1]	20,700	26,000	40,800
WAILANI DRAINAGE CANAL						
Downstream limit of study	1.57	---[1]	---[1]	---[1]	2,681	---[1]
Upstream limit of study	1.14	---[1]	---[1]	---[1]	2,220	---[1]
WAILELE STREAM (LEFT/RIGHT OVERBANK)						
Downstream limit of study	1.323	---[1]	---[1]	---[1]	2,601	---[1]
Upstream limit of study	1.090	---[1]	---[1]	---[1]	2,257	---[1]
WAILELE STREAM						
0.8 miles upstream of Cane Haul Road	1.21	1,753	2,476	3,084	3,736	5,479
WAIMALU STREAM						
1,200 feet downstream of Moanalua Road	6.11	3,958	5,755	7,300	9,018	13,637
At confluence with East Loch	8.29	4,398	6,525	8,382	10,466	16,162
WAIMANALO: STREAM A						
Just upstream of confluence with Waimanalo Stream B	0.38	736	1,053	1,323	1,620	2,431
At confluence with Waimanalo Stream	1.34	1,887	2,663	3,314	4,011	5,871
WAOLANI STREAM						
At confluence with Nuuanu Stream	1.81	2,180	---[1]	3,650	4,400	6,450
Near St. Francis Hospital	1.34	1,680	---[1]	2,810	3,400	4,980

[1]Not computed

For all other streams on the Island of Oahu which were studied by approximate methods, the 1-percent annual chance discharges were computed using the following methods:

If a stream gaging station with an adequate length of record was situated on the stream to be studied, the 1-percent annual chance peak discharge was computed using a log-Pearson Type III distribution (Water Resources Council, 1977). For streams without gaging stations, the 1-percent annual chance peak discharge was computed using a previous regional study developed by the USACE (USACE, Oahu Streams).

For the entire detailed studied shoreline of the Island of Oahu, all of which was studied by detailed methods, tsunami wave elevations were determined utilizing a length of record of 142 years (1837-1979). A hybrid finite element numerical model was developed to supplement historical data in determining the ten largest tsunami elevations from 1837 to 1979. The finite element model provides an accurate representative response of the island flood elevations to tsunami activity due to rapid bathymetric and/or wave height variations. The numerical model was adjusted and verified by comparing the numerical calculations with tide gage recordings of the 1960 and 1964 tsunamis. Tsunami wave elevations at a location 200 feet inland on the Island of Oahu were developed using the USACE report prepared by the U.S. Army Waterways Experiment Station (USACE, 1977).

Tsunami elevations, as the wave travels inland and the maximum inundation limits reached, were determined utilizing a study by Charles L. Bretschneider and Peter G. Wybro entitled Tsunami Inundation Prediction (C. L. Bretschneider, undated). Runup elevations and inundation limits are dependent upon initial tsunami elevations, ground elevations 200 feet inland, roughness factors (Manning's "n"), terrain slope, and Froude's Number (F=1 for non-bore; F=2 for bore formation).

A detailed coastal hurricane storm surge and wave height analysis was performed by RMTC/URS a JV. The Advanced Circulation model for Coastal Ocean Hydrodynamics (ADCIRC) (Luettich, 1992), developed by the USACE was selected to develop the stillwater elevations or storm surge for the State of Hawaii. ADCIRC is a two-dimensional depth integrated, finite element, hydrodynamic model that solves the equations of motion for a moving fluid on a rotating earth. Water surface elevations are obtained from the solution of the depth-integrated continuity equation in the generalized wave continuity equation form. Velocities are obtained from the solution of the two-dimensional momentum equations. The model has the capability to simulate tidal circulation and storm surge propagation over large domains and is able to provide highly detailed resolution along the shoreline and other areas of interest.

The ADCIRC grid was sourced from an existing grid developed by the USACE. The USACE grid was used for offshore areas, whereas new higher resolution nearshore and topographic coverage was added around the islands of Kauai, Oahu, Molokai, Lanai, Maui, and Hawaii. The greater part of the bathymetric data set was comprised of 255 individual National Oceanic and Atmospheric Administration (NOAA) National Oceanographic Survey hydrographic surveys, collected from 1900 to 2005. The USACE Joint Airborne LiDAR Bathymetry Technical Center of Expertise provided bathymetric LiDAR collected in 1999 and 2000. This dataset provided high-resolution coverage of the nearshore bathymetry, where available. The USACE, Honolulu District, provided a 2004 hydrographic survey of Honolulu Harbor. A 2004 multibeam survey of Pearl Harbor conducted by the U.S. Navy was provided by the NOAA National Geophysical Data Center. All soundings were converted to the Local Tidal Datum using relationships developed from NOAA gages. Finally, all datasets were merged and overlapping data were removed.

The topographic portion of the ADCIRC grid was populated with LiDAR data collected for the project along the southern coasts of the six islands in the study. The LiDAR data were collected in fall of 2006, post-processed to bare earth and quality controlled to meet FEMA mapping standards. To facilitate use with ADCIRC, elevations were converted to meters. LiDAR elevations were delivered in the Local Tidal Datum; therefore no vertical datum conversion was necessary.

Wind and pressure fields were required for input. A model called the Planetary Boundary Layer model (PBL), developed by V.J. Cardone (Cardone, 1992) was used for this study. The PBL model uses the parameters from a hurricane or tropical storm to simulate the event and develop wind and pressure fields. The PBL model simulates hurricane-induced wind and pressure fields by applying the vertically integrated equations of motion.

The storms applied in this study (Table 4, "Summary of Historical Storm Events Selected for Development of Storm Surge Elevations") were selected so as to represent the range of different storm magnitudes impacting the study area. Storm selection was limited to events passing within 200 statute miles of at least two islands in the study area. In total, 11 hurricane and tropical storm events were selected for storm surge modeling. Due to the low number of historical storms identified in the storm selection, the historical storm events were duplicated and shifted laterally by one radius to maximum winds in order to represent the potential range of tracks that future storms may take. In total, 100 storms were generated for developing stillwater elevations within the study area.

Table 4: Summary of Historical Storm Events

Selected for Development of Storm Surge Elevations

Name of Storm	HURDAT Identification Number	Begin Date	End Date
Tropical Storm Hiki	10	August 12, 1950	August 21, 1950
Tropical Storm Della	65	September 1, 1957	September 11, 1957
Tropical Storm Nina	74	November 29, 1957	December 6, 1957
Hurricane Dot	93	August 1, 1959	August 8, 1959
Tropical Storm Maggie	222	August 20, 1970	August 26, 1970
Tropical Storm Diana	250	August 11, 1972	August 19, 1972
Hurricane Iwa	411	November 19, 1982	November 24, 1982
Tropical Storm Gil	418	July 23, 1983	August 4, 1983
Tropical Storm Dahlia	532	July 11, 1989	July 21, 1989
Hurricane Iniki	598	September 5, 1992	September 13, 1992
Tropical Storm Daniel	707	July 23, 2000	August 5, 2000

The ADCIRC model was calibrated by simulating tidal cycles, and then validated by performing storm hindcasts. The tidal calibration is conducted by forcing tides at the open ocean boundaries of the model using known values (Le Provost, 1998), and comparing the simulated water levels to observations over a specific time period or a tidal signal re-synthesized from known tidal constituents. Storm hindcasts are performed upon successful completion of tidal calibrations to evaluate the ability of the model to replicate historical storm events. A wind and pressure field representing a historical storm event is input into the model then resulting water elevations are compared to observed water levels and records. Model validation was performed against Hurricanes Dot and Iniki for this study. Simulated water levels for each event were compared to observed water levels at the NOAA tidal gauge in Nawiliwili Harbor which represented the best available data. Results from both events showed good agreement with observed storm hydrographs.

The Emprical Simulation Technique (EST) model was used for the stage-frequency analysis. The EST generates a large population of life-cycle databases that are processed to compute mean value frequencies. Input vectors describe the characteristics of each storm such as central pressure and maximum winds. Input vectors for EST analysis included: tidal phase, minimum distance from eye to station, central pressure deficit, maximum winds in hurricane, forward speed of eye of hurricane, and radius to maximum winds. The input response vector was the maximum surge elevation recorded at each station for each storm simulated with ADCIRC. The output is a stage-frequency curve for each station in the study area. The EST model performed a hundred simulations at each station, for a period of 500 years. The mean value was selected from the entire EST simulation population at each station, and the return period elevation is the final resultant value.

Stillwater elevations for the State of Hawaii, obtained using the ADCIRC and EST models, are summarized in Table 5, "Summary of Coastal Stillwater Elevations." Locations of the surge stations are shown in Figure 23, "Stillwater Station Location Maps 1-3." Please note that the station numbers for surge stations do not coincide with the transect numbers.

Table 5: Summary of Coastal Stillwater Elevations†

ISLAND OF OAHU						
Flooding Source and Location			Elevation (ft ltd)			
Station	Longitude (NAD83)	Latitude	10-Percent	2-Percent	1-Percent	0.2-Percent
Pacific Ocean						
399	-158.26326	21.58067	0.66	0.81	1.05	1.94
400	-158.28172	21.57619	0.66	0.79	1.02	1.87
401	-158.26468	21.55869	0.66	0.83	1.08	2.01
402	-158.24607	21..54823	0.66	0.83	1.09	1.99
403	-158.24004	21.53757	0.66	0.83	1.09	1.98
404	-158.23497	21.52894	0.66	0.84	1.10	2.00
405	-158.23459	21.51158	0.66	0.82	1.07	1.95
406	-158.23518	21.49424	0.66	0.82	1.06	1.93
407	-158.23014	21.47926	0.66	0.81	1.02	1.87
408	-158.22432	21.47481	0.66	0.85	1.11	2.07
409	-158.22083	21.46873	0.66	0.82	1.06	1.93
410	-158.21633	21.45847	0.66	0.80	1.00	1.80
411	-158.20936	21.45766	0.66	0.85	1.14	2.12
412	-158.20324	21.45159	0.66	0.85	1.12	2.04
413	-158.19284	21.44412	0.66	0.86	1.15	2.21
414	-158.19290	21.44111	0.66	0.83	1.10	2.02
415	-158.18697	21.43189	0.66	0.84	1.10	2.07
416	-158.18304	21.42594	0.66	0.86	1.14	2.15
417	-158.18129	21.41713	0.66	0.84	1.10	2.02
418	-158.18024	21.40415	0.66	0.79	0.98	1.71
419	-158.17521	21.39722	0.66	0.83	1.06	1.92
420	-158.15475	21.38563	0.66	0.85	1.11	2.05
421	-158.14810	21.38044	0.66	0.83	1.08	1.96
422	-158.13974	21.37028	0.66	0.84	1.10	1.99
423	-158.13625	21.36185	0.66	0.85	1.12	2.03
424	-158.13270	21.34983	0.66	0.86	1.11	2.03
425	-158.13035	21.34077	0.66	0.82	1.05	1.89
426	-158.12613	21.32902	0.66	0.84	1.09	2.01
427	-158.12396	21.32058	0.66	0.86	1.13	2.11
428	-158.11751	21.30564	0.66	0.84	1.09	1.98
429	-158.11113	21.29643	0.66	0.83	1.05	1.93

†These elevations reflect the stillwater elevations associated with the hurricane hazard only. Tsunami hazards may dominate in certain areas.

Table 5: Summary of Coastal Stillwater Elevations† (continued)

ISLAND OF OAHU						
Flooding Source and Location			**Elevation (ft ltd)**			
Station	**Longitude (NAD83)**	**Latitude**	**10-Percent**	**2-Percent**	**1-Percent**	**0.2-Percent**
Pacific Ocean						
430	-158.09522	21.29253	0.66	0.83	1.09	2.04
431	-158.07882	21.29529	0.66	0.90	1.22	2.38
432	-158.06173	21.29864	0.66	0.91	1.25	2.44
433	-158.04741	21.29932	0.66	0.89	1.21	2.38
434	-158.02976	21.30223	0.66	0.90	1.21	2.42
435	-158.01410	21.30689	0.66	0.91	1.24	2.56
436	-157.97875	21.31490	0.66	0.91	1.30	2.82
437	-157.97404	21.31885	0.66	0.99	1.43	3.02
438	-157.97010	21.32412	0.66	0.98	1.45	3.12
439	-157.97100	21.33589	0.66	1.01	1.57	3.58
440	-157.97965	21.34777	0.66	1.06	1.69	3.97
441	-157.99064	21.35129	0.66	1.10	1.76	4.23
442	-157.99663	21.35552	0.66	1.12	1.81	4.38
443	-158.01065	21.35627	0.66	1.16	1.89	4.45
444	-158.01850	21.35772	0.66	1.26	2.06	4.71
445	-158.02032	21.36118	0.66	1.31	2.21	5.03
446	-158.02004	21.36496	0.66	1.36	2.34	5.30
447	-158.01617	21.36545	0.66	1.26	2.16	4.98
448	-158.01773	21.37337	0.66	1.38	2.42	5.49
449	-158.01088	21.37295	0.66	1.30	2.23	5.22
450	-158.00728	21.37044	0.66	1.23	2.10	5.05
451	-158.00134	21.36183	0.66	1.14	1.88	4.59
452	-157.98797	21.36161	0.66	1.12	1.82	4.58
453	-157.96886	21.34333	0.66	1.03	1.60	3.81
454	-157.97397	21.36584	0.66	1.09	1.77	4.41
455	-157.98174	21.36594	0.66	1.10	1.80	4.42
456	-157.99037	21.37755	0.66	1.19	1.96	4.78
457	-157.99181	21.38545	0.66	1.26	2.08	5.01
458	-157.98364	21.38267	0.66	1.17	1.96	4.83
459	-157.97625	21.37713	0.66	1.13	1.85	4.66
460	-157.97212	21.37014	0.66	1.10	1.78	4.47

†These elevations reflect the stillwater elevations associated with the hurricane hazard only. Tsunami hazards may dominate in certain areas.

Table 5: Summary of Coastal Stillwater Elevations† (continued)

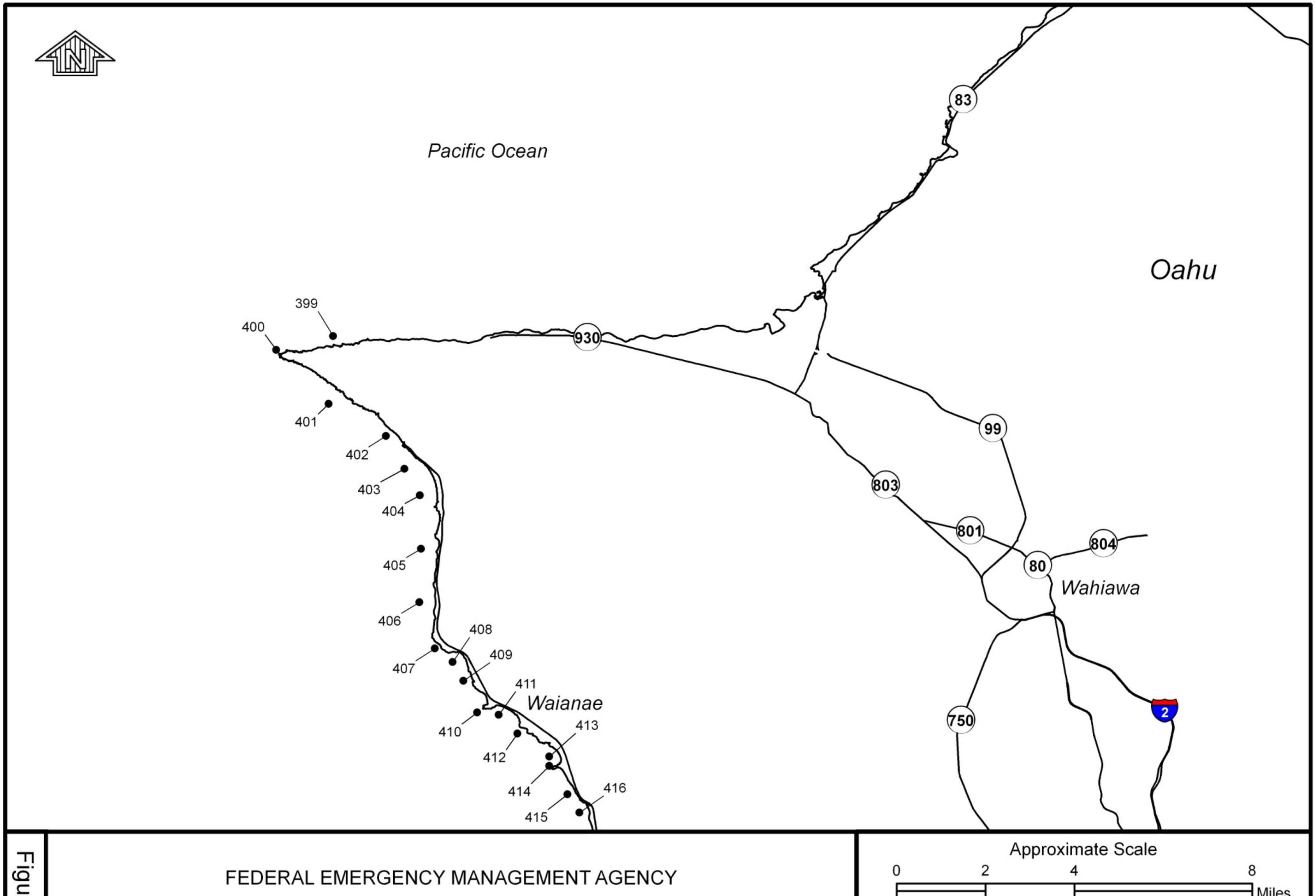
ISLAND OF OAHU (continued)						
Flooding Source and Location			**Elevation (ft ltd)**			
Station	**Longitude (NAD83)**	**Latitude**	**10-Percent**	**2-Percent**	**1-Percent**	**0.2-Percent**
Pacific Ocean						
461	-157.96822	21.36996	0.66	1.09	1.77	4.45
462	-157.96610	21.37746	0.66	1.11	1.79	4.54
463	-157.96864	21.38558	0.66	1.23	2.07	5.04
464	-157.95409	21.38246	0.66	1.10	1.80	4.65
465	-157.94488	21.37900	0.66	1.08	1.77	4.58
466	-157.94144	21.37488	0.66	1.05	1.71	4.44
467	-157.93518	21.37440	0.66	1.05	1.72	4.50
468	-157.93928	21.36836	0.66	1.04	1.69	4.37
469	-157.94589	21.36194	0.66	1.04	1.66	4.26
470	-157.94898	21.35489	0.66	1.04	1.64	4.17
471	-157.94204	21.35802	0.66	1.04	1.65	4.21
472	-157.94380	21.35110	0.66	1.03	1.61	4.12
473	-157.95741	21.35338	0.66	1.04	1.64	4.13
474	-157.96533	21.35174	0.66	1.04	1.65	4.07
475	-157.96931	21.35884	0.66	1.06	1.70	4.22
476	-157.95757	21.36118	0.66	1.05	1.67	4.24
477	-157.95424	21.36985	0.66	1.07	1.72	4.41
478	-157.96384	21.32440	0.66	0.96	1.40	3.11
479	-157.95653	21.31627	0.66	0.92	1.30	2.76
480	-157.94733	21.31307	0.66	0.92	1.28	2.70
481	-157.94824	21.30216	0.66	0.84	1.08	2.11
482	-157.92525	21.30329	0.66	0.86	1.15	2.30
483	-157.90660	21.30397	0.66	0.87	1.19	2.47
485	-157.90437	21.32260	0.66	1.12	1.79	4.12
486	-157.89598	21.32972	0.66	1.11	1.81	4.27
487	-157.89290	21.31975	0.66	0.99	1.48	3.48
488	-157.89058	21.31342	0.66	0.93	1.33	3.04
489	-157.88439	21.29963	0.66	0.83	1.09	2.30
490	-157.87588	21.31183	0.66	0.91	1.26	2.82
491	-157.86617	21.31316	0.66	0.91	1.25	2.73
493	-157.86997	21.29728	0.66	0.89	1.18	2.44
494	-157.86610	21.29315	0.66	0.85	1.12	2.21
495	-157.85714	21.29313	0.66	0.86	1.14	2.35

†These elevations reflect the stillwater elevations associated with the hurricane hazard only. Tsunami hazards may dominate in certain areas.

Table 5: Summary of Coastal Stillwater Elevations† (continued)

ISLAND OF OAHU (continued)						
Flooding Source and Location			Elevation (ft ltd)			
Station	Longitude (NAD83)	Latitude	10-Percent	2-Percent	1-Percent	0.2-Percent
496	-157.85111	21.28872	0.66	0.89	1.18	2.44
497	-157.84624	21.28190	0.66	0.87	1.14	2.29
498	-157.84338	21.28652	0.66	0.89	1.21	2.60
499	-157.83471	21.27641	0.66	0.84	1.10	2.27
500	-157.82495	21.26990	0.66	0.88	1.16	2.34
501	-157.81717	21.25469	0.66	0.83	1.05	1.98
502	-157.80733	21.25230	0.66	0.82	1.04	1.95
503	-157.79068	21.25380	0.66	0.85	1.10	2.08
504	-157.77822	21.26551	0.66	0.93	1.25	2.66
505	-157.76312	21.27268	0.66	0.94	1.27	2.85
506	-157.75583	21.27151	0.66	0.87	1.13	2.34
507	-157.75108	21.27417	0.66	0.91	1.21	2.61
508	-157.73613	21.27707	0.66	0.90	1.22	2.64
509	-157.72102	21.28170	0.66	1.03	1.50	3.46
510	-157.71167	21.27445	0.66	0.90	1.21	2.51
511	-157.70436	21.28289	0.66	0.66	0.69	0.86
512	-157.69576	21.29402	0.66	0.66	0.69	0.86
513	-157.71261	21.26282	0.66	0.83	1.05	1.93
514	-157.70005	21.25884	0.66	0.86	1.10	2.03
515	-157.69504	21.27115	0.66	0.91	1.19	2.37
516	-157.68734	21.26957	0.66	0.88	1.13	2.15
517	-157.67720	21.27947	0.66	0.88	1.13	2.19
518	-157.66921	21.28516	0.66	0.87	1.10	2.12
519	-157.65447	21.29566	0.66	0.86	1.10	2.13
520	-157.64784	21.30343	0.66	0.85	1.06	2.03
521	-157.64992	21.31222	0.66	0.86	1.08	2.08
522	-157.65864	21.31369	0.66	0.89	1.14	2.29

†These elevations reflect the stillwater elevations associated with the hurricane hazard only. Tsunami hazards may dominate in certain areas



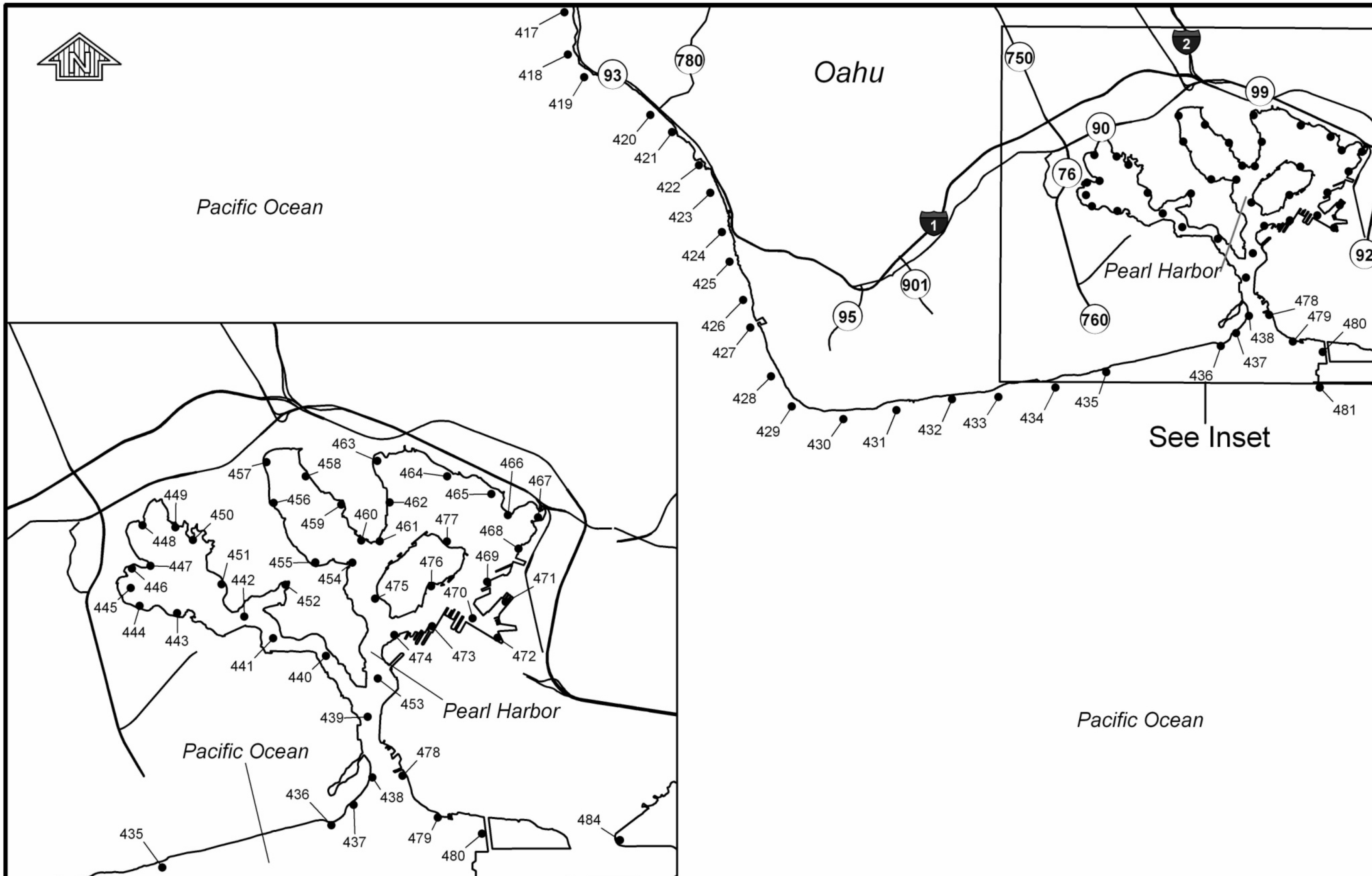
FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY AND COUNTY OF HONOLULU, HAWAII

ISLAND OF OAHU

STILLWATER STATION LOCATION MAP 1

Figure 23



FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY AND COUNTY OF HONOLULU, HAWAII

ISLAND OF OAHU

STILLWATER STATION LOCATION MAP 2

Figure 23

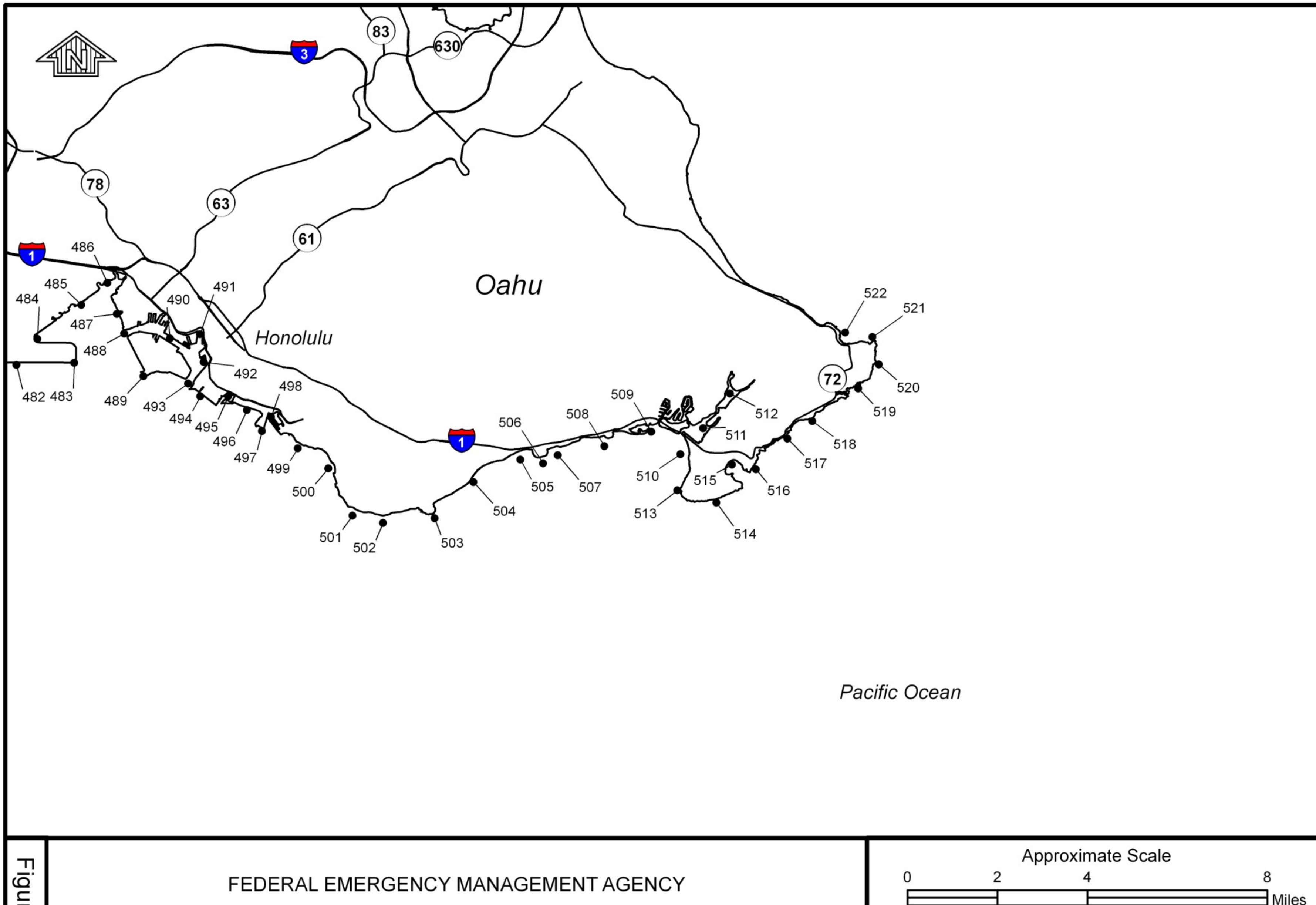


Figure 23

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY AND COUNTY OF HONOLULU, HAWAII

ISLAND OF OAHU

STILLWATER STATION LOCATION MAP 3