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STAFF SUBMITTAL

COMMISSION ON WATER RESOURCE MANAGEMENT

March 20, 2013
Honolulu, Hawaii

Request to Authorize the Chairperson to
Enter into a Joint Funding Agreement with U.S. Geological Survey to
Estimate Low-Flow Characteristics for Streams in Hawai'i

SUMMARY OF REQUEST

Staff is requesting that the Commission on Water Resource Management (Commission) authorize the Chairperson to enter into a Joint Funding Agreement (JFA) with the U.S. Geological Survey (USGS) to cooperatively study low-flow characteristics for streams in Hawai'i.

BACKGROUND

Quantifying and understanding the availability of surface water in watersheds throughout Hawai'i is important for managing surface water resources. The characterization of low-flow conditions is essential for the Commission to set instream flow standards and ultimately manage competing instream and non-instream uses. Additionally, calculating water availability is important to protect and support public interest objectives, including but not limited to aquatic biota, freshwater ecosystems, traditional land customary Hawaiian rights, recreation, municipal and agriculture water use. Currently, setting measurable instream flow standards is hindered by the lack of information on natural low-flow conditions. Therefore, this study will not only be crucial for quantifying low-flow duration discharges on streams with gaging stations, but also in developing regionalized methods to estimate low-flow duration discharges for streams where streamflow data are limited or unavailable.

Low-flow conditions are characterized by low-flow duration discharges between the 50 and 95 percentiles. Flow duration discharges are the representative average flow characteristics for a specified period of time. For example, the median value of flow (Q50) for a particular period is the discharge that is equal to or exceeded 50 percent of the time. In instream flow standard analyses, the flow at 90 percent exceedence probability (Q90) is used to characterize low flows, and 95 percent exceedence (Q95) flows represent extreme low-flow conditions.

Incorporating calculated duration discharges from gaged sites and regional regression equations into the tool, StreamStats, will allow for a comprehensive estimation of water availability throughout the state of Hawaii. StreamStats is a web-based geographic information system (GIS) interactive tool that allows users to easily obtain streamflow statistics and basin characteristics for user-selected sites along streams. This tool is efficient and accurate in estimating streamflow statistics. A study by Rosa and Oki (2010) used StreamStats to estimate the magnitude of peak discharges at ungaged sites on unregulated streams. This same web-based application will be used to estimate low-flow duration discharges throughout Hawaii. Overall, Hawaii StreamStats for low-flow conditions is an important tool that is more cost-effective and computationally efficient than current site specific low-flow studies currently being undertaken for instream flow standards.

SCOPE OF SERVICES AND FUNDING

The attached proposal is for a 7-year cooperative study for estimating the low-flow characteristics of Hawaii's streams. The objectives are to: 1) estimate selected natural low-flow duration discharges for streams with existing streamflow data at gaged sites; and 2) develop methods to estimate selected natural low-flow duration discharges at ungaged sites. The study will apply regionalization techniques to estimate low-flow duration discharges for streams at sites where streamflow data are limited or unavailable on the islands of Kauai, Oahu, Molokai, Maui, and Hawaii.

Phase 1 is a 2.5-year study that includes data compilation and the computation of low-flow duration discharges for gaged sites. Phase 1 is a 2.5-year study and is budgeted at $350,000.

In Phase 1, the USGS will:

1. Compile existing data from continuous record stream gaging stations, low-flow partial-record and miscellaneous discharges measurement sites;
2. Incorporate calculated duration discharges into StreamStats;
3. Explore different methods in developing regional regressions models for estimating low-flow characteristics at ungaged sites; and
4. Identify additional data needs.

Phase 2 is a 4.5-year study that will include the development of regional regression equations for low-flow duration discharges at ungaged sites and the implementation of the web-based StreamStats application. Phase 2 is expected occur between FY2016 and FY2020, and is budgeted at $1,968,000. The USGS and the Commission are working together to seek other County, State, Federal, and private partners. A separate staff submittal will be presented to the Commission for Phase 2.

In Phase 2, the USGS will:

1. Collect additional data;
2. Compute low-flow duration discharges at new sites;
3. Identify and quantify relevant basin characteristics;
4. Incorporate new data and relevant basin characteristics into StreamStats;
5. Identify regions and develop regressions equations for each; and
6. Implement StreamStats for ungaged locations.

This initial joint funding agreement for $175,000 covers one-half the total cost for Phase 1. This will be shared equally by the Commission ($87,500) and the USGS ($87,500), and allows the USGS to

initiate the study while seeking additional funding partners to complete the remainder of this much needed work.

DELIVERABLES

Phase 1 deliverables:

1. Low-flow duration discharges at existing measurement sites;
2. Identification and prioritization of sites for additional data collection in Phase 2.
3. USGS scientific investigation report made available to the public.

Phase 2 deliverables:

1. The StreamStats web-based application will: 1) provide low-flow duration discharges at existing measurement sites; and 2) estimate low-flow duration discharges for ungaged streams on the islands of Kauai, Oahu, Molokai, Maui, and Hawaii;
2. USGS scientific investigation report made available to the public.

ENVIRONMENTAL REVIEW (Haw. Rev. Stat. Chapter 343)

1. Chapter 343 – Environmental Assessment (EA) Compliance

EA Triggers
In accordance with §HRS 343-5(a), the proposed action triggers the need for an EA based on the use of state funds.

EA Exemption
The proposed action qualifies for an exemption from an EA based on §HAR11-200-8(A)(5), for basic data collection, research, experimental management and resource evaluation activities which do not result in a serious or major disturbance to an environmental resource.

RECOMMENDATIONS

Staff recommends that the Commission:

1. Authorize the Chairperson to enter into a Joint Funding Agreement between the Commission and the U.S. Geological Survey to conduct a study on estimating low-flow characteristics for streams in Hawaii, and to approve funding not to exceed $87,500 to complete the study. Commission funding will be from general or special funds or a combination of both, subject to the availability of funding. This Joint Funding Agreement is for one-half of Phase 1 in the amount of $175,000, shared equally by the Commission ($87,500) and the U.S. Geological Survey ($87,500).

2. Authorize the Chairperson to make such further amendments or modifications of the contract agreement (consistent with the terms set forth above) as may be necessary to accomplish the goals described here, provided that any amendment or modification does not require additional Commission funding.

3. Find and determine that the work is exempt from the requirement to prepare an EA.

The terms of this agreement will be subject to the availability of funding and approval of the Chairperson and the Department's Deputy Attorney General. Contract execution will be done in accordance with Chapter 103D, HRS, and Chapter 3-122, Hawaii Administrative Rules.

Respectfully submitted,

WILLIAM M. TAM
Deputy Director

Exhibit 1: USGS Proposal for a Study on Estimating Low-Flow Characteristics of Streams in Hawaii.

APPROVED FOR SUBMITTAL:

WILLIAM J. AILA, JR.
Chairperson

ESTIMATING LOW-FLOW CHARACTERISTICS FOR STREAMS IN HAWAI'I

U.S. Geological Survey
Pacific Islands Water Science Center
Proposal, February 2013

SUMMARY

Surface-water uses during low-flow conditions greatly influence water availability for ecosystems, aquatic biota, and people. In Hawai'i, management of the surface-water resources for many streams is problematic because of a lack of information on the availability of water during low-flow conditions. Knowledge of low-flow characteristics is fundamental to establishing reasonable and defensible instream-flow standards. Furthermore, the use of stream water for agriculture and municipal purposes, protection of traditional and customary Hawaiian rights, maintenance of ecologic balance, aesthetic differences between dry and flowing streams, and recreational use of the streams are factors that will play a role in planning and management decisions by many agencies. This cooperative study applies regionalization techniques to estimate low-flow duration discharges for streams at sites where streamflow data are limited or unavailable on the islands of Kaua'i, O'ahu, Moloka'i, Maui, and Hawai'i. An understanding of the availability of streamflow is essential for proper planning and management of surface-water resources.

The objectives of this 7-year cooperative study are to (1) provide estimates of selected natural low-flow duration discharges, between the 50 and 95 flow-duration percentiles, for streams with existing streamflow data at gaged sites, and (2) develop methods to estimate selected natural low-flow duration discharges at ungaged sites on the islands of Kaua'i, O'ahu, Moloka'i, Maui, and Hawai'i. At these ungaged sites, regionalization techniques will be used to estimate low-flow characteristics based on data collected at gaged streams in similar hydrologic settings.

This study is divided into two phases. Phase 1 accomplishes the first study objective by compiling and analyzing all existing discharge measurements from the USGS National Water Information database, hard copy files, and published reports. Selected natural low-flow duration discharges at continuous-record stream-gaging stations and low-flow partial-record (LFPR) sites will be computed. Different methods will be identified and evaluated for use in developing regional-regression models for estimating low-flow characteristics at ungaged sites on Hawaiian streams. Information collected from phase 1 of the study will be used in phase 2 to accomplish the second study objective. During phase 2, LFPR sites will be established and seepage runs will be conducted in selected areas requiring additional data. Natural low-flow duration discharges at LFPR sites will be computed. Basin characteristics that can be used to regionalize low-flow characteristics will be identified and quantified. Multiple-regression equations will be developed for separate regions to estimate selected duration discharges for ungaged sites. Finally, regional-regression models for estimating low-flow characteristics at ungaged sites will be incorporated into StreamStats.

Findings from phase 1 and 2 will be published separately in the USGS Scientific Investigations Report series. It is anticipated that the study will take 7 years to complete from the time work is commenced and will cost $2,318,000.

EXHIBIT 1

INTRODUCTION

Surface water in Hawai'i is a valuable resource that has economic, ecologic, cultural, and aesthetic importance. Flow in many streams in Hawai'i is currently diverted for agricultural, industrial, or municipal uses. An assessment of the streams in Hawai'i identified 376 perennial streams, of which 125 were diverted to some extent (Hawaii Cooperative Park Service Unit, 1990). Although streams supply only a few percent of the drinking water statewide, surface water is the main source of drinking water in some places. Streams also provide important riparian and instream habitats for many unique native species, and support traditional and customary Hawaiian gathering rights and the practice of taro cultivation. Streams affect the physical, chemical, and aesthetic quality of receiving waters, such as estuaries, bays, and nearshore waters, which are critical to the tourism-based economy of the islands.

PROBLEM

The diversion of surface water during low-flow conditions greatly influences water availability for ecosystems, aquatic biota, and people. In Hawai'i, management of the surface-water resources for many streams is critical, yet problematic because of the lack of information on natural stream discharge during low-flow conditions. As the population of Hawai'i increases and development expands to new areas, it is critical to effectively manage the State's water resources for current and future needs. Surface-water resources in an area must be quantified as part of evaluating existing and potential uses. Ideally, accurate long-term streamflow data are used to provide information on the availability of streamflow. The U.S. Geological Survey (USGS) has operated hundreds of stream-gaging stations in Hawai'i since the early 1900s, although information on natural flows for many streams is unavailable because many of the gages were located downstream of surface-water diversions or were operated for only short periods. Reliable estimates of natural low-flow duration discharges for ungaged streams

represent basic information necessary for quantifying streamflow availability in Hawai'i. For the purposes of this proposed study, low-flow duration discharges that will be considered are between the 50 and 95 flow-duration percentiles. Because the cost of maintaining continuous-record stream-gaging stations at all sites of interest on all streams is prohibitive, methods for estimating the low-flow characteristics of ungaged streams are needed to fill an important information need. Methods for estimating flood frequencies in Hawai'i currently exist (Oki and others, 2010b), although methods for estimating low-flow duration discharges throughout Hawai'i are limited.

At sites where streamflow data are unavailable, regionalization techniques provide estimates of low-flow duration discharges based on data collected at gaged streams in similar hydrologic settings. Fontaine and others (1992) developed multiple-regression equations to estimate the median discharge (the discharge that is equaled or exceeded 50 percent of the time during a specified period, or Q_{50}) for undiverted perennial streams in Hawai'i. Flows lower than the median discharge cannot be directly estimated using the equations developed by Fontaine and others (1992). Gingerich (2005) later developed regression equations to estimate the Q_{50} and Q_{95} discharges for total flow and base flow for undiverted sites in northeast Maui, Hawai'i. (The Q_{95} discharge is the discharge that is equaled or exceeded 95 percent of the time during a specified period.) Existing regression equations are useful for estimating median discharges or for particular geographic areas. However, a method is needed to estimate a suite of low-flow duration discharges for natural flow conditions throughout the State of Hawai'i. These estimates will be useful for characterizing streamflow availability for streams where gaging-station streamflow data do not currently exist.

StreamStats (Ries and others, 2005) is an integrated Geographic Information System (GIS) web application that makes the process of computing streamflow statistics much faster,

more accurate, and more consistent than previous manual methods. StreamStats incorporates (1) a map-based user interface for site selection, (2) a database (StreamStatsDB) that provides streamflow statistics and other information for stream-gaging stations, (3) a GIS program that determines boundaries of drainage basins, measures physical characteristics of the drainage basins, and solves regression equations to estimate streamflow statistics for the sites, and (4) a GIS database needed to display maps and determine the physical characteristics of the drainage basins. StreamStats has been implemented in Hawai'i for estimating the magnitude of peak discharges at ungaged sites in unregulated streams (Rosa and Oki, 2010) and also will be used for this study to facilitate the estimation of selected low-flow duration discharges

This proposed study applies regionalization techniques to estimate natural low-flow duration discharges for streams at sites where streamflow data are limited or unavailable on the islands of Kaua'i, O'ahu, Moloka'i, Maui, and Hawai'i. An understanding of the availability of streamflow is essential for proper planning and management of water resources. The use of stream water for agriculture, protection of traditional and customary Hawaiian rights, maintenance of ecologic balance, aesthetic qualities of streams, and recreational use of the streams are factors that will play a role in planning and management decisions by many agencies. Because of the various surface-water uses, agencies and local community groups may require flow information on different locations along a stream. StreamStats will allow the user to select a point of interest on a stream where low-flow information is needed. This is a robust approach that meets the data needs of different agencies and communities in their water-management decisions.

OBJECTIVES

The objectives of this 7-year cooperative study are to (1) provide estimates of selected natural low-flow duration discharges, between the 50 and 95 flow-duration percentiles, for

streams with existing streamflow data at gaged sites, and (2) develop methods to estimate selected natural low-flow duration discharges at ungaged sites on the islands of Kaua'i, O'ahu, Moloka'i, Maui, and Hawai'i. This study is divided into two phases. Phase 1 accomplishes the first study objective by compiling and analyzing all existing discharge measurements from the USGS National Water Information (NWIS) database, hard copy files, and published reports. Selected natural low-flow duration discharges at continuous-record stream-gaging stations and low-flow partial-record (LFPR) sites will be computed. Streams in geographic, geomorphic, or hydrogeologic settings for which limited existing stream-gaging data exist will be identified. Different methods will be identified and evaluated for use in developing regional-regression models for estimating low-flow characteristics at ungaged sites on Hawaiian streams. Results of this exploratory effort also will be used to help identify areas for additional data collection during phase 2 of the study.

Information collected from phase 1 of the study will be used in phase 2 to accomplish the second study objective. During phase 2, LFPR sites will be established for additional data collection and seepage runs will be conducted in selected areas requiring additional data. Basin characteristics that can be used to regionalize low-flow characteristics will be identified and quantified. Multiple-regression equations will be developed for separate regions to estimate selected natural low-flow duration discharges for ungaged sites. Finally, regional-regression models for estimating low-flow characteristics at ungaged sites will be incorporated into StreamStats.

RELEVANCE AND BENEFITS

Land-use changes have significantly altered the hydrology of the Hawaiian Islands. Surface-water use has shifted from supporting a mainly traditional Hawaiian lifestyle to providing irrigation water for large-scale plantation agriculture. Most recently, increasing

urbanization has placed further stress on the limited water resources to support the needs of a growing population. To sustainably manage Hawai'i's water resources for current and future needs, surface-water resources in an area must be quantified, which is the principal goal of the proposed study. The following sections describe the relevance of the proposed study to each water-use issue and how policymakers and natural-resource managers from State and County agencies can benefit from the results of this study.

Native Hawaiian Culture

Streams are the most vital natural resources in the lives of Native Hawaiians. Native communities lived in ahupua'a and depended on streams for drinking water, growing crops, raising livestock, supporting vegetation that provided materials for medicine and shelter, and other religious and cultural practices. Migrating from ocean into the streams were unique species of freshwater animals (for example, 'o'opu, 'ōpae, and hīhīwai) that were food sources for Native Hawaiians. Streams were commonly diverted into 'auwai (watercourse for irrigation) to provide water for taro cultivation and a majority of the diverted water was returned downstream from the points of diversion. As the sugar industry became established in Hawai'i, large engineered diversion systems were built and transported water across ahupua'a, altering drainage patterns within them. Stream reaches downstream of the engineered-system diversion intakes commonly were dry because the diversions captured all of the dry-weather flow of streams.

Government agencies that represent the interests of Native Hawaiians include, but are not limited to, the Office of Hawaiian Affairs (OHA) and the State Department of Hawaiian Home Lands (DHHL). The mission of the OHA is to preserve the Native Hawaiian culture and lifestyle that depended on streams for sustenance (State of Hawai'i, 2012). In June 2006, the OHA partnered with the City and County of Honolulu, State Department of Land and Natural Resources, U.S. Army, and the National Audubon Society and purchased Waimea Valley,

O'ahu, in an effort to protect and preserve the cultural and natural resources of the ahupua'a (Waimea Valley Hi'ipaka LLC, 2006). The OHA also played an important role in the Supreme Court case to restore flow to the Nā Wai 'Ehā streams, Maui (Office of Hawaiian Affairs, 2011). The importance of water and critical issues related to water and the native communities are communicated in OHA's monthly newsletter "Ka Wai Ola". The DHHL is working toward establishing a self-sufficient Hawaiian community by delivering Native Hawaiians a permanent land base for homestead farming (State of Hawai'i, 2002a). As of June 30, 2001, the DHHL owns over 200,000 acres of land in the State of Hawai'i with about 7,000 Native Hawaiian households and an additional 30,000 applications to be processed (State of Hawai'i, 2002b). These lands are to be designated residential, agricultural, or pastoral homesteads as outlined in the DHHL General Plan (State of Hawai'i, 2002a) and accurate scientific information on the available water resources to support each type of homestead development is needed to plan for current and future needs of the communities. Furthermore, these agencies need baseline information to help prioritize potential watershed management and restoration projects to protect the ahupua'a and the water source, and to mitigate adverse impacts to the environment.

Results of this proposed study will help these agencies accomplish their missions by providing a tool for estimating low-flow characteristics of Hawaiian streams, which will inform policymakers and communities about the status of their surface-water resources. The study will also investigate the interaction between surface water and groundwater in the watersheds, and provide information on the occurrence of gaining and losing stream reaches in some streams. Results of the study will help answer the key question of whether enough water is available to support the various traditional and cultural purposes, as well as to meet present and future human and environmental requirements.

Water Quality and Watershed Protection

Urbanization and the potential loss of natural vegetated lands encourage the need for watershed conservation, which has recently become the focus for drinking water protection (Dudley and Stolton, 2003; Ernest and others, 2004; Wickham and others, 2011). Water is one of the most important resources from Hawai'i's forests. Healthy forested watersheds have higher soil infiltration rates, which could potentially enhance recharge into the aquifer. Ernest and others (2004) conducted a survey of 27 drinking water facility treatment costs and associated watershed characteristics and found that water-treatment costs decrease by 20 percent for every 10 percent increase in forest cover of the water-source area. The State Department of Health (DOH) is responsible for ensuring clean public drinking water as well as improving stream water quality through the establishment of total maximum daily loads (TMDLs), the maximum amount of contaminant that may discharge to a water body while still meeting water quality standards (State of Hawai'i, 2008). To determine the load of a constituent in a stream, streamflow information is needed, especially during low-flow conditions when less dilution occurs. This study aims to quantify low-flow conditions for Hawaiian streams, which is necessary for determining the TMDL that will help to restore impaired water statewide.

Healthy forested watersheds also reduce the erosive effects of rainfall and the load of sediment that enters streams and the ocean, which are critical for providing suitable habitats for fish and wildlife and preserving recreational opportunities such as fishing and swimming. The State Department of Land and Natural Resources Division of Forestry and Wildlife (DOFAW) and the county water departments have been supporting management practices (for example, reforestation, fencing, removal of feral animals) that protect watersheds and mitigate adverse impacts to forests. Many watershed partnerships, with support from various government and private agencies, have been established to target watershed-protection efforts at specific

locations. Evaluation of watershed-protection efforts is essential for planning purposes and streamflow information generated from this study is a measurable milestone that can be established for monitoring the implementation of watershed protection measures. Results of this study may be helpful to natural resource-protection agencies in developing watershed-protection measures as well as understanding their effects on the watersheds. One of the products of this study is a web application (StreamStats) that can be used to estimate low-flow characteristics at ungaged streams. This will enable agencies and communities to identify critical areas where further watershed management is necessary.

Agricultural Water Use

With the decline of plantation agriculture in the 1990s, large amounts of prime agricultural lands were made available for conversion to diversified agriculture. With increasing population, expanding the diversified agricultural industry in Hawai'i will lead to greater self-sufficiency and reduce the need to import fruits and produce. One of the challenges in developing and strengthening the local diversified agricultural industry is to rehabilitate and modify the existing engineered diversion systems that were affected by plantation closures for diversified agricultural use (State of Hawai'i, 2004a). The State of Hawai'i Department of Agriculture (DOA) is tasked with developing viable agricultural business by providing adequate and reliable water supply for farming. To accomplish this goal, the DOA must determine potential areas for diversified agriculture, the potential demand for irrigation water, and whether that irrigation-water need can be met.

Results of this study will allow the DOA to make cost-effective management plans regarding water use and diversion-system rehabilitation. The proposed study will provide scientific information on the availability of surface water. This information is necessary for the DOA to determine whether the irrigation-water demand for farming in an area can be met.

Information on water availability may also be helpful to the DOA in identifying which diversion systems and associated reservoirs to rehabilitate and to what extent the rehabilitation and maintenance work should be done for the intended uses. For example, the diversion systems that provided irrigation water for early plantations were built to support water needs of less efficient irrigation methods (for example, flood irrigation). Thus, the amount of water needed for the early plantations may be higher than that required by diversified agriculture. With the advent of more efficient irrigation systems (for example, drip irrigation) and the generally long-term downward trends in base flow of Hawaiian streams (Oki, 2004), existing engineered diversion systems may not require restoration to handle discharges that were prevalent during the plantation era.

Municipal Water Use

The resident population in the State of Hawai'i increased from 768,561 in 1970 to 1,360,301 in 2010, which represents an increase of about 75 percent. On the Island of Maui alone, population increased from 38,691 in 1970 to 144,444 in 2010, which represents an increase of more than 270 percent (U.S. Census Bureau, 2011). Because of the increase in population, the demand for municipal water will likely continue to increase in the future and meeting that demand may be challenging.

The State Department of Health and the county water departments are responsible for providing clean and sufficient drinking water through proper management of limited water resources. Hawai'i is mostly dependent on groundwater for municipal water supply and groundwater withdrawals can affect streamflow in some places. Izuka and Oki (2002) found that groundwater withdrawals from the Hanamā'ulu and Puhi areas of the southern Līhu'e Basin, Kaua'i, will reduce base flows in neighboring streams. Oki (2006) concluded that long-term water-level declines caused by groundwater withdrawals will eventually reduce groundwater discharge to Punalu'u Stream, O'ahu. The effect of groundwater withdrawal on streamflow

depends on factors including the rate of withdrawal and the proximity of the pumped wells to the streams. To reduce the amount of potable groundwater used to meet nonpotable needs, alternative surface-water sources can be considered. However, surface water should not be planned for other uses until water availability is determined (Honolulu Board of Water Supply, 2009, p. 22).

The proposed study provides information on the current status of surface-water availability, which is important to the DOH and county water departments in planning for current and future water needs of the growing population. This information may also be useful in management decisions regarding improvements to and/or building of drinking-water infrastructures. The study will also explore the interaction between surface water and groundwater in the watersheds and will provide information to evaluate how groundwater availability may be affected by surface-water diversions and how surface-water availability may be affected by groundwater withdrawals. Results of this proposed study can be used to identify critical areas where watershed protection, stream restoration, and water-use restriction efforts could be focused.

Allocation of Water

Competition for limited water resources for offstream and instream uses has been, and continues to be a major issue in Hawai'i. The diversion of surface water for offstream uses reduces flow in the downstream reaches, which can adversely affect traditional Hawaiian practices, stream ecology, water quality, recreational activities, and aesthetics. The Hawai'i State Water Code mandates that the Commission on Water Resource Management (CWRM) establish a statewide instream-use protection program (Chapter 174C-71, Hawaii Revised Statutes) for the purpose of protecting these instream uses. The principal mechanism that the CWRM has for protecting these instream uses is to establish instream-flow standards. "Each instream flow

standard shall describe the flows necessary to protect the public interest in the particular stream. Flows shall be expressed in terms of variable flows of water necessary to protect adequately fishery, wildlife, recreational, aesthetic, scenic, or other beneficial instream uses in the stream in light of existing and potential water developments including the economic impact of restriction of such use" (Chapter 174C-71, Hawaii Revised Statutes). Quantitative instream-flow standards that account for economic, cultural, ecologic, recreational, and aesthetic needs have not yet been established for most streams in the State of Hawai'i.

Finding a balance between offstream and instream uses is difficult because it requires information on the current and future water demands, as well as the availability of water. Conflicts have led to costly litigation over rights to the water between those currently diverting the water and those desiring sufficient flow in the stream for instream uses. On the island of O'ahu, a contested-case hearing was initiated in 1995 to address competing uses of surface water and groundwater in the Waiāhole area of windward O'ahu (Miike, 2004). The Waiāhole Ditch diverted large amounts of dike-impounded groundwater at high altitudes that previously fed Waiāhole (and its tributaries Waianu and Uwau), Waikāne, and Kahana Streams through seeps and springs, resulting in diminished base flows in these streams. In 2005, the Punalu'u Watershed Alliance, comprised of the Punalu'u Community Association, Kamehameha Schools, Honolulu Board of Water Supply, USGS, and the CWRM, was formed to address community issues and coordinate efforts to establish an instream-flow standard for Punalu'u Stream (State of Hawaii, 2007). On the island of Maui, the Native Hawaiian Legal Corporation filed a petition to the CWRM in 2001 for flow to be restored to 27 streams in northeast Maui (State of Hawai'i, 2001). These streams were diverted mainly by the East Maui Irrigation Company for irrigating sugarcane cultivated in central Maui. In 2004, Earthjustice filed a petition, which later became a contested-case hearing, to amend instream-flow standards for the Nā Wai 'Ehā streams (Waihe'e

River and Waiehu, ʻĪao, and Waikapū Streams) in the eastern part of West Maui (State of Hawai'i, 2004b). For these cases, streamflow data under natural flow conditions for the streams involved were limited or unavailable at the time of the disputes. Consequently, the USGS, in cooperation with various agencies (see Gingerich, 2005; Oki and others, 2006; Yeung and Fontaine, 2007; Oki and others, 2010), provided the information necessary for planning and management of the water resource.

Scientific information generated from this study will assist the CWRM in determining equitable, reasonable, and beneficial instream and offstream uses of surface-water resources throughout the State of Hawai'i. Results from the study will assist the CWRM in (1) documenting water rights and uses associated with the perennial streams in Hawai'i; (2) assessing the effects of existing uses on these streams; and (3) determining quantitative and technically defensible instream flow standards for these streams.

APPROACH

To accomplish the objectives of this study, the USGS proposes to undertake a 7-year study with the 2-phased approach described below. Figure 1 is a schematic that summarizes the study approach. Four categories of stream sites that will be used in the low-flow analysis are defined: (1) an index site is a site with a long-term continuous-record stream-gaging station with daily streamflow record under natural-flow conditions; (2) a low-flow partial-record (LFPR) site is a site where about 10 discharge measurements are made during varying low-flow periods under natural-flow conditions; (3) a miscellaneous discharge-measurement site is a site with only a few discharge measurements made during any flow condition; and (4) an ungaged site is a site where no discharge measurements have been made.

Phase 1. Objective - Provide estimates of selected natural low-flow duration discharges for streams with existing streamflow data at gaged sites

Compilation of existing data. Data from continuous-record stream-gaging stations, LFPR sites, and miscellaneous discharge measurement sites will be compiled from USGS files and published USGS reports, and entered into the NWIS database. LFPR sites offer a cost-effective way of expanding the geographic coverage of low-flow information (Curran and others, 2012). Data from LFPR sites commonly are used to estimate low-flow duration discharges at sites without a long-term continuous-record stream-gaging station. LFPR sites are also useful for extending the applicable range of basin characteristics for regression models in estimating low-flow characteristics at ungaged sites, although the errors associated with flow estimates are greater than those associated with continuous-record stream-gaging stations. About 10 discharge measurements generally are made at the LFPR sites during periods of low flow. Low-flow duration discharges are estimated using record-extension methods that relate discharge measurements at the LFPR sites and concurrent daily mean discharges at nearby index stations. Miscellaneous and seepage-run discharge measurements may also be available for other areas. Seepage runs are typically conducted to identify gaining and losing reaches of a stream. Existing data will establish the basis for identifying data needs.

Computation of low-flow characteristics at existing sites. Low-flow duration discharges will be estimated for sites with existing data. At continuous-record stream-gaging stations, the full period of record excluding pre-1940s streamflow data will be used to compute low-flow characteristics. At LFPR sites with existing data, low-flow duration discharges relevant to a selected base period will be estimated. Selection of the base period will be dependent on (1) availability of data, (2) relevance to current conditions, and (3) desired accuracy of estimates. To extend the record from a LFPR site to the selected base period, the discharges at the LFPR site

must be related to concurrent discharges at an index station (or stations), which also must have representative data during the base period. Streamflow data collected prior to the 1940s may not reflect current or future conditions (Oki, 2004); these data likely will not be used in the low-flow analysis. Longer records generally will result in greater accuracy in estimated long-term duration discharges (Fontaine and others, 1992).

Low-flow duration discharges at the LFPR sites will be estimated using record-extension methods that relate discharge measurements at the LFPR stations and concurrent daily mean discharges at the index stations (Hirsch, 1982). A graphical-correlation method (Searcy, 1959) or the maintenance of variance extension, type 1 (MOVE.1) method (Hirsch, 1982) may be used to determine the relation between concurrent discharges at the LFPR and index stations. The graphical-correlation method is used for cases in which curvature is detected in the relation between the concurrent discharges, whereas the MOVE.1 method is used for cases in which little or no curvature exists in the relation between the concurrent discharges (Ries, 1993). In some streams, seepage-run measurements may be available to estimate duration discharges downstream from continuous-record stream-gaging stations or LFPR sites. Seepage-run measurements provide estimates of streamflow gain or loss within the reach between adjacent measurement sites and have been used to estimate duration discharges in Hawaiian streams (Oki and others, 2006; Oki and others, 2010a).

Incorporation of duration discharges into StreamStats. Low-flow duration discharges estimated at existing measurement sites will be incorporated into StreamStats. StreamStats will allow users to select an existing measurement site and the selected low-flow duration discharges will be displayed.

Exploratory analysis. Different methods will be evaluated for use in developing regional-regression models for estimating low-flow characteristics at ungaged sites. This is important for

identifying other areas for additional data collection that will be conducted during phase 2 of the study. Duration discharges will be evaluated as the dependent (response) variable in the regional regression analysis. In addition, normalized duration discharges will be considered as a possible dependent variable. Normalized duration discharges may also be useful for identifying regions for which regression models are developed. Low-flow duration discharges from continuous-record stream-gaging stations and LFPR sites can be normalized by the median discharge. Preliminary analysis indicates that streams with similar low-flow variability but different flow magnitudes tend to group in regions that may reflect common hydrogeologic characteristics. Another method that will be explored is using the rate of base-flow recession to define regions. The base-flow recession rate is an important low-flow characteristic in streams that provide information on the hydrogeological controls of streamflow. Streams that are largely supported by groundwater discharge will have slower rates of base-flow recession than streams that are hydraulically disconnected from the groundwater sources. Curran and others (2012), Eng and Milly (2007), and Funkhouser and others (2008) used the base-flow recession rate as a potential basin characteristic for regional low-flow regression models.

Identification of data needs. Maps showing locations of continuous-record stream-gaging stations, LFPR sites, and miscellaneous measurement sites will be developed to identify areas where additional data are needed. The number of years of record at each continuous-record stream-gaging station and the number of discharge measurements at each LFPR site and miscellaneous measurement site will be displayed on these maps. Stream reaches where seepage runs have been conducted also will be delineated. Map layers showing areas of high-level groundwater, springs, the distribution of rainfall, and geology will be created. Figures 2 to 6 show locations of continuous-record stream-gaging stations, LFPR, seepage-run, and miscellaneous measurement sites on the islands of Kaua'i, O'ahu, Moloka'i, Maui, and Hawai'i

that are currently in the NWIS database. As part of this phase of the study, the maps (figs. 2-6) will be updated to include sites with data that are not in NWIS. Streams in under-represented geographic areas and hydrogeologic settings will be considered for additional data collection. Existing sites with less than 10 discharge measurements will also be considered for reoccupation. Results of the exploratory analysis from phase 1 of the study will help to identify other areas for additional data collection.

Phase 2. Objective - Develop methods to estimate selected natural low-flow duration discharges at ungaged sites.

Collection of additional data. About 10 new LFPR sites will be established on Kaua'i, O'ahu, Moloka'i, Maui, and Hawai'i. At an LFPR site established in an ungaged location, about 10 discharge measurements will be collected over a period of two years to allow for measurements during independent flow recessions and varying discharges. At an LFPR site reestablished at a previously gaged location, the number of discharge measurements that will be made as part of this study depends on the number of existing discharge measurements that can be used in the regional low-flow analysis. Field data collection will be conducted by two teams of two people, allowing data to be collected on two islands concurrently and in a shorter time period. Seepage runs will be conducted in a limited number of streams where LFPR sites are established as part of this study to characterize streamflow gains and losses, unless gains and losses have previously been quantified. Seepage runs also may be useful to conduct in streams with an existing continuous-record stream-gaging station to quantify streamflow gains and losses and provide a means by which to estimate duration discharges at ungaged sites on the stream. To characterize seepage magnitude changes with flow, seepage runs will be conducted in a few streams on the island of O'ahu during different low-flow conditions. Potential measurement

errors will be considered when analyzing differences in seepage gains or losses under varying low-flow conditions within the same stream.

Computation of low-flow characteristics at new sites. Low-flow duration discharges relevant to a selected base period will be estimated for the new LFPR sites. Refer to Phase 1, the section on "Computation of low-flow characteristics at existing sites," for discussion on the selection of base period and record-extension methods that will be used to estimate low-flow duration discharges at the LFPR sites established as part of this study.

Identification and quantification of relevant basin characteristics. Methods for quantifying common drainage-basin morphometric characteristics (for example, area, perimeter, and relief) as well as rainfall and soil permeability are available in StreamStats. It is expected that low-flow characteristics of streams also may be related to the hydrogeological setting, which generally controls the occurrence of gaining and losing stream reaches. Information related to seepage runs, presence of high-level groundwater, volcanic dikes, springs, and geology will be considered in developing relevant and quantifiable basin characteristics that can be used in a regional regression model of low-flow duration discharges. The geospatial datasets that will be used for this study will be incorporated into StreamStats. This incorporation will ensure that future users of StreamStats will be able to (1) estimate the low-flow duration discharges in a manner consistent with the assumptions of the regional-regression models, and (2) generate reproducible low-flow discharge estimates.

Identification of regions and development of regression equations. Both duration discharges and normalized duration discharges likely will be evaluated as the dependent (response) variable in the regional regression analysis. To improve low-flow estimates, basins will be grouped into regions and separate regression models will be developed for each region. Regions can be defined using the following methods: (1) geography, (2) heuristic methods

relying on an understanding of the hydrogeology of an area, (3) identifying groups of basins from the residuals of regression equations, and (4) statistical clustering (principal components or cluster analysis). Multiple-regression methods will be used to develop regional regression models relating low-flow duration discharges at gaged sites to various basin characteristics. Regression models can be developed using ordinary least-squares (OLS) and weighted least-squares (WLS) estimates of model parameters using the WREG program (Eng and others, 2009). Curran and others (2012) found that the WLS method is more suitable for developing regional regression models that use streamflow data from partial-record sites because the WLS method allows more weight to be given to partial-record sites with more reliable low-flow estimates.

Selected basin characteristics will be used as explanatory (independent) variables in the regression analysis. Scatterplots of the non-transformed and log-transformed (base-10 logarithm) duration discharges and each explanatory variable will be used to evaluate whether log-transformation of the explanatory variables improves the correlation between discharge and each explanatory variable. A stepwise regression analysis and all-possible-subsets regression analysis will be considered in reducing the list of explanatory variables by adding and subtracting variables at each iteration to find the best combination of remaining basin attributes. Multi-colinearity among explanatory variables will be tested using the variance inflation factor (VIF) (Helsel and Hirsch, 1992). The explanatory variables and transformations in the best ordinary least squares regression models will then be used to develop the final models using the WREG program (Eng and others, 2009). Sites with large leverage or influence (Tasker and Stedinger, 1989; Helsel and Hirsch, 1992) from the models will be identified by the WREG program and considered for exclusion.

Implementation of StreamStats. Low-flow duration discharges estimated at the new measurement sites will be incorporated into StreamStats. Similar to phase 1, StreamStats will

allow users to select the new measurement sites (established as part of this study) and the selected low-flow duration discharges will be displayed. Regional regression models for estimating low-flow duration discharges will be incorporated into StreamStats. Regions defining where each regression model is applicable and possible exclusion zones defining where estimates of low-flow duration discharges are not reliable also will be incorporated into StreamStats. Once fully implemented, StreamStats will allow users to select an ungaged site on a stream and estimate selected low-flow duration discharges. StreamStats will automatically delineate the drainage basin, select the appropriate regression models, quantify required basin characteristics, and compute the low-flow duration discharges at the selected site.

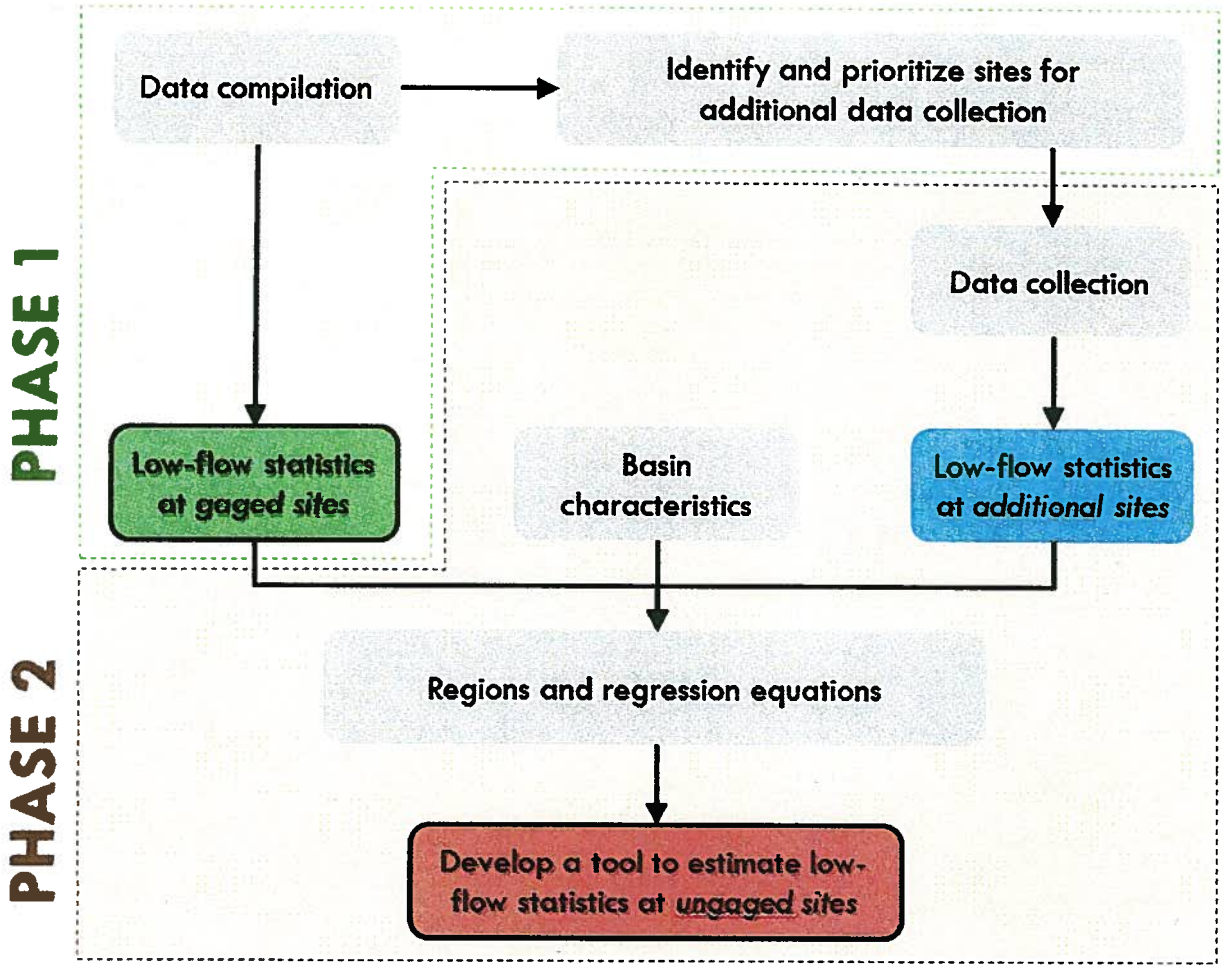

Figure 1. Schematic summarizing the 2-phased study approach.

PRODUCTS

The main product for this study is the StreamStats web application that will (1) provide low-flow duration discharges at existing measurement sites, and (2) estimate low-flow duration discharges for ungaged stream sites on the islands of Kaua'i, O'ahu, Moloka'i, Maui, and Hawai'i. The StreamStats application is readily accessible to the public. Additional products of this study include two USGS Scientific Investigations Reports that document the methods and results of each phase of the study. The reports will be made available to the public via the internet.

Table 1. Milestone dates for deliverables of this study.

	USGS Scientific Investigations Report				StreamStats
Probable title	First draft	Review	Approval	Publication	
Low-flow characteristics for gaged streams in the State of Hawai'i	1/2015	2/2015	4/2015	6/2015	9/2015
Regionalization of low-flow characteristics for ungaged streams in the State of Hawai'i	4/2019	5/2019	7/2019	9/2019	1/2020

TIMELINE

The major tasks and associated periods of activity for this study are summarized in Table 2. Phase 1 is a 2.5-year study with a focus on data compilation and computation of low-flow duration discharges for gaged sites. Phase 2 is a 4.5-year study with a focus on developing regression equations for estimating low-flow duration discharges at ungaged sites. Much of the data collection and analysis will be done during the fourth and fifth years of the overall study. Data analysis associated with estimating duration discharges and developing regression equations will be completed during the sixth year of study.

Table 2. Project timeline.

Tasks	FY13 Q3	FY13 Q4	FY14 Q1	FY14 Q2	FY14 Q3	FY14 Q4	FY15 Q1	FY15 Q2	FY15 Q3	FY15 Q4	FY16 Q1	FY16 Q2	FY16 Q3	FY16 Q4	FY17 Q1	FY17 Q2	FY17 Q3	FY17 Q4	FY18 Q1	FY18 Q2	FY18 Q3	FY18 Q4	FY19 Q1	FY19 Q2	FY19 Q3	FY19 Q4	FY20 Q1	FY20 Q2
Phase 1																												
Compile data	■	■	■	■																								
Duration discharges				■	■	■																						
Exploratory analysis					■	■	■																					
Data needs								■																				
Report						■	■	■	■																			
StreamStats										■																		
Phase 2																												
Data collection											■	■	■	■	■	■	■	■	■	■	■	■						
Duration discharges																				■	■	■						
Basin characteristics											■	■	■	■	■	■	■	■										
Regression analysis																					■	■	■					
Report																							■	■	■	■		
StreamStats																											■	■

BUDGET

It is anticipated that a total of $2,318,000 is needed for this 7-year study, $350,000 for phase 1 and $1,968,000 for phase 2. A cost breakdown for phase 1 and 2 of the study is provided in Tables 3 and 4, respectively. Labor includes salary and indirect costs for leave, facilities, and overhead assessments. Science support includes indirect costs for project management, technical services, and report processing fees.

Table 3. Project budget for phase 1 of the study.

Category	FY13	FY14	FY15
Labor	$ 48,747	$ 189,642	$ 66,210
Science Support	$ 7,253	$ 28,358	$ 9,790
Total	$ 56,000	$ 218,000	$ 76,000

Table 4. Project budget for phase 2 of the study.

Category	FY16	FY17	FY18	FY19	FY20
Labor	$ 389,028	$ 383,747	$ 414,137	$ 132,295	$ 6,926
Travel	$ 125,813	$ 133,309	$ 122,534	$ -	$ -
Supplies	$ 2,000	$ 1,500	$ 1,000	$ -	$ -
Science Support	$ 77,158	$ 77,443	$ 80,330	$ 19,705	$ 1,074
Total	$ 594,000	$ 596,000	$ 618,000	$ 152,000	$ 8,000

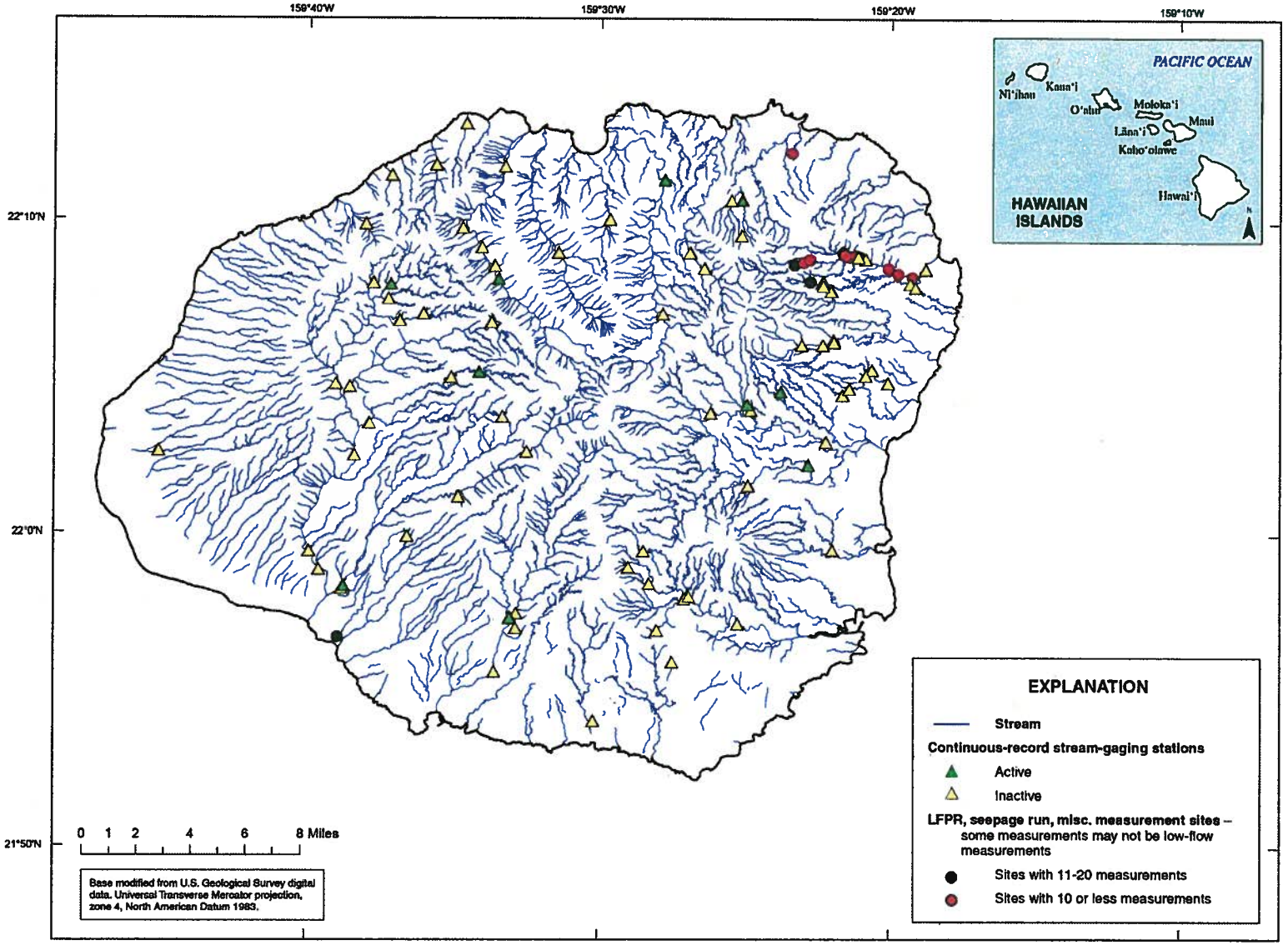

Figure 2. Continuous-record stream-gaging stations, low-flow partial-record, seepage-run and miscellaneous measurement sites, Island of Kaua'i, Hawai'i. (Information retrieved from the U.S. Geological Survey National Water Information System database.)

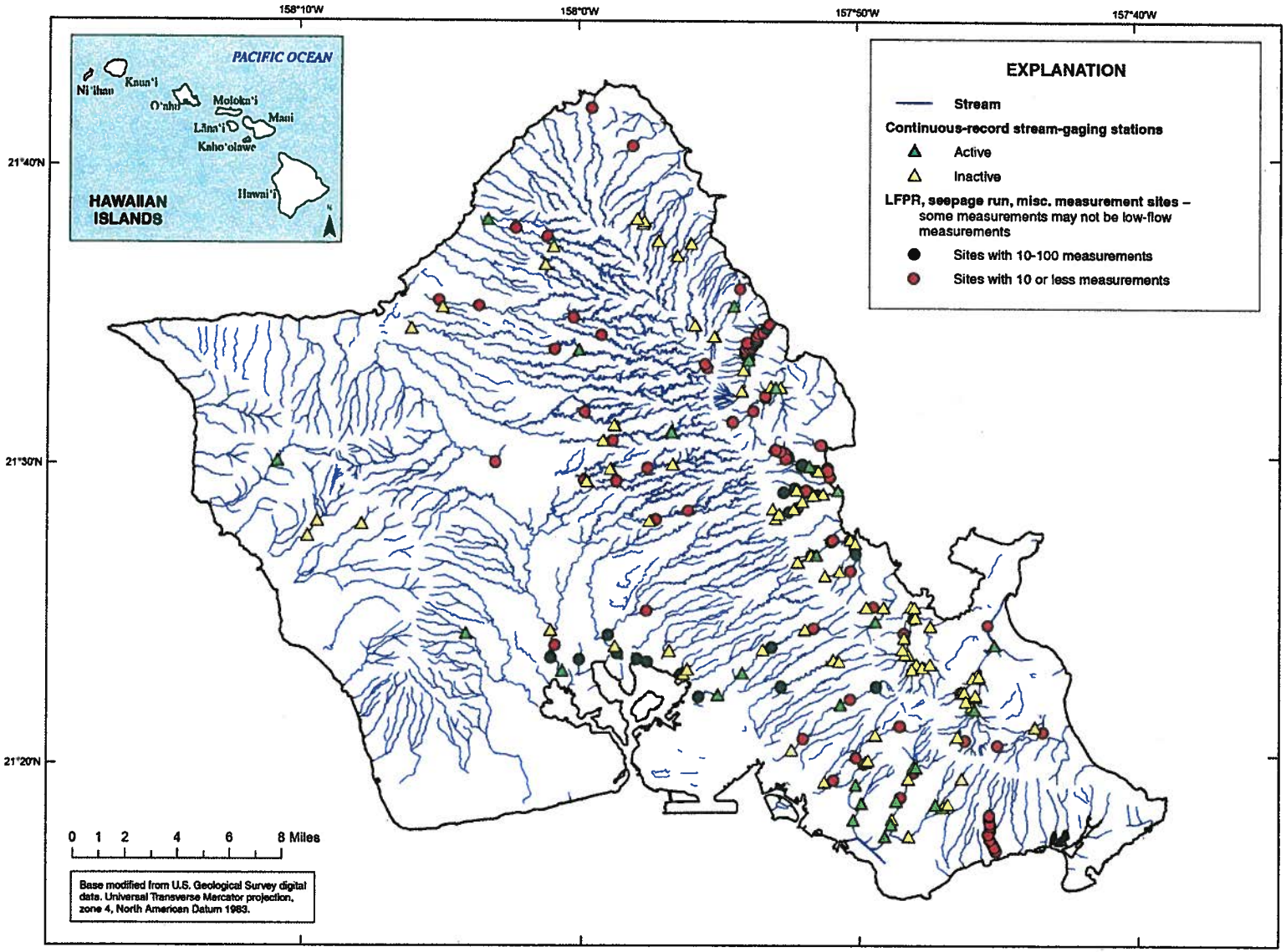

Figure 3. Continuous-record stream-gaging stations, low-flow partial-record, seepage-run and miscellaneous measurement sites, Island of O'ahu, Hawai'i. (Information retrieved from the U.S. Geological Survey National Water Information System database.)

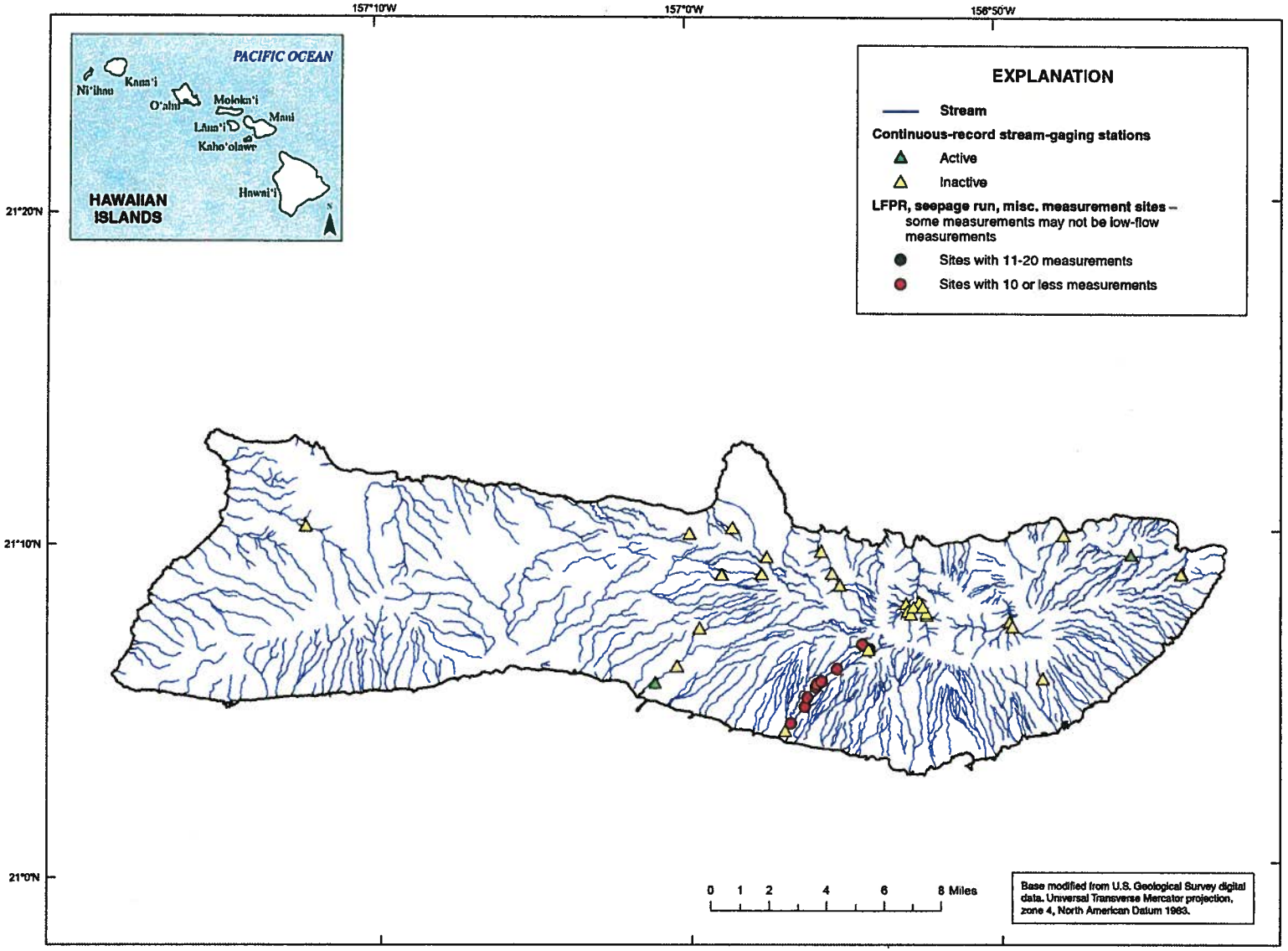

Figure 4. Continuous-record stream-gaging stations, low-flow partial-record, seepage-run and miscellaneous measurement sites, Island of Moloka'i, Hawai'i. (Information retrieved from the U.S. Geological Survey National Water Information System database.)

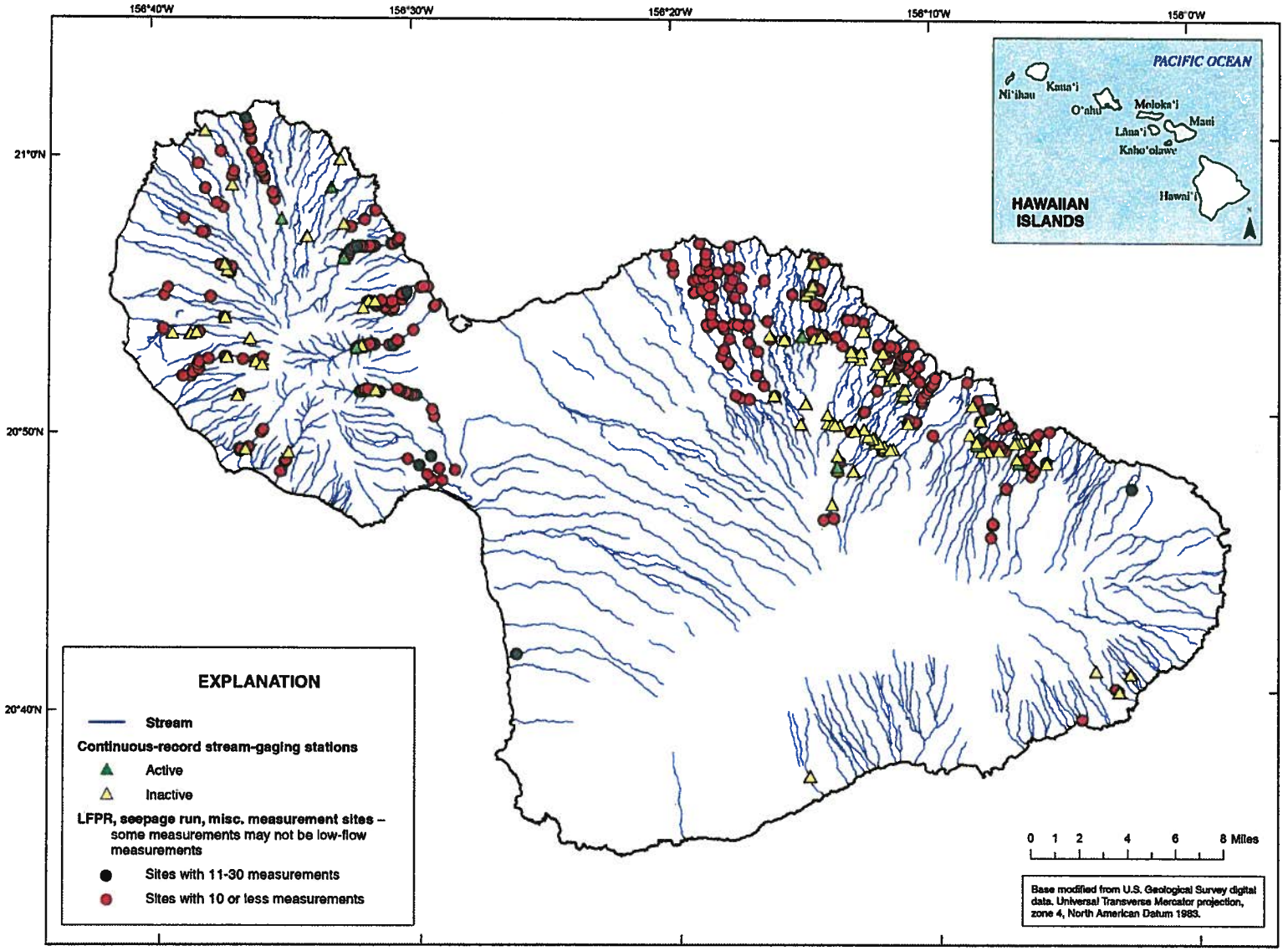

Figure 5. Continuous-record stream-gaging stations, low-flow partial-record, seepage-run and miscellaneous measurement sites, Island of Maui, Hawai'i. (Information retrieved from the U.S. Geological Survey National Water Information System database.)

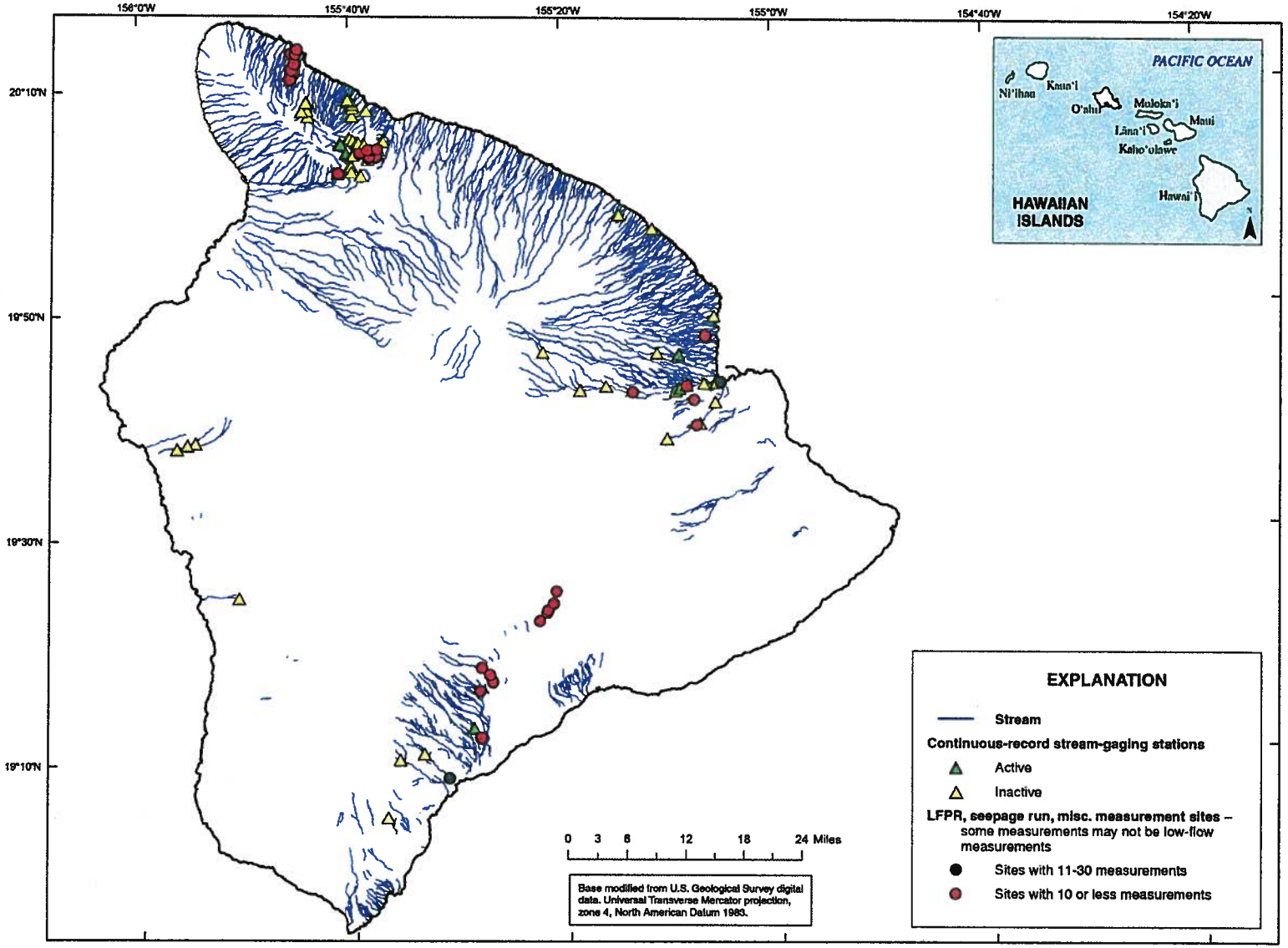

Figure 6. Continuous-record stream-gaging stations, low-flow partial-record, seepage-run and miscellaneous measurement sites, Island of Hawai'i, Hawai'i. (Information retrieved from the U.S. Geological Survey National Water Information System database.)

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