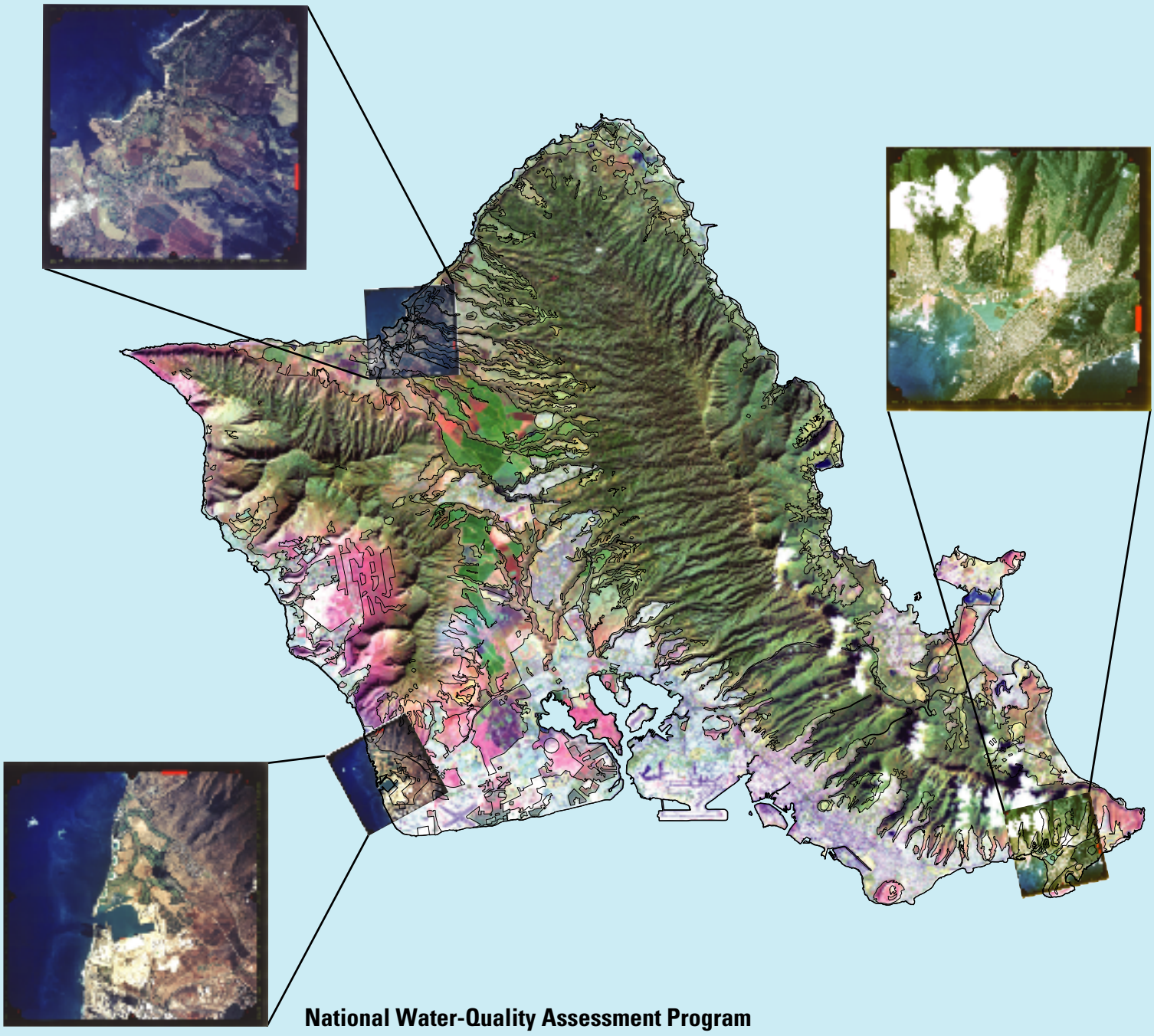
USGS
science for a changing world

Land Use on the Island of Oahu, Hawaii, 1998

U.S. Department of the Interior
U.S. Geological Survey

Water-Resources Investigations Report 02-4301



National Water-Quality Assessment Program

About the Cover: The base image is from Landsat 7 Enhanced Thematic Mapper (ETM), acquired by the U.S. Geological Survey, EROS Data Center http://edc.usgs.gov/ from multiple dates in 2000, georeferenced in an Albers equal area projection. The NOAA National Ocean Service, Coastal Services Center, Coastal Change Analysis Program at http://www.csc.noaa.gov/crs/lca/hi_index.html provided a cloud-reduced composite image of this data (using a band ratio technique to identify clouds and cloud shadow areas and mask them out of the imagery). Overlain on the satellite image are true color aerial photographs, also from 2000, provided by NOAA National Ocean Service, Center for Coastal Monitoring and Assessment, Biogeography Program at http://biogeo.nos.noaa.gov/. Both imagery sources were used to verify mapped land use (black lines in cover image).

Land Use on the Island of Oahu, Hawaii, 1998

By Frederick L. Klasner and Clinton D. Mikami

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 02-4301

Honolulu, Hawaii
2003

U.S. DEPARTMENT OF THE INTERIOR

GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY

Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
677 Ala Moana Blvd., Suite 415
Honolulu, HI 96813
http://hi.water.usgs.gov/

Copies of this report can be purchased from:

U.S. Geological Survey
Information Services
Box 25286
Denver, CO 80225-0286

FOREWORD

The U.S. Geological Survey (USGS) is committed to serve the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life, and facilitates effective management of water, biological, energy, and mineral resources. (http://www.usgs.gov/). Information on the quality of the Nation's water resources is of critical interest to the USGS because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is suitable for industry, irrigation, and habitat for fish and wildlife. Escalating population growth and increasing demands for the multiple water uses make water availability, now measured in terms of quantity *and* quality, even more critical to the long-term sustainability of our communities and ecosystems.

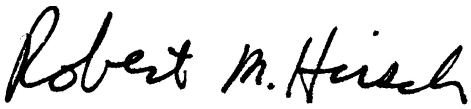
The USGS implemented the National Water-Quality Assessment (NAWQA) Program to support national, regional, and local information needs and decisions related to water-quality management and policy. (http://water.usgs.gov/nawqa/). Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA Program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities. NAWQA results can contribute to informed decisions that result in practical and effective water-resource management and strategies that protect and restore water quality.

Since 1991, the NAWQA Program has implemented interdisciplinary assessments in more than 50 of the Nation's most important river basins and aquifers, referred to as Study Units. (http://water.usgs.gov/nawqa/nawqamap.html). Collectively, these Study Units account for more than 60 percent of the overall water use and population served by public water supply, and are representative of the Nation's major hydrologic landscapes, priority ecological resources, and agricultural, urban, and natural sources of contamination.

Each assessment is guided by a nationally consistent study design and methods of sampling and analysis. The assessments thereby build local knowledge about water-quality issues and trends in a particular stream or aquifer while providing an understanding of how and why water quality varies regionally and nationally. The consistent, multi-scale approach helps to determine if certain types of water-quality issues are isolated or pervasive, and allows direct comparisons of how human activities and natural processes affect water quality and ecological health in the Nation's diverse geographic and environmental settings. Comprehensive assessments on pesticides, nutrients, volatile organic compounds, trace metals, and aquatic ecology are developed at the national scale through comparative analysis of the Study-Unit findings. (http://water.usgs.gov/nawqa/natsyn.html).

The USGS places high value on the communication and dissemination of credible, timely, and relevant science so that the most recent and available knowledge about water resources can be applied in management and policy decisions. We hope this NAWQA publication will provide you the needed insights and information to meet your needs, and thereby foster increased awareness and involvement in the protection and restoration of our Nation's waters.

The NAWQA Program recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The Program, therefore, depends extensively on the advice, cooperation, and information from other Federal, State, interstate, Tribal, and local agencies, non-government organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.



Robert M. Hirsch
Associate Director for Water

CONTENTS

Figures

Tables

CONVERSION FACTORS AND DATUMS

Multiply	By	To obtain
acre	4,047	square meter
acre	0.4047	hectare
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
yard (yd)	0.9144	meter
square foot (ft^2)	0.09290	square meter
square mile (mi^2)	2.590	square kilometer

Datums

Vertical coordinate information is referenced relative to mean sea level.
Horizontal coordinate information is referenced relative to the North American Datum of 1983 (NAD83).

Land Use on the Island of Oahu, Hawaii, 1998

By Frederick L. Klasner and Clinton D. Mikami

Abstract

A hierarchical land-use classification system for Hawaii was developed and land use on the island of Oahu was mapped in support of the U.S. Geological Survey National Water-Quality Assessment Program. The land-use classification system emphasizes agriculture, developed (urban), and barren/mining uses. Areas with other land uses (conservation, forest reserve, natural areas, wetlands, water, and barren [sand, rock, or soil] regions, and unmanaged vegetation [native or exotic]) were defined as "other." Multiple sources of digital orthophotographs from 1998 and 1999 were used as source data. The 1998 island of Oahu land-use data are provided in digital format at http://water.usgs.gov/lookup/getspatial?oahu_lu98 for use in a Geographic Information System (GIS), at 1:24,000-scale with minimum mapping units of 2 hectares (4.9 acres) area and 30-meters (98.4 feet) feature width.

In 1998, a total of 59,195 acres (15.4 percent) of the island of Oahu were classified as agricultural land use; 98,663 acres (25.7 percent) were classified as developed; 1,522 acres (0.4 percent) were classified as barren/mining; and 224,331 acres (58.5 percent) were classified as other. An accuracy assessment identified 98 percent accuracy for all land-use classes. In windward (moister) areas, dense vegetation and canopy cover along with rapid recolonization by vegetation potentially obscured land use from photo-interpretation. While in leeward (drier) areas, sparse vegetative cover and slower vegetation recolonization may have resulted in more frequent recognition of apparent land-use patterns.

INTRODUCTION

The U.S. Geological Survey (USGS) National Water-Quality Assessment program (NAWQA) was designed to evaluate the status and trends in the quality of the island of Oahu's ground- and surface-water resources. Land use is one of the most influential human activities affecting water quality and natural resources in Hawaii. Land use affects the quality of water through modification of drainage and infiltration patterns, modification of vegetative cover, and the addition of physical and chemical compounds. Knowledge of land-use spatial patterns and change is necessary information for natural and cultural resource management. For example, soil and agricultural resource management require inventory and monitoring of land resources as identified in land-use maps; water-quality conditions can be compared between watersheds with similar or different land uses; and planning for future agriculture and development activities requires data on existing land use, trends, and resource availability. In Hawaii, there are a range of use intensities and great variability in the scale (areal extent) of these uses. Patterns of land use reflect multiple influences, including land ownership, available water resources, soil type, and economic opportunity. A description of land use during 1998 provides a reference for describing the dynamic nature of land use and its influence on resources of the island of Oahu.

Hawaii's landscape provides a background for juxtapositions and contrasts in land use. For example, traditional, subsistence agriculture can be found immediately adjacent to industrial areas and resort tourist destinations. And because of Hawaii's tropical location centered in the Pacific Ocean, many land-use practices are specialized, such as hybrid seed-corn research with a 3 to 4 crop per year rotation and ginger root cultivation by land lease-holders with an approximately 5-year return interval to minimize nematode infestation. Recently, land use has changed rapidly and

dramatically in Hawaii—evident in the expansion of urban and suburban development and the growth of diversified agriculture—with many of these changes occurring on former sugar and pineapple plantations.

Purpose and Scope

The purpose of this report is to describe a hierarchical land-use classification system and land use during 1998 mapped on the island of Oahu. This report and accompanying data set provide a generalized map of land use on the island of Oahu, including developed (sometimes referred to as urban) and agricultural areas, as well as barren areas resulting from mining or similar resource extraction. The land uses identified and mapped from 1998 and 1999 digital orthophotographs (DOQs) document land-use patterns through photointerpretation. These results may differ from the actual land use.

Appropriate product use. There are a wide variety of appropriate uses for this product, including research, comparative land-use and land-cover analyses, and identification of generalized urban and suburban development or agricultural practices (including identification of land-use change and urban encroachment upon agricultural or coastal areas). Although the State tax map key and zoning designations are sometimes referred to as "land use" in Hawaii, the land use identified and delineated in this report reflects the classification system described. No effort was made to identify or delineate along legal or other boundaries. Accordingly, appropriate use of this product is best limited to applications where remotely sensed imagery is needed for identifying land use restricted to agriculture, developed, and barren/mining areas. The land-use map is intended for use at 1:24,000-scale or smaller.

This product can be used in conjunction with other natural and cultural resource investigations to form a more comprehensive picture of land use and land cover in Hawaii. The Hawaii Natural Heritage Program and the National Oceanic and Atmospheric Administration (NOAA), among others, are identifying and delineating what is here defined as "other" land-use and land-cover types (conservation, forest reserve, natural areas, and naturally or non-maintained barren, wetlands, forested, shrubland, or herbaceous cover types, see appendix A). Developed, agricultural, barren, and other land uses also were mapped using similar techniques during the late 1970s (U.S. Geological Survey, 1979). This and other previous investigations provide comparable reference materials for investigating land-use change.

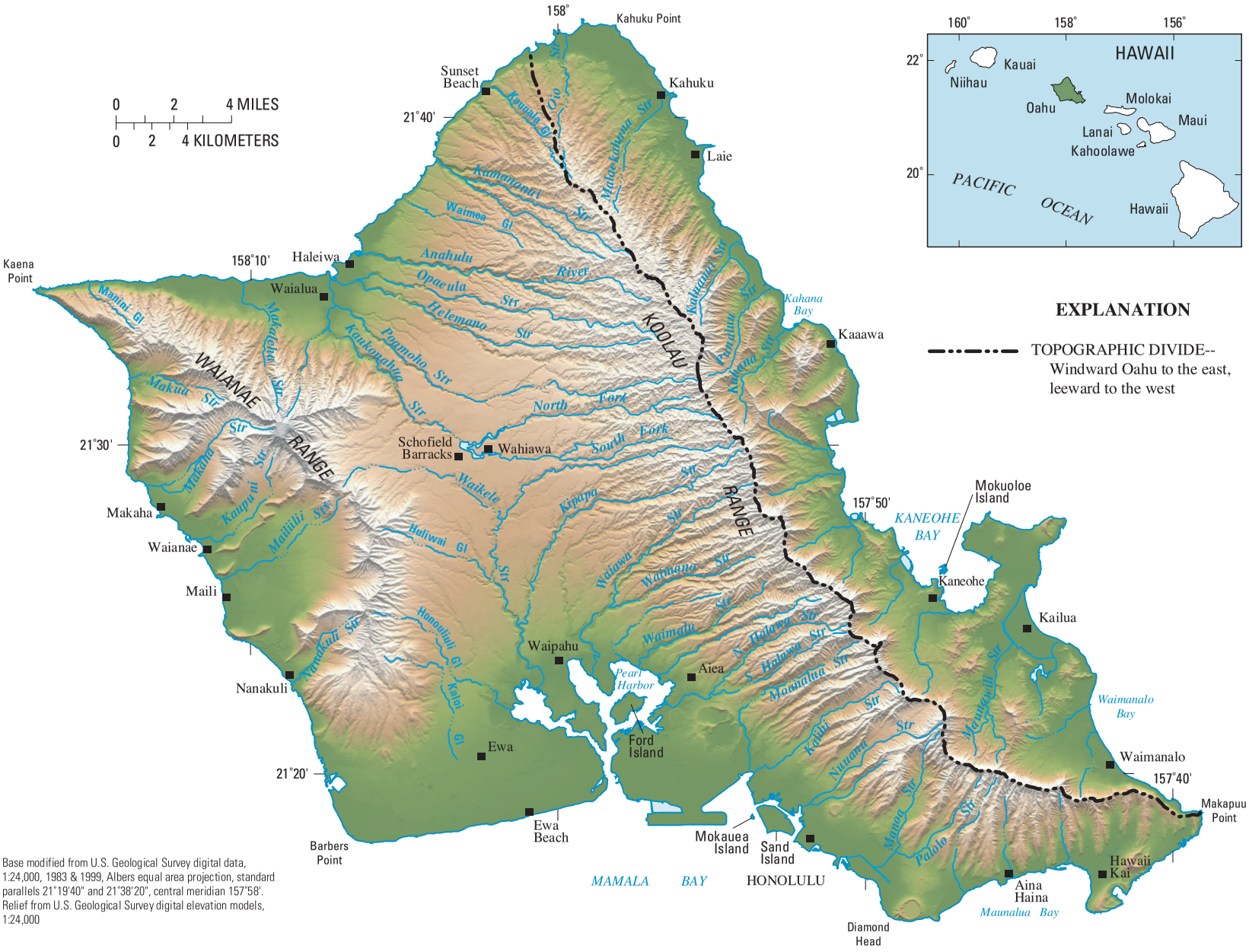
Previous Investigations

The USGS described land use in Hawaii as early as the 1880s (Dutton, 1884). The USGS GIRAS (Geographic Information and Analysis System) protocol for collecting land-use and land-cover data (Mitchell and others, 1977) was applied on Oahu and throughout Hawaii (U.S. Geological Survey, 1979; U.S. Geological Survey, 1980), using the land-use and land-cover classification system established by Anderson and others (1976).

Hawaiian land divisions are described by Chinen (1958), with assignment of land ownership in the 1840s "Great Mahele" providing a common reference point for identifying early land ownership, land use, and land-use change in the Hawaiian Islands (see Moffat and Fitzpatrick, 1995). The Hawaiian Government Survey from the late 1800s provides one of the first detailed, comprehensive, and consistent land maps of the main Hawaiian islands. Territorial Planning Board reports for Hawaii provide a general perspective on land use for the first half of the 1900s (see for example, Territorial Planning Board, 1939). The U.S. Department of Agriculture, University of Hawaii, and State of Hawaii, Department of Agriculture produced a variety of reports and maps for documentation and planning purposes, such as "Agricultural Land-Use Planning in the Territory of Hawaii, 1940" (Coulter, 1940) and "Detailed Land Classification - Island of Oahu" (Sahara and others, 1972). The "Inventory of Available Information on Land Use in Hawaii" (Harland Bartholomew and Associates, 1957) and the University of Hawaii, Land Study Bureau's (1971) annotated bibliography provide summaries of available land-use products for the State of Hawaii.

Description of the Study Area

The study area encompasses the entire island of Oahu and populated islets, using the shoreline identified in the 1999, 1:24,000-scale National Hydrography Dataset. Oahu consists of the eroded remnants of two volcanic mountain ranges, the Waianae Range and the Koolau Range (fig. 1). Weathering, erosion, and slope failure have modified the original domed surfaces of the



Base modified from U.S. Geological Survey digital data, 1:24,000, 1983 & 1999, Albers equal area projection, standard parallels 21°19'40" and 21°38'20", central meridian 157°58'. Relief from U.S. Geological Survey digital elevation models, 1:24,000

Figure 1. Study area with generalized topography and geographic features, island of Oahu, Hawaii.

volcanoes, dissecting the east and west parts of the island into a landscape of deep valleys and steep ridges. A gently sloping saddle lies between the two mountain ranges, although 45 percent of the land area has a slope 20 percent or greater (State of Hawaii, 1999). A coastal plain surrounds much of the island. The subtropical climate of Oahu is characterized by mild temperatures, moderate humidity, prevailing northeasterly tradewinds, and extreme variation in rainfall over short distances, with rainfall regimes divided into windward (moist catchments) and leeward (dry rain shadows) areas.

Honolulu, one of the 25 largest cities in the Nation, is located in southeastern Oahu. The resident population of Oahu, which has more than doubled since 1950, was about 876,000 in 2000. The actual population, which includes an average number of visitors to the island at any time, was about 923,400 in 1998. The State of Hawaii zoning classification for land use on Oahu in 1999 was about 40 percent conservation, 34 percent agriculture, and 26 percent urban (State of Hawaii, 1999). The principal industry is tourism, followed by military activities and agriculture. Major land use changes are occurring in central Oahu. During the past several decades, plantation agriculture, primarily sugarcane and pineapple, which dominated for approximately 100 years, has declined and in its place has been an incursion of suburban development and a shift to diversified agriculture, including flowers, vegetables, fruits, and aquaculture.

Acknowledgements

Staff at numerous State and Federal agencies provided invaluable assistance and guidance. The Natural Resources Conservation Service (NRCS) provided agriculture land-use data, assistance establishing the classification system, and reviewed the land uses mapped. The NOAA, Coastal Change Analysis Program (C-CAP) shared data resources. The U.S. Fish and Wildlife Service (USFWS) provided assistance establishing the classification system. The State of Hawaii Department of Agriculture and City and County of Honolulu reviewed mapped land uses. Numerous private land owners also provided cooperation and assistance.

METHODS OF DATA COMPILATION AND CLASSIFICATION

The land-use classification system and map draw on existing USGS, NRCS, and NOAA C-CAP land-use mapping guidelines and recommendations. These existing methodologies and classifications systems were adapted to better reflect land use in Hawaii. These adaptations, essentially selections among existing methodologies, emphasized consistent use of data sources, establishment of a hierarchical classification system, repeatable land-use identification and delineation techniques, field verification, accuracy assessment, and documentation.

Classification System

"National Land Cover Data - Land Cover Class Definitions" (U.S. Geological Survey, 2001) were customized to better represent tropical Pacific island land uses. Five primary criteria governed the modification of existing land-use classification systems (see Gilliom and Thelin, 1997): (1) relevance to existing land-use management practices, (2) scale of the classification system appropriate for the scale of analysis and collapsible to more general classification systems, (3) transferable to smaller scales and to remote sensing source data of differing scales, (4) criteria for defining categories are stable over time, (5) classification system is practicable and applicable to other areas—particularly other Hawaiian and Pacific islands. This classification system emphasizes human use of land, in general categories of agriculture, developed, and barren/mining. This classification system was not structured for other land uses (defined by land-cover type as water, barren, wetland, forest, shrubland, or herbaceous, see appendix A).

In addition to the National Land Cover Data class definitions, other land-use mapping reports were used to refine the classification system (table 1, at end of report), including: the Middle Rio Grande Basin study (Mladinich, 1999), NOAA C-CAP protocols (Dobson and others, 1995), and Anderson and others (1976). Koterba's (1998) and Gilliom and Thelin's (1997) classification systems were adapted to address agriculture and water-quality concerns. Agriculture categories were refined with local NRCS staff, integrating plant morphology, spatial arrangement of fields, and crop types as defined by the State of Hawaii (Hawaii Agriculture Statistics Service, 1999). Developed categories

were refined by Oahu NAWQA Study Unit staff, emphasizing typical development patterns in Hawaii. The classification structure indicates the primary land use interpreted from the source data. For example, combined commercial-residential properties are classified according to the majority use.

Agriculture, military, and tourism activity in Hawaii required special attention when classifying land use. For example, diversified agriculture development and promotion programs have resulted in areas with diverse agriculture practices intermixed with residential land uses. Military land uses such as offices, residences, ammunition storage bunkers, communications infrastructure, and other military equipment occupy a significant portion of land on Oahu. These uses are identified as developed, and are segregated by the type and density of development, as opposed to land ownership. Military target and bombing ranges in a natural or semi-natural state are not treated as agriculture or developed land uses.

The hierarchical classification system provides generalized, less precise identification of land use at level 1 or level 2. More precise identification of land use is described in level 3 or level 4. Uncertainty or generalization in land-use identification is indicated by the use of only generalized categories; for example, where the type of orchard crop could not be identified, the land use is Agriculture (level 1), Planted/cultivated (level 2), Orchard (level 3), and no crop specific identifier (level 4) is provided. Definitions of land-use levels 1 through 4 for agricultural and developed categories and levels 1 and 2 for barren/mining categories are in table 1.

Source Data

Multiple sources of data were used to identify land use, primarily 1-m (3.3 ft) ground resolution black-and-white DOQs, from 1998 and 1999 (U.S. Geological Survey, 1996). Five meter (16.4 ft) ground resolution color infrared digital orthophotos and non-georectified, true color photographs (1:24,000 nominal scale) also were used. Ancillary sources, including USGS 7.5 minute topographic quadrangle maps, the City and County of Honolulu's parcel and zoning information database, local road guides, and field observations in March and April 2001 augmented the base data.

Identification and Delineation of Land Use

Land use was identified and delineated through photo-interpretation of DOQs. Recognition elements (observable characteristics) interpreted from the image data included shape, size, pattern, shadow, tone, texture, association, and site (Avery and Berlin, 1985). Photo-interpretation was completed on computer workstations using ESRI's (Environmental Systems Research Institute) ArcView GIS (version 3.2) software. The DOQ data was displayed in its original datum and projection (Universal Transverse Mercator [UTM] zone 4 projection, North American Datum 1983 [NAD83]). The shoreline identified, the seaward limit of SEA/OCEAN (the approximate line of mean high water) from 1999, 1:24,000-scale National Hydrography Dataset for Oahu, determined the spatial extent of land use.

Minimum mapping units of 2.0 ha (4.9 acres) and a minimum polygon width of 30 m (98.4 ft) were used. Areas (slivers) that did not meet these minimum criteria were evaluated individually and absorbed into the adjacent polygon as appropriate. Some map-worthy ground features were slightly exaggerated or generalized in area or width to meet the minimum size requirements (see Mladinich, 1999). Some features too small to be collected were collapsed into a single feature. The data was interpreted and compiled in blocks of USGS 7.5-minute topographic quadrangles. Quadrangle land-use data was edge-matched and paneled together in a seamless unit. All polygons contain one label point, are closed, and adjacent polygons do not have identical attributes.

Agriculture, developed, and barren/mining land uses were identified according to the classification system. Other areas (water, wetland, forest, shrubland, and herbaceous land uses, appendix A) were identified as "other." The areal extent of each land use was delineated to the most detailed possible category in the classification system—a more general category was used when land use could not be identified to the more detailed category. Ancillary data sources were used to help in interpretation.

Field Verification and Adjustments

Land-use data interpretations were verified through field checking. All areas where photo-interpreters noted uncertainty in the classification were visited. Land-use identification, boundary delineation,

and adjacent polygon(s) identifications were verified at regularly spaced point locations (2-km [1.2 mi] intervals, at a total of 385 locations). Also, a minimum of one field validation plot was located in each land-use category found in each USGS 7.5 minute quadrangle. Expert assessments were also made, with NRCS field staff identifying local agricultural land uses. Collaborators, including the U.S. Fish and Wildlife Service and the State of Hawaii Department of Agriculture, helped ensure that remote developed areas were not overlooked. NOAA C-CAP land-cover data were used for verification. On the basis of these procedures, adjustments were made to polygon boundaries and land-use categories.

Accuracy Assessment

Accuracy of mapped land use was evaluated using randomly generated locations, stratified by level 1 land use. Within a total of 250 2-ha (4.9 acres) circular polygons, the accuracy of the mapped land use was assessed and the boundaries of adjacent land-use polygons verified. Of these 250 accuracy assessment locations, one-fifth (50) were within areas where land use was classified as "other" (level 1), two-fifths (100) of the samples were within areas classified as agriculture (level 1), and the remaining two-fifths (100) were within areas classified as developed or barren/mining (level 1). Accuracy was assessed through review of image data sources for each location. Land use was considered accurate if the same land-use attributes and boundaries were photo-interpreted during the accuracy assessment. Ancillary data sources were used when original image data sources did not provide adequate detail. If uncertainty remained regarding land use after the accuracy assessment, site visits were made to the location.

LAND USE

The hierarchical land-use classification system emphasized human use and land surface modification interpreted from digital aerial photographs. The categories presented reflect land use on Oahu. Other Pacific islands may include additional land uses; for example, orchard crops such as lychee (*Litchi* spp.) are present on the island of Hawaii, but were not found on Oahu in areas large enough to meet the minimum mapping unit criteria. Also, agriculture practices may evolve such that a plant currently cultivated only as horticulture may some day also be grown as a row crop. Additional land-use studies would likely need to add categories to the hierarchical classification to address such changes.

Land use was identified, in the most general categories, as agriculture, developed, barren/mining, and other. While not intended to be exclusive, these generalized categories required interpretive decisions, such as where small-scale farms were mixed with residential areas. Similar decisions were made at more detailed levels of the classification system.

The total land area studied for this report was 383,711 acres: 382,711 acres on the island of Oahu, 455 acres on Ford Island, 514 acres on Sand Island, 8 acres on Mokauea Island (near Sand Island), and 23 acres on Mokuoloe Island (also known as Coconut Island) (fig. 2).

Map Accuracy

The land uses mapped are a generalization of conditions observed in photographs. These data may not reflect ground conditions actually present at the site. Land use was interpreted from DOQ data and boundaries may cross natural or artificial features (such as streams or roads) to encompass an entire area where a pattern was interpreted as existing. Additionally, boundaries between distinct land uses must incorporate a natural or artificial feature where the width or area of the intervening feature does not meet the minimum mapping unit requirements. Thus, line work may not always match other digital data, such as land ownership, roads, or streams (see Mladinich, 1999).

An accuracy assessment, repeating the photo-interpretation of land use at 250 randomly selected locations, identified 98 percent accuracy for all land uses. Developed and barren/mining areas combined had a 98 percent accuracy rate, while agricultural areas also had a 98 percent accuracy rate. No "other" areas identified in the accuracy assessment should have been classified as agricultural, developed, or barren/mining.

Accuracy for windward areas of the island was 100 percent, where under-representation errors were more likely to fail to identify developed, agricultural, or barren/mining land use in areas of dense canopy or vegetative cover. Accuracy in dry, leeward areas of the island was 98 percent, where over-representation errors more likely identified unused land as developed, agricultural, or barren/mining when it should not have

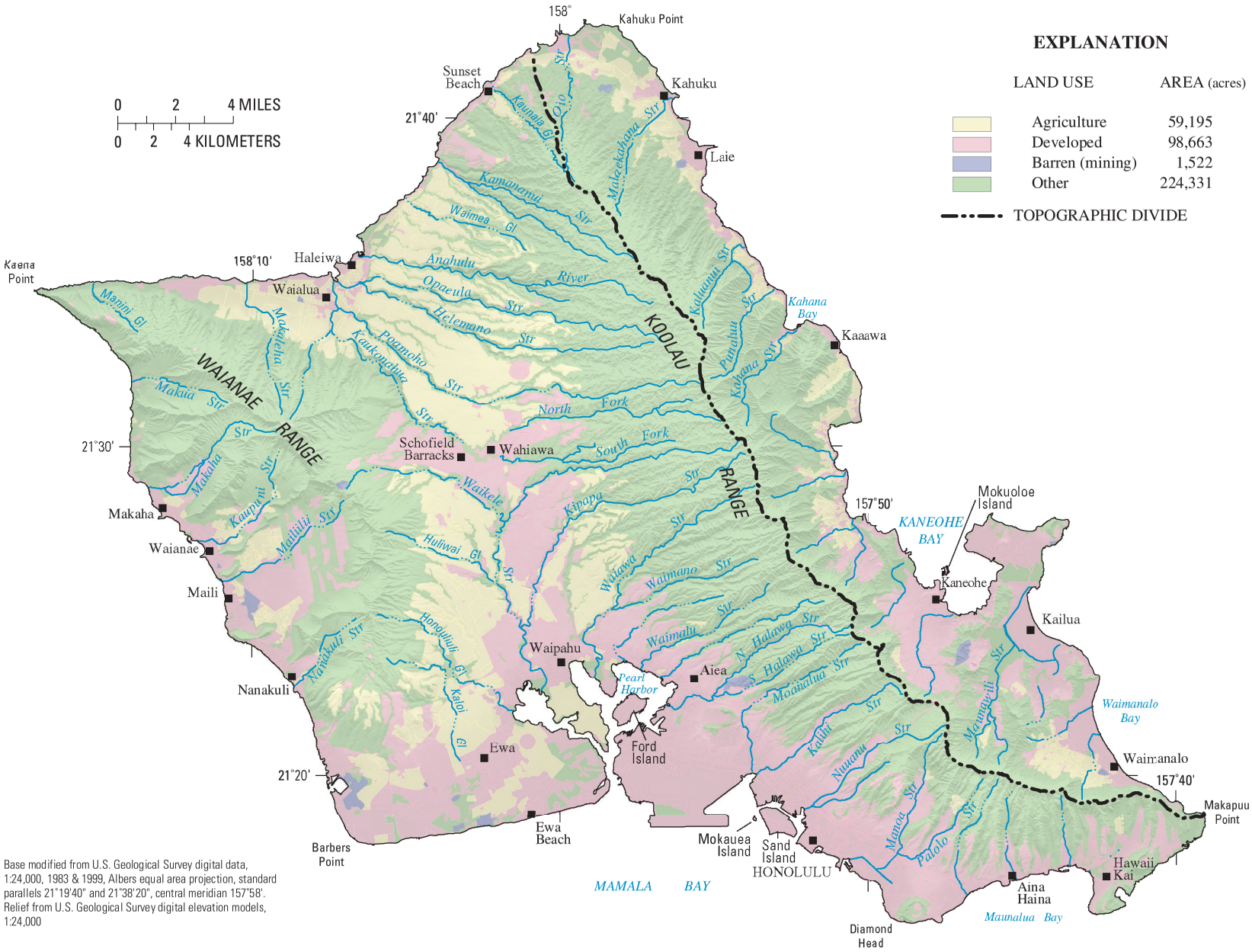


Figure 2. Level 1 land use in 1998: agriculture, developed, and barren/mining, island of Oahu, Hawaii.

been because of sparser vegetation and slower vegetation recolonization rates.

Agricultural Land Use

Hawaii's isolated, tropical location combined with traditional, diversified, and plantation agriculture has resulted in several unusual land-use patterns compared with the rest of the Nation. The "small-scale rural" (level 2) category is a by-product of diversified agriculture programs resulting in areas with intense and diverse agriculture practices intermixed with residential land uses. The State of Hawaii "Agricultural Parks Program" provides an example of how this process occurs, with long-term leases for crop production (and sometimes residences) provided to small farmers (http://www.hawaiiag.org/hdoa/arm_agparks_info.htm accessed 7/11/02). Another unusual category is "grasses, biomass" (level 3, level 4), an experimental bio-energy crop in the early 1990s no longer in cultivation as of 2002. A third unusual agricultural land-use category is "abandoned," typically dominated by exotic grasses, with clear evidence of previous agricultural practices still apparent. Plantation agriculture in Hawaii has been declining for several decades, with much sugarcane and pineapple land abandoned during this time. Cycles in horticulture and aquaculture industries have also resulted in abandoned agricultural land.

Agricultural land use occupied 59,195 acres (15.4 percent) of the study area in 1998 (fig. 3). Acreages for levels 1 through 4 land-use categories are found in table 2 (at end of report).

Developed Land Use

Several facets of developed land-use patterns are unusual to Hawaii, particularly in regards to the intensity and variability of uses, all with political, economic, and cultural influences. Tourist destinations commonly intermix a variety of use types within a single area (such as multi-story resorts, adjacent to golf courses, adjacent to landfills). Local concepts such as "ohana" (extended family) housing in a single family residence are incorporated through residential density classifications rather than a distinction between single versus multi-family housing. Land areas with combined or interspersed businesses and residences are classified according to the primary use evident in the imagery, as commercial or residential. Military land uses occupy a significant percentage of land in Hawaii and these uses also are segregated by the density of development. Military ammunition storage bunkers, communications, or other equipment may be disguised to prevent accurate identification from aerial photography sources, which may be reflected in this land-use map.

Developed land use occupied 98,663 acres (25.7 percent) of the study area in 1998 (fig. 4). Acreages for levels 1 through 4 land-use categories are found in table 2.

Barren Land Use

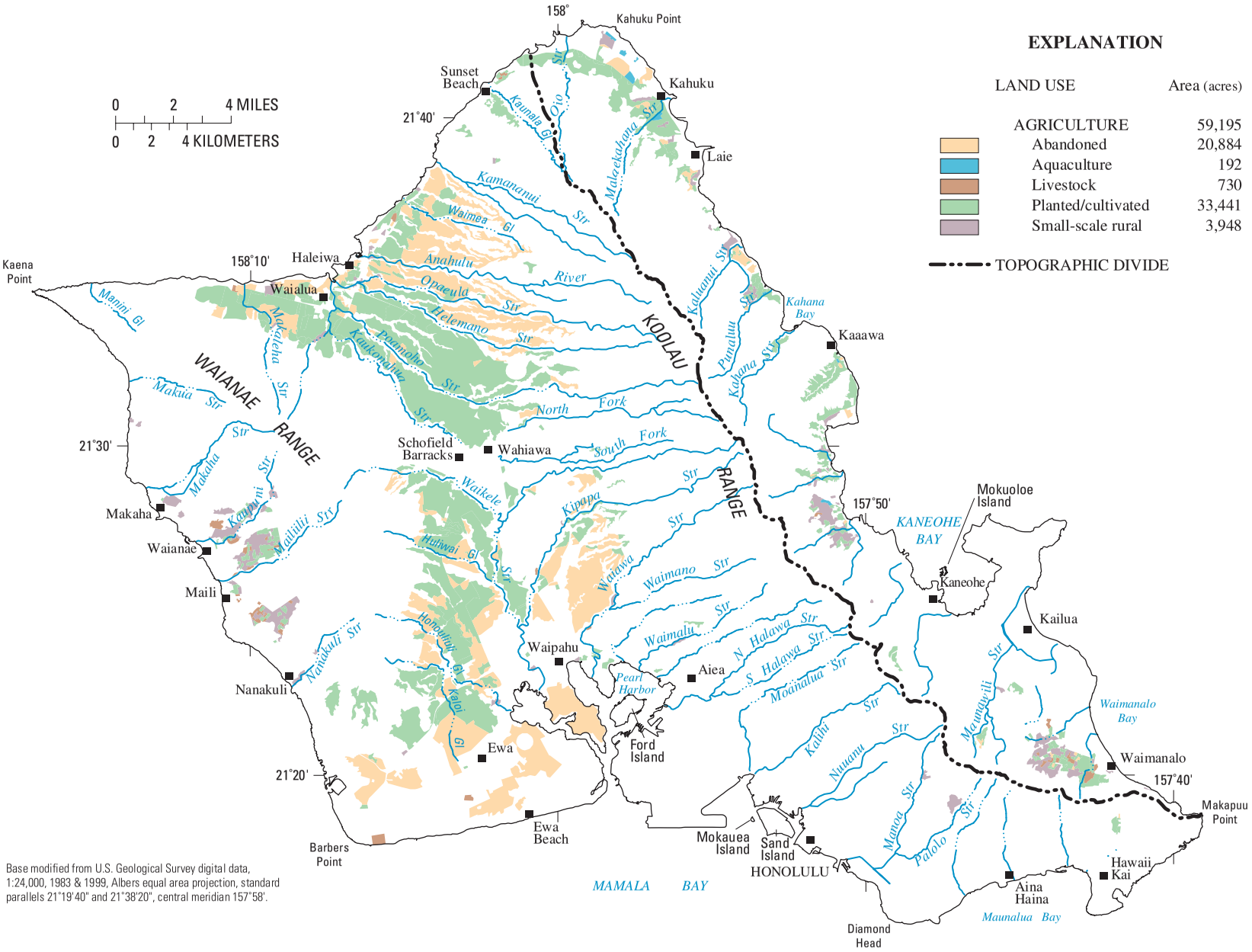
In the barren land-use category, only land use in the level 2 mining category was identified. Hawaii has very little mining or extractive activity, other than extraction, collection, and storage of aggregate and fill materials such as soil, sand, gravel, rock, and dredge spoils. Other barren sub-categories are included as "other" land uses.

Barren/mining land use occupied 1,522 acres (0.4 percent) of the study area in 1998 (fig. 5). Acreages for levels 1 through 4 land-use categories are found in table 2.

Other Land Use

Land uses other than agriculture, developed, and barren/mining were identified as "other" in the photo-interpretation process. These other land uses, described in appendix A on the basis of land cover, include water, barren (other than mining), wetland, forest, shrubland, and herbaceous. The methods used, including the accuracy assessment, verified the appropriate land-use designations assigned for the entire island, including these areas, and no unique concerns for these land uses were identified beyond what was previously discussed.

Other land use occupied 224,331 acres (58.5 percent) of the study area in 1998 (fig. 2).



Base modified from U.S. Geological Survey digital data, 1:24,000, 1983 & 1999, Albers equal area projection, standard parallels 21°19'40" and 21°38'20", central meridian 157°58'.

Figure 3. Level 2 agriculture land use in 1998, island of Oahu, Hawaii.

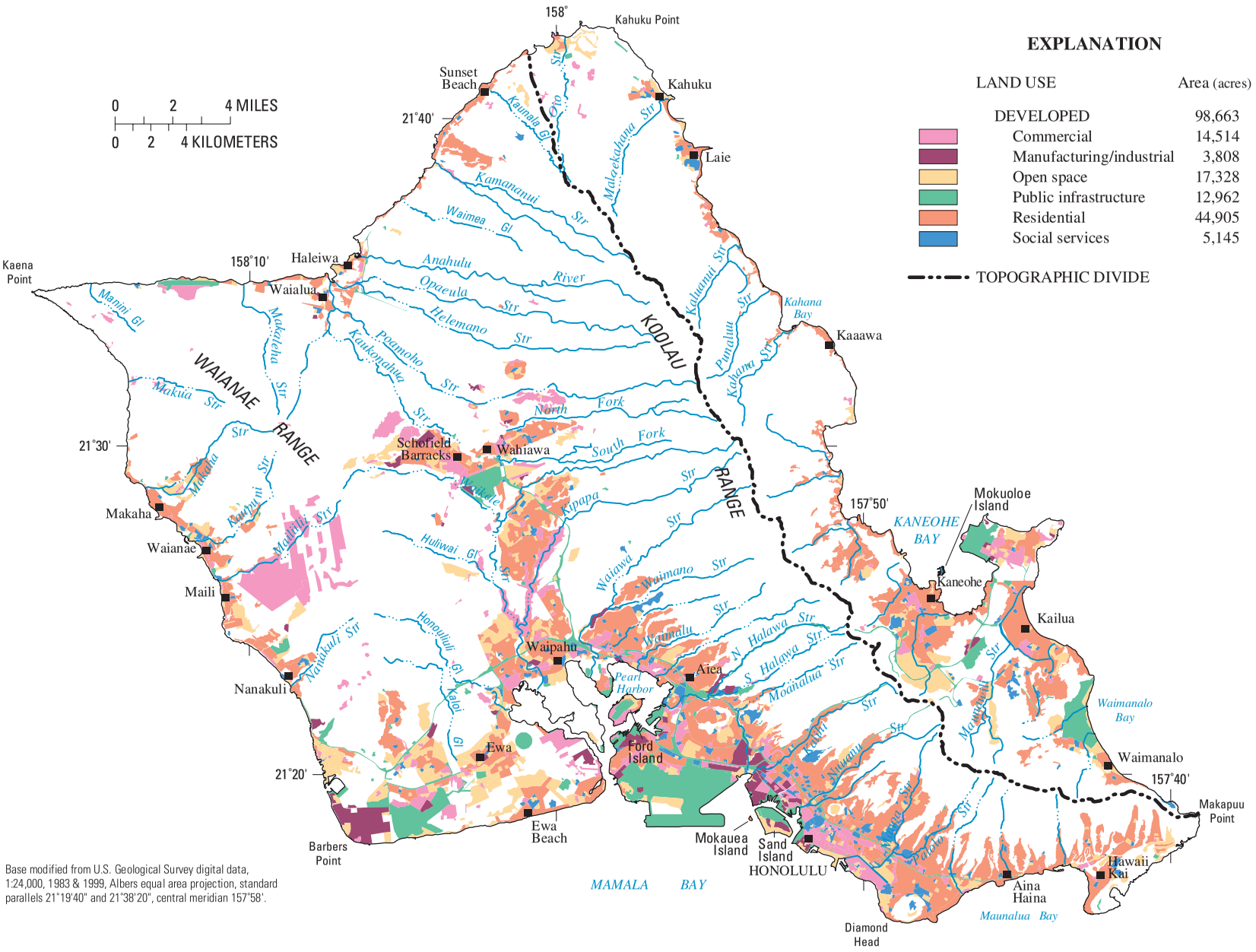
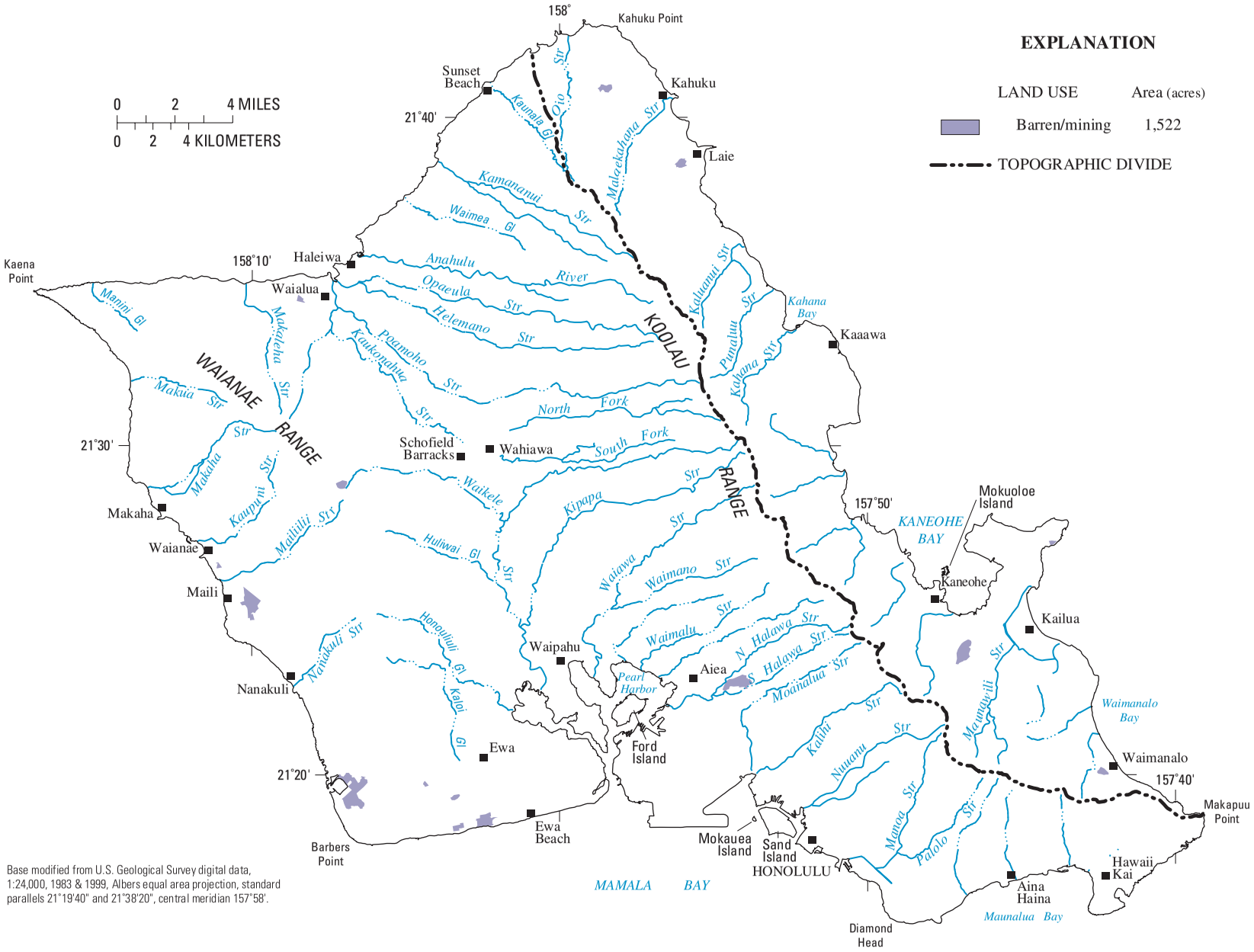


Figure 4. Level 2 developed land use in 1998, island of Oahu, Hawaii.



Base modified from U.S. Geological Survey digital data, 1:24,000, 1983 & 1999, Albers equal area projection, standard parallels 21°19'40" and 21°38'20", central meridian 157°58'.

Figure 5. Level 2 barren/mining land use in 1998, island of Oahu, Hawaii.

SUMMARY AND CONCLUSIONS

A hierarchical classification for identifying and mapping land use (for use throughout the State of Hawaii) was developed emphasizing human modification of land surfaces.

Agricultural, developed, and barren/mining land use on the island of Oahu and adjacent islets was mapped using DOQs from 1998 and 1999. In 1998, agriculture land use occupied 59,195 acres (15.4 percent of total study area), developed land use occupied 98,663 acres (25.7 percent of total study area), barren/mining land use occupied 1,522 acres (0.4 percent of total island area). Other land uses occupied 224,331 acres of total study area of 383,711 acres (58.5 percent). An accuracy assessment of the spatial data (98 percent accuracy for all land uses) permits users to quantify variability when making land use comparisons.

Oahu land-use data and FGDC metadata for 1998 for this report are available at http://water.usgs.gov/pubs/wri/wri024301, for use in a Geographic Information System (GIS) accepting Federal Geographic Data Committee (FGDC) Spatial Data Transfer Standard (SDTS) or ArcInfo Export file (version 8.0.2) formats.

REFERENCES CITED

Anderson, J.R, Hardy, E.E., Roach, J.T., and Witmer, R.E., 1976, A land use and land cover classification system for use with remote sensor data: U.S. Geological Survey Professional Paper 964, 28 p.

Avery, T.E., and Berlin, G.L., 1985, Fundamentals of remote sensing and airphoto interpretation, 5th edition: Upper Saddle River, New Jersey, Prentice-Hall, Inc., 472 p.

Chinen, J.J., 1958, The Great Mahele: Hawaii's land division of 1848: Honolulu, Hawaii, University of Hawaii Press, 34 p.

Cowardin, L.M., Carter, V., Golet, F.C., and LaRoe, E.T., 1979, Classification of wetlands and deepwater habitats of the United States: Fish and Wildlife Service, U.S. Department of the Interior, Washington, D.C., 49 p.

Coulter, J.W., 1940, Agricultural land-use planning in the territory of Hawaii, 1940, Extension Bulletin No. 36: Honolulu, Hawaii, Agricultural Extension Service, University of Hawaii, 124 p.

Dobson, J.E., Bright, E.A., Ferguson, R.L., Field, D.W., Wood, L.L., Haddad, K.D., Iredale III, H., Jensen, J.R., Klemas, V.V., Orth, R.J., and Thomas, J.P., 1995, NOAA coastal change analysis program (C-CAP): guidance for regional implementation: Department of Commerce, NOAA Technical Report NMFS 123, 75 p.

Dutton, C.E., 1884, Hawaiian volcanoes: *in* Powell, J.W., 1884, Fourth annual report of the United States Geological Survey to the Secretary of Interior 1882–'83: Washington, Government Printing Office, p. 75–219.

Gilliom, R.J., and Thelin, G.P., 1997, Classification and mapping of agricultural land for national water quality assessment: U.S. Geological Survey Circular 1131, 70 p.

Harland Bartholomew and Associates, 1957, An inventory of available information on land use in Hawaii: volume 2: Annotated bibliography and summary of interviews: Honolulu, Hawaii, Harland Bartholomew and Associates, 134 p.

Hawaii Agricultural Statistics Service, 1999, Statistics of Hawaii agriculture, 1999: Honolulu, Hawaii, Hawaii Agricultural Statistics Service.

Koterba, M.T., 1998, Ground-water data-collection protocols and procedures for the national water-quality assessment program: Collection, documentation, and compilation of required site, well, subsurface, and landscape data for wells: U.S. Geological Survey Water-Resources Investigations Report 98-4107, 91 p.

Land Study Bureau, 1971, Annotated bibliography of reports and other land fact data: Honolulu, Hawaii, University of Hawaii, 11 p.

Mitchell, W.B., Guptill, S.C., Anderson, K.E., Fegeas, R.G, and Hallam, C.A., 1977, GIRAS—A Geographic Information and Analysis System for handling land use and land cover data: U.S. Geological Survey Professional Paper 1059, 16 p.

Mladinich, C.S., 1999, COVERAGE LU90—High resolution land use/land cover 1996/1997 Front Range infrastructure resources project demonstration area: U.S. Geological Survey Rocky Mountain Mapping Center, http://rockyweb.cr.usgs.gov/html/front-range/NMD/data/lu90.html (accessed July 11, 2002).

Moffat, R.M., and Fitzpatrick, G.L., 1995, Surveying the mahele: mapping the Hawaiian land revolution: Honolulu, Hawaii, Editions Limited, 120 p.

Sahara, T., Murabayashi, E.T., Ching, A.Y., DeVight, G.D., Fujimura, F.N., Awai, E.L., Nishimoto, L.S., Baker, H.L., 1972, Detailed land classification - island of Oahu, Land Study Bureau Bulletin No. 11: Honolulu, Hawaii, Land Study Bureau, University of Hawaii, 314 p.

State of Hawaii, 1999, The State of Hawaii data book 1999, a statistical abstract: v32, State of Hawaii Department of Business, Economic Development and Tourism, http://www.hawaii.gov/dbedt/db99/index.html (accessed July 11, 2002).

Territorial Planning Board, 1939, First progress report–an historic inventory of the physical, social and economic and industrial resources of the Territory of Hawaii:

Honolulu, Hawaii, Advertiser Publishing Co., 322 p. + supplement.

U.S. Geological Survey, 1979, Land use and land cover and associated maps for Honolulu County, Hawaii: U.S. Geological Survey Open-File Report 79-572, 5 map sheets 1:100,000-scale.

U.S. Geological Survey, 1980, Land use and land cover, 1976–78, Honolulu county, Hawaii: U.S. Geological Survey Report L-0122, 1 map sheet 1:100,000-scale.

U.S. Geological Survey, 1996, Standards for digital orthophotos: U.S. Geological Survey, National Mapping Program, Technical Instructions, 46 p.

U.S. Geological Survey, 2001, National land characterization data, land cover class definitions: U.S. Geological Survey, http://landcover.usgs.gov/classes.html.

Appendix A. Generic land-use and land-cover classification system framework

[Modified from Anderson and others, 1976, Cowardin and others, 1979, and U.S. Geological Survey, 2001]

Level 1	Description
Agriculture	Areas characterized by human modification used in connection with planting, growing, and harvesting crops; and raising, pasturing, and feeding of livestock and poultry. Includes herbaceous vegetation planted or cultivated for production of food, feed, seed, or fiber; fish farms; feedlots; holding pens; breeding and training facilities; and greenhouses. This land-use category takes precedence over other land-use categories except for developed.
Developed	Areas characterized by a high percentage of modification by and for human use, such as where the land-surface is covered by structures, prepared materials, or otherwise urban. Does not include areas used for agriculture or barren (such as from surface mining). This land-use category takes precedence over other land-use categories, except for agriculture.
Barren	Areas characterized by rock, gravel, sand, silt, clay, or other earthen material, not covered by water, with less than 25 percent vegetative cover or less than 5 percent vegetative cover in arid areas. (Not differentiated except to identify mining surfaces).
[a]Water	All areas of open water or permanent ice or snow cover.
[a]Wetland	Areas where the soil or substrate is periodically saturated with or covered with water (as defined by Cowardin and others, 1979).
[a]Forest	Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall), tree canopy accounts for 25–100 percent of land cover.
[a]Shrubland	Areas characterized by natural or semi-natural woody vegetation with aerial stems, generally less than 6 meters tall, covers 25–100 percent of land. Vegetation that is small or stunted because of environmental conditions is included.
[a]Herbaceous	Natural or semi-natural herbaceous vegetation is 75–100 percent of land cover.

[a]Identified as “other”

Table 1. Land-use classification system and definitions

Level 1	Level 2	Level 3	Level 4	Land-use codes	Definition
Agriculture				a	Areas characterized by human modification used in connection with planting, growing, and harvesting crops; and raising, pasturing, and feeding of livestock and poultry. Includes herbaceous vegetation planted or cultivated for production of food, feed, seed, or fiber; fish farms; feedlots; holding pens; breeding and training facilities; and greenhouses. This land-use category takes precedence over other land-use categories except for developed.
	Planted/ cultivated			ap	Areas characterized by vegetation planted or cultivated by humans for production of food, feed, fiber, pasture, seed, or ornamental plant products.
		Orchard		ap-o	Areas with woody or semi-perennial herbaceous vegetation planted or maintained for production of fruits, nuts, or other plant products.
			Banana	ap-ob	Orchards and other areas used for the production of banana and other species in the genus *Musa*.
			Coffee	ap-oc	Orchards and other areas used for the production of coffee and other species in the genus *Coffea*.
			Guava	ap-og	Orchards and other areas used for the production of guava and other species in the genus *Psidium*.
			Macadamia nuts	ap-om	Orchards and other areas used for the production of macadamia and other species in the genus *Macadamia*.
			Papaya	ap-op	Orchards and other areas used for the production of papaya and other species in the genus *Carica*.
			Coconut	ap-ou	Orchards and other areas used for the production of coconut and other species in the genus *Cocos*. Includes orchard production of trees for ornamental plantings.
		Row crops		ap-r	Areas used for the production of herbaceous crops or plants where fields exhibit row or strip characteristics similar to rows, includes pineapple, sugarcane, corn, and fruits and vegetables (only those exhibiting row characteristics).
			Corn	ap-rc	Fields exhibiting row characteristics where corn (both sweet and seed varieties) and other species in the genus *Zea* are cultivated.
			Pineapple	ap-rp	Fields exhibiting row characteristics where pineapple and other species in the genus *Ananas* are cultivated, includes both planted and fallow fields.
			Mixed fruit or vegetable	ap-rm	Areas used for row crop production of fruits or vegetables, including eggplant, lettuce, melons, ginger root, cabbage, tomatoes, basil, and other species. May include small areas of horticulture crops.
			Wetland	ap-rw	Areas used for production of wetland row crops, including taro (*Colocasia* spp. and others), watercress (*Rorippa* spp.), and similar species.
		Horticulture		ap-h	Areas used for the production of horticultural crops and plants. Common crops include flower production, potted plants, ornamental plants, turf grass, ti, community gardens, upland taro (*Colocasia* spp. and others), cassava (*Manihot* spp.), and kawa. Also includes areas with a diverse variety of crop types, often interlaced with orchard-bananas or row crops-mixed fruit or vegetable.
		Grasses		ap-g	Areas of grasses or legumes, used for production of vegetation biomass, livestock feed and fodder, seed or hay crops, or as pasture or grazing maintained through fencing, grazing, harvesting, or other land-surface modification. Includes areas with less than 25 percent forest or shrubland.
			Pasture and grazing	ap-gy	Areas used for production of herbaceous feed and fodder for livestock. Includes areas used for livestock grazing (such as range land) when fenced or with land-surface modification and less than 25 percent forest or shrubland.
			Biomass	ap-gb	Areas of planted vegetation used for biomass generation, such as the energy production crops kenaf (*Hibiscus cannabinus*) and sunn hemp (*Crotalaria juncea*).

Table 1. Land-use classification system and definitions--Continued

Level 1	Level 2	Level 3	Level 4	Land-use codes	Definition
		Shade houses		ap-s	Areas covered by shade cloth or similar structures intended to regulate the amount of light available for plant development, growth, and production. Also includes covered areas for use in hydroponics.
	Livestock			al	Areas and associated paddocks where livestock, including cows, horses, sheep, goats, hogs, and poultry, are confined, manipulated, and treated. Food and water are provided from external sources, does not include aquatic species.
	Aquaculture			aq	Submerged, raised, and other open or covered areas used for cultivation of marine or freshwater products such as fish, shellfish, seaweed, algae, and associated equipment and staging areas.
	Small-scale rural			as	Areas where agriculture land use of any type is dominant, and residential land uses are also a significant component. Commonly a matrix of composite land owners/lessee's with multiple residences and agricultural practices such as State of Hawaii Agricultural Parks, subsistence agricultural areas, or small ranches. Extensive backyard gardens are not included.
	Abandoned			aa	Areas where evidence of past agriculture or aquaculture use is evident although not actively practiced, as seen in extensive presence of non-target species (typically semi-naturalized exotic species) that prohibit crop harvest, usually dominated by grasses (commonly former sugarcane or pineapple fields). Field boundaries are well defined although crop type may not be evident. Does not include areas currently fallow, between crop rotations.
Developed				d	Areas characterized by a high percentage of modification by and for human use, such as where the land-surface is covered by structures, prepared materials, or otherwise urban. Does not include areas used for agriculture or barren (such as from surface mining). This land-use category takes precedence over other land-use categories, except for agriculture.
	Manufacturing/industrial			dm	Structures and associated grounds used for fabrication, storage, distribution, and finishing of commercial and industrial goods and services. Includes petro-chemical refineries and storage, power generation, mills, shipping and distribution centers, military bases with corresponding land-use patterns, and all highly developed areas not classified as commercial, residential, social services, or public infrastructure.
	Commercial			dc	Areas characterized by structures and associated grounds used for the sale of products and services, light industry, business, military bases with corresponding land use patterns, ammunition bunkers, and structures where military services are provided.
		High density		dc-h	Greater than 75 percent of land area developed for commercial use.
			Low story	dc-hs	Structures of less than 5 stories, or where evidence of similar height buildings is seen in imagery.
			Multi-story	dc-h+	Structures of 5 or more stories, or where evidence of similar height buildings is seen in imagery.
		Moderate density		dc-m	25 to 75 percent of land area developed for commercial use.
			Low story	dc-ms	Structures of less than 5 stories, or where evidence of similar height buildings is seen in imagery.
			Multi-story	dc-m+	Structures of 5 or more stories, or where evidence of similar height buildings is seen in imagery.
		Low density		dc-l	Less than 25 percent of land area developed for commercial use, includes low or multi-story, military ammunition bunkers, and similarly spaced structures
	Residential			dr	Areas used for human habitation.
		High density		dr-h	Greater than 75 percent of land area developed for human habitation.
			Low story	dr-hs	Structures of less than 5 stories, or where evidence of similar height buildings is seen in imagery.
			Multi-story	dr-h+	Structures of 5 or more stories, or where evidence of similar height buildings is seen in imagery.

Table 1. Land-use classification system and definitions--Continued

Level 1	Level 2	Level 3	Level 4	Land-use codes	Definition
		Moderate density		dr-m	25 to 75 percent of land area developed for human habitation.
			Low story	dr-ms	Structures of less than 5 stories, or where evidence of similar height buildings is seen in imagery.
			Multi-story	dr-m+	Structures of 5 or more stories, or where evidence of similar height buildings is seen in imagery.
		Low density		dr-l	Less than 25 percent of land area developed for human habitation, includes low or multi-story, ranchettes, homesteads, extensive yard landscaping, etc.
	Social services			ds	Government and private areas serving as schools, universities, government administrative offices, and health and welfare facilities (hospitals, public service venues, and recreation structures [enclosed stadiums, gymnasiums, swimming pool complexes]).
		Government		ds-g	Public and private facilities and associated grounds used for government and public welfare such as religious complexes, memorials, hospitals, government facilities, community centers, and enclosed stadiums. Does not include vegetated recreation areas (such as ball fields or large open spaces) or cemeteries.
		Education		ds-e	Public and private educational facilities and associated grounds such as schools, seminaries, university campuses, museums, and research centers. Includes enclosed recreation areas as part of an educational facility; does not include vegetated outdoor recreation areas (ball fields and large open spaces).
	Public infrastructure			du	Areas used for transportation, communication, and utilities, including facilities, associated lands, right-of-ways, and median strips for roads, parking facilities, railroads, airports, ports, utility transmission, power substation, water supply, and waste treatment and storage.
		Utilities		du-u	Structures, facilities, and associated grounds used for power transmission, communications, treatment and storage of drinking water, and pumping stations.
		Waste management		du-w	Structures and associated land area used for solid and liquid waste treatment or disposal, such as sewage treatment, solid waste transfer, disposal, and recycling.
			Landfill	du-wl	Structures, facilities, and associated grounds actively used for waste management and storage, including combinations of waste management activities. Land previously used for landfills, where the surface has been reclaimed for other uses (such as developed or vegetated), are not included.
			Sewage Treatment	du-ws	Structures, facilities, transmission lines, and settling ponds (not natural wetlands) used in treatment of liquefied human and animal waste.
		Airport		du-a	Maintained active and overrun areas of runways, landing strips, taxiways, and intervening land; along with terminals, hangers, service buildings, offices, and navigation aids.
		Automotive		du-c	Streets, roads, highways, and associated facilities, including maintained medians and shoulders considered part of the road prism.
		Port		du-p	Docks, boat ramps, vessel storage areas, and associated structures of a port facility adjacent to water.
	Open space			do	Urban parks, recreation areas and associated facilities, golf courses, playing fields, cemeteries, and other maintained, semi-maintained, or vacant lots where structures occupy less than 25 percent of available space.
		Recreation		do-r	outdoor recreation areas with demarcated, maintained vegetation occupying more than 25 percent of land area, such as baseball fields, and football fields. Includes associated structures and rest rooms occupying less than 25 percent of total developed area. Does not include multi-purpose parks with grass surfaces.
		Maintained vegetation		do-m	vegetated surfaces where cover type is actively managed through physical or chemical means, including golf courses and multi-purpose parks. Includes areas with less than 75 percent tree or shrub cover, when herbaceous ground cover vegetation is actively maintained.

Table 1. Land-use classification system and definitions--Continued

Level 1	Level 2	Level 3	Level 4	Land-use codes	Definition
			Golf courses	do-mg	golf courses and associated service facilities. Clubhouses, parking facilities, and multipurpose facilities are considered as separate categories when exceeding the minimum mapping units.
			Multi-purpose	do-mm	maintained herbaceous vegetation including parks, multipurpose open space, cemeteries, facility grounds, and other maintained areas with less than 75 percent tree canopy and structures are less than 25 percent of area.
		Vacant		do-v	land surfaces where the vegetation is occasionally or erratically maintained to sustain a vacant or open land area suitable for development, and built structures occupy less than 25 percent of area. Includes barren areas under construction.
[a]Barren				b	Areas characterized by rock, gravel, sand, silt, clay, or other earthen material, not covered by water, with less than 25 percent vegetative cover or less than 5 percent vegetative cover in arid areas. (Not differentiated except to identify mining surfaces).
	Mining			bm	Areas of extractive mining activities and greater than 25 percent surface disturbance. Inactive or unreclaimed areas are included until another category is applicable, includes mines, gravel pits, stockpiles, dredge spoils, and other earthen aggregate.
Other				other	All areas not encompassed in the above class definitions; including water, wetland, forest, shrubland, herbaceous, and barren (other than mining).

[a] Mining, such as quarries, strip mines, and gravel pits, is the only *Barren* category considered, all other *Barren* categories are included in "other"

Table 2. Land-use area by classification, Oahu, Hawaii, 1998

Level 1	Level 2	Level 3	Level 4	Level 1 acres[a]	Level 2 acres	Level 3 acres	Level 4 acres
Agriculture				59,195	-	-	-
	Planted/cultivated			-	33,441	-	-
		Orchard		-	-	3,576	(597)[b]
			Banana	-	-	-	1,188
			Coffee	-	-	-	352
			Guava	-	-	-	13
			Macadamia nuts	-	-	-	33
			Papaya	-	-	-	1,272
			Coconut	-	-	-	120
		Row crops		-	-	19,330	(264)
			Corn	-	-	-	835
			Pineapple	-	-	-	11,585
			Mixed fruit or vegetable	-	-	-	6,341
			Wetland	-	-	-	304
		Horticulture		-	-	1,581	-
		Grasses		-	-	8,718	(582)
			Pasture and grazing	-	-	-	7,018
			Biomass	-	-	-	1,119
		Shade houses		-	-	236	-
	Livestock			-	730	-	-
	Aquaculture			-	192	-	-
	Small-scale rural			-	3,948	-	-
	Abandoned			-	20,884	-	-
Developed				98,663	-	-	-
	Manufacturing/industrial			-	3,808	-	-
	Commercial			-	14,514	-	-
		High density		-	-	4,960	-
			Low story	-	-	-	3,547
			Multi-story	-	-	-	1,413
		Moderate density		-	-	2,445	-
			Low story	-	-	-	2,226
			Multi-story	-	-	-	219
		Low density		-	-	7,109	-
	Residential			-	44,905	-	-
		High density		-	-	33,803	-
			Low story	-	-	-	32,638
			Multi-story	-	-	-	1,164

Table 2. Land-use area by classification, Oahu, Hawaii, 1998--Continued

Level 1	Level 2	Level 3	Level 4	Level 1 acres[a]	Level 2 acres	Level 3 acres	Level 4 acres
		Moderate density		-	-	8,285	-
			Low story	-	-	-	8,168
			Multi-story	-	-	-	117
		Low density		-	-	2,818	-
	Social services			-	5,145	-	-
		Government		-	-	1,609	-
		Education		-	-	3,537	-
	Public infrastructure			-	12,962	-	-
		Utilities		-	-	566	-
		Waste management		-	-	784	-
			Landfill	-	-	-	530
			Sewage treatment	-	-	-	254
		Airport		-	-	7,306	-
		Automotive		-	-	3,201	-
		Port		-	-	1,105	-
	Open space			-	17,328	-	-
		Recreation		-	-	1,353	-
		Maintained vegetation		-	-	11,277	-
			Golf courses	-	-	-	6,386
			Multi-purpose	-	-	-	4,891
		Vacant		-	-	4,698	-
[c]Barren				1,522	-	-	-
	Mining			-	1,522	-	-
Other				224,331	-	-	-

[a] Whole acreages may not add precisely due to rounding

[b] For categories where more specific land uses were not always assigned the generic acreage portion is included in parentheses (), for example, a generic Agriculture, Planted/cultivated, grasses category was used in addition to the specific biomass and pasture and grazing categories

[c] Mining, such as quarries, strip mines, and gravel pits, is the only *Barren* category included, all other *Barren* categories are included in "other"