Hawaii
Wetland Resources

Wetlands constitute less than 3 percent of the State of Hawaii but have had a major economic effect on the development of Hawaiian society both before and after European contact. Native Hawaiian communities depended on wetlands for cultivation of taro and other staple food crops and for coastal fisheries. After the arrival of European and Asian immigrants, wetlands were used for rice and watercress cultivation. These agricultural uses of wetlands continue to the present, although their economic importance has declined because of demographic shifts and increased importation of food.

Wetlands provide important waterfowl and shorebird habitat. Endemic and endangered species that rely on Hawaiian wetlands include the Hawaiian stilt, Hawaiian coot, Hawaiian gallinule, and Hawaiian duck (Hawaii Department of Land and Natural Resources, 1988). Wetlands also are used by migratory shorebirds such as the Pacific golden plover and waterfowl such as the pintail duck (Hawaii Department of Land and Natural Resources, 1988). Some endemic Hawaiian plants are found only in wetlands (Vogl and Henrickson, 1971; Elliot, 1981).

In recent years, recreational, educational, and scientific uses of wetlands have increased. The Waimanu Valley on the island of Hawaii (figs. 1 and 2*A*) is managed as a part of the National Estuarine Research Reserve system for such purposes.

Wetlands can improve water quality (Hemond and Benoit, 1988) and reduce flooding (Carter, 1986). Wetlands in Pearl Harbor are being considered for use as sediment traps by the U.S. Navy (Stephanie Aschmann, U.S. Navy, oral commun., 1992). The Kawainui Marsh is an example of a wetland managed for flood protection.

Figure 1. Estuarine wetland in Waimanu Valley on the island of Hawaii. *(Photograph by B.R. Hill, U.S. Geological Survey.)*

TYPES AND DISTRIBUTION

Wetlands are lands transitional between terrestrial and deepwater habitats where the water table usually is at or near the land surface or the land is covered by shallow water (Cowardin and others, 1979). The distribution of wetlands and deepwater habitats in Hawaii is shown in figure 2*A*; only wetlands are discussed herein.

Wetlands can be vegetated or nonvegetated and are classified on the basis of their hydrology, vegetation, and substrate. In this summary, wetlands are classified according to the system proposed by Cowardin and others (1979), which is used by the U.S. Fish and Wildlife Service (FWS) to map and inventory the Nation's wetlands. At the most general level of the classification system, wetlands are grouped into five ecological systems: Palustrine, Lacustrine, Riverine, Estuarine, and Marine. The Palustrine System includes only wetlands, whereas the other systems comprise wetlands and deepwater habitats. Wetlands of the systems that occur in Hawaii are described below.

System	Wetland description
Palustrine	Nontidal and tidal-freshwater wetlands in which vegetation is predominantly trees (forested wetlands); shrubs (scrub-shrub wetlands); persistent or nonpersistent emergent, erect, rooted herbaceous plants (persistent- and nonpersistent-emergent wetlands); or submersed and (or) floating plants (aquatic beds). Also, intermittently to permanently flooded open-water bodies of less than 20 acres in which water is less than 6.6 feet deep.
Lacustrine	Nontidal and tidal-freshwater wetlands within an intermittently to permanently flooded lake or reservoir larger than 20 acres and (or) deeper than 6.6 feet. Vegetation, when present, is predominantly nonpersistent emergent plants (nonpersistent-emergent wetlands), or submersed and (or) floating plants (aquatic beds), or both.
Riverine	Nontidal and tidal-freshwater wetlands within a channel. Vegetation, when present, is same as in the Lacustrine System.
Estuarine	Tidal wetlands in low-wave-energy environments where the salinity of the water is greater than 0.5 part per thousand (ppt) and is variable owing to evaporation and the mixing of seawater and freshwater.
Marine	Tidal wetlands that are exposed to waves and currents of the open ocean and to water having a salinity greater than 30 ppt.

On the basis of mapping by the FWS National Wetland Inventory, wetland area in Hawaii has been estimated to be 110,810 acres (Hawaii Department of Land and Natural Resources, 1988). The estimate includes areas of mixed wetlands and upland rain forest (Dennis Peters, U.S. Fish and Wildlife Service, written commun., 1993). Almost 90 percent of the wetland area is palustrine wetlands (Hawaii Department of Land and Natural Resources, 1988). The FWS survey did not include marine wetlands, which are small and are not considered in this report. About 70 percent of Hawaiian wetlands are 5 acres or less, 20 percent are between 5 and 25 acres, and the remaining 10 percent are larger than 25 acres (Hawaii Department of Land and Natural Resources, 1988).

Palustrine wetlands.—The largest wetlands in the State are palustrine wetlands on the windward (northeastern) mountain slopes on the islands of Kauai, Maui, and Hawaii. These are primarily emergent and scrub-shrub wetlands and are known locally as bogs. Palustrine emergent wetlands also are present upstream from some coastal, estuarine wetlands.

Lacustrine wetlands.—Only a few lacustrine wetlands exist in the Hawaiian Islands. Lake Waiau is a small natural lake near the summit of Mauna Kea on the island of Hawaii. A number of small lakes occupy topographic depressions on Niihau. Several reservoirs are located on Kauai, Oahu, Molokai, and Maui.

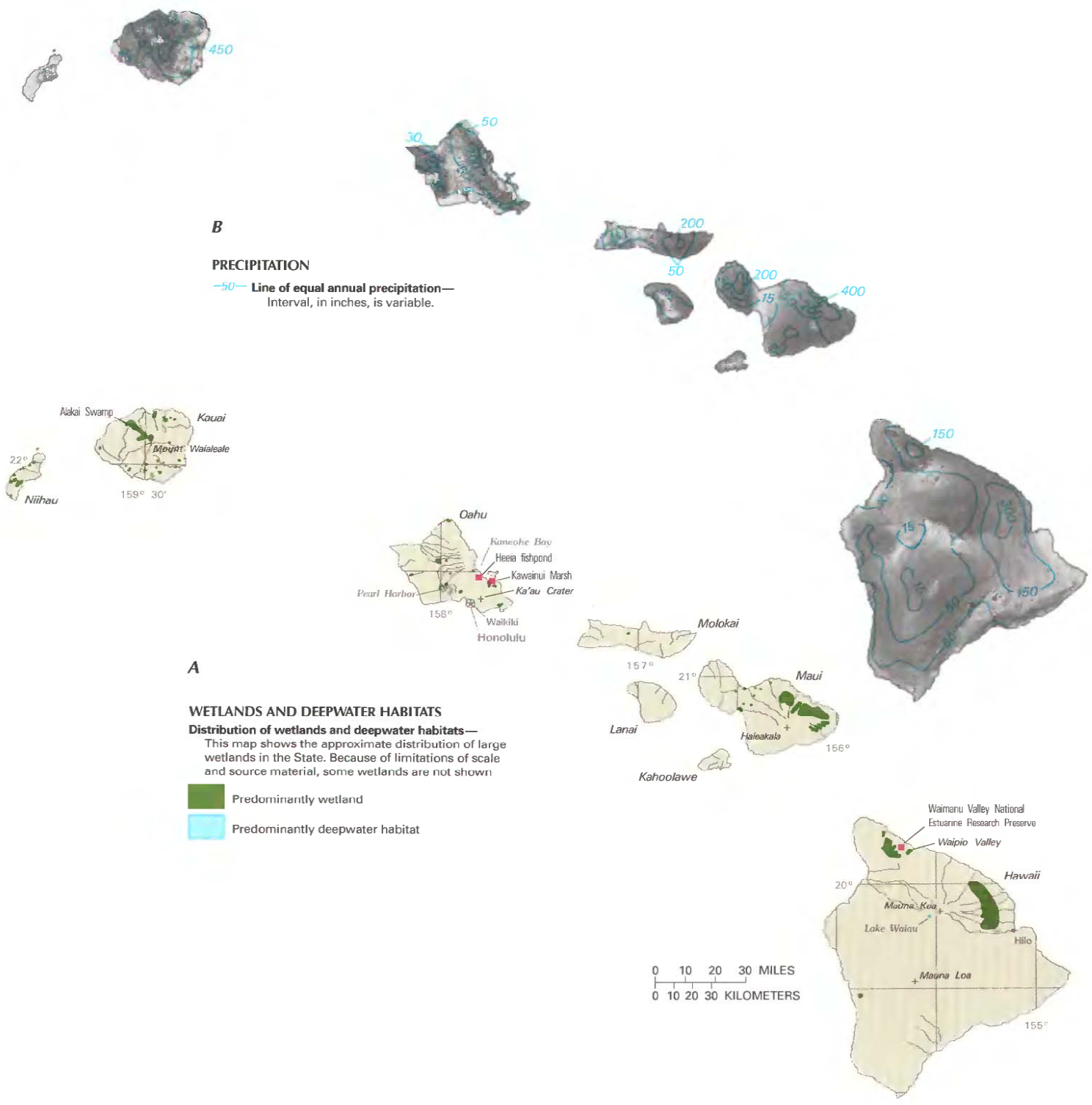

Figure 2. Wetland distribution and average annual precipitation in Hawaii. ***A***, Distribution of wetlands and deepwater habitats. ***B***, Average annual precipitation. *(Sources: A, T.E. Dahl, U.S. Fish and Wildlife Service, unpub. data, 1991. B, Lee and Valenciano, 1986.)*

Riverine wetlands.—Riverine wetlands in the State are in all four subsystems of the FWS classification: Tidal, Lower Perennial, Upper Perennial, and Intermittent. A total of 376 perennial streams and more than 100 intermittent streams were identified in Hawaii in a recent survey by the Hawaii Cooperative Park Service Unit (1990).

Estuarine wetlands.—Estuarine emergent wetlands are present at the mouths of many rivers, usually along the wet, windward shores of the major islands. Forested estuarine wetlands also have formed because of the introduction of mangrove in some coastal areas on Oahu and Molokai.

Anchialine pools are a unique type of estuarine wetland. These pools form in collapsed lava tubes and have a subsurface connection to the ocean. Therefore, the pools are affected by tidal action, although they are rarely, if ever, inundated by seawater. These wetlands pools average about 1 acre in area (Hawaii Department of Land and Natural Resources, 1988) and support populations of endemic shrimp. Anchialine pools were not included in the FWS National Wetlands Inventory maps; the Hawaii Department of Land and Natural Resources (1988) estimated that the pools have a total area of about 700 acres.

Fishponds constructed by native Hawaiians along the shores of the islands are another type of estuarine wetland. The ponds are formed by walls built of stone. Although artificial, these ponds are economically and culturally important and support several plant and animal species (Hawaii Department of Land and Natural Resources, 1988). Heeia fishpond on Oahu is an example of one such pond that is now preserved because of its cultural importance.

HYDROLOGIC SETTING

Hydrologic conditions on the Hawaiian islands are largely determined by climate and topography. When moisture-laden air masses moving with the trade winds reach the volcanic mountains that form the islands, the air masses are forced up the slopes, where they cool in the higher altitudes and release their moisture. Because of this climatic phenomenon, known as the orographic effect, rainfall is more plentiful on the windward sides of the islands (fig. 2*B*) (Blumenstock and Price, 1961). On the highest mountains (Haleakala on Maui, maximum altitude of 10,021 feet; Mauna Kea and Mauna Loa on Hawaii, maximum altitudes of 13,796 and 13,078 feet, respectively), the trade winds move around the peaks, and the maximum rainfall is at altitudes of 2,000 to 4,000 feet; on the lower mountain ranges, the trade winds move over the mountains, and the rainfall maximums are at or near the crests (Blumenstock and Price, 1961). Rainfall gradients on the larger islands are high; average annual totals can range from greater than 200 inches to as little as 10 inches within 10 miles (fig. 2*B*). Geographically, evaporation is inversely proportional to rainfall and is less variable; the maximum annual pan-evaporation rate is about 106 inches, and the minimum is about 17 inches (Hawaii Department of Land and Natural Resources, 1973). Runoff averages about 40 percent of rainfall (Takasaki, 1978). Ground water on each island occurs primarily as a basal lens of freshwater floating on denser saltwater (fig. 3) (Valenciano, 1985). These floating freshwater lenses are known in Hawaii as basal ground water. The upper extent of a lens, the basal water table, is generally less than 100 feet above sea level (Takasaki, 1978; Valenciano, 1985).

Despite large amounts of rainfall in some areas, wetlands are not extensive in the Hawaiian islands because of the generally steep topography and the high permeability of bedrock (Elliot, 1981). Most water falling as rain travels rapidly to the ocean as surface-water and ground-water flow (Takasaki, 1978). Wetlands form only where local hydrologic conditions favor retention of water near the land surface (fig. 3).

Water is more likely to accumulate where precipitation is high and evaporation is low. In Hawaii, extensive bogs are confined to areas where rainfall exceeds 150 inches annually (fig. 2*A* and 2*B*). These areas are at altitudes between 1,500 and 5,000 feet on windward slopes. On the basis of limited pan-evaporation data, evaporation in these areas ranges from 50 to 95 inches annually (Hawaii Department of Land and Natural Resources, 1973).

Wetlands commonly form only where the water table intersects the land surface. Topography and water-table configuration determine the extent of areas where the land surface and water table intersect. Most of the land surface of the islands is many hundreds of feet above the basal water table. Therefore, basal ground water supports only a narrow zone of estuarine and palustrine wetlands near the shore, where the water table and the land surface intersect (fig. 3).

Many of Hawaii's estuarine wetlands have developed over geologic time as a result of gradual subsidence of the islands and the resulting rise in sea level relative to the land surface (Macdonald and others, 1970). The relative rise in sea level reduced the gradi-

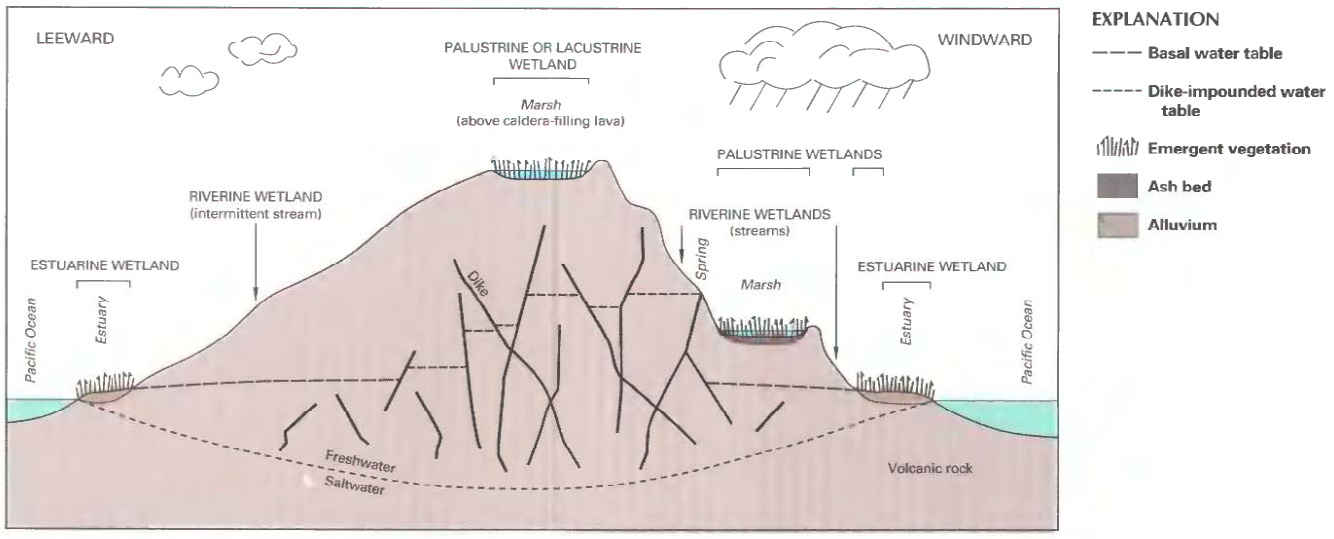

Figure 3. Generalized cross section of a Hawaiian island showing hydrologic and geologic features that affect wetland distribution. *(Source: Modified from Takasaki, 1978.)*

ent of streams entering the ocean. Sediments carried by the streams were deposited near the stream mouths, and the accumulated deposits were colonized by wetland vegetation. Wetlands in Pearl Harbor on Oahu and in Waimanu and Waipio Valleys on the island of Hawaii are examples of this process.

Topography affects the retention of surface runoff during rainstorms. On the steep, highly eroded slopes of Oahu, runoff is rapid; water does not accumulate at the land surface, and wetlands are rare (fig. 2*A*). On the younger islands of Maui and Hawaii, stream erosion has not progressed to the same extent as on Oahu, and much of the gently sloping surface of the original volcanic domes is still intact. On Kauai, caldera filling has resulted in nearly flat areas near the summit of Mount Waialeale. The extensive bogs on Kauai, Maui, and Hawaii occupy gently sloping mountainsides where rainfall is retained at the land surface (Fosberg, 1961, p. 21; van't Woudt and Nelson, 1963 p. 23; Vogl and Henrickson, 1971, p. 479).

Geologic heterogeneities, including andesitic lava flows, volcanic dikes, ash beds, soils, and alluvium, can restrict infiltration of rainfall, resulting in surface saturation. The extensive bogs on the islands of Kauai, Maui, and Hawaii have formed on soils, ash layers, or andesitic lava less permeable than the underlying basaltic lava (Stearns and Macdonald, 1942, 1946; Macdonald and others, 1960).

Low-permeability clay layers underlie many bogs in Hawaii. These clays result from weathering of bedrock in high-rainfall areas that have abundant plant remains on the forest floor. The organic acids derived from decaying plants cause rapid chemical weathering of bedrock. Although the characteristic clay layers have been considered a factor in bog development (Skottsberg, 1940; Fosberg, 1961; van't Woudt and Nelson, 1963; Vogl and Henrickson, 1971), the clay might actually be a result rather than a cause of impeded drainage (Wentworth and others, 1940).

Not much is known concerning the hydrologic functions of Hawaiian wetlands. Coastal wetlands are generally in ground-water discharge zones, and upland bogs are generally in ground-water recharge zones, but the importance of wetlands in controlling rates of ground-water movement is not known. A study of the Alakai Swamp on Kauai indicated that recharge from the swamp to the basal aquifer was not significant (van't Woudt and Nelson, 1963). Storage of surface runoff in bog peat (partially decomposed plant material) might supply streamflow following rains (Skottsberg, 1940; van't Woudt and Nelson, 1963). The bog in the Ka'au Crater on Oahu was formerly used as a water-supply reservoir (Elliot, 1981). When bog peat is completely saturated, bogs can act as sources of overland flow during rainstorms and might increase runoff (van't Woudt and Nelson, 1963). Coastal wetlands can reduce flooding because of their capacity to store surface runoff.

Table 1. Selected wetland-related activities of government agencies and private organizations in Hawaii, 1993

[Source: Classification of activities is generalized from information provided by agencies and organizations. •, agency or organization participates in wetland-related activity; .., agency or organization does not participate in wetland-related activity. MAN, management; REG, regulation; R&C, restoration and creation; LAN, land acquisition; R&D, research and data collection; D&I, delineation and inventory]

Agency or organization	MAN	REG	R&C	LAN	R&D	D&I
FEDERAL						
Department of Agriculture						
Consolidated Farm Service Agency	..	•	..	..	..	..
Forest Service	..	..	•	..	•	..
Natural Resources Conservation Service	..	•	•	..	..	•
Department of Commerce						
National Oceanic and Atmospheric Administration	•	•	..	..	•	..
Department of Defense						
Army Corps of Engineers	•	•	•	..	•	•
Marine Corps	•	..	..	..	..	..
Navy	•	..	•	..	•	..
Department of the Interior						
Fish and Wildlife Service	•	..	•	•	•	•
Geological Survey	..	..	..	..	•	..
National Biological Survey	..	..	..	..	•	..
National Park Service	•	..	•	•	•	..
Environmental Protection Agency	..	•	..	..	..	..
STATE						
Department of Health						
Office of Environmental Quality Control	..	•	..	..	..	..
Department of Land and Natural Resources						
Commission on Water Resource Management	..	•	..	..	..	..
Division of Forestry and Wildlife	•	•	•	•	•	•
Division of Water and Land Development	..	•	..	..	•	..
Division of Land Management	..	..	..	•	..	..
Office of Conservation and Environmental Affairs	..	•	..	..	..	..
Office of State Planning						
Coastal Zone Management Program	•	..	..	..	..	..
University of Hawaii						
Environmental Center	..	..	..	..	•	..
Water Resources Research Center	..	..	..	..	•	..
COUNTY						
City and County of Honolulu						
Department of Land Utilization	..	•	..	..	..	..
County of Hawaii						
Planning Department	..	•	..	..	..	..
County of Kauai						
Planning Department	..	•	..	..	..	..
County of Maui						
Planning Department	..	•	..	..	..	..
PRIVATE ORGANIZATIONS						
Ducks Unlimited	..	..	..	•	..	..
Hawaii Audubon Society	•	..	..	..	..	..
National Audubon Society	..	..	•	..	•	..
Native Hawaiian Plant Society	..	..	..	..	•	..
Outdoor Circle	..	..	..	•	•	..
The Nature Conservancy	•	..	•	•	•	..

TRENDS

The Hawaii Department of Land and Natural Resources (1988) estimated that total wetland acreage in Hawaii before European contact in 1778 was 110,000 acres. Wetland area was about 114,000 acres in 1900 because of increased wetland agriculture as rice production became important. Since then, wetland agricultural acreage has declined by about 10,000 acres to a remnant of 420 acres used for taro and watercress production.

According to a recent FWS report (Dahl, 1990), Hawaii has lost about 7,000 acres of wetlands since the 1780's. These losses were in coastal estuarine and palustrine wetlands at altitudes less than 1,000 feet (Andy Yuen, U.S. Fish and Wildlife Service, written commun., 1992). Estimates of predevelopment wetland area (58,800 acres) and recent wetland area (51,800 acres) used by Dahl (1990) to compute losses are lower than those reported by the Department of Land and Natural Resources (1988) because Dahl's (1990) estimates do not include some areas of mixed wetland and rain forest at altitudes greater than 1,000 feet that were included in the Department's estimates (Andy Yuen, U.S. Fish and Wildlife Service, written commun., 1992). On the basis of the Department's estimates of 110,000 original wetland acres and Dahl's (1990) estimate of 7,000 acres lost, Hawaii has lost about 6 percent of its original wetlands.

Coastal wetland losses have been greatest on Oahu, where most of the population of the State resides. Maps and aerial photographs of the Honolulu area before 1940 show many agricultural and coastal wetlands that no longer exist. Much of the resort area of Waikiki was wetland before the dredging of the Ala Wai Canal. Many other wetlands have been partly or completely filled for industrial and

residential developments. The FWS has estimated that 58 percent of wetlands in the Kaneohe Bay area were lost between 1927 and 1978 (Andy Yuen, U.S. Fish and Wildlife Service, written commun., 1992).

The most extensive wetlands in the State are in remote mountainous areas removed from agricultural and urban areas (fig. 2*A*). These wetlands are not presently threatened by human activities but are being degraded by trampling and rooting by feral animals, particularly pigs, and by the introduction of exotic plants (Elliot, 1981).

CONSERVATION

Many government agencies and private organizations participate in wetland conservation in Hawaii. The most active agencies and organizations and some of their activities are listed in table 1.

Federal wetland activities.—Development activities in Hawaii wetlands are regulated by several Federal statutory prohibitions and incentives that are intended to slow wetland losses. Some of the more important of these are contained in the 1899 Rivers and Harbors Act; the 1972 Clean Water Act and amendments; the 1985 Food Security Act; the 1990 Food, Agriculture, Conservation, and Trade Act; the 1986 Emergency Wetlands Resources Act; and the 1972 Coastal Zone Management Act.

Section 10 of the Rivers and Harbors Act gives the U.S. Army Corps of Engineers (Corps) authority to regulate certain activities in navigable waters. Regulated activities include diking, deepening, filling, excavating, and placing of structures. The related section 404 of the Clean Water Act is the most often-used Federal legislation protecting wetlands. Under section 404 provisions, the Corps issues permits regulating the discharge of dredged or fill material into wetlands. Permits are subject to review and possible veto by the U.S. Environmental Protection Agency, and the FWS has review and advisory roles. Section 401 of the Clean Water Act grants to States and eligible Indian Tribes the authority to approve, apply conditions to, or deny section 404 permit applications on the basis of a proposed activity's probable effects on the water quality of a wetland.

Most farming, ranching, and silviculture activities are not subject to section 404 regulation. However, the "Swampbuster" provision of the 1985 Food Security Act and amendments in the 1990 Food, Agriculture, Conservation, and Trade Act discourage (through financial disincentives) the draining, filling, or other alteration of wetlands for agricultural use. The law allows exemptions from penalties in some cases, especially if the farmer agrees to restore the altered wetland or other wetlands that have been converted to agricultural use. The Wetlands Reserve Program of the 1990 Food, Agriculture, Conservation, and Trade Act authorizes the Federal Government to purchase conservation easements from landowners who agree to protect or restore wetlands. The Consolidated Farm Service Agency (formerly the Agricultural Stabilization and Conservation Service) administers the Swampbuster provisions and Wetlands Reserve Program. The Natural Resources Conservation Service (formerly the Soil Conservation Service) determines compliance with Swampbuster provisions and assists farmers in the identification of wetlands and in the development of wetland protection, restoration, or creation plans.

The 1986 Emergency Wetlands Resources Act and the 1972 Coastal Zone Management Act and amendments encourage wetland protection through funding incentives. The Emergency Wetland Resources Act requires States to address wetland protection in their Statewide Comprehensive Outdoor Recreation Plans to qualify for Federal funding for State recreational land; the National Park Service (NPS) provides guidance to States in developing the wetland component of their plans. Coastal States that adopt coastal-zone management programs and plans approved by the National Oceanic and Atmospheric Administration are eligible for Federal funding and technical assistance through the Coastal Zone Management Act.

Several Federal agencies manage wetlands as wildlife refuges and other conservation areas. The FWS manages about 1,400 acres of refuge lands in Hawaii. The U.S. Navy and Marine Corps also manage wetland refuges. Other wetlands are managed by the NPS.

State wetland activities.—Hawaii has no laws specifically relating to wetland protection, but chapter 205A of the Hawaii Revised Statutes provides for regulation of coastal areas, including wetlands, in conjunction with the Federal Coastal Zone Management Act and Clean Water Act. Under the provisions of these and other laws, several State and county agencies regulate the use of wetlands in Hawaii (table 1). The Office of State Planning's Coastal Zone Management Program provides wetlands policy guidance. Policy is enforced through regulation by the county planning departments, which have permitting authority for designated Special Management Areas. These areas generally are within 300 feet of the shoreline but can extend much farther inland. The Office of Conservation and Environmental Affairs of the Department of Land and Natural Resources has permitting authority for all designated conservation lands, which can include upland as well as coastal wetlands. The Department of Health and the Coastal Zone Management Program make determinations of consistency with Federal laws for permits issued by the Corps. The Commission on Water Resource Management, a part of the Department of Land and Natural Resources, has authority to regulate channel alterations and enforce instream-flow standards. The Office of Hawaiian Affairs acts as an advocate for native Hawaiian concerns relating to wetlands. An effort to review State wetland policies is under way; this effort is being coordinated by the Office of Environmental Quality Control in the Department of Health.

The Division of Forestry and Wildlife of the Department of Land and Natural Resources is the principal State wetland-management agency. The Division manages wildlife refuges and other wetlands. The wetlands in Waimanu Valley on the island of Hawaii are included in the Waimanu National Estuarine Research Reserve, which is administered by the Department of Land and Natural Resources in cooperation with the National Oceanic and Atmospheric Administration. Hydrologic data are collected in this reserve by the U.S. Geological Survey in cooperation with the Department.

Private wetland activities.—Several private organizations engage in wetland activities (table 1) in Hawaii. The Nature Conservancy manages wetlands within its preserve system. Other groups, including the National and Hawaii Audubon Societies and Ducks Unlimited, are involved in efforts to acquire wetlands for conservation purposes. In addition, many other organizations take advocacy roles before government agencies in matters concerning wetlands. These include the Native Hawaiian Legal Corporation, the Sierra Club Legal Defense Fund, the Kawainui Heritage Foundation, and the National and Hawaii Audubon Societies.

References Cited

Blumenstock, D.I., and Price, Saul, 1961, Climates of the States—Hawaii: U.S. Department of Commerce, Environmental Science Services Administration, climatography of the States 60–51, 27 p.

Carter, Virginia, 1986, An overview of the hydrologic concerns related to wetlands in the United States: Canadian Journal of Botany, v. 64, p. 364–374.

Cowardin, L.M., Carter, Virginia, Golet, F.C., and LaRoe, E.T., 1979, Classification of wetlands and deepwater habitats of the United States: U.S. Fish and Wildlife Service Report FWS/OBS–79/31, 131 p.

Dahl, T.E., 1990, Wetlands—Losses in the United States, 1780's to 1980's: Washington, D.C., U.S. Fish and Wildlife Service Report to Congress, 13 p.

Elliot, M.E., 1981, Wetlands and wetland vegetation of the Hawaiian Islands: Honolulu, University of Hawaii, M.A. thesis, 228 p.

Fosberg, F.R., 1961, Guide to excursion III: Honolulu, Tenth Pacific Science Congress and University of Hawaii, 207 p.

Hawaii Cooperative Park Service Unit, National Park Service, 1990, A preliminary appraisal of Hawaii's stream resources: National Park Service Report R84, 294 p.

Hawaii Department of Land and Natural Resources, 1973, Pan evaporation in Hawaii 1894–1970: Hawaii Department of Land and Natural Resources Report R51, 82 p.

_____1988, State recreation functional plan technical reference document and State comprehensive outdoor recreation plan, wetlands resources plan addendum: Honolulu, Hawaii, Department of Land and Natural Resources, variously paged.

Hemond, H.F., and Benoit, Janina, 1988, Cumulative impacts on water quality functions of wetlands: Environmental Management, v. 12, no. 5, p. 636–653.

Lee, Reuben, and Valenciano, Santos, 1986, Hawaii surface-water resources, *in* U.S. Geological Survey, National water summary 1985—Hydrologic events and surface-water resources: U.S. Geological Survey Water-Supply Paper 2300, p. 201–206.

Macdonald, G.A., Abbott, A.T., and Peterson, F.L., 1970, Volcanoes in the sea—The geology of Hawaii: Honolulu, University of Hawaii Press, 517 p.

Macdonald, G.A., Davis, D.A., and Cox, D.C., 1960, Geology and groundwater resources of the island of Kauai, Hawaii: Hawaii Division of Hydrography Bulletin 13, 212 p.

Skottsberg, Carl, 1940, Report on Hawaiian bogs—Proceedings of the Sixth Pacific Science Congress, July 24–August 12, 1939, Berkeley, Stanford, and San Francisco: Berkeley, University of California Press, v. 4, p. 659–661.

Stearns, H.T., and Macdonald, G.A., 1942, Geology and ground-water resources of the island of Maui, Hawaii: Territory of Hawaii Division of Hydrography Bulletin 7, 344 p.

_____1946, Geology and ground-water resources of the island of Hawaii: Territory of Hawaii Division of Hydrography Bulletin 9, 363 p.

Takasaki, K.J., 1978, Summary appraisals of the nation's ground-water resources—Hawaii region: U.S. Geological Survey Professional Paper 813–M, 29 p.

Valenciano, Santos, 1985, Hawaii ground-water resources, *in* U.S. Geological Survey, National water summary 1984—Hydrologic events, selected water-quality trends, and ground-water resources: U.S. Geological Survey Water-Supply Paper 2275, p. 185–191.

van't Woudt, B.D., and Nelson, R.E., 1963, Hydrology of the Alakai Swamp, Kauai, Hawaii: Hawaii Agricultural Experiment Station Bulletin 132, 30 p.

Vogl, R.J., and Henrickson, James, 1971, Vegetation of an alpine bog on East Maui, Hawaii: Pacific Science, v. 25, p. 475–483.

Wentworth, C.K., Wells, R.C., and Allen, V.T., 1940, Ceramic clay in Hawaii: The American Mineralogist, v. 25, no. 1, p. 2–33.

FOR ADDITIONAL INFORMATION: District Chief, U.S. Geological Survey, 677 Ala Moana Boulevard, Suite 415, Honolulu, HI 96813; Regional Wetland Coordinator, U.S. Fish and Wildlife Service, 911 NE 11th Avenue, Portland, OR 97232

Prepared by
B.R. Hill,
U.S. Geological Survey