Kawai Nui Marsh Invasive Aquatic Plant Study Final Report

Kawai Nui Marsh, Kailua, O'ahu

Prepared for:

U.S. Army Corps of Engineers
Honolulu District
Building 230
Fort Shafter, HI 96858-5440

Sponsored by:

Department of Land
and Natural Resources
Division of Forestry and Wildlife

Prepared by:

oceanit

828 Fort Street Mall
Suite 600
Honolulu, HI 96813

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Department of Land and Natural Resources
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2135 Makiki Heights Drive
Honolulu, HI 96822

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Prepared by:
Oceanit Laboratories, Inc.
828 Fort Street Mall, Suite 600
Honolulu, HI 96822

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Executive Summary

The State of Hawaii's Department of Land and Natural Resources, natural resource managers of Kawai Nui Marsh, have a long-term objective to control invasive plants and increase habitat for endangered Hawaiian waterfowl within the marsh. In support of this objective, this study completed a botanical and habitat survey of the marsh to quantify the distribution of native and alien plants within the marsh. This survey also collected physical data including water depth, mud depth, and physical water quality parameters which influence the distribution of plants. Results of the survey were used in conjunction with historical information to develop a comprehensive analysis identifying critical problems and information needs to meet the long-term habitat objectives. This analysis concludes with recommendations for projects and programs that could be implemented to control invasive species and restore waterfowl habitat to the marsh.

Kawai Nui Marsh is located in the lower watershed of Kailua on windward Oahu, Hawaii. It is the largest wetland in the Hawaiian Islands and is noted as a "Wetland of International Importance" in accordance with the U.N. Convention on Wetlands (Ramsar, Iran, 1971). Early descriptions of the wetland describe 400 acres of open water, which is presently reduced to 40 acres, only 4 acres of which are not covered by floating plants. Most of the historic mix of vegetated marsh and open water is now covered with vegetation supported by a floating mat of peat. This has led to a significant decline in the value of Kawai Nui Marsh as habitat to support recovery of endangered waterbirds such as the Hawaiian Coot, Hawaiian Gallinule, Hawaiian Duck, and Hawaiian Stilt. At one time, the large body of water at Kawai Nui Marsh was a significant attraction to migrating waterfowl from the continental areas that border the North Pacific Ocean. The value of the marsh as a significant habitat for native and migrating waterfowl has been lost.

Background literature and graphic surveys (maps and photos) indicate a progressive loss of natural resource value, primarily over the last 150-200 years associated with modern human agriculture, mining, and urban development activities.

The field efforts undertaken for this study in August 2005 focused on the composition of the vegetation and the nature and distribution of the marsh substratum, with emphasis on the layer of peat extensive across the part of the marsh thought to have been a large body of open water up until the 1800's. The vegetation survey identified the plant species present, categorized these into plant species assemblages that could be recognized on aerial photographs, and developed a vegetation map of the wetland.

Although a significant amount of the wetland now supports assemblages characterized as either dominated by alien (non-native) species or invaded by non-native species (including many upland species normally not associated with wetlands), a large proportion of the vegetation consists of native wetland plants. The native species dominated assemblages cover 52% of the marsh surface. This finding is extraordinary in that Kawai Nui Marsh represents the largest area of native plant cover on lowland Oahu (elevations below 1000 feet). Two indigenous species account for this finding: Saw-grass and Neke fern.

The vegetation mapping effort recognized 16 mapable wetland vegetation units plus one upland unit. The marsh can be divided into three broad regimes: 1) an upper marsh and marsh margins of minimal or no peat accumulation, 2) a lower marsh with an average 3.7-foot thick accumulation of peat, often above water to a depth of over 16 feet, and 3) open water areas typically covered with floating plants.

Neke fern (*Cyclosorus interruptus*) is widely distributed in the wetland and a significant contributor to the peat layer. Native saw-grass (*Cladium jamaicense*) covers extensive areas of peat, sometimes combined with Neke. It is not known if saw-grass develops its own peat layer, or takes over from Neke after the fern forms a substantial deposit.

Disturbances of these native assemblages, particularly those that disrupt saw-grass, enhance invasion by other species, particularly non-natives. Many of the invasive species found in the marsh also appear capable of invading monotypic stands of neke. Prominent invasive species of Kawai Nui marsh are:

- California grass (*Urochloa mutica*)
- Water Hyacinth (*Eichhornia crassipes*)
- Kariba Weed (*Salvinia molesta*)
- Cattail (*Typha latifolia*)
- Papyrus (*Cyperus papyrus*)
- Umbrella Sedge (*Cyperus involucratus*)
- Various Trees (particularly *Schefflera* and *Citharexylum*)
- *Vigna luteola* (Definitive common name not established)
- *Paederia foetida* (Definitive common name not established)

The harm posed by these species as invasives of the marsh is viewed from two perspectives: threats to open water and threats to native plant assemblages. Endangered waterfowl are impacted primarily by plant species which encroach over their open water habitat. The native assemblages, including neke and saw-grass, appear capable of obliterating open water with time. Sufficient knowledge and understanding is lacking of the system prior to the 1800s, when few if any of the non-natives were present in the Hawaiian Islands, to draw any conclusions relative to which plant species caused the loss of open water.

Threats to open water and subsequent loss of wetland fauna habitat, is a consequence of 1) aggressive floating plant species, 2) incursions of emergent plants from water body margins, especially by cattail and California grass, and 3) reversion by mat formation. Reversion involves interactions between organic rich sediments, changes in water level, and plants capable of weak organic mat formation. The impact of many of these and other invasive plant species on the marsh, and especially on the native plant dominated areas, appears to be one of progressive intermingling with concomitant loss of native dominance, accumulation of organic matter (peat), and reduction of many wetland functions and values, including loss of native fauna habitat and flood water retardation.

Possible approaches to the control of the vegetation in the marsh are considered. Any project should be tested first at a pilot scale to determine unanticipated secondary effects. Much of the marsh is presently supporting native plants. Past experiences suggest disturbances of these native plant areas may promote invasion by non-natives. A few species, such as kariba weed, water hyacinth, papyrus, and trees growing on the floating peat mat are suitable choices for eradication resulting in ecological benefit. The peat layer makes the marsh vulnerable to invasion by a host of non-wetland species, including trees. There are many areas in the marsh, especially in the upper marsh and around the margin of the lower marsh, where removal of the accumulated recent sediments and vegetation would contribute to both enhancement of open water for improved waterbird habitat and flood control properties of Kawai Nui Marsh.

In establishing priorities for enhancement of native plant expansion, waterbird habitat, flood control, or all three, it is important to consider a number of factors including practicality, likelihood of success, ecological benefit, and difficulty. Difficulty combines several considerations such as approach (chemical treatments, removal using hand tools, removal requiring mobilization of land-based or barged-mounted equipment, etc.). Practical and relatively low cost programs that could be started with minimal mobilization and a high chance of success include eradication of trees on the floating peat mat, kariba weed and the well-defined circles of papyrus. These are species with relatively small areal extent in Kawai Nui Marsh, but have potential for considerable future harm given their ability to invade open water (kariba weed) and peat areas (papyrus). Mangrove removal would fit into the category of easiest to remove, but it does not pose a threat to the marsh, being distributed only in the brackish canals beyond the marsh outlets.

Invasive plants such as Umbrella sedge and Water hyacinth have the potential for successful removal, although requiring more complex mobilization than the first group discussed above. This would involve more planning and higher costs. Various trees, including the native Hau, and invasives such as Wild Cane, fall within the same level of priority and potential, although complete eradication of these may be difficult if not impossible. Considerations of ecological benefit need to be carefully weighed against costs.

The remaining invasive species—Elephant grass, Cattail, California grass, and Great bulrush—are widespread across the marsh. Significant effort would be required to achieve eradication. However, areas of the assemblages dominated by these species are prime candidates for dredging sites to deep water: removing the usable habitat for the plant species and returning it to open water.

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List of Acronyms

ACOE	United States Army Corps of Engineers
AML	Ahahui Malama I Ka Lokahi
C&C	City and County of Honolulu, Oahu, Hawaii
CEQ	Council on Environmental Quality
COE	United States Army Corps of Engineers
DLNR	Department of Land and Natural Resources, State of Hawaii
DOFAW	Division of Forestry, DLNR, State of Hawaii
DOQQ	Digital Orthophoto Quarter Quadrangle
GIS	Geographic Information System
GPS	Global Positioning System
KBAC	Kailua Bay Advisory Council
MSL	Mean Sea Level
NGA	National Geospatial-Intelligence Agency
NRCS	National Resources Conservation Service
PED	Preconstruction Engineering and Design
PIER	Pacific Islands Ecosystems at Risk Project
USDA	United States Department of Agriculture
USGS	United States Geological Survey

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Section 1. Introduction & Study Objective

1.1 Study Objective

The State of Hawaii, Department of Land and Natural Resources (DLNR), Division of Forestry and Wildlife (DOFAW) requested the U.S. Army Corps of Engineers' (Corps) assistance with the preparation of a plan for the characterization and control of non-indigenous invasive aquatic plant species for the Kawai Nui Marsh. The marsh is overgrown by aquatic, wetland, and terrestrial plants that threaten aquatic ecosystems and impede flood mitigation measures in the Kawai Nui Marsh system. The project is being conducted under Section 104 of the River and Harbors Act of 1958, as amended.

The overall objective of this study is to develop a detailed report on the quantity and extent of invasive plant species in the marsh, as well as develop a set of prioritized plans to control these invasive plants and increase habitat for endangered Hawaiian waterfowl within Kawai Nui Marsh. Enhancement of waterbird species habitat is a key objective of the Kawai Nui Marsh Master Plan (1994) and previous planning documents relating to conservation efforts in the marsh. This plan may then be implemented through federal, state, and community actions. The ultimate environmental restoration goal of this initiative is to return the ecosystem to a semblance of a pre- human impact condition with more open water areas and greater abundance of native (indigenous) Hawaiian wetland plants and waterfowl. This restoration would directly support habitat recovery goals for at least three species of endangered waterfowl.

Section 2. Background Data Inventory

2.1 Purpose

The purpose of this Background Data Inventory is to identify and discuss:

- previous reports and information related to the history of the marsh
- surface and groundwater quantity, quality, drainage, and use
- point and non-point source pollution
- stakeholder identification and information
- information on ecological communities and botanical studies
- rare and endangered plants and animals

2.2 Previous Reports Relating to the Natural History of Kawai Nui Marsh

Key studies related to the natural history of Kawai Nui Marsh and used heavily in this report are listed below (See Appendix G: Bibliography and References for a complete listing of reports reviewed.).

- Final Environmental Impact Statement Kawai Nui Marsh Flood Damage Mitigation Project by M&E Pacific, 1990
- Final Detailed Project Report and Environmental Impact Statement for Kawai Nui Marsh Flood Control Project by the U.S. Army Corps of Engineers, 1992
- Kawai Nui Marsh Environmental Restoration Project Final Ecosystem Restoration Project and Environmental Assessment by the U.S. Army Corps of Engineers, 2000
- Kawai Nui Marsh Master Plan by Wilson Okamoto and Associates, Inc., 1994
- Management Plan for Kawai Nui Marsh Final Environmental Assessment by the Department of Land and Natural Resources, 2000
- Resources Management Plan for Kawai Nui Marsh by the Department of Planning and Economic Development, 1983
- Studies Relevant to Restoration Efforts in Kawai Nui Marsh by Ahahui Malama I Ka Lokahi (hereafter AML), 2004

2.3 Description of Project Area

The 894-acre Kawai Nui Marsh is located on the windward side of Oahu. It is the largest remaining wetland and was once the largest ancient freshwater fishpond in Hawaii. Feeder streams flow into the marsh today at an average rate of 6.8 million gallons of water per day (Drigot, 1982). The marsh provides primary habitat for four of Hawaii's endemic and endangered waterbirds, and contains archaeological and cultural resources, including ancient walled pond fields (loi) where taro was cultivated. Kawai Nui Marsh stores surface water, providing flood protection for the adjacent Kailua neighborhood of Coconut Grove.

The Kawai Nui Marsh slopes 1º-3º seaward (Allen-Wheeler, 1981), the basin ranging in elevation from 20 feet above to just below present sea level (Dames and Moore, 1961). The present surface of the marsh vegetation lies at an average elevation of about 5 feet above sea level (Athens et al., 1992; Wilson Okamoto & Assoc., 1994). The marsh is almost completely covered by a mat of peat formed from dead vegetation that ranges considerably in thickness, and floats on water and water-sediment slurry. This mat has a profound impact on marsh hydrology, habitats, and water quality.

2.4 General Biogeography and Geomorphology of Kawai Nui Marsh

Wetlands and marshes in particular, are usually viewed as environments in transition. While all environments on the planet are slowly changing, for example , mountains wear away by erosion, rivers reduce the steepness of their gradients, for wetlands the processes of change is relatively rapid on a geologic time scale. Smith (1978) described Kawai Nui Marsh as a wetland seemingly well along in the "process of terrestrialization." Terrestrialization is the sequence of physical changes that convert an open body of water such as a pond or lake into a marsh and ultimately into terrestrial forest. Many wetlands arise from infilling of geologic basins that initially were open water ponds or lakes, and this process proceeds, typically within centuries, to alter the near surface hydrology such that a vegetation-covered marsh replaces open water. Mineral soils may accumulate in the basin shoaling it, or emergent vegetation may creep in from the margins, creating peat and providing a matrix which traps water-borne sediment. In the classic case of hydrarch succession (Wilson and Loomis, 1967), a wetland surrounds an open body of water such as a lake, the latter is slowly reduced in area as the wetland develops out into it, and the outer margin of the wetland accumulates soil and especially plant debris as peat, eventually becoming upland in character. At some point, the lake disappears, the water-filled basin having nearly filled with sediment and peat. Because the process is largely the result of the inhabitants altering the environment (e.g., plants producing peat that fills in the basin), it is termed *autogenic succession*. This process is in contrast to allogenic (essentially outside, typically abiotic) succession where infilling is often accelerated by human activities or other outside factors.

This view of succession was once the prevailing paradigm in community ecology, but is not so widely accepted today. There is very little evidence in the literature that the classical description actually leads to upland replacing wetland (Mitsch and Gosselink, 1986). It is perhaps more often the case, where studied in temperate climates, that a bog is the ultimate result (Walker, 1970; Redfield, 1972) and evidence exists that some bogs have remained unchanged for at least the last 1000 years (Mitsch and Gosselink, 1986). Clearly, Kawai Nui appears to show evidence of both transitions. Autogenic succession in the middle of the marsh appears to be forming a stable bog habitat. Around the perimeter of the marsh allogenic succession towards dry land habitats is occurring, primarily through man's interaction. In different parts of the marsh, *allogenic* factors may be more important than *autogenic* factors. It is therefore important that the factors driving change are identified in Kawai Nui Marsh and attempts are made to better define their geographic distribution across the marsh.

Kawai Nui Marsh started as a basin created by first receding sea levels during Pleistocene ice ages (10,000 BC) that promoted valley deepening, and then rising sea level that flooded the valley, creating an embayment (Kraft, 1980). In this tropical setting of northeast Oahu, a coral reef community developed within the embayment, and reef growth—proceeding fastest near the mouth of the bay—eventually reached and maintained itself near the water surface as a barrier reef (AML, 2004). The lagoon behind this barrier reef was now the basin that would ultimately become Kawai Nui ("the big water").

The story of the early transitional changes of this basin is written in the stratigraphy of the bottom sediments (Moye, 2002a). Above the eroded surface of the original valley floor is found a layer of biogenic marine debris: sands and fragments of corals, calcareous algae, and other marine organisms. This is the “Marine Facies” (Moye, 2002a) and its thickness is largely unknown. Above this layer, clay-rich sediment deposits with minimal organic content mark a late lagoon stage. Presumably, the basin had become too brackish to support the previously flourishing marine assemblages. This layer (“Lagoon Facies” of Moye, 2002a) is typically only 4 – 9 inches thick.

During the time of early Polynesian settlement (500 AD), the basin was a large brackish lake with a single southern stream outlet to the ocean, and was utilized as a fishpond (Kelley and Nakamura, 1981; AML, 2004). Sediment brought in by streams draining Maunawili and Kapaa valleys was infilling the more interior (southern) areas of the basin, allowing for the conversion of these lands into pond fields (loi) for the production of food (kalo). Marsh plants surrounded the lake and Hawaiian farmers exercised some control over tidal waters in order to prevent saline water from entering their loi. The early Hawaiians also may have performed maintenance around the lake to minimize encroachment by wetland emergent vegetation (McAllister, 1933; Summers, 1964). Peat formation was likely well underway in areas of emergent wetland vegetation.

Descriptions from 19th century visitors put this lake or fishpond at some 445 acres (180 ha; Summers, 1964) or about all of the “lower marsh” as shown in Figure 1. Just when this feature “disappeared” is a subject of interest and speculation. It was present in some form through the turn of the century (Kelley and Nakamura, 1981), although maps from the late 1800’s (reproduced in Smith, 1978) show open water to be dwindling. Territorial and later USGS maps produced between 1908-1968 (collected in Mann and Hammatt, 2003, one of which, the 1927 USGS map is included as Figure 2 in this report) shows little open water—about the same as today. If these dated observations are reliable, the change in the lower marsh from a large fishpond to a vegetated marsh occurred quickly: mostly within the latter half of the 19th century.

The sequence of events during the critical period (see Table 1) from the mid-1800’s to the mid-1900’s is complicated by the fact that with the coming of sugar cane farming and cattle ranching in the lowlands and valleys of eastern Koolaupoko, greater manipulations of water levels in the basin were initiated. Initially, water was pumped for export to Waimanalo sugar growers from near the outlet of the marsh and downstream of the rice fields. Channels were constructed across the lower marsh to feed the pump and perhaps to drain areas for expanding rice production (Figure 2). Then water level was raised to store more water for export and later lowered to expose more pasture for grazing (Smith, 1978; see AML, 2004).

Natural or manmade changes in water level have profound impacts on the evolution of a wetland from open water lake to marsh or even non-wetland. Raising the basin outlet elevation expands open water by flooding areas of exposed soil and vegetation; lowering the outlet elevation enhances a conversion to dry land, draining wetland areas. Although raising the water level sets back the process of open water loss, this is only true if the outlet water level is set “permanently” high. Otherwise, raising the water level tends to promote sediment accumulation just as

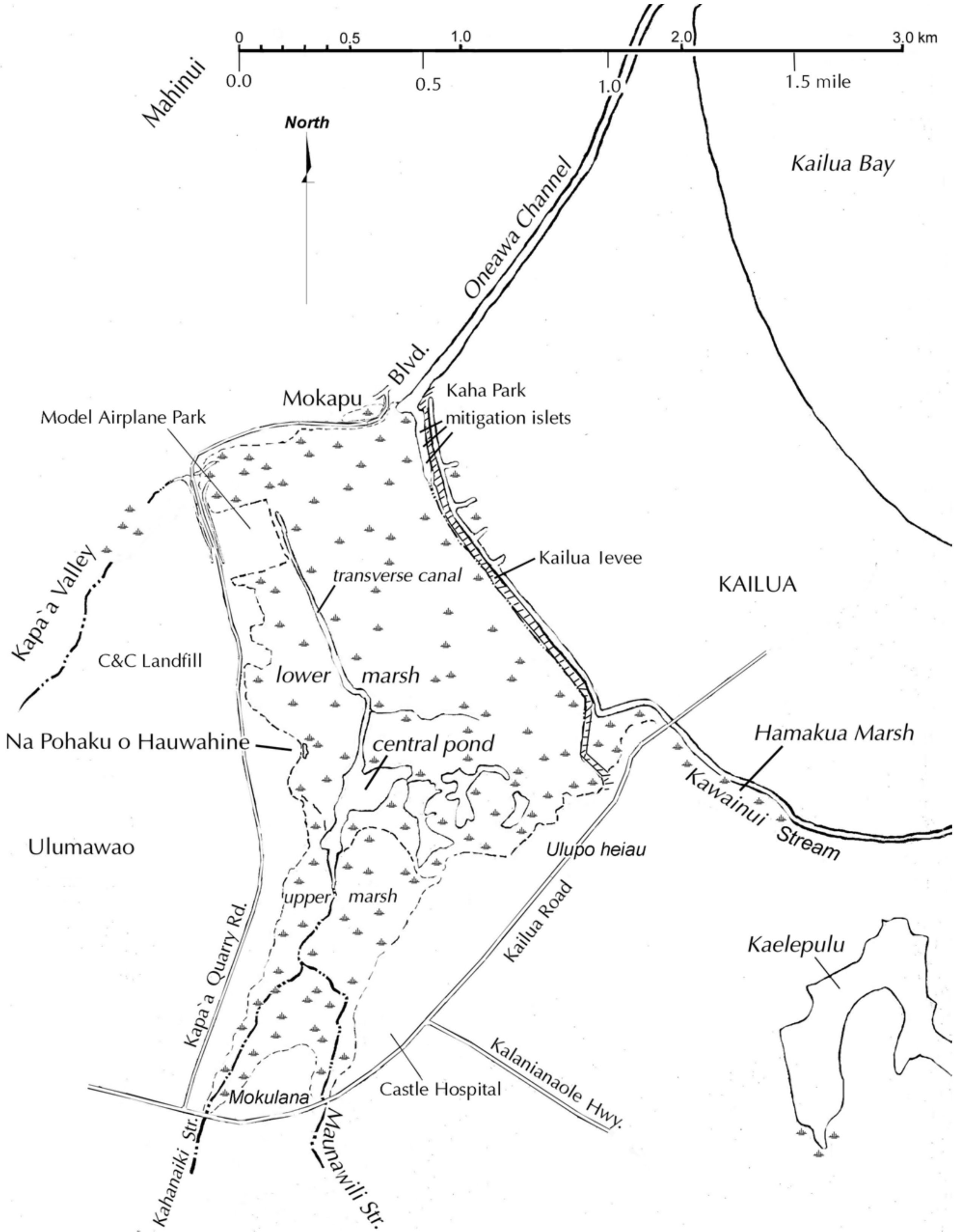

Figure 1. Map of Kawai Nui Marsh and nearby landmarks (after Ahahui Malama I ka Lokahi (AML), 2004).

Table 1. Timeline of Selected Kawai Nui Marsh Events

YEAR	DATE	EVENT
Prehistoric	to 1880's	Lower marsh used as a fishpond; upper marsh used to grow taro. Likely also when Kawai Nui Marsh changed from open pond to vegetation covered marsh.
1872		Population of Koolaupoko District at all time low: 2,028.
1880's		Rice culture replaces taro in the upper marsh. Begin water diversion for Waimanalo Sugar Plantation and other agriculture.
1890's		Cattle grazing on upper marsh; rice culture extending into parts of lower marsh.
1902		Major flood of lands surrounding Kawai Nui Marsh.
1904		Major flood of lands surrounding Kawai Nui Marsh.
1920's		Water pumped from the lower marsh to Waimanalo.
1921		Major flood of lands surrounding Kawai Nui Marsh.
1927		Introduction of rice borer beetle destroys local rice growing industry.
1940		Major flood of lands surrounding Kawai Nui Marsh, primarily Kailua
1950	May 17	Congress authorizes Corps to construct new outlet channel (Oneawa) and flood control levee behind Kailua; Kailua population at 7,740.
1951	March 26-27	Major flood of lands surrounding Kawai Nui Marsh (maximum flood flow of on record, exact value unknown).
1956		Water level lowered to accommodate cattle ranching.
1960		Kailua population at 25,622. Begin pumping of 2˚ treated sewage, 2200 yd^3/day, into marsh.
1963		Major flood of lands surrounding Kawai Nui Marsh.
1965		Cessation of irrigation water withdrawals from the marsh.
1965		Major flood of lands surrounding Kawai Nui Marsh.
1966		Corps flood protection project: levee completed.
1988	January 1	Flood of Coconut Grove area in Kailua
1988	ca. March	C&C creates emergency 45-65 ft-wide trench along interior (mauka) edge of levee.
1989	November	Aerial application of herbicides on ca. 90 ha. (See Section 4.3.4).
1990	February	Test blasting experiment conducted along proposed waterways
1997		Levee-raising & transverse canal excavation completed

lowering the water level can promote sediment removal. Thus, it is not necessarily the case that these manipulations had contrary impacts on the rate (or direction) of a transitional process from open water to wet ground. It is likely that these manipulations were complimentary in accelerating the eventual reduction of open water and ultimately permanent wetland itself. During and after these periods, activities, notably expanded western agriculture and development of housing in the watershed, increased the delivery of both sediment and plant nutrients from the upper watershed, contributing to infilling the basin with eroded sediment and enhanced production of plant debris. Sewage discharges into streams above the marsh and directly into the marsh for over a decade beginning in 1957 likewise promoted plant growth.

The loss of open water described above is a separate process from that of loss of basin capacity. Once a lagoonal feature was created behind the Kailua barrier reef, hydrologic isolation produced an essentially closed depositional basin. The largely autogenic accumulation of marine debris was gradually replaced by allogenic sediment accumulation. Without direct discharge to the ocean and tidal flushing, the basin became a sediment trap. Moye (in AML, 2004) described this process thusly:

> "Numerous factors …affected the rate of sediment accumulation. Reorganization of terrestrial and aquatic ecosystems accompanied variations in Holocene sea level and associated local and global climatic variations. Variations in average annual rainfall and degree of ocean connection and tidal influence determined sediment input and basin flushing. The incidence of major storms, tsunamis, and other natural disasters may have periodically affected basin sedimentation. Within the last 1500 years, surface disturbance accompanying increasingly invasive anthropogenic land use practices may have facilitated accumulation of terrestrial sediments in the Kawai Nui Basin. Sediment accumulation may have increased significantly during rapid urbanization of the Kailua watershed during the 1970's through 1990's."

Infilling of the basin with sediment is a less visible, although no less important, process in the transition from open water to marshland. Hydrology and basin configuration in relation to outside sources of sediment establish where sediments are deposited. In Kawai Nui Marsh, the large Maunawili watershed inland of the marsh is certainly the source for much of the sediment which is primarily responsible for the character of the "upper marsh" being much different than that of the "lower marsh" (Figure 1). However, erosion of soils from slopes bordering the basin has also contributed to the infilling of the basin (WOA, 1994). Moye (AML, 2004) claimed his observations at Na Pohaku o Hauwahine suggest a major influx of eroded topsoil from the adjacent slopes within the last 50-100 years.

Direct infilling of the marsh perimeter has occurred since the early 1900's as a result of landfill and quarry operations, road building, farming and placement of flood prevention structures.

Quarry operations on the northwest corner of the marsh constructed the Kapaa Quarry Road and produced thousands of cubic yards of "overburden" material from what is now the City and County landfill. The quarry road was constructed across the northwest corner of the marsh, effectively isolating about 27 acres of wetland from the body of Kawai Nui Marsh. The excavation to create the initial roadbed remains as the stagnant canal on the northern side of the road. Overburden soil was placed 30-50 feet deep over wetlands, a stream, and farmlands to create what is now the Kapaa Triangle light-industrial area. Wetlands between the industrial area and the Kapaa Quarry Road, presently a green waste facility and model airplane field, became a sanitary landfill and was eventually capped with dirt in 1965. Table 2 contains a summary of the infilling activities and the marsh area lost.

Recognizing the separate processes diminishing the capacity of the Kawai Nui Basin is central to understanding the role vegetation is playing in the marsh. A majority of studies that have

Table 2. Acres of Kawai Nui Marsh filled during modern times.

LOCATION	APPROXIMATE DATE	ACRES FILLED
Quarry Phase-I tailings – Model Airplane Field	1953	23
Quarry Road Extension North	1950	3
Kalanianaole Hwy.	1951	5
Kailua Landfill – Present location of Kapaa Triangle & Green Waste Facility	1965	27
Flood Control Levee	1965	9
TOTAL		67

attempted to broadly define the vegetation of the marsh (Smith, 1978; Drigot and Seto, 1982; AML, 2004) have all recognized two broad wetland categories; allogenic sediment deposits, and autogenic peat deposits. Of particular interest for the present report is the impact on transitional processes of the introduction during the last 200 years of numerous aggressive alien plants. Aggressive alien invasive plant species will be discussed in detail in the next sections, but it needs to be emphasized that the marsh was not without "aggressive" wetland plants prior to the modern period. The present research effort demonstrates that substantial areas of the modern marsh are dominated by emergent plant species native to the Hawaiian Islands.

2.5 Surface and Groundwater Quantity, Quality, Drainage, and Use

2.5.1 Hydrogeology of the Marsh

The historic outlet for the marsh was through the existing Kawai Nui Stream (Figure 1), joining with Kaelepulu Stream and flowing to the ocean at the south end of Kailua Beach. Because of chronic flooding of the developed area of Coconut Grove throughout the first half of the 20th century (Table 1), Congress authorized the U.S. Army Corps of Engineers to take action. The Corps completed a Survey Report in May 1950 and a General Design Memorandum in 1957. The report detailed the inadequacy of the existing streams to safely transport floodwaters to the ocean. Large flood flows would overtop the existing stream banks and flood the Coconut Grove area. The report led to the construction of a trapezoidal channel, 9,470 feet long (Oneawa Channel), and an earthen levee with a crest elevation at 9.5 ft MSL and a length of 6,850 feet. The levee diverts floodwaters from Kawai Nui Stream to the Oneawa Channel, which connects the marsh to the ocean at Kapoho Point at the north end of Kailua Bay.

Since project completion in August 1966, dense, floating wetland vegetation continued to develop within the marsh impeding the movement of water into the interior of the marsh and out the Oneawa Canal. This resulted in water levels at the southern end of the marsh exceeding the 9.5 ft MSL crest elevation of the original levee. The New Year's Flood on December 31, 1987 through January 1, 1988 exceeded the crest of the levee and Coconut Grove sustained severe flood damages. Following the New Year's Eve storm, an emergency ditch was excavated on the marsh side of the levee to increase outflow to the marsh. However, this ditch was inadequate to protect Coconut Grove from flooding unless the levee height was increased.

In response to the New Year's Flood, the City and County of Honolulu and the U.S. Army Corps of Engineers developed a Detailed Project Report and Environmental Impact Statement dated July 1992, which recommended increasing the levee height by four feet and adding a four feet high concrete floodwall on top of the existing levee. This project was completed in June 1997.

2.5.2 Streams and Surface Water

The largest natural water source into Kawai Nui Marsh is Maunawili Stream, which drains a 5.58 square mile watershed. The smaller Kahana Iki Stream's watershed is approximately 1.92 square miles and feeds the marsh with less than 1/6 of the water contributed by Maunawili Stream. Both streams flow beneath Pali Highway near Maunawili with a confluence in the marsh approximately 2,800 feet downstream of the highway. Kapaa Stream, also a small intermittent stream, enters the marsh near the present location of the industrial park.

Table 3 summarizes major hydrological features in the Kawai Nui Watershed. The total freshwater input to Kawai Nui Marsh is estimated at 6.8 mgd (25,700 m^3/day) to 9.5 mgd (35,900 m^3/day), with 6.3 mgd (23,800 m^3/day) discharged to Kailua Bay through the Oneawa Channel and 3.2 mgd (12,100 m^3/day) lost to evapotranspiration (AML, 2004).

The original drainage through Kawai Nui Stream was redirected to Oneawa Channel by construction of the aforementioned dike along the northeast side of the marsh. The modified stream channel remains, draining the north side of the levee. Oneawa Channel drains the marsh from the north corner. The upper streams, remnant ponds and all vegetated areas in the marsh are fresh water, with an average elevation of 3-4 feet above mean sea level. The water within Oneawa Channel is brackish and is influenced by tidal fluctuation.

2.6 Point and Non-Point Source Pollution

2.6.1 Wastewater

When increased urbanization and population size exceeded wastewater infrastructure capacities beginning in 1957 and 1961, partly treated effluent was discharged directly into Kawai Nui Marsh in at least two locations to the southern part marsh. Nutrient loading stimulated growth of the vegetation in the Marsh, far exceeding the mass of total solids from the wastewater. Total volume of effluent was estimated at 1,200 m^3 per day from the two sites. Two additional sewage treatment plants emptied 570 m^3 directly to Maunawili Stream beginning in 1965 (Smith, 1978).

All of these flows ceased in the early 1970's when the Kailua Wastewater Treatment Plant began receiving these flows. A first order estimate is approximately 350 tons of total solids introduced to the marsh from wastewater (50 mg/L for 10 years).

Table 3. Summary of Significant surface water and topographical features in the Kawai Nui Watershed.

Kawai Nui Marsh	
Maunawili Valley	Maunawili Valley contains multiple streams and springs that feed into Kawai Nui Marsh
Kaelepulu Pond	A 90-acre estuary (Enchanted Lake) once linked to Kawai Nui Marsh. Co-owned by the Enchanted Lake Resident's Association and a private landowner.
Kaelepulu Stream	This City-owned stream drains Kaelepulu Pond to the ocean at the Kailua Beach Park. Also receives drainage from the Kawai Nui Stream
Kawai Nui Marsh	The 697-acre Kawai Nui Marsh is the largest wetland in the state and also functions as a large sedimentation basin.
Kawai Nui Stream	The now dead-end remnant stream that used to drain the marsh only receives drainage from the area mauka of the town of Kailua. Often referred to as the "Hamakua Canal".
Oneawa Channel	Completed in 1956 as part of the original Kawai Nui Marsh Flood Control Project, the canal features a 9,470-foot-long trapezoidal channel. The channel begins at the northwest corner of Kawai Nui Marsh and empties into the northern edge of Kailua Bay.

(KBAC 2002)

2.6.2 Flooding/Sedimentation

The marsh acts as a flood control reservoir, ponding runoff from major rainfall events on the watershed that is gradually discharged to Kailua Bay. The marsh is also a sediment trap and sink for nutrients and pollutants, reducing negative impacts associated with runoff into Kailua Bay.

Expanding urbanization into the upper Kailua watershed after 1966 increased soil erosion and produced higher rates of marsh sedimentation, steadily decreasing the water storage capacity. The peat layer, in place since before the turn of the century, impedes flow through friction and damming, ponding water in the marsh and slowing outflow. Reduced storage capacity and ponding contribute to the threat posed by floodwater topping the levee. An average annual sediment yield for the watershed in the early 1990's was computed at 1,049 tons/square mile, or 10,081 tons/year to the marsh (KBAC 2002).

2.7 Circulation

Prior to 1956, water from Kawai Nui Marsh flowed into Kawai Nui Stream to the east. The original flood control project started in 1951 blocked this flow completely by 1966, causing the Kawai Nui Stream to suffer from poor water circulation. The lack of flow into Kawai Nui Stream presently results in stagnation of the entire stretch of the channel down to its intersection with Kaelepulu Stream.

2.7.1 Climate and Rainfall

Kawai Nui Marsh is located within a climatic region known as the windward lowlands. On Oahu, this region lies more or less perpendicular to the prevailing flow of the trade winds, and is moderately rainy, with frequent trade wind showers. Rainfall varies from approximately 8 inches per month during the winter, to 4 inches per month during the summer. Mean annual rainfall at the site is approximately 60 inches. Annual rainfall totals generally increase in the mauka portions of the marsh area. Where Maunawili Stream merges with Kawai Nui Marsh, average rainfall is 60-65 inches per year (AML 2004).

Temperatures at the site are generally mild and fluctuate little throughout the year. The mean annual temperature is approximately 74 degrees Fahrenheit (°F); temperature extremes at the site range from 52-93°F. The mean daily temperature during the winter is 71.6°F, while the mean daily temperature in the hottest summer month (August) is 77.4°F (AML 2004).

2.8 Stakeholder Identification

The Department of Land and Natural Resources is the proposing agency for this project. This project is being funded and completed by the U.S. Army Corps of Engineers. Stakeholders in this project are:

- U.S Army Corps of Engineers
- U.S. Department of Fish and Wildlife
- State of Hawaii, Department of Land and Natural Resources
    - Division of Aquatic Resources

- Division of Forestry and Wildlife
    - Division of State Parks
    - Division of Historic Preservation
    - Division of Land
- State of Hawaii, Department of Health, Office of Environmental Quality Control
- City and County of Honolulu, Department of Planning and Permitting
- Hawaii Audubon Society
- Ahahui Malama i ka Lokahi (AML)
- Ducks Unlimited
- Kawai Nui Heritage Foundation
- Kailua Bay Advisory Council
- Hoolaulima ia Kawai Nui
- Kailua Neighborhood Board
- Hawaii's 1000 Friends
- Le Jardin Academy
- The Wildlife Society Hawaii Chapter
- Windward Ahupua'a Alliance

2.9 Ecological Communities and Botanical Surveys

The most conspicuous characteristic of Kawai Nui Marsh today is the predominance of emergent vegetation, both floating and standing, which covers most of the 894-acre expanse of the marsh, giving it a deceptive appearance from a distance of being a lush green pasture. Upon closer examination, however, it becomes apparent that the cattle confine themselves to grazing the upper, wet meadow and that the vast interior remains a vegetation and peat-clogged body of water.

Smith (1978) utilized a classification scheme developed by Dansereau and Segadas-Vianna (1952) and Rigg (1942) to classify the vegetation of Kawai Nui Marsh into two types: (1) a **bulrush marsh** with floating mat of live vegetation and peat development and (2) a **bog meadow** of California grass, flooded only during the rainy season and resting on mineral soil rather than peat.

Drigot and Seto (1982) divided the vegetation comprising Kawai Nui Marsh into several distinct plant assemblages:

The **grass community** consists principally of California grass (*Urochloa mutica*) interspersed with honohono (*Commelina diffusa*), arrowhead (*Sagittaria latifolia*), and scattered stands of cattail (*Typha latifolia*). California grass (also known as paragrass) is a large, perennial grass that forms thick patches up to two meters high in Kawai Nui Marsh, and spreads by long running stems. California grass can establish thick mats in wet areas such that "...ponds have been completely lost to view because of the floating thick layers of vegetation". (Bown et al, 1966)

A **bulrush community** consists of *kaluha* or bulrush (*Schoenoplectus californicus*), saw-grass (*Cladium jamaicense*), and *neke* or swamp fern (*Cyclosorus interruptus*). The grass and bulrush communities each occupy approximately equal areas in the marsh. Together they occupy several hundred acres of the wetland, excluding them as use for waterbird habitat.

A **shrub and tree community**. On the outer edges of the grass and bulrush plant communities along the slopes above the marsh, there exists a tree and shrub community consisting primarily of koa haole (*Leucaena leucocephala*), guava (*Psidium guajava*), Chinese banyan (*Ficus microcarpa*) and monkeypod (*Samanea saman*). Linda Smith (MS, Botany, UH Manoa) noted about 119 plant species occurring in the shrub and tree community; including eight native species, none of which are endangered.

An **open-water community** exists along the inner edges of the grass and bulrush communities, in the marsh interior, at the marsh's borders, as well as in the canals entering and exiting the marsh. The open-water today consists of floating vegetation, which is mostly covered, by floating plants.

A dominant species in open water areas along the levee (eastern shore) is water lettuce (*Pistia stratiotes*), a floating aquatic herb with a rosette of leaves and abundant dangling dark roots. Water lilies (*Nymphaea* sp.) and the water hyacinth (*Eichhornia crassipes*) are the predominant floating plant species that occupy the remaining open water areas in the marsh interior. A highly aggressive aquatic fern known as kariba weed or *Salvinia molesta* is present in drainage canals along the northwestern areas of the marsh along the Kapaa Quarry Road.

More recently, Guinther (AML, 2004), mapped vegetation communities in the marsh, recognizing an open-water assemblage (with variants), three floating peat mat assemblages: a) saw-grass, b) bulrush, and c) cattail, and several wet-meadow or pasture grass assemblages: a) California grass, b) elephant grass (*Pennisetum purpureum*), c) Hilo grass (*Paspalum conjugatum*), and other mostly minor patches, including hau (*Hibiscus tiliaceus*) around the margins of the wetland. Essentially two upland or non-wetland assemblages surround the marsh: a haole koa (*Leucaena leucocephala*) scrub and Guinea grass (*Panicium maximum*) in somewhat drier areas (closer to the coast) and a haole koa and monkeypod forest in slightly wetter areas (away from the coast).

It is apparent from previous efforts that the plants of the marsh co-occur in combinations that may defy easy classification. Most "distinct" assemblages are distinct only over a limited area, merging with others along broad gradients or containing, as minor components, species that are dominants or co-dominants in adjacent assemblages.

2.10 Rare and Endangered Plants and Animals

Kawai Nui Marsh and Neighboring Hamakua Marsh are designated as "Wetlands of International Importance" by the Ramsar Convention on Wetlands (Ramsar, Iran, 1971, www.ramsar.org). The marsh is presently home to four endangered species: the Hawaiian duck (Koloa), Hawaiian stilt (Aeo), Hawaiian gallinule (Alae Ula), and the Hawaiian coot (Alae keokeo). Reviews of plant lists of past botanical surveys of the marsh noted the absence of any endangered flora (Smith, 1978; Guinther, 2004, pers. comm.; Morin, 2006, pers. Comm.; Bruegmann, 2006, pers. Comm.). An endangered species of sedge, *Cyperus trachysanthos*, is present at Hamakua Marsh along Kawai Nui Stream, just outside of the study area.

The State DLNR is the local sponsor for the *Kawai Nui Marsh Restoration Project*, an ecosystem restoration project being developed under the Continuing Authorities Program, Section 1135 of the Water Resources Development Act of 1986 by the Corps. The project is currently in the Preconstruction Engineering and Design (PED) phase, with construction award scheduled for October 2006. However, award is subject to the sponsor securing a land transfer for the project site from the City and County of Honolulu to the State.

The restoration project focuses on the southern portion of the marsh on habitat restoration primarily for the Hawaiian stilt and the Hawaiian Moorhen. It includes creating more than 60 acres of mudflats and shallow ponds, restoring 2,800 lineal feet of riparian habitat along Kahana Iki and Maunawili Streams, installing predator exclusion fencing, implementing a predator trapping program, controlling vegetation on 17 acres, and assuring a water supply system to the ponds. The existing thick floating mat of vegetation has been steadily growing and has the effect of converting a once thriving water-based habitat into an upland ecosystem. These new shallow ponds would assist in natural recovery and passage of migratory species. Native diadromous aquatic species such as the endemic goby (oopu nakea) and shrimp (opae kalaole) have been found in the Oneawa Channel, but are absent or present in very small numbers in the Maunawili Stream system. Flora in and around the marsh will be discussed in detail in the following section of this report: “Botanical and Habitat Study”.

2.11 Aerial and/or Space Imagery and Maps

A satellite image from Space Image Inc., dated January 9, 2004 is the most current image used for this study. Vegetation composition and boundaries were ground-truthed as part of the field component of this project. Other photographic and map resources that include the Kawai Nui Marsh area are listed in Table 4. These images, four of which are included in this report, document the large changes both in Kawai Nui Marsh itself and the effects of the changes of its surroundings over the past 120 years (Figure 2, Figure 3, Figure 4, and Figure 6).

Table 4. List of images and maps available for the Kawai Nui Marsh area, from 1884 - present.

Date	Image Information
1884	Map of marsh area, State of Hawaii Land Survey Office, Honolulu
1890	Map of marsh area, B.P. Bishop Museum, Honolulu
1899	Map of marsh area by W.A. Hall, State of Hawaii Land Survey, Honolulu
1908-1913	Topographic map: Hawaii Territorial Survey, Sheet 10; reproduced by Mann and Hammatt, 2003
1926	Aerial Photo. U.S. Army War Department. U.S.G.S file copy. Honolulu
1927-1930	Topographic map: USGS Map 1:20,000; reproduced by Mann and Hammatt, 2003 (Figure 2 in this report)
1943	Topographic map: USGS Map 1:20,000; reproduced by Mann and Hammatt, 2003
1945	Aerial Photo. Reproduced by M&E Pacific 1990
1951-54	Aerial photo: USACE; Printed by Detailed Land Classification, Island of Oahu (1963)
1955	Aerial Photo. R.M. Towill Corp. Honolulu
1962	Aerial Photo. R.M. Towill Corp. Honolulu
1968	Topographic map: USGS Map 1:20,000; reproduced by Mann and Hammatt, 2003
1969	Aerial Photo. R.M. Towill Corp. Honolulu; reproduced by Mann and Hammatt, 2003
1971	Aerial Photo, U.S. Navy. Naval Undersea Center, Hawaii Laboratory, Kailua Hawaii
1974	Aerial Photo. NASA U-2 photo. State of Hawaii, Department of Planning and Economic Development. Honolulu
1981	Aerial Photo. USACE, Reproduced by M&E Pacific 1990
1983	Topographic map: USGS Map 1:20,000; reproduced by Mann and Hammatt, 2003
1986	Aerial Photo. Reproduced by M&E Pacific 1990
1988	USACE bathymetry CAD map, 3 sheets, by Austin Tsutsumi & Associates
1990’s	Aerial photo: AML (after C&C dredging, before levee enhancements)
July 14, 1992	Scanned and registered aerial photograph of Kawai Nui Marsh, Kailua, Oahu. Photo scanned at 150 dpi by NGA (formerly Defense Mapping Agency). The 28"x36" natural color print had an approximate scale of 1"=400’. RM Towill Corporation photo number 8827-2 (Figure 3 in this report)
June 2, 1996	Air Survey Hawaii No. 1588 1-2; Dave Smith, DOFAW
July 13, 1996	Scanned and registered aerial photograph of Kawai Nui Marsh, Kailua, Oahu by Air Survey Hawaii. Archive No. 6960703
March 20, 2001	U.S.D.A. (Natural Resources Conservation Service, Farm Service Bureau) DOQQ Mokapu_sw.SID converted to natural color by U.S. Army Corps of Engineers, Honolulu District, Technical Integration Group (Figure 4 in this report)
January 9, 2004	IKONOS Satellite Image, by Space Image, Inc. (Figure 6 in this report)

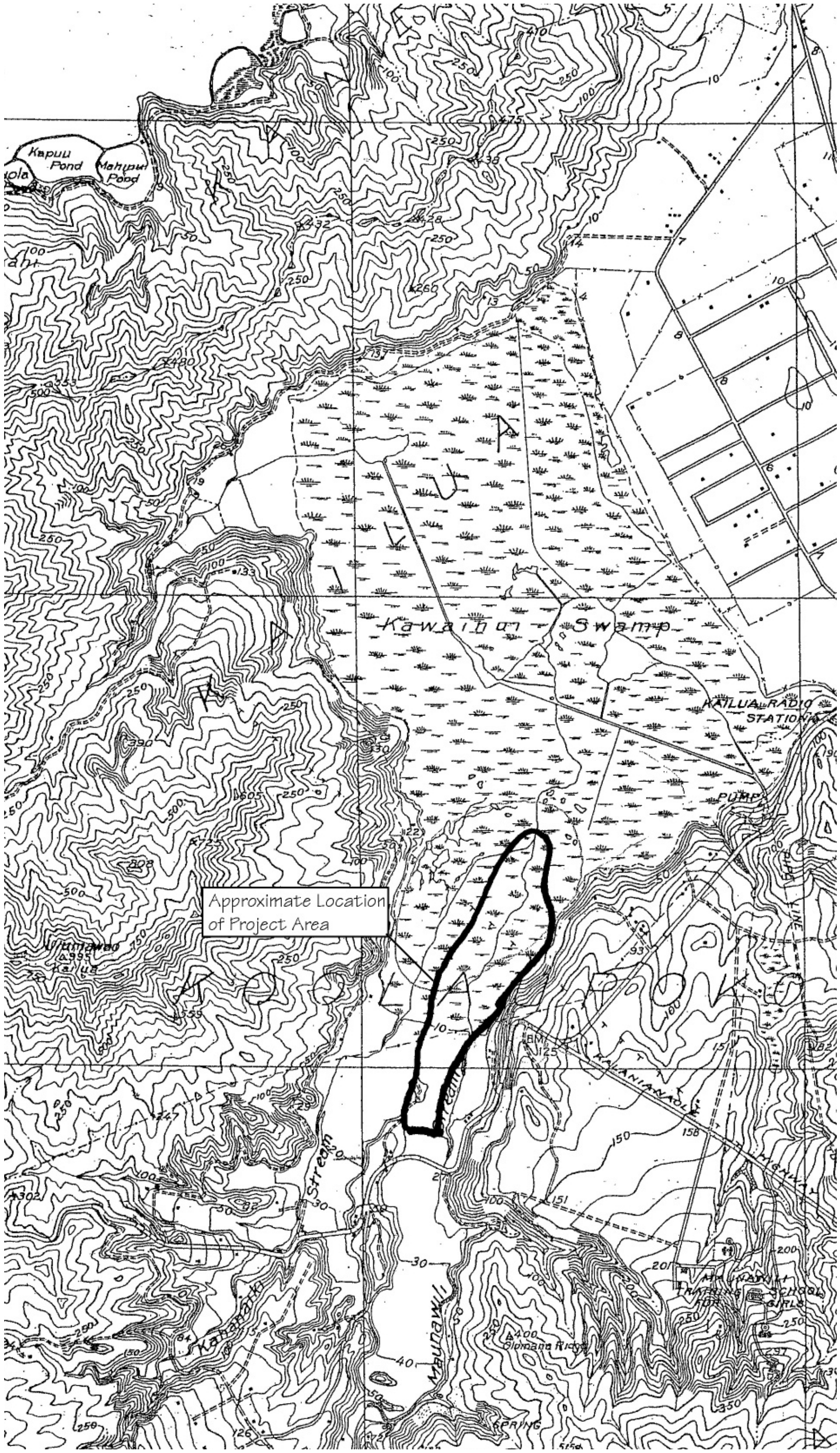

Figure 2. Portion of the 1927 USGS Map of the Kawai Nui Marsh. Reproduced in Mann and Hammatt, 2003. The marked area refers to a DLNR water bird habitat restoration project in the upper marsh, which is in the Preconstruction Engineering and Design Phase (See Section 2.10, on page 12).

Figure 3. 1992 Aerial photo of Kawai Nui Marsh. Open water areas artificially enhanced. Scanned by NGA (Formerly Defense Mapping Agency) RM Towill Corporation. Photo No. 8827-2. Scale unavailable.

Figure 4. 2001 Aerial Photo (DOQQ) of the Kawai Nui Marsh. An example of the images used to track vegetation and use changes in the marsh.

Section 3. Botanical and Habitat Study

3.1 Methods

The botanical and habitat survey sought to characterize the existing vegetation cover, peat mat distribution, and basin bathymetry of Kawai Nui Marsh using a combination of ground surveys and aerial remote sensing images.

Eighty-eight plots along 11 transects of variable length, were surveyed between July 11 and August 18, 2005 (Appendix B, Map 2). Using a recent satellite image (Figure 6), and input from past and present researchers at the Kawai Nui Marsh, transects were selected to include all representative vegetation assemblages. Proposed transects were marked on a digital map in a handheld GPS device. In the field, effort was made to follow planned transects. Along each transect, plots were spaced every 150 feet or less. All parameters, abiotic and biotic, were measured at every plot with the exception of transects 4 and 9.

Due to the thickness of the vegetation, it was not possible to randomize the location of the 11 ft^2 ($1m^2$) quadrant. As each plot location was reached (150 foot spacing along GPS transit line) the quadrant was placed directly in line with the transect line over undisturbed vegetation. At each plot, plants within the quadrant were identified, and percent cover values estimated (Figure 5). Any additional plant species encountered along the transect prior to the plot, including those in the immediate vicinity were also noted. The presence of water birds and/or mammals was also recorded, although this occurrence was very rare.

Figure 5. Placement of 11 ft^2 (1 m^2) quadrat for percent cover estimation, in this case 100% California grass.

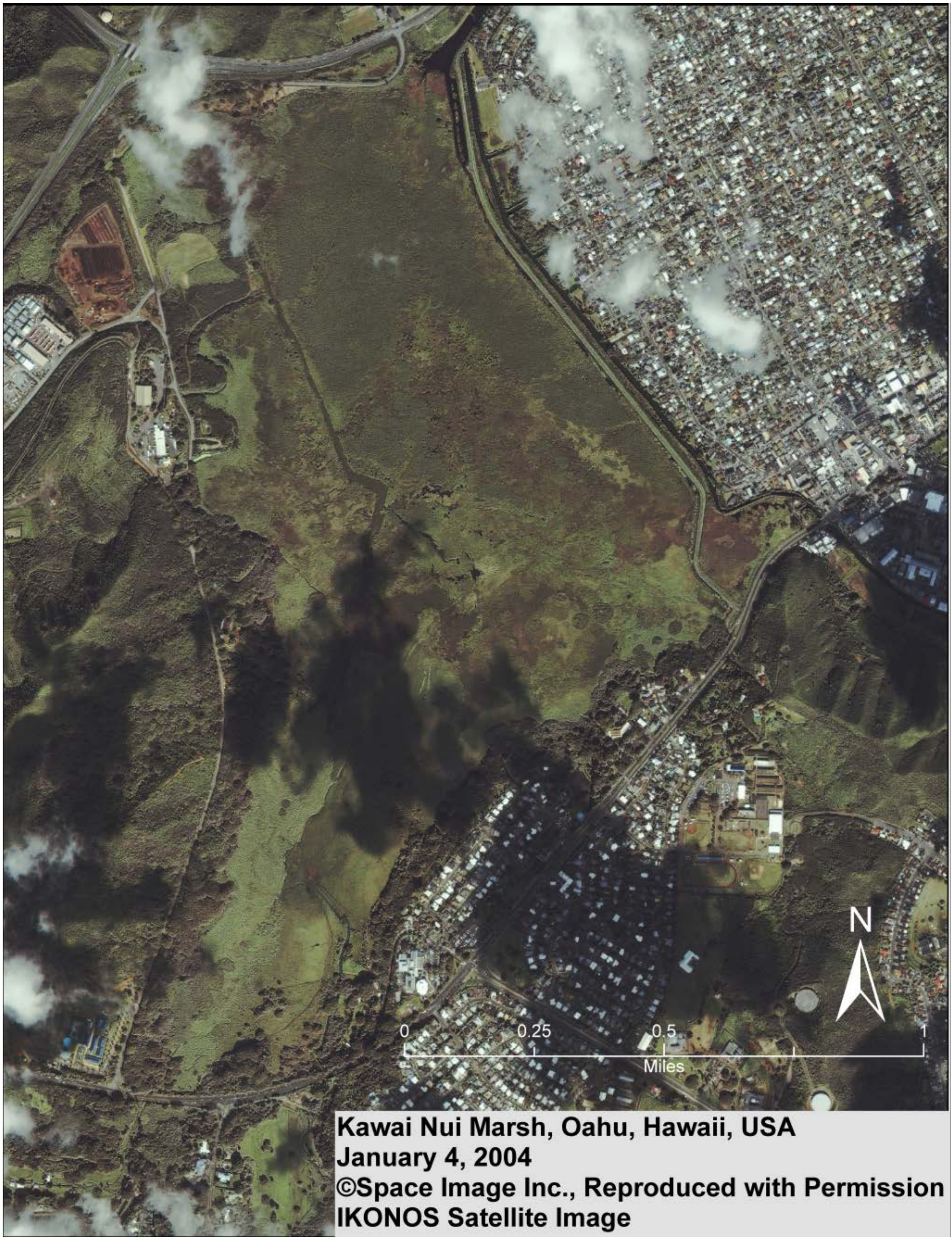

Figure 6. Recent IKONOS Satellite Image of Kawai Nui Marsh (Multi-spectral) used to generate vegetation cover map.   Vegetation cover in the cloudy sercation in the center was discernable using the infrared band.

3.1.1 Measuring Thickness of Peat Layer

Vegetation was cleared to the top of the peat layer using a hand sickle. After cutting an approximately 20-inch diameter hole through the peat with a long-bladed spade (Figure 7), peat thickness was measured using PVC calipers (Figure 8). It was not possible to excavate/cut through peat greater than 3 feet thick (arms length; Figure 9) although peat thickness exceeded three feet at many of the plots. In such cases, peat thickness was measured by pushing the narrow end of a surveyor's pole through the remaining peat and estimating the distance at which the resistance changed, presumably signifying the pole breaking through the bottom of the peat layer.

3.1.2 Water Quality

A *YSI Datasonde* (Model 6920) water quality measuring instrument was deployed for 3-4 minutes immediately after each hole was excavated (Figure 10). The device measured temperature, conductivity, pH, dissolved oxygen (DO), and turbidity every 30 seconds (a minimum of six readings per site) and recorded data to memory. Every effort was made to place the instrument as deep as possible. Where the hole penetrated the peat mat, the Hydrolab was placed through the hole and off to the side of the opening, under the mat. Because most plots had peat thickness in excess of three feet, the datasonde was placed as deep as possible in the excavated hole. Ultimately, turbidity data were omitted from the analyses after determining that the excavation disrupted the water, biasing the results.

3.1.3 Depth Measurements

Depth-to-mud was measured by fixing a 6-inch metal disc (dulled saw blade) to the end of a survey pole, and dropping the pole through the excavated hole until it came to rest, reading the water level on the pole (Figure 11). Where the hole did not penetrate through the entire mat (most cases), the pole, without the disc, was forced through the peat, and depth-to-mud estimated once resistance was encountered below the lower edge of the peat mat.

Depth to a hard surface (Figure 11) was determined by pushing the pointed end of the pole through the hole and down through the mud as far as physically possible. In many cases, a hard surface was never encountered, exceeding the length of the 16.4-foot pole. Where a hard surface was encountered, depth was measured at the water level. Water level in the marsh was recorded on each survey date by reading a staff gauge set up at Na Pohaku o Hauwahine (AML, 2004) and correlated with the NOAA level gauge (#16264600) on the upper east side of the marsh.

3.1.4 Points of Interest

Additional data were collected from 33 "points of interest" throughout the marsh. These included notable vegetation transitions, points where a transect terminated at the transverse canal, and encounters with miscellaneous bodies of open water within the Marsh. These data were collected in a less prescribed manner and therefore were not grouped with the main plot data.

Figure 7. Peat "core." Cut out using spade and removed, exposing water beneath.

Figure 8. PVC Caliper used to measure peat thickness. The tail of the "L" is under the peat in this photo.

Figure 9. Excavation of peat material by hand. If the peat was greater than arms length thick, an alternate method of measuring thickness was employed (see text).

Figure 10. YSI Datasonde deployed in cut-out hole taking water measurements.

Figure 11. Survey pole with 6-inch metal disc (dulled saw blade) inserted in hole (in this case measuring depth to hard bottom). Depth to mud was measured by reversing the pole and inserting the pole disc first.

3.1.5 Data Entry and Analysis

Data were recorded manually and electronically in the field, and were downloaded in the office and checked for errors the next day. Data were merged into a Microsoft Access® database and ArcGIS map projects (ESRI) for analysis. Data from previous studies was also entered into the GIS. Data were entered manually where electronic formats did not exist, including spatial and bathymetric data from 1988 Austin Tsutsumi and Associates. The vegetation map was entered into the GIS by hand, tracing significant boundaries on the 2004 satellite image (Figure 6). Automated mapping programs (using supervised and unsupervised classification) were not able to resolve vegetation cover sufficiently.

3.2 Species Accounts

This section presents descriptions of common plant species found in Kawai Nui Marsh, as well as some uncommon species that could potentially be invasive in the marsh. Appendix B lists 183 species identified to date from Kawai Nui Marsh or on lands adjacent to the marsh, including species listed in previous studies. 118 of the 183 species are plants associated with upland or non-wetland environments. Only 65 of the listed species are reported growing in the marsh. This finding is not unusual because wetland habitats are not suitable for most plants. The physical limitations impacting most species adapted to upland conditions arise from flooding and saturated soils, which result in inadequate amounts of oxygen reaching plant roots. Tissues are killed in species not adapted to low oxygen conditions in soil or water (in effect, the plant "drowns").

Descriptions of the most prevalent 25 plant species are presented, arranged in rough order from most dependent upon an aquatic environment to least dependent. The descriptions here focus on the relationship between the plant and the marsh and the potential invasiveness of the plant.

3.2.1 Duckweed, *Lemna aequinoctialis* Welw.

Duckweeds (Family Lemnaceae) typically appear as small, bright-green leaves (3-6 mm long) floating on the water (or wet mud) surface. In *Lemna aequinoctialis*, a single, thin white root extends down from the underside. Whether *L. aequinoctialis* is native or an introduced species in Hawaii has not been determined despite being recorded in Hawaii for over 100 years. *L. aequinoctialis* is considered native to other islands in the Pacific. *L. aequinoctialis* is not discussed in Smith (1978), although three species are listed in the reference's Table 3: (*L. minor [=L. aequinoctalis]*, *Spirodella punctata [=Landoltia punctata]*, and *Wolffia columbiana [= W. globosa]*). Elliot and Hall (1977) list *Spirodella polyrhiza* from Kawai Nui Marsh, another species that might be either native or introduced (Wagner, et al., 1990).

All of these duckweeds are ecologically similar: small and only conspicuous when massed over the surface of a pond. *L. aequinoctialis* appeared on its own in the newly opened ponds at Na Pohaku o Hauwahine in late 1999, completely covering the water surface by February 2000. However, this plant disappeared during summer low water and later did poorly in larger ponds with fish present. *L. aequinoctialis* reappeared briefly in Spring 2001, but has not reappeared at Na Pohaku o Hauwahine since.

It remains worth mentioning that various duckweed species are sometimes listed on web sites as "invasive" or even "extremely invasive," although these tend to be sites that lack credibility both with regard to the use of the term "invasive" and a demonstrated understanding of the ecology of the plants listed. Generally, Duckweed species can reproduce very rapidly under the right conditions and may quickly cover most of a water surface in certain circumstances. However, such blooms tend to be seasonal and limited to still waters. *L. aequinoctialis* presents no known risks in Kawai Nui Marsh, although Pacific Island Ecosystems at Risk (USFS) (PIER 2005) describes "other" species as potentially invasive if they displace native species.

3.2.2 Water hyacinth, *Eichhornia crassipes* (Mart.) Solms

Water hyacinth (Family Pontideriaceae) is a floating plant distinguished by each leaf having an inflated petiole (leaf stem) forming an air-filled float. The leaves are arranged in a rosette, from the base of which feathery roots extend downwards into the mud or water. Water hyacinth spreads rapidly by runners (stolons). Conspicuous violet flowers develop on a stalk rising up from the basal rosette.

Smith described water hyacinth as "occur[ing] rarely among the bulrushes" and "most conspicuous in a small pond (about 5 x 10 m [6 x 11 yd]) near Kailua Road, where it occasionally forms a complete cover." However, this species is mentioned in Conant (1981) as the main component of the choking vegetation of open water areas of the marsh. That is the case today, where nearly all of the open water of the marsh (central pond and transverse canal) is covered more or less completely (areas remain open, but these shift around) by water hyacinth

Figure 12. Water hyacinth covering the entire transverse canal (taken 8/2005).

(Figure 12). Shallenberger (1977) noted that a major storm in 1977 cleared large portions of the marsh open water, significantly increasing the quantity and quality of waterbird habitat that year.

Water hyacinth is sometimes noted growing on water-saturated soils and in isolated ponds in the marsh, where it appears to have been carried by flooding from the population in the Central Pond. Rarely seen at the wetland enhancement area at Na Pohaku o Hauwahine, water hyacinth presumably disperses via seeds or seedlings carried in by animals.

Eichhornia crassipes is one of the most serious invasive species in the tropics. Its growth rate is among the highest of any plant known: hyacinth populations can double in as little as 6-18 days (Uni. Florida, 2005). Water hyacinth is listed as an invasive species in Hawaii by PIER (2005).

3.2.3 Water lettuce, *Pistia stratiotes* L.

Water lettuce (Family Araceae) is another floating plant that grows in the form of a rosette of fuzzy, pale green leaves resembling a small head of bib lettuce. It is an introduced species common in freshwater canals in Hawaii and noted by Smith (1978) without comment or indication where it was observed in the marsh. It was not seen in the central waterways of the marsh, being common only along the inside of the levee in Kawai Nui Marsh.

Water lettuce is regarded as a pest species throughout the Southeastern US, and is listed by PIER (2005) as invasive in Hawaii. It is a potential pest in taro loi, but presently of limited concern in Kawai Nui Marsh.

3.2.4 Kariba weed, *Salvinia molesta* D.S. Mitch.

Salvinia molesta (Family Salviniaceae), commonly referred to by its genus names "*Salvinia*" in Hawaii, is also known as kariba weed. Kariba weed is a naturalized, floating fern that has proven to be very aggressive in warm climates, growing rapidly over the surface of open water bodies. Kariba weed was not noted by Smith (1978) and probably was not present in the marsh until relatively recently. This plant was noted as naturalized and growing in Kaelepulu Pond (Enchanted Lake) and Lake Wilson (Wahiawa Reservoir) in April 1999 (Palmer, 2003), and subsequently found growing in the drainage channels along Kapaa Quarry Road where it persists to this day, despite attempts at eradication there.

Kariba weed (*Salvinia molesta*) is regarded as a significant pest species in many tropical and subtropical locations (Parsons and Cuthbertson, 1992) particularly if introduced into man-made reservoirs where it quickly covers the surface and can result in declines in water quality, especially dissolved oxygen levels. Kariba weed is listed in PIER (2005) as an invasive species for Hawaii and the Pacific Islands.

3.2.5 Aquatic fern: azolla fern, *Azolla filiculoides* Lam.

Another introduced floating fern, *Azolla filiculoides* (Family Azollaceae), is seen covering open water and exposed mud along the marsh drainage stream paralleling the inside margin of the flood control levee. This species can be easily separated from bright green *Salvinia* by the fact that *Azolla* typically develops a dark red to purple coloration. The pinnae (0.25-1.0 inch long) are much smaller than those of *Salvinia* (1-1.5 inches). According to Wilson (1996), it was "deliberately brought into the Islands as part of a mosquito abatement program in rice fields."

Azolla filiculoides is listed by PIER (2005) as an invasive species in Hawaii, although it is not an especially aggressive plant and no harm is listed as resulting from its appearance in aquatic ecosystems. It may be more widespread in Kawai Nui Marsh than presently known, occurring seasonally in wet parts of the upper marsh.

3.2.6 Arrowhead, *Sagittaria latifolia* Willd.

Arrowhead (Family Alismataceae) is an introduced plant that grows from a low stem, sending up bright green, arrowhead shaped leaves on hollow petioles, much like kalo. The flowers are white and somewhat showy.

Smith (1978) described this species (as *S. sagittifolius*) evident only during the wet season occurring near the large lake (i.e., the central pond), where over a limited area it comprised almost 50% of the plant cover. This study's surveys concur that this wetland obligate is found at or near the shore of the central pond and occasionally along the dredged lateral canal. *S. latifolia* also grows in the upper areas of the marsh in monotypic stands in channels with slow moving water. Arrowhead may be less conspicuous during the dry season, seeming to prefer some flowing surface water, but due to a long wet season in 2005 was widely distributed around the marsh during these surveys. Arrowhead is not listed by PIER (2005) as an invasive aquatic.

3.2.7 Bulrush, *Schoenoplectus californicus* (C.A. Mey.) Palla and *Schoenoplectus lacustris* (L.) Palla

Great Bulrushes (Family Cyperaceae)[1] are very distinctive plants, even from a distance. A creeping rhizome (stem) remains buried in mud, sending up tall, hollow stems called culms that are green and sharp-pointed at the tip. No leaves are produced, and flowers are individually small and brown, growing from a branched structure that erupts below the culm tip. Where previous studies (Smith 1978) mention only one bulrush species (*Scirpus californicus*), researchers in this study observed both *Schoenoplectus californicus* and *S. lacustris* throughout the marsh. *S. californicus*, a non-native species introduced early last century, typically grows somewhat taller, often exceeding 10 feet. Its culms have a greater diameter (to as much as one inch at the base) and are distinctly triangular, noticeable as one rolls the culm between two fingers (Figure 13). Generally speaking, *S. californicus* is more of a pale green color than *S. lacustris*, which has a color closer to teal, or blue-green (Figure 14). *S. lacustris*, considered an indigenous species, grows to a maximum of 10 feet, most culms 6-9 feet high. Its round culms (typically one "edge" can be felt rolling the culm between the fingers) have a maximum diameter at the base of approximately ½ inch.

Smith (1978) regarded bulrush as the dominant plant of the "ponding basin" or lower marsh and having a cover value of 75-80% in the "bulrush community." Both California grass and saw-grass were noted as intermingling with bulrush where the former grew in monotypic stands adjacent to the bulrush. Bulrush is recorded by Smith as dominant in only one area (quadrats 30-33). Everywhere else, saw-grass was co-dominant or the transect could not be completed because coverage by saw grass was considered impenetrable.[2]

In terms of present day coverage across the lower marsh, bulrush is a prolific species, forming sometimes nearly monotypic stands and at other times, stands occurring mixed with California grass and/or neke fern. Bulrush is also conspicuous near channels at the edge of the marsh, especially near the levee (where the Smith transects were run). While this study's surveys detected both *S. californicus* and *S. lacustris*, it was not evident why one or the other was present at a certain place. Dense stands of bulrush were either *S. californicus* or *S. lacustris*, never both, suggesting these stands enlarge mostly by vegetative growth. In areas where neke (*C. interruptus*) co-occurs with bulrush, *S. lacustris* was more likely to be present. It was also in these neke areas that both species were observed to be present, but in relatively in low densities.

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[1] The Family Cyperaceae includes the rushes, sedges, bulrushes, and similar plants, many of which are adapted to conditions of wet soils and are considered typical inhabitants of marshes. This family is well represented in the list of species discussed here.

[2] A total of five transects were run by Smith, but two were terminated after 65 feet (2 samples) because the stand was purely *C. .jamaicense* beyond that point.

Figure 13. Cross-sections of Bulrush culms side-by-side. ***S. Californicus*** **on the left (note triangular shape),** ***S. lacustris*** **on the right (round shape).**

Figure 14. Bulrush culms side-by-side. ***S. lacustris*** **on the left,** ***S. californicus*** **on the right. Note color difference.**

Schoenoplectus species are not listed by PIER (2005) as invasive aquatics, although *S. californicus* is clearly invasive in Kawai Nui Marsh. Uncertainty about the status of *S. lacustris* (Naturalized or indigenous) clouds assessment of the long-term role of great bulrush in the ecology of the marsh. Large areas are occupied by bulrush, but these are generally distinct from areas covered by saw-grass.

3.2.8 Uki, saw-grass, *Cladium jamaicense* Crantz

Uki or saw-grass (Family Cyperaceae) is a native (indigenous, pan-tropical) sedge abundant in Kawai Nui Marsh. These robust plants consist of long, narrow, arching, light green leaves forming a dense bunch, growing to considerable size (3 feet high and perhaps 6 feet) (Figure 15). The leaves are armed with sharp, backward set teeth that easily cut flesh if movement is against the orientation of the teeth. The plants reportedly spread by horizontal stems (rhizomes; Wagner, et al., 1990), although researchers in this study have observed prolific rooting of shoots from the nodes of arching inflorescences, especially where these touch wet ground or water. From a distance, saw-grass is easily observed when the plants are in flower (late summer) as the flowers are small, but numerous, from light to dark brown and borne on stalks that arch above the plant. The flowers give the whole stand a brownish tinge, recognizable at distances of up to ½ mile.

Smith (1978) described saw-grass (as *C. leptostachyum*) as “the second most dominant plant in this [bulrush] community…” noting that it “occurs as discrete patches and to some extent intermingled with [*Schoenoplectus*].” Cover value for saw-grass for all of the bulrush community was given as 5-10% by Smith (1978). However, as noted above, the present study finds that bulrush and saw- grass typically form distinctly separate stands, with saw-grass covering large areas and as abundant in the marsh as giant bulrush.

Saw-grass is one of two abundant native species presently found in the marsh, and its ecological role is likely a significant one.

3.2.9 Common cattail, *Typha latifolia* L.

Cattails (Family Typhaceae) have tall gray-green, strap-like leaves arising from near the base of the plant and a distinguishable congested flower spike at the end of the a vertical stem that matures and partly persists as a dark brown "bob." The green part of the plant grows up from a creeping, underground stem called a rhizome (Figure 16).

Of the two cattail species found in Hawaii, one, *Typha latifolia* can be found in Kawai Nui Marsh. Smith (1978) noted that cattail occurs in the “bulrush community” as monotypic stands 15-70 feet across. Total coverage by cattail in the bulrush community was estimated at less than 1%, but Smith did not map this species. Today, cattail is a dominant plant in many parts of the lower marsh and across the boundary into the upper marsh. More than 1% of the marsh is occupied by cattail, which tends to form monotypic stands, although stands mixed with California grass and neke are not uncommon.

Cattails are often regarded as invasive plants in wetlands throughout the world. The Center for Aquatic and Invasive Plants at the University of Florida describes cattails as: “Though most *Typha* species in Florida are native (and not "exotic invasives"), they nonetheless often grow to

Figure 15. Saw-grass (*Cladium jamaicense*) culm, arching to the side. Note inflorescence, and the sprouting taking place at each node. The sprouts will root if the culm makes contact with the substrate, becoming a new individual. Neke in the foreground.

Figure 16. Cattail (*Typha latifolia*) surrounded by sword fern (*Nephrolepis multiflora*)

cover large areas of wetlands, lakes and rivers. They are among the most common of all aquatic and wetland plants anywhere" (University of Florida, 2005). However, cattails are not native to Hawaii, and the abundance of *T. latifolia* in wetlands on Kauai and Oahu is regarded as an invasive exotic species. The National Resource Conservation Service (NRCS 2005) erroneously lists both species found in Hawaii as natives. Cattail is not listed by PIER (2005).

3.2.10 Papyrus, *Cyperus papyrus* L.

Egyptian papyrus is a large, distinctive sedge (Family Cyperaceae) that roughly resembles the umbrella sedge (*C. alternifolius*). However, in Kawai Nui Marsh, the culms (hollow stems) of papyrus are 10-16 feet in length (Figure 17). These are topped by a dense head or tuft of narrow rays. This plant is a popular ornamental in small garden ponds, and not widely naturalized. It is very apparent in Kawai Nui Marsh, although limited to stands that are circular in shape, each presumably representing vegetative growth outwards from a single initial colonization. Presently, six rings are distributed on the eastern side of the marsh (off Ulupo), with an additional three found in the western and upper marsh areas. Papyrus may not have been present in Kawai Nui Marsh[3] at the time of Smith's (1978) survey.

Figure 17. Papyrus (*Cyperus papyrus*). Note young shoot in foreground. Culms in this patch were over 10 feet tall.

[3] The very conspicuous growth of papyrus near the west side of the central pond is adjacent to the area of significant arrowhead growth described by Smith (1981) indicating, we think, that she explored this area and certainly would have noted any sizable papyrus plants which now tower over all other vegetation in this area.

The papyrus stands in Kawai Nui Marsh support no other vegetation except that *maile pilau* (*Paederia scandens*), a vine, sometimes invades around the margins. The stands appear to simply expand by vegetative growth outwards, displacing other plants. Invasive properties of this species are discussed further in this report. However, Egyptian papyrus is not recognized as an invasive species in PIER (2005). Kawai Nui Marsh may be the only natural wetland in Hawaii where this species is present.

3.2.11 Makai, kaluha, *Bulboschoenus maritimus* (L.) Palla subsp. *paludosus* (A Nels.) T. Koyama

This native (indigenous) wetland bulrush (Family Cyperaceae) is very distinctive with its 3-sided, upright growth and multiple, full, light brown flower heads. This species is found typically in wetlands close to the sea. Three small plants were collected from a drainage ditch at Kapiolani Park and planted at Na Pohaku o Hauwahine in June 2000. The plants have spread rapidly, by both seed and runners, and new plants are large compared with their parent population. Growth is seasonal, with mature upright growth turning brown and production of new shoots curtailed during the colder months.

3.2.12 Akiohala, hau hele wai, *Hibiscus furcellatus* Desr.

This native (indigenous) hibiscus (Family Malvaceae) was once common on Oahu, but is seldom seen any more (Wagner, et al., 1990). It grows as a somewhat lanky shrub with distinctive brownish-red stems covered with stiff hairs. The plant bears solitary, pale lavender to rose-colored flowers on bare branches that rise above the sparse foliage. It was reported by Smith (1978) (as *H. youngianus*), who saw a single specimen in Kawai Nui Marsh. More recent accounts note Hau hele wai growing naturally in the marsh along the transverse canal in small numbers (R. Guinther, pers comm. 2005). Plantings made at Na Pohaku o Hauwahine have continued to spread.

3.2.13 Umbrella sedge, *Cyperus involucratus* Roxb.

Umbrella sedge is a distinctive sedge (Family Cyperaceae), growing to 10 feet in height and bright green in color, with a head of leaves whorled at the upper end of a long culm (hollow stem) appearing somewhat umbrella-like. *Cyperus alternifolius* is a synonym long used in Hawaii.

Smith (1978) noted the presence of Umbrella sedge in the marsh. AML (2004) suggested that this plant was invading the marsh along the boundary between the upper and lower marsh. It is now found in small clumps widely distributed around the marsh. This survey found sparse small clumps of Umbrella sedge along the central and perimeter canal edges. Dense, very tall (10 feet) stands of this sedge are found at the northeastern corner of the marsh near the Oneawa Channel outlet. *C. involucratus* is recognized as invasive in PIER (2005).

3.2.14 Wild cane, *Saccharum spontaneum* L.

Wild cane (Family Poaceae) is a large grass that forms conspicuous, isolated clumps or stands of clumps scattered about the marsh. In addition to arching green leaves, there are usually numerous dead leaves present, giving the bunches a distinctive appearance. Bunches are somewhat stunted compared with the normal growth in upland disturbed sites, and flowering is seldom observe in the marsh population. Smith observed about 10 stands (presumably one or a few plants per stand) of wild cane near the levee, noting them only because they were conspicuous. This plant appears scattered about the central pond and along the margin of the transverse canal. In some cases, the plants appear to be associated with a fragment of floating mat separate from the main mat. It may be that these are fragments or clumps carried into the marsh during freshets. It is suspected that wild cane is well established upstream of the marsh along Kahana Iki Stream, which may be the source of this plant around the central pond.

Wild cane is considered a federal noxious weed (NRCS, 2005), and is listed by PIER (2005) as invasive species in Hawaii.

3.2.15 Aeae, water hyssop, *Bacopa monnieri* L. Wettst.

Aeae (Family Scrophulariaceae) is a low-growing (creeping) rather succulent plant, bright green in color with white to pale lilac, 5-petal flowers. Water hyssop forms mats on wet ground or floating out across a water surface, the stems rooting regularly at the nodes. This native (indigenous) species is typically found in lowland wetlands in Hawaii. Smith (1978) included this species as having been recorded by Elliott and Hall (1977). During the present survey, it was abundant along the narrow marsh drainage stream immediately south of the levee.

This plant is sometimes regarded as a pest in waterbird refuges because it can grow rapidly over exposed freshwater mudflats, presumably reducing habitat suitability for endangered Hawaiian stilt (*Himantopus mexicanus knudseni*). However, being a pest in a man-made environment does not qualify the species as an invasive, particularly since aeae grows most explosively over bare wet ground. Minimal habitat exists in Kawai Nui Marsh for this species, although it is the dominant wetland plant in the marsh enhancement project area at Na Pohaku o Hauwahine (AML, 2004). Aeae is not listed the PIER nor NRCS databases.

3.2.16 Honohono wai, dayflower, *Commelina diffusa* N. L. Burm.

This mostly creeping wetland plant (Family Commelinaceae) typically consists of prostrate to short erect, jointed stems with roots forming at nodes, alternate, pointed leaves, and small, bright blue flowers. This is a naturalized species widespread in wet areas in Hawaii. Smith (1978) lists this species as an upland plant at Kawai Nui Marsh, and it can persist in upland areas, especially through the wet season, although it is mostly an opportunistic invader of wet areas such as along streams, ponds, and marshes. Honohono grows extensively along pond margins and especially in areas of wet soil and abundant light. It is generally difficult to control by hand weeding or cutting, because pulling the running stems leaves nodes behind that quickly resprout new growth. Persistent weeding in areas of established aeae and herbicide sprays in monotypic honohono wai stands can eliminate growth of this species, which relies on vegetative growth to spread and dominate, apparently rarely producing viable seeds.

Honohono is listed by PIER (2005) as invasive species in Hawaii.

3.2.17 *Cyperus polystachyos*

Cyperus polystachyos (=*Pycreus polystachyos*) is a native (indigenous) sedge (Family Cyperaceae) typically less than one foot tall. Having appeared naturally sometime in late 2001 at the Na Pohaku o Hauwahine wetlands enhancement site (AML, 2004), this plant has since spread rapidly, producing large amounts of viable seed. Not noted previously from Kawai Nui Marsh, nor encountered on these surveys of the central marsh, *C. polystachyos* was observed near the water along the Kawai Nui Marsh Flood Control levee.

3.2.18 Kamole or primrose willow, *Ludwigia octovalvis* (Jacq.) Raven

Kamole (Family Onagraceae) is thought to be a Polynesian introduction to the Hawaiian Islands. This herbaceous shrub with yellow, 4-petal flowers grows in wet places, and is regarded as a weed in *kalo* pond fields. The leaves are long and narrow and the fruit a long, ribbed capsule. Smith (1978) mentioned this species only in context of the stream banks at the extreme upper end of the marsh where "a *Xanthosoma* [also] was found sparsely to rarely". Although it does occur elsewhere around the margins of the marsh, it is rare to find it in the wetland, except at Na Pohaku o Hauwahine, where it is an early invader of pond banks if these are barren of plants in the spring (AML, 2004).

Kamole is listed by PIER (2005) but not considered invasive in the Pacific Islands including Hawaii.

3.2.19 Hau, *Hibiscus tiliaceus* L.

Hibiscus tiliaceus is a tree or shrub is a type of hibiscus (Family Malvaceae) with long, sometimes arching branches that spread laterally to form a dense thicket. Hau is native (indigenous) and grows typically in wet places as along slow moving streams and wetland margins. Listed by Smith (1978) as an upland plant, in this present survey it was seen growing down to and out over the edge of the marsh, and to a limited extent, out in the marsh.

Hibiscus tiliaceus is not listed by PIER (2005), although there are few plants in the Hawaiian Islands that can match its ability to completely obliterated small marshlands. These are not destroyed as wetlands, simply transformed from open areas of emergent herbaceous growth into monotypic stands of dense hau growth characterized by moderately deep shade and a tangle of horizontal and vertical trunks and vertical stems.

3.2.20 California grass, *Urochloa mutica* (Forssk.) T.Q. Nguyen

California grass or Paragrass is an introduced grass (Family Poaceae) that is widespread in wet to mesic areas in the tropics. California grass is a large grass with a spreading habit (Figure 18). Although not aquatic, the long stems can grow horizontally as much as 20 feet out from the shore of ponds and wet areas, eventually covering the surface and obscuring open water. California grass will grow to a height of 4-5 feet, or higher if supported on other vegetation. Smith (1978) considered the "grass community" to be nearly a monotypic stand of California grass. It was also noted that it appeared in the bulrush community "where low spots create a situation of permanently standing water."

Figure 18. California grass (*Urochloa mutica*)

California grass is the dominant species in the upper marsh and all around the margin of the lower marsh. The observation by Smith that invasion of the lower marsh occurs where permanent standing water is present is contrary to observations from this study. California grass grows in areas where there is less likelihood of standing water, and the advance of California grass from the upper to the lower marsh may be retarded in the wet season or in very wet years, when ponding is most prevalent. Nonetheless, there are many places where California grass occurs in the lower marsh as the dominant vegetation. Flooding of these California grass areas does not lead to its eradication. This circumstance may be due to the rapid growth of the plant from the "shore". No matter what harm befalls California grass in flooded areas, the dead stems merely serve as a bed for expansion of the grass from rooted areas higher up once the water level begins to drop.

Urochloa mutica is listed as invasive in PIER (2005) and must be regarded as one of the more serious invasive plants in Kawai Nui Marsh and all other wetlands at low elevation in Hawaii.

3.2.21 Neke or swamp fern, *Cyclosorus interruptus* (Wild.) H. Ito.

The swamp fern (Family Thelypteridaceae) or neke is a native (indigenous) fern with leathery green fronds with coarse, saw-like edges (Figure 19). Fronds may exceed 3 feet in length

Figure 19. Monotypic stand of neke fern (*Cyclosorus interruptus*), a major contributor to the peat in the bog.

(generally smaller in the marsh). Neke is common in wet areas and is likely the most abundant native plant in Kawai Nui Marsh.

Smith (1978) noted that it occurred throughout the bulrush community, “and in one small area (about 40 feet across) forms an almost monotypic stand.” The peat mat formed by the intertwining roots and rhizomes of this fern is strong. This fern is widely scattered in the lower marsh, sometimes inconspicuous among other species, sometimes co-dominant with uki, and in a few areas, forming monotypic stands being far more extensive than described by Smith. Stands of great bulrush, cattail, or saw-grass lacking neke are exist, however most areas where the plant assemblage is of mixed species, neke fern is present. On the other hand, neke is uncommon the upper marsh.

3.2.22 Marsh pea, *Vigna luteola* (Jacq.) Benth. and other vines

The marsh pea is an introduced or non-native vine that closely resembles the native nanea or beach pea, and until just recently this plant in the marsh was thought to be nanea (*V. marina*). This twining vine may be a recent introduction to the islands and is potentially a pest species in Kawai Nui Marsh. It is widely distributed in the lower marsh, but especially abundant only in widely scattered areas, where it grows up into the taller vegetation. The leaves are often contorted by what appears to be plant mite infestation.

Mauna loa (*Canavalia cathartica*; Family Fabaceae), and climbing vine with medium sized leaves occurs sporadically throughout the marsh. Higher densities were observed in neke-bulrush areas in the central areas of the lower marsh.

3.2.23 Fleabanes: *Pluchea indica* (L.) Less and *Pluchea caroliniensis* (Jacq.) G.Don

Indian fleabane (*P. indica*; Family Asteraceae) is a shrub regarded as a wetland border plant throughout the tropics where it is widely naturalized. It was noted by Smith (1978) as occurring in or around the marsh. During this study's surveys, this species was not observed within the marsh, but it was seen in some disturbed areas, for example along the inside face of the levee and on the mitigation islets.

The sourbush or *Pluchea caroliniensis* is a similar looking plant with larger, hairy leaves. In some areas, *P. caroliniensis* and *P. indica* are found growing together, and their cross (*Pluchea* X *fosbergii*) may be present as well. However, *P. caroliniensis* is less often associated with wetlands and was not observed in the marsh, but it was observed in open uplands associated with the pasture setting of the upper marsh.

Both *Pluchea indica* and *P. caroliniensis* are listed in PIER (2005) as invasive species throughout the Pacific Islands, including Hawaii.

3.2.24 Trees, including Paperbark tree, *Melaleuca quinquenervia* (Cav.) S.T. Blake and others

Also called swamp mahogany, *Melaleuca quinquenervia* is a moderately popular landscape tree and a highly adaptable species. Smith (1978) mentioned that "[t]here are about 30 paperbark trees..." near the Kawai Nui Marsh Flood Control levee. This number appears to not have increased much in the past 25 years (perhaps 100 paperbark trees are present today), although the number of invasive individual trees of other species in the marsh is now well into the thousands. Efforts by the state to remove trees from the marsh have resulted in removal of approximately 1000 in 2002 (David Smith, pers. comm.). Paperbark is present in the northern and middle part of the marsh, but not the southern part.

A number of upland tree species are invading areas of the marsh, including in rough order of present day abundances: fiddlewood (*Citharexylum caudatum*), octopus tree (*Shefflera actinophylla*), Paperbark, Moluccan albizia (*Falcataria moluccana*), Chinese banyan (*Ficus microcarpa*), Christmasberry (*Schinus terebinthefolius*), ironwood (*Casuarina equisetifolia*), and monkeypod (*Samanea saman*). Hau (see above) should also be considered invasive in the same respect as these others where hau plants are established within the marsh (as opposed to the marsh border).

3.2.25 Miscellaneous herbaceous species

Numerous other herbaceous plant species that would not be regarded as wetland plants can be found growing in different parts of the marsh. One of the more ubiquitous is *maile pilau* (*Paederia scandens*; Family Rubiaceae). This vine covers areas of the upper marsh where it either dominates or intermingles with California grass and cattail.

There are a number of other weedy species of non-wetland plants found in this study as well as listed by Smith (1978) as part of the bulrush community, but each having cover values less than 1 %: *Conyza bonariensis*, *Emilia fosbergi*, *Sonchus oleraceus*, and *Spathoglotis plicata*. Other potential wetland species observed by Elliott and Hall (1977), but not seen by either Smith

(1978), AML (2004), or by this study include *Ceratopteris siliquosa* (swamp fern), *Eleocharis acicularis*, *E. obtusa*, and *Monochoria vaginalis.*

The ground orchid, *Spathoglotis plicata*, while not especially abundant, was observed in this study as a regularly occurring in parts of the neke assemblage, especially where upland trees heavily invade neke.

3.3 Plant Assemblages

Ecological theory includes the concept of the biocoenosis (Möbius, 1877): characteristic plant and animal species live in associations called biological communities and these are established and integrated in such a way that the assemblage itself confers a measure of stability on the landscape. These assemblages tend to evolve as a unit, or are characterized by a regular succession of species replacing one another, until relative stability is achieved. To avoid the implication that the mapping units described in this report are communities in this biological sense, these "recognized" units are herein referred to as *assemblages*. The assemblages constitute mapable areas based upon dominant plant species. The outlining of assemblages is difficult because few species form widespread monotypic stands, and the proportions of species in mixed assemblages can vary significantly over short distances.

The distribution of the individual plant populations overlaps in combinations that frequently defy easy delineation. Most "distinct" assemblages are distinct only over a limited area, merging with others along broad gradients or containing as perhaps relatively minor components, species that are dominants or co-dominants in other assemblages. Smith (1978) described "two major communities" (3 mapable units including open water) and Guinther (AML, 2004) recognized some 18 mapable units. This report recognizes three basic areas within the marsh: 1) open water, 2) peat covered central marsh, and 3) marsh margins and upper marsh. The open water area has a single assemblage, central marsh has seven assemblages, and the marginal areas have five assemblages. Each of the assemblages found on the Vegetation Cover Map (Appendix A, Map 1) are described in detail below. The table accompanying the map in Appendix A lists the codes for the corresponding assemblages described below and marked on the vegetation map.

3.3.1 Open Water

By itself, open water (mapping units 01-04, Appendix A, Map 1) is not a plant assemblage. Submerged vegetation has not been observed in Kawai Nui Marsh, so open water areas would support either phytoplankton (suspended microscopic algae) or benthic, filamentous algae or cyanobacteria. Several subcategories of open water are differentiated, as streams and channels entering (map unit **04,** Appendix A, Map 1); in the marsh interior and not covered by floating plants (map unit **01**, Appendix A, Map 1); and channels exiting the marsh (map unit **03**, Appendix A, Map 1), each having specific salinity regimes from fresh water to brackish and tidal.

3.3.1.1 Floating-plant assemblage

The **floating-plant assemblage** (map unit **02**, Appendix A, Map 1), with various characteristic floating plants, exists across the central pond and transverse channel, in smaller areas within the marsh interior, and in dredged areas at the marsh margins. Ninety-five percent of the open-water habitat (excluding the Oneawa channel area), by visual estimate from a recent satellite image (January 9, 2004), is covered by this floating plant assemblage. However, this value is known to fluctuate throughout the year and from year to year.

Water hyacinth (*Eichhornia crassipes*) is the predominant floating plant species that occupies open water areas in the marsh interior. Water lilies (*Nymphaea* sp.) were only observed in marsh-interior ponds, as well as in the drainage channels at the northwest side of the marsh (Figure 20). Water lettuce (*Pistia stratiodes*) dominates open-water areas along the levee (northeastern shore; Figure 21). *Salvinia molesta* is currently found in drainage channels along the northwestern edge of Kawai Nui Marsh, near the model airplane field.

The only open-water areas in the Kawai Nui Marsh free of floating vegetation are portions of the central pond, some very isolated ponds in the interior, flowing water entering or exiting the marsh as streams, and brackish water at the head of Oneawa Channel.

3.3.2 Central Wetland Assemblages

Wetland assemblages (map units 10-16, Appendix A, Map 1) occupy much of the lower marsh, excluding "open-water" areas. Smith (1978) defined this area as mostly a "bulrush community." One major difference between this study's classification and that of previous studies is the need to take greater account for the presence, if not predominance, of neke fern in almost all these

Figure 20. Water hyacinth surrounds a small patch of water lilies at the edge of one of the large interior ponds.

Figure 21. Water lettuce and burgundy-colored *Azolla* on channel beside levee.

wetland assemblages. The key distinction between the central wetland assemblages and the marginal wetland assemblages is substrate. The marginal wetland assemblages grow on sediment or soil, while the central marsh assemblages grow on peat.

3.3.2.1 Saw-grass Assemblage

The **Saw-grass Assemblage** (map unit **10**, Appendix A, Map 1) encompasses a significant proportion of the lower marsh area. This assemblage is the easiest of all of the assemblages to describe because it consists of monotypic stands of saw-grass (*Cladium jamaicense*) and mixes with neke in other areas (Figure 22). Saw-grass does not appear intermixed with most of the other species of the marsh, except where these are relatively minor components. For this reason, mapping saw-grass areas was not difficult. Marsh pea (*Vigna luteola*) can sometimes be found with saw-grass.

3.3.2.2 Bulrush Assemblage

A **Bulrush Assemblage** (map unit **11**, Appendix A, Map 1) occupies patches of varying size throughout the lower marsh. The two bulrush species present (*Schoenoplectus californicus* and *S. lacustris*) were rarely found growing intermingled (Figure 23). In places where both were

Figure 22. Predominately saw-grass area (an occasional neke frond is visible). Culms are typically wind-blown to one side. Note flowers/fruiting bodies (darker brown) at top of image.

Figure 23. Bulrush Assemblage including patches of *S. lacustris* (left) and *S. californicus* (right). In foreground are a floating plant assemblage dominated by *Pistia* and a Cattail Assemblage at the near shore (bottom).

observed growing in the same area, neke fern was typically dominant. Differentiation between the two species was possible in the field, but not on air or satellite images. Field notes from this project accurately indicate which species was present at each of the stations, but due to the patchiness of bulrush across larger scales, the classification scheme used in this study with remote sensing data does not differentiate between the two species. In monotypic stands, *S. californicus* is more abundant, forming dense patches in areas with standing water, and rarely amongst other species (e.g., neke), whereas *S. lacustris* was found growing densely on the edges of pools and standing water as well as sparsely with neke. The predominance in these areas of both neke and saw-grass warrants a classification that takes these other very abundant species into account, especially considering that the latter are native and the more abundant. Great bulrush (*S. californicus*) is a relatively late arrival to the marsh. Commonly found along with bulrush was maile pilau (*Padaeria foetida*), an opportunistic upland vine, which varies in density up to forming a mesh tying bulrush culms into a nearly impenetrable mat.

3.3.2.3 Cattail Assemblage

A **Cattail Assemblage** (map unit **12**, Appendix A, Map 1) is common along the levee, the marsh near Na Pohaku o Hauwahine, and across the southern areas of the lower marsh below the California grass (and pasture). Where the Cattail Assemblage is dominant, the peat layer is generally thin (< 2 feet). This observation fits with the hypothesis put forward by Guinther (AML, 2004) that cattail is a pioneer species in a process (called "reversion") whereby open ponds are obliterated to become monotypic stands of cattail. Where cattail is mixed with neke, however, peat layer thickness correlates more closely with that of the fern and it is reasonable to infer that in these areas cattail is invading the neke.

3.3.2.4 Neke Assemblage

A **Neke Assemblage** (map unit **13**, Appendix A, Map 1) dominates a majority of the lower marsh. This assemblage is subdivided into three sub-units. Monotypic neke stands (map unit **13A**, Appendix A, Map 1) are relatively small in area, but numerous (Figure 19). The neke co-dominant with bulrush (map unit **13B**, Appendix A, Map 1) covers vast swaths of the lower marsh (Figure 24). This includes all areas without saw-grass and without California grass (both cases readily distinguished on aerial images). The neke co-dominant with various non-wetland trees (map unit **13C**, Appendix A, Map 1) is defined by trees growing in broad areas at the middle of the lower marsh (Figure 25).

3.3.2.5 Papyrus Assemblage

A **Papyrus Assemblage** (map unit **14**, Appendix A, Map 1) is easily defined by the unique circular patches of papyrus (*Cyperus papyrus*) found in the eastern and western parts of the marsh. Present exclusion of all other species in these papyrus "rings" is probably due to shading and the massive size of this sedge compared with all others in the marsh. Comparisons of date-sequenced aerial images show that the diameters are increasing at an average rate of 7.4 feet in diameter per year, and new colonies are being established.

Figure 24. Example of a Neke Assemblage: neke co-dominant with bulrush, one of the most widespread assemblages in the marsh.

Figure 25. Marsh area covered by a neke co-dominant with various non-wetland trees (13C). Note monotypic stand of neke in the foreground, lying between the tree-invaded area and Saw-grass Assemblage (behind photographer).

3.3.2.6 Umbrella Sedge Assemblage

This study also distinguishes an **Umbrella Sedge Assemblage** (map unit **15**, Appendix A, Map 1). While individuals of this species (*Cyperus involucratus*) occur in many areas throughout the lower marsh, its behavior, once it establishes, resembles somewhat that of papyrus, forming circular patches that exclude other species. This pattern of growth is most evident (and is mapped) in the northernmost part of the marsh, near the Oneawa Channel outlet. Technically, umbrella sedge is presently a component of the Bulrush or Cattail assemblages, separated here primarily because of this study's assessment of its potential to establish and spread, becoming a distinguishable mapping unit.

3.3.2.7 Wild Cane Assemblage

The light color of **Wild Cane Assemblage** (map unit **16**, Appendix A, Map 1) is distinguishable in small areas on aerial images, however, wild cane (*Saccharum spontaneum*) itself is often mixed with other species and other assemblages (Figure 26). Nonetheless, wild cane forms distinctive and small, monotypic stands that can be mapped.

Figure 26. Wild Cane Assemblage with some cattail and bulrush present.

3.3.3 Upper and Marginal Wetland Areas

The upper and marginal marsh plant assemblages (mapping units 20-24, Appendix A, Map 1) include plant groupings and monotypic stands that cover the upper marsh and areas in the lower marsh around the margin of the central wetland assemblages (Section 3.3.2 above).

3.3.3.1 Pasture Land Assemblage

A **Pasture Land Assemblage** (mapping unit **20**, Appendix A, Map 1) occupies the upper marsh, mostly to the east of the stream channel, and consists primarily of California and Hilo grasses (*Urochloa mutica* and *Paspalum conjugatum*) grazed by cattle (Figure 27). The low stature of the grasses due to grazing in this area is easily distinguishable on aerial imagery. In general, the grazing cattle stop at the stream edge or where the ground is too mucky to support their weight, although these boundaries are likely to change somewhat on a seasonal basis.

3.3.3.2 California Grass Assemblage

A **California Grass Assemblage** (mapping unit **21**, Appendix A, Map 1; Figure 28) dominates many areas of the marsh, though it is often mixed with various vines and/or cattail and bulrush. Because California grass (*Urochloa mutica*) is a component of both the Cattail and Bulrush assemblages, intermixing of these species produces much of the uncertainty of the boundaries between mapping units. In the upper marsh, ungrazed California grass occupies the area of, and

Figure 27. Cattle grazing in pasture lands assemblage in the upper marsh area.

Figure 28. California Grass Assemblage in an area sometimes grazed by cattle.

on the west side of, the stream channel. In the lower marsh, it occupies a zone distributed around the margin of Kawai Nui Marsh.

3.3.3.3 Hau Assemblage

A **Hau Assemblage** (mapping unit **22**, Appendix A, Map 1) consists of mostly monotypic stands of hau (*Hibiscus tiliaceus*) growing predominately around the very edges of the marsh, where it roots in upland soil and extends out over wetter areas. This riparian "behavior" however, was also observed occurring in at least three areas in the lower marsh, where hau was rooting on the peat and extending out over narrow channels or over the transverse canal.

3.3.3.4 Elephant Grass Assemblage

An **Elephant Grass Assemblage** (mapping unit **23**, Appendix A, Map 1), consisting of a mostly monotypic stand of elephant or Napier grass (*Pennisetum purpureum*) covers a large area in the upper marsh. Its tall stature makes it distinguishable both in the field and with remote sensing. Smaller patches were also observed in the lower marsh visible from the levee. This grass is prominent along the entrant streams where the tree cover is open.

3.3.3.5 Mangrove Assemblage

A **Mangrove Assemblage** (mapping unit **24**, Appendix A, Map 1) occupies a small area at the very head of the Oneawa Channel. American or red mangrove (*Rhizophora mangle*) is an introduced species that is generally limited in its distribution to tidal waters. Seeds germinate on the mother tree and fall as floating seedlings. These cannot drift further into the marsh except perhaps in the area of the mitigation islets inside the northwest end of the levee.

3.4 Vegetation Assemblage Cover

Vegetation assemblage covers are shown on Map 1 in Appendix A, and summarized below in Table 5. The first digit of the numerical code corresponds with the broad assemblage categories (Open-water – 0, Lower marsh – 1, Margins & Upper marsh – 2, Upland – 3). The total area surveyed for analysis in this map is 894.5 acres, of which 697.1 acres is marsh and 197.4 acres is

Table 5: Summary of Plant Assemblage Coverages (See Associated Map in Appendix A).

Code		Acres	% Area
	Open Water Assemblages		
01	Open, fresh water, central complex, lower marsh	4.8	0.7
02	Open, fresh water, covered by floating plants	35.2	5.1
03	Open water, brackish	5.5	0.8
04	Open, fresh water, flowing stream	1.1	0.2
	Subtotal:	46.5	
	Central Marsh Plant Assemblages		
10	Saw-grass dominated	149.9	21.5
11	Bulrush dominated	53.0	7.6
12	Cattail dominated	9.7	1.4
13A	Neke Dominated	7.8	1.1
13B	Neke with bulrush	167.0	24.0
13C	Neke with non-wetland trees	36.7	5.3
14	Papyrus	3.2	0.5
15	Umbrella sedge	0.6	0.1
16	Wild cane	1.0	0.1
	Subtotal:	428.8	
	Marsh Margin and Upper Marsh Plant Assemblages		
20	Pasture lands, California grass/Hilo grass	81.7	11.7
21	California grass	121.3	17.4
22	Hau	11.6	1.7
23	Elephant grass	6.3	0.9
24	Mangrove	0.7	0.1
	Subtotal:	221.6	
	Total Marsh Area	697.0	
	Terrestrial Plant Assemblages*		
30	Upland forest	197.5	
	Total Survey Area (Acres)	894.5	

*Area surveyed *around* the marsh, bounded by Kapaa Quarry road to the north and west, Kailua Road to the south, and the levee to the east. This area is not included for vegetation cover and marsh area calculations.

upland. The predominance of saw-grass and neke-dominated assemblages in the marsh is obvious, representing 361.4 of 697.1 acres (51.9%) of the marsh which makes it one of the highest concentrations of native plant cover in lowland areas in all of Hawaii.

The majority of the limited acreage of open, vegetation-free water (4.8 acres) is found in one central pond. While this number fluctuates with weather and water conditions, the floating plant assemblage is covering over 85% of the potential open, vegetation-free area (approximately 31 acres).

The majority of the cover of the lower marsh is split between saw-grass and neke-dominated assemblages. Given neke's presence in almost all assemblages, it is clearly an important contributor to this marsh system. Wild cane and umbrella sedge cover values, based on this remote sensing analysis, are underestimated. Wild cane is masked by its similarity in color to California grass, and umbrella sedge due to its growth locations along the transverse canal and levee edge canals. Papyrus is a non-native species with significant potential for invasiveness, although present coverage is only 3.2 acres.

The areas where trees grow mixed with neke are found predominately in the center of the lower marsh, a large patch on the east of the transverse canal and smaller one on the west side.

California grass covers just over 20% of the marsh. Monotypic areas of California grass, not including the upper marsh areas, are found predominately along the marsh edges.

3.5 Peat Mat

A mix of native and alien vegetation today covers more than 99 % of the surface of the Kawai Nui Marsh. The accumulation of dead plant material below this vegetation has formed a peat layer characterized by a buoyant, inundated, anoxic, organic layer. This waterlogged, oxygen-deficient state arrests decomposition of vegetation causing accumulation. In some areas of the marsh, this peat layer is capable of supporting the weight of upright trees, while in others it can barely support the weight of a human. In parts where the upper marsh area and marsh margins are covered in California grass, a peat layer has not formed.

3.5.1 Peat Thickness

Peat layer thickness measurements ranged from 0 feet to over 8 feet (Appendix B, Map 3) with higher values typically found towards the center of the marsh. The peat thickness averaged 4.1 feet across all the plots visited. Closer to the edges of the marsh, the peat rests directly on the mud substratum, elsewhere it floats on a layer of water or water and mud slurry. Over half of the peat thickness readings fell in the 0-4 foot range with only two plots exceeding the 8-foot measurement (Figure 29).

In saw-grass-dominated areas, the associated peat mat ranges from 3-7 feet thick. The structure of the mat differs from that found under neke, being much weaker. Despite high densities of saw-grass in some areas, individual clumps are distinguishable. Between these clumps, the mat is thinner and sometimes waterlogged, making passage on foot difficult. Past studies have noted that saw-grass was seemingly impassible, or not supported by a mat. Travel through saw-grass is difficult, but not impossible.

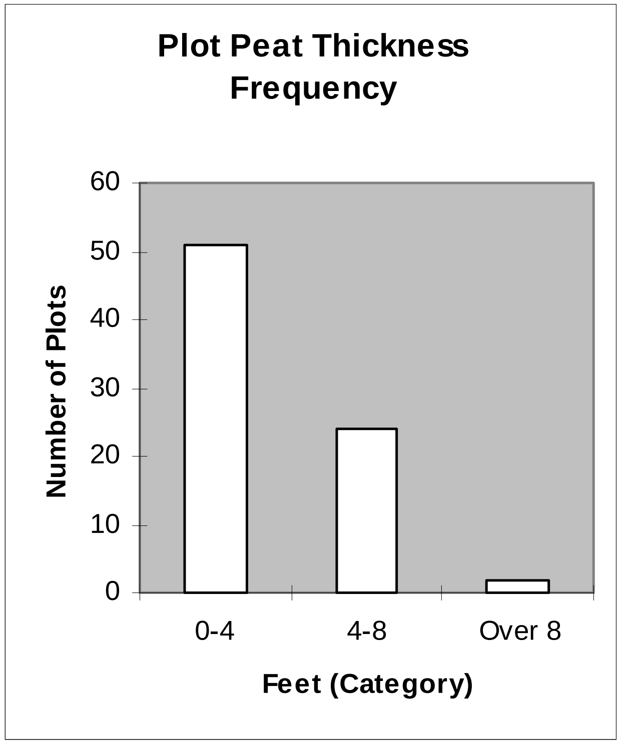

Figure 29. Graph of peat thickness frequency in plots.

Cattail appears less frequently as peat thickness increases. In plots where cattail had high cover values (over 50% cover), peat thickness was always less than 2 feet. Peat mat thickness under cattail falls mostly in the 1-2.5 foot range. However, when cattail was mixed with neke, the range extended to over five feet thick. Cattail, with its thin mat, is an early colonizer, especially of disturbed areas. It may, however, provide support for other species, such as neke, to take over and build thicker peat mats.

The peat mat below the bulrushes is difficult to characterize, especially where bulrush is predominant. In monotypic bulrush stands, measurements were possible, but the horizontal stems of the plants are below the peat surface. Where bulrush is mixed with other species, a majority of the measurements of the mat were less than four feet thick. However, bulrush was also often present in areas where the mat was thicker, making a correlation with thickness not apparent.

California grass generates a layer sometimes as much as three feet thick of mixed dead and live culms. Either open water, soil, or peat was found under this layer. Soil occurred under the California grass in the upper marsh (grazed on cattle pastures). Open water was found under the grass in numerous small patches, both in the interior of the marsh and especially along the marsh edges. Where California grass dominates (greater than 50% cover, see Section 3.4), thickness values ranged from 0 to just under 3 feet. California grass differs from neke, in that it can continue to grow vertically (building up the dead material/stem layer described earlier).

3.5.2 Water and Sediment Below the Peat

Map 4 (Appendix B) illustrates areas of the marsh that have a distinct water layer beneath the peat mat. With changes in the water levels of the marsh, the values fluctuate. During this study, water levels were considered above average at approximately three feet above mean sea level (MSL) due to rainfall. Variation measured since 2002 on the staff gage at Na Pohaku o Hauwahine shows occasional high water levels of almost 5 feet MSL and typical low water levels of around 2 feet MSL during the dry season (AML, 2004). In general, the vegetation in the lower marsh is growing on peat that is floating, with "water thickness" (water below the peat and above the mud) decreasing towards the edges. Even with above-average water levels in the marsh, it is worth noting how little of the vegetation mat is actually "floating". Much of the mat is resting on either a mud or hard bottom, and will continue to settle as water levels recede. Should water levels decrease, and remain low, which allows water to drain out of the peat, the vegetation could conceivably send roots deeper, permanently anchoring the mat to the substrate. "No peat layer" in Map 3 indicates either vegetation growing directly on soil or the dominant species (most likely Bulrush or *C. alternifolius*) not forming a distinct peat layer.

Depth to the surface of the mud layer measurements are illustrated in Map 5 (Appendix B), and range from 0 to greater than 16 feet (the maximum length of the survey pole), again with shallower values found towards the edges of the marsh. These measurements reflect the water depths of the marsh if the peat mat were absent. Figure 30 shows the distribution of plots measured grouped into depth categories. No plots with depth to mud measurements in the 12-16 foot category were encountered, though they certainly exist.

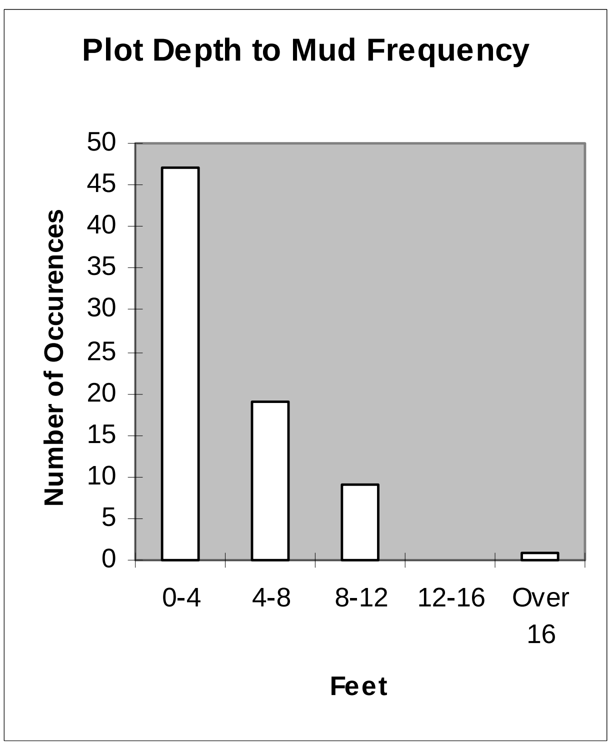

Figure 30. Graph illustrating depth to mud frequencies in plots.

Water depths at the edge of the transverse canal exceeded the length of the 16-foot survey pole. There was a steep slope at its edges. The main ponds in the marsh center, un-dredged, have depths in the 4-6 foot range. All the small pools encountered away from the central marsh area are shallower, in the 1-4 foot range. As stated earlier, the small limited areas of open water have remained in the same locations since the early 1900's. It is unclear why these relatively shallow areas remain open water while other areas clearly deeper (> 4 feet) have closed over with peat.

Map 6 (Appendix B) illustrates measurements of the depth to a hard bottom. Values ranged from zero, where the survey pole did not penetrate, i.e. hard soils in the upper marsh pasture area, to exceeding the 16-foot long pole. In general, the depth to hard bottom increased towards the center of the marsh. In areas where a hard surface was encountered, the survey pole usually penetrated through mud beforehand. Many of the measurements, however, fell beyond 16 feet (Figure 31). Evidence of the past, natural, outflow of the marsh still exists at the eastern part of the marsh with similar depth recordings to the current outflow at the mouth of the Oneawa Channel.

3.6 Physical Water Quality

Physical measurement of water quality: temperature, pH, conductivity, and turbidity, were taken at every plot along each transect. In part, these measurements were taken to determine if there were differences in water quality across the wetland that could provide clues to water source or direction of flow. Water from springs is often cooler than surface waters and typically has a lower ion content, which may be measured as lower conductivity. Water blocked from sunlight typically has very low dissolved oxygen levels due to a lack of by photoautotrophs. In wetlands,

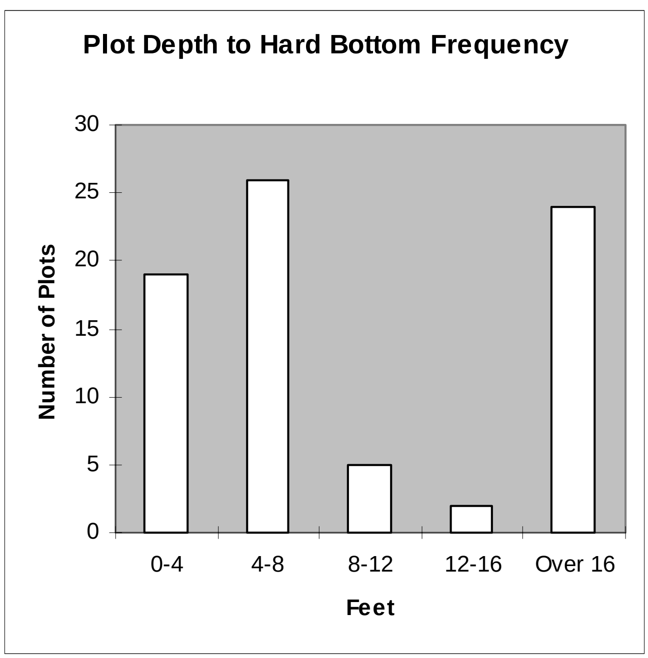

Figure 31. Graph illustrating the depth to hard bottom frequencies in plots.

typically loaded with ample organic material (especially organic acids) and low oxygen levels, pH may be lowered significantly. Table 6 presents remaining water quality results for the 75 stations where measurements were made.

3.6.1 pH

pH is the measurement of the acidity of a substance on a scale of 1-14, with purified water having a pH of 7. Lower pH readings indicate an acidic environment, which is typically found in areas where decomposition is taking place. pH readings in the plots ranged from 5.88-7.09, with a majority of the readings falling between 6.00 and 6.50 (Figure 32). Color-coded pH values are overlaid on the site map in Map 7 (Appendix B). pH readings from the transverse channel, main pond, and stream have approximately the same range (6.05-6.99), but overall, the pH in these miscellaneous points were somewhat higher than in the balance of the marsh. There does not appear to be any strong spatial correlation of pH values, although measurements in shallower water around the periphery of the marsh tended to be higher, and associated with more oxygenated waters. Water from the center of the marsh with relatively thick layers of peat and floating mat typically displayed low pH values. Eutrophic environments are often slightly basic. Acidity comes from organic acids resulting from breakdown of plant matter and perhaps from productions of CO_2.

Table 6. Physical Water Quality Data by Transect and Plot

Transect	Plot	Temperature Fahrenheit	Conduct.	Dis. Oxy % Sat.	Depth feet	pH
1	1	75.99	340	8.2	0.3	6.06
1	2	78.97	303	11.0	1.9	6.31
1	3	79.08	292	5.1	3.2	6.43
1	4	79.17	301	6.9	2.5	6.32
1	5	79.83	356	7.8	2.7	6.32
1	6	77.72	320	11.4	2.7	6.14
1	7	77.04	321	8.7	2.5	6.17
1	8	80.01	302	8.1	3.4	6.23
2	1	74.63	343	7.9	0.9	6.30
2	2	74.74	303	6.7	1.0	6.26
2	3	75.62	41	6.3	0.2	6.21
2	4	77.31	298	10.4	0.9	6.17
2	5	76.49	293	6.7	0.6	6.11
2	6	76.15	310	7.3	2.4	6.25
2	7	76.07	303	3.9	2.7	6.16
2	8	75.73	350	3.3	2.2	5.95
2	9	77.67	490	4.4	0.8	6.09
2	10	75.39	379	4.1	1.5	5.95
2	11	74.11	347	3.0	2.2	5.88
2	12	76.59	360	3.9	2.1	5.91
3	1	74.37	291	5.9	1.1	6.18
3	2	74.66	324	5.3	1.2	6.18
3	3	75.63	321	4.2	1.6	5.90
3	4	75.30	324	3.9	2.0	6.18
3	5	78.31	313	4.7	2.7	6.20
3	6	76.11	301	7.0	1.7	5.88
3	7	76.37	334	4.1	2.8	6.39
3	8	75.15	277	9.4	2.3	6.07
3	9	75.49	283	5.0	1.1	6.30
4	2	75.53	775	20.4	0.0	7.09
4	4	76.06	836	6.9	0.6	6.37
4	5	77.47	854	4.4	0.5	6.23
4	6	75.57	541	4.1	0.6	6.09
4	7	74.31	537	18.5	1.6	6.06
4	8	75.51	478	4.7	0.8	6.11
4	9	74.45	388	3.3	2.2	5.98
5	2	76.19	432	7.4	0.4	6.30
5	4	85.16	292	123.2	0.1	6.88
5	5	75.95	231	53.0	0.1	7.04
5	6	76.60	298	7.1	2.6	6.46
5	7	76.89	393	7.3	2.1	6.39
5	8	77.20	314	6.6	1.4	6.11
5	9	77.78	343	6.1	1.2	6.23
5	10	76.99	324	5.4	1.7	6.31
6	1	75.71	314	4.0	3.8	6.16
6	2	75.39	289	6.6	2.5	6.45
6	3	75.74	293	9.3	2.8	6.34
6	4	75.69	323	2.4	1.8	6.10
6	5	76.16	316	7.7	1.9	6.24
7	1	78.44	645	3.6	0.6	6.64
7	2	77.20	357	4.3	2.0	6.72
7	3	76.63	366	8.3	2.1	6.45
7	4	75.97	327	5.5	1.6	6.48
7	5	75.30	321	5.9	1.8	6.53
7	6	76.39	335	10.6	2.0	6.52
7	7	76.65	409	3.4	0.7	6.77
8	1	75.88	357	8.7	2.6	6.15
8	2	75.11	361	7.1	2.5	6.07
8	3	76.05	456	9.9	1.8	6.12
8	4	74.61	367	7.3	2.4	6.09
8	5	75.86	441	7.5	2.0	5.94
8	6	76.51	421	7.2	1.7	6.03
9	6	75.33	na	36.1	0.0	7.39
9	7	75.25	na	32.6	0.1	7.47
9	8	75.09	na	20.0	0.0	7.46
9	9	75.82	na	10.0	0.1	7.46
9	10	75.61	na	17.1	0.3	7.46
10	2	78.57	263	81.5	2.3	6.82
10	3	78.55	306	54.4	0.1	7.00
11	1	77.02	330	6.4	1.5	6.12
11	2	81.48	295	15.5	1.4	6.77
11	3	77.40	299	5.8	1.8	6.32
11	4	74.53	314	8.9	2.4	5.91
11	5	76.61	314	12.0	2.0	5.92
11	6	76.10	314	6.4	3.0	5.88

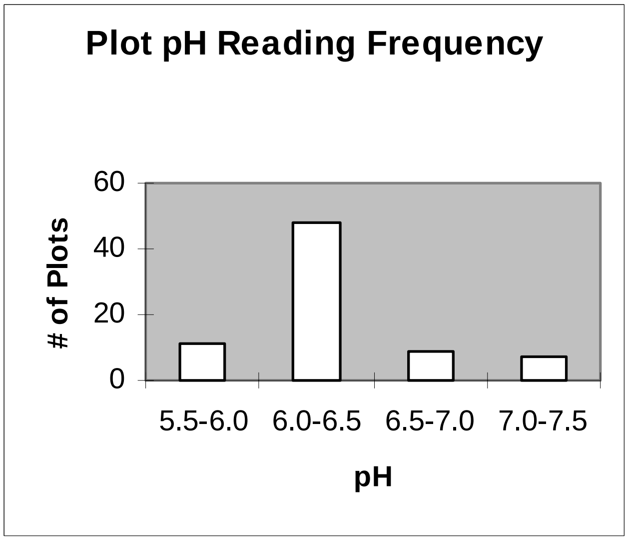

Figure 32. Graph illustrating pH frequencies in plots

3.6.2 Oxygen

Oxygen levels in the water were measured as percent saturation. Fresh water at 25°C is 100 % saturated with oxygen at about 8.5 mg/L. Levels below 50% saturation are generally not conducive to fish life, and levels consistently below 20% saturation are lethal to the majority of water-breathing fish and invertebrates. Oxygen levels beneath or in the mat over the marsh were generally below 10% saturation with some readings as low as 2% (Figure 33). These low readings are expected for an environment which lacks the light to support photosynthesizing (oxygen producing) algae and plants. In this oxygen-limited environment, roots and organisms quickly take up available oxygen. Percent saturation readings above 20% were invariably in areas of open water or in very shallow pools around the periphery of the marsh (Appendix B, Map 8).

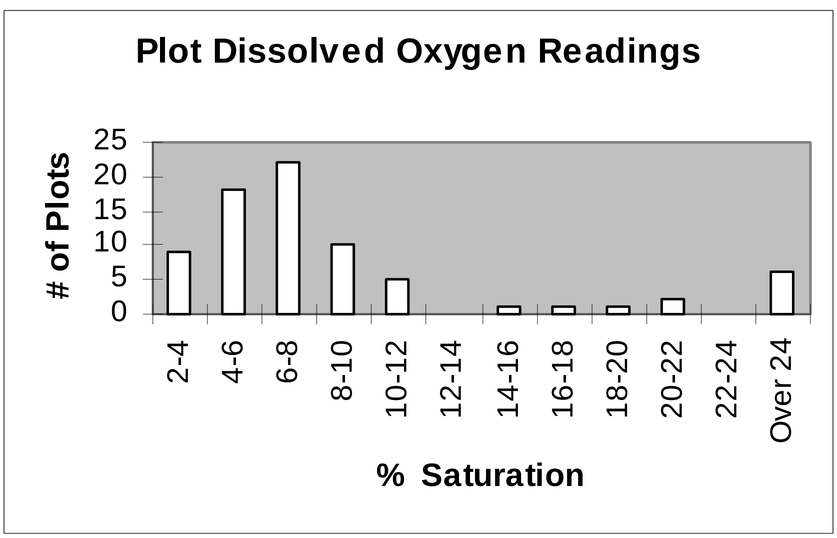

Figure 33. Graph illustrating dissolved oxygen readings in plots.

3.6.3 Temperature

Temperature readings in the marsh generally were within a narrow range between about 74 and 78 ^{o} F (Figure 34). Spatial correlations across the marsh are difficult to make. The temperature readings at each site are displayed over a map of the marsh in Map 9 (Appendix B). Although the cooler measurements tend to be seen around the perimeter of the marsh, this is also correlated with the beginning of each daily survey during the early part of the day before there was significant time for solar heating. One set of exceptions to this were the slightly higher readings obtained along transect 1 from the lower edge of the active pasture area to the center of the marsh. Only near Na Pohaku o Hauwahine were any areas of significantly cooler water were encountered that could represent a significant source of cooler groundwater to the wetland. Slightly cooler water encountered along transect 8, just north of Na Pohaku o Hauwahine, and associated with slightly higher conductivity may signify a ground water source, but the correlation is weak.

3.6.4 Conductivity

Electrical conductivity of water is proportional to the quantity of ions present in the water that can conduct an electrical current. In streams water from surface runoff tends to have low conductivity (<200 µS/cm), whereas water from springs carrying dissolved minerals tends to have higher conductivity (>300 µS/cm). Conductivity readings ranged from 40-854 µS/cm and averaged 361 µS/cm (Figure 35). Conductivity tends to increase downstream in a stream system. Mixing with seawater will greatly increase conductivity. Spatial examination of the conductivity data (Appendix B, Map 10) laid over a map of the site, shows transects 4 and 8 just north of Na Pohaku o Hauwahine with conductivity reading consistently above 300 µS/cm. Coupled with the slightly cooler waters seen at these locations, this indicates a weak source of groundwater entering from western side of the marsh.

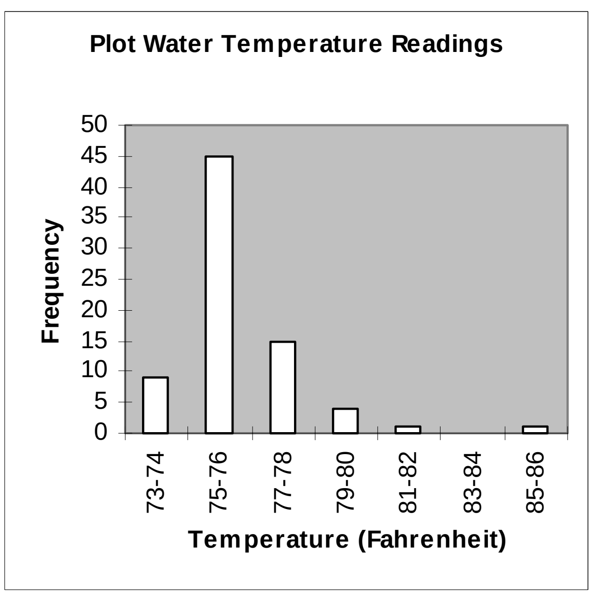

Figure 34. Graph illustrating frequency of temperatures in plots.

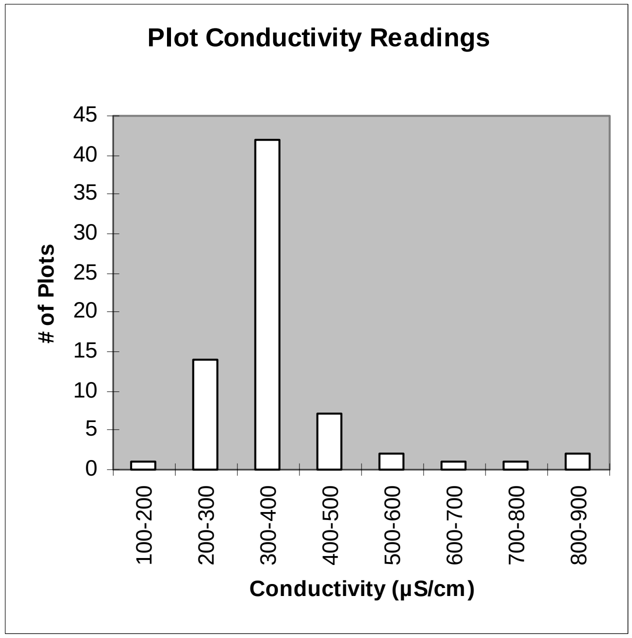

Figure 35. Graph illustrating conductivity frequencies in plots.

3.6.5 Turbidity

Turbidity is an indication of the quantity of solids suspended in water as measured by the scattering of light. It is expressed in nephlometric turbidity units (NTU's). Water is perceptibly cloudy at turbidity values greater than 5 NTU, murky with visibility less than 3 feet at greater than about 30 NTU, and opaque at turbidity values greater than about 100 NTU. The most lenient State Water Quality standard in Hawaii is for stream waters where turbidity should not exceed 25 NTU more than 2% of the time, with the presumption that 2% represents storm events. There are no state standards for wetlands.

Unusually high values resulted from walking on the mat above the sample, and creating the hole through the peat layer, which was cut/dug using a spade and a handheld sickle. Inevitably, the cutting and digging disturbed the water which caused high turbidity values. It was presumed that the cut holes would penetrate the peat, allowing access to the underlying water. However, the peat layer was thicker than anticipated (marsh-wide). In most cases, cutting all the way through the peat was impossible, and therefore, the reading instrument was placed in the water-filled hole that had been cut, giving false readings. For this reason discreet turbidity readings were omitted from this report. The turbidity data were not true measurements of undisturbed water below the mat.

Any management activities involving removal or disruption of the peat will easily cause the turbidity to increase to levels exceeding 500 NTU. Turbidity readings at the "points of interest" were substantially lower.

It is reasonable to expect that where there is water below the peat layer (where the peat is floating), the water is actually less turbid than the channels and open water areas, though this study does not present data in support of this. There are few if any organisms living below the mat, due to the low oxygen levels. The water in the open channels and ponds (including those covered by the floating plants) is full of photosynthetic algae, making is less clear than under the peat mat.

Section 4. Comprehensive Analysis

Kawai Nui Marsh has undergone significant changes in the past 150 years. Some of the processes inducing these changes were transitionary, while others, such as invasive species intrusion, continue today. This section compiles information from past and present studies and examines factors affecting change in Kawai Nui Marsh today. In addition, this section examines the feasibility of various restoration and enhancement methods and programs based on an analysis of findings.

4.1 Analysis of Results from Present and Past Botanical Surveys

Data from the present survey illustrates the extent to which non-native species have made inroads into the marsh. This section details the findings of the current botanical survey, notes changes in plant composition and distribution since previous studies, and highlights critical issues facing Kawai Nui Marsh with respect to vegetation and waterbird habitat.

4.1.1 Native Species Dominance

Smith (1978) broadly classified the marsh vegetation into grass and bulrush assemblages, noting that open, central "pond" areas existed, and that California grass and upland forest were found on the edges of the central marsh. Smith stated that a "California grass community" covered 300 acres of the marsh, a "Bulrush community" covered 400 acres, and open water areas occupied five acres. Studies since then have only sought to update and augment species lists, not quantify the actual area covered by each species (except Guinther in AML 2004). The present study shows significant differences from Smith, attributable to both broader consolidation of plant groupings (less resolution) on Smith's part, and changes that have occurred in the past 30 years.

Despite the invasion by numerous non-native plant species, one of the important findings of this study is the extent of native species, notably saw-grass and neke fern, in Kawai Nui Marsh. Excluding pasturelands and California grass areas growing on soil (upper marsh), more than 40 percent of the remaining 530 acres of the Marsh are covered by assemblages composed in part or wholly of native neke fern (Table 10). This value may be an underestimate, as many saw-grass-dominated areas have neke present. Based on peat thickness measurements and plant species found at each site, it appears that this fern is a major contributor to the formation of the peat layer found beneath most of the marsh vegetation (Figure 7). Photographs in Hammatt et al (1990) show neke fern colonizing saw-grass areas that had been sprayed with herbicide in late 1988, possibly confirming neke's role as an early colonizer on peat. Saw-grass occupies 149.9 acres (21.5%) of the marsh area. Together, neke and saw-grass assemblages cover 51.9% of the entire marsh. While neke and saw-grass do occur together, fewer alien plant species are found mixed with saw-grass than neke.

This study revises previously described plant assemblages (Smith, 1978; Drigot and Seto, 1982; AML, 2004) to reflect neke fern as a dominant "community" type reflecting observations made during field surveys for this study, examining both the plants and the peat mat at widespread locations all across the marsh. Neke is capable of producing a thick accumulation of peat and may represent the most significant plant of the lower marsh preceding the introduction of all of the alien plant species. The "bulrush community" of Smith (1978) is actually neke fern and/or saw-grass assemblages that have been invaded by bulrush in relatively recent decades. Smith erroneously regarded the bulrush, *Scirpus californicus* (= *Schoenoplectus californicus*) as a native plant, and was not aware that the smaller *S. lacustris*, which is native, was also present in the marsh. *S. californicus* was first described in Hawaii from specimens collected on Molokai in 1912 (Wagner, Herbst, and Sohmer, 1990).

Unknown is the extent to which these native plant species did or had the capacity to cover significant areas of open water prior to the arrival of the Polynesians. Alien plant species introduced in the last 200 years are presently covering most open water areas and displacing native vegetation from the edges (e.g., California grass) and from within (e. g., Papyrus).

4.1.2 Invasive Species

The term "invasive" as applied to biological species is imprecise and loaded with meanings that may or may not be intended. A well-considered definition is that given in Wikipedia (2005):

> A **species** is regarded as **invasive** if it has been introduced by human action to a location, area, or region where it did not previously occur naturally (i.e., is not native), becomes capable of establishing a breeding population in the new location without further intervention by humans, and becomes a pest in the new location, threatening the local biodiversity. The term **invasive species** refers to a subset of those species defined as introduced species.

U.S. Executive Order 13112 defines "invasive species" as "an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health" (CEQ, 1999). Thus, the term is used to imply a sense of actual or potential harm, something that may not be true for all "introduced species". This being the case, in this report it is important to attempt to identify those species among the non-native plants present or potentially present that are now or could cause harm to the Kawai Nui Marsh ecosystem.

Some native species are considered invasive as well. Therefore, expectations of conditions to be preserved or restored must first be established when defining "harm." That is, something is harmful to an environment only from the perspective of species (including man) that suffer for the change. These expectations may require consideration of all plants present in the marsh, irrespective of status. An excellent example is hau (*Hibiscus tiliaceaus*), thought to be either an early Polynesian introduction or an indigenous species. This plant is found around Kawai Nui Marsh and at scattered locations in the interior. Certainly for smaller wetlands, overgrowth by hau is a significant reality throughout the Hawaiian Islands: the manner of growth is somewhat mangrove-like and monotypic stands result. The plant is moderately tolerant of saline conditions, although generally not a threat to coastal marshes. Another example is aeae (*Bacopa monnieri*), an indigenous low-growing wetland plant that quickly grows over exposed mud flats. This plant is regarded by USFWS as invasive in wetland bird refuges because once established, it can quickly convert open mud flats into vegetation-covered flats, thereby reducing the feeding area utilized by the endangered Hawaiian stilt.

Despite nearly complete coverage of the marsh by vegetation for most of the past century, the relatively recent introduction and rapid spread of papyrus, umbrella sedge, and cattail illustrate the vulnerability of the Kawai Nui Marsh system to new invasions. Papyrus and umbrella sedge, currently found in relatively isolated patches, continue to expand in area, displacing both native and non-native species around them. Cattail also continues to spread, though in a more diffuse manner.

The following list considers some of the more obviously invasive species present in Kawai Nui Marsh. Descriptions of the characteristics that are thought important to consideration as invasive, especially in light of the this study's survey results which showed non-native species present in over 90% of the surveyed plots, are found later in this section

- Water Hyacinth (*Eichhornia crassipes*)
- Kariba Weed (*Salvinia molesta*)
- California grass (*Urochloa mutica*)
- Cattail (*Typha latifolia*)
- Papyrus (*Cyperus papyrus*)
- Umbrella Sedge (*Cyperus involucratus*)
- Various Trees
- *Vigna luteola*
- *Paederia foetida*

4.1.3 Threats to Open Water

4.1.3.1 Floating Plants

A marsh is a complex of wet habitats that range from open water ponds to areas densely covered by herbaceous plants. There is no easy distinction to be made between a marsh with open water ponds and a pond or lake surrounded by a marsh. However, with regard to waterfowl, open water is a critical component of the environmental matrix required by most species. Thus, enhancing populations of threatened or endangered waterbirds typically requires creation of aquatic environments with various degrees and configurations of associated vegetation (a "marsh"). In Kawai Nui Marsh, with respect to its resource value for supporting native waterbirds, the problem is not that there is too little marsh, or even that the marsh itself is transitioning to a different assemblage of plants from that which was formerly present (e.g., native to non-native, herbaceous to woody). The central problem is the considerable reduction in open water areas. Therefore, from the waterbird resource value perspective, invasive species are those that pose the biggest threat to reducing open water. These can be either floating plants or emergent rooted plants that grow out from shallow water margins.

Floating plants are true aquatic plants in the sense that they grow in aquatic environments (as opposed to water saturated soils). With a constant supply of water taken up by submerged roots and typically little or no competition from larger shading plants, floating plants require only the addition of nutrients to achieve high growth rates and can quickly cover all available water surfaces. The shading impact of a dense layer of vegetation on the water column can be a drastic reduction in dissolved oxygen, producing fish kills (Univ. Florida, 2005). Excluding peat covered areas, 46.6 acres of the marsh is open water. However, 75.5 percent, or 35.2 acres (Table 5), are presently covered by floating plants making these plants a significant concern for loss of waterbird habitat, as well as a concern that any removal of peat covered areas to expand open water areas would be threatened by overgrowth.

4.1.3.1.1 Water Hyacinth (*Eichhornia crassipes*)

In Kawai Nui Marsh, water hyacinth is the only significant invader observed in the central ponds: the largest open water areas (~40 acres) remaining (not covered by peat). The water hyacinth population expands and contracts over time, with huge masses of the plants shifting about under strong winds to reconfigure the remaining open water. Shallenberger (1977) noted that a major storm in 1977 cleared large portions of the marsh open water of water hyacinth, significantly increasing the quantity and quality of waterbird habitat that year. This phenomenon regularly occurs, dependent upon the severity of flood flows from Maunawili and Kahana Iki Streams.

4.1.3.1.2 Kariba Weed (*Salvinia molesta*)

Salvinia molesta is a free-floating fern that is capable of doubling in volume within 2-3 days, forming extensive floating mats. The dense mats of *S. molesta* clog waterways and irrigation canals, block passages, obstruct irrigation pumps, prevent light from reaching submerged plants, and reduce the oxygen content of the water and thus degrading the quality of the water.

Few plants have been studied more extensively towards the goal of eradication in bodies of water than *Salvinia molesta*. This plant is an invasive of open bodies of water such as reservoirs, but not of wetlands. Kariba weed infestations are presently limited to the drainage ditches along Kapaa Quarry Road that feed the marsh. However, Kariba weed's presence here is a clear threat to open waters further out in the marsh, and removal from the watershed should be a high priority. Kariba weed is a sterile hybrid (Loyal and Grewal 1966) and can only spread by fragments being carried into the interior. Various waterbirds, especially aukuu and mallards, regularly move around the marsh and could spread this plant in the manner.

4.1.3.1.3 Other Species

Several other species of floating aquatic plants are present: the azolla fern (*Azolla filiculoides*; not considered invasive) and water lettuce (*Pistia stratiotes*) in ponding parts of the drainage ditch paralleling the inside of the Kailua levee. Duckweed (*Lemna aequinoctialis;* not considered invasive) also appears on occasion in open water areas at the edges of the marsh.

Although azolla fern and water lettuce have potential to invade the central ponds of the marsh, they have not been reported from anywhere in the marsh interior. The reasons for this are unclear. Possibly introductions have occurred but are overwhelmed by water hyacinth, a much larger floating plant. Juvenile plants of both water hyacinth and duckweed (*Lemna aequinoctialis;* not considered invasive) have infrequently appeared at the Na Pohaku o Hauwahine wetland enhancement project, suggesting these two species are being spread by some natural means.

4.1.3.2 Rooted Plants

Threats to the persistence of open water environments can come from the margins where the expansion of rooted emergents results in a gradual reduction in the area of open water. Such a pattern of plant growth presumably reflects classical autogenic succession, although applicability to the open waters of Kawai Nui Marsh is by no means established fact. Emergent wetland plants have adaptations for spreading or advancing into ponds from growth at the pond margin. Bulrush (*Schoenoplectus* spp., *Bulboschoenus* spp.) and cattail (*Typha* spp.) grow by underground stems called rhizomes that spread within the mud, sending up an emergent, green culm (and leaves when present). Saw-grass (*Cladium jamaicense*) produces numerous vegetative juveniles in the axils of its elongated, much branched, and pendulus inflorescence. Arching away from the mother plant, these growths take root if landed on suitable substrate. Both umbrella sedge (*Cyperus alternifolius*) and papyrus (*C. papyrus*) spread by stems (rhizomes) that grow over wet ground, sending up vertical culms similar to the manner of growth of bulrush and cattail. California grass is included here because its spread by long stolons confers the ability to spread from pond edges out over the open water. The peat layer that covers most of the lower marsh area provides an ideal substratum for these wetland plants.

Further investigation into the use by native waterbirds of these rooted species is necessary. For example, the extent to which Hawaiian gallinule use rooted plants as habitat is not well understood. While these plant species pose threats to open water, some may serve as important habitat for gallinule.

4.1.3.2.1 California Grass (*Urochloa mutica*)

Urochloa mutica is described in Section 3.2.20. California grass encroaches on the lower marsh opportunistically from the margins making up 17.4% (121.3 acres) of the marsh area and cover non-pasture areas of the upper marsh in nearly monotypic stands. Where grazed, the grass is co-dominant with Hilo grass. Percentage of plots dominated by California grass is much higher at the edges of the marsh than central areas (Figure 37). During drier periods, as “obligate” (roots must be submerged) wetland plant species such as the bulrushes retreat, California grass advances and establishes. As newly colonized areas are re-inundated, California grass appears to die back, although, where California grass has built up, exposed portions survive. Remnants of California grass areas, presently dominated by other species, are found throughout most of the marsh (excluding saw-grass-dominated areas). Smith noted while studying aerial photos that grasses advanced and receded while water levels in the marsh were deliberately manipulated in the early 1900’s. While this hypothesis offers the best explanation for the distribution of California grass today, it remains an untested hypothesis. Regardless, California grass surrounding the marsh poses a great risk of invasion should water levels fall below current elevation.

Where California grass predominates near the margins of ponds, this plant creates a floating mat of stolons. The expansion of rooted emergents via stolons results in a gradual reduction in the area of open water. The stolons die because of submergence as new growth is piled on top. The entire dead mass of poorly decomposed stolons tends to remain floating below the water line while living culms and blades flourish above.

California grass presents perhaps the greatest threat to open water habitats in the upper marsh and around the entire margin of the marsh because, as described above, this plant spreads horizontally from the shore out over the water surfaces. In the upper marsh, California grass is presently controlled by cattle grazing and mechanical removal by freshet flows. Within areas accessed by cattle from Knott's Ranch, the grass generally fails to develop beyond basal bunches (height and stolon development are curtailed).

4.1.3.2.2 Cattail and the Reversion Process

Cattail (*Typha latifolia*) is widespread in Kawai Nui Marsh, although as a pioneer species it may be more of a problem in restoration/enhancement projects than in the ecology of the marsh. This species has spread widely and effectively throughout the marsh in just a few decades. It intermixes with other species, especially bulrush and neke. Currently, monotypic stands of cattail cover approximately 2% of the marsh, although its extent is greater due to its coexistence with other species. Cattail is found in high densities in the ditch along the marsh side of the levee, taking advantage of the shallow water. Cattail occurs in various densities together with neke in the eastern parts of the marsh, in a "swath" across the marsh to the western edge, bounded only to the south by the upper marsh (pasture). The remainder of the marsh to the north, currently occupied by neke, bulrushes and saw-grass, is potential habitat for cattail.

Cattail is central to another process by which open waters are obliterated, described in AML (2004) as a "reversion process;" by which attempts to create open water habitat are reversed. The more insidious form of reversion is the accumulation and eventual exposure of mud slurry on the bottom of the ponds. The mud slurry exposed during this reversion is extremely susceptible to colonization by cattail. As observed at Na Pohaku o Hauwahine, this process consists of the following stages:

1. A layer of silt or mud slurry builds up on the pond bottom;

2. This layer comes to within inches of the water surface either because of accumulation of material or falling water level;

3. An algal coating forms on the mud surface, promoting consolidation of the surface, and results in the surface layer rising up in pieces;

4. Once exposed, the mud surface dries slightly, becoming even more buoyant and forming a bed ideal for wind-drifted cattail seeds that then germinate over the surface;

5. Cattail stems and roots proceed to bind the new mat together, forming a layer of increasing thickness.

Once the cattail stand is established, the natural return of the area to open water, in the absence of currents to move the initially weak mat around, is problematic. This process was observed numerous times during the AML (2004) study, and it has been confirmed that there is a separation between the upper, floating mat and the lower slurry layer. In other words, some slurry may be left behind, but the process involves formation of a distinct mat of lower than average density, than the slurry. With mature cattail stands found along the windward (eastern) edges of Kawai Nui Marsh, any management activity needs to suppress the formation, via removal or otherwise, of these mud slurry/algae "chunks" following clearing of peat or vegetation.

Each of the steps outlined above requires further study to determine causes. For example, the origin of the mud slurry is unknown, in the sense that initial excavation of a pond results in a body of water several feet deep without obvious stratification. Over time, however, the slurry appears, either from settlement of particles suspended by the digging process or gravity flow and leveling of slurry from adjacent areas.

One hypothesis, based on recent observations, is that the mud appearing on the surface has separated from the bottom. That is, in at least some cases, the mud floats as a layer or as isolated chunks, becoming exposed. Algal growth on the surface is apparent in many cases, and this growth could both bind the mud together and, by generating oxygen bubbles that are trapped in the filaments, contribute to the overall reduced average density. This phenomenon has been described elsewhere. Additionally, the process of reversion will proceed through this step even where the mechanism of exposure is simply lowering of the water to the slurry surface.

Once bare mud is exposed, seeds of cattail germinate. Control of cattails requires minimizing exposures of bare mud. Once exposed soil supports other species, cattail seedling germination is substantially reduced. Seedlings that establish on trails well above the water line, for example, are slow growing and easily weeded out. These observations suggest that cattail throughout Kawai Nui Marsh maintains itself largely through vegetative growth. As pioneer species, these stands may be overtaken by other species, notably the bulrush.

In the observed sequences of plants that have come to be prominent or dominate an area within the restoration boundary, success and later failure of the cattail stands out. As areas of mixed vegetation have been cleared (usually by cutting or spraying) to facilitate digging of the ponds, cattail regrowth and establishment slowly came to dominate all of the areas beyond created ponds and active digging sites. Disturbance of the area clearly favored cattails, and stands of these marked the area of clearing efforts. As each area has been converted to open water, islets and margins of vegetation, and elevated trails, cattails have become almost absent, especially as the last of buried rhizomes are dug up and removed. Seedlings still establish, but in small numbers.

Drigot and Seto (1982, p. 132) provide an interesting description of the cattail as invasive in Kawai Nui Marsh:

> One of the species of the grass community, the cattail or *Typha angustata* [= *Typha latifolia*] is an emergent wetland plant that has recently become a pest "weed" of major proportions. Formerly, it was confined to small, widely dispersed pockets near the open pond areas, but now this plant forms an almost impenetrable stand occupying several acres near the confluence of Kahana Iki and Maunawili streams as they converge into the marsh. This recent cattail encroachment in the marsh was a condition that developed after heavy rains in April 1977, which delivered tons of topsoil from the Maunawili valley down into the marsh. The sediment runoff formed an expansive mudflat upon which the aggressive cattail species quickly invaded [compare with excerpt from AML, 2004].

The excerpt indicates cattail was not only first noted in 1977, but it also documents the potential of cattail as a “pest” species in the marsh. However, the common species in the marsh today, *T. latifolia*, was not collected on Oahu until 1979 (Wagner, Herbst, and Sohmer, 1990). Today, this cattail is widespread in the marsh, especially around the margins of open water ponds. Another species, *T. domingensis*, is described as sparingly naturalized, at least in the Pearl Harbor area, since 1939 (Wagner, Herbst, and Sohmer, 1990).

It is worth noting that this process is independent of the bottom configuration of the open water pond. That is, obliteration by emergent vegetation typically proceeds outward from the shore because the usual bottom configuration of a pond is one of increasing water depth out from shore. Thus, emergent plant growth extends into a pond until a depth limit is reached. The rate and direction of advancement is dependent upon water level and/or sediment and plant debris accumulation; the process may even reverse from seasonal or other increases in water depth. Because open water areas in much of Kawai Nui Marsh appear to be essentially openings in a floating mat of peat, the depth at the edge of the water feature is not necessarily related to the occurrence of the marginal emergent plants. Indeed, these plants may be limited in their ability to expand into a pond by water that is too deep immediately off the “shore.”

As difficult as controlling this invasive would seem, the AML project at Na Pohaku o Hauwahine was able to prevent reinvasion by cattail once the plant rhizomes were dug out (herbicides applied to areas of cattail growth kill the upright growth but the plants regrow quickly from the underground stems). Re-invasion by creeping rhizome growth is possible from the edges of areas where the plant has been eradicated. It was observed at Na Pohaku o Hauwahine that cattail seedlings only appeared in areas of open, very wetted muds. If bare wetland soils or peat could be colonized quickly by species such as aeae, this growth greatly reduced (and mostly eliminated) successful germination of cattail seeds, despite the fact that much of the time seeds reach every corner of the wetland carried on the wind from the literally billions produced daily when the fruits mature (AML, 2003). At Na Pohaku o Hauwahine, the open water areas were designed with steep banks so that the edges remain flooded regardless of the water level. Therefore, any natural drop in the water level, especially in the spring through summer, does not expose bare mud areas. Any exposed narrow banks are rapidly covered by aeae, thereby preventing invasion of cattail seedlings. Although it is not likely this approach has wide application in Kawai Nui, it does suggest a consideration in designing specific restoration areas to minimize cattail growth. It also suggests that enhancement of the wetland for the benefit of wading birds such as the endangered Hawaiian Stilt can only be considered in places where manipulation of water level is part of the design.

4.1.4 Threats to Native Plant Assemblages

Threats to the native plant assemblages found in Kawai Nui Marsh are substantially different from threats to open waters (essentially threats to waterbirds) of the marsh. Going back to a time when only endemic and indigenous species were present and the marsh offered expansive waterbird habitat could lead to the conclusion that the loss of the latter was directly a consequence of reduction in the former. Put another way: was the nature of the marsh with only “native” wetland plants extant far superior to the situation today where a plethora of non-natives are present and in many places dominating?

First, the present day circumstances with respect to native species abundance and distribution in the marsh need to be visited. The list of native plant species that exist in the marsh includes:

Bacopa monnieri (aeae) – ind.
Cladium jamaicense (uki, saw-grass) – ind.
Cyclosorus interruptus (neke) – ind.
Hibiscus furcellatus (akiohala) – ind.
Hibiscus tiliaceus (hau) – ind.
Schoenoplectus lacustris (akaakai) – ind.

These six species represent only 11% of the number of species identified as inhabiting the marsh (vegetation area categories beginning with the numbers 0, 1, and 2 in Appendix B and simplified in Table 5). Abundance, especially in relation to the many more species of non-natives present, is a separate but important consideration. *Cladium jamaicense* (saw-grass), *Cyclosorus interruptus* (neke), and *Schoenoplectus lacustris* (one of the bulrush species) are among the most abundant plants found in Kawai Nui Marsh, together covering just over 60% of the 700 acre lower marsh area. Each is widespread and is clearly the dominant species occupying many acres of peat land in some places. Although just as in all other lowland Oahu habitats, native biota in wetlands has been severely impacted by both habitat modification and introduction of alien species. A greater concentration of native plants does not exist below 1000 feet elevation on Oahu. Sixty-six percent of the 77 separate sample plots where plant data were collected (of 88 total plots) contained at least one native plant species. However, 96% of the plots, supported growth of non-native plant species.

Of the remaining three native species, *Bacopa monnieri* is not extensive because its preferred habitat is rare in the marsh; *Hibiscus tiliaceus* may be more common in Kawai Nui, but its spread represents a detriment to the marsh environment; and *Hibiscus furcellatus* appears to be a relic population—formerly known to have been common along streams in the watershed (Wagner, Herbst, and Sohmer, 1990)—now just maintaining small numbers of individuals in the marsh.

The three abundant native species are well adapted to growing on the peat mat, and may be responsible for much of the production of the peat that is present. In this regard, neke fern appears to be an especially prolific contributor, predominant in, or a major component of over 35% of the marsh area. Uki (saw-grass) maintains a nearly monotypic stands over vast areas, with other extensive areas harboring an abundant understory growth of neke fern, 21.5% of the total marsh area. Although only speculation, it is possible that uki is successful at invading neke fern areas, eventually to the detriment of the low growing fern. This is based on the examination of aerial photos, and photos in Hammatt et al (1990) where areas that had been sprayed by herbicide in 1988, were first colonized by neke fern, but today are partially covered in saw-grass.

Neke fern areas, on the other hand, appear vulnerable to invasion by many other species, including California grass and both species of *Schoenoplectus*. These invasions may not entirely eliminate fern growth from the resulting mixed assemblage.

Stands of the native bulrush (*S. lacustris*) are less abundant than those of the introduced bulrush (*S. californicus*). If these two species are competing for space on the peat, logic would lead to the conclusion that the native is losing ground at a slow rate.

The chrono-sequenced aerial photos suggest one mechanism by which native species loss is accelerated in Kawai Nui Marsh: disturbance. The best example is the previously mentioned herbicide-treated flight paths, which, in addition to recovery by native species, have been partially colonized by previously absent non-native (upland) tree species. Disturbances, mainly anthropogenic, help explain other vegetation patterns observed in the marsh today, including the area along the levee, which, following emergency excavations after the 1988 New Year's Eve flood event, now support non-native cattail and various floating plant species. Observation suggests neke fern may now be re-establishing in this area (Figure 36). Traces of canals that were cut across the entire marsh for water diversion purposes persist. The current path of the transverse canal was selected, in part, to follow the course of a previous diversion canal. Various ponds along the western banks of the marsh have vanished under the assault of cattail possibly due to deliberate water-level changes (before the 1950's) or the reversion process described above. Silting in of the edges of the marsh caused by various adjacent land use practices is providing a soil matrix for California grass to expand inward.

4.1.4.1 Papyrus (*Cyperus papyrus*)

Papyrus is a very large sedge for which no controls appear to exist once the plants come to dominance. Initially stands form circular rings, expanding vegetatively outward and becoming monotypic. Comparing diameter measurements of eight *Cyperus papyrus* circles from a 2001

Figure 36. Neke rhizomes spreading out across a bed of water lettuce that is floating on water on the marsh side of the levee.

air photo and a 2004 satellite photo (see Table 4, scales normalized) showed an average increase in diameter of 7.4 feet per year.

A control mechanism for these plants, once established, is unknown. However, in Kawai Nui Marsh, where papyrus cover is relatively limited, eradication efforts may still be successful. Cutting and herbicide application before the circles become too large is an option, but the below ground rhizomes will also likely need removal/excavation or follow-up herbicide treatments to kill.

4.1.4.2 Umbrella Sedge (*Cyperus alternifolius*)

Umbrella sedge grows in a similar fashion as Papyrus, spreading in a circular fashion from the original individual, but appears to be dispersing by seeds judging from the rapid appearance of newly established growths. In areas near the Oneawa Channel at the northern end of the Kawai Nui Marsh, large patches of umbrella sedge are forming, some exceeding heights of 8 feet. Like papyrus, the expanding vegetative growth of umbrella sedge excludes other species.

4.1.4.3 Trees

Linda Smith (1978) mentioned that "[t]here are about 30 paperbark [(*Melaleuca quinquenervia*)] trees..." near the Kailua levee. This number has grown somewhat in 25 years (AML, 2004; David Smith estimates a little less than 100 trees are now present, pers. comm.), although the number of invasive individual trees of various species is now well into the thousands. Efforts by the Department of Land and Natural Resources (DLNR) accomplished a removal of some 1000 trees from the marsh in 2002 (Dave Smith, pers. comm.). Paperbark is present in the northern part of the marsh, but not present in the middle or southern part. However, a number of other terrestrial tree species are invading both areas, including (in rough order of present day abundances, paperbark is perhaps third): octopus tree (*Schefflera actinophylla*), fiddlewood (*Citharexylum caudatum*), Java plum (*Syzigium cuminii*), Moluccan albizia (*Falcataria moluccana*), Chinese banyan (*Ficus microcarpa*), Christmasberry (*Schinus terebinthefolius*), ironwood (*Casuarina equisetifolia*), and monkeypod (*Samanea saman*). Hau should also be considered invasive in the same respect as these others where hau plants are established in the interior of the marsh. The trees, particularly octopus trees and fiddle wood, are colonizing the lower marsh at an increasing rate. Depth to hard bottom readings, mud depth readings, peat thickness readings did not explain the distribution pattern of the trees.

Trees have a much higher fiber content per square meter than marsh grasses or ferns. If they are cut when small, their mass is not sufficient to support the propagation of additional trees. If they are cut when full grown, or left unchecked to eventually topple, they will form a more solid base for the growth of additional trees and promote infilling of the wetland. Hand removal of trees followed by herbicide stump treatment is effective, but labor intensive. Tree removal does not contribute directly to waterbird habitat creation; however, tree presence throughout the peat-covered areas of the marsh is incompatible with goals of creating a healthy, functioning wetland system.

4.1.4.4 Other species

Vigna luteola and *Canavalia cathartica* (Fabaceae) — *Vigna* a native look-alike for nanea, the beach pea, and *Canavalia* are recent introductions but have spread widely across the lower marsh. It is perhaps too early to determine if these two vines are causing ecological harm.

Paederia foetida (Rubiaceae) — A twining vine know as maile pilau, this plant is a widespread invasive of lowlands in wet to mesic areas of Oahu. Its harm to marsh ecology is uncertain, though it was observed climbing over many species. In monotypic *S. californicus* patches, this plant occurs in high densities and weaves the culms together, forming impenetrable walls. This may or may not have an effect on the bulrush's susceptibility to wind-throw.

4.2 Changing Water Levels

Natural and manmade changes in water level have profound impacts on the evolution of a marsh from open water lake to non-wetland meadow or forest. Raising the basin outlet elevation expands open water by flooding areas of exposed soil and vegetation; lowering the outlet elevation enhances the rate of conversion to dry land. Although raising the water level sets back the process of wetland loss, this is only true if the outlet water level is set "permanently" high. Otherwise, raising the water level tends to promote sediment accumulation just as lowering the water level can promote sediment removal. Thus, it is not necessarily the case that these manipulations had contrary impacts on the rate (or direction) of the transitional process from open water to solid ground. It is more likely that these manipulations were complimentary in accelerating the eventual reduction of open water and ultimately wetland itself. During and after these periods, activities (notably expanded western agriculture and development of housing) in the watershed increased the delivery of both sediment and plant nutrients from the upper watershed.

Unfortunately, species-species interactions are extremely complex and therefore difficult to predict without extensive and detailed study, and represents a significant gap of information. Various physical conditions that are likely to vary cyclically—such as the amount of direct rainfall, stream inflow patterns, frequency of freshet events, and severity and frequency of wind storms, each alter conditions for a time to favor certain species and not others. Water level changes brought about over the last 100 or more years could have had profound impacts on the distribution of species within the basin, especially the upper marsh where small water level changes can greatly alter soils from dry to saturated (i.e., upland to wetland). The 1945 photograph (Table 4) is interesting because it suggests that the water level was maintained so low that a canal was dug completely across the middle of the lower marsh from north to south to provide water flow to a pump located near Kailua Road not far west of the present-day levee access road. This water was pumped to Waimanalo for sugar cane production until 1965. Many other channels are shown on the 1927-1930, 1943, and 1968 USGS maps of Kawai Nui Marsh (Table 4, and Mann and Hammatt, 2003). The lower marsh (see Figure 1) is shown as wetland in all of the USGS maps. Although not necessarily a good indication of the division between the pasture (upper marsh) and the lower marsh, the upper end of wetland is always shown near Kalanianaole Highway and Kailua Road junction (i.e. modern-day Castle Hospital) on these maps.

4.3 Vegetation Control

One approach to replacing alien plant species growth with native plant species growth is "weeding." Alien species are selectively removed, and growth advantage goes to remaining species (native and non-native) to occupy the open niche. The process is extended to confer ultimate superiority to desired native species. Examples of plants that would benefit from this forms of control exist with the various floating plant assemblages in Kawai Nui Marsh, dominated by water hyacinth, water lettuce, water lily, azolla fern, or Kariba weed. This habitat (open freshwater surface) may or may not have previously supported a native plant (perhaps duckweed).

Efforts to remove alien plant species must consider the likelihood of reinvasion. Can the species be completely eradicated in a short period and are sources of propagules subject to control? As discussed earlier, certain species (Kariba weed, water hyacinth) can be eliminated from the marsh and re-establishment is either unlikely or anticipated to occur at a rate that allows for practical control. Other species (California grass, cattail, giant bulrush) are simply too widespread for eradication to be considered unless species-specific chemical or biological agents become available. Still others (for example, various trees) can be successfully removed, but have a high chance of continuing re-infestation from various (including terrestrial) sources in the watershed. The physical space and ecological niche of a species may be assumed by another alien species, and not all alien species can be eradicated given present technology.

Not all of the species discussed produce seeds, some spreading by fragmentation and vegetative growth. Understanding the manner of spread or dispersal is essential to effect control over undesirable plants, although information is limited on most of the more aggressive alien species in Kawai Nui Marsh. Of the two species of *Cyperus* (papyrus and umbrella sedge), the distribution of papyrus suggests growth is entirely vegetative. The appearance of new growth locations is rare, and the expanding papyrus circles suggest growth outward from a single colonizing fragment. Umbrella sedge, on the other hand is widespread in the marsh as small irregularly shaped clumps; seeds, perhaps carried by birds, may be a primary source of new plants. Bulrush plants may spread to a limited extent by seeds, although vegetative growth from pre-existing rhizomes (sub-surface runners) appears to be the primary means of dispersal. Information on these plants is limited to observations at Na Pohaku o Hauwahine. Both native and non-native bulrushes were introduced to the constructed ponds and spread was primarily vegetative via rhizomes for both: Great bulrush seedlings have not been observed there, but kaluha seedlings were seen occasionally. The situation for saw-grass or uki is, to the extent that observations at Na Pohaku o Hauwahine are typical, that spreading occurs by juvenile plants as described, with no seedlings having been observed. Cattail is perhaps the most prolific seed-producing plant in the marsh, and its seeds are wind-dispersed (float on the wind). However, as discussed previously in Section 4.1.3.2.2, seeds only germinate under a specific set of conditions. Where these conditions are met, cattail is prolific in its ability to disperse.

4.3.1 Fire

Unintentional fires have burned across Kawai Nui Marsh as recently the 1960, and used as a management tool, presents a clear risk of setting the peat to smoldering. It is a process that could be especially destructive to the ecosystem, difficult to control, and has no long-term beneficial outcome. The result would likely be conversion of only a small proportion of the peat layer to smoke pollution, with no additional waterbird habitat created and recolonization by native plants unlikely in the short term.

4.3.2 Grazing

Grazing is an effective control of grasses such as California grass in limited areas of the upper marsh, but enhances nutrient recycling within the marsh, perhaps encouraging plant growth, especially that of floating plants such as water hyacinth.

4.3.3 Biological Controls

Biological control agents are known for both water hyacinth and kariba weed, for example weevils and a carp. However, these would generally not be suitable for Hawaiian aquatic environments for several reasons: 1) control agents require introducing an exotic organism to the aquatic environment and could not be introduced here without considerable research effort to insure specificity against the target weed, 2) populations of pest species are generally small and widely scattered in Hawaii as compared with mainland locations such as Florida where infested waterways are extensive, and 3) over time, biological controls tend to achieve at best reduction in spread and growth rates (a potentially significant gain in areas dealing with very large infestations) rather than local eradication.

Biological controls presently do appear to exist for some of the alien plants regarded as invasive at Kawai Nui Marsh. For example, the red-eared slider (*Trachemys scripta elegans*) feeds on the dangling roots and lower stem of water lettuce. In an area of deeper water where turtles have access to the undersides of the floating plants, this predation limits the spread of the water lettuce across the surface (E. Guinther, pers. comm.). Species such as azolla fern and duckweed also have severe limitations on population growth, perhaps in part due to predation by herbivores or environmental limitations on growth. Both spread rapidly over a water surface, but usually disappear equally rapidly. It was noted at Na Pohaku o Hauwahine that duckweed regularly appeared in the spring in the ponds until poecilids (top minnows) appeared in the ponds. Thereafter, duckweed only appeared en mass over small, isolated pools. Water hyacinth and kariba weed are regarded as more serious invasive species than these other floating plants because the former have such high growth rates and no effective herbivore predators in Hawaii.

4.3.4 Chemical Controls

Numerous herbicides are effective against floating aquatic plants. These commercially available herbicides also break down quickly into inactive compounds, lessening their impact on the ecosystem. The tradeoffs, however, are cost and that repeated treatments are generally always needed. Ideally, plants that are killed should be removed (essentially mechanical control) for three reasons: to reduce regrowth from surviving propagules, adverse declines in dissolved oxygen caused by sinking decaying vegetation, and recycling of biologically sequestered nutrients that promoted the infestation in the first place.

Herbicide (Rodeo ~ glyphosate) application was thought to offer an effective method of controlling vegetative cover over the main portion of the marsh with floating peat in the 1990

EIS (M & E Pacific). Two swaths totaling 90 acres were treated in November 1989 with a herbicide from helicopters using a 40-foot wide spray boom. A single application was effective at killing the live vegetation along this swath, but it was noted that the structure of the dead saw-grass or bulrush remained standing and would still provide resistance to flood waters. More significantly, the application contributed more organic material to the underlying peat, which supports the vegetation. Plants quickly recolonized the floating surface. Revegetation was noted within nine months of the application. A review of photographs in Hammatt et al 1990 seemed to show that neke fern recolonized the bare peat initially (perhaps from rhizomes not killed in the peat). Review of photographs taken over the years following leads to the conclusion that the ultimate impact of spraying over such a wide area was to promote the invasion by alien plant species of a previously native saw-grass assemblage. The spraying, in fact, may have fostered octopus tree invasion, although saw-grass has returned as well.

Clearly the application of herbicide to plant assemblages growing on floating peat, is not an effective mechanism to create open water. The peat layer is not impacted by the herbicide and the newly created open areas allow alien species the opportunity to colonize the marsh.

Herbicide was also sprayed on water hyacinth in conjunction with the 1988 application to open up the waterways in the marsh. While a effective technique (and bi-annual spraying was recommended in the 1990 EIS) no follow-up was implemented and extensive regrowth in the open channels nine months following application ensued.

Spraying of only the floating plants, however, does not eliminate concern about the remaining dead material decomposing and further impacting the system. Ideally, employing a combination of mechanical removal followed by herbicide spot-treatment would most effectively accomplish the desired goal of exposing open water.

4.3.5 Mechanical Controls

4.3.5.1 Harvesting

Mechanical control methods (essentially harvesting) are preferred for control of floating vegetation and peat to the extent that they are practical to apply. Absent mechanical removal, other methods leave dead and decaying plant matter behind with attendant water quality problems. The more difficult problems with mechanical approaches, especially true in Kawai Nui Marsh, tend to be those of accessing and removing the floating plant population with equipment capable of physically removing large amounts of vegetation spread across the water surface. A kariba weed infestation in Lake Wilson, Wahiawa in 2001 required the eventual removal of tons of plant material at a cost of over one million of dollars. The City & County of Honolulu crews have been attempting to eradicate kariba weed from the ditches near the land fill/transfer station along Kapaa Quarry Road for over a year.

Natural mechanical removal involves the persistence of certain open-water areas because of infrequent flood flows from the watershed. These flows push back or perhaps even remove the encroaching mass of grass, maintaining the transverse channel open. The upper marsh is a significant floodway, and the forces generated during floods must be a significant determinant of the local marsh ecology. Observations during high flow conditions suggest most of the width of the upper marsh participates in this flow, involving areas of pasture as well as the low flow channel.

Completion of plans to develop diked impoundments for water bird habitat in much of the existing pasture along the eastern side of the low flow channel (US Army Corps of Engineers in cooperation with the State of Hawaii DLNR, project in design phase), will alter the freshet flow characteristics. More water will be forced into the low flow channel—presently clogged by vegetation in comparison with the adjacent pasture—opening up the vegetation in this area and perhaps enlarging the central pond in the upstream (mauka) direction.

4.3.5.2 Cut and Dredge

Cut and dredge options were investigated in the 1990 Final Environmental Impact Statement for Kawai Nui Marsh Flood Damage Mitigation Project (EIS, M & E Pacific 1990) and concluded that removal costs varied depending on proposed method and rate of removal. One proposal to remove 5,000 metric tons to create a channel required an estimated equipment and set-up cost (no operation or handling) of approximately $1.5 million. A second response offered several options ranging from $123,000-$285,000 in equipment (plus two operators for six months). These costs have likely increased significantly in the years since the study.

The present study's objectives of creating waterbird habitat combined with the findings of the present study may not warrant extensive dredging, removal of vegetation, or removal of peat.

4.3.5.3 Explosives

Researchers completing studies for the 1990 EIS (M & E Pacific) found explosives to be an effective tool to break up and disperse both peat and vegetation creating open water areas. It was noted, however, that within two months that "material from beneath the excavation had 'rebounded,' i.e. hydrostatically adjusted to the removal of the overburden." Seventeen years following the explosive excavations, neither of the roughly 45 by 33 foot explosion sites is visible. More recent observations show that after removal, fine, organic sediments will rise towards the surface forming a thin floating layer of mud at or just under the water surface (See Section 4.1.3.2.2: Reversion). This layer allows cattail seeds to germinate, quickly covering the open area.

The use of explosives is not recommended because it does not remove biomass, nutrients or substrate from the marsh and, without continuous maintenance, provides open surface areas for recolonization by alien species.

4.4 Native Species Recovery

The composition of the vegetation existing in Kawai Nui Marsh at some time prior (i.e. historically) is poorly known and obviously dependent upon what period is selected for reference. With respect to a historical reference, it must be considered that conditions in the Kawai Nui Basin have slowly changed from an open marine bay, to a semi-enclosed (and presumably eventually brackish) lagoon, to an freshwater realm over the last perhaps three thousand years. This history includes the unidirectional loss of open water and its replacement by a floating mat of vegetation.

Construction of the flood control levee nearly 50 years ago, perhaps raising the base level for the marsh slightly, somewhat off-setting the decline in sea level relative to the basin geology, but not its chemistry. The base elevation today is maintained by a set of factors, including outflow and the repositioned outlet at Oneawa Channel.

A wetlands enhancement project has been underway at the base of the rock formation known as Na Pohaku o Hauwahine on the western side of Kawai Nui Marsh since about 1998 (AML, 2004). This project involves removal of the extant vegetation (mostly California grass and cattail in this location) and the layer of accumulated peat to create open water ponds. The margins of the ponds are planted and maintained in native species of plants appropriate to the environment. Although the process of reforming the wetland from one overgrown with alien vegetation to one of open water habitat and native vegetation (and thus an enhancement project and not a restoration) differs in many respects from that proposed for the upper end of the marsh by the Corps in cooperation with the DLNR, the experiences gained at Na Pohaku o Hauwahine have applicability to many other places, especially with respect to plant species interactions and successions.

4.5 Peat mat

Prior to construction of the Oneawa Channel and the original levee (the same levee present today which was raised in 1997), Dames and Moore (1961) conducted a survey of the marsh from which Smith (1978) created an idealized cross section (Figure 5, in Smith 1978) showing a layer of roots and peat varying from 1-4 feet thick, however no measurements were actually made of peat thickness. At the time of Smith's study, a primary concern was the approximately 2,200 yd^3 (1,700 m^3) of secondary treated sewage per day entering the marsh, and the ability of the marsh to handle this nutrient load. Smith conducted growth rate studies and estimated a production rate average of about 60 pounds per day per acre (between 7.5 and 6.9 g/m^2 day for California grass and bulrush respectively), which was estimated to be more than adequate to uptake the nitrogen, and phosphorous loads from the sewage. Of the nitrogen and phosphorous entering the marsh as effluent from sewage treatment plants (2.20 and 1.05 mg/L respectively) only 8% of the nitrogen and 54% of the phosphorous were found in water leaving the marsh. Accumulated nitrogen was thought to be accounted for by denitrification and adsorption of phosphorous by mineralization in the sediments. Smith assumed that the aerobic (above ground) vegetative decay and decomposition of the peat were in balance with the production rates, but did not supply any data to support this conclusion.

While the present study did not conduct any growth rate experiments, the current survey of the marsh provides concrete insight into the present status of the peat thickness marsh-wide. The present results are consistent with previous studies (M & E Pacific 1990, Hammatt et al 1990), though actual data from those previous studies are no longer available. The peat thickness across all plots surveyed in 2005 averaged just over 4.1 feet. These data were collected from more stations closer to the edges (where all transects began), than in the central areas of the marsh (See Appendix B, Map 2). To determine if this distribution introduced bias, the average of peat thickness measurements of plot numbers four and greater along each transect (with the exception of transect 7, which began and ended at a marsh edge) were taken. The resulting average peat thickness for this subset of central marsh plots was 3.75 feet: within the error margins of the data and not substantial enough to call the average of all plots into question.

Considering the six most common species growing in the marsh, Figure 37 shows the percent of plots in which each species appeared, grouped by peat thickness category. Neke fern's ubiquity stands out, with presence in 40% or more of all plots across all categories, followed closely by both bulrush species. Also noteworthy is the greater diversity of species where the peat is less thick.

Field observations indicate neke-dominated areas (greater than ~40% cover) form the strongest peat mat. In shallow areas of the marsh basin the peat thickness is limited (it rests on the mud substratum). In deeper areas of the basin, neke peat thickness measurements of over four feet were observed. In neke-dominated areas, peat-layer growth seems limited only by the depth to mud.

California grass also appears to be a contributor to the formation of peat. Layers of dead California grass stolons can be found within the peat mat: holes cut through the peat reveal strata of California grass in the lower (older) peat layers. Caution is urged when interpreting this information. The sequence or successional steps of the marsh vegetation and subsequent peat deposition are not well understood. For example, the cause, order, and the process of neke overgrowing California grass which is evident in the strata visible in a cross-section of the peat in some areas, have not been studied.

4.5.1 Peat Removal

Peat Removal was considered in the EIS (M & E Pacific 1990), where it was estimated that the total vegetation biomass over the inundated areas of the marsh (excluding grazed areas) at about

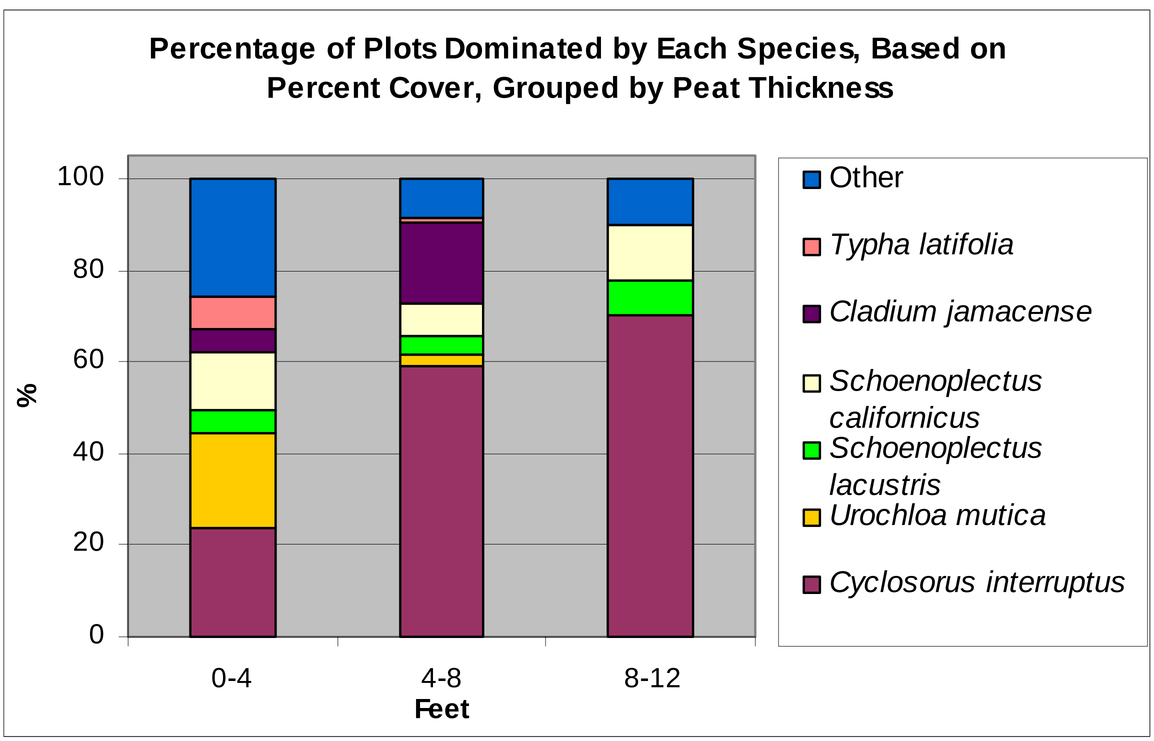

Figure 37. Graph illustrating plant composition on top of peat, grouped by peat thickness

33,000 metric tons. This estimate was based upon standing vegetation biomass data from the marsh (Smith, 1978) and theoretical production rates and submerged biomass degradation rates from other studies (See Table B-25, M & E Pacific 1990). The EIS calculations assume a submerged biomass equal to (for grasses) or less than (for bulrush) the standing crop and a comparable 100% degradation rate (8-12 years) for both submerged and standing crops. This grossly underestimates the mass of the floating peat in the marsh and the period required for degradation of the peat layer. The average thickness of the floating peat layer is 4.1 feet. This yields an estimated wet volume of the peat layer over 548 acres of about 3.6 million cubic yards, the volume of 30, 100 foot X 100 foot 30-story buildings. The average wet weight of the peat (M & E Pacific 1990: Table B-12) is 1,600 pounds per cubic yard (957 kg/m^3). Field estimates indicate that the wet weight (drained) of freshly cut peat is about a third of absolute density or 530 pounds per cubic yard. Absolute density over the 548 acre area of the inundated marsh yields a total harvested weight of the peat is approximately 85,000 metric tons. Using the estimated weight of the standing crop (M & E Pacific 1990, Table B-25) of 18,000 tons (bulrush: 13,083 tons + grass ungrazed: 4,960 tons) yields a total vegetation biomass of 103,000 metric tons over 548 acres or about 190 tons per acre.

Peat removal techniques vary. Experimentally blasting of the peat with dynamite charges placed at 4-foot depths in the 1990 EIS (M & E Pacific) were met with a mixed outcome. Areas were immediately cleared, but within a period of months, the submerged peat and sediments became buoyant and rose to the surface, reversing the benefit (Section 4.3.5). Mechanical harvesting with a bucket dredge harvesting device that removes the material is the best option for creating deep water (greater than 1 foot) waterbird habitat. Other options, including shallow water habitat are discussed next.

4.6 Habitat Modification

Changing some aspect of the physical nature of a location is certainly within modern capabilities, and typically has a profound impact on the vegetation that occurs there. The native wetland enhancement project at Na Pohaku o Hauwahine provides an example of what is possible. This project involved removal of mud and peat along a limited stretch of marsh margin previously dominated by cattail and California grass. The result of the effort is a complex of ponds dominated by native vegetation that has proven surprisingly resilient to invasion by many problem species in the marsh. The experience gained answered many practical questions about how to maintain what was created (AML, 2004). A different approach is being taken in the upper marsh, where basins are to be created that can be flooded to serve as waterbird habitat with the distinct advantages that water level control confers on habitat maintenance (Oceanit, 2004). Whether native plant species will be a significant aspect of these man-made and controlled ponds remains an open question that will likely be decided on very practical considerations. However, both of these projects in Kawai Nui Marsh provide examples of habitat modification producing vegetation changes.

For most of the marsh, removal of shallow or emergent substratum by dredging (including removal of peat) is the only practical alteration. This approach will require significant mechanized efforts to recover large areas of the marsh no longer useful to either waterfowl or native plants. However, the AML project demonstrates what can be created and potentially result without constant maintenance. It is realistic to consider massive habitat restructuring of the marsh towards recovery of native endangered species, but it is unlikely that the cost of any restructuring would be authorized if the long-term prospect is one of continuing, expensive maintenance.

Various control methods are effective against aquatic floating plants. Of greater concern is that of high vegetation production rates, raised by M & E Pacific (1989). Vegetation production in an anoxic marsh environment translates into peat accumulation, and has nearly as much potential for reducing the capacity of the flood basin, as does sediment input from the watershed if estimates of both are accurate.

4.6.1 Excavation

Invasive species control and waterbird habitat creation may best be achieved through excavation of non-native vegetation and underlying soils at the edges of the marsh, but especially in the upper marsh along the streams thereby creating shallow ponds/pools ideal for the Hawaiian stilt. Two recent observations support this management option: Hawaiian gallinules are utilizing streams more so than marshes and wetlands, and the highest abundance of Hawaiian stilt in Kawai Nui Marsh is in the muddy transition area between the pasture (upper marsh) and open water (D. Smith, Pers. Comm.). Parts of the streams feeding the marsh should remain intact under this approach, to serve as habitat for Hawaiian gallinule, while excavation of wide, shallow delta areas (1 – 6 inch depth range), along with control of California grass, would create ideal habitat for the Hawaiian stilt. Control of floating plant species such as water hyacinth might be necessary, although floating plants mostly would be swept out during freshet flows. A similar approach, using excavation combined with vegetation management has been successful in nearby Hamakua Marsh. The higher salinity of the water at Hamakua, however, may prevent intrusion by certain invasive species there, especially cattail, which would be of great concern in the upper marsh. It was in just this stream/pond/mudflat environment that cattail was first noticed in Kawai Nui Marsh (Drigot and Seto, 1982).

4.7 Bathymetry

Bathymetry of the Kawai Nui Marsh has been of great importance with respect to functionality as a flood control basin. Depth from the water surface to the mud surface is significant when considering the thickness of the peat layer and whether the peat is floating or not. Existing bathymetry of the marsh relative to mean sea level is portrayed in the 1990 EIS (M & E Pacific) and incorporated data from two surveys:

1. Bathymetry of the marsh was measured in 1988 by Austin Tsutsumi and Associates for the Army Corps of Engineers, following the New Years Eve flood, December 31, 1987-January 1 1988 (Full size drawings available from the Corps Honolulu District Office). The survey was conducted by Tsutsumi & Associates using a helicopter to transfer survey personnel from point to point. Measurements were taken using a survey pole thrust through the mat and readings were verified from a transit station placed on the flood control levee. Corps personnel (J. Pennaz) provided a tabular data sheet of "depth to mud" and "depth to hard bottom" measurements corresponding to 118 points distributed across the marsh and plotted on levee drawing No. 40-05-02.

2. Cummins and Cummins conducted a second survey in 1990 for M&E Pacific. A platform hanging beneath a helicopter shuttled personnel to points across the marsh. At each point, surveyors thrust a survey pole to estimate peat thickness, depth to mud, and depth to hard substrate (P. Cummins, pers. communication). Elevation measurements were taken from a transit located on the levee (tied into a benchmark on Kailua Road). These points were displayed along two transects through the marsh but the data corresponding to these points are untraceable.

The bathymetry lines on the EIS map (Figure A-66, M & E Pacific 1990) represent the elevation of the hard bottom from mean sea level (MSL). Hard bottom was defined as "depth to resistance" on a standard survey pole (without bottom disc) thrust through the mat. Given an elevation of the marsh surface of 4.7 feet (MSL) in this previous study, the '0' line on this bathymetric chart represents a water depth of about 4.7 feet. The average elevation of the marsh surface portrayed on the 1990 EIS maps is about 4.7 feet above MSL and was obtained from photogrametric methods. Figure 38 (Figure A-73, M & E Pacific 1990) represents the centerline of a proposed channel on a north-south orientation through the center of the marsh showing the top of the mat at about +4 feet, top of the mud bottom at about -1 feet, and hard bottom varying from 0 feet down to -16 feet (MSL).

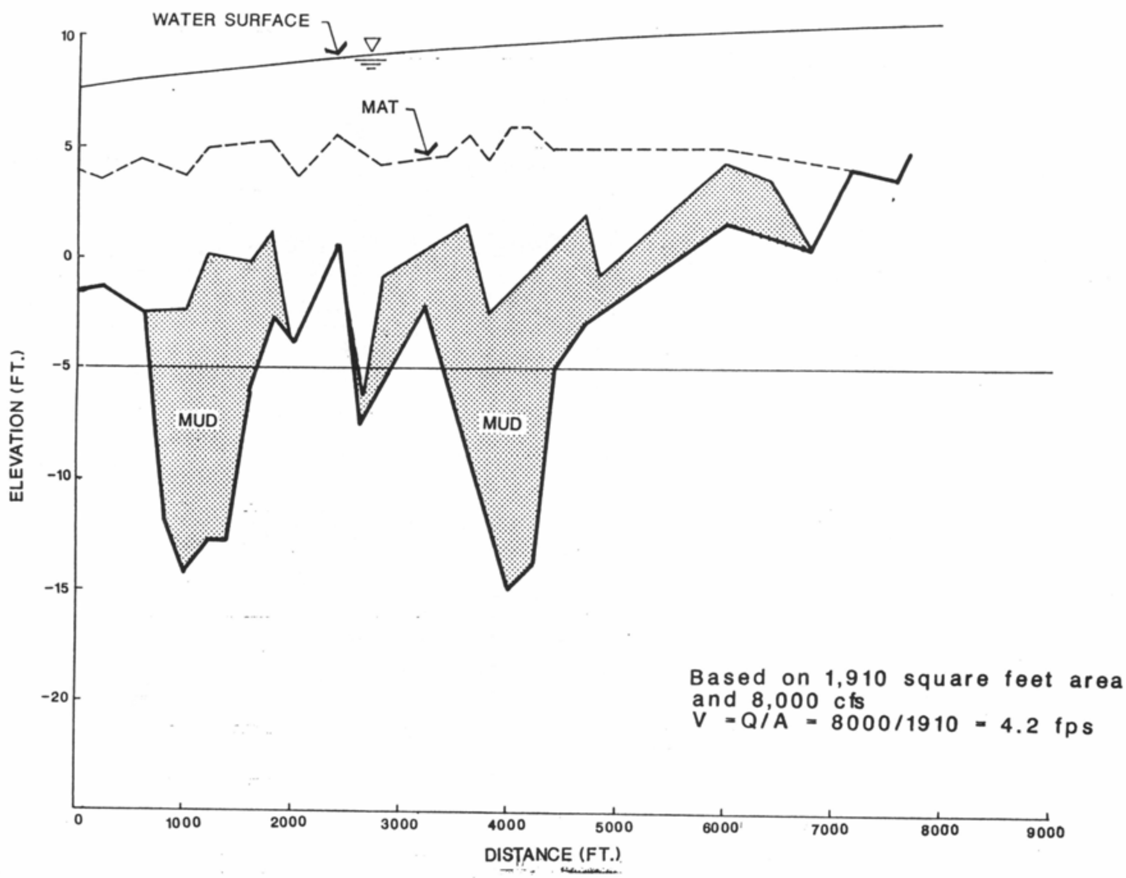

Figure 38. Cross-sectional bathymetry along a proposed channel through the middle of the marsh. The mat thickness falls between the water surface and the dashed "Mat" line. The space between the dashed "Mat" line and either mud or solid bottom is the water layer present below the mat (M & E Pacific 1990).

These results are generally in agreement with those obtained in the present survey. Cultural Surveys Hawaii (Hammatt et al, 1990) cored the marsh sediments at ten locations in the marsh, however the methods used were not consistent with other bathymetry studies and the data were not included in this study.

Measurements in the present survey of Kawai Nui Marsh were recorded as depth from water surface (See Maps Appendices for original data) and then converted to elevation by subtracting the water surface elevation as given by the upper USGS gauge (#16264600) at the southern end of the levee. The elevation of the marsh water surface was nearly constant throughout the period of the survey. Given the maximum length of the survey pole (16.4 feet) and the average elevation of the marsh water surface (+3.2 feet MSL), the greatest measurable depth was -13.3 feet MSL. These points are plotted over the two pre-existing data sets (Figure 39 & Figure 40). Values for the M & E Pacific (1990) data were interpolated from the bathymetry lines drawn from maps in the appendices of 1990 EIS (M & E Pacific 1990). The revised bathymetry maps (Figure 39 & Figure 40) were then drawn by inspection using the combined data sets. A large number of the "depth to mud" and "depth to hard substrate" data points (Austin, Tsutsumi & Assoc. 1988) are significantly shallower (1-4 feet) than the M & E Pacific 1990 data, and present data from nearby locations. It is understood that the accuracy and repeatability of assessing the "depth to resistance" varied considerably between the data collected for the 1990 EIS and data for this report. The resulting depth contours are not highly accurate given the inherent variability of measuring a defined surface over a silt bottom of progressive density.

The average water surface elevation in the marsh during the period of the current survey was 3.2 feet MSL. If this elevation is typical and marks the boundary of the free water surface of the marsh, this yields a maximum potential open water area of 548 acres within Kawai Nui Marsh. Two bathymetry surfaces are generated: Elevation of Hard Bottom (relative to MSL), using the combined data sets (Figure 40), and Elevation of Mud surface (relative to MSL) using only the data from the present study (Figure 39). While depth to hard bottom often exceeds 13 feet below the water surface (-10 feet MSL), the depth to mud is typically only about 8 feet below the water surface (-5 feet MSL). Ignoring the volume of the floating peat layer, this yields a total water plus mud volume of 7.3×10^6 cubic yards (4500 acre-feet) within the marsh at a water surface elevation of 3.2 feet MSL. The volume of open water (again not counting the volume of the peat) from this survey's "depth to mud" bathymetry is about 4×10^6 cubic yards (2500 acre-feet). This is slightly greater than the design estimate established from the Storage-Elevation Curve developed by the Corps of Engineers (M & E PACIFIC, 1990; Figure B-6). The volume of soft mud between the open water and the hard bottom is approximately 3×10^6 cubic yards (2000 acre-feet) over this same area or an average thickness of about 3.7 feet. Table 7 summarizes this study's findings.

Bathymetry plays an important role in the context of this project's purpose, native plant and animal habitat restoration, especially with respect to water levels (see Section 4.2) and the amount of material that may have to be removed (peat or dredged sediment). Improper or incomplete removal of peat and/or sediment would result in "reversion" or rapid recolonization of areas by non-native invasive plant species, for example California grass or cattail.

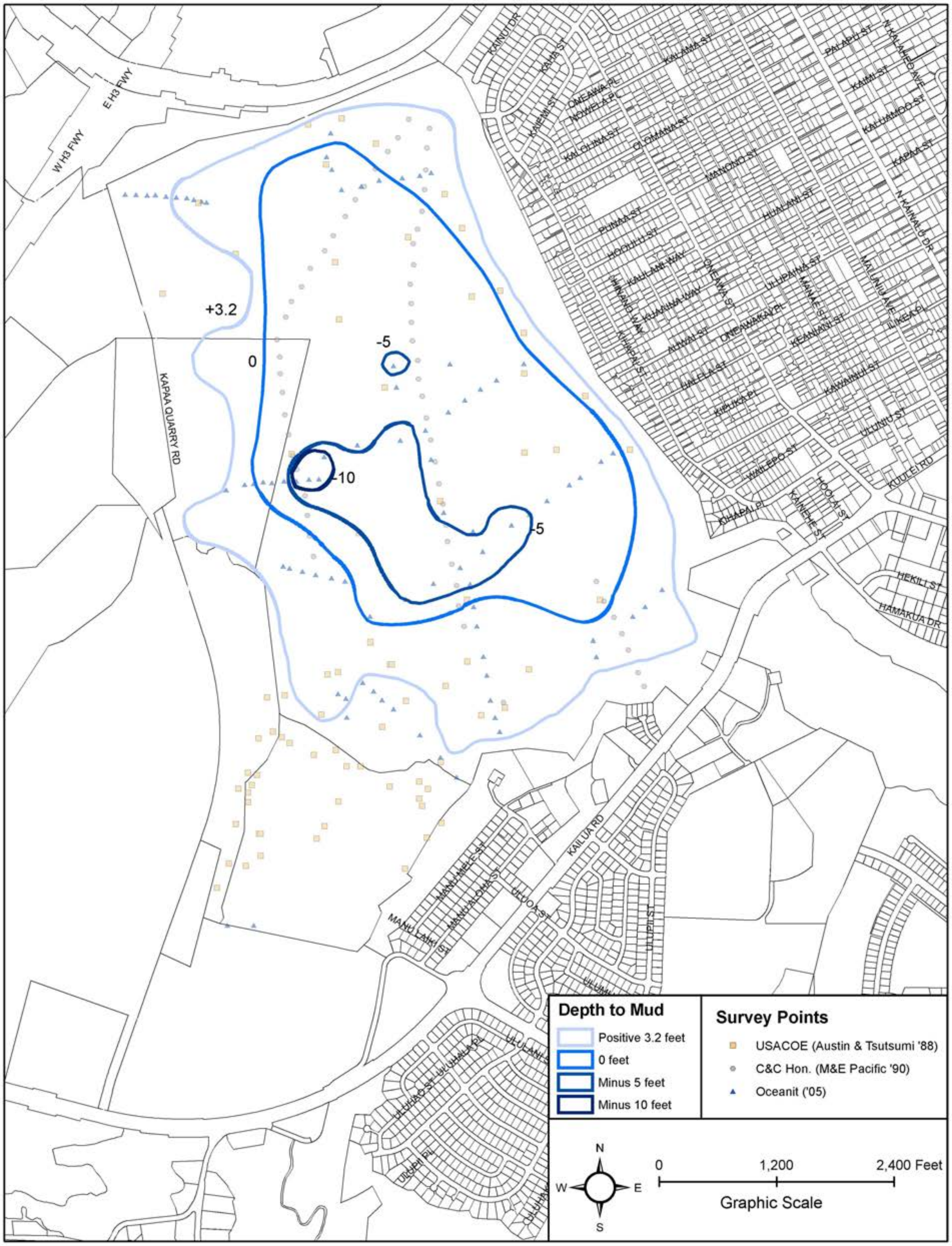

Figure 39. Map of Kawai Nui Marsh bathymetry: Depth to mud (water depth) corrected to MSL.

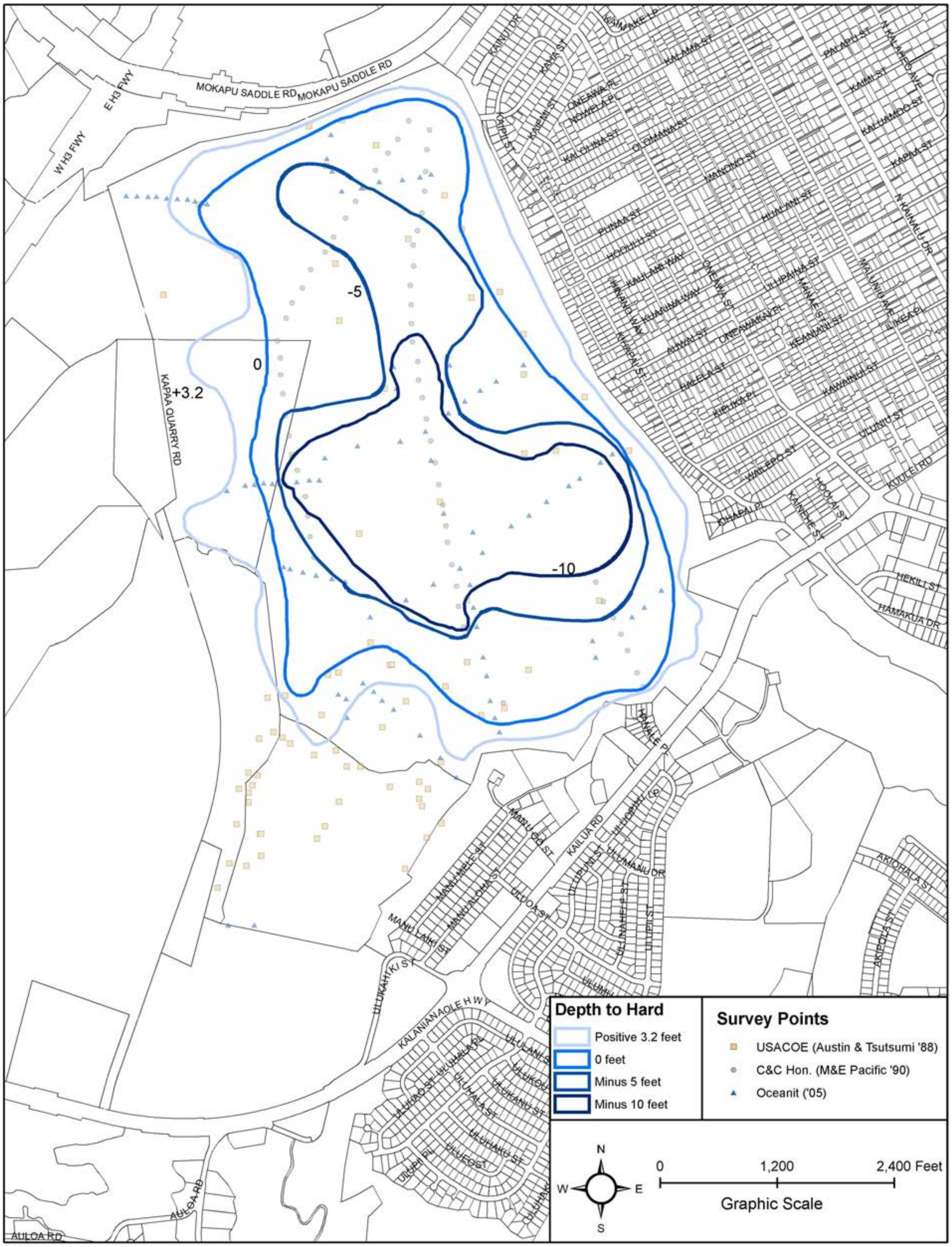

Figure 40. Map of Kawai Nui Marsh bathymetry: Depth to hard bottom corrected to MSL.

Table 7. Summary of marsh volume based on past studies and the current bathymetric survey.

Depth to Hard Bottom (Feet)	Area (Acres)	(ft^3)	**Total Volume** (Mud + H_2O)	Depth to Mud Bottom (Feet)	Area (Acres)	(ft^3)	**Water Volume**	**Mud Volume** (by subtraction of Water Volume from Total Volume)
> 10	96	20908800 ft^3	774400 yd^3	> 10	3	653400 ft^3	24200 yd^3	
5 -10	209	45520200 ft^3	1685933 yd^3	5 - 10	49	10672200 ft^3	395267 yd^3	
0 - 5	429	93436200 ft^3	3460600 yd^3	0 - 5	294	64033200 ft^3	2371600 yd^3	
3.2 - 0	548	38193408 ft^3	1414571 yd^3	3.2 - 0	497	34638912 ft^3	1282923 yd^3	
			7335504 yd^3				4073990 yd^3	3261514 yd^3
			4547 ac ft.				2525 ac.ft	2022 ac.ft

4.8 Information Needs

4.8.1 Flood Hydrology

1) The hydrological studies conducted for the EIS (M & E Pacific 1990) do not offer a recommendation for any optimal or maximum removal of vegetation mat to improve flood characteristics of the basin.

2) The impact of establishing 150 acres of open water to flood basin characteristics is unknown.

3) Sediment characteristics within the wetland beneath the floating peat layer are not well understood as they relate to preferred depth of dredging to prevent re-suspension during flood conditions.

4.8.2 Vegetation Removal and Dredging Technologies

1) Biochemical and physical characteristics of the mud, peat, and plant materials are not well enough understood to maximize potential value of products produced from these materials.

4.8.3 Biological Information

1) The dynamics of California grass growth, dieback cycles during and after inundation, and competitive relationships with other species are not well understood.

2) The impacts of the non-native octopus and paperback trees on the peat mat are not known, especially in the case of mat integrity and ability to float free in a flood event.

3) The impacts on marsh ecology from colonization of large areas of newly oxygenated and sunlit waters by fishes and invertebrates are unknown.

4.8.4 Water Quality Information

1) The impact of re-oxygenation and raised pH of overlaying waters to the overall water quality is probably positive, but more information about possible re-solublization of pollutants from sediments is needed.

Section 5. Recommendations

5.1 Projects and Programs: Options for Ecological Restoration

A substantial proportion of the lower marsh remains dominated by native plants. However, nearly all of the upper marsh and margins of the lower marsh are dominated or heavily invaded by non-native plant species. A review of time-sequenced aerial photos of Kawai Nui Marsh reveals that many areas dominated by non-native species are associated with some physical disturbance that damaged or destroyed the native assemblage. In many instances, the disturbance (e.g. dredging of channels) greatly altered the habitat, and regrowth has been dominated by non-native species.

It is possible that many of these disturbed areas are simply in long-term transition from a disturbed community to a native-dominated climax community. The temporal perspective on such natural plant succession may be too short to comprehend the patterns and directions of change. Projects that attempt to alter the direction of this change, towards an ecosystem more supportive of endangered waterbirds, are discussed below with the emphasis on control of the invasive species.

5.1.1 Species-Specific Invasive Plant Control

This section highlights control options for seven species/groups of plants identified as pests in the marsh. Control programs are prioritized based on degree of infestation and impact on the ecosystem. For species, such as papyrus and water hyacinth, control and even eradication are likely to be successful, whereas control of cattail and California grass will require extensive effort, including studies to better understand their ecology in the case of California grass.

Control programs for papyrus, kariba weed, and water lily boast greater chances of success of complete eradication using initial high intensity removal efforts, with low intensity follow up. The advantage of the eradication of both kariba weed and water lily at present is the elimination of threat while the infestations are relatively small.

The eradication of water hyacinth to expose open water, while feasible, will require greater time and effort. The potential, however, for immediate creation of habitat for Hawaii's endangered waterbirds and migratory birds makes water hyacinth removal a high priority.

Removal of trees will be labor intensive, but benefits include the immediate elimination of upland species that compete with native wetland plant species for resources and reduced habitat for non-native birds.

Finally, control programs for cattail and California grass will require extensive studies and planning. Control plans for cattail and California grass involve minimizing negative impacts, such as arresting encroachment into habitat for native plants and animals or containment measures.

Control options are presented here in a species-specific fashion for clarity. Some options require that other threats be addressed beforehand or simultaneously—illustrating the complexity of modifying ecological systems—and therefore require additional research, resources, and planning. For example, efforts to remove water hyacinth could quickly become moot if appropriate actions were not taken to simultaneously remove water lily populations. Likewise, dredging or expansion of open waters around the edges of the marsh may prove useless if water lettuce, *Azolla* and *Salvinia* were not first eradicated.

5.1.1.1 Papyrus (*Cyperus papyrus*)

Two considerations affect the ranking of papyrus as a high priority for eradication. First, it is highly successful at displacing most or all other wetland species in the marsh. Second, it expands slowly but steadily by vegetative growth, rarely establishing new "colonies," suggesting papyrus in this setting is not capable of reproducing by seed. Physical removal by hand remains an option, but would be difficult as it requires access by a large crew applying methods similar to those used for tree removal (5.1.1.5 below). The "stalks" or upright culms can be easily cut down and herbicide applied to the exposed rhizomes that form an extensive intertwining network over the substratum. Initial experimentation on the effectiveness of this approach, particularly with regard to selection of a herbicide and complete exposure of the rhizome network, would need to be undertaken. Repeated treatments might be required. Removal of the eight or more circular growths of this plant would effectively remove one potent threat to the marsh. Removal should be followed up with a survey of the watershed to determine if a source of reinvasion by this species exists.

5.1.1.2 Kariba Weed (*Salvinia molesta*)

Salvinia molesta is a threat to any open water area created by removal of other floating plants and/or peat mat. Given the high probability of successful eradication, removal of *Salvinia* from the limited areas currently infested in ditches along the edges of the marsh adjacent to Kapaa Quarry Road must be one of high priority.

For successful eradication to be achieved, 100 percent of the weed must be removed from the system. Control of anything less than 100 percent of the growth followed by a period of no control will result in failure through rapid regrowth. Physical removal and application of herbicide (to control the rapid regrowth of the plant from any remaining small pieces and propagules) demands persistent effort and rapid response to any new growth.

5.1.1.3 Water Lily (*Nymphaea* sp.)

The water lily grows from a stem rooted in the mud substrate, sending leaves to the surface on long petioles. Herbicide sprays and/or physical removal of the floating plant parts on the water surface would have minimal effect on the plant, which safely grows at depth and produces new leaves when required. Since extensive growth seen on the surface is likely coming from but a few adult plants rooted on the bottom, physical removal via extraction from the substrate by equipment or divers would be effective at eliminating this species from any pools where it exists. This plant is not extensive in Kawai Nui, so attempting complete removal would be realistic. As with papyrus (Section 5.1.1.1), sources around the marsh (presumably upstream of the marsh) in private water gardens would need to be located. This plant is likely invading only by escaping corms or offsets (subdivisions of the mature, submerged stem) although some species produce small plantlets on the leaves (Staples and Herbst, 2005).

The minimal presence of water lily should not be underestimated. Reports indicate that water lily was at one time more widespread. Any plans to create open water habitat for waterbirds, will also create habitat for this plant although the species is not clearly naturalized on Oahu. The eradication of water lilies in the Kawai Nui marsh system would best be applied as a part of other eradication efforts, such as with water hyacinth. Water lilies observed growing in this study, along transect 1 (Appendix B, Map 2), were found in waters not deeper than 6 or 8 feet.

5.1.1.4 Water Hyacinth (*Eichhornia crassipes*)

Water hyacinth is a floating plant with roots that hang down into the water or grow into the mud in shallow water. This form of growth makes the plant susceptible to herbicide sprays. While effective at killing the plant, like *Salvinia* discussed in Section 5.1.1.2, effective removal requires persistent effort. Any plants remaining alive on the surface will reproduce quickly. Plants can be easily corralled for removal, but the wet weight is substantial. Removal from the central pond, where the most serious infestation is located, would require using booms or other similar devices to "corral" plants. The equipment would be used to lift the plants out of the water and deposit them "on-shore" where they will quickly desiccate and die. Herbicide would be used to treat areas where the plants cannot otherwise be reached for corralling and to kill small pockets left behind to prevent reinfestation. Specialized harvesters are available commercially, designed specifically for water hyacinth removal. Harvesters can be used to clear channels of water hyacinth infestations.

The successful outcome of applying herbicide over the entire area of growth without attempting to remove the dead plants remains untested, but is considered a feasible alternative, if no suitable means of plant removal can be devised. Another alternative would be loading a barge using some type of floating equipment and barging the plants to the proposed "green waste" facility adjacent to the Model Airplane Field. Masses of the plants would be gathered and transported to the site via the transverse canal (itself presently overgrown with water hyacinth) where a small crane or conveyor belt on shore would lift the plants out of the water onto trucks that would deliver the waste across the road to the green waste facility (presently under the name of "Hawaiian Earth Products"). The loads would be reduced significantly if allowed to dry before transporting.

Eradication of water hyacinth is, after papyrus the most achievable mass removal of an invasive plant at Kawai Nui Marsh. While the creation of more open water would benefit migratory species, the impact on the endangered Hawaiian gallinule is unknown and may be adverse. On the other hand, recent observations suggest that Hawaiian gallinule are utilizing stream areas with flowing water, such as streams. The population of gallinule would need to be assessed, and its distribution in relation to the water hyacinth determined. Limited removal of the water hyacinth would benefit the species by reducing access of predators to nesting areas.

5.1.1.5 Trees

Tree removal from areas of the marsh has been attempted and shown to be feasible (Dave Smith, DLNR pers. comm.). Presently many trees remain to be removed and the numbers are growing. Seeds are most likely dispersed from mature trees in the marsh and uplands by birds. The most abundant species are octopus tree (*Schefflera actinophylla*) and fiddlewood (*Citharexylum* sp.). Thick peat presumably provides the substratum for successful germination and growth in the marsh of these non-wetland trees. Additionally, tree invasion of other areas is occurring on a more limited scale.

Manual removal of the trees using saws and treatment of stumps with herbicide would have a two-fold impact. First, removal of the trees eliminates the seed source from within the marsh. Second, the herbaceous marsh vegetation, i.e. bulrushes, is less attractive to fruit and seed-eating non-native bird species. Tree removal eliminates perches, or resting places, for the birds (mostly non-native passerines) that bring seeds in from outside the marsh boundaries. The cut material would not have to be simultaneously removed. Natural decomposition processes or peat mat removal activities would sufficiently address the cut tree parts.

5.1.1.6 Cattail (*Typha latifolia*)

Short-term control of cattail is not feasible and is not recommended. It has long been regarded as a difficult plant to control in wetlands everywhere. One somewhat effective method is to cut all the upright growth to below the waterline. This presumably has the effect of starving the underground rhizomes of oxygen and thereby killing them. The method might work where the rhizomes are growing in anoxic mud and completely dependent upon the hollow leaves and culms to direct oxygen into the subsurface stems. However, control of water level in relation to the parts of this plant would be impossible in Kawai Nui marsh.

Cattail has been removed on a small scale in ponds at the Na Pohaku o Hauwahine restoration site with success through excavation of the underground stems and the elimination of exposed mud area by constructing steep banks at pond edges (See last paragraph in section 4.1.3.2.2). This method is ideal for any other restoration site.

5.1.1.7 California grass (*Urochloa mutica*)

California grass is arguably the most invasive plant in Kawai Nui Marsh and other marshes throughout the state, reducing the habitat value of invaded areas to zero with respect to both native plants and wetland birds. The central parts of Kawai Nui appear to be less susceptible to domination by this grass, although the reasons are unknown. Effective control of this species will require great effort, and persistent physical removal.

Herbivores (cattle and horses) are able to keep the normally large plants cropped in the pasture area of the upper wetland. It is difficult to assess the value of the grazing activity, since the area supports little in the way of wetland resources.

5.1.2 Peat Mat Removal

Mechanical removal of vegetation to expand open water habitat for waterbirds in the marsh should be considered for areas presently dominated by non-native plant species. Conversion of some peat substratum areas to open water could serve multiple purposes related to endangered and migratory waterbird use, flood storage capacity, flood water circulation, and alien plant removal. Any vegetation and peat removal operation, however, would have to control or eradicate the floating plants that might opportunistically and rapidly colonize the newly created open water areas. Succinct mechanisms for maintenance of the newly created open water areas have yet to be defined. Therefore, initial effort to remove the floating peat mat should be limited to relatively small areas of a few acres. Any test acres opened as such should be closely monitored to provide data to fill information gaps.

Conceptually, there may be both practical and ecologically beneficial consequences to dredging/excavating open waters at the margins of the marsh where invasive alien species are dominant. Creating moat-like features around the edges, as opposed to expanding open water from the center, has distinct advantages, including easier equipment access (with equipment locally available), improved predator control, removal of alien-dominated vegetation, and creation of scenic and recreation opportunities. Dredging and/or excavation at the margins of the marsh should also be subject to a pilot project to gather data to fill information gaps.

The direct benefit of removal of vegetation and peat from central areas of the marsh is the creation of additional (mainly migratory) waterbird habitat. Following implementation of floating-plant control measures, mechanical removal of the peat and vegetation would have to commence in areas contiguous with the transverse canal. Caution is urged, however, because unlike marsh margin excavation previously discussed, a much greater percentage of vegetation removed would be native. Any peat removal project should have an upper limit goal to excavate no more than 100-150 acres, and take place only in those areas where nonnative species, such as bulrush or cattail, are dominant. The utopian conceptualization of peat and vegetation removal from the entire marsh is impractical ecologically and with present technologies. Total peat removal would also eliminate the core of native plant species occupying the central marsh. Converting Kawai Nui into a large lake might benefit some waterbird and fish species, although not necessarily those considered native. Potentially adverse impacts on flood control and water quality (including effects on Kailua Bay) would need to be considered carefully.

5.1.3 Inland Extension of the Oneawa Channel

More than once in the past, a solution to the “problems” of the marsh involving extending the upper end of the Oneawa Channel inland has been presented. This action would be relatively straightforward to accomplish working with a floating dredge from the canal itself. The hydrological consequences could be beneficial, as the marsh would drain faster during floods. However, the ecological consequences would be disastrous. The canal is brackish to marine, and the connection between the upper end of the canal projecting southwest is unknown, but may involve a natural or man-made berm of some kind.[4] A narrow band of bulrush growing at the "shore" of the canal often shows an adverse impact attributed to increase salinity in dry months. The vegetation towards the interior appears ecologically isolated from the waters of the canal with exchange occurring from marsh to canal. Extending the channel inland would mean opening this end of the marsh to tidal action and potential salinity impacts. Increased salinity would likely keep the new connection open by killing the vegetation and eroding the peat layer. However, connecting the channel directly to the marsh would result in a lowering of the water level in all of the marsh to something closer to MSL or 3-4 feet lower than at present. The floating peat, coming down against a sediment bottom, could effectively isolate most of the marsh from adverse salinity impacts. A declining water level would start a process of wetland loss around the margins and especially in the upper marsh.

5.2 Sample Programs

One concept in general keeping with the Master Plan developed for Kawai Nui Marsh (DLNR, 1994) is the expansion of open water areas by dredging or excavation. Previously, this activity was envisioned involving expansion of the central ponds (southern part of the lower marsh). Presumably, the open water of the ponds and the formerly dredged transverse canal would afford access to a floating dredge and barges required to haul sediment and peat away. However, in order to avoid or minimize impacts to existing native plant communities, dredging in this area would be limited to the south and west sides of the central pond (Figure 42). Both directions would have an advantage of enlarging the open waters in directions that could be combined with land-based dredging either from the pasturelands to the south or to the west. Removing vegetation and underlying peat to the north or east of the central pond has three principle disadvantages: 1) removes plant assemblages with a significant native component, 2) enhances the hydrological connection between the stream input and the southeast end of the levee, where overtopping occurred in 1989, and 3) is distant from transfer points and opportunities to connect with shore-based dredging sites.

Enlarging the transverse canal by dredging along the edges is a recommended approach. While the canal transects the native plant assemblage along the west side this assemblage is somewhat fragmented. Avoiding these remnants, open water would be extended westward through areas heavily invaded by bulrush. The main thrust in this area must come from shore to create open water and remove alien vegetation in the form of a moat dredged from the solid ground between Na Pohaku o Hauwahine and the Model Airplane Field. These margin areas already have small channels maintained by the City and County as part of the drainage system for their property (former sanitary landfill) on the mauka side of Kapaa Quarry Road. Enlarging and connecting the narrow ditches in the marsh would improve the hydrology and reduce maintenance. The extent to which creating waterbird habitat in an area directly down-slope of the former landfill potentially exposing biota to contaminants contained in groundwater from the landfill would

[4] The extension, or "arm" of the Oneawa canal that extends southeast past the "mitigation islets" receives fresh water from the marsh flowing over a berm of some kind along the border with the marsh vegetation. This is especially evident when marsh water levels are above normal following heavy rainfall, and small waterfalls are observed flowing into the canal.

require investigation. This area cannot be dismissed as unsuitable without an understanding of the present contaminants and only of reduced priority compared with other potential sites. Groundwater monitoring wells around the landfill are monitored annually by the City & County of Honolulu, but the reports were not reviewed for this study.

Other potential dredging areas to create moat-like features from the land side are: 1) off Kapaa Valley to the vicinity of the intersection of Kapaa Quarry Road and Mokapu Boulevard (Figure 42) and 2) the western edge of the upper marsh. Dredging in margin areas and the upper marsh involves removal of alluvial sediments. Dredging further out, near the central pond and transverse canal, involves dealing with large quantities of peat.

Land-based excavation to create shallow ponds particularly along the Kahana Iki and Maunawili Streams in the upper marsh has also been recommended as a means for creating habitat for the Hawaiian stilt. The ease of access for equipment, and the predominance of non-native vegetation (primarily elephant and California grasses) make this alternative suitable for the upper marsh. Relatively large areas of non-native vegetation would be removed with immediate creation of shallow water habitat preferred by the Hawaiian stilt. These shallow ponds would become incorporated in the stream flow, creating a complex environment of ponded water, flowing water, and wetland vegetation. Constant maintenance would be required to keep invasive plants from eliminating all traces of open water.

5.3 Prioritization of Invasive Species Removal Recommendations

Programs utilizing the approaches discussed for eradication of various alien plant species involve applying the previously described methods. Both details and alternatives would need to be explored on a case-by-case basis as part of developing strategies prior to seeking funding. For some species (e.g. water hyacinth, kariba weed), the goal should be complete removal from the outset. For others (trees, papyrus) it may be advantageous to begin with trial areas designed to test methods and assess results.

A simple prioritization model was designed to guide recommendations. Four primary factors affect the prioritization of potential projects in Kawai Nui Marsh. They include:

- **Difficulty** of achieving control or eradication (subdivided further, see text below).
- **Ecological Benefit** of the species being removed and subsequently absent from the marsh,
- **Costs** of achieving the goal of eradication or removal, and
- **Area** occupied by the species (based on acreage values in Table 5)

Each of the primary factors affecting prioritization is weighted equally, scaled 0-3. Figure 41 is a schematic illustrating how the components of the model are related and influence prioritization. Lower scores imply higher benefit for the effort required, and thus higher priority. The three sub-factors contributing to the difficultly score are also scaled 0-3, the sum of which is multiplied by one third so that each of the four primary factors contributes equally (25%) to prioritization.

Efforts were made to minimize subjectivity. Scoring of ecological benefit was based on improvements to the marsh ecosystem through the control or removal of the species, increasing habitat for both native plants and waterbirds. Potential ecological damage was also considered. For example, while papyrus has a relatively small presence in terms of acreage in the marsh today, reports elsewhere and data collected for this study indicate that its potential to become widespread is very high. Cost score was based on the following cut-offs: 1 = 0 - $50,000; 2 = $50,001 - $500,000; 3 = > $500,000. Three sub-categories contributed to the difficulty rating assigned to each species.

5.3.1 Difficulty of Removal

Difficulty itself is but one consideration (along with cost, acreage and ecological benefit) taken into account in prioritizing programs to eradicate or control invasives. The three sub-factors utilized are a) likelihood of reinvasion, b) relative dispersion across the marsh, and c) complexity of methodologies needed to implement effective eradication. A score from 0-3 was assigned to each species for each of these three factors. The scores are included in Table 8.

Although a number of sub-factors were considered in establishing a difficulty score, it was decided that three met the criteria of 1) being relatively free of interlocking considerations and 2) related to difficulty of the task and not more significantly part of a prioritization scheme (Section 5.1.1). The difficult score was re-weighted so that it has the same potential contribution (25%) as the three other factors contributing to the priority rating.

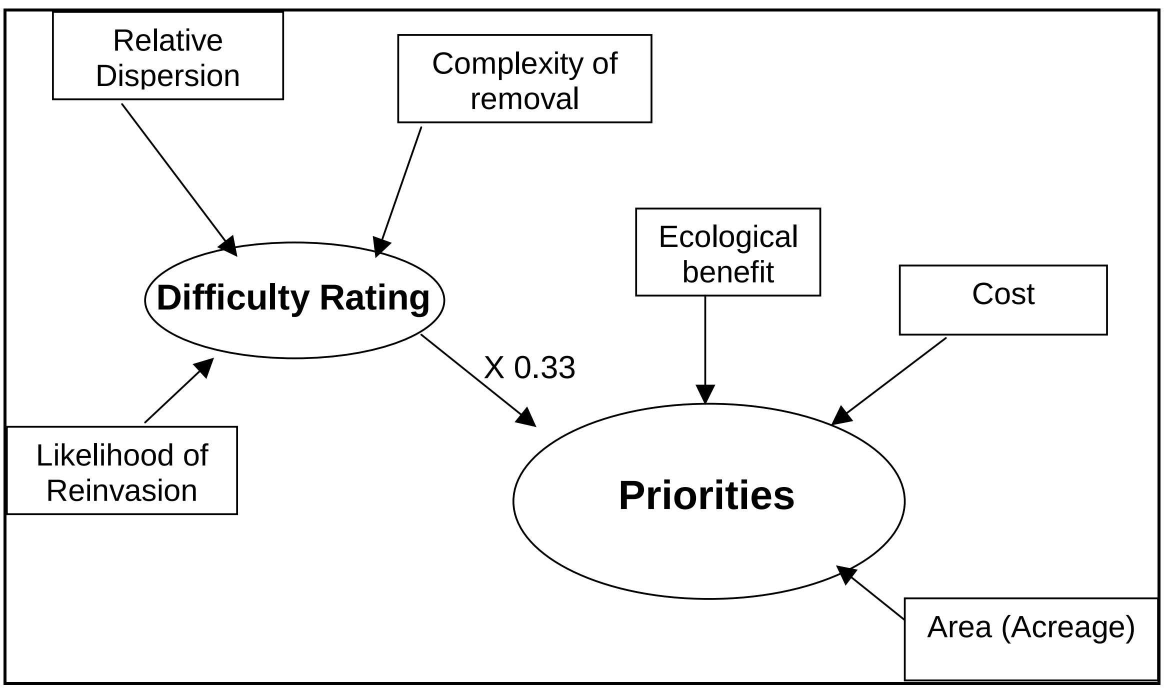

Figure 41. Model illustrating variables and how each contributes to prioritization of invasive species control or eradication in Kawai Nui Marsh. Each factor in a rectangle is scaled 0 – 3. The combined difficulty rating is re-weighted by multiplication by a factor of 0.33.

Table 8. Difficulty rating for selected invasive species in Kawai Nui Marsh, each scored on a scale of 0-3, for a combined scale of 0-9. The higher the score the greater the difficulty of the recommended action.

Species	DIFFICULTY SCALE Reinvasion	Dispersion	Removal	Combined
Mangrove	1	0	1	2
Salvinia	1	0	1	2
Papyrus	0	1	2	3
Water hyacinth	1	2	2	5
Hau	2	2	2	6
Trees	2	2	2	6
Wild Cane	3	2	1	6
Elephant Grass	3	1	3	7
Umbrella sedge	3	3	1	7
California Grass	3	3	2	8
Cattail	3	3	2	8
Bulrush	3	3	3	9

Key: *Reinvasion likelihood*: 0=none, 1=slight, 2=medium, 3=high; *Dispersion (Clumpiness)*: 0=single isolated population, 1=few high density locations, 2=mixes with other species, 3=diffuse/heavily mixed with other species; *Removal (Herbicide-assisted implied)*: 1=Manual, 2=Land-based Mechanical, 3=Water & Land-based Mechanical.

5.3.2 Prioritized Recommendations

Incorporating findings from previous reports and this study, Table 9 contains a prioritized list of recommended actions for removal or control of invasive species, which, together with the previous sections of this report, provide insight into the status of invasive species threats in Kawai Nui Marsh. Also included in Table 9 are each of the scores used to determine the final prioritization so that adjustments can be made as necessary. Different circumstances (i.e. a drought, funding) may require adjusting the scores or re-weighting the contribution of each factor.

Table 9 successfully incorporates the threat posed by each species to Kawai Nui Marsh with feasibility of control and eradication action recommended in this report. A lower score in this table does not necessarily mean that the species is highly detrimental to the marsh, nor does a low rank mean that control efforts would be in vain. The combination of the factors incorporated into the presented model make this a priority list for recommended actions at this point in time.

It is no surprise that Kariba weed (*Salvinia molesta*) is at the top of this list. Its small area of infestation, high potential threat, yet relative ease of eradication combines to make the highest eradication recommendation.

Table 9. Prioritized list of recommended eradication and control programs for non-native invasive plant species in Kawai Nui Marsh, Oahu, Hawaii**

Species	Difficulty*	Ecological Benefits	Cost	Area	Priority Score**
Salvinia	0.67	2	1	1	4.67
Papyrus	1.00	2	1	1	5.00
Mangrove	0.67	3	1	1	5.67
Umbrella sedge	2.33	1	2	1	6.33
Hau	2.00	2	1	2	7.00
Water hyacinth	1.67	2	2	2	7.67
Trees	2.00	2	2	2	8.00
Wild Cane	2.00	3	2	1	8.00
Elephant Grass	2.33	2	2	2	8.33
Cattail	2.67	1	3	2	8.67
California Grass	2.67	1	3	3	9.67
Bulrush	3.00	2	3	3	11.00

* Reweighted difficulty score, see text for details.
**The lower the score, the higher the priority.
Key: Ecological Benefits (from alien species absence): 1=great, 2=medium, 3=slight; Cost: 1 = 0 - $50,000, 2 = $50,001 - $500,000, 3 = > $500,000; Area: 1=<5 acres, 2=<50 acres, 3=>50 acres

A factor that quantifies "contribution to creating waterbird habitat" was not included in this prioritization scheme. Inclusion, however, would clearly raise the priorities of some actions such as water hyacinth removal and California grass control, but would mask the importance of other factors such as cost. Nonetheless, as stated from the outset, this report focuses on invasive species control mainly for the purpose of enhancing waterbird habitat in Kawai Nui Marsh.

5.3.3 Invasive Species Control with Dredging.

In combination with the prioritized invasive species control or eradication recommendations, results of the present study indicate that vegetation clearing should be accompanied by limited dredging to remove sediments that will re-suspend and provide both floating substrate and nutrients to cattail and other early invasive plant colonizers. Achievement of a maximum of 100-150 acres of open water area, particularly if these areas are interspersed around the marsh, would likely be sufficient to achieve the flood control, waterfowl habitat, and other goals of the Kawai Nui Master Plan. A 5-year project time frame would allow for easier planning modifications during implementation. A longer timeframe would allow for realistic product processing and timing through adjacent green waste and dredge-spoil dewatering sites.

5.4 Study Recommendations

5.4.1 Recommendations based on areas of the Marsh

The following actions are recommended to control invasive species and restore waterfowl habitat to the marsh for four management areas: 1) open water, 2) peat covered, 3) lower marsh edges, and 4) upper marsh.

5.4.1.1 Open Water Areas

Recommendations for open water areas include the immediate and complete eradication of floating plant species including kariba weed (*Salvinia molesta*) and water hyacinth. Eradication would also be required for any activity that would create open water contiguous with or in close proximity to any areas infested with floating plants.

5.4.1.2 Peat Covered Areas

Recommendations for the peat covered areas of the marsh include eradication of papyrus, eradication of all trees, and at a larger scale, removal of peat to expand existing open water areas for use as waterbird habitat. These recommendations would apply along the perimeter of the marsh and/or expansion of the central pond areas.

5.4.1.3 Lower Marsh Edge Areas

Recommendations for the lower marsh edges include excavation of non-native vegetation and sediments to depths that inhibit intrusion of California grass and other non-native species. Simpler recommendations include removal of patches of mangrove and hau.

5.4.1.4 Upper Marsh Areas

Recommendations for the upper marsh include removal of non-native vegetation through excavation and grading of areas adjacent to streams that feed the marsh. Excavation to depths of 1-6 inches to create large ponds with muddy substrate would create Hawaiian stilt habitat.

5.4.2 Additional Recommendations

1) Conduct a comprehensive study to examine the benefits of varied water depths (shallow versus deep water) on waterbird habitat enhancement options;

2) Implement a small-scale pilot clearing of 2 – 4 acres to obtain data on the potential effects on waterbird habitat;

3) Remove sediment sufficient to prevent "rebounding" of substrata, conducting concurrent research to better understand the processes involved;

4) Expand project time (ie. 5 years) to allow for modifications to the selected plan and logistical coordination for green waste removal;

5) Conduct maintenance clearing of floating plants; and

6) Clear 100 – 150 acres of the marsh of vegetation and/or associated peat for creation of waterbird habitat.

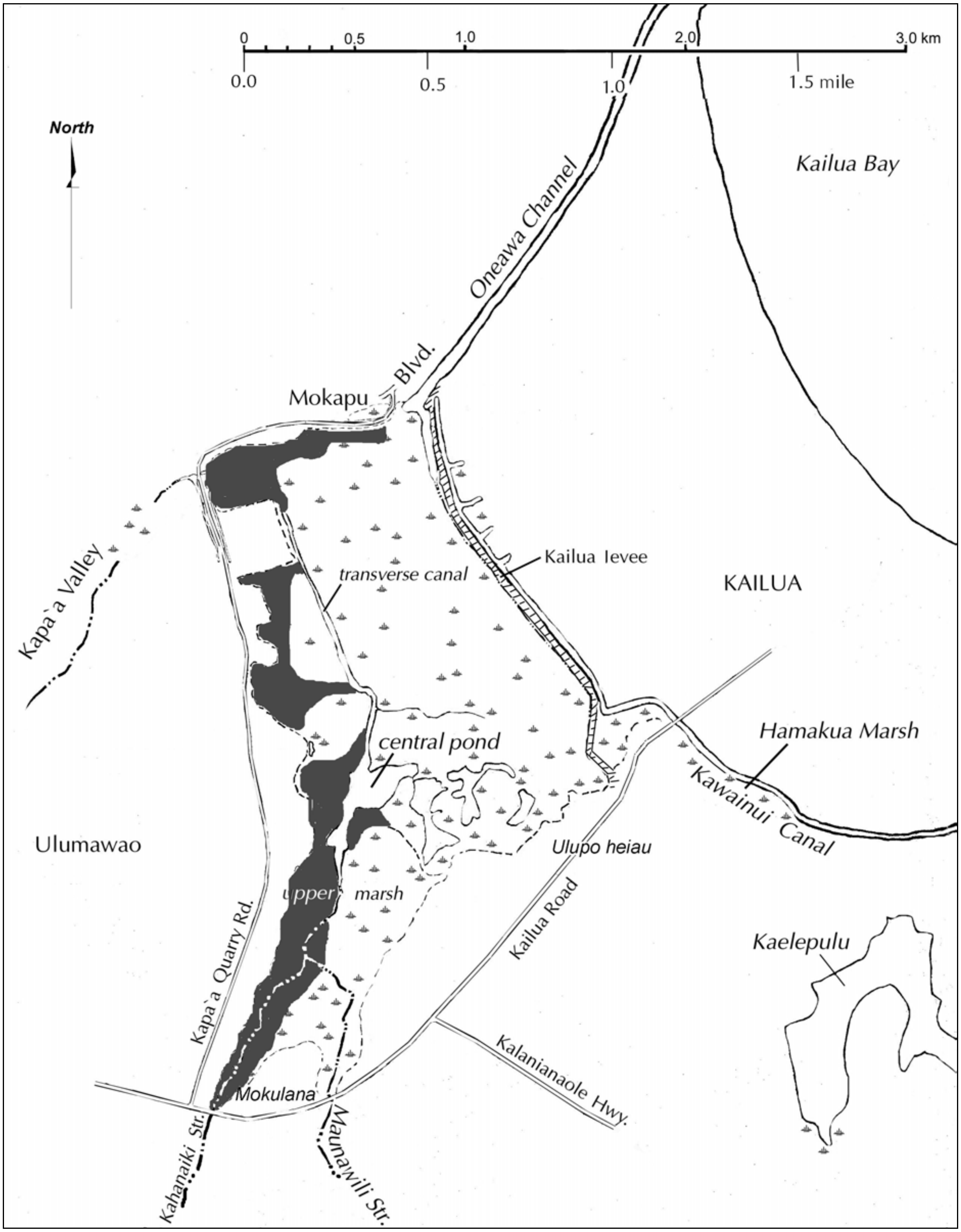

Figure 42. Areas (dark gray) recommended for dredging of peat and sediment to accomplish removal of invasive plant species, creation of waterbird habit, improvement of hydrology and flood capacity, creation of recreational resources minimizing adverse impacts on native flora and flood prevention properties of the marsh. Additionally, the area along the levee could also be dredged again, taking into account the effects of saltwater intrusion near the Oneawa Channel opening