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FINAL TECHNICAL REPORT

THE APPLICATION OF REMOTE SENSING DATA TO GIS STUDIES OF LAND USE, LAND COVER, AND VEGETATION MAPPING IN THE STATE OF HAWAII

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Project Final Report

The Application of Remote Sensing Data to GIS Studies of Land Use, Land Cover, and Vegetation Mapping in the State of Hawaii

Abstract

A land cover-vegetation map with a base classification system for remote sensing use in a tropical island environment was produced of the island of Hawaii for the State of Hawaii to evaluate whether or not useful land cover information can be derived from Landsat TM data. In addition, an island-wide change detection mosaic combining a previously created 1977 MSS land classification with the TM-based classification was produced.

In order to reach the goal of transferring remote sensing technology to State of Hawaii personnel, a pilot project was conducted while training State of Hawaii personnel in remote sensing technology and classification systems. Spectral characteristics of young island land cover types were compared to determine if there are differences in vegetation types on lava, vegetation types on soils, and barren lava from soils, and if they can be detected remotely, based on differences in pigments detecting plant physiognomic type, health, stress at senescence, heat, moisture level, and biomass. Additionally, literature of mapping in Hawaii was reviewed since national mapping systems for remote sensing do not include tropical island environments. Geographic information systems (GIS) and global positioning systems (GPS) were used to assist in image rectification and classification. GIS was also used to produce large-format color output maps. An interactive GIS program was written to provide on-line access to scanned photos taken at field sites.

The pilot project found Landsat TM to be a credible source of land cover information for geologically young islands, and TM data bands are effective in detecting spectral characteristics of different land cover types through remote sensing. Landsat TM is the most powerful satellite sensor available to date; none of the current satellite sensors are ideal for the level of land information desired or needed in a mountainous, tropical island environment with cloud forests and erupting volcanoes. The environment of Hawaii requires extensive field work because there are established vegetation mosaics and numerous transition zones which change over very short distances, unlike ecozones in the temperate zone. The mountainous terrain covers over 4,000 sq. mi., ranging from sea level to the summit of Mauna Kea at 13,796 ft. along a mere 17 mile long transact. Land cover change is based on climate, elevation, moisture, with primary succession after volcanic eruptions. Large agriculture field patterns were resolved and mapped successfully from wildland vegetation, but small agriculture field patterns were not. Additional processing was required to work with the four TM scenes from two separate orbits which span three years, including El Nino and drought dates. Results of the project emphasized the need for further land cover and land use processing and research. Change in vegetation composition was noted in the change detection image.

It is hoped that future satellite sensors and other remote sensing instrumentation will address the orbit and scene constraints by developing systems that are able to scan a whole island in 1-2 North-South scenes and continue to improve bandwidths to address the plant community level, smaller land use patterns, fire and acid rain from volcanic eruptions, and include radar as a band, ideally with the same spatial resolution, for cloudy environments.

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PREFACE

Since Hawaii has a growing interest in using remote sensing to monitor land cover, land use, and environmental questions, the summary for this pilot project is expanded to include a wider audience than originally planned for NASA. The need is great on all islands, where resource managers and researchers are without tools to monitor the resources they are responsible for. Resource management funds are limited and focus is on maintenance and control needs such as fencing, cattle guards to protect land from pigs, cattle, and goats, bio and chemical controls. Funds are needed to map change in land cover and land use.

The funds to produce this map were minimal and the result is a map which is considered base in areas where field data needs processing or collection.

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Aloha Aina

Take Care of the Land

Christine Hogan

REPORT
ON
REMOTE
SENSING
SUPPORT

Introduction

The NASA Mission to Planet Earth has a program for environmental monitoring with remote sensing technology. The Environmental Analysis and Applications Program awarded a federal grant to The University of Hawaii's Office of Technology Transfer and Economic Development (OTTED), administrator of the grant for the State of Hawaii Office of State Planning, (OSP), Department of Land and Natural Resources (DLNR), University of Hawaii Planetary Geosciences, and Department of Geography. A portion of the grant provided for a remote sensing pilot project using NASA Landsat Thematic Mapper (TM) digital data with ER-2 (U-2) photography from NASA at Ames Research Center. The purpose of this pilot project was to train State of Hawaii personnel in uses of remote sensing by helping them produce a baseline land cover, vegetation, and land use map of the Hamakua Coast area and the Island of Hawaii, with a subtropical land cover-use classification system for Hawaii's island environment. Each agency can further process the data for their agency needs.

The pilot project produced a reconnaissance level land cover and land use map by pre-processing and classifying four Landsat TM scenes. Map compositions of the island-wide mosaics were produced of the TM raw data, the spectral land cover classification, and a change detection image; which combined the Landsat TM with MSS data from 1977. The remote sensing software ERDAS/Imagine v 8.1 for the HP was used in combination with ESRI/ArcInfo v 6.0 - 7.0 for GIS. The migration of remote sensing and GIS to the desktop, combined with network and Internet access, make this technology a flexible and affordable tool for resource management, research, and education.

Problem Definition

The Hawaiian Archipelago is the most isolated major island chain on earth. The islands are actually the emergent tops of huge volcanic mountains, ranging from sea level to 13,796 feet (G. Walker). From the town of Hilo at sea level to the summit of Mauna Kea at 13,796 feet, road mileage is a mere 44.2 miles of mostly paved roads, with ecozones ranging from tropical rain forests and woodlands to alpine deserts. The distance from sea level to the summit is a mere 17 miles on a NOAA chart. Mapping land cover and land use in this tropical and mountainous island environment presents problems not found on continents or flatland areas with little topographic variability. Operating funds for field work have been declining for several years and ways to extend field work are needed. Therefore, alternative reliable methods of monitoring land cover and land use are needed for planning, management, and research at the landscape level.

The last complete set of land use and land cover maps for the State of Hawaii was made in 1963 from aerial photography flown in 1950. Since that time, extreme changes in land cover and land use have taken place. These changes include decline of agriculture based on sugar cane and pineapple, deforestation, grazing, noxious weeds and pests from overseas, hurricanes, urbanization, fire, and on-going volcanic eruptions on the geologically young island of Hawaii. For the nation's only tropical rain forests the crisis is urgent since trees catch rainfall, protecting the forested watershed and its ecosystems which provide water and cool temperatures to help sustain Hawaii's environment. Following the loss of native forests in the 1900's, there was an increased awareness of their importance for irrigation and fluming so important to Hawaii's sugar industry. Hawaiian forests were considered "protection forests" as opposed to "supply forests", and water production was considered their most valuable product (Judd 1927; Cuddihy and Stone 1990).

The largest sections of undisturbed native communities remaining today are primarily Montane Wet Ohia or Ohia-Koa forest communities in areas generally considered unsuitable for timber production, agriculture, or ranching (Jacobi 1990). There is limited time available to find and implement solutions to monitor change in land cover for management, research, and conservation. The survival of native ecosystems depends on adequate, protected habitat, and research and management to prevent further loss of plant communities (Gagne and Cuddihy in Wagner et al).

Purpose and Need for Action

Land use needs to be monitored with the on-going ecological and economic crisis in Hawaii. Management needs visual tools and ground field site data for monitoring and planning land use and zoning changes in agriculture, conservation areas, ranching, forest reserves and plantations, to locate indigenous community and archeological sites, and urban encroachment.

Hawaii contains the highest number of native plant species for any plant region in the world, with 89% being endemic or found only in Hawaii. Today, Hawaii's major ecosystems are in crisis from the continued introduction of non-native plants from overseas and the destruction of natural habitat which opens up sites for colonization by alien plants. Non-native plants amount to 47% of Hawaii's vegetation at the species level, higher than first anticipated and more is expected, especially as Kauai is further surveyed (Wagner et al).

The source of rapid ecological change in 'paradise' is the islands' natural beauty and the ever increasing number of people bringing in non-native species, intentionally or accidentally within the last two hundred years, since the rediscovery of Hawaii by Europeans in 1778. Humans thus effectively broke the natural isolation barrier of the Hawaiian Islands. (Mueller-Dombois; Nelson). Non-native plants arrive in Hawaii via the pathway of uninformed or careless inspections and shipping, or smuggling: airline passengers 27%, First Class mail 24%, cargo 16%, military 13%, foreign inspection 13%, and private yachts 6%. (DLNR).

Although Hawaii accounts for 0.2% of the nation's land area, 75% of the U.S. recorded extinction's are Hawaiian. Today Hawaii is home to 40% of the nation's endangered or protected plant and animal species. (Department of Land and Natural Resources). Research has shown extinction is preventable if appropriate habitat conservation, education, and management methods are taken (Wagner et al).

Applying Remote Sensing - Ecosystem Management and Research

Incorporating satellite and low altitude remote sensing imagery with other land information provides a visual tool for monitoring change in landscape. The timing in Hawaii's history is both critical and opportune for finding ways of monitoring the complex interactions of both native and disturbed environments. The unique visual and spectral data provided by remote sensing technology is identified as one tool for monitoring landscape change. Offering repeat coverage of the same geographic area, multiple resolution image data is combined from satellite, sensors on-board aircraft, or spectra data from other types of instruments.

By absorbing and reflecting energy in the environment, the imagery contains information responsive to vegetation type, pigments detecting health or stress, cell structure remaining at senescence, biomass, and moisture levels. Imagery also contains information responsive to water, substrate, land cover and use, temperature, and atmosphere. There are infinite applications for visual display, land cover and land use mapping, and other types of digital mapping.

Background

The State of Hawaii had previously been involved in the NASA Ames Research Center's Western Regional Application Program (WRAP) from the late 1970's until the program was discontinued in the early 1980's. While participating in the WRAP, State of Hawaii personnel were introduced to the use of digital data collected by satellite to discriminate various classes and patterns of land use and land cover. As an adjunct to the application of remote sensing technology, State personnel were also introduced to the use of the relatively new technology of geographic information systems to integrate mapped information with processed satellite images. NASA's VICAR/IBIS was used for producing a Prime Forest Overlay from the supervised classification of the island of Hawaii.

When the WRAP was discontinued in the early 1980's due to Federal budget cuts, advances in computer technology and GIS software eventually enabled the State to initiate a GIS program in the late 1980's.

Since the State's GIS was envisioned to be a multi-agency system accessible to all State agencies with an interest in spatial data, the Office of State Planning within the Office of the Governor, was designated as the lead agency for planning and developing the State's GIS program. The foundation of the system was the development of a centralized database which would be accessible to all user agencies to avoid duplication of effort in the costly area of database development, while maximizing efficiency in data management in State government.

Although the implementation of a GIS offered a wide range of applications, the initial focus of the database development efforts were concentrated on land use planning and resource management uses. In addition to the development of the requisite base maps, most of the data layers which were initially developed included environmental and natural resources-related data layers.

In March 1993, NASA representatives contacted State of Hawaii officials to discuss the potential benefits of incorporating the use of remotely sensed data with the State's existing GIS to support resource planning and ecosystem management decision making. State of Hawaii personnel expressed interest in this initiative, since it would augment the existing GIS database and also provide an opportunity to evaluate the feasibility of using Landsat Thematic Mapper (TM) imagery to develop land use, land cover, and vegetation data sets.

In its previous experiences through the WRAP, the State's Landsat Demonstration Project utilized Multi-Spectral Scanner (MSS) data to develop land cover/land use classifications of the island of Hawai'i and O'ahu. Since the State had already worked with MSS data with 4 spectral bands and approximately 1 acre resolution (79mx79m), this new initiative offered the State an opportunity to evaluate the viability of using TM data which has a higher resolution (28.5m x 29.5m) and with 7 spectral bands of covering land.

State of Hawaii Consortium for Technology Transfer

Cooperative alliances between public and private organizations are critical to find the authority and resources to address the needs of Hawaiian ecosystems, planning effectively for new land use and creating new jobs, recovering and sustaining forest lands and the remaining island ecosystems of Hawaii and the Pacific. (Tropical Forestry Plan 1995). Although the State of Hawaii constituencies have their own priorities and responsibilities, collectively they need visual tools and base maps for assessing and sustaining Hawaiian ecosystems at risk. Imagery provides one layer to monitor the changes visibly evolving in land cover and land use.

The University of Hawaii's Office of Technology Transfer and Economic Development (OTTED), representing a number of State and University Departments, applied for a Federal grant from the National Aeronautics and Space Administration (NASA). OTTED served as the administrator of the grant, on behalf of the State of Hawaii Office of State Planning (OSP), Department of Land and Natural Resources (DLNR) and the University of Hawaii's Department of Planetary Geosciences and Department of Geography. In August 1993, the above consortium was awarded a grant from NASA Headquarters to in part, demonstrate the potential benefits of the Environmental Analysis and Applications Program being developed by NASA's Office of Mission to Planet Earth, while helping the State of Hawaii re-establish its in-State remote sensing analyses and image processing capabilities.

Project Requirements and Goals

By carrying out a remote sensing pilot project using Landsat TM, to produce a baseline land cover classification map of the island of Hawaii, the State of Hawaii hopes to attain the following project goals.

- Design a system for State employees to process and retrieve remotely sensed image data on the State of Hawaii GIS.
- Train State employees to produce a baseline land cover, land use, and vegetation classification map of Hawaii Island from Landsat TM data.
- Integrate processed Landsat image data with the State of Hawaii's existing GIS database design.
- Evaluate the usefulness of Landsat imagery for carrying out land cover/land use and vegetation classifications.
- Evaluate the usefulness of Landsat data for detecting changes in land cover/land use, vegetation and the environment.
- Establish a new base line of data to be used for "change detection."
- Establish within the State of Hawaii, the capability of reformatting and distributing remote sensing digital data.
- Position the State of Hawaii to become a possible "Center of Excellence" for the Pacific Basin in GIS and remote sensing technology.

Implementation of the Plan

A collaborative effort by the State and University of Hawaii entities was initiated in order to meet the stated project goals. OTTED, as the grantee, was in charge of overall project management and federal grant administration. OTTED also served as the State's point of contact with NASA's Earth Observing System (EOS) Program.

The University of Hawaii's Planetary Geosciences Department was in charge of receiving the acquired data and reformatting multiple sets onto CD-ROM. They also were the point of contact for distributing copies of the CD-ROM to State of Hawaii.

The University of Hawaii Geography Department had students participate in the initial ERDAS software training and later on in the change detection portion of the project. Remote Sensing is offered in addition to their cartography and GIS curriculum.

The Division of Forestry and Wildlife and Office of State Planning assumed the role of the application project team in order to develop in-house image processing expertise by actually participating in the image analysis and classification pilot project for the Island of Hawaii. The Division of Forestry and Wildlife also provided ground support for field data collection.

OSP served as the State agency liaison with OTTED and was also responsible for upgrading existing State GIS equipment and procuring image processing software for State agency use. DOFAW was in charge of coordinating and leading the necessary field work efforts on the Island of Hawaii.

Observations

This technology transfer pilot project outlines methodology to incorporate and process remote sensing imagery in a centralized location with access to State databases for State and University personnel. The sensors included are NASA's Landsat TM and MSS, and color infrared photography (CIR) from the ER-2 (U-2). The need is great on all of the islands where resource managers and researchers are left without access to these visual tools for management and research of the lands they are responsible for. It is time to expand the resources and knowledge to the locations that need them most. The interest level in remote sensing is seeded, as exemplified by the recent purchase of statewide coverage of SPOT Image data. Public and private personnel will form alliances to use and share data and information.

Acquisition of Hardware and Software

A portion of the grant was allocated for the purchase of workstation hardware and software designed to process remotely sensed image data and to integrate the data into the state's GIS. Remote sensing software provides tools to process image data with an overview of landscape (30m), where land features look small; or, very high resolution data (1-10m) from an airborne scanner, where land features look big. A total of 2 ERDAS/Imagine software licenses were purchased for the State GIS. ERDAS is the industry leader in remote sensing software and provides the most compatibility with the State's Arc/Info GIS.

Hiring of Consultants

Since the State and the University of Hawaii did not have personnel available to produce the pilot project, and in order to effectively carry out the technical requirements of the grant, the State opted to use a portion of the federal grant to hire a consultant to facilitate the technology transfer process. In this regard, OTTED solicited proposals to develop in-State expertise in analyzing and processing remotely sensed data and then applying such information to the State's GIS.

A proposal submitted by Geographic Decision Systems International (GDSI) and Hogan Co. was selected. The proposal offered project management at the State site using the systems approach to a remote sensing project. This approach guides image database organization and parameters for pre-processing data for the sensors used in the project. The remote sensing project system is composed of three functional dimensions which correspond to the ecosystems of the project site. The remote sensing project design is further divided into subsystems for processing: input, analysis, and product database subsystems. They are represented by the project flow on the following pages.

The remote sensing phase of the project was led by Hogan Co., and the GIS phase was led by GDSI. GDSI provided custom software where needed for map production and the multi-media AML to view photos of GPS sites. Together with Office of State Planning and DLNR they provided on-going support for map production, GPS editing, and the multi-media AML program LSVIEW.

Training in the basics of image processing and GIS were taught using the State's hardware/software and the pilot project's data, to produce a baseline land cover, land use, and vegetation map. Small scale maps used for administrative purpose and large scale maps for the field were produced. This approach delivers the capability of further processing, which allows State personnel to process the data in a working environment they are familiar with. Independence is established to analyze remote sensing imagery, produce maps, and to establish remote sensing data within the GIS database design. Introductory training of 17 participants included OSP, DLNR, ICSD, and UH. Following the initial two weeks of training, the consultants worked closely with the State personnel when they were available to participate in the project.

LANDSAT TM - PILOT PROJECT SYSTEM DESIGN

The project flow was as follows:

- Introduction by NASA
- A Remote Sensing System - scene, sensor system, processing system
- State of Hawaii Requirements and Objectives
- Establish feasibility
- Project Plan
- Project Implementation
- Remote Sensing Classification hierarchy -major land cover ecosystems
- Output Database Subsystem - processing standards for Landsat TM in State GIS, archive/retrieval format/media, geometric grid: terrain, cell size for image/GIS layers, map scales, interactive use, classification tree.
- Input Subsystem - scene acquisition and formatting for distribution
- Deposit new TM and 1977 MSS raw data on GIS file server
- Import data into ERDAS/Imagine for image modeling and processing
- Analysis Subsystem - georectify TM data to UTM Zone 4 and correct for terrain displacement with 32m pixels, to comply with the State GIS
- Unsupervised classification of each of the four scenes for Hawaii Island
- Ground field data collection
- Produce GPS Point Coverage of ground field data
- Supervised classification and training field extension of north scenes
- Field data collection and verification
- Supervised classification with training field extension of four scenes
- Produce whole-island raw data and classification mosaics by modeling
- Unsupervised classification examples on whole-island raw data mosaic
- Change Detection Analysis - georectify 1977 MSS to TM in State GIS
- Change Detection - of combined MSS_TM image
- Supervised Classification Masking Examples in ERDAS/Imagine v8.2
- Vectorize supervised classification for GIS layer in Arc/Info Version 7.0
- Map production / GIS support as maps produced for Output Database
- Create multi-media application LSVIEW to demonstrate use of GPS
- Products archived on: tape, optical disk, film, CD, paper, or file server

Technology Transfer Output Product Design

Building an image database requires agreeing to the same standards for product design, reassessing them as needed, and documenting sources on image/GIS layers. Specific needs must be addressed in the process if land cover information is incorporated into a larger mapping system of resource data.

Map products for the pilot project were produced with ERDAS/Imagine and ESRI/ArcInfo software, but ArcInfo was used more by the State since they have custom AML programs in place to automate map production. The University of Hawaii used the SUN platform with demo license of ERDAS/Imagine v8.2 to produce their products. The products from this project are outlined below and listed in the Appendices as Appendix H:

1) an unsupervised land cover classification of the Hamakua test site area, extending from west of Honokaa to Laupahoehoe.
2) a base subtropical land cover-use classification system for use with remote sensing data in Hawaii's island environment.
3) a base land cover, land use, and vegetation map of the island of Hawaii, produced at 1:250,000 in image, hard copy, and 4X5 negative format.
4) a digital six band color mosaic of the four TM scenes including Maui.
5) color composite of TM bands 7-5-3 scaled at 1:250,000 showing separation of vegetation from re vegetated lava flows, lava, agricultural areas and urban classes (Hilo, Kona, Waimea) where cloud cover permitted. Digital, hard copy, and a 4X5 negative transparency is available.
6) a ten band change detection composite image of Hawaii with multiple resolution Landsat data combined from 1977 MSS channels 4-5-6-7 as layers 1-2-3-4 of the image and TM bands 1-2-3-4-5-7 as layers 5-6-7-8-9-10 of the image. Digital and hard copy examples of areas showing significant change are in 8.5 X 11.0 inch format and a digital composite of TM 7-5 with MSS 6 as layers 10-9-3.
7) Vectorized land cover, land use, and vegetation maps formatted in 7.5' quadrangles scaled at 1:24,000. (1.5gb data can be loaded as needed).
8) State personnel with training in remote sensing project system design.

Both electronic and hard copy maps are available, located at the State GIS for manipulation and further processing by the agency personnel. Image, vector, CD, hard copy maps, and 35mm and 4 X 5 in. negative transparencies were produced.

Cost Effectiveness of Remote Sensing Surveys

This is a value judgment area that needs reassessment throughout a project as factors effecting project flow are identified. If the level of information awareness or need increases, the cost and value of the map also increase. Readjusting cost and value of the map is required.

Vegetation patterns mapped in an area with minimal field samples, levels of data, or funds is unfortunately reflected on the map. With powerful sensors like Landsat TM and use of multiple resolutions and scales of data, techniques for 'data mining' are available to discern multiple levels of land cover information, depending on need.

The Island of Hawaii - Project Site

Geologically, Hawaii is the youngest island in the archipelago and expanding with the addition of new land from the active lava flows of Kilauea's on-going eruption 1983-present. The big island is (4,638.2 sq.mi.), two times the combined size of all other Hawaiian islands, four times larger than the eastern state of Rhode Island, and approximately the size of Connecticut (4,845 sq.mi.) with Kilauea forming new land. Hawaii has well-defined vegetation zones based on moisture-climate, elevation, and vegetation-habitat zones with physiognomic types of, e.g., forest, shrub, grass. (Jacobi et al. 1986; Gagne, and Cuddihy).

Hawaii is the largest island in the Hawaiian Archipelago. The archipelago is formed by volcanic islands consisting of 8 major islands, islets, reefs, and small atolls in the central Pacific. The archipelago extends from Hawaii Island in the southeast to Kure Atoll and Midway in the northwest; totaling 10,932 sq. mi., with a land area of 6,459sq.mi. (16,729 sq.km.). The 8 main islands comprise more than 99% of the land area and extend from Hawaii Island at 18 degrees N latitude in the southeast to Niihau at 22 degrees N latitude in the northwest, and the northwest islands and atolls extend to 28 degrees N latitude (G. Walker).

Mapping land cover and land use in this tropical and mountainous island terrain presents problems not found in continental, flatland areas with little topographic variability. The uniqueness of the vegetation is a result of geologic history, extreme isolation from continents, variation in substrate, topography, and climatic changes over short distances, which allow the vegetation to migrate radically into available niches. These factors contribute to the diverse mosaic formations of the natural plant communities. (Wagner 1994, Mueller-Dombois, Bridges, & Carson, 1981).

Physical Ecosystems of Hawaii Island

Hawaii Island is formed by 5 volcanoes: Kohala in north, Hualalai in west, Mauna Kea (13,796 ft. or 4,205m) and Mauna Loa near the center, and Kilauea on the southeast slope of Mauna Loa. Kilauea is the most active volcano in the world with the current eruption expanding 1983 to present. Kilauea is now the largest and longest rift eruption in recorded history, forming Pu'u O'o on January 3, 1983. In 1986, a change in eruption activity formed the shield Ku'paianaha (the mysterious) with a lava lake within it's summit feeding a network of lava tubes, which flowed to the ocean producing 500,000 cu. yds. of molten lava daily to 1992. A fissure opened in Pu'u O'o and this fissure along with others continues to feed lava tubes extending to the sea from 1992-date (HVNP).

Mauna Loa (13,677 ft. or 4,169m) is the world's largest volcano, rising almost 30,000k from ocean floor and approximately 70mi. (97 km) wide at its base, erupting recently in 1950, 1975, with the last eruption in 1984, with subsequent hot spots visible on infrared imagery to date.

The last eruption of Hualalai was in 1800-1 and the last eruption for Kohala was some 60,000 years ago.

There are diverse climatic and precipitation changes over short distances from topography ranging from sea level to the summit of Mauna Kea at 13,798 ft. elevation. This elevation change is a mere 17 mile long transact when drawn on a NOAA navigation chart of the Hawaiian Islands (ed. 1991) or 44.2 miles by roads. Recent geologic age, solar radiation and latitude, slope, and aspect affect veg type and density which causes change in spectral values.

Biological Ecosystems of Hawaii Island

Vegetation is the obvious biological process visible in the imagery. The Hawaiian flora is well known for being the most distinct plant region in the world, dominated by native plants found no where else. The native land cover of Hawaii are forests and Hawaii is the only state with tropical rain forests and habitat (Cuddihy and Gagne).

Island ecosystems are different than continental ecosystems due to geographic isolation, predominately small geographic areas, and recent geologic age with well developed biological differences resulting in extremely visible interaction between native species and native with non-native species (D. Mueller-Dombois). Forest succession is on geologically young land, there are established vegetation mosaics, and abundant transition zones with diverse vegetation types changing in short distances and time spans, based on climate, elevation, and moisture.

Gagne and Cuddihy modified Jacobi's outline of vegetation zones, based on five elevation zones of coastal, lowland, montane, sub alpine, and alpine. Three moisture zones are described as wet, medic, and dry, with five physiognomic plant types defined as grassland, shrubland, forest, open forest, and parkland (Gagne and Cuddihy). The combined information was adapted to fit the NASA pilot project based on the data's spatial, spectral, and temporal resolution (including two orbits and three years) and includes Tropical Wildland, Physical, and Manmade systems.

The diverse ecosystems are complex based on elevation, moisture, and climatic zones, volcanic activity, and time described here for Landsat TM's resolution and the field work collected. The minimum resolution is 6(32.0m x 32.0m) spatially, derived from the six Landsat spectral bands, over three years time including El Nino and drought years, with atmospheric effects of clouds, precipitation, ice, snow, and VOG.

Manmade Systems - Land Use and Vegetation Introductions

Hawaii has abundant indigenous populations and ancient archeology sites which interact in both remote and urban environments. Colonization of Hawaii by the Polynesians is recorded from archaeological sites with settlement time 300-400 A.D. at Bellows Waimanalo on O'ahu (Kirch 1974; Cuddihy and Stone 1990). By the 6th century, all islands had permanent settlements. Alien plant introductions began with the Polynesians, who brought with them about 32 species. Of these 32 species less than 25 escaped cultivation (Cuddihy 1990; Nagata 1985)). The enormous increase in non-native plant and animal introductions has occurred in the past two hundred years by humans. (D. Mueller-Dombois).

Economic changes, like ecological changes, are more apparent on islands than continents, again because of isolation and limited resources on generally small and geologically young land masses.

There are major economic changes present with the immediate end of the sugar industry and 80,000 acres of abandoned cane fields in transition. The last harvest for Hamakua Sugar taking place during the project's field work in 1994 and in the winter of 1996 for Kau, C & H Sugar in the Pahala area. The Kahala Sugar Company discontinued production in 1977, the same year of the Landsat MSS data. Some land use conversion is on-going. There is a potential for reforestation with native Koa, non-native forest species of eucalyptus, sugi, ash, or bamboo, or to extend crops such as truck farming, wine grapes, coffee, taro, macadamia nut, cattle, and nurseries of flowers and trees.

Island of Hawaii - Remote Sensing Project System

A remote sensing project system is composed of image scenes for a project site, the resolution domain of a sensor system to record information, and a processing system for analysis and output products. This system corresponds to physical, biological, and manmade ecosystem domains of the project site. The scene corresponds to ecosystems in front of the sensor including the atmosphere, the multispectral sensor records visible, infra-red, and thermal information contained in the scene, and the processing system analyzes the information visually and numerically, and produces trained personnel and image or map products (See sections on: Landsat TM - Pilot Project System Design and Product Design).

For example, in this project image data from three dates of one sensor (Landsat TM), is combined with ancillary information to produce the multidate classification map. Image data from more than one sensor is combined to produce the multiple resolution change detection composite mosaic of Hawaii, with Landsat MSS and TM.

Selecting Landsat TM Scenes for the Island of Hawaii

In addition to the federal grant, NASA provided seven Landsat TM scenes as part of their bulk purchase plan of data. The scenes of Kauai, Oahu, and Hawaii were unacceptable due to clouds over the island land masses and could not be used for land cover classification or change detection. The data was ordered in the Space Oblique Mercator (SOM) projection with a cubic convolution resampling method.

This project typifies image processing problems found in tropical island environments at a latitude where the sun angle and azimuth are close. Imagery from different dates was used because of the separation of adjacent satellite paths (N-S orbit) and cloud cover on the available data. Visible atmospheric conditions occur over cloud forests and from volcanic activity (VOG). Forest succession is on geologically young land.

For the pilot project site of the island of Hawaii, four TM scenes were required to mosaic a whole island composite image. A planning meeting was held in May 1994, to meet the project team and select big island data from 8.5 X 11 in. black and white copy. The quality of available imagery was an immediate concern for vegetation classification. The scenes with the least amount of cloud cover and temporal differences were selected by University of Hawaii Department of Planetary Geosciences/Hawaii Institute of Geophysics (PG/HIG), Department of Geography, Office of State Planning, Hogan Co., and GDSI.

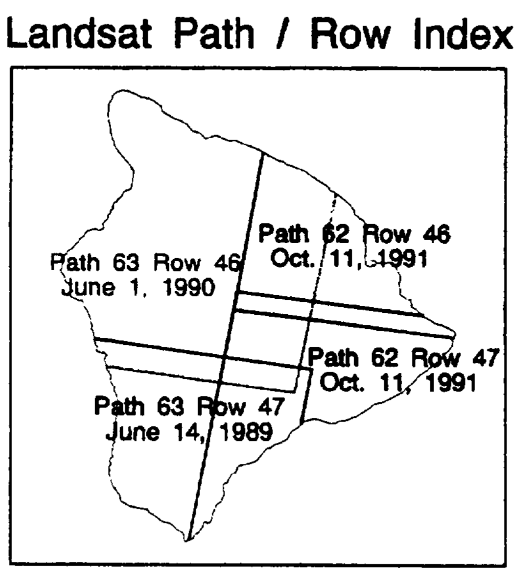

Figure 1 : Dates of digital scenes with corresponding Orbit Path and Row are indexed along with their map extent.

The data cover three years and include both El Nino and drought years, as well as seasonal variation. Mauna Kea received 17 feet of snow in March 1990, with snowfall recorded through July 1990. On the 1991 drought image named Kalapana, the visible Kilauea volcano eruption sites are from Pu'u O'o (formed in 1983) and the shield Kupaianaha (formed in 1986). 'Skylights' of molten lava, burning vegetation, and VOG are visible. Kupaianaha was active from 1986-1992 when activity moved back up the east rift to Pu'u O'o, where it remains active to date. The effects of the visible atmospheric differences and moisture stress in the vegetation on the drought years adds dimensions of data to process in an environment that is already complex. The impact of these differences on the classification are impossible to determine definitively (Matt McGranaghan).

APPENDIX A - Landsat TM Scenes and NOAA data

Sensor Characteristics - NASA's Landsat TM Sensor

The sensor characterizes the scene by absorbing and reflecting radiation energy from the ground site. Remote sensing image data is acquired by a scanner with detectors for recording defined bands of reflective and emitted light in the visible, infra-red, and thermal wavelengths. Through a process known as digitization, the analog signal is converted into a numerical format of binary digital data. Through the telemetry process, the resultant image data can be processed on a computer with the individual radiation bands displayed as intensity measurements in a gray scale with digital numeric values (DN) ranging from 0-255. Scanners record in either pre-defined bands as Landsat does, or they record in bands that are selectable and defined by a specific need to detect spectral land cover information.

The bands are designed to detect health (i.e. chlorophyll, carotene pigments), senescence/stress (i.e. carotene, xanthophyll, and anthocyan pigments), biomass (dense or open), moisture or dryness in vegetation and soils. Physical systems include water, ice, snow, and atmospheric conditions such as clouds and VOG. Revegetation on flows, soil types, and characteristics of lava, such as type and age are also detected.

NASA's Landsat TM scans bands of electro-magnetic energy in seven wavelength areas, including pre-selected bands in the visible blue, green, and red; reflective-near and middle infrared; and the thermal infrared regions. Various band combinations are used to discern the complexity of azonal substrate regions and zones of vegetation-substrate cover observed. TM bands are used for analyzing the separation of lava, soil, vegetation moisture-heat, and vegetation pigmentation concentrations characterizing health or stress. These bands also detect the heat from the 'skylights' of active lava flows and older, cooled lava, atmospheric effects, and biomass.

Landsat TM data is digitized to 8-bit precision per pixel and is scaled with 256 gray levels of radiometric data displayed in a black-and-white gray scale ranging from black = 0 and white = 255. The data were ordered in Space Oblique Mercator map projection, with earth ellipsoid of International 1909. The data was resampled by the cubic convolution method, producing a spatial resolution size of 28.5m x 28.5m per pixel. The format was band sequential or BSQ, with the data of each TM spectral band organized in a separate file.

The Pilot Project Processing System

The processing system for this project is located completely in Hawaii and includes the main processing areas of georectification, classification, mosaicing, change detection, and map production. The scenes were georectified to UTM Zone 4 to comply with the State database design. Land cover, vegetation, and land use classifications were produced. A change detection image was produced by combining the Landsat TM and 1977 Landsat MSS. Map products were produced with ERDAS/Imagine and ESRI/ArcInfo software and are described in the Technology Transfer Product Design Section, Report on GIS Support, and in the Appendices.

Preliminary Processing of the TM Scenes

The University of Hawaii Department of Planetary Geosciences/Hawaii Institute of Geophysics (PG/HIG) was in charge of pre-processing the raw digital TM data files by formatting them for distribution. The data were delivered to PG/HIG from EROS on high density 9-track tapes in band sequential (BSQ) format. Hogan Co. worked with PG/HIG to make sure the data entry process would be as simple as possible, since this would occur in a secured room without access to project participants. PG/HIG stored each image band in a separate file, with the associated header and calibration information stored in separate text files. The reformatted data were provided to agency participants on high-density 9-track tape and CD-ROM.

Loading Image Data to the State GIS File Server

Training began in July, 1994 following the June arrival of ERDAS/Imagine v 8.1 for the HP platform, which the State OSP has. An overview and history of remote sensing was presented for 20 State agency personnel from Office of State Planning, Department of Land and Natural Resources - Division of Forest and Wildlife, and Information and Communication Systems Division (ICSD), where the State GIS lab is located. The first week of initial training focused on the basics of remote sensing with students using the images provided with ERDAS/Imagine software in the first few lab session until the importing of the project data was possible.

Ideally, raw data is loaded directly into Imagine from EOSAT or EROS source 9-track tapes or CD-ROM using the import menu function. Because the initial release of Imagine v 8.1 lacked peripheral support on the HP-UNIX platform, the import function did not work with the State's hardware.

First, the project team attempted to read the EROS 9-track tapes directly into Imagine using Imagine tape import function. This was not recommended for the duration of this project because the tape drive was in a secured environment and it is unsupported by ERDAS. Several phone calls to ERDAS hardware support in Atlanta enabled reading of the first tape volume of three. A bug in Imagine BSQ import did not prompt the system manager to mount the second and third tape volumes of the multivolume NW big island scene.

Data entry resorted to CD-ROM in the UNIX operating system command 'tar', which was a distribution method suggested as a test in the proposal for this project. This turned out to be the only way data could be easily transferred from the University of Hawaii PG/HIG to the pilot project GIS lab site.

Each image band and calibration file were archived as separate files on CD-ROM and read to the file server using the 'tar' command. The Imagine Viewer does not recognize these files since they do not have a ERDAS Imagine image file extension (image band.img), and they cannot be viewed as a single gray scale band or as a color composite on a monitor until they have this extension.

Each band was read into Imagine using the import function with the generic binary read option, to obtain an Imagine image file extension. This is not an easy method of handling image data for newcomers because the data is viewed in numerical format, and it can be difficult to see where a leading header record and trailer end and the image begins. The text files contain the image dimensions which is needed to import data. Initial disk space allocation was insufficient to load the NW scene for several days, but in a few days room was made for the two north scenes of the island. Individual gray scale bands of Landsat TM data could be viewed on the monitor, with the 256 levels of spectral data ranging in a scale of values from 0-255, black equal to 0 and white equal to 255. Values in between are viewed in shades of gray. A color composite consisting of all the imported bands still needed to be made for processing the image data. The viewer menu and button options did not have a way to build a composite image from the individual gray scale bands and a spatial model was needed to generate a color composite consisting of all six bands.

Creation of Composite Images

The Spatial Modler provided the graphics tools to build custom models consisting of a raster layer for each image band, a function tool for data generation to stack the layers, and a color composite raster layer. Starting with the north west scene, 6-dimensional color composite images were produced of TM bands 1,2,3,4,5 and 7, using a custom stack model in Imagine. Bands 1-5, and 7 have different spectral bands of information, but spatially they are all 28.5m x 28.5m. Three spectral bands of the composite can be displayed at one time through the red, green, and blue filters of a color monitor. Composite processing time required 4 - 6 hours per scene. TM band 6 was made into an Imagine image file and saved on line because Band 6, a thermal infrared covers spectral bandwidth (10.4-12.4um) and has a different spatial resolution of 120m. Allocation of space consisting of two file servers became available over several months time, and these steps were repeated for the two southern scenes of the big island.

Remote Sensing Classification Systems

Building an image database requires agreeing to the same standards throughout a project and when there is a need to reassess. Knowledge of the domain of the sensor(s), the image data, the level of land cover information class needed, and nomenclature for a base classification system are required before the classification process.

Standards for preprocessing, georeferencing, and minimum map unit are needed. Image data has a specific resolution and is typically without a scale, except for U.S.G.S. digital orthophoto quads (DOQ) which are not available for Hawaii to date. Knowing the source information of data is critical in Hawaii, when data from different zones, island projections, and digital DLGs are combined with data from paper topographic maps or orthophoto quads.

Ancillary photography for photo interpretation and signature development is used with vegetation descriptions and keys. Field sampling includes GPS for signature development during the classification and analysis process, and for field verification. Nomenclature is developed for the ecozone domains and the level of vegetation, substrate, and other land cover needed. This changes during analysis, the map verification process, and accuracy assessment.

National resource systems including imagery are being developed which rely on field data and interpretation with the local resource agency personnel responsible for managing the local area.

In general, national mapping systems for remote sensing reflect the continent, excluding vegetation differences of subtropical and tropical zones, especially island environments such as the State of Hawaii, U.S. territories, and other Pacific islands. Some of the vegetation and image processing differences are explained in this report.

Ecosystems Visible in the TM Imagery

Pattern recognition recognizes multiple spatial and temporal scales in ecosystem processes (Allen and Starr 1982). Ecozones in spectral imagery range from general to specific, depending on resolution of the data (spatial, spectral, temporal, and atmospheric), information class need, or by combining multiple resolutions and scales of digital imagery with ancillary photography, GPS, and other field site data.

During training, the land cover of the project site was divided into two broad categories based on cloud free land cover seen in the imagery and needed on the map (signal), and data to generalize because it is not visible, needed, or accounted for (noise). An example is water, some agency participants wanted water on the map and some did not. Water classes were obtained from an automated classifier and saved as a file which can be used to mask water for subsequent classifications. This approach is used in multi-agency projects with different priorities and with project sites containing complex systems such as Hawaii.

After dividing the scene into the two groups, the visible land cover was further divided for the initial classification scheme. Three top level subtropical ecosystems were listed: Physical, Biological, and Man-Made Systems. Subsystems reflecting the 30m TM resolution and the sub-tropical island environment were listed under each top level system, along with the legend from a coarse level classification scheme for 1977 Landsat MSS data with 57 x 79m resolution. The classification system that evolved is adapted for using the Landsat TM sensor in Hawaii's island environment, and based on the processed GPS and non-GPS field data.

Island of Hawaii - Remote Sensing Classification System

The classification system that evolved in the pilot project is for land cover resolved from Landsat TM remote sensing data, collected field data, and resolved adaptations from Hawaii vegetation classification systems. Vegetation from the classification system of Gagne and Cuddihy, and Jacobi Level II, were combined with modifications to resource oriented remote sensing systems to account for the differences in a subtropical island environment.

Remote sensing systems evolved from the first land use system for remotely sensed data developed by Anderson (U.S.G.S., 1974), with consideration of a nomenclature framework for different agency use and ecosystems from (Rhind and Hudson, 1980), and consideration of tropics systems and islands from life zone ecology for Costa Rica (Holdridge 1966,79). The relationship between level of information class detail in the classification system and sensor systems is from (NASA, 1983 Botkin et al., 1984).

The development of the remote sensing classification system was based on the TM image resolutions, the collection of field site data, and the software. The minimum image map unit for area measurements and location control is based on the pixel resolution domain of Landsat TM 6(32.0m x 32.0m) grid cells, which means land covers smaller than this area are not classified. A minimum image map unit of 10 to 40+ acres is more common and valid. Exceptions to this general rule that are often cited for the purpose of example are streams, gulch and riparian vegetation, pixels for monitoring change and transition, roads, or bridges (i.e. Hilo breakwater and Saddle Road).

For the pilot project, a hierarchy of desired land cover information classes was constructed in information-tree or taxonomic form, descending from general to more specific classes. As field data was acquired during the project, classification of the hierarchical tree was expanded in descending order.

Top Level Ecosystems

These systems are presented in a hierarchical information tree form and subdivided by criteria from the three main ecozones processes seen in the project site: Physical, Biological, and Man-Made Ecosystems. These systems are further divided by information class need, physiognomic plant type (forest, shrub, grass), moisture, elevation, climate, separable spectrally or by masking, and pilot project funds constraints. Under Biological Systems, vegetation is the subsystem needed for the map. Native vegetation is tropical, whereas the origin of non-native vegetation is world-wide. Under Manmade Systems, land use plantations of sugar cane and macadamia nut were visible in the Lowland Zones where large fields occur. Nursery roof tops were also visible. Physical Systems are largely azonal occurring at multiple elevation zones, except for water classes.

An example of change information extracted from the system is remnant forest and revegetated lava which were listed in the classification scheme of the last project and again on the first day of project participant training. Originally there were three

GPS points for revegetated lava, but lack of field time to collect points necessary to account for all the variables caused misclassification of some of these areas as cloud (spectral space must go somewhere). The information class Revegetated Lava was considered an intermediate class, needing additional ground truth to discriminate and label the actual information classes.

On the second field survey, a transact was made across accessible lava flows in the overlap area of the north scenes to account for the enormous variability of pioneer land cover on the flows. Revegetated lava became several classes further down the hierarchical tree including the 1984 A'a flow with licken which was inaccessible on a previous survey. This process was repeated for accessible areas on the Puna and Kalapana scenes, although A'a-Lichen is colored differently in these areas.

Some Ohia classes on the mosaic are considered intermediate classes in the Lowland and Montane elevation zones where mixed classes for co-dominant cover types are missing. Additional data, funds, and time are needed to develop Ohia - Strawberry Guava and Ohia - Myrica faya information classes. Also, Myrica faya is mapped with only the core area of concentration and a lowland occurrence with Molasses Grass.

In many ways, this organization of classification layers represents the temporal differences in the data and the order they were processed in, with the least amount of processed field data following the elevation areas with cloud cover (Kona, Puna, and parts of the southern scenes).

Processing for the temporal differences provided some control over the temporal differences and allowed the classification system to be conditioned on a previous classification, so the categories can be changed at any branch node (i.e. add vegetation information based on missing variability of type, elevation, slope, or aspect).

Figure 2 on the following page (and Appendix C - Classification System- Charts of the Vegetation and Other Landcover Types in the Landsat TM Classification System, Signature file Class Names list with corresponding Legend used for the pilot project of the Island of Hawai'i).

Island of Hawai'i-Landsat TM
Subtropical Hierarchical Land Cover Classification

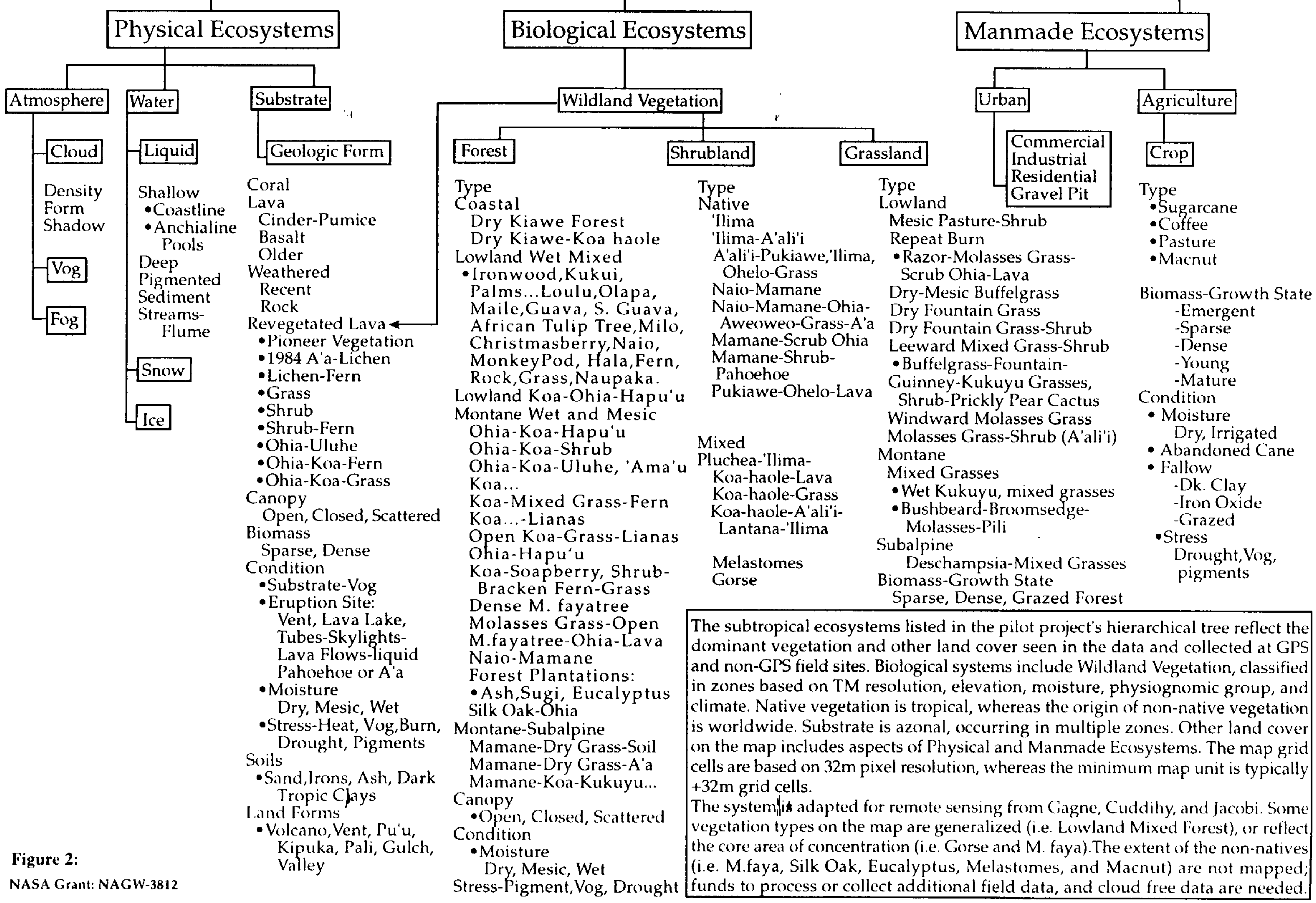

Figure 2:

NASA Grant: NAGW-3812

Georectification

Building a shared image database requires agreeing to the same standards for georeferencing or documenting sources for shared data requiring further processing.

Geometric corrections provide a system to represent an image on a plane surface or grid with known map coordinates, or to align an image with another image as is used in medical imaging and remote sensing change detection analysis.

Remotely sensed data are imaged by a scanner on a platform such as a satellite or aircraft and have distortions caused by the rotation and the curvature of the earth, atmospheric conditions, or by the sensor being used. The scanned image data is grided, and each grid cell is called a pixel with column/row (x,y) coordinates instead of ground coordinates like a map. Georectification is the process of coding pixels in an image to the geographical coordinates of a map projection or another coordinate system using a *nth* order polynomial equation. The pixels of the new grid do not align or fit at corners with the pixels of the original grid, requiring a process known as resampling. Resampling extrapolates data values for pixels for the pixels on the new grid from the values of the original (source) pixels, although there are methods to shift and rotate pixels without interpolating new pixel values in the new corner areas of neighbor pixels.

There are several considerations for the method used to georectify the projects data, including: map scale requirements for field work (1:24,000), the use of Global Positioning System (GPS) and DLG data for ground control points, map products (including vegetation classification and GPS overlay), the resolution of the TM data, existing and needed map production tools, and integration to the State GIS database design. (Radiometric errors of TM or SPOT satellite data are corrected by the companies responsible for their distribution, namely EOSAT and SPOT).

For georeferencing spatial data to a map base, Arc/Info uses an affine equation which changes X,Y coordinates and pixel size, thereby losing a linear one-to-one correspondence in the process. Arc/Info is a GIS software package and does not include a polynomial equation to maintain pixel location and spectral resolution of remotely sensed image data. Pixel values can be changed locally. For this reason, the use of Arc/Info for georeferencing and image registration is not recommended for remote sensing image data.

Remote sensing data requires remote sensing software for georeferencing. ERDAS/Imagine was used for georeferencing. After locating corresponding points on an image and on a map (e.g. road intersection), remote sensing professionals require software to georectify image data by the following parallel steps: 1) calculate a transformation matrix (coefficients) from distance between source ground control point (GCP) locations and new GCP location using a least-squares polynomial equation (Schowengerdt) to order the transformation (convert coordinates) for a linear pixel shift or non-linear pixel bend or warp and 2) resample data which assigns image pixels to the resultant grid with options to extrapolate pixel values (maintain or change pixel values as required by different types of image processing).

Each TM composite scene was georectified to United States Geological Survey base maps of coastlines and roads (DLG's) already contained in the State's GIS. A resampling method of nearest neighbor was used since the data was ordered in the Space Oblique Mercator (SOM) projection with a cubic convolution resampling method (and had been convolved once already). The unusual presence of visible mountain roads in the summit areas of Mauna Kea and Mauna Loa provided an excellent source of control point data to help correct for terrain displacement. Including DEM data in the layer stack is another source (Schowengerdt). Map area measurements and location control for the raw data mosaic product is based on 6(32.0m x 32.0m) grid cells and vegetation and other land cover map products are based on a single thematic layer of 32.0m x 32.0m grid cells.

The Hawaiian Archipelago lies in UTM Zone 4, except for the island of Hawaii which lies mostly in UTM Zone 5. All geographic databases of the State of Hawaii Geographic Information System are in UTM Zone 4. Each of the four scenes in the Landsat TM mosaic were georectified to UTM Zone 4, Clarke 1866 Ellipsoid, Old Hawaiian Datum, to comply with the State of Hawaii database design which allows plotting and printing of the whole archipelago in one UTM zone. The mosaic section of this report explains why a model was necessary to process the four scenes together into a whole island mosaic.

There is a need to be aware of the different ellipsoid and datum systems used in Hawaii and to know what sources a project is using. Problems occur when sources are not known. This affected the project in two areas: change detection image-to-image registration with Landsat TM and 1977 Landsat MSS data; and using a version of distribution maps of Hawaiian vegetation (hereinafter called "Jacobiveg") Level II overlays, to compare Level II nomenclature and ecozone boundaries with the NASA projects GPS field site data and ecozones in the imagery.

The Clarke 1866 ellipsoid is used in the State GIS database and is centered island-by-island. The U.S.G.S. uses Clarke 1866 for DLG's, but not for topographic maps. On topographic maps, U.S.G.S. uses the International 1909 ellipsoid and NAD27 Datum (Ev Wingert 1995). This was used to georeference the 1977 Landsat MSS data to UTM Zone 5 in the previous project.

The different datums are Old Hawaiian Datum, NAD27, and NAD 83. Old Hawaiian Datum is used in the State of Hawaii database design and has four different centerings, centered on a latitude / longitude system. Old Hawaiian is sometimes mistakenly referred to as NAD 27 which is globe centered (Ev Wingert).

Problems occur when transferring field data plotted on U.S.G.S. quads into the State GIS, if the sources are not known. The ecozone boundaries of Jacobiveg Level II digital overlays were displayed offset from the image data in some areas. The source of Jacobiveg mylars is stereo pair photos interpreted and plotted onto paper source orthophoto quads with the fitting in UTM Zone 5, International 1909 ellipsoid. The project source is digital in UTM Zone 4, but a X,Y shift is required on many quads. They need to be re projected for the State GIS database to date.

Spectral Image Classification

Digital image classification is the process of deriving land cover and land use classes from multispectral images. Through this process, the multiple spectral bands of the image are reduced to a single layer of information for interpretation in land management or research use. Image classification is a method of processing spectral data from a satellite or aerial reconnaissance view, which is combined with ground view information or field spectra data for mapping and analysis.

The Landsat TM satellite view is unique, recording radiation bands of intensity measurements in visible, infrared, and thermal wavelengths. During the classification process, the multi-band image is grouped into a analyst-defined number of clusters, based on the intensity values of the image pixels (grid cell). Each image pixel is described by a vector through the total number of bands in the image file (n-dimensions), or a subset of bands given to the classifier. With spectral data a statistical model is used to set the natural variability of vegetation and other land cover classes and the classes average. A decision rule determines which class vegetation goes to. Statistical decision rules assign the value of one of the clusters to the 6-d measurement vector for each pixel in the image. Descriptive statistics are saved to a numerical signature file for analysis and different band combinations of clusters can be displayed in 2-d graphical plots of histograms or ellipses. The resultant thematic image is colored and interpreted one category at a time, while using ancillary information such as photography and vegetation keys, GPS points, field sampling information, and vegetation overlays.

The spectral image analysis process requires knowledge of which spectral regions identify different types and level of land cover information needed. The resolution domain of the sensor, knowledge of the analysis process and the ground, help to locate which spectral regions identify ecozone patterns for the level of land cover information needed.

This means the resolution domain of a sensor and data need to correspond to the domain of the ecosystems being mapped. Natural variables of each land cover type in a ecosystem need to be identified when producing a classification with hierarchical layers, ranging from general to specific. The natural variables of each land cover ecozone or transition zone still need to be identified when producing a classification with the variables grouped into more general classes. Land cover variables improve classification accuracy, because spectral space will go somewhere if a land cover is not accounted for.

Classification Methods

There are two methods of image classification, supervised and unsupervised. The value of a particular method and decision rule depends on how accurately the image data is represented for the classification level or change detection that is needed. The speed of the program, time for field data collection and interpretation are critical factors. Data compression techniques prior to the classification process, reduce the dimensionality of information in huge data sets like Landsat TM or hyper spectral data, or data from multiple remote sensing platforms .

An unsupervised clustering is a semi-automated approach to classification, whereby the image data points (pixels) are grouped into non-overlapping clusters, based on measuring similar pixel values in the image file. The analyst specifies the number of clusters, the number of iterations or passes through the data, and a convergence value, which is the percentage of data that is successfully assigned to a class before clustering (or partitioning) is finished. The classifier assigns the value of one of the clusters to each pixel in the image. The resultant clustered image is a gray scale and the classes produced are spectral classes. They are interpreted one category at a time, while labeling clusters with color and land cover names.

Although general, land cover derived from an unsupervised classification with 30-50 clusters can be processed and interpreted in 2-4 days time, depending on available ancillary information, knowledge of the ground, and plotting and printing capability.

In a supervised classification, the analyst manually selects training sites on the image monitor for each known land cover in a geographic area. Each training site represents a sample of pixel values in the image, which corresponds to a field site of land cover on the ground. The values of pixels in the training site are used to compute cluster statistics of each band for a corresponding class. The classifier assigns the value of training site statistics to each pixel in the image. The training site is located by knowledge of the ground with ancillary data such as photography, GPS, vegetation and soils overlays, elevation, or other types of field data. The size of the sample needed varies with the sensor used and the number of dimensions in the image set. The type of classes that are produced are trained information classes instead of unsupervised spectral classes.

In either classification method, the analyst interprets the resultant thematic image, with the cluster numbers ranging from low to high, based on the associated image pixel brightness values. A cluster number for recent pahoehoe lava is low with associated dark pixel values, while cloud cover has high cluster numbers associated with high pixel values. In either method, there are tradeoffs of time and method of sampling selection. The supervised classification method is more interactive and time consuming, followed by unsupervised classification with a large number of clusters if a prior knowledge or photography are missing.

<u>Island of Hawaii - Discussion of Landsat TM Image Classification</u>

The classification methods described were used for land cover mapping of the Island of Hawaii, using Landsat TM data and ERDAS/Imagine v 8.1 which has interchangeable classification tools. In this project, four georectified TM scenes were classified individually to produce map products. Because the spectral and temporal resolutions of the project data are very different, their interaction for land cover classification was a concern from the initial Hawaii Island planning meetings in April, 1994. Images from two different satellite orbits with different atmospheric conditions, one an El Nino and the other a drought year, were going to be part of the same land cover classification map product.

Additional processing was needed before mosaicing the four scenes to extract the temporal land cover information processing for different moisture levels and growth states of vegetation, primary succession on lava flows, substrate changes in agriculture and volcanically active areas, and atmospheric conditions.

Spectral Band Combinations Used for Classification and Analysis

Various band combinations were used to discern the complexity of azonal substrate regions and vegetation-substrate cover observed in zones. TM bands 7-5-3 were used for analyzing the separation of lava, soil, vegetation moisture, and vegetation pigmentation concentrations. These bands also detect the heat from the 'skylights' of active lava flows and older, cooled lava. Bands 7-5-4 were used to visualize moisture in grasses, biomass, and atmospheric effects along with 7-5-1. Bands 7-4-3 provided maximum separation (or decorrelation) of soil, lava and vegetation biomass. Band combinations 4-5-3 and 4-7-3 were especially useful for biomass and maximum separation of Ohia-Koa from other species, i.e. Dense Myrica faya and Tropical Ash. However, several vegetation types in the project area displayed dense biomass or different moisture contents from the El Nino and drought years, appearing saturated in one or the other band combinations. More grass and shrub were visible in the vegetation mosaics on the drought dates than on the El Nino dates, probably due to moisture stress and wilting.

Unsupervised Classification Process - Island of Hawaii

The unsupervised classification algorithms in ERDAS Imagine v 8.1 were used with the four Landsat TM scenes to derive land cover and land use information, and to monitor change. ISODATA (Iterative Self-Organizing Data Analysis Technique, Tou and Gonzalez 1974) with the minimum distance decision rule was used as well as RGB partitioning (ERDAS, 1994).

ISODATA clustering is a semi-automated classifier, allowing the analyst some control by specifying the number of clusters, iterations, and a convergence factor, which is the per cent of data classified before clustering is finished. Through this process multiband spectral images are grouped into a analyst-specified number of clusters, based on spectral groupings of image pixel values around their average. The minimum distance statistical rule is used to assign the value of one of the clusters to each pixel in the image. Final clusters are represented by a normal distribution.

Instead of using a specified classification system, unsupervised classification relies on defining the spectral classes during the interpretation process. The clustered image that is produced is a single clustered layer (thematic layer), and interpreted by labeling each cluster with color and a vegetation, land cover , or land use name.

The project team used the ISODATA method so all six TM bands could be processed and the number of classes and iterations were varied to distinguish spectral classes of land cover and land use. Band 6, a thermal, was left out because of its coarse 120m spatial resolution. The algorithm is iterative and cluster means are re-calculated each iteration before final clusters are represented by a normal distribution (bell shaped curve of probability distribution).

Clustering by specifying a large number of clusters helps to represent the full range of pixel intensity values in the image data (0 -255). The resultant clusters are interpreted, given a land cover name, and grouped together forming spectral patterns and land cover classes. Clustering with this approach was used to specify 200 to 255 categories, and 10 and 100 iterations, using the default convergence to end clustering. Analysis requires apriori knowledge of the ground and knowledge of how to locate the spectral clusters that identify the land cover classes needed. Sample areas from these maps were useful in the field.

Clustering with 40 classes and 35 iterations per scene was easy to interpret and provided adequate separation of classes to provide preliminary map products to begin the field survey, although land cover patterns were generalized. The whole classification and interpretation process took 1.5 man days to complete each time the classifier was processed. These maps were very informative for collecting field data to use in the subsequent supervised classification and to monitor spectral areas difficult to classify in the supervised classification.

Two obvious areas needing monitoring occurred where there are two classes that are close to each other spectrally located between 5,000-6,000 feet in two different wet zones; one area is rainforest with Montane open Koa-grassland infested with dense banana-poka, while the other area has Montane Grazed Grassland infested with Gorse in the mountain pastures.

The second confusion occurred in the transition zones of mixed grazed grasslands in leeward areas where grass-cactus-shrub confused with Montane Wet Eucalyptus in Laupahoehoe. During the subsequent field surveys, the area was monitored and GPS and non-GPS points were taken to determine their spectral regions.

Examples of RGB clustering were made during training. RGB clustering is more automated and allows for only three spectral bands, which does not take advantage of the multi-dimensions of Landsat TM or hyper spectral data. RGB clustering performs a principal component analysis prior to partitioning the data one time for clustering. The classification is based on systematic sampling of image pixels that may pass over spectral regions needed for a land cover classification.

Ancillary information for the unsupervised process included ground information from DOFAW/Hilo, orthophoto quads, the previous MSS classification, a DOFAW forest atlas, color infrared photography from Air Survey Hawaii and the ER-2 (U-2) from NASA at Ames Research Center.

Field Work

Following the generation of the unsupervised classifications for the north scenes, an Arc/Info Point coverage was generated to overlay on the unsupervised classification map along with roads and management layers.

A field survey collected data to evaluate the classification of the north west scene and to collect ground location data with the GPS for the training sites needed for the subsequent supervised classification. While resource managers use aerial photography to plot ecozone boundaries and monitor land, they are more familiar with a horizontal view of pattern recognition than a reconnaissance view. While gathering field data, adjusting to the reconnaissance view requires consideration the image date, spectral wavelengths, and the minimum spatial resolution and map unit of the land cover-vegetation map product. Relating field ecozone information to the spectral regions in the imagery is a critical part of the classification process. GPS points provide accurate ground location coordinates of vegetation and other land cover in the landscape, for the otherwise difficult job of locating corresponding areas on the imagery.

Initially, field sites were chosen that typified the major wildland vegetation and other land cover types to be used for the supervised classification of the two north scenes. A total of 41 points were taken over 3 days. A sample raw data image and unsupervised classification map were used to avoid taking GPS readings in areas of the scene containing clouds and shadows, but four points were taken near these areas because they provided needed information for the map. These points were saved for future use, but could not be used with this data. For each point, a site description and photographs were taken. GPS location information for the major land cover and land use was used in the supervised classification.

Additional GPS points were collected in field sites, while assessing the accuracy of the supervised classifications of the north scenes. The goal was to locate land cover areas needing correction, while collecting new field samples. Points were taken to locate transition boundaries of some ecozones seen on the imagery and misclassified on the maps of the north scenes.

The abundant transition zones were found to contain spectral regions representing diverse land cover type variables. Examples are two dominant grassland areas of Parker Ranch, mixing with two other grass types and shrub types that change based on elevation, moisture-climate, and grazing management patterns. (Another example is the re vegetated lava class described in the Island of Hawaii-Classification System section). The same occurs for all natural variability found in vegetation ecozones and patterns at the landscape level.

GPS Methodology

The field team used a Trimble 6 channel Pathfinder Basic with an external antenna for obtaining GPS position data. GPS uses the L-band group of radio frequencies to collect signals locating ground position, and documents these positions in the field. (Data is collected using WGB84 frequencies). Field data were differentially corrected to the local base station on the big island. The process compares your field position data against stationary receiver data collected by a base station. The base station at the National Historic Park, (National Park Service) of Kaloko-Honokohau in the Kailua-Kona area of the big island was used to improve accuracy.

The corrected GPS points were projected into UTM Zone 4 to include the whole island with the State of Hawaii database design. Accuracy of approximately 1m is available with differentially corrected GPS points. Differential correction of the GPS data was done by DLNR staff using PFINDER SOFTWARE version 2.4. GPS data processing yielded text files with UTM coordinates. The text files were used to generate a point coverage in Arc/Info., and the collected field information was entered as attribute data for each point.

Non-GPS Points

Field samples of areas lacking GPS points were plotted on maps and raw data prints throughout the project. Hamakua Sugar Co. and Kau C and H Sugar Co., provided small and large scale maps containing field numbers for sugar and macadamia crops, and field data of the dates of the sugar crop planting cycle, revealing the end of the sugar industry on the big island.

Raw data prints and classification maps from an 8.5X11in. printer, photography, and topographic maps were used to plot field samples of some of the differences found in the main ecozone domains of Hawaii Volcano National Park, Puna, Kona, and Kahala areas.

APPENDIX B - Ancillary Field Data

Supervised Classification - Island of Hawaii

The supervised classification programs in ERDAS/Imagine v 8.1 were used to process the four multiband TM scenes to derive a single, corresponding layer of land cover categories for the Island of Hawaii. The supervised classification for the Island of Hawaii began with the north scenes which contain the Hamakua coast, and is the initial project site for processing Landsat TM and the previous projects MSS data set. In the supervised classification process, a numerical file of spectral signatures was built for use with the maximum likelihood decision rule. The supervised classification process involves three areas: training the classifier, classification with a decision rule, and product evaluation.

Training is the process of selecting samples of image data that represent ground land cover to develop numerical training signatures that guide the classification of the whole image. The training sites are used to build the numerical signature file of spectral signatures for processing each land cover information class needed on the map. Regions on the image represent spectral data samples of the field sites visited on the ground, or found on photography. The training process is usually repeated before the desired signatures are produced. Descriptive statistics are displayed for training sites of each land cover type and for combinations of land cover types that may confuse. During the training process, areas are flagged for additional field work. The unsupervised classifications are informative visual tools during this process.

The classifier computes spectral patterns in the image data training set using a pre-defined statistical decision rule. Each pixel in the image is compared numerically to each training site category in the numerical signature file and categorized to the land cover class it is most like. The category label assigned to each pixel in this process is recorded in a corresponding cell of the classified image.

The supervised classification image is evaluated on a monitor, tabular, or map forms. Following evaluation, training sites are added, modified, or deleted to derive the data representation of each field site that corresponds to a land cover or land use site found on the ground.

Processing for Subtropical Differences - Island of Hawaii

The Hawaiian Archipelago has physical, biological, and manmade ecozone processing requirements that are different from continental environments. Contributing physical ecosystems are vast amounts of water and cloud cover, coral and anchialine pools along the coast, small land areas with extreme elevation changes, on-going volcanic eruptions with skylights of molten lava from networks of lava tubes, and both substrate and atmosphere contain VOG. Contributing biological ecosystems change from tropical cloud forests to woodlands, sub alpine shrubland, and alpine cinder fields and deserts. Contributing manmade ecosystem include quarries and gravel pits of lava, fish ponds, tropical agriculture of sugar cane, abandoned sugar fields, macadamia, coffee, and nurseries with tropical trees and flowers. The need for multiple scenes to cover a relatively small area is also common.

The multitemporal data sets for this project, increase the dimensionality of the imagery to process, by requiring the addition of spectral sub-classes for different dates of available field sites. In the future, each new set of image data will have unique characteristics that also require some custom processing.

Developing a spectral signature file for the island of Hawaii began with appending water and cloud signatures from the files generated by the four unsupervised classifications to account for orbital and atmospheric differences of the adjacent scenes. A signature file for the north west scene was used as the base for all four scenes of the big island since this scene contains most of the island land mass and the test site. The water and cloud signatures were used during the classification process and the water signatures were also used in a masked classify application. These techniques are especially helpful for image processing in Hawaii's complex environment.

Water masks were made in ERDAS/Imagine and ArcInfo to exclude land cover information from processing and to combine layers processed separately. Water masks were made at the coastline and to include off shore islands. The masks can be used in subsequent classifications of this image or registered to new data. In Imagine, the combined water classes from the four unsupervised classifications were used as a mask, as were the infrared bands to determine the water-land boundary. The water classes from the unsupervised classification were easier to use than the infrared bands of the different dates.

For clouds, determining limits for the brightness values of cloud cover, urban, and dry grass was also required to avoid misclassification of cloud edges as dry grass. (A post-classification mask was made for the Cloud to Urban category, which is the last category in the masked classification mosaic).

Processing for Subtropical Manmade Ecosystems-Land Use

The supervised classification training process started with the sugar plantation data from Hamakua Sugar Company in Paauilo, including the Kahala area which ended sugar production in 1977, the same year of Landsat MSS data. Ancillary data included sugar maps with field numbers, and data for crop calendar and the termination of production. Color infrared photography was also used for interpretation and to monitor land use change. Individual training sites were developed with the tools in Imagine and edited in the signature file.

Abandoned cane and pastures with Christmas berry, Ironwood, Koa haole, or kiawe were found on the ground in north Kohala and the Waipio side of Hamakua, but the imagery was covered with clouds. The increase of nursery rooftops was noted in Hilo and Puna areas, along with macadamia and papaya fields on lava or grass.

Land use plantations of sugar and mac nut were resolved in Lowland areas containing large fields. The small diversified ag fields containing mac nut and other crops on grass need multiple resolutions of image data or photography, field work, and GPS to be resolved. The small Lowland Diversified Ag fields of ca. 1-5 acres and Montane zone mac nut orchards confused with some tropical wildland vegetation and gorse, and were eliminated from the signature file.

Some land use conversion was observed during field survey of Waikea and Puna areas. Small nurseries containing palm confused with wildland palm and were grouped into the Lowland Mixed Forest class. Papaya was not trained on because of the need for historical crop calendar information. Urban areas and nursery rooftops confused with cloud and were masked in the densest areas as the last information class on the masked classification.

Processing for Subtropical Biological and Physical Ecosystems

The GPS points were used to develop signatures by locating image data points with corresponding ground field sites of wildland vegetation and physical ecosystems. The GPS points and their attributes were displayed over the TM imagery to locate the corresponding field site boundaries. GPS and non-GPS points were used with other field data information to locate a cluster of points representing the land cover ecozone where they taken. Spectral and spatial response patterns of the different vegetation and land cover were analyzed for natural variation. On the image data, the GPS point correspond to a vector through 6-dimensions of the image coordinate (for TM bands 1-2-3-4-5 -7). The GPS points were especially useful in the rain forest areas with dense biomass; in some locations of closed canopy GPS positioning required moving to a slightly open area to collect GPS points under forest canopy.

The north scenes contain five forest classes with banana poka in Hamakua and various band combinations reveal pigmentation and moisture stress levels. The project's GPS points were used with Jacobiveg to compare the new GPS point data with Jacobiveg Level II polygons. Coarse distribution maps were also used for support information (F. Warshauer, J. Jacobi, A. La Rosa, J. Scott, Cliff Smith, 1983).

Jacobiveg was used to see how the training signatures with GPS points were classifying at the canopy level on the Kalapana and South Point scenes that lacked ground truth initially. The vegetation ecozone coverage of Jacobiveg Level II were also used with the GPS points and the classification summary of W. Gagne and L. Cuddihy Pratt (in Vegetation, Manual of Flowering Plants, 1994). Differences in ecozone boundaries of raw imagery and the classification map were noted.

Training sites were generally located on the raw data using available ancillary information including color prints from Imagine viewer annotated with field data, GPS coordinates, aerial photographs, field data supported by topographic maps, orthophoto quads, an outdated forest type atlas, sugar plantation maps, and vegetation overlays.

During the analysis process, several processing techniques were developed to visualize some of the impact caused by the temporal, seasonal, and elevation differences. The signature file developed for the north west scene (El Nino date), was used to process the north east, Kalapana, and South Point scenes. Initially, multi-date signatures were not developed to visualize the effects and a mosaic was built. In Imagine, the mosaic output is a gray scale image associated with a gray scale bar, until the image is loaded as pseudo color with the color bar or the R-G-B values from the original classified images.

Several land cover types did not correlate across scene boundaries due to temporal and seasonal differences of some land cover types. This caused the same land cover and geographic area to classify in different information class positions of the classified image and gray scale bar. The color look-up-tables (LUT) from each scene were loaded manually in the mosaic and flooded the adjacent scenes, where classified as the same land cover type but a different information class number or where classified as a similar land cover type. Part of the problem is a raster hardware and software constraint, lacking the ability to trap class color boundaries the way a GIS package is able to.

Once the temporal differences were resolved, several land cover types still did not correlate across scene boundaries due to a few signatures being unique to one or two scenes, so the number of information classes were different for corresponding scenes. This also caused the same land cover and geographic area to classify in different information class positions of the classified gray scale image and gray scale bar.

On the north west scene, the spectral confusion between grass-shrub-cactus and eucalyptus was resolved by developing spectral signatures with vegetation change based on elevation and moisture differences. Five information classes were discerned for the mixed grass-shrub types in the transition zone. These five classes are colored with Fountain grass-Mixed grasses on the map, but they can be colored individually in the raster or vector files. Classes range from Buffelgrass-Fountain grass, to Buffelgrass-Fountain grass-Guinney-Kukuyu grass with shrubs.

Multi-Date Classification for Whole Island Mosaic

The final solution to mosaic the whole island map, was to construct one main signature file, which was used to classify each scene individually. The main file was modified for each scene by weighting the land cover signatures unique to a geographic area of the island or to one scene. This method requires an inordinately large number of repetitive training sites to develop a higher dimension of statistics for the temporal dates, and the information is repeated in the class names list of the raster attribute table of the final classified mosaic.

Training site samples were chosen that uniquely represented the date of their corresponding land cover and land use field site. This means a higher dimension of statistics was needed to account for the visible moisture and biomass levels, and growth states. The multitemporal data represents a vast amount of added information and processing complexity needed to extract information. Training sites were evaluated prior to classification by image and numerical analysis. Histogram displays of the descriptive statistics in training sites, were used to insure separability and determine how the data covary. Descriptive statistics of pixel values for each training site were used to identify the spectral signature that best represented a corresponding land cover/land use class. Multivariate analyses of cluster plots and feature space images were used to quantify the separability or spectral difference between training sites and to anticipate misclassification of classes.

Pixels in each image are assigned to a class by the multi-date maximum likelihood decision rule unless a mask is applied to omit a specific value or range of values, representing land cover.

On the mosaic, there are vegetation types with only the core area of their concentration mapped to a intermediate class. More field data and processing is needed to map their extent with spectral regions for land cover class variables. Examples are Ash, Sugi, Eucalyptus, and Gorse which appeared on earlier maps of the two north scenes, and Myrica faya-Ohia.

Dense Myrica faya (fayatree or firetree) with a closed canopy was mapped in the Hawaii Volcano National Park area and in Hamakua using coarse distribution maps to locate field sites (Tunison and Camrath 1992; and Whiteaker and Gardner 1985). Fayatree occurs in two mixed classes of the classnames list/Legend in Appendix C.

Additional data was collected but not processed, and more data is still needed to date. Scattered pixels of Gorse on the map were field checked and do occur north of the Saddle Rd. It is unknown to date what signatures could be developed for intermediate classes and how these would classify, but additional classes exist. Renaming existing classes to Myrica faya on the individual scenes is possible, but changing the color with the current mosaic constraints would cause the class to appear over extended on adjacent scenes. This area could be masked on the mosaic, but the color tables for the corresponding Ohia class number on adjacent scenes without Myrica faya would be corrupted or change to the color of Myrica faya or Myrica faya-Ohia.

Signature development for these land cover types was successful on the individual scenes, and in decision rules of the intermediate iterations in the main signature file. The signature was minimized in the last iterations of all four scenes when new field data was added. This is fixable through successive image processing. The cell array information in Imagine documents the current iteration.

Visual systems are needed on all islands where land managers and researchers are left without visual tools for the lands they are responsible for. A portable system would include outer island resource personnel in the processing, and help everyone involved.

APPENDIX C - Classification System

Whole Island Mosaics

The mosaic process assembles the four adjacent scenes into the whole island together with Maui. This process requires georectification of the scenes to the same map projection (UTM, UTM Zone, spheroid, and datum) prior to the mosaic process for consistency with State of Hawaii database design. The process was repeated for the four georectified composite scenes and the 4 supervised classification images. Initially, all of the automated menu options were tried but these placed conspicuous and unacceptable lines or wedges through Mauna Kea, the unfortunate location decided by the automated menus. The adjacent scenes were of the extreme temporal differences of a El Nino year (June 1, 1990) and a drought year (October 11, 1991), and from different seasons; differences in the moisture level and chlorophyll concentrations of adjacent scenes were quite obvious; for example, biomass of understudy and ground cover was more apparent in 'local area' mosaics of open vegetation.

Clouds in the 11% overlap area between scenes were cut off leaving a sharp boundary line where there wasn't cloud cover on the adjacent scene. Custom models were built in order to have flexibility over where to place the mosaic boundary and to reduce cloud cover in the overlap area, thereby recovering cloud free data in the adjacent scene. This process recovered image data of some of the forest reserves in the overlap area between adjacent scenes.

The process works only in the 11% overlap area of adjacent scenes because the area of interest (AOI) processing used in the modeling requires the geographic area of second image to fill in data for the current blank area. If there is cloud on the first scene, the grouped AOI's point the model to the same geographic area in the second scene of the model, which fills the overlap area of the adjacent scene with data.

The final step in the image classification was to mosaic the classified images into a composite consisting of the whole island of Hawaii. This process was time consuming because of the temporal differences in the data (adjacent El Nino and drought years). The classification and mosaic process of each of the four scenes was repeated when additional ground truth was collected.

Importing the classification RGB color tables, class names column, and the addition of a legend column were required to group the individual class names in the mosaic image (Appendix C). A parameter to automatically build this information from each of the classified images and a trap for boundaries is needed in the raster processing.

APPENDIX D - Mosaic Process

MAP COMPOSITION AND MASKING

Masking is a type of area of interest processing used to select land cover information for processing, combine layers processed separately, or edit misclassification. This is especially helpful for processing in Hawaii's complex environment. The various masking tools in Imagine and Arc/Info were used.

Masking clouds was used in the initial part of the whole island mosaic process. Masking was required to assemble the four scenes into an image containing the whole island, and to exemplify renaming of misclassified land cover types on the supervised classification land cover map. See the section titled Mosaic.

The whole island mosaics were processed in Imagine v8.1 on the HP platform, which required building a graphical model since the menus did not work completely. Areas were grouped in multiple or nested polygons, extracting only the areas needed to assemble the four scenes together.

Water masks were difficult to make using the infrared bands of the multitemporal scenes and mosaic, so signatures for water classes were extracted from the unsupervised classifications and appended to main signature file instead. They can be used this way or to classify water and land separately to improve per class accuracy.

Examples of masking the classification using the Spatial Modler were processed on a temporary license of ERDAS/Imagine v 8.2 for the SUN Microsystems platform at The University of Hawaii Geography Department. Urban was intentionally added at the end of the image processing to avoid confusion with other land cover types in the classification. The software menus for recoding classes with new class numbers was used with a area-of-interest polygons digitized on the color monitor. This streamlined processing considerably and was somewhat of an inter-active process.

The raw data color composite of bands 7-5-3 and the masked land cover map were exported from Imagine and into the ArcInfo graphics files for map composition. The map production AML's contained in the State of Hawaii/GIS were used to compose these maps.

APPENDIX G - Map Composition

Accuracy

Accuracy assessment consisted of several field surveys for map validation, renaming, and field data collection. The land cover map produced at 1:250,000 and 1:24,000 scale is an overview level or base where field sampling of ecozones is unprocessed or missing. This reflects the domain of the sensors resolutions combined with the lack of funds for the level of land cover variables present in Hawaii ecosystems and temporal data (i.e.. cloud cover).

If the image classes are renamed to a coarser level where needed, classification accuracy improves. If the imagery is classified on a 7.5' quad basis, and combined with GPS, or multiple sensor platform levels (and georeferenced scales), and detailed vegetation or soils overlays, the level of spectral classification accuracy increases.

Additionally, some recoding of classes or masking can be done on the GIS side (with reclass) to improve classification accuracy before dissolving polygon boundaries into larger map units. Both are typical parts of the project flow. (See Vectorization).

Change Detection Image

Image data that is georeferenced together from multiple sensors, provide multiple resolutions and additional dimensions of land cover. If the data are processed and plotted at a specific scale, then multiple scales of land cover patterns are available.

The change detection image provides greater spectral separability between the 1977 Landsat MSS mosaic and the new multi-temporal Landsat TM mosaic. Information is visible in this image that may not be obvious in the MSS or TM by themselves. Registering new data from different sensors and resolutions to the existing image database allows processing and plotting at multiple scales to produce multiple scales of land cover patterns (i.e.. under flight). Processing these data sets requires historical information in conjunction with current field sampling.

The 1977 MSS data from the previous NASA project was a mosaic assembled of two scenes from one satellite path (N-S orbit) and from two rows, with analog pixels of 79 X 79m digitized to 56m X 79m pixels of the ground. The data were quantified to 6 bits ranging from 0-63. The scene dimensions were 2340 lines X 3240 columns covering 185 X178km on the ground. The mosaic was processed during the previous NASA project (C. Hogan, G. Fosnight, Ed Petteys, C. Tasaka, D. Morse, P. Costales, M. Buck, and Pat Chavez; principal investigator Ken Nishioka).

Pat Chavez of USGS, Flagstaff, Arizona generated spectral transformations on the 1977 MSS mosaic during the previous NASA project, since he had developed algorithms which NASA/Ames did not have at the time. (The mosaic from the previous NASA project appears in Volcanoes of the National Parks - MacDonald, Wright, and Erickson; 1989).

During this project, the MSS data was transferred from 9-track tape to CD in UNIX in BSQ format, using the UNIX command 'tar' at University of Hawaii PG/HIG. The MSS data was transferred again from CD to the file server at State of Hawaii GIS lab by systems analysts in secured environment.

The ERDAS/Imagine Import utility was used to load each band into Imagine with generic binary read option, to obtain the ERDAS image file format (.img file format). A graphical stack model was used to make a four band color composite of the 1977 MSS mosaic.

An image-to-image registration of 1977 MSS big island mosaic and the new TM mosaic, were combined producing a new ten band image. In the previous project, the 1977 MSS mosaic was georeferenced to UTM Zone 5, using topographic maps. New control points were located on the images and the 1977 MSS was registered to the Landsat TM in UTM Zone 4, Clarke 1866, Old Hawaiian Datum. The Clarke 1866 ellipsoid is centered island by island. On topographic maps, U.S.G.S. uses the International 1909 ellipsoid.

False color or 'pseudo-color' composites of different band combinations were displayed in which the reflected ground features do not always appear in natural colors. The order of the bands in the composite correspond to the red, green, and blue (RGB) color guns of the monitor. Band combinations were charted and areas of change in vegetation composition, biomass, moisture, atmospheric effects, and new lava flows were observed, often times looking opaque.

Jacobiveg Level II vegetation overlays for five quads were displayed over areas of change with GPS field points or non-GPS field points. The most obvious areas of change are cloud cover, reduction in the number of sugar fields, moisture conditions over the Hamakua and Volcano area forests and grasslands on the drought dates, Hilo, and the dense biomass increase of the non-native Gorse, in the high pastures East of Mauna Kea. Jacobiveg and the 1977 Landsat MSS data provided needed historical information to monitor gorse.

The ten band image was compressed and deposited on-line at The University of Hawaii Geography Department. In the final stages of this project, change detection analysis was performed on the combined TM/MSS image file by Renee Louis and Eric Yamashita during a Remote Sensing Research Seminar conducted by Dr. Matthew McGranaghan. Seven (7) map compositions were completed using a 60-day ERDAS IMAGINE version 8.2 license and plotted on an HP650C.

The following six (6) map compositions were chosen to demonstrate the power and versatility of this technology. The map titled Gorse and Koa-Banana reveals the extent of pristine forest depredation due to the invasive nature of two exotic plants, Gorse and Banana Poka. The map titled Mauna Kea Area Reserve provides evidence that Landsat TM bands 7 and 5 are excellent for analyzing the separation of lava, soil, and vegetation. The Keyhole map demonstrates the land cover change detection capabilities of this technology by showing the keyhole pattern in three (3) images, each with different band combinations (MSS data only, TM data only, and TM/MSS combined data). In the map titled Lava Flows, the lava flow which began in 1983, and is still active today, is pointed out in the image showing both TM and MSS data. The Northwest Hawai`i Golf Courses map clearly depicts the addition a new golf course and the modification of existing manmade features. The last map, titled Hamakua, Hawai`i Island shows both the combined data and the TM extracted classification of this area.

APPENDIX F - Change Detection

Vectorization/GIS Layer

The classification mosaic with areas of example masking was vectorized on a 7.5 minute quad basis (1:24,000 scale) at the GDSI office in Manoa. This product contains 1.5gb of data which can be loaded to the file server one quad at a time as needed. The Arc/Info command Polygrid was used to generate a 1,000 m buffer into the ocean surrounding the big island to include 'the new land' from the eruption of Kilauea's Puu O'o and to include off-shore islands. The buffer was adapted from the one used on the two island mosaic products, which blank out the water at the coastline.

Classes were renamed or renumbered to a limited extent with recode and mosaic in the Imagine v 8.2 because of the LUT's processing constraint of a temporal image mosaic. The same problem may exist using the reclass command in Arc, which essentially does the same thing prior to dissolving boundaries. Trapping class-color boundaries and logic can be used with the reclass command and knowledge of the ground, the analysis process, and map composition in a team approach improve the process. Care must be taken not to re-introduce areas of previous confusion in the classifier. The reclass command does not reclassify the data, since there is no quantitative spectral information once the data is in a GIS package. The prime color palette used in Imagine was R-G-B, however Approximate True Colors was also used. It is important to use one color palette if the image is going to be vectorized. There are places where the color selector wheel truncates the R-G-B values and the longer R-G-B values in the cell array need to be exported. This is a problem where every pixel is used in the dissolve process. The class names and legend lists are not carried over to the mosaic and were imported from the individual classified images.

Technology Transfer Conclusion

One of the main features of the project is technology transfer to the State of Hawaii. Time was spent developing a preliminary remote sensing classification system to use in Hawaii's tropical island environment. Landsat TM proved to be powerful for this complex environment and incorporating multiple sensor platforms in key areas would be beneficial. The consultants and university taught project participants about remote sensing, image processing, and GIS, and the State of Hawaii taught about Hawaiian vegetation. Project participants consider the project a success. The main project objectives of technology transfer for the production of a digital base land cover classification map, raw data island mosaic, and change detection image of the TM and 1977 MSS mosaics are met. Project participants put together a multi media demonstration using GPS points and field photos with the raw mosaic of the big island.

The products from this project are being used in several ways. Office of State Planning is using the LSVIEW program to demonstrate the project to visitors and to monitor change in Hamakua land use. Division of Forestry and Wildlife is using the map product information in Arc View and will plot the vectorized 7.5 minute quads for big island forestry and wildlife as needed. Hilo forestry references the various 8.5X11 hard copy prints and map at 1:250,000 since they do not have access to a image processing/GIS system. University of Hawaii Geography Department graduate students charted their own band combinations and made 8.5 X 11 in. digital posters describing land cover changes in the various band combinations and put them on the Internet. Other government agencies and commercial companies throughout Hawaii are interested in the technology and the products.

APPENDIX H - Project Products

Recommendations

Building a remote sensing/GIS work environment includes data from different sensors to obtain multiple resolutions, aerial photography, stereo plotter for viewing and delineating ecozone boundaries, field spectrometer, image data, map and data storage cases, hardware/software for image processing, GPS, and GIS, and peripheral devices for input and output.

Input devices include CD reader, various tape media drives, table digitizer, and scanners. Output devices include black-and-white and color printers, CD writer, plotters, camera and image setter output.

Cover types with only the core area of concentration mapped need funds for personnel to collect and process data. A portable system to take image data and processing to resource managers and researchers outer island is needed, along with color prints of the data and other information needed to develop more spectral classes.

Register new TM data, and data from different sensors and resolutions to the existing image database. Process and produce products at multiple scales to build a remote sensing database with multiple scales of land cover patterns for the requirements of different land managers and administrators. Incorporate under flights, elevation, slope and aspect data to use as a mask if needed, add new multiple resolution data sets including radar if necessary. Maintain Jacobiveg vegetation overlays by combining GPS point data, image data, and Arc. Use as a mask to classify on 7.5 minute quad basis in addition to the base classification provided in a classification mosaic.

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REPORT
ON
GEOGRAPHIC
INFORMATION
SYSTEM
(GIS)
SUPPORT

REPORT ON GEOGRAPHIC INFORMATION SYSTEM (GIS) SUPPORT

Geographic Decision Systems International (GDSI) provided GIS support to the project. This support had three major components:

1) GIS Training

2) Application Development

3) On-going GIS Support and Trouble-shooting

1) GIS TRAINING

The State of Hawaii has largely standardized on Arc/Info software for their GIS work. Both OSP and DLNR have Arc/Info running on the same Hewlett-Packard UNIX workstations on which the Imagine software is running. GDSI provided a one week course titled "Introduction to Arc/Info" which covered the basics of using Arc/Info for digitizing, editing and displaying geographic data. The course included a textbook titled "Understanding GIS, The Arc/Info Method" and a complete set of course notes including descriptions of the State GIS and GIS standards. Each student was provided the textbook and course notes to keep after the course was complete. Because most of the project participants already had GIS experience, only two students took the course, one from OSP and one from DLNR. Since completing the course, both have been able to use Arc/Info independently and continue to expand their knowledge of Arc/Info and GIS.

Recommendation: It is important that personnel working with remotely sensed data be aware of GIS technology and how to utilize GIS data for image rectification and classification, and how to use GIS for display and map preparation. Although Imagine has map making tools, the remote sensing consultant reported problems with the HP version of Imagine in this regard. Therefore, Arc/Info was heavily utilized for map making. In the future, GIS training is necessary not only for the technical skills for using Arc/Info, but also for the introduction it gives to spatial data and map projections. However, if the map making tools can be used in Imagine, it would probably be more efficient to use those tools for map-making rather than using Arc/Info.

2) APPLICATION DEVELOPMENT

Part of the remote sensing exercise was the collection of field data for classification. In addition to noting the land cover at a site, project participants also used Global Positioning Systems (GPS) to locate their position in UTM coordinates that could be later used in Arc/Info and Imagine. They also took photographs at many of these sites. Although it was relatively easy to prepare paper maps showing the location of the GPS sites, project participants wanted the ability to see the photos taken at site to help them remember the site and to assist in classification.

GDSI used the Arc/Info AML programming language to develop an application to do this. We also had to scan in the photographs taken at the field sites. The photos were scanned using an 8.5" x 14" 24bit color desktop scanner at both 150dpi and 300dpi. It was found that 150dpi was sufficient to capture the photo on the screen and was therefore used to save space since these files can be rather large. The scanned photos were processed on a PC computer at GDSI, sometimes with adjustments for contrast and brightness, and saved as TIFF files. These TIFF files were transferred to the UNIX workstations at GDSI across the network. The TIFF files were then available for display from Arc/Info. But we needed a way to link the photos with the GPS sites and to display the LANDSAT image underneath along with pertinent GIS layers such as major and minor roads. Thus the need for the application which we call LSVIEW.

LSVIEW is totally menu driven using popup windows on the UNIX workstations. It is easy to use without requiring extensive experience with either GIS or remote sensing. After starting LSVIEW, the user sees the Big Island outline and optionally the LANDSAT mosaic. The user can turn on and off other GIS layers by clicking buttons on the menu. The interesting GIS layer to display is the GPS layer. When the GPS layer is turned on, small red circles appear on the map at all of the GPS sites. The user can then click on a site and, if there is a photo of that site, it will be displayed on the screen in a popup window. If there is more than one photo, multiple popup windows will appear until all the photos for that site are displayed. Closing the popup window removes the photo from the display.

LSVIEW also allows the user to zoom in on areas of interest for a closeup view. Each area of interest can be named so that it can be immediately returned to later in the session or in subsequent sessions. Users can also zoom in on the photos themselves to try and see more detail, although for this to be more effective the photos would have to be scanned at a higher resolution, perhaps 300 dpi or higher.

LSVIEW is being used by project personnel and has been demonstrated live on a UNIX workstation at the Hawaii State GIS Conference. People are very interested in the mosaic image and in how the photos of a site can be popped up on the screen. A copy has also been sent to NASA for an earlier demonstration.

Appendix E contains annotated screen captures to give a quick tour of LSVIEW capabilities.

Recommendation: LSVIEW made the LANDSAT data more accesible to non-experts and was useful in providing linked photos to help with classification. There is now software available (ArcView2) that could be programmed to have similar capabilities to LSVIEW but with the additional advantage that the programs can be run on UNIX, PC and MAC environments. In the future efforts should be made to implement LSVIEW capabilities in ArcView rather try to enhance the functionality of LSVIEW. Now that a classified image exists, it would also be nice to be able to display either the raw mosiac or the classified image. Also, when displaying the raw mosaic, it would be nice to choose which bands would be used.

3) ON-GOING GIS SUPPORT AND TROUBLE-SHOOTING

Due to the extended time-period for this project, on-going GIS support and trouble-shooting became another major part of GDSI's contribution to the project. We stopped in at the lab periodically to see how things were going and also worked with OSP project personnel to modify their AML programs for map production to generalize them and make them more automatic. GDSI was also on call to help whenever there was a problem with Arc/Info and the GIS. Although there were many minor troubles, two major areas bear individual attention:

A) Transfer of Imagine color pallettes into Arc/Info

Because the plotting part of Imagine didn't seem to be working on the HP platform, it was decided to do the plotting of the maps using Arc/Info. However, project personnel were spending lots of time trying to get the colors in Arc/Info to match the on-screen colors in Imagine. GDSI worked with OSP personnel to develop an AML to automatically transfer the color pallette from Imagine to Arc/Info. The user need only save the color pallette as an ASCII file from Imagine, then start Arc/Info and run our AML. The AML reads the ASCII file and creates the color table and legend key to be used for the Arc/Info map. It all works automatically. This AML greatly increased the project personnel's capability to produce maps.

B) Image conversion for plotting

Once the map was created in Arc/Info it was necessary to plot it out on a large format color plotter. Both GDSI and OSP use the HP650C color inkjet plotters which can plot up to E-size in color at 300dpi. However, the map graphics files (Encapsulated Postscript) were so large, due to the large size of the raw and classified images contained therein, that the plotters ran out of memory before completeing the map. The HP650C uses the RTL graphics format internally and apparently had to store the entire Postscript file in memory and also compose the page to plot in RTL in memory at the same time.

GDSI had an upgraded version of Arc/Info that the State did not yet have. This version had an RTL command that purported to create an RTL format file that could be sent direct to the plotter. So we took the graphics file and used the RTL command. We still ran out of memory but were able to reduce the size of the image until it plotted out. These were the first plots of the raw image that was then taken into the field. In the meantime, we continued to investigate why there was still an out of memory error. It turns out that the Arc/Info RTL command doesn't produce pure RTL files but rather a combination of HPGL-2 and RTL. Therefore, the plotter still had to store the the input data in memory while it composed the page in memory. Thus the continued out of memory error.

An enquiry over the Internet (comp.infosystems.gis) brought a majority response that a software package calle Image Alchemy would be what we needed. We ordered the software ($1000 at the time, now $495 on UNIX, $395 on PC) and gave it a try. Image Alchemy composes the RTL graphics page using UNIX resources rather trying to do it on the plotter. It can take large amounts of hard disk space (700 Mb) and large amounts of time (4-6 hours), but it creates a pure RTL file that can be spooled to the plotter and plotted as it is recieved. This removes the plotter memory limitation.

All subsequent large format color maps for the project have been produced using this method, both at GDSI and at OSP. An upgrade for Image Alchemy (1.8) has come out since we started (with 1.7) and we have noticed that the colors produced by 1.7 are lighter and more pleasing than those produced by 1.8. There are probably switch settings to compensate for this but for now we used the Alchemy 1.7 for the final project maps plotted at GDSI.

Recommendation: The color pallette problem presumably would not have occurred if the maps had been produced directly by Imagine, however since our AML has solved the problem, and since project personnel are more proficient at producing maps with Arc/Info than with Imagine, they will probably not switch back to Imagine even if the map production problem on the HP is fixed. This project was done using Imagine version 8.1 and there is now version 8.2 in which the problem may have been fixed. Also, unless Imagine has a pure RTL driver similar to Image Alchemy's, the same problem with memory will occur when plotting. Image Alchemy or similar products will continue to be necessary so the ability to solve this problem has been a valuable contribution of this project to both remote sensing and GIS users in the State. Several other Federal, State and County agencies have adopted it after seeing our work on this project.

CONCLUSION

There is great interest in the GIS community in Hawaii for using remotely sensed imagery for landcover classification and for landcover change analysis. Hawaii's unique natural heritage and wide range of diverse ecosystems makes this a challenge, but one that governmental and private organizations are eager to overcome. In this project we have shown that Arc/Info and Imagine can co-exist and can work together to provide the tools for using LANDSAT data for landcover classification. As identifed in the rest of this report, there have certainly been many painful lessons for project personnel about the limitations still present. But we have found ways to overcome these problems, and have created a landcover map of the Big Island that is the envy of the rest of the GIS community. The final maps have generated great interest among the GIS community both in the maps themselves (everyone wants a copy), in acquiring LANDSAT and SPOT satellite imagery (SPOT has a cooperative project in the State of Hawaii), and in learning more about remote sensing.

APPENDICES

LIST OF APPENDICES

APPENDIX A - Landsat TM Scenes and NOAA Data

1) Scene Image: TM6346_90
2) Scene Data Sheet: TM6346_90
3) Scene Image: TM 6246_91
4) Scene Data Sheet: TM6246_91
5) Scene Image: TM6247_91
6) Scene Data Sheet:TM6247_91
7) Scene Image: TM6347_89
8) Scene Data Sheet:TM6347_89
9) Scene Image: TM6545_92
10) Scene Data Sheet: TM6545_92
11) NOAA Station Map
12) NOAA Temperature Chart - June 1989
13) NOAA Precipitation Chart - June 1989
14) NOAA Temperature Chart - June 1990
15) NOAA Precipitation Chart - June 1990
16) NOAA Temperature Chart - October 1991
17) NOAA Precipitation Chart - October 1991

Scene Image: TM6346_90
Maui, NW Big Island
June 1, 1990

Halcakala
Mauna Kea
4L

EARTH OBSERVATION SATELLITE COMPANY
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Ship Date: 08-feb-1994

Customer Account #: 3000874   Customer Order #: 300087494010

Invoice #: 94020050   Customer Ref #: 0119312140063

SHIP TO:
USGS/EROS DATA CENTER
ATTEN: DATA MANAGEMENT/CEES
MUNDT FEDERAL BUILDING
SIOUX FALLS, SD, USA
57198-0001

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ATTN: LANDSAT DATA USER
Phone #: 605-594-6511

BILL TO:
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EROS DATA CENTER
CUSTOMER SERVICES
SIOUX FALLS, SD, USA
57198

Product Order Number	Product Code	L#	Path	Row	Scene ID %Shift	Acq-Date	Mode	Mux
94010004-01	GLOBLT	4	063	046	00	90152 (01-jun-90)	1	0

Maximum Full Scene Cloud Cover: 0   Bands Processed: 1234567

Resample Method/Interval: CC /28.50

Earth Ellipsoid: INTERNATIONAL 1909

Map Projection: SPACE OBLIQUE MERCATOR

Scene Data Sheet: TM6346_90
Maui, NW Big Island
June 1, 1990

Appendix A #2

Scene Image: TM6246_91
NE Big Island
October 11, 1991

EARTH OBSERVATION SATELLITE COMPANY
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Customer Account #: 3000874 Customer Order #: 300087494032

Invoice #: 94020091 Customer Ref #: 119312150007

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Phone #: 605-594-6511

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EROS DATA CENTER
CUSTOMER SERVICES
SIOUX FALLS, SD, USA
57198

Product Order Number	Product Code	L#	Path	Row	%Shift	Scene ID Acq-Date	Mode	Mux
94032003-01	GLOBLT	5	062	046	00	91284 (11-oct-91)	1	0

Maximum Full Scene Cloud Cover: 30 Bands Processed: 1234567

Resample Method/Interval: CC /28.50

Earth Ellipsoid: INTERNATIONAL 1909

Map Projection: SPACE OBLIQUE MERCATOR

Scene Data Sheet: TM6246_91
NE Big Island
October 11, 1991

Scene Image: TM6247_91
SE Big Island
October 11, 1991

Big Island
So. Pt. to
Muralum

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Customer Account #: 3000874 Customer Order #: 300087494032

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Phone #: 605-594-6511

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EROS DATA CENTER
CUSTOMER SERVICES
SIOUX FALLS, SD, USA
57198

Product Order Number	Product Code	L#	Path	Row	%Shift	Scene ID Acq-Date	Mode	Mux
94032004-01	GLOBLT	5	062	047	00	91284 (11-oct-91)	1	0

Maximum Full Scene Cloud Cover: 30 Bands Processed: 1234567

Resample Method/Interval: CC /28.50

Earth Ellipsoid: INTERNATIONAL 1909

Map Projection: SPACE OBLIQUE MERCATOR

Scene Data Sheet: TM6247_91
SE Big Island
October 11, 1991

Scene Image: TM6347_89
S Big Island
June 14, 1989

EARTH OBSERVATION SATELLITE COMPANY
*** Shipping Notice ***

Ship Date: 09-feb-1994

Customer Account #: 3000874 Customer Order #: 300087494010

Invoice #: 94020059 Customer Ref #: 0119312140061

SHIP TO:
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MUNDT FEDERAL BUILDING
SIOUX FALLS, SD, USA
57198-0001

ATTN: LANDSAT DATA USER
Phone #: 605-594-6511

Univ of HI

BILL TO:
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EROS DATA CENTER
CUSTOMER SERVICES
SIOUX FALLS, SD, USA
57198

Product Order Number	Product Code	L#	Path	Row	Shift	Scene ID Acq-Date	Mode	Mux
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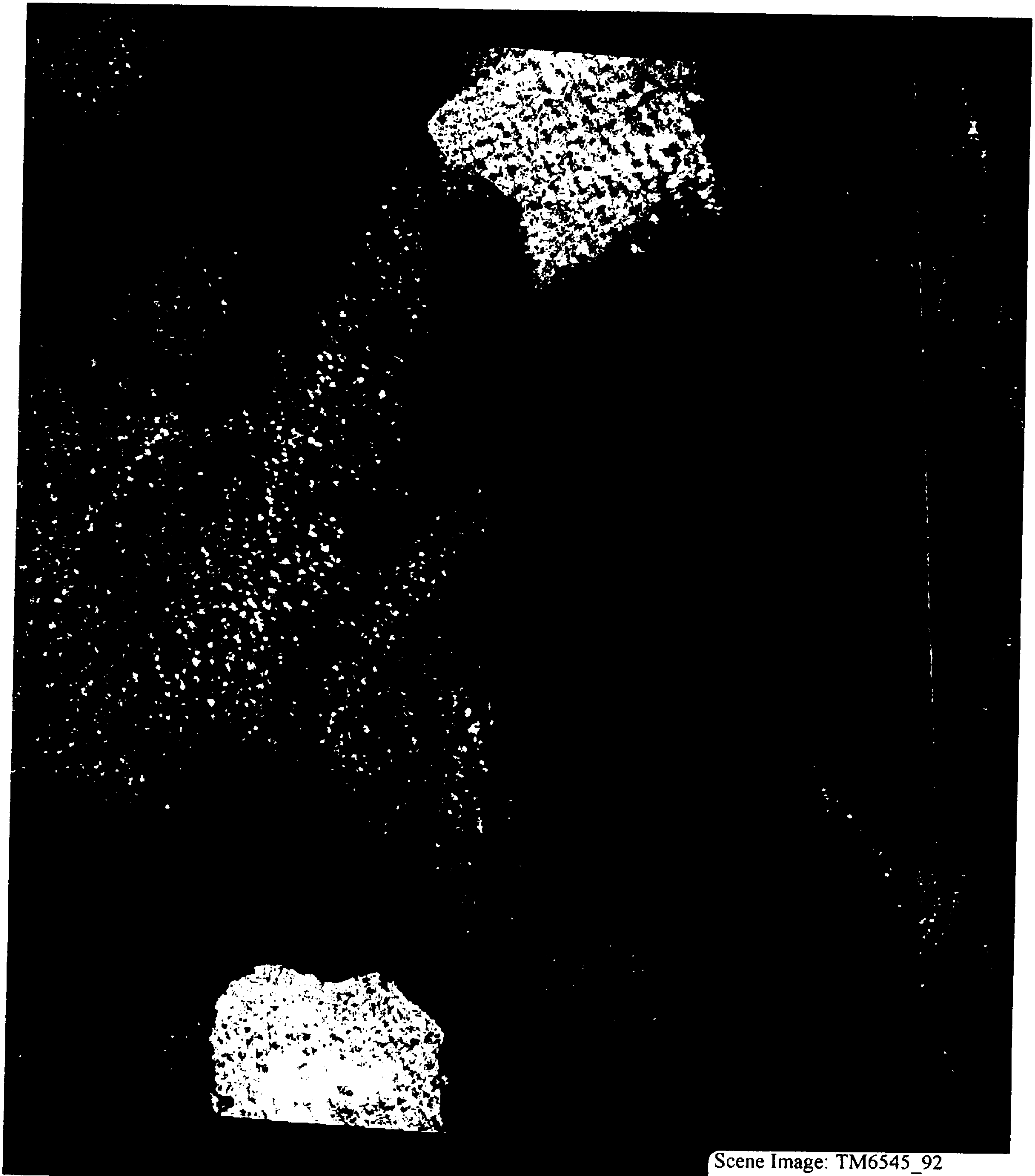
Maximum Full Scene Cloud Cover: 0 Bands Processed: 1234567

Resample Method/Interval: CC /28.50

Earth Ellipsoid: INTERNATIONAL 1909

Map Projection: SPACE OBLIQUE MERCATOR

Scene Data Sheet: TM6347_89
S Big Island
June 14, 1989



Scene Image: TM6545_92
E Kauai, W Oahu
April 1, 1992

Kauai

EARTH OBSERVATION SATELLITE COMPANY
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Ship Date: 16-feb-1994

Customer Account #: 3000874

Customer Order #: 300087494032

Invoice #: 94020100 Customer Ref #: 0119312150012

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ATTEN: DATA MANAGEMENT/CEES
MUNDT FEDERAL BUILDING
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57198-0001

ATTN: LANDSAT DATA USER
Phone #: 605-594-6511

Unc-OHI

BILL TO:

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EROS DATA CENTER
CUSTOMER SERVICES
SIOUX FALLS, SD, USA
57198

Product Order Number	Product Code	L#	Path	Row	%Shift	Scene ID Acq-Date	Mode	Mux
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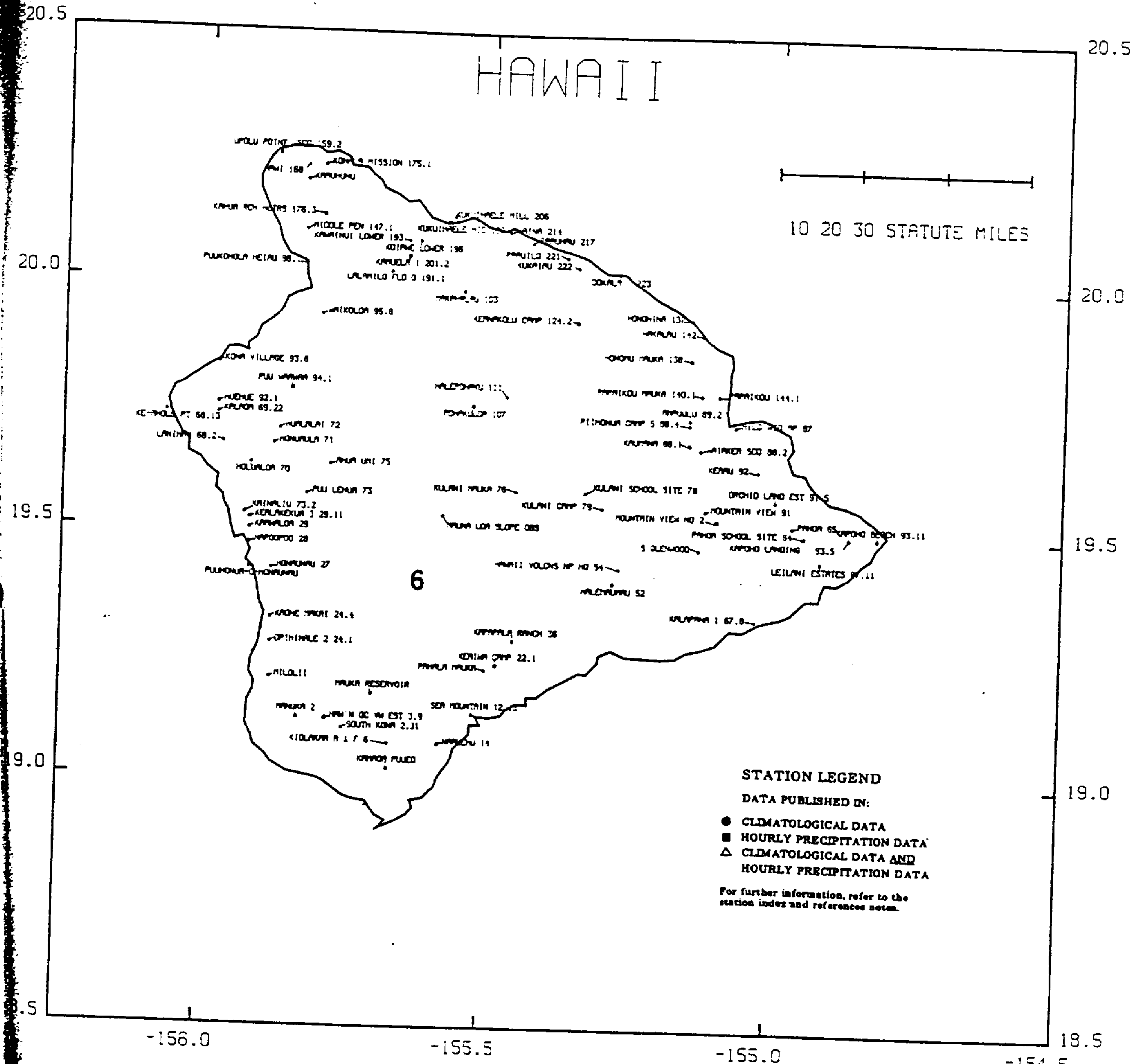
Maximum Full Scene Cloud Cover: 30 Bands Processed: 1234567

Resample Method/Interval: CC /28.50

Earth Ellipsoid: INTERNATIONAL 1909

Map Projection: SPACE OBLIQUE MERCATOR

Scene Data Sheet: TM6545_92
E Kauai, W Oahu
April 1, 1992



NOAA Station Map
Big Island
Temperature and Precipitation

DAILY TEMPERATURES (°F)

HAWAII AND PACIFIC
JUNE 1989

DAY OF MONTH

STATION	OBS TIME	MAX MIN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	AVERAGE
ISLAND OF MAUI																																		
HALEAKALA R S 338	08	MAX	55	58	64	63	59	60	64	62	59	68	69	66	64	67	68	73	70	68	66	68	63	62	59	63	60	62	58	61	61	60		63.3
		MIN	47	44	49	46	47	49	48	45	47	51	47	53	48	49	49	57	55	55	57	54	45	44	44	42	43	42	43	47	46	47		48.0
HANA AIRPORT 355	08	MAX	82	83	82	81	82	83	82	81	82	81	80	81	76	82	80	81	82	78	82	83	81	82	79	82	82	82	83	82	82	81		81.3
		MIN	69	68	70	71	69	70	69	71	71	69	67	73	66	66	69	69	71	70	70	71	70	69	75	68	67	69	68	69	69	69		69.4
KAHULUI WSO 398 AP	MID	MAX	86	87	86	84	85	84	85	84	85	84	84	81	84	84	84	85	83	86	87	84	87	89	87	86	84	88	86	86	86	85		85.2
		MIN	68	64	68	72	70	73	71	72	69	73	71	71	68	70	71	69	73	72	73	67	67	64	66	66	69	64	64	73	73	71		69.4
KAILUA 446	07	MAX	76	78			78	78	76	76	77			77	77	78	77	77			78	78	76	77	78			78	78	78	79	78		77.4
		MIN	66	66			66	67	68	68	68			66	64	67	67	67			68	69	68	65	67			64	66	67	67	67		66.7
KAPALUA-WEST MAUI AP	08	MAX	81	85	85	85	82	84	81	82	82	83	81	83	81	83	79	83	82	79	83	85	83	85	84	85	85	85	84	84	84	84		83.1
		MIN	69	69	72	72	70	71	71	71	73	71	71	70	70	70	70	71	71	71	72	71	72	70	71	71	69	69	69	71	71	70		70.6
KULA BRANCH STN 324.5	07	MAX	67	73	72	74	74	74	74	74	71	79	71	76	77	73	73	74	74	74	74	72	69	73	71	70	72	74	69	74	74	73		73.0
		MIN	60	57	58	58	58	58	58	58	58	56	56	56	56	57	57	59	60	60	57	58	58	56	58	56	56	57	57	60	58	58		57.6
KULA HOSPITAL 267	07	MAX	67	71	71	71	74	74	73	70	71	77	70	73	71	72	71	71	73	75	72	72	71	71	72	69	71	73	71	71	74	74		71.9
		MIN	58	56	56	56	57	58	55	56	57	55	54	55	53	54	55	57	58	59	56	56	57	55	56	57	57	56	57	57	57	57		56.2
LAHAINA 361	07	MAX	83	87	86	89	87	88	87	87	86	86	86	85	85	87	88	86	87	85	88	86	84	88	85	85	86	88	85	85	87	88		86.3
		MIN	70	69	72	72	73	72	69	69	70	70	69	68	68	69	67	70	71	74	69	70	72	69	71	70	69	69	69	71	74	72		70.2
MAKENA GOLF COURSE 249	08	MAX	85	87	88	89	88	90	87	86	87	87	87	87	80	85	85	85	87	86	88	89	84	86	86	88	87	87	88	86	88	89		86.7
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PUUKOLII	07	MAX	81	83	83	83	86	82	84	83	84	84	84	83	85	84	85	84	84	85	84	84	84	83	85	84	84	84	84	84	84	83		83.8
		MIN	67	66	68	68	68	72	69	67	67	68	69	69	67	68	66	66	68	68	67	67	68	69	67	68	67	68	67	67	67	69		67.7
ISLAND OF HAWAII																																		
HAWAII VOLCNS NP HQ 54	08	MAX	73	72	74	72		72	69	68	71			73	73	72	73	69	75	73	68	71	75		72	73	73	74	72	72	72	64		71.7
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HILO WSO AP 87	MID	MAX	82	82	82	80	80	80	81	81	81	80	81	77	81	81	81	81	83	82	83	81	81	82	83	82	82	83	81	82	82	82		81.3
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KAINALIU 73.2	07	MAX	78	80			78	80	78	78	78			79	80	78	78	79			79	77	78	78	77			78	76	76	76	77		78.0
		MIN	63	63			62	66	64	64	64			63	65	63	65	66			65	65	65	64	65			63	62	65	64	64		64.1
KE-AHOLE PT 68.13	08	MAX	86	87	88	85	85	87	87	87	88	87	86	87	86	86	89	89	87	85	87	89	87	88	89	90	87	87	89	89	87	83		87.1
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KULANI CAMP 79	07	MAX	66	67	67	67	67	67	67	62	62	66	66	66	66	66	66	66	67		67	63	62	63	63	63	63	55	62	61	60	57		64.1
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LALAMILO FLD O 191.1	16	MAX	76	74			74	70	71	73	73				73	71	72	71			73	71	74	77	75			75	74	75	73	74		73.3
		MIN	54	52			55	62	60	60	61				59	68	62	63			60	50	56	55	54			53	53	61	61	61		58.1
MAUNA LOA SLOPE OBS	09	MAX	46	49	55	59	58	57	48	47	52	53	55	56	57	58	61	60	57	61	61	62	66	57	56	57	54	58	53	57	58	64		56.4
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MOUNTAIN VIEW NO 2	07	MAX	79	83			83	77	76	77	78			81	73	82	80	80			79	81	80	81	77			82	82	78	83	80		79.6
		MIN	59	60			61	63	60	63	65			62	60	63	65	64			63	60	61	61	62			60	58	62	64	63		61.8
NAALEHU 14	08	MAX	80	80	79	80		75	79	78	81	76	80		79	79	76					79	80	78	79	77	79		78	79	75	79		78.5
		MIN	66	67	68	68		67	66	66	67	66	64		65	65	67					67	68	67	66	65	64		65	65	66	66		66.1
OOKALA 223	06	MAX	79	80	80	80	80	75	78	76	79	80	78	79	73	79	79	77	79	80	81	81	79	80	80	80	80	80	80	80	81	80		79.1
		MIN	70	67	67	69	69	69	68	69	70	70	68	69	69	68	69	70	70	70	72	70	70	69	68	69	69	71	68	68	68	68		69.0
OPIHIHALE 2 24.1	07	MAX	77	81	81	80	78	81	80	79	82	80	79	80	81	81	81	80	77	83	78	82	78	80	79	77	78	79	79	79	78	75		79.4
		MIN	61	64	62	62	62	63	65	61	62	65	66	61	69	61	61	64	66	68	64	66	65	63	64	63	62	62	61	66	64	62		63.5
PUUKOHOLA HEIAU 98.1	08	MAX	87	86	87	88	92	90	90	91	90	91	89	90	90	85	90	91	87	88	80	80	89	87	86	86	87	87	88	88	88	90		87.9
		MIN	69	70	72	74	73	76	70	70	70	70	73	72	69	71	73	73	75	72	70	69	71	70	69	69	69	71	71	71	73	74		71.3
SEA MOUNTAIN 12.15	07	MAX	83	83	84	84	84	84	82	83	83	85	85	85	76	84	84	84	82	82	81	84	84	83	81	82	82	83	83	82	84	84		83.0
		MIN	68	69	69	69	70	69	67	67	67	68	67	67	69	68	67	68	71	70	70	69	68	70	70	66	66	68	68	68	68	68		68.3
SOUTH KONA 2 2.32	07	MAX	75	77	75	79	80	78	74	77	79	83	79	79	71	79	79	76	76	76	76	77	74	82	78	76	76	74	75	74	74	73		76.7
		MIN	59	60	59	62	59	61	59	57	59	61	61	58	61	57	61	60	62	62	60	59	58	59	60	58	57	60	58	62	60	60		59.6
UPOLU POINT USCG 159.2	08	MAX	85	86	86	86	85	85	83	85	85	85	86	86	80	86	84	82	84	85	85	86	82	86	88	88	86	85	86	86	87	85		85.1
		MIN	69	68	70	71	69	70	69	69	69	69	69	70	71	70	69	70	75	70	70	75	69	71	67	67	70	70	70	71	69	70		69.9

SEE REFERENCE NOTES FOLLOWING STATION INDEX

NOAA Temperature Chart
Maui, Big Island
June 1989

AMAUULU 89.2	A	21.93	7.30	•	•	•	1.94	•	•	•	•	•	•	5.94	•	•	•	•	•	•	6.10	•	•	•	•	•	•	.65	•	•	•		
HAINA 214		11.44			.21	.02	.10	.72	.90	.79	.54	.60	.10	2.00	1.52	.24	2.55	.10	.44												.50	.03	
HAKALAU 142		9.12	.01		•	•	1.44	1.36	.16	.45	.33	•	•	.97	1.18	.06	.34	.24	•	•	.43			.08	.27		•	.89		•	.35	.56	
HALEMAUMAU 52	A	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-		
HALEPOHAKU 111	A	.80						•	•	•	•	•	.46	.27	.07																		
HAWAII VOLCNS NP HQ 54		7.87	.05	1.10	.20	.20	•	2.59	T	.54	T	T	T	.14	1.06	.06	.25	.00	.11	.27	.03		.12	•	.19	.07	T	.19	.07	.02	.10	.27	
HAWI 168	A	7.37	1.64		.16	.01	•	.50	.13	.27	T	•	•	•	•	1.01	1.60	.24	.14	.07	.09	•	.22	.01	•	•	.06				.72	.10	
HILO WSO AP 87	R	7.03		.27	.54	.40	1.00	.40	.37	.04			.20	1.21	.04	.74	.07	.17	.21	.15	T	.10	.16	.05	.01	.16					.32	.20	
HOLUALOA 70	A	.00	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	T	•	•	•	
HONAUNAU 27		6.07	.03	.33	•	•	1.35	T	.33	T		•	•	.43	.16	.01	T	.02	•	•	.13	.06	.02	.01	2.01	•	•	.94	.02	.18	.02	.02	
HONOHINA 137		10.51	.02		•	•	1.07	2.00	.17	.96	.43	•	•	1.45	.05	.11	.52	.29	•	•	.54		.07	.22				.79			.48	.58	
HONUAULA 71	A	.00	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
HUALALAI 72	A	.00	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
HUEHUE 92.1	A	2.41	•	•	•	•	.24	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	1.13	.90	•	•	•	•	•	•	.14	
KAAWALOA 29	A	2.12	•	•	•	•	•	.11	•	•	•	•	.14	.04	•	.02	•	•	•	.44	.02	•	.09	•	.78	•	.05	.08	•	.35	•	•	
KAINALIU 73.2		4.57	.04	.01	•	•	1.10	.02	.15			•	•	.09	.03	.01	.01	.06	•	•	.70	.03	.04	.11	.75	•	•	.99	.01	.18	.05		
KALAPANA 1 67.8		M	-	-	-		-	-	-		-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-		
KAMAOA PUUEO		2.78		.49	.06			.18	.05	.55					.63		.10	.07	.05	.11			.14		.06	.08	.12	.09					
KAPAPALA RANCH 36	A	3.38	.50	.15				.65		.05					1.34					.01					.36			.28	.04				
KAPOHO BEACH 93.11		M 4.59			.17	.06	.79	.70	.02			.01		.91	.03	.03	.04	.22	.13	.09	T	•	•	•	•	•	•	1.18	•	.21			
KAPOHO LANDING 93.5	A	6.84	•	.85	•	•	•	•	•	•	2.00	•	•	•	•	•	•	1.65	•	•	•	•	•	•	1.04	•	•	•	•	•	•	1.30	
KAWAINUI LOWER 193	A	11.95	•	•	•	•	•	5.85	•	4.18	•	•	•	•	•	•	•	•	•	•	•	•	•	•	1.92	•	•	•	•	•	•	•	
KEAAU 92		8.26	.01	•	•	.85	.70	1.68	.05	.28	.07	•	.20	1.49	.65	.02	.56	.07	•	.45			.40	.08	.06	•	.09	.12		.03	.28	.12	
KE-AHOLE PT 68.13		.22	T																				.08					.07		.05		.02	
KOHALA MISSION 175.1		8.36	1.35		•	•	.35	.70	.10	.44					1.25			1.96				.78	.22	•	•	•	•	•	•	.25	.84	.12	
KOIAWE LOWER 196	A	8.12	•	•	•	•	•	2.90	•	3.75	•	•	•	•	•	•	•	•	•	•	•	•	•	•	1.47	•	•	•	•	•	•	•	
KONA VILLAGE 93.8		.80					.30		.10														.40										
KUKAIAU 222		12.77			.70	.01	.33	3.04	.15	.72	.07	•	.08	1.76	1.33	.36	2.82	.30	.40	.04											.31	.35	
KUKUIHAELE HIC 199		13.61	.07		.02		.31	1.70	.09	.30	.13	.15	.05	2.40	1.18	.34	2.53	1.30	1.67	.06			.12	.02				.32			.32	.53	
KUKUIHAELE MILL 206	A	9.79	.01		T		.06	1.20	.03	.63	.17		.07	2.30	1.12	.11	1.73	.72	.89				.01	.03				.23			.29	.19	
KULANI CAMP 79		9.53	.02	1.15	.37	.28	.13	3.70	.09	.80	.05		.50	.03	.90	.05	.08	.02	.03		.10		.15		.09			.25	.35	.09	.09	.21	
KULANI MAUKA 76	A	2.61	•	•	•	•	•	.84	•	•	•	•	•	1.51	•	•	•	•	•	•	.24	•	•	•	•	•	•	.02	•	•	•	•	
KULANI SCHOOL SITE 78	A	8.40	•	•	2.85	•	•	•	•	•	•	4.35	•	•	•	•	•	•	1.20	•	•	•	•	•	•	•	•	•	•	•	•	•	
LALAMILO FLD O 191.1		1.76	1.35		•	•	.05	.12		.01		•	•	•	.02	.03	.11	.01	•	•	.02	•	.02	•	•	•	•	•	•	•	.01	.01	

SEE REFERENCE NOTES FOLLOWING STATION INDEX

DAILY PRECIPITATION (INCHES)

STATION		TOTAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
LANIHAU 68.2		3.01		.06	.38				.48				.15							.26	.12			.07	.55		.26		.68				
LEILANI ESTATES 67.11		7.87	.01	.03	.73	.33	.43	1.44	.10	.02	T	T		1.20	.42	.03	.14	.12	.22	.70	.01	.01	.25	.49	.34	.05	.19	.26	.01	.10	.22	.52	
MAHAILUA	A	.87	•	•	•	•	.10	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	.17	•	•	•	•	•	•	•	.60	
MAKAHALAU 103	A	.75										•	•	•	.75																		
MANUKA 2	A	2.24	.23	.06	•	•	1.02	.34				•	•	.32	.06	T			•	•	.18			T		•	•	.03		T			
MAUKA RESERVOIR		M 2.52	-	-	•	•	•	•	•	•	1.78	•	•	•	•	•	•	.06	•	•	•	•	•	•	.16	•	•	•	•	•	•	.52	
MAUNA LOA SLOPE OBS		1.37	.07	.99				.01	.06	.03	.01			.20																			
MIDDLE PEN 147.1	A	.16	•	.16								•	•																				
MILOLII		2.69	T		1.62	•	.02		.14	.15		.02	.01			.01		T		.01	T	.01			•	.01	T	.14	T	.05	.06	.44	
MOANUIAHEA	A	1.80	•	•	•	•	.81	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	.65	.15	•	•	•	•	•	•	.19	
MOUNTAIN VIEW NO 2		14.12	.39		•	•	1.22	3.71	.15	.85	.11	•	•	.66	2.36	.22	.77	.27	•	•	1.01		.51		.22	•	•	.87	.05	.07	.32	.36	
NAALEHU 14	A	2.60		.58				.40	.10	.12					.60		.06	.10	•	•	.06				.13	.20	.12	.13					
NAPOOPOO 28	A	2.47	•	•	•	•	1.21	•	•	•					.38	•	•	•	•	•	.06							.82					
OOKALA 223		12.33	.01		.19	.14	.48	2.15	.15	.66	.35	.05	.11	1.60	2.28	.08	1.81	.41	.52	.05	T	•	.09	.02	•	•	•		•	•	.60	.58	
OPIHIHALE 2 24.1		3.12	T	T	1.72	T	T		.22	.02	T		.13	T	.07	T		.08	T	.03	.14	.05	T	T	.22	.10	.13	.05	.01	.09	.03	.03	
ORCHID LAND EST 91.5	A	10.52	•	1.67	•	•	•	•	•	•	2.58	•	•	•	•	•	•	2.60	•	•	•	•	•	•	1.67	•	•	•	•	•	•	2.00	
PAAUHAU 217		8.73			.02	.05	.14	.70	.13	.43	.10	.02	.10	1.60	1.47	.22	2.47	.27	.25	T				T							.58	.18	
PAAUILO 221		11.92			.02	.02	.30	2.64	.15	.81	.06	.17	.10	1.34	1.49	.42	2.76	.30	.41	.01								.01			.72	.19	
PAHALA MAUKA		4.62	.44	1.05	•	•	.03	.52	.01	.04					1.42	.02		.02	•	•	.14				.32	.04	.03	.19	.01	.33	.01		
PAHOA 65		M 8.64	.03	•	•	1.27	.20	1.20	.05	.46	•	•	.02	1.40	.86	.02	.21	•	•	.55		.03	.30	•	•	•	.95	.35	.05	.33	.36	-	
PAPAIKOU 144.1		7.92	.01		•	•	1.08	.72	.18	.70	.06	•	•	1.35	1.25	.11	.65	.24	•	•	.44		.15	.17	.02	•	•	.21		•	.28	.30	
PAPAIKOU MAUKA 140.1	A	18.52	3.20	•	•	•	1.62	•	•	•	•	•	•	6.75	•	•	•	•	•	•	6.12	•	•	•	•	•	•	.83	•	•	•	•	
PIIHONUA CAMP 5 88.4	A	20.36	•	•	•	•	8.10	•	•	•	•	•	•	5.70	•	•	•	•	•	•	5.60	•	•	•	•	•	•	.96	•	•	•	•	
PUUKOHOLA HEIAU 98.1		.87			T																			.26	.61								
PUUHONUA-O-HONAUNAU		.82			.09															.04		.11			.10	.06	.08			.07		.27	
SEA MOUNTAIN 12.15		1.52		.31				.24		.12					.38		.02								.15	.09	.04	.17		T			
S GLENWOOD		14.66		.51	.50	.73	3.10	•	•	2.30	.17	.03	1.58	1.36	.12	1.01	.11	.43	.71	.03	.01	.54	.02	.15	.07	.13	•	.50	.07	.12	.07	.29	
SOUTH KONA 2 2.32		1.15		.09	.12		.09	.12		.04					.25								.02		.08		.17	.14		.02		.01	
UPOLU POINT USCG 159.2		4.52		1.14	.02	.05	.01	.20	.02	.02				.55	.12	.13	1.32	.12	.08	.21	.02	.01	.08		.01						.40	.01	
WAIAKEA SCO 88.2		18.01	.01	.37	.82	.59	.20	2.30	.18	4.60	.07	.17	.29	1.21	3.00	.34	.46	.12	.92	.66	.09		.29	.09	.08		T	.26	.02	.04	.42	.41	
WAIKOLOA 95.8		.57																					[illegible]	[illegible]					.18				

NOAA Precipitation Chart
Big Island
June 1989

STATION	OB. TIME	MAX/MIN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ISLAND OF MAUI																	
HALEAKALA R S 338	08	MAX	72	72	68	74	71	65	62	71	65	68	71	71	71	66	62
		MIN	56	56	56	53	48	42	47	54	50	48	55	61	49	47	46
HANA AIRPORT 355	08	MAX	80	80	81	81	81	80	82	82	83	81	81	83	82	83	82
		MIN	69	70	70	71	70	69	69	69	70	68	68	72	68	68	68
KAHULUI WSO 390 AP	M10	MAX	85	83	84	86	85	86	88	86	85	85	87	85	85	85	84
		MIN	72	73	73	72	71	71	71	72	73	70	68	70	72	71	71
KAILUA 446	07	MAX	80			79	79	79	80	80			80	79	78	78	78
		MIN	68			67	67	67	67	68			66	68	67	66	67
KAPALUA-WEST MAUI AP	08	MAX	83	83	83	79	84	82	83	86	83	83	82	85	82	83	83
		MIN	71	71	71	72	72	71	72	71	71	71	70	72	73	72	71
KULA BRANCH STN 324.5	07	MAX	74	74	74	72	69	72	71	73	74	74	72	71	75	76	75
		MIN	59	56	55	59	56	56	58	58	55	54	56	56	56	58	58
KULA HOSPITAL 267	07	MAX	70	73	74	71	72	71	71	73	71	74	72	73	72	75	76
		MIN	56	55	54	55	56	56	57	56	54	55	56	56	55	55	57
LAHAINA 361	07	MAX	86	87	87	88	86	85	87	87	87	86	87	87	87	88	87
		MIN	71	68	68	70	72	69	70	70	70	68	69	69	68	72	71
MAKENA GOLF COURSE 249	08	MAX	88	87	87	88	88	87	88	86	87	88	89	87	87	89	89
		MIN	70	66	65	67	67	69	67	68	67	66	65	66	65	68	67
PUUKOLII	07	MAX	87	84	85	84	83	82	82	83	84	85	85	84	84	81	82
		MIN	67	68	68	68	68	68	68	66	67	65	67	68	68	69	67
ISLAND OF HAWAII																	
HAWAII VOLCNS NP HQ 54	08	MAX	73	73	65	73	71	67	71	67	60	64	72	72	69	71	64
		MIN	56	55	55	54	54	55	53	61	56	56	52	54	54	51	54
HILO WSO AP 87	M10	MAX	83	82	82	83	83	83	84	83	83	82	85	82	82	81	82
		MIN	68	71	68	69	68	68	67	70	68	67	67	66	67	66	68
KAINALIU 73.2	07	MAX	80			80	79	78	78	78					80	80	80
		MIN	62			65	65	64	64	64					63	63	63
KE-AHOLE PT 68.13	08	MAX	87	85	86	87	84	87	85	88	89	87	87	87	89	87	88
		MIN	75	72	70	70	70	69	69	75	72	73	71	73	71	72	72
KULANI CAMP 79	07	MAX	68		66	67	66	61	62	65	66	66	65	65	64	65	61
		MIN	47		47	50	49	52	47	48	48	42	41	45	45	46	46
LALAMILO FLD O 191.1	16	MAX	74			74	73	74	75	72				74	72	71	73
		MIN	58			59	60	58	53	62				51	60	55	58
MAUNA LOA SLOPE OBS	09	MAX	60	60	60	59	61	62	60	58	58	61	59	60	64	62	56
		MIN	43	41	41	41	37	35	41	40	41	37	48	48	46	41	40
NAALEHU 14	08	MAX															
		MIN															
OOKALA 223	06	MAX	80	81	80	80	81	81	80	81	80	81	80	80	79	80	80
		MIN	70	69	69	71	69	67	68	70	70	69	67	70	69	68	68
OPIHIHALE 2 24.1	07	MAX	81	81	80	81	82	84	82	84	83	78	82	84	82	82	82
		MIN	64	64	66	65	61	64	62	62	65	64	63	65	64	64	64
PUUKOHOLA HEIAU 98.1	08	MAX	85	82	84	85	86	84	84	84	83	83	84	85	82	84	87
		MIN	69	68	68	68	72	70	68	66	68	68	68	71	71	71	71
EA MOUNTAIN 12.15	07	MAX	85	85	85	84	84	84	82	83	83	85	82	82	83	83	81
		MIN	63	63	63	71	71	71	69	69	68	67	68	68	68	68	67
OUTH KONA 2 2.32	07	MAX	78	78	76	81	78	77	80	78	80	80	80	82	81	81	79
		MIN	59	58	59	63	59	62	58	58	58	58	58	59	60	60	58
POLU POINT USCG 159.2	08	MAX	83	84	84	82	85	85	86	87	85	85	85	86	85	84	84
		MIN	70	71	72	70	70	69	68	68	70	69	69	70	69	69	69

STATION	MAX/MIN	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	AVERAGE
ISLAND OF MAUI																		
HALEAKALA R S 338	MAX	55	57	61	55	56	60	67	67	66	67	63	60	61	69	67		65.3
	MIN	48	48	45	45	48	51	53	50	46	47	46	45	51	53	50		49.8
HANA AIRPORT 355	MAX	82	76	81	76	81	75	80	80	78	77	80	81	81	81	81		80.4
	MIN	68	68	67	67	67	70	69	67	68	68	67	67	67	69	69		68.6
KAHULUI WSO 390 AP	MAX	81	84	82	84	83	86	84	83	84	85	85	87	87	84	85		84.0
	MIN	70	71	71	70	71	71	71	70	71	70	70	67	71	71	71		70.9
KAILUA 446	MAX			77	75	77	74	78			77	79	78	79	78			78.2
	MIN			65	66	66	67	67			65	66	67	68	68			66.8
KAPALUA-WEST MAUI AP	MAX	83	77	81	79	81	82	83	82	81	81	82	83	86	84	83		82.4
	MIN	70	69	71	69	69	71	71	69	69	69	69	73	72	70	72		70.8
KULA BRANCH STN 324.5	MAX	78	69	74	73	73	71	74	73	69	71	75	70	75	76	75		73.1
	MIN	58	56	56	57	58	61	59	54	56	56	54	55	56	58	56		56.7
KULA HOSPITAL 267	MAX	76	75	76	73	71	72	73	74	75	71	75	71	74	78	75		73.2
	MIN	57	57	55	56	57	59	62	55	56	57	54	56	58	57	57		56.2
LAHAINA 361	MAX	88	83	87	87	86	86	87	87	84	85	87	87	87	87	87		86.6
	MIN	71	71	71	70	71	73	70	69	69	70	68	70	69	70	71		69.9
MAKENA GOLF COURSE 249	MAX	89	91	89	87	85	84	87	87	87	87	87	87	86	89	90		87.6
	MIN	67	67	67	68	69	69	70	68	67	65	65	66	66	68	68		67.1
PUUKOLII	MAX	82	80	81	79	84	80	84	80	78	78	81	83	88	84	85		82.7
	MIN	68	67	69	67	67	67	68	67	67	67	69	67	67	70	69		67.6
ISLAND OF HAWAII																		
HAWAII VOLCNS NP HQ 54	MAX		66	63	69	68	65	67	64	69	62	64	73	67	72	70		68.0
	MIN		56	55	54	54	57	56	56	58	55	51	58	55	57	55		55.1
HILO WSO AP 87	MAX	81	82	81	81	77	81	81	81	81	80	78	81	83	82	82		81.7
	MIN	70	70	69	68	68	70	67	67	69	69	68	69	67	70	70		68.3
KAINALIU 73.2	MAX			77	76	74	78	77			75	74	77	77	76			M
	MIN			64	63	64	64	65			64	63	63	63	64			M
KE-AHOLE PT 68.13	MAX	88	86	86	85	85	87	86	85	85	86	86	87	87	87	87		86.5
	MIN	71	73	73	70	72	71	73	75	73	73	72	72	70	72	72		71.9
KULANI CAMP 79	MAX	63	60	58	61	60		62	61	61	60	61	64	62	57	67		63.0
	MIN	51	52	51	50	50		50	49	49	51	45	55	51	51	51		48.5
LALAMILO FLD O 191.1	MAX			73	73	70	73	72			73	72	73	72	71			M
	MIN			59	58	60	62	60			58	58	61	61	62			M
MAUNA LOA SLOPE OBS	MAX	55	62	56	54	54	57	53	62	60	60	61	59	60	63	59		59.2
	MIN	37	37	39	46	41	45	44	45	45	45	41	48	48	46	46		42.4
NAALEHU 14	MAX																	M
	MIN																	M
OOKALA 223	MAX	80	79	79	79	78	74	78	80	79	80	77	76	79	79	81		79.4
	MIN	68	72	67	66	68	68	68	67	68	67	62	68	69	65	70		68.2
OPIHIHALE 2 24.1	MAX	82	79	78	80	79	78	79	79	76	78	80	75	82	77	77		80.2
	MIN	64	62	63	62	63	63	65	64	65	65	60	62	62	62	67		63.5
PUUKOHOLA HEIAU 98.1	MAX	87	85	86	86	82	82	81	85	85		85	83	83	87	87		84.3
	MIN	71	72	70	71	71	71	72	70	69		67	67	69	72	71		69.7
EA MOUNTAIN 12.15	MAX	83	83	83	84	84	84	84	84	84	79	81	84	84	84	84		83.3
	MIN	67	67	67	67	67	67	67	67	67	68	66	66	66	66	66		67.2
OUTH KONA 2 2.32	MAX	80	77	78	80	79	78	77	73	74	72	75	76	76	76	74		77.8
	MIN	59	64	60	60	63	63	63	59	60	58	57	62	58	58	58		59.6
POLU POINT USCG 159.2	MAX	84	84	83	83	83	81	83	83	84	84	83	83	84	84	86		84.1
	MIN	68	68	68	67	70	70	70	67	68	68	68	68	67	67	71		68.9

SEE REFERENCE NOTES FOLLOWING STATION INDEX

12

NOAA Temperature Chart
Maui, Big Island
June 1990

DAILY TEMPERATURES(°F)

Appendix A #14

STATION		TOTAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
[illegible] 441	A	[illegible]																															
WAILUKU 386	A	M																															
WAIOPAI RANCH 256	A	.00																															
ISLAND OF HAWAII																																	
AMAUULU 89.2	A	17.01	1.11	*	*	.53	*	*	*	*	*	*	.93	*	*	*	*	*	*	5.62	*	*	*	*	*	*	8.82	*	*	*	*	*	
HAINA 214		8.32		.10	.02			.02							.03	.05	.21	1.15	1.00	.97	1.40	T	.02	.60	.08	.56	.60	.36	.38		.68	.09	
HAKALAU 142		M11.90	.03	*	*	.17	.30	.28	.01	.12	*	*	.09	.06	.20	*	.91	*	*	3.33	.51	.43	*	1.69	*	*	1.00	.05	1.85	.29	.58	-	
HALEMAUMAU 52	A	1.21	*	*	*	*	*	*	*	*	.25	*	*	*	*	*	*	.72	*	*	*	*	*	*	.12	*	*	*	*	*	*	.12	
HALEPOHAKU 111	A	.26																			.02	*	.10	*	*	*	*	.14					
HAWAII VOLCNS NP HQ 54		8.34	.02	T	T	.31	.48	.39	.05	.10			.03		.13	.06	1.11	.78	1.62	.87	.10	.05	.65	.19	.06	.63	.29	.16	.19	.07			
HAWI 160	A	4.94	.06	*	*	*	*	*	*	.19	*	*	*	*	*	*	.51	*	*	2.39	*	*	.51	.02	.07	*	.21	.04	.47	.14	.33	*	
HILO WSO AP 87	R	10.04			.10	.18	.42	.12	.03	.02	.01	.03	.06	.12	.21	.54	.37	1.35	.60	.28	.19	1.21	.09	.16	.69	1.62	.12	.42	.56	.07	.38	.09	
HOLUALOA 70	A	1.24	*	*	*	*	*	*	*	1.24	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
HONAUNAU 27		M .95		*	*	.07					*	*	.13					*	*	.20	.01	.03		.02	*	*	.12	.08			.29	-	
HONOHINA 137		11.31		.03	.12	.27	.17	.12	.05	.03		.05		.19	.06	.63	.85	1.46	.73	.91	.12	1.30	.39	.12	.74	.80	.09	.64	.99	.09	.35	.01	
HONUAULA 71	A	.55	*	*	*	*	*	*	*	.55	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
HUALALAI 72	A	11.10	*	*	*	*	*	*	*	11.10	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
HUEHUE 92.1	A	.16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	.16	*	
KAAWALOA 29	A	1.29	*	*	*	*	*	*	.03	.04	.08	*	*	*	*	*	*	*	.09	.32	.01	T	.09	.12	T	.40	.01	*	*	.08	.02	*	
KAINALIU 73.2		1.58		*	*	.01					*	*	*	.20		.04		*	*	.11	.12	.12		.04	*	*	.44	.42			.08		
KAHAOA PUUEO		.96														.02			.03				.25				.36		.27	.03			
KAPAPALA RANCH 36	A	.16																	.14										.01	.01			
KAPOHO BEACH 93.11		3.77	.03		.04	.02	.23	.14	.04			T		.15	.03	.21	.30	.64	.04	.16	.13	.64	.21	T	.07		T		.30	.03	.20	.16	
KAPOHO LANDING 93.5	A	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
KAWAINUI LOWER 193	A	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
KEAAU 92		M 6.27	*	*	.05	.08	.15	.31	.02	*	*	.06	.05	.08	.25	.24	*	*	.67	*	.88	.25	1.26	*	*	*	.98	.15	.68	.11	-	-	
KE-AHOLE PT 68.13		.10																				.08	.02										
KOHALA MISSION 175.1		M 6.65	.03	*	*	.05	*	.05		.30		*	*	.07	.05	*	*	*	*	3.45	.37	*	*	.55	*	*	.50	*	*	.98	.25	-	
KOIAWE LOWER 196	A	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
KONA VILLAGE 93.8		.30																	.30														
KUKAIAU 222		9.46	T	.54	.03	T	.08	.01									.21	1.15	1.30	.64	.38	T	.17	.33	.65	1.28	1.35	.73	.30	.06	.17	.08	
KUKUIHAELE HIC 199		9.33	.11	.10	.13	T	.06	T		.01	.08	.04					.15	.69	.65	.76	.60	.04	.26	.71	.17	1.13	1.18	.36	.27	.62	.81	.40	
KUKUIHAELE MILL 206	A	4.65	.04	.04	.03	T	T	T			.01				.03		.19	.52	.30	.45	.32		.07	.38	.06	.75	.22	.14	.21	.34	.43	.12	
KULANI CAMP 79		6.51	.02			.14	.22	.19		.05	.01			.01	.04	.02	.74	.65	1.33	.87	.22	.74	*	.13	.05	.39	.23	.12	.19	.15			
KULANI MAUKA 76	A	.98											*	*	*	*	*	*	.84	*	*	*	*	*	*	.14	*	*	*		*	*	
KULANI SCHOOL SITE 78	A	7.31	.13	.02	.91	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	5.00	*	*	*	*	1.25	*	*	
LAE APUKI 67.11		2.54		T				.11							.04	.13	.05	.16	.41	.10	.02	.20	.17			.55			.60				

SEE REFERENCE NOTES FOLLOWING STATION INDEX

DAILY PRECIPITATION (INCHES)

STATION		TOTAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
			DAY OF MONTH																														
LALAMILO FLD O 191.1		M .24		*	*	.02		.03	.01	.01	*	*	*	.04	.01			*	*	.01		.06	.01	.01	*	*	.01		.01		.01	-	
LANIHAU 68.2		2.41		.04			.12		.08			.10	.04		.39					.37		.23	.10	.10	.27		.04	.49		.04			
LEILANI ESATES 67.11		7.90	.03	.05	.05	.09	.38	.22	.18	.08	.01	.10	.08	.30	.17	.52	.59	.62	.27	.48	.12	.76	.55	.32	.06	.23	.08		.72	.14	.42	.28	
MAHAILUA	A	.30	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	.30	*	
MAKAHALAU 103	A	3.00												2.00														1.00					
MANUKA 2	A	.03							.01											T										.02			
MAUKA RESERVOIR		M 2.32	-	*	*	*	*	*	*	.19	*	*	*	*	*	*	.47	*	*	*	*	*	*	.94	*	*	*	*	*	*	.72		
MAUNA LOA SLOPE OBS		.01																					.01										
MIDDLE PEN 147.1	A	.00	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
MILOLII 2.34		.54																		.03				.27		.07	.07					.10	
MOANUIAHEA	A	.34	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	.34	*	
NAALEHU 14	A	.75															.03						.20				.13	.01	.38				
NAPOOPOO 28	A	.38	*	*	*	.01	*	*	*	*	*	*	*	.04	*	*	*	*	*	.19	*	*	*	*	*	*	.14	*	*	*	*	*	
OOKALA 223		10.73		.04	.03	.02	.20	.07	.06		.04				.04	.04	.52	1.32	2.00	.70	.60	.03	.65	.62	.10	.97	1.03	.22	.90	.19	.28	.06	
OPIHIHALE 2 24.1		1.40				.01					.02	.03			.13			T		.01	.57	T		.10	.03	.08	.04	.05	T	T	.13	.20	
ORCHID LAND EST 91.5	A	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
PAAUHAU 217		6.59		.09	.01		.20	.02							.04		.16	.75	.98	.87	.41		.03	.57	.07	.61	.70	.16	.39	.08	.40	.05	
PAAUILO 221		7.40		.79	.01		.04	.01									.18	.79	.90	.58	.25	T	.09	.59	.26	1.08	.95	.43	.22	.03	.18	.02	
PAHALA MAUKA		.04																*	*	.02									.02				
PAHOA 65		M 7.69	*	*	.06	.05	.24	.26	.19	*	*	.40	.10	.27	.25	.51	*	*	2.34	.36	.08	.61	.78	*	*	.74	.23	.22	-	-	-	-	
PAPAIKOU 144.1		M10.37	.07	*	*	.28	.28	.34	.01	.16	*	*	.06	.12	.24	*	1.21	*	*	2.95	.39	.41	*	1.44	*	*	1.58	.13	.70	-	-	-	
PIIHONUA CAMP 5 88.4	A	17.07	.97	*	*	.52	*	*	*	*	*	*	1.22	*	*	*	*	*	*	5.35	*	*	*	*	*	*	9.01	*	*	*	*	*	
PUUKOHOLA HEIAU 98.1		.00																															
PUUHONUA-O-HONAUNAU		.95				.03						.02						.03		.27	.40				*	.05	.03	.12					
EA MOUNTAIN 12.15		.08																											.08				
GLENWOOD 91.8		16.91		.15	.15	*	.96	.16	.26	.01		.14	.13	.55	.80	.95	1.36	1.49	.82	.54	.39	1.43	.67	.25	2.60	1.17	.27	.68	.47	.24	.14	.13	
SOUTH KONA 2 2.32		.20															.06							.08		.02	T	.04					
UPOLU POINT USCG 159.2		3.38	.06			.08	.07	.06		.06						.07	.27	.90	.36	.21	.34		.03			.07	.01	.01	.26	.09	.43		
WAIAKEA SCD 88.2		15.41		.30	.04	.40	.39	.57		.05	.03		.05	.08	.36	.06	1.12	1.16	1.84	.88	.51	.33	1.28	.99	.20	1.71	.72	.44	.92	.53	.40	.05	
WAIKOLOA 95.8		M .03																					.03									-	
WAIKOLOA BEACH RSRT 95.9		.00																															

NOAA Precipitation Chart
Big Island
June 1990

DAILY TEMPERATURES (°F)

STATION	OB. TIME	MAX/MIN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	AVERAGE
ISLAND OF MAUI																																		
HALEAKALA R S 338	08	MAX	63	70	59	61	64	60	66	64	62	66	69	71	67	62	67	62	65	65	64	68	64	67	63	59	63	58	59	57	59	64	63	63.6
		MIN	50	45	44	47	49	46	43	52	49	52	55	53	47	49	52	49	50	49	53	49	48	46	51	50	47	44	44	46	46	47	47	48.4
HANA AIRPORT 355	08	MAX	84	84	83	83	82	81	83	80	83	84	81	82	85	85	84	85	84		84	83	80	81	81	82	82	82	82	78	81	82	83	82.5
		MIN	69	72	71	69	68	68	68	68	68	65	64	64	64	65	75	75	75		66	70	71	70	67	67	67	67	67	69	66	66	67	68.3
KAHULUI WSO 398 AP	MID	MAX	88	88	87	86	85	86	87	88	91	88	85	85	89	89	88	93	91	89	86	85	86	86	87	86	86	88	84	86	86	86	86	87.1
		MIN	72	66	70	72	70	71	68	74	71	67	66	65	67	70	74	74	71	67	64	73	71	72	71	72	72	66	66	68	70	66	67	69.5
KAILUA 446	07	MAX	83	83	80	81			83	81	84	82	82			83	83	86	82	82			83	82	81	80	81			80	82	83	82	82.1
		MIN	62	69	66	65			65	69	67	64	63			63	64	69	72	69			68	67	65	64	65			64	64	65	64	65.8
KAPALUA-WEST MAUI AP	08	MAX	86	86	85	85	85	84	84	88	85	88	85	84	83	85	87	84	84	84	85	85	83	83	84	85	83	83	85	82	85	85	84	84.6
		MIN	70	74	73	73	72	72	72	71	73	71	70	69	70	72	74	74	73	71	71	71	71	74	71	72	73	70	71	71	71	70	72	71.7
KULA BRANCH STN 324.5	07	MAX	75	77	76	77	76	76	75	75	72	75	75	74	74	74	75	81	81	72	74	72	75	73	79	74	74	75	75	75	75	75	75	75.2
		MIN	58	57	57	56	57	57	57	61	63	58	58	58	57	58	61	62	61	58	58	58	56	61	58	59	60	59	60	58	58	58	58	58.6
KULA HOSPITAL 267	07	MAX	72	73	76	71	75	71	71	75	73	73	71	72	69	74	82	75	71	73	74	74	74	75	75	73	73	73	72	68	69	72	72	72.9
		MIN	58	57	57	56	56	57	58	58	58	56	55	54	55	56	56	57	60	56	57	57	57	56	56	57	57	57	57	57	58	58	58	56.8
LAHAINA 361	07	MAX	90	88	87	87	87	88	87	86	87	88	85	86	85	85	86	86	87	85	86	88	85	85	86	85	87	85	85	82	85	85	85	86.1
		MIN	72	70	71	69	72	72	69	71	73	71	69	69	70	73	74	73	73	69	70	71	71	71	69	70	70	69	70	71	71	69	70	70.7
MAKENA GOLF COURSE 249	08	MAX	86	88	89	88	88	87	86	86	89	87	85	86	86	86	86	85	86	85	84	85	83	83	83	81	86	86	85	85	84	85	84	85.6
		MIN	70	68	68	67	67	67	66	66	73	69	68	68	67	65	65	74	74	69	67	69	68	68	67	67	69	68	67	68	69	69	67	68.2
PUUKOLII	07	MAX	89	89	86	87	87	86	86	87	87	86	85	86	83	82	82	82	85	83	87	86	88	86	89	86	85	85	86	86	86	84	85	85.7
		MIN	69	69	70	71	70	71	69	70	72	70	67	68	68	70	73	72	72	69	68	68	68	69	68	69	70	67	68	68	69	69	69	69.4
ISLAND OF HAWAII																																		
HAWAII VOLCNS NP HQ 54	08	MAX	77	72	73	72	72	68	75	77	78	76	75		76	78	73	69	76	76	75	75	76	74	69	74	73	72	74	74	72	74	76	74.0
		MIN	55	53	53	54	55	54	56	59	57	51	50		49	54	60	61	55	53	54	53	54	51	54	54	55	53	51	54	54	53	56	54.2
HILO WSO AP 87	MID	MAX	87	86	84	84	82	84	82	84	85	84	83	83	85	89	87	86	86	85	84	84	84	84	83	83	83	84	84	86	82	84	83	84.3
		MIN	70	68	68	66	69	68	70	72	69	66	66	67	64	66	69	72	69	69	66	66	67	70	66	69	68	68	66	69	68	67	69	68.0
KAINALIU 73.2	07	MAX	82	78	81	80			81	82	78	80	80			80	82	81	83	77			81	78	80	80	81			81	80	77	80	80.1
		MIN	65	64	64	63			62	65	67	64	63			62	64	66	67	64			64	63	63	64	62			64	64	69	64	64.2
KE-AHOLE PT 68.13	08	MAX	88	84	87	86	87	87	87	86	87	88	87	85	86	86	86	86	88	87	89	88	88	89	85	86	86	85	86	86	84	81	86	86.4
		MIN	72	70	71	70	71	71	69	73	76	70	69	70	69	69	73	73	75	73	71	72	70	71	71	72	69	70	71	71	71	70	70	71.1
KULANI CAMP 79	07	MAX	69	64		62	62		66	68	68	69					66					68	68	67	64	66	63	62	64	64	67	65	63	M
		MIN	44	49		50	43		49	49	49	46										44	44	50	47	47	47	51	46	46	46	47	51	M
		OBS									59																							
LALAMILO FLD O 191.1	16	MAX	78	75	75	76			76	79	79	79	76			79		82	77	78			78	75	74	75	75			77	78	77	77	77.0
		MIN	53	51	51	51			60	56	55	48	48			46		47	60	52			51	60	59	59	60			51	52	51	62	53.8
MAUNA LOA SLOPE OBS	09	MAX	59	61	63	55	59	61	62	60	55	56	61	57	57	54	55	52	50	55	56	55	57	57	57	55	54	48	47	47	50	50	54	55.5
		MIN	44	43	41	43	45	44	46	46	41	39	41	41	39	39	41	43	39	41	41	38	41	40	43	40	39	35	35	34	44	39	38	40.7
MOUNTAIN VIEW NO 3 91.	07	MAX	80	77	78	76	77	78	74	78	78	80	80	78	78	80	84	79	79	76	78	79	77	78	75	78	76	76	78	78	80	76	79	78.0
		OBS							64																									
		MIN	57	57	60	56	56	56	60	63	63	56	56	56	54	55	60	66	61	60	57	57	57	61	57	57	58	59	58	60	59	57	57	58.3
NAALEHU 14	08	MAX	84	82	81	80	83	83	83	82	82	81	82	82	82	81	82	83	80	80			82	81	79	81	81	82	83	82	82	80	83	81.7
		MIN	72	70	69	65	65	67	65	71	70	68	66	66	67	65	63	70	70	69			66	66	66	66	67	70	69	66	67	68	68	67.5
OOKALA 223	06	MAX	83	83	83	83	83	82	83	80	83	83	83	83	83	83	84	83	83	84	82	84		84	82	82	82	80	82	82	82	80	83	82.6
		MIN	71	72	69	70	69	70	69	72	72	70	69	68	67	68	70	70	71	72	71	67		67	69	70	69	69	70	69	68	69	71	69.6
OPIHIHALE 2 24.1	07	MAX	83	84	80	82	81	78	80	81	82	77	80	80	78	79	83	89	83	78	79	82	79	79	78	80	81	81	80	80	79	79	80	80.5
		MIN	63	65	62	61	63	65	60	64	68	63	62	63	61	58	66	65	68	65	63	65	64	64	62	61	62	61	62	65	62	63	62	63.2
PUUKOHOLA HEIAU 98.1	08	MAX	82	83	85	85	85	85	85	85	82	83	83	84	84	84	84	84	84	83	82	82	82	82	84	85	82	84	84	81	81	81		83.3
		MIN	70	69	69	63	66	66	66	69	69	67	66	66	66	66	70	69	68	66	68	69	67	67	67	70	66	67	68	69	66	67		67.4
SEA MOUNTAIN 12.15	07	MAX	83	84	84	78	83	83	82	84	85	85	82	81	83	83	83	76	81	81	82	84	79	75	83	82	84	80	84	84	83	81	84	82.1
		MIN	72	69	69	66	67	67	70	70	71	68	68	67	68	66	66	72	69	68	66	68	68	68	66	69	67	67	68	68	69	68	69	68.2
		OBS											78																					

SEE REFERENCE NOTES FOLLOWING STATION INDEX

NOAA Temperature Chart
Maui, Big Island
October 1991

Station		Total	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
AMAUULU 89.2	A	3.88	.27	.06	.21		.01	.06	.16	.50	.11			.01				.11	.13				11	.10	.01	58	47	.01	.92		.01		.04
HAINA 214		1.27	T				.08	.05	T	.15								.30						.60			.01	.08					
HAKALAU 142		3.84	.05		.26	•	•	•	.33	.40	.02							.03	.03					.25	.02	.73	•	•	•	1.71	.01		
HALEMAUMAU 52	A	3.66	•	•	•	•	.02	•	•	•	•	•	•	•	.21	•	•	•	•	•	1.51	•	•	•	•	•	•	.05	•	•	•	•	1.87
HALEPOHAKU 111	A	1.24												•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	1.24		
HAWAII VOLCNS NP HQ 54		4.31	.07	T	.10	T	T	.02	T	.42	.08	T	T		T		.18	1.27	.10	.10	T	T	.02	.09	.06	T	.07	.05	.05	.16	1.45	.02	T
HAWI 168	A	4.12		.02	.07	•	•	•	.60	.20	T					T		.20	1.27	.02			T	.17		.16	.07	•	•	1.29	.02		.03
HILO WSO AP 87	R	5.15	.06	.10	.20	.01	.07	.01	.22	.60	T						.10	.14	.10	T	.09	T	.03	.22	T	.66	1.09		.13	.51			.81
HOLUALOA 70	A	1.43	•	•	•	•	•	•	•	•	•	•	1.43	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
HONAUNAU 27		3.06	.01	.03	.02	.15	•	•	.40	T	.18	.01							.12	.45	•	•	.15	.38	.09		T	•	•	1.07		T	
HONOHINA 137		4.58		.02	.32		.14	.24	.22	.08							.03		.01		.06		.13	.18	.01	1.96	.94		.13				.11
HONOKOHAU HARBOR 68.14		2.21	.03								.28								.46					.34				.04	.28	.78			
HONUAULA 71	A	.83	•	•	•	•	•	•	•	•	•	•	.83	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
HUALALAI 72	A	1.20	•	•	•	•	•	•	•	•	•	•	1.20	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
HUEHUE 92.1	A	1.63	•	•	•	•	•	•	•	•	•	•	•	•	•	•	.16	•	.63	.52	•	•	.22	•	•	•	•	•	•	•	•	•	.10
KAAWALOA 29	A	3.21	.15	.01	.21	•	.41	•	•	.71	•	•	•	•	•	•	•	•	•	.55	•	•	.10	.28	•	•	.69	.10	•	•	•	•	•
KAHUKU MILL CAMP 6.3		5.58	.10		.12	.04				.05	.05		.05	.17			.05	1.50	.08			.33		.22	.22			.30	.25	1.70	.35		
KAINALIU 73.2		2.87	.01	.02		.42	•	•	.29		.31	.02						.02	.07	.30				.10	.18		.01	•	•	1.11	.01		
KAMAOA PUUEO		2.78			.06						.17	.04		.04	.03		.14	1.20	.09		.03	.02		.32	.21					.18	.25		
KAOHE MAKAI 24.4		2.68	.08					.37			.02	.08							.58		.08						1.47						
KAPAPALA RANCH 36	A	4.30	.10								.43	.07		.10			.13	.58	.20	.04	.09	.01	.04	.16	.01			.32		1.59	.41	.02	
KAPOHO BEACH 93.11		5.48	.14	.26	.13		.05	.03	.30	.66	.20						.28	.30				.08	T	.38	.09	1.19	.59	.44	.22	T	T		.14
KAPOHO LANDING 93.5	A	6.34	•	•	•	.51	•	•	•	•	•	•	1.74	•	•	•	•	•	•	1.19	•	•	•	•	•	•	2.90	•	•	•	•	•	•
KAHAINUI LOWER 193	A	5.28	•	•	•	•	•	•	•	•	•	•	•	•	•	5.28	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
KEAAU 92		4.04	.13	.03	.15	.01	•	.16	.14	.64	.08							.55	.06		•	•	.03	.13	.11	.43	1.14	•	.03	.01	.16		.05
KE-AHOLE PT 68.13		.23	.21																											.02			
KOHALA MISSION 175.1		1.75	•	.24	•	•	•	•	•	•	.45						•	.23	.26	•	•	•	•	•	.35	.06	.14						.02
KOIAWE LOWER 196	A	5.41	•	•	•	•	•	•	4.20	•	•	•	•	•	•	1.21	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
KONA VILLAGE 93.8		.64															.12	.14										.13	.12	.13			
KUKAIAU 222		1.01	.08		T					.03	T			.02				.06						.32	T	.02	.13	.12		.23			
KUKUIHAELE HIC 199		2.18	T				T	.10	T	.98								.31				.04		.17	.10		.23	.05					.20
KUKUIHAELE MILL 206	A	1.59	.02				.11	.08	.05	.30								.20						.34	.05		.22	.03					.19

SEE REFERENCE NOTES FOLLOWING STATION INDEX

DAILY PRECIPITATION (INCHES)

STATION		TOTAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
KULANI CAMP 79		1.63	.07	.05	•	.04	.01	•	.02	.20	.09		.10	•	•	.02		.22	.12	.02			.02	.05	.10	.02	.02	.17	.10	.12	.07		
KULANI MAUKA 76	A	.27	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	.02	•	•	•	•	•	•	.25	•	•	•
KULANI SCHOOL SITE 78	A	3.06	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	2.24	•	•	•	•	•	•	.82	•	•	•	•
LAE APUKI 67.11		2.44	.01	.01	.05		.02			.59		.10	T				.20	.80	.22							.23				.21			
LALAMILO FLD O 191.1		.64	.02							.27							•	.35															
LANIHAU 68.2		3.35		.19	.03			.02	.26	.02	.32							.05	.03	.52		.12				.15		.08	1.56				
LEILANI ESATES 67.11		7.35	.01	.01	.20	.01	.08	.25	.10	1.39	.29	.01	.01	.01	.01		.52	1.60	.25	.01	.11	.01	.01	.25	.10	.65	1.01	.18	.10	.05	.01	.01	.10
MAHAILUA	A	1.10	•	•	•	•	•	•	•	•	•	•	•	•	•	•	.14	•	.80	.06	•	•	.05	•	•	•	•	•	•	•	•	•	.05
MAKAHALAU 103	A	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MANUKA 2	A	2.03								.05	.73	T		•	•	.01			T		•	•	.07	.12	T		.09	•	•	.96			T
MAUKA RESERVOIR		5.44	•	•	•	.32	•	•	•	•	•	•	.35	•	•	•	•	•	•	1.29	•	•	•	•	•	•	•	•	•	.58	•	•	2.90
MAUNA LOA SLOPE OBS		.17																.12												.05			
MIDDLE PEN 147.1	A	.00																															
MILOLII 2.34		4.21				.04	.60	.02			.06			.02			.02		2.14			.04		.14					.30	.33		.20	.30
MOANUIAHEA	A	.98	•	•	•	•	•	•	•	•	•	•	•	•	•	•	.23	•	.40	.03	•	•	.03	•	•	•	•	•	•	•	•	•	.29
MOUNTAIN VIEW NO 3 91.9		8.68	.50	.01	.33	.03	.02	.05	.01	1.05	.45	.01		T	•	•	•	.58	.34	.17	T	.21	.01	.22	.09	.13	.83	.15	.02	.24	3.22	.01	T
NAALEHU 14	A	3.87				.01					.98			.05			.02	2.08	.11	.02	•	•	.09	.42				.05		.02	.02		
NAPOOPOO 28	A	1.91	•	•	•	•	•	•	.29	•	•	•	•	•	•	.59	•	•	•	•	•	•	.62	•	•	•	•	•	•	.41	•	•	•
OOKALA 223		2.50	.11	.02	.07	.01		.13	.02	.02	.02							T				.03		.25	.03	.12	1.02	.11		.53	.01	T	
OPIHIHALE 2 24.1		4.41				.12	.10	.44	.02		.12	.23	.05					.02	2.30	.02				.35	T	T	T	.27	.32	.03		.02	T
ORCHID LAND EST 91.5	A	5.34	•	•	•	.73	•	•	•	•	•	•	1.95	•	•	•	•	•	•	1.13	•	•	•	•	•	•	1.53	•	•	•	•	•	•
PAAUHAU 217		1.17					.01	.02	.02	.03								.33						.48		.06	.05	.15					.02
PAAUILO 221		.96	.04							.03								.08						.38			.15	.17		.11			
PAHALA MAUKA		4.62	.05			.08				.03	.98	.05	T	.11			.07	.80	.36	.04	•	•	.12	.50				.03		1.30	.04	.06	T
PAHOA 65		5.90	.05	•	.48	•	•	•	.48	1.18	•	•	•	•	•	.15	•	1.32		•	•	.24	•	.30	•	.95	•	•	.57	.05	.03		.10
PAPAIKOU 144.1		5.20	.53	.01	1.13	.03	•	•	.35	.43	.24							.01	.07		•	•	.02	.38	•	.52	.96	•	•	.40	.11	•	.01
PIIHONUA CAMP 5 88.4	A	4.77	•	•	•	•	•	•	.98	•	•	•	•	•	•	.98	•	•	•	•	•	•	•	•	•	•	1.73	•	•	1.08	•	•	•
PUUKOHOLA HEIAU 98.1		.36									.04			T				.10	.22														
PUUHONUA-O-HONAUNAU		3.42			.05	.04		.87			.61	.01							.01	.33			.01	.17				1.30	.02				
SEA MOUNTAIN 12.15		3.15								.06	.53	.02	.01	.02	.01		.08	2.02	.23	.02	.01			.12					.01		.01		
S GLENWOOD 91.8		6.48	.04	.34		.11	.03	•	.75	.33		.02				.03	1.63	.45	.03		.05		.30	.08	.12	.53	.12		.34	1.18			
SOUTH KONA 2 2.32		1.89	.03			.02						.23		.02			.09	.60	T					T	.09		02	.17	.48	.14			
UPOLU POINT USCG 159.2		1.74	.02		.12		.17	.08	.05	.30									.43			.01	T	.02		.03	.06			.44			.01
WAIAKEA SCD 88.2		7.10	.63	.01	.25			.07	.08	.90	.46							.18	.35	.09		60		43	.10	.04	1 80	02	.11	67	.31		
WAIKOLOA 95 B		[illegible]									[illegible]																						

NOAA Precipitation Chart
Big Island
October 1991

APPENDIX B - Ancillary Field Data

1) Sample Field Data Sheet
2) GPS Sites Data Sheets
3) Sample Cane Field Map and Cane Planting Data
4) Hamakua Test Site Area
5) Gorse in Pastures / Ohia-Koa Forest; Bands 4-5-3
6) Gorse-ohia Classes over Raw Data
7) Fountain Grass and Grazing Areas
8) Kilauea Caldera, Volcanoes National Park
9) Island of Hawaii 7.5 Minute Quad Index
10) Soils Series Data from NRCS

FIELD DATA VERIFICATION FORM - ISLAND OF HAWAII

LANDSAT TM VEGETATION MAP
STATE OF HAWAII-NASA HEADQUARTERS

LANDSAT TM SCENES:

HAWNW 63/46 JUNE1, 1990 HAWNE 62/46 OCTOBER 11,1991
SOUTH POINT 63/47 JUNE14, 1989 KALAPANA 62/46 OCTOBER 11,1991

SITE NUMBER ON MAP: ________ DATE: ________

ROAD MILE MARKER/TURNOFF: ________________

QUAD NUMBER: ________ QUAD NAME: ________________

GPS NUMBER: ________ GPS COORDINATES: ________ N ________ W

ELEVATION: ________ SLOPE/DIRECTION: ________________

LANDCOVER CLASS: ________________

ECOZONE DATA:

COASTAL - DRY/MESIC/WET LOWLAND - DRY/MESIC/WET

LOWLAND TO MONTANE - DRY/MESIC/WET MONTANE - DRY/MESIC/WET

SUBALPINE - DRY/MESIC/WET ALPINE - DRY/MESIC/WET

DOMINANT OR CO-DOMINANT GROUNDCOVER: ________________

____

MID-STORY GROUNDCOVER: ________________

UNDERSTORY GROUNDCOVER: ________________

GROUND COVER ON SOIL OR LAVA:

TOPOGRAPHY:
SOIL: TYPE/DEPTH LAVA FLOW: DATE/TYPE/NEW/WEATHERED/BROKEN/CRACKS/ROCKS

____

____

NOTES/SKETCH/PHOTOGRAPH ROLL-FRAMES:

Sample Field Data Sheet

Main text

sort ↓

GPS Site#	Land Cover	Land Use	GPS ID	Class
45	A'a Dense Lichen		4212400A	E
6	A'a Lava		4080223A	E
17	Ash-Banana Poka		4080321B	I
5	Barren		4080222B	C
37	Beach		4080500A	W
38	Buffelgrass-Kiawe		4080500B	U
50	Cinder-Barren		4121423A	C
55	Coastal Shrub-Grass-Lava		5031900A	
23	Dry Koa-Banana Poka		4080400A	L
54	Eucalyptus-Plantation	Forest Plantati	4121523A	M
31	Gorse-Grassland	Range	4080402C	aa
30	Gorse-Grassland	Range	4080402B	aa
53	Grass-Cactus-Shrub	Rangeland	4121521A	P
52	Grass-MaunaLani		4121520A	P
7	Grass-Shrub Mamane-Naio		4080300A	S
29	Grassland	Range	4080402A	P
41	Grassland-Fountain Grass		4080502A	N
40	Grassland-Fountain Grass		4080501B	N
39	Grassland-Fountain Grass		4080501A	N
49	Grassland-Gorse-Lava		4121421B	
32	Grassland-Mullein	Range	4080403A	P
33	Grassland-Range	Rangeland	4080421A	P
22	Grassland-Range	Rangeland	4080323B	P
11	Grassland-Range	Rangeland	4080319A	P
34	Kiawe		4080422A	U
36	Kiawe		4080423A	U
35	Kiawe		4080422B	U
14	Koa		4080320B	L
27	Koa Community-Grassland	Rangeland	4080400F	P
26	Koa Community-Grassland	Rangeland	4080400E	P
18	Koa-Banana Poka		4080322A	I
19	Koa-Banana Poka		4080322B	I
20	Koa-Fern with Banana Poka		4080322C	I
12	Koa-Ohia		4080319B	B
54	Lasuanna-Ohia-Fern-Lava		5031823A	
21	Macnut-Apple Orchard	Orchard	4080323A	V
9	Mamane-Mix Grass Shrub	Forest Reserve	4080300C	T
8	Mamane-Mix Grass-Shrub	Forest Reserve	4080300B	T
10	Mamane-Soil-A'a Lava	Forest Reserve	4080301A	T
62	Mix Shrub-Grass-Pahoehoe		5032002A	
61	Mixed Grass-Shrubland		5032001B	
63	Mixed Shrubs-Grass		5032003A	
58	Molasses-B.Beard-Broomsed		5031923A	
47	Ohia-A'a Lava		4121420A	H
2	Ohia-Dense		4080220B	J
56	Ohia-Guava-Melastome-Fern		5031901A	
13	Ohia-Koa		4080320A	F
15	Ohia-Koa		4080320C	F
43	Ohia-Lava		4121323B	H
3	Ohia-Lava		4080221B	F
1	Ohia-Lava		4080220A	H
60	Ohia-Maman-Shrub-P Lava		5032001A	
53	Ohia-Olapa-Treefern-Lava		5031920A	
42	Ohia-Uluhe Fern		4121323A	J

GPS Sites Data Sheet
Sorted by Land Cover
Page 1 of 2

GPS Site#	Land Cover	Land Use	GPS ID	Class
44	Ohia-Uluhe-Tree Fern		4121323C	J
4	Pahoehoe Lava		4080222A	D
46	Pine Forest-Grass-Fern	Plantation	4121401A	M
59	Pukiawe-A'alii-Ulei-Lava		5032000A	
48	Shrub-Grassland		4121421A	S
51	Subalp Pukiawe-Ohelo-Aali		4080500A	T
28	Sugi Forest Plantation	Plantation	4080401A	M
16	Tropical Ash Plantation	Plantation	4080321A	M

Sort ↓ – Appendix

GPS Site#	Land Cover	Land Use	GPS ID#	Class
1	Ohia-Lava		4080220A	H
2	Ohia-Dense		4080220B	J
3	Ohia-Lava		4080221B	F
4	Pahoehoe Lava		4080222A	D
5	Barren		4080222B	C
6	A'a Lava		4080223A	E
7	Grass-Shrub Mamane-Naio		4080300A	S
8	Mamane-Mix Grass-Shrub	Forest Reserve	4080300B	T
9	Mamane-Mix Grass Shrub	Forest Reserve	4080300C	T
10	Mamane-Soil-A'a Lava	Forest Reserve	4080301A	T
11	Grassland-Range	Rangeland	4080319A	P
12	Koa-Ohia		4080319B	B
13	Ohia-Koa		4080320A	F
14	Koa		4080320B	L
15	Ohia-Koa		4080320C	F
16	Tropical Ash Plantation	Plantation	4080321A	M
17	Ash-Banana Poka		4080321B	I
18	Koa-Banana Poka		4080322A	I
19	Koa-Banana Poka		4080322B	I
20	Koa-Fern with Banana Poka		4080322C	I
21	Macnut-Apple Orchard	Orchard	4080323A	V
22	Grassland-Range	Rangeland	4080323B	P
23	Dry Koa-Banana Poka		4080400A	L
26	Koa Community-Grassland	Rangeland	4080400E	P
27	Koa Community-Grassland	Rangeland	4080400F	P
28	Sugi Forest Plantation	Plantation	4080401A	M
29	Grassland	Range	4080402A	P
30	Gorse-Grassland	Range	4080402B	aa
31	Gorse-Grassland	Range	4080402C	aa
32	Grassland-Mullein	Range	4080403A	P
33	Grassland-Range	Rangeland	4080421A	P
34	Kiawe		4080422A	U
35	Kiawe		4080422B	U
36	Kiawe		4080423A	U
37	Beach		4080500A	W
51	Subalp Pukiawe-Ohelo-Aali		4080500A	T
38	Buffelgrass-Kiawe		4080500B	U
39	Grassland-Fountain Grass		4080501A	N
40	Grassland-Fountain Grass		4080501B	N
41	Grassland-Fountain Grass		4080502A	N
42	Ohia-Uluhe Fern		4121323A	J
43	Ohia-Lava		4121323B	H
44	Ohia-Uluhe-Tree Fern		4121323C	J
46	Pine Forest-Grass-Fern	Plantation	4121401A	M
47	Ohia-A'a Lava		4121420A	H
48	Shrub-Grassland		4121421A	S
49	Grassland-Gorse-Lava		4121421B	
50	Cinder-Barren		4121423A	C
52	Grass-MaunaLani		4121520A	P
53	Grass-Cactus-Shrub	Rangeland	4121521A	P
54	Eucalyptus-Plantation	Forest Plantati	4121523A	M
45	A'a Dense Lichen		4212400A	E
54	Lasuanna-Ohia-Fern-Lava		5031823A	
55	Coastal Shrub-Grass-Lava		5031900A	

GPS Sites Data Sheet
Sorted by GPS ID#
Page 1 of 2

GPS Site#	Land Cover	Land Use	GPS ID	Class
56	Ohia-Guava-Melastome-Fern		5031901A	
53	Ohia-Olapa-Treefern-Lava		5031920A	
58	Molasses-B.Beard-Broomsed		5031923A	
59	Pukiawe-A'alii-Ulei-Lava		5032000A	
60	Ohia-Maman-Shrub-P Lava		5032001A	
61	Mixed Grass-Shrubland		5032001B	
62	Mix Shrub-Grass-Pahoehoe		5032002A	
63	Mixed Shrubs-Grass		5032003A	

Main text

Sort ↓

Non GPS Site#	Land Cover
18	Abandonned Sugar Cane
19	Abandonned Sugar Cane
13	Active Lava Flow
16	Barren
1	Barren - Cinder - Ice
12	Coastal Strand
17	Gorse - Grass - Koa
6	Hala (Pandanus) - Grass
7	Loulu - Ohia - Hapu'u
9	Lowland Gulch Forest
8	Lowland Gulch Forest
15	Lowland Koa
14	Mamane - Naio - Grass
2	Mixed Grass - Mullein
5	Molasses - B. Bunch Gras
20	Monkey Pod - Mixed Grass
3	Myrica faya - Ohia
4	Ohia - Hapu'u Tree Fern

Non-GPS Sites Data Sheet
Sorted by Land Cover
Page 1 of 1

Sample Cane Field Map
Hamakua, Big Island

Appendix B #3

Field	1990 Plant	Ratoon
54332	85.70	
54390	85.00	
1991		
10120		74.55
10130		119.60
10171-10172	15.10	
10180	83.20	
10180-10183	3.50	
10181-1	97.90	
10190-10197	13.56	
10230	19.54	
10230-10231	94.88	
10241	23.00	
10251	29.10	
10252	37.91	
10260	90.90	
10270	55.30	
10282	43.30	
10282-10289		37.50
10291	74.11	
10370	138.10	
10380-10383		7.00 SR
11020	95.66	
11060	96.89	
11061	29.30	
11151	92.60	
11160	116.70	
11161	63.73	
11171	52.94	
11180	[illegible]	74.60
11181	62.80	
11182	59.50	
11190		144.80
11191	44.00	
11360	39.60	
11380		105.24
11390	151.10	
11470	165.50	
20020	46.00	
20030	67.34	
20040	81.52	
20070	173.84	

1991

Field	Plant	Replant
20130	62.12	
20130-20131	19.21	
20210	32.39	
20220	100.82	
20230	40.32	
20240	32.37	
20250	79.77	
20270-20272	67.49	
20280	124.38	
20300	42.77	
20311	12.40	
20310	41.44	
20320-20321	22.87	
20330-20331	63.78	
20340	59.07	
20360		44.22
20430	92.27	
20500	127.28	
20510	49.47	
20520	71.51	
20530	72.60	
21130	9.43	
21200		37.57
21270-1271	22.03	
24200	25.60	
24220	19.30	
24230		9.04 SR
43011-43013		36.80 SR
43140	3.86	
43140-43143	9.41	
43140-43145	34.87	
43170-43171	49.89	
43170-43172	33.57	
43170-43173		21.81 SR
43180	37.76	
43181-43182		23.44 SR
43210-43211	228.30	
51010-51012		72.95
51070		
51100		
51180		
51180-51184		
51190-[illegible]		

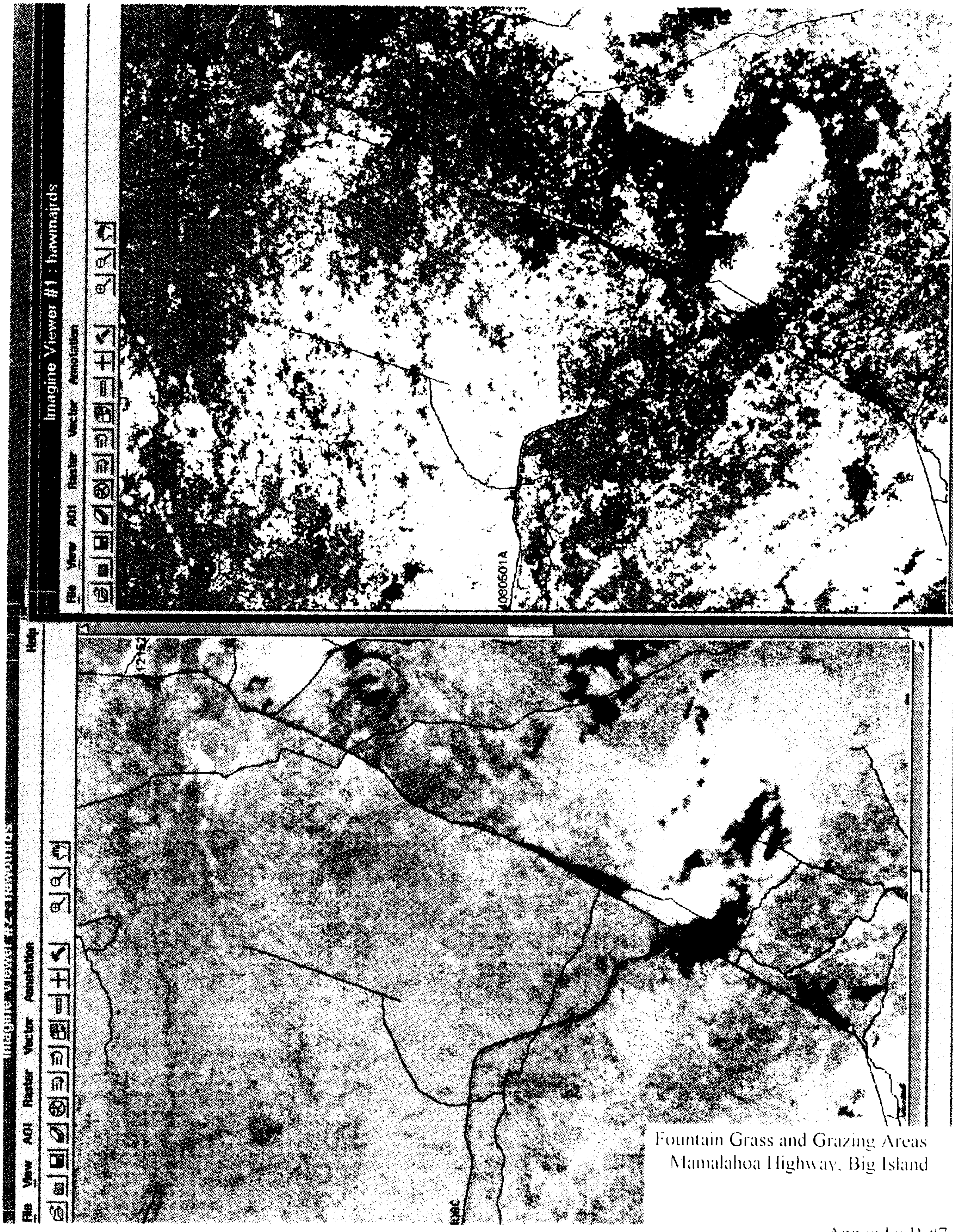
Sample Cane Planting Data
Hamakua, Big Island
By field as shown on map

Appendix B #3

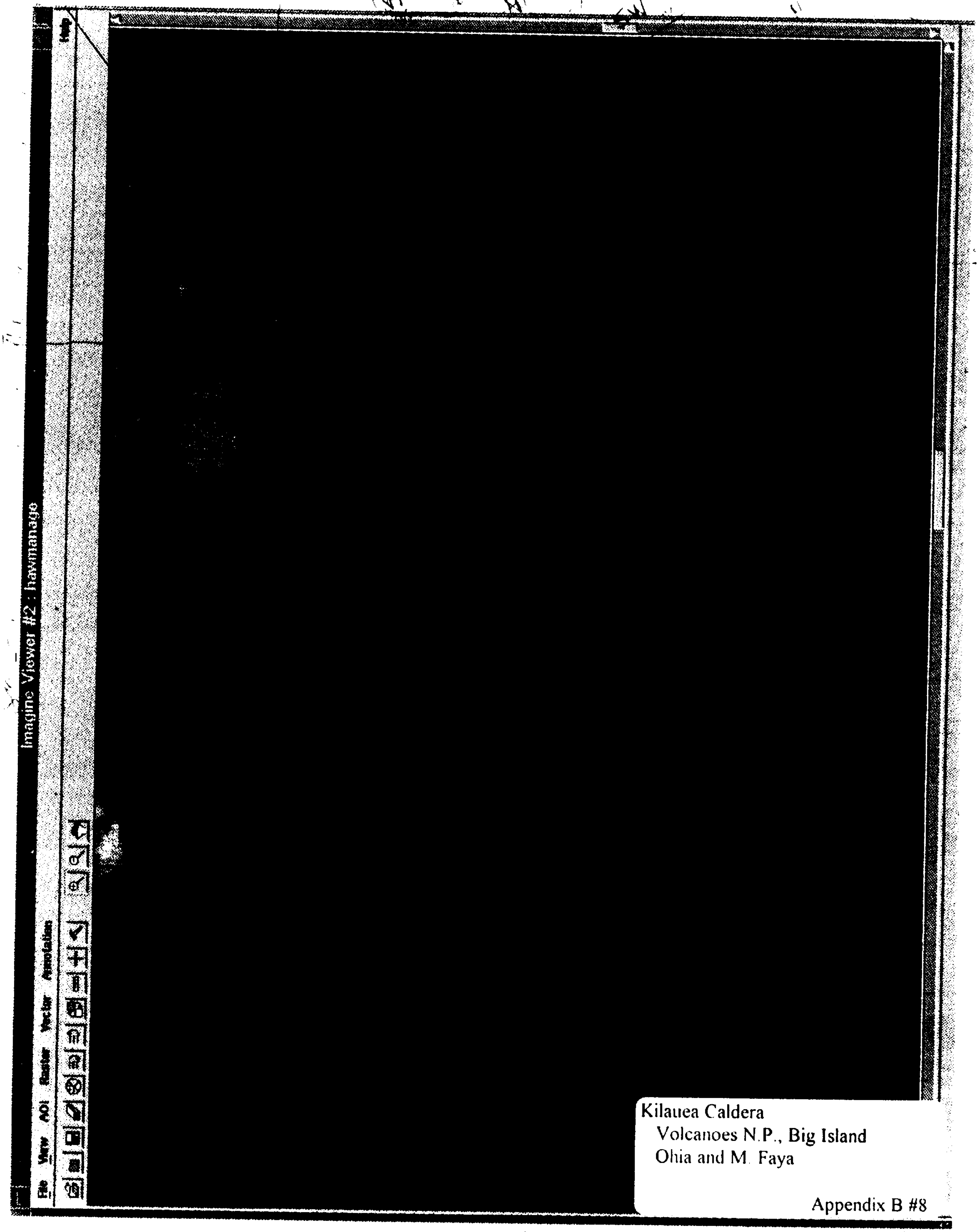
Hamakua Test Site Area
Hamakua, Big Island
Showing cane fields, tropic soils

Gorse in Pastures
Mauna Kea, Big Island
Bands 4-5-3

Gorse-Ohia Classes Over Raw Data
Mauna Kea, Big Island



Fountain Grass and Grazing Areas
Mamalahoa Highway, Big Island

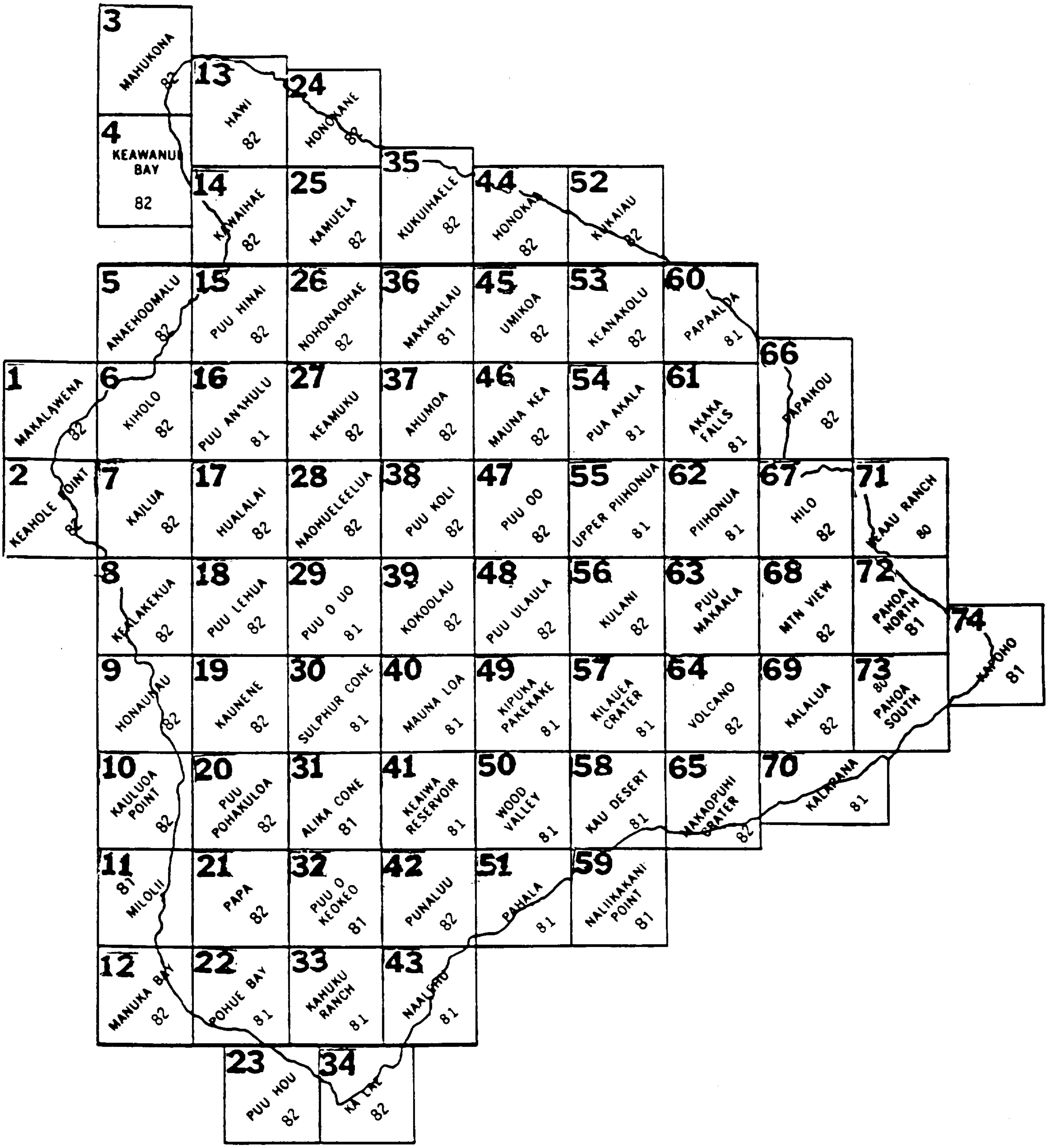


Kilauea Caldera
Volcanoes N.P., Big Island
Ohia and M. Faya

Appendix B #8

Volcano House, Kilauea Volocano: Bands 4, 2 and 1 (r, g, b); 1 m/px

HAWAII TOPOGRAHIC MAP INDEX



Island of Hawaii
7.5 Minute Quad Index

Appendix B #9

United States Department of Agriculture

Natural Resources Conservation Service

P. O. Box 636
Kealakekua, HI
96750-0636
Phone (808) 322-2482
Fax (808) 322-3735

General Soils Map -- Island of Hawaii

Soil Series / Map Units

Draft 6 -- 5/95

file: Gen-map-06

Robert Gavenda, Soil Survey Project Leader

Note:
1) The proposed classifications presented here are best estimates and are based on limited (often extrapolated) lab data. The classification presented here assumes that Hydrudands will key out before Melanudands, and Folist great groups will be based on moisture regimes.
2) All new series and changes in classification in established series are in italics.

Map Units

1 - Lava flows, a'a and pahoehoe undifferentiated
Published series/miscellaneous land types:
- Lava flows, a'a
- Lava flows, pahoehoe
- Rock land

Proposed series/miscellaneous land types:
- Lava flows, a'a
- Lava flows, pahoehoe
- Cinder land
- *Typic Ustifolists*
- *Lithic Ustifolists*
- *Typic Udifolists*
- *Lithic Udifolists*

2 - Lava flows - Cinder land
Published series/miscellaneous land types:
- Lava flows, a'a
- Lava flows, pahoehoe
- Cinder land

Proposed series/miscellaneous land types:
- Lava flows, a'a
- Lava flows, pahoehoe
- Cinder land
- *Nenenui: pumiceous, isomesic Lithic Ustorthents*
- *?????: euic, isomesic Typic Ustifolists*
- *?????: euic, isomesic Lithic Ustifolists*

3 - Lava flows - Haplustolls - Torriorthents (aridic, hyperthermic)

Palapalai: medial, isothermic *Humic Haplustands*

11 - Fulvudands (udic, isothermic)
Published series/miscellaneous land types:
Niulii: thixotropic, isothermic Hydric Dystrandepts
Proposed series/miscellaneous land types:
Niulii: *hydrous*, isothermic Hydric *Fulvudands*

12 - Andaquepts - Endoaquands (udic, isothermic)
Published series/miscellaneous land types:
Kehena: thixotropic, acid, isothermic Aeric Andaquepts
Amalu: fine, mixed, acid, isomesic Histic Placaquepts
Tropaquepts
Rough broken land
Proposed series/miscellaneous land types:
Kehena: *hydrous*, acid, isothermic Aeric Andaquepts
?????: hydrous, isothermic Histic Endoaquands

13 - Hydrudands - Placudands - Placaquepts (perudic, isomesic)
Published series/miscellaneous land types:
Manahaa: thixotropic, isomesic Hydric Dystrandepts
Kahua: thixotropic, isomesic Typic Placandepts
Maile: thixotropic, isomesic Hydric Dystrandepts
Amalu: fine, mixed, acid, isomesic Histic Placaquepts
Proposed series/miscellaneous land types:
Kahua: *hydrous*, isomesic *Hydric Placudands*
Maile: *hydrous*, isomesic *Typic Hydrudands*
Amalu: fine, mixed, acid, isomesic Histic Placaquepts

14 - Haplustolls (aridic, thermic)
Published series/miscellaneous land types:
Puu Pa: medial-skeletal, isothermic Ustollic Eutrandepts
Kamakoa: ashy over loamy isothermic Mollic Ustifluvents
Proposed series/miscellaneous land types: Andic
Puuhinai: medial-skeletal, thermic ~~Torrertic~~ Haplustolls
?????: medial, thermic ~~Torrertic~~ Haplustolls Andic
Kamakoa: ashy over loamy, *thermic* Mollic Ustifluvents
Popoo: medial-skeletal, thermic Typic Haplustolls
Lahuipuaa: sandy-skeletal, thermic Typic Torriorthents

15 - Haplustands (ustic, isothermic)
Published series/miscellaneous land types:
Puu Pa: medial-skeletal, isothermic Ustollic Eutrandepts
Waikaloa: ashy, isothermic Ustollic Eutrandepts
Waimea: medial, isothermic Typic Eutrandepts
Kikoni: medial, isothermic Typic Eutrandepts
Kilohana: ashy, isomesic Typic Ustipsamments
Proposed series/miscellaneous land types:
Waikaloa: *medial*, isothermic *Typic Haplustands*
Waawaa: medial, isothermic Typic Haplustands
Waimea: medial, isothermic Typic *Haplustands*
Kikoni: medial, isothermic Typic *Haplustands*

16 - Ustifolists - Haplustands - Ustorthents (ustic, isothermic)
Published series/miscellaneous land types:
Lava flows, a'a
Lava flows, pahoehoe
Very stony land
Rock land

Hanipoe: medial, isomesic *Thaptic Haplustands*
Laumaia: medial, isomesic *Humic Haplustands*
Cinder land
Lava flows, a'a

21 - Fulvudands (udic, isomesic)
Established series/miscellaneous land types:
Umikoa: medial, isomesic Entic Dystrandepts
Hanipoe: medial, isomesic Typic Dystrandepts
Puu Oo: thixotropic, isomesic Hydric Dystrandepts
Puukala: thixotropic-skeletal, isomesic Hydric Lithic Dystrandepts
Proposed series/miscellaneous land types:
Umikoa: medial, isomesic *Hydric Fulvudands*
Hanipoe: medial, isomesic *Hydric Fulvudands*
Puu Oo: *hydrous*, isomesic Hydric *Fulvudands*
?????: hydrous-skeletal, isomesic Hydric Lithic Fulvudands

22 - Hydrudands (perudic, isomesic)
Established series/miscellaneous land types:
Piihonua: thixotropic, isomesic Typic Hydrandepts
Akaka: thixotropic, isomesic Typic Hydrandepts
Proposed series/miscellaneous land types:
Piihonua: *hydrous*, isomesic Typic *Hydrudands*
?????: dysic, isomesic Typic Troposaprists
Piha: ?????

23 - Hydrudands (perudic, isothermic)
Established series/miscellaneous land types:
Kaiwiki: thixotropic, isothermic Typic Hydrandepts
Akaka: thixotropic, isomesic Typic Hydrandepts
Keei: euic, isothermic Lithic Tropofolists
Proposed series/miscellaneous land types:
Kaiwiki: *hydrous*, isothermic *Acrudoxic Hydrudands*
Akaka: *hydrous, isothermic Acrudoxic Hydrudands*
?????: dysic, isothermic Typic Troposaprists

24 - Hydrudands (perudic, isohyperthermic)
Established series/miscellaneous land types:
Hilo: thixotropic, isohyperthermic Typic Hydrandepts
Proposed series/miscellaneous land types:
Hilo: *hydrous*, isohyperthermic *Acrudoxic Hydrudands*

25 - Lava flows - Ustifolists - Ustorthents (ustic, isothermic)
Established series/miscellaneous land types:
Lava flows, a'a
Lava flows, pahoehoe
Cinder land
Kekake: dysic, isomesic Lithic Tropofolists
Mawae: euic, isomesic Typic Tropofolists
Kilauea: ashy-skeletal, isothermic Typic Ustorthents
Kona: euic, isothermic Lithic Tropofolists
Proposed series/miscellaneous land types:
Lava flows, a'a
Lava flows, pahoehoe
Cinder land
Kilauea: ashy-skeletal, isothermic Typic Ustorthents
?????: euic, isothermic Lithic Ustifolists

26 - Lava flows - Udifolists (udic, isomesic)
Established series/miscellaneous land types:

Olaa: thixotropic over fragmental, isohyperthermic Typic Hydrandepts
Panaewa: thixotropic-skeletal, isohyperthermic Lithic Hydrandepts

Proposed series/miscellaneous land types:

Lava flows, a'a
Lava flows, pahoehoe
Papai: euic, isohyperthermic Typic *Udifolists*
Keaukaha: euic, isohyperthermic Lithic *Udifolists*
Opihikao: euic, isohyperthermic Lithic *Udifolists*
Malama: euic, isohyperthermic Typic *Udifolists*
Olaa: *hydrous-skeletal*, isohyperthermic Typic *Hydrudands*
Panaewa: *hydrous*-skeletal, isohyperthermic Lithic *Hydrudands*

30 - Perudifolists - Lava flows (perudic, isothermic)

Established series/miscellaneous land types:

Lava flows, a'a
Lava flows, pahoehoe
Keei: euic, isothermic Lithic Tropofolists
Kiloa: euic, isothermic Typic Tropofolists

Proposed series/miscellaneous land types:

Lava flows, a'a
Lava flows, pahoehoe
?????: dysic, isothermic Lithic Perudifolists
?????: dysic, isothermic Typic Perudifolists

31 - Perudifolists - Hydrudands - Lava flows (perudic, isomesic)

Established series/miscellaneous land types:

Lava flows, a'a
Lava flows, pahoehoe
Keei: euic, isothermic Lithic Tropofolists
Kiloa: euic, isothermic Typic Tropofolists
Lalaau: euic, isomesic Typic Tropofolists
Kahaluu: euic, isomesic Lithic Tropofolists
Puukala: thixotropic-skeletal, isomesic Hydric Lithic Dystrandepts
Piihonua: thixotropic, isomesic Typic Hydrandepts

Proposed series/miscellaneous land types:

Lava flows, a'a
Lava flows, pahoehoe
Kahaluu: *dysic*, isomesic Lithic *Perudifolists*
Lalaau: *dysic*, isomesic Typic *Perudifolists*
?????: hydrous-skeletal, isomesic Lithic Hydrudands
Piihonua: *hydrous*, isomesic Typic *Hydrudands*

32 - Ustorthents - Haplustands - Lava flows (ustic, isothermic)

Established series/miscellaneous land types:

Lava flows, a'a
Lava flows, pahoehoe
Kilauea: ashy-skeletal, isothermic Typic Ustorthents
Heake: medial, isothermic Lithic Dystrandepts

Proposed series/miscellaneous land types:

Lava flows, a'a
Lava flows, pahoehoe
Kilauea: ashy-skeletal, isothermic Typic Ustorthents
Heake: medial, isothermic Lithic *Haplustands*

33 - Ustifolists - Haplustands - Lava flows (ustic, isomesic)

Established series/miscellaneous land types:

Lava flows, a'a
Lava flows, pahoehoe
Hanipoe: medial, isomesic Typic Dystrandepts
Kekake: euic, isomesic Lithic Tropofolists

Naalehu: medial, isohyperthermic *Humic Haplustands*

38 - Haplustands (ustic, isothermic)
Established series/miscellaneous land types:
Kamaoa: medial, isothermic Typic Eutrandepts
Proposed series/miscellaneous land types:
Kamaoa: medial, isothermic Typic *Haplustands*
Keaa: medial-skeletal, isothermic Lithic Haplustands

39 - Haplustands (ustic, isohyperthermic)
Established series/miscellaneous land types:
Pakini: medial, isohyperthermic Entic Eutrandepts
Kaalualu: medial-skeletal, isohyperthermic Ustollic Eutrandepts
Naalehu: medial, isohyperthermic Typic Eutrandepts
Proposed series/miscellaneous land types:
Pakini: medial, isohyperthermic *Typic Haplustands*
Kaalualu: medial-skeletal, isohyperthermic *Humic Haplustands*
Naalehu: medial, isohyperthermic Typic *Haplustands*

40 - Lava flows - Ustifolists (ustic, isohyperthermic)
Established series/miscellaneous land types:
Lava flows, a'a
Lava flows, pahoehoe
Punaluu: euic, isohyperthermic Lithic Tropofolists
Kaimu: euic, isohyperthermic Typic Tropofolists
Kainaliu: medial-skeletal, isohyperthermic Typic Eutrandepts
Proposed series/miscellaneous land types:
Lava flows, a'a
Lava flows, pahoehoe
Punaluu: euic, isohyperthermic Lithic *Ustifolists*
Kaimu: euic, isohyperthermic Typic *Ustifolists*
Kainaliu: medial-skeletal, isohyperthermic Typic *Haplustands*

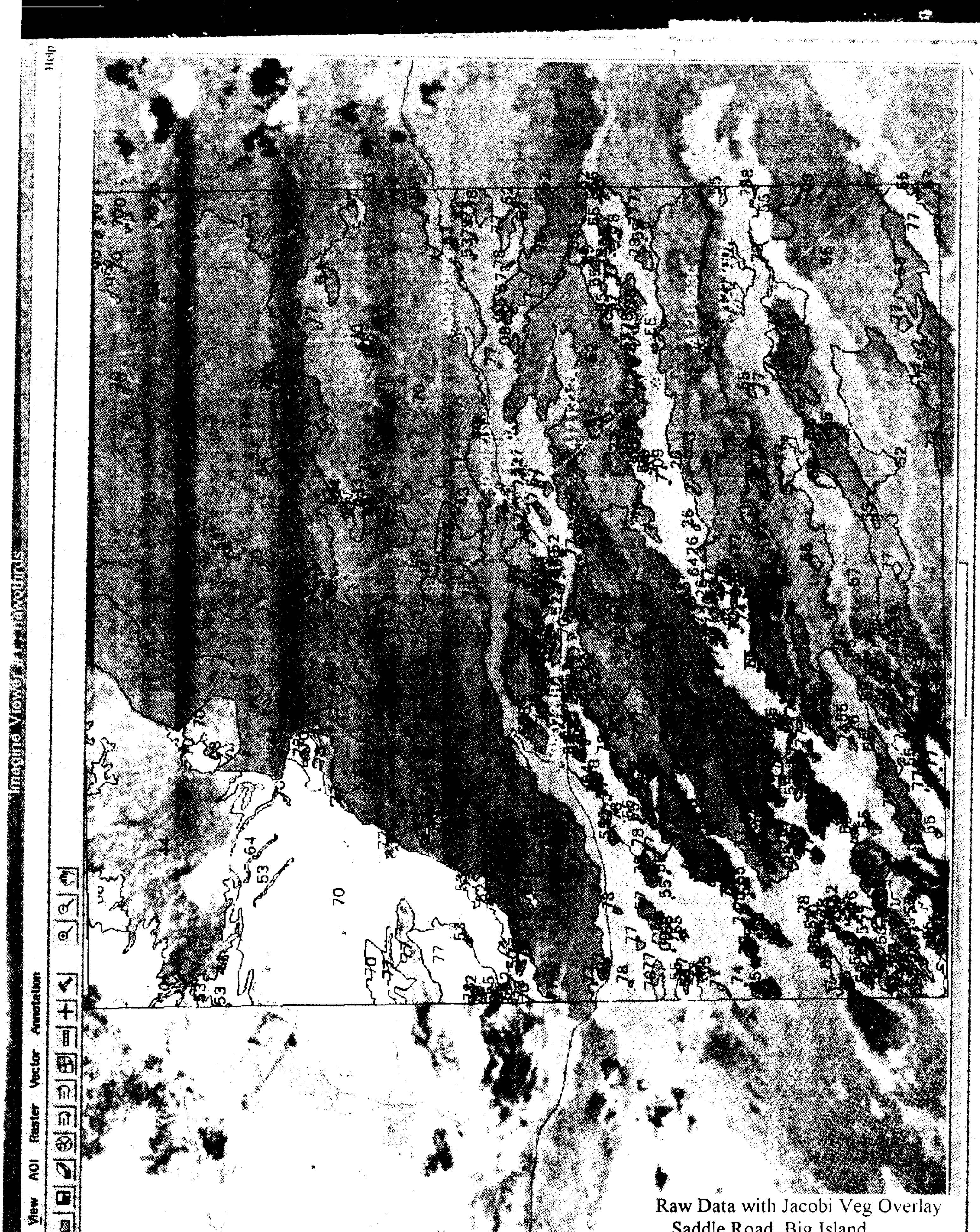
41 - Ustifolists - Haplustands - Lava flows (ustic, isohyperthermic)
Established series/miscellaneous land types:
Lava flows, a'a
Lava flows, pahoehoe
Punaluu: euic, isohyperthermic Lithic Tropofolists
Kaimu: euic, isohyperthermic Typic Tropofolists
Kainaliu: medial-skeletal, isohyperthermic Typic Eutrandepts
Waiaha: medial-skeletal, isohyperthermic Lithic Eutrandepts
Proposed series/miscellaneous land types:
Lava flows, a'a
Lava flows, pahoehoe
Punaluu: euic, isohyperthermic Lithic *Ustifolists*
Kaimu: euic, isohyperthermic Typic *Ustifolists*
Kainaliu: medial-skeletal, isohyperthermic Typic *Haplustands*
Waiaha: medial-skeletal, isohyperthermic Lithic *Haplustands*

42 - Ustifolists - Lava flows (ustic, isothermic)
Established series/miscellaneous land types:
Lava flows, a'a
Lava flows, pahoehoe
Puna: euic, isothermic Typic Tropofolists
Kona: euic, isothermic Lithic Tropofolists
Proposed series/miscellaneous land types:
Lava flows, a'a
Lava flows, pahoehoe
Kapua: euic, isothermic Typic *Ustifolists*

Hokukano: hydrous, isomesic Lithic Haplustands
Kealoha: medial-skeletal, isomesic Typic Haplustands
Hapuu: loamy-skeletal, isomesic Ustic Humitropepts
Nenenui: pumiceous, isomesic Lithic Ustorthents
Ohianui: pumiceous, isomesic Lithic Ustorthents

APPENDIX C - Classification System

1) Raw Data with Jacobiveg Level II Overlay
2) Sample Class Name List and Map
3) Hilo Urban Areas with Roads
4) Signature File and Legend
5) Island of Hawaii - Landsat TM Subtropical Hierarchical Classification System



Raw Data with Jacobi Veg Overlay
Saddle Road, Big Island
Bands 7-5-3, Jacobi Level II
GPS sites in yellow text

Appendix C #1

Sample Class Name List and Map
Mauna Kea, Big Island

Appendix C #2

Raster Attribute Editor -- hawnw_nwneswse2.img(:Layer_1)

File Edit

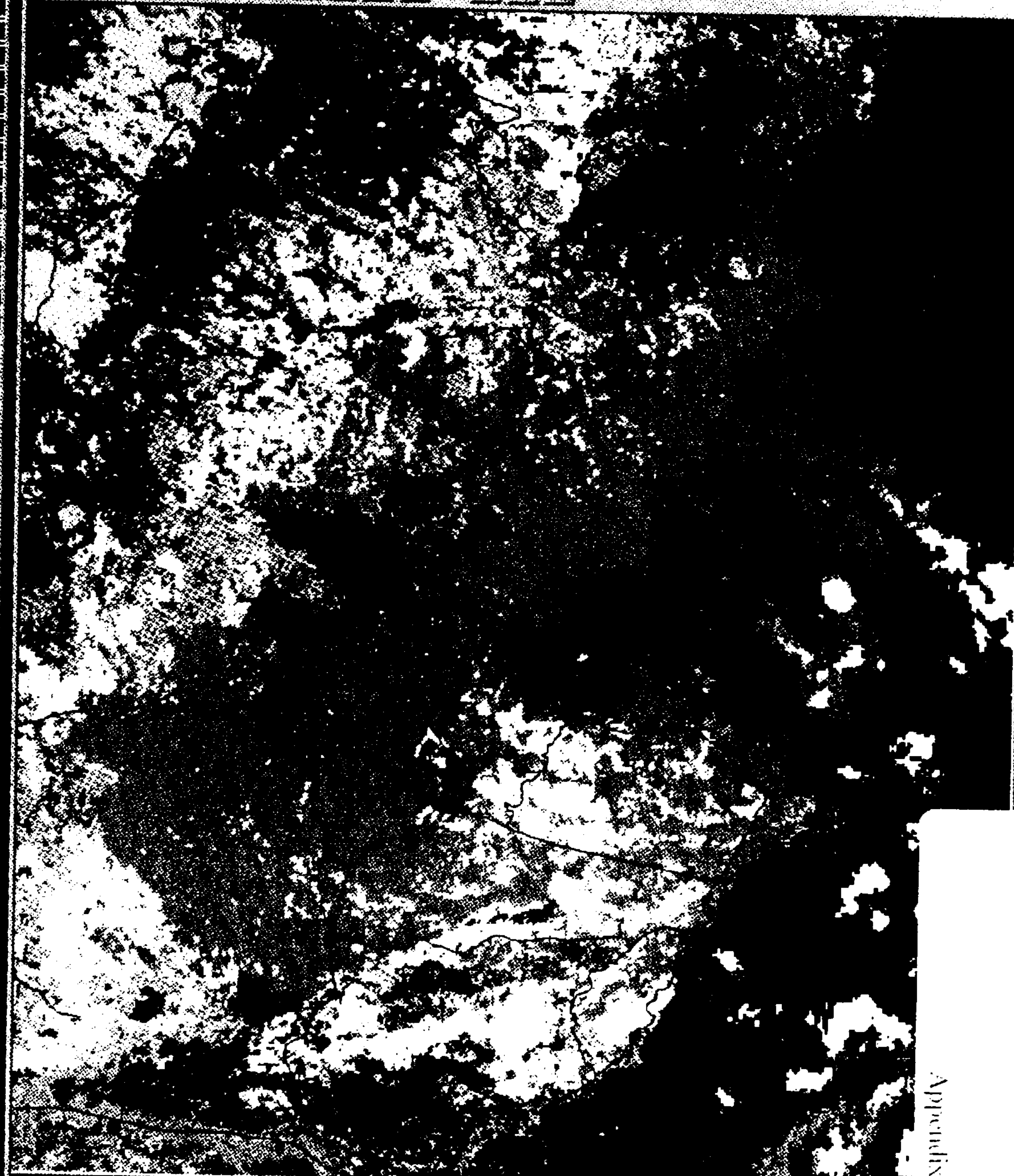
Row	Class_Names
3	Lowland Wet Rain Forest (Maulio Stream Gulch)
4	Montane Ohia-Weather Lava 1855- w Mx Gras, Mat Fern GPS4080221B
5	Bare Soil - Hamakua Sugar Co Field 20470 W Kaumoali Stream
6	Older Lava, Mauna Loa
7	Recent Lava; 1843 1935 flows-W Pu'u Nene; GPS4080223A; A'A Lava
8	Recent Pahoehoe Lava GPS4080222A
9	Shadow
10	Water (hawnw_scl)
11	Mature Sugar Cane- Hamakua Sugar Co Field 54060/51310 E Paauilo
12	Young Sugar Cane-Soil- Hamakua Sugar Co Field 43200; N Paauilo
13	Bare Soil, Hamakua Sugar Field 22300/20310; E Honokaa on H-19
14	Dry Koa Community-w Exotic Grassland; Pasture GPS4080400F
15	Bare Lt. Soil- Hamakua Fields 24390/24630/31370; SE of Honokaa
16	Coastal Kiawe Forest GPS4080423A
17	Montane Dense Mesic Ohia-Uluhe Fern, GPS4121323A
18	Bare Soil Hamakua Field 88600; SE Lapahoehoe W Maauilo Stream
19	Montane Dry Koa Community- w X Grass-Mx Shrub; Rang GPS4080400E
20	Barren-Cinder Mauna Kea
21	Cinder- E. Mauna Kea Summit by Pu'u Wekiu
22	Wet Koa-Ohia Forest w/ other Native Trees, Shrub, Treefern
23	Barren-Cinder 1, Mauna Kea, GPS4121423A
24	Beach GPS4080500A
25	Subalpine Dry Na Shrub-Lava, Pukiawe, Ohelo, A'alii GPS4121500A
26	Lowland Wet Ohia-Koa, Hapu'u Treefrn, Shrub-Gras GPS4080320A
27	Lowland Wet Koa-Hapu'u Treefern, Shrub <80% Canopy GPS4080320B
28	Montane Wet Ohia-Koa >65% Canopy GPS4080320C
29	Montane Dry Tropical Ash Forest Plantation GPS4080321A,hnw
30	Montane Dry X Tropicl Ash Plantati-B Poka Liana GPS4080321B;hnw
31	Montane Wet Non-Native Sugi Pine, Forest PlantationGPS4080401A
32	Montane Dry Koa-with Banana Poka Liana GPS4080322B
33	Coastline
34	Montane Mesic Open Koa-w B. P. Liana, Fern-Grass GPS4080322C
35	Montane Dry Koa-Mamane w Banana Poka Liana-Grass GPS4080400A
36	Wet Ohia Forest- w Treefern-Native Shrub underst E-GPS4080220B
37	X Gra - Mx Shrub w Fountain Grass,Cacti, Mullein, SE GPS4121523A
38	Gorse-Mixed Grasses, Soil_NW GPS4080402C
39	Montane Wet Exotic Grass-Rangeland GPS4080402A
40	ane, Hamakua Sugar Co. Field 20330; SE of Honokaa
41	
42	Aband ned Sugar Cane, Hamakua Field 11030, E of Waipio
43	Montane Dry X Grass-Mullein- w Koa-Mamane, Rangelan GPS4080403A
44	Subalp Dry Mamane Woodland-Mix Grass,Shrub, Cindr GPS4080301A
45	Coastal-Lowland Exotic Grassland-Lava with Fountain Grass
46	Cloud Shadow (forest W of Onema-River)
47	Montane Dry Mamane Woodlan-w Mx Grass-Shrub 50% Can GPS4080300B
48	Montane Dry Mamane Woodlan-w Mx Grass-Shrub 50% Can GPS4080300C
49	Lowlan-Montane Mamane-Naio Woodland-w Mix Shrub-Grass
50	Subalp Gras-Shrub-Cinr-w Desch,K. Haole, Puk, Aali GPS4080300A
51	Lowland Dry Grassland w Fountain Grass GPS4080501A

Press Right Button for Color Menu

ERDAS IMAGINE

Imagine Viewer #1 : hawmajrds

File View AOI Raster Vector Annotation Help



Urban Areas With Roads
Hilo, Big Island
Major roads in red
Minor roads in black

Appendix C #3

Legend

Signature File	Legend	
Unclassified	Unclassified	
Dense Wet Ohia-Koa w Hapu'u Treefern, Shrub, Grass; HVNP	Lowland to Montaine Dense *Ohia Koa* Wet Forest	
Recent Lava, Mauna Loa Summit	Bare Lava	
Lowland Wet Rain Forest (Mauulio Stream Gulch)	Lowland Dense Mixed Wet Forest	
Montane Ohia-Weather Lava 1855- w Mx Gras, Mat Fern GPS4080221B	Montaine Open *Ohia* Mesic Forest	
Bare Soil - Hamakua Sugar Co Field 20470 W Kaumoali Stream	Bare Soil	
Older Lava, Mauna Loa	Bare Lava	
Recent Lava; 1843 1935 flows-W Pu'u Nene; GPS4080223A; A'A Lava	Bare Lava	
Recent Pahoehoe Lava GPS4080222A	Bare Lava	
Shadow	Shadow	
Water (hawnw_scl)	Water	
Mature Sugar Cane- Hamakua Sugar Co Field 54060/51310 E Paauilo	Sugar Cane	
Young Sugar Cane-Soil- Hamakua Sugar Co Field 43200; N Paauilo	Sugar Cane	
Bare Soil, Hamakua Sugar Field 22300/20310: E Honokaa on H-19	Bare Soil	
Dry Koa Community-w Exotic Grassland; Pasture GPS4080400F	Montaine Open Mesic *Koa* Forest (Grazed)	
Bare Lt. Soil- Hamakua Fields 24390/24630/31370; SE of Honokaa	Bare Soil	
Coastal Kiawe Forest GPS4080423A	Coastal Open Dry *Kiawe* Forest	
Montane Dense Mesic Ohia-Uluhe Fern, GPS4121323A	Montaine Dense Mesic *Ohia* Forest	
Bare Soil Hamakua Field 88600; SE Lapahoehoe W Maauilo Stream	Bare Soil	

Montane Dry Koa Community- w X Grass-Mx Shrub; Rang GPS4080400E	Montaine Open Dry *Koa* Forest (Grazed)	
Barren-Cinder Mauna Kea	Bare Cinder	
Cinder- E. Mauna Kea Summit by Pu'u Wekiu	Bare Cinder	
Wet Koa-Ohia Forest w/ other Native Trees, Shrub, Treefern	Montaine Open *Ohia* Wet Forest	
Barren-Cinder 1, Mauna Kea; GPS4121423A	Bare Cinder	
Beach GPS4080500A	Bare Sand Beach	
Subalpine Dry Na Shrub-Lava: Pukiawe, Ohelo, A'alii GPS4121500A	Subalpine Open *Pukiawe Ohelo Aalii* Shrubland	
Lowlan Rain Forest-w Ohia-Koa, Hapu'u Treefrn, Gras GPS4080320A	Lowland Dense *Ohia Koa* Wet Forest	
Low-Montane Rain Forest- w Koa, Hapu'u <80% Canopy GPS4080320B	Lowland to Montaine Dense *Ohia Koa* Wet Forest	
Montane Wet Ohia-Koa >65% Canopy GPS4080320C	Montaine Open *Ohia* Wet Forest	
Montane Dry X Tropic Ash Plantation 80% Canopy GPS4080321A; Kal	Forest Plantation (Fraxinus)	
Montane Dry X Tropicl Ash Plantati-B Poka Liana GPS4080321B;Kal	Forest Plantation (Fraxinus) with *Banana Poka*	
Montane Dry Koa-w B. Poka Liana on trunks-canopy GPS4080322A	Montaine Open Koa Mesic Forest with *Banana Poka*	
Montane Dry Koa-with Banana Poka Liana GPS4080322B	Montaine Open Koa Mesic Forest with *Banana Poka*	
Coastline	Coastal Surf	
Montane Mesic Open Koa-w B. P. Liana, Fern-Grass GPS4080322C	Montaine Open Koa Mesic Forest with *Banana Poka*	

Montane Dry Koa-w Banana Poka Liana-Grass GPS4080400A	Montaine Open Koa Mesic Forest with *Banana Poka*	
Wet Ohia Forest- w Treefern-Native Shrub underst E-GPS4080220B	Montaine Open *Ohia* Wet Forest	
X Gras-Mx Shrub w Fountain Grass,Cacti, Mullein; SE GPS4121523A	Lowland Dry Open MixedShrublands with *Fountain Grass*	
Gorse-Mixed Grasses, Soil_NW GPS4080402C	Montaine Wet Grasslands with *Gorse*	
Montane Wet Exotic Grass-Rangeland GPS4080402A	Montaine Wet Grasslands (grazed)	
Sugar Cane, Hamakua Sugar Co. Field 20330; SE of Honokaa	Sugar Cane	
Montane Wet X Gorse-Nat Mamane-X Grass,Cinder; h_ne GPS4080402C	Montaine Wet Grasslands with *Gorse*	
Abandoned Sugar Cane, Hamakua Field 11030, E of Waipio	Sugar Cane	
Montane Dry X Grass-Mullein- w Koa-Mamane; Rangelan GPS4080403A	Montaine Dry Open *Koa Mamane* Forest (grazed)	
Subalp Dry Mamane Woodland-Mix Grass,Shrub, Cindr GPS4080301A	Montaine Dry Open *Koa/Mamane* Forest	
Coastal-Lowland Exotic Grassland-Lava with Fountain Grass	Lowland Dry Open Grasslands with *Fountain Grass*	
Cloud Shadow (forest Wof Onema-River)	Shadow	
Montane Dry Mamane Woodlan-w Mx Grass-Shrub 50% Can GPS4080300B	Montaine Dry Open *Mamane* Forest	
Montane Dry Mamane Woodlan-w Mx Grass-Shrub 50% Can GPS4080300C	Montaine Dry Open Forest	
Lowlan-Montane Mamane-Naio Woodland-w Mix Shrub-Grass	Montaine Dry Open*Mamane/Naio* Forest	
Subal D Gras-Shrub-Cinr-w Desch,K. Haole, Puk, Aali GPS4080300A	Subalpine Dry Open Mixed Shrubland	

Lowland Dry Grassland w Fountain Grass GPS4080501A	Lowland Dry Open Grasslands with *Fountain Grass*	
Barren-Cinder 2, Mauna Kea, GPS4121423A	Cinder	
Barren Cinder 3, Mauna Kea; GPS4121423A	Cinder	
Dense Young Ohia-Uluhe fern- w dead tree trunks, GPS4121323A	Montaine Wet Dense *Ohia* Forest with *Uluhe*	
Montane Nativ Shrubs-Lava; Pukiawe, Ohelo, A'ali'i GPS4121500A	Montaine Mesic Open Mixed Native Shrubland	
Dry Gras-Shrub w Fountain Gras,Cacti +/or Mullein E GPS4121523A	Lowland Dry Open Grasslands with *Fountain Grass*	
Coastal Kiawe Forest >70% Canopy GPS4080422B	Coastal Dry Dense *Kiawe* Forest	
Dry Grass-Rock, Shrub, P. Pear Cactus, Mullein SE GPS4121523A	Lowland Dry Open Grasslands	
Coastal Mix Grass-A'A Rock w open dead Kiawe Forest GPS4080500B	Coastal Dry Open *Kiawe* Forest	
Lowland Dry Exotic Eucalyptus Forest Plantation GPS4121523A	Forest Plantation (Eucalyptus)	
X Grass-Shrub, P.P. Cactus, Mullein, Range NE Saddle Rd./H-190	MontaineDry Open Shrublands	
Lava Flow 1899- w Montane Nat Shrubs Pukiawe-Ohelo GPS4121421A	Montaine Mesic Open Shrublands	
Montane Grasslan- w Molasses-B Beard-Broomsedge-Pili Steam Vent	Montaine Mesic Grasslands	
Class 34-Cloud-Urban from Unsupervised 40 Classification	Cloud	
Montane Dense Wet Ohia-Shrub-Ama'u Fern-L Flow 1855 GPS4080220A	Montaine Wet Dense *Ohia*/Shrub Forest on Lava	
Class 36-Cloud from Unsup 40 Classification	Cloud	
Class 37-Cloud from Unsup 40 Classification	Cloud	

Montane Wet Ohia-Weathered Lava Flow of 1881; GPS4121323B	Montaine Wet Dense Ohia Forest on Lava	
Montane Dense Wet Ohia-Hapu'u Tree fern-Uluhe fern; GPS4121323C	Montaine Wet Dense *Ohia/Hapuu* Forest	
Montane A'A Lava Flow 1984-Dense Lichen GPS4121400A	Montaine Wet Dense Lichen on Lava	
Montane Mesic Open Ohia-Uluhe Fern (6 in.-2'); GPS4121420A	Montaine Mesic Open *Ohia/Uluhe* Forest	
Montane Slash or Loblolly Pine-Forest Plantation; GPS4121401A	Forest Plantation (Pine)	
Coastal Grassland-Molasses-B. Beard w Pluchea-Guava-Rose Apple	Coastal Mesic Mixed Shrub/Grasslands	
Cloud shadow-Kalapana	Cloud Shadow	
Cloud Shadow S of Keanakolu Rd.	Cloud Shadow	
Montane X Grassland-Mullein- w Koa SW GPS4080403A MK Rd	Montaine Open Mesic Koa Forest (grazed)	
Macadamia Orchard, Mauna Loa Gardens	Macadamia Orchard	
lava 5 kileauea crater-Kalapana (UCL40)	Bare Lava	
Roseapple (Vive)-Guava-Strawberry Guava w Molasses-Mix Grass	Coastal Mesic Mixed Shrub/Grasslands	
Cinder-Ash; SW Kilauea Crater Rim Drive	Cinder	
Montane Dry Koa-w Banana Poka Liana, Grass GPS4080400A; hawnw	Montaine Open Koa Dry Forest with *Banana Poka*	
Coastal Wet Grassland-Shrub - Molasses w Pluchea; burn 83/6-91	Coastal Wet Mixed Shrub/Grasslands	
Water (hawneuc! merge 9-16)	Open Water	
Montane Mesic S gi Pine Forest Plantation GPS 4080401A; hawnw	Forest Plantation (*Sugi*)	
Exotic Grass-Rangeland GPS4080403A; hawnw	Montaine Mesic Grasslands (grazed)	
Coastal Kiawe Forest-Soil GPS4080423A;hawnw	Coastal Dry Open *Kiawe* Forest	

Montane Dry Koa Community- w Mx Gras-Shrub; Rang GPS4080400E;nw	Montaine Dry Open *Koa* Forest (grazed)	
Montane Dry Koa Community- w Mx Gras-Shrub Range GPS4080400F nw	Montaine Dry Open *Koa* Forest (grazed)	
Cloud from sup40; Spont	Cloud	
Deep Water; Spoint	Open Water	
Cloud Shadow; Spoint	Shadow	
Cloud shadow over cane; Spoint	Shadow	
Lowland Wet Koa-Ohia w Hapu'u Trefern-w Shrub-Gras-Clidemia-SG	Lowland Wet Open *Koa/Ohia* Forest with *Hapuu* and Clidemia	
Hilo Bay	Open Water	
Kealakekua water	Open Water	
Dry Koa-Banana Poka Liana with Grass GPS4080400A	Montaine Open Koa Mesic Forest with *Banana Poka*	
Lowland Grassland-Mix Shrub; Fountain Grass, Koa Haole-Pluchea	Lowland Dry Open Shrub/Grasslands with *Fountain Grass*	
Melastomes	Lowland Mesic Dense Shrublands with Melastomes	
Coastal Grassla-Mix Shrub-Lava; Buffel Grass-Pluchea-Koa Haole	Coastal Dry Open Shrub/Grasslands on Lava	
Montane Mesic vog Ohia-Uluhe-w BBeard Molas Brooms Gras	(either Montaine Mesic Open *Ohia* Forest/Shrubland OR Vog)	
Halema'uma'u-Kalapana Volcanic Gases-Solfataras sulfer fumes	Vog	
Monta D Ohia Wodlnd-w Ohia, Aali-Ulei-Puk-Ohelo-Cindr: Klookout	Montaine Dense Ohia Forest/Shrubland on Lava	
Montane Dry Shrubland-w A'ali'i, Pukiawe, Ohelo, Cinder; USGS M	Montaine Open shrubland on Lava	
Class 1-Kilauea Iki, halema'uma'u	Bare Lava	
Water-Reservoir SW Hilo	Open Water	
Halema'uma'u-Kilauea Iki	Bare Lava	

Chris's .Sig File and Class-Names List	Chris & Ron's List DOFAW	lowland to 3000 montane to 8000 subalpine to 10000 alpine ~~to 8000~~ up
Pahoehoe Lava Flow -1974	Bare Lava	
Lowlan Dry Koa Community w Molasses-B. Beard Grass; Hilina Pali	Lowland Dry Open *Koa* Forest/Grassland	
Kilauea Crater	Bare Lava	
Lowland Dry Grassland- with Molasses Grass, Thatch, Pili	Lowland Dry Grassland	
Mont dead Ohia Woodland-Shrub-Grass-Fern-Berry; E Kipuka Puaulu	Montaine Mesic Open *Ohia* Forest/Shrubland	
Class 2-Halema'uma'u Kilauea, Puu O'o, Hilina Pali	Bare Lava	
Coastal Wet Forest - Roseapple-Guava w/ Molasses Grass	Coastal Dense Wet Mixed Forest	
Snow Mauna Loa	Snow	
Coast-Low D Shrubla- w Kiawe, Aali, OhiaKoa, Mol Gras E harturn	Coastal Dry Open *Kiawe* Forest	
Soapberry-Koa-Ohia w X Grass, Mamane-Blackberry-X Mas Berry	Montaine Wet Dense Mixed Forest/Shrubland	
Firetree (Myrica faya)-Volcano House	Montaine Wet Dense Mixed Forest with Firetree	
Macadamia Orchard_SPoint Scene(small for hnw)	Macadamia Orchard	
Silk Oak-Grass_SPoint	Montaine Mesic Dense Mixed Forest with Silk Oak	
Low-Mo Dry Ohia-Mfaya Forest-w Aali, Amau, fern, Cin-Ash 2,500'	Lowland Dry Open Ohia Forest/Shrubland on Lava	
Lowl D vog Shrubl-w Aalii, few Ohia, Molas Grass; hairpin turn	Lowland Dry Open Shrub/Grassland on Lava	
Low D vog Ohia Forest- w Aali, Mola Gras, Spars Ohia E hairturn	Lowland Mesic Dense Ohia Forest/Shrubland	
Macadamia Orchard-C. Brewer, Kau Sugar Co. Pahala (field size)	Macadamia Orchard	
Class 6-Halema'uma'u Kilauea, Mauna Lua Flow to coast	Bare Lava	
lava 7-Kilauea Crater and 19?? flow Kau Desert, Kona 19??	Bare Lava	

.73
Burned Lowland Wet Open Mixed Forest-Grassland - with Molasses-Razor Grass, Pluchea, Lantana, Ohia-Hala
.82
Lowland Wet Grassland - with dense Molasses Grass, Pluchea, Bamboo Orchid
.1
Lowland Wet Dense Koa-Ohia Forest - with Hapu'u Treefern, Mixed Shrub-Grass
.3
Lowland Wet and Mesic Dense Mixed Forest - with Ohia-Hala, Roseapple, Wiliwili, Kukui, Ironwood, Mango, Guava, Monkey Pod, Strawberry Guava, Guava, Java Plum; Loulu, Coconut, and Australian Palms, Christmasberry, Silk Oak, Hapu'u Treefern, Ulei, Pluchea; mixed sedges-grasses with Ohe-Uki, Naupaka, ferns Ama'u-Uluhe
.30
Lowland Wet Open Koa Forest - with Hapu'u Treefern, Banana Poka and other Lianas
.4
Montane Wet Ohia-Shrub - with Pukiawe, Ohelo, Orchid on weathered lava 1855 flow
.17
Montane Wet Open Ohia-Koa Forest - with Hapu'u Treefern, mixed shrub grass
.38
Montane Wet Grassland - with Gorse, mixed grasses
.39
Montane Wet Grazed Grassland - with Kikuyu, mixed grasses
.62
Montane Wet Open Shrubland-Lava - with Ama'u, Ohia-Deschampsia ecozone edge
.70
Montane Wet Lichen on 1984 Lava Flow - with Pioneer Ohia along road-ecozone edge

.98
Lowland Mesic Dense Shrubland - with Melastomes
.14
Montane Mesic Open Grazed Koa Forest - with Kikuyu-mixed grasses, Rubus, trunks
.63
Montane Mesic Open Grazed Grassland - with Molasses Grass, Bush Beard Grass, Pili, Broomsedge, Bamboo Orchid on weathered Pahoehoe Lava
.71
Montane Mesic Open Ohia-Uluhe - with Bush Beard Grass, Bamboo Orchid
.117
Montane Mesic Mixed Forest - with Fire Tree-Ohia, Molasses Grass, mixed grasses
.120
Montane Mesic Dense Mixed Forest - with Silk Oak, Ohia-Koa, Beard Grass, Ulei
.55
Subalpine Mesic Open Shrubland - with Pukiawe, Ohelo, Lepo-nene on lava

.16
Coastal Dry Kiawe Forest - with Kiawe, Buffelgrass, Pluchea on weathered lava
.99
Coastal Dry Open Grass-Shrubland - with Buffelgrass, Pluchea, Lantana, Koa haole
.37
Lowland Dry Open Shrub-Grassland - with Koa haole, Pukiawe, Prickly Pear Cactus, Lantana, dense Fountain Grass
.110
Lowland Dry Dense Grassland - with Molasses, Pili, Bush Beard Grass, A'ali'i
.115
Lowland Dry Open Mixed Forest-Shrubland - with Molasses Grass
.49
Montane Dry Open Mamane-Naio Woodland and Forest - with scattered Ohia, Koa, mixed grasses, mixed shrub, on weathered lava
.43
Montane Dry Open Koa-Mamane Forest - with A'ali'i, Pukiawe, Bush Beard Grass, Uki, Deschampsia

.61
Montane Dry Open Grazed Grass-Shrubland - with Fountain Grass, mixed grasses, Mullein, Prickly Pear Cactus, Koa haole, Lantana, A'ali'i, Koa trunks
.50
Subalpine Dry Open Grass-Shrubland - with Dechampsia, Pukiawe, Ohelo on lava
.25
Subalpine Dry Native Shrubland - with Pukiawe, Ohelo, A'ali'i on lava
.44
Subalpine Dry Open Mamane Forest - with Pukiawe, Ohelo, Deschampsia on lava

.2
Bare Lava
.5
Bare Soil
.20
Cinder Fields-Ash
.9
Shadow, Water
.11
Sugar Cane - data from Hamakua and Kau Sugar Companies
.77
Macadamia Orchard and Coffee
.64
Cloud, Snow, Volcanic Gases, Urban

Island of Hawai'i-Landsat TM
Subtropical Hierarchical Land Cover Classification

Physical Ecosystems

Atmosphere
- **Cloud**
  - Density
  - Form
  - Shadow
- **Vog**
- **Fog**

Water
- **Liquid**
  - Shallow
    - •Coastline
    - •Anchialine Pools
  - Deep
  - Pigmented
  - Sediment
  - Streams-Flume
- **Snow**
- **Ice**

Substrate
- **Geologic Form**
  - Coral
  - Lava
    - Cinder-Pumice
    - Basalt
    - Older
  - Weathered
    - Recent
    - Rock
  - Revegetated Lava (← Wildland Vegetation)
    - •Pioneer Vegetation
    - •1984 A'a-Lichen
    - •Lichen-Fern
    - •Grass
    - •Shrub
    - •Shrub-Fern
    - •Ohia-Uluhe
    - •Ohia-Koa-Fern
    - •Ohia-Koa-Grass
  - Canopy
    - Open, Closed, Scattered
  - Biomass
    - Sparse, Dense
  - Condition
    - •Substrate-Vog
    - •Eruption Site:
      - Vent, Lava Lake, Tubes-Skylights-Lava Flows-liquid Pahoehoe or A'a
    - •Moisture
      - Dry, Mesic, Wet
    - •Stress-Heat, Vog, Burn, Drought, Pigments
  - Soils
    - •Sand, Irons, Ash, Dark Tropic Clays
  - Land Forms
    - •Volcano, Vent, Pu'u, Kipuka, Pali, Gulch, Valley

Biological Ecosystems

Wildland Vegetation

Forest
- Type
- Coastal
  - Dry Kiawe Forest
  - Dry Kiawe-Koa haole
- Lowland Wet Mixed
  - •Ironwood, Kukui, Palms...Loulu, Olapa, Maile, Guava, S. Guava, African Tulip Tree, Milo, Christmasberry, Naio, MonkeyPod, Hala, Fern, Rock, Grass, Naupaka.
- Lowland Koa-Ohia-Hapu'u
- Montane Wet and Mesic
  - Ohia-Koa-Hapu'u
  - Ohia-Koa-Shrub
  - Ohia-Koa-Uluhe, 'Ama'u
  - Koa...
  - Koa-Mixed Grass-Fern
  - Koa...-Lianas
  - Open Koa-Grass-Lianas
  - Ohia-Hapu'u
  - Koa-Soapberry, Shrub-Bracken Fern-Grass
  - Dense M. fayatree
  - Molasses Grass-Open
  - M.fayatree-Ohia-Lava
  - Naio-Mamane
  - Forest Plantations:
  - •Ash, Sugi, Eucalyptus
  - Silk Oak-Ohia
- Montane-Subalpine
  - Mamane-Dry Grass-Soil
  - Mamane-Dry Grass-A'a
  - Mamane-Koa-Kukuyu...
- Canopy
  - •Open, Closed, Scattered
- Condition
  - •Moisture
    - Dry, Mesic, Wet
- Stress-Pigment, Vog, Drought

Shrubland
- Type
- Native
  - 'Ilima
  - 'Ilima-A'ali'i
  - A'ali'i-Pukiawe, 'Ilima, Ohelo-Grass
  - Naio-Mamane
  - Naio-Mamane-Ohia-Aweoweo-Grass-A'a
  - Mamane-Scrub Ohia
  - Mamane-Shrub-Pahoehoe
  - Pukiawe-Ohelo-Lava
- Mixed
  - Pluchea-'Ilima-Koa-haole-Lava
  - Koa-haole-Grass
  - Koa-haole-A'ali'i-Lantana-'Ilima
- Melastomes
- Gorse

Grassland
- Type
- Lowland
  - Mesic Pasture-Shrub
  - Repeat Burn
  - •Razor-Molasses Grass-Scrub Ohia-Lava
  - Dry-Mesic Buffelgrass
  - Dry Fountain Grass
  - Dry Fountain Grass-Shrub
  - Leeward Mixed Grass-Shrub
  - •Buffelgrass-Fountain-Guinney-Kukuyu Grasses, Shrub-Prickly Pear Cactus
  - Windward Molasses Grass
  - Molasses Grass-Shrub (A'ali'i)
- Montane
  - Mixed Grasses
  - •Wet Kukuyu, mixed grasses
  - •Bushbeard-Broomsedge-Molasses-Pili
- Subalpine
  - Deschampsia-Mixed Grasses
- Biomass-Growth State
  - Sparse, Dense, Grazed Forest

Manmade Ecosystems

Urban
- Commercial
- Industrial
- Residential
- Gravel Pit

Agriculture
- **Crop**
  - Type
    - •Sugarcane
    - •Coffee
    - •Pasture
    - •Macnut
  - Biomass-Growth State
    - -Emergent
    - -Sparse
    - -Dense
    - -Young
    - -Mature
  - Condition
    - • Moisture
      - Dry, Irrigated
    - • Abandoned Cane
    - • Fallow
      - -Dk. Clay
      - -Iron Oxide
      - -Grazed
    - •Stress
      - Drought, Vog, pigments

The subtropical ecosystems listed in the pilot project's hierarchical tree reflect the dominant vegetation and other land cover seen in the data and collected at GPS and non-GPS field sites. Biological systems include Wildland Vegetation, classified in zones based on TM resolution, elevation, moisture, physiognomic group, and climate. Native vegetation is tropical, whereas the origin of non-native vegetation is worldwide. Substrate is azonal, occurring in multiple zones. Other land cover on the map includes aspects of Physical and Manmade Ecosystems. The map grid cells are based on 32m pixel resolution, whereas the minimum map unit is typically +32m grid cells.
The system is adapted for remote sensing from Gagne, Cuddihy, and Jacobi. Some vegetation types on the map are generalized (i.e. Lowland Mixed Forest), or reflect the core area of concentration (i.e. Gorse and M. faya).The extent of the non-natives (i.e. M.faya, Silk Oak, Eucalyptus, Melastomes, and Macnut) are not mapped; funds to process or collect additional field data, and cloud free data are needed.

Appendix C #5

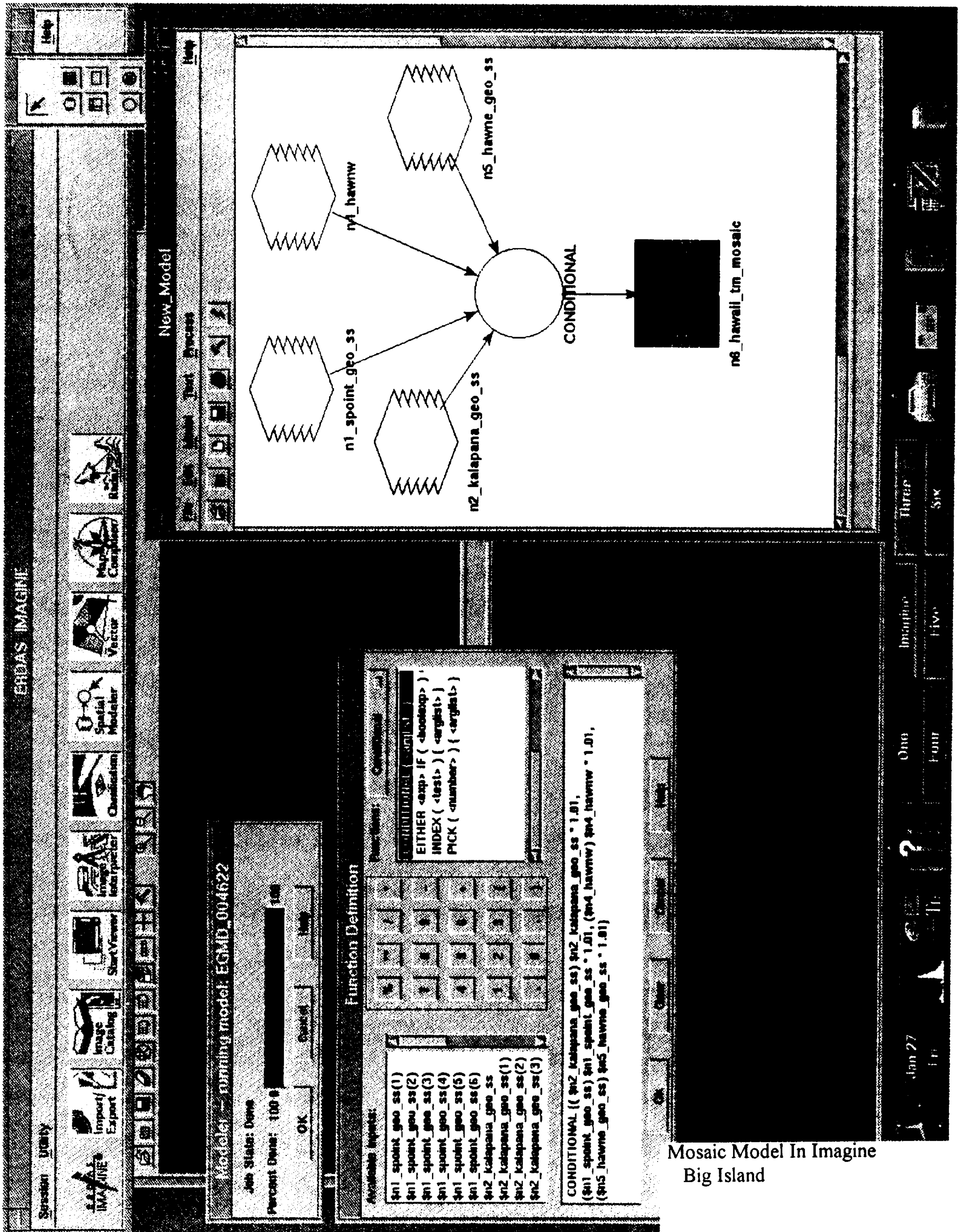
NASA Grant: NAGW-3812

APPENDIX D - Mosaic Process

1) Landsat TM Scenes Before Mosaic
2) Mosaic Model in Imagine
3) Sample Area of Interest for Mosaic
4) Raw Data Mosaic of the Island of Hawaii with Maui
5) Classified Mosaic and Legend of the Island of Hawaii

Landsat TM Scenes Before Mosaic
Big Island

Appendix D #1



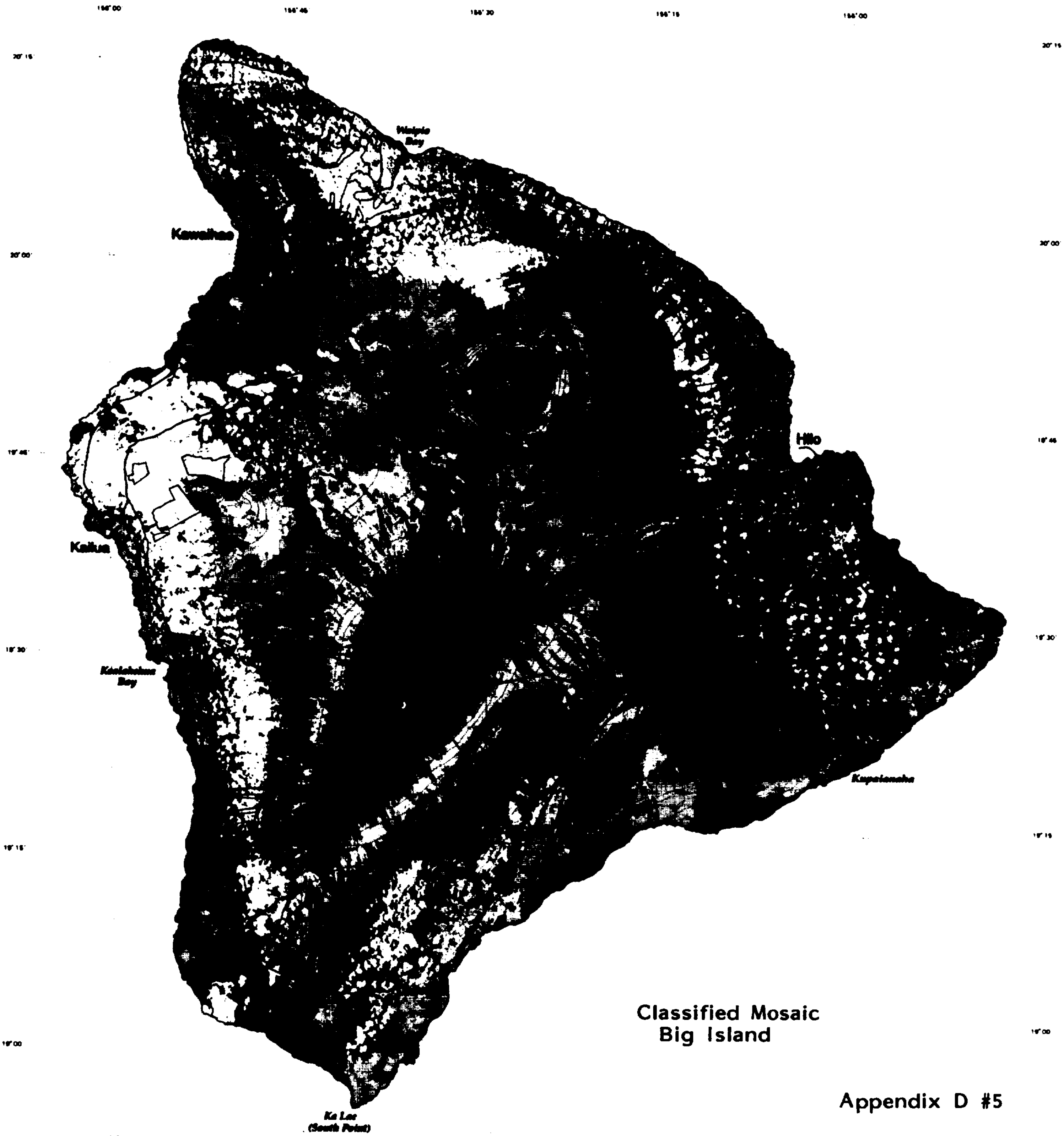
Mosaic Model In Imagine
Big Island

Sample Area of Interest for Mosaic
South Point, Big Island

Appendix D #4

LANDSAT VEGETATION AND LANDCOVER MAP

Island of Hawaii



Classified Mosaic
Big Island

Appendix D #5

This map is produced by the State of Hawaii Office of State Planning, Department of Land and Natural Resources / Division of Forestry and Wildlife, Geographic Decision Systems International (GDSI), and Hogan Co. through NASA Grant NAGW-3812, initiated by Craig Tasaka of Office of State Planning. Classification of dominant Hawaii Island Plant Communities and other Land Cover are derived from four different Landsat Thematic Mapper (TM) Satellite Images with ERDAS Imagine v 8.1. Dates of the digital scenes and their corresponding Satellite Path and Row are indexed to the right.

The Hawaiian Island Archipelago is in UTM Zone 4, except for the Island of Hawaii, which is in UTM Zone 5. All geographic databases of the State of Hawaii Geographic Information System are in UTM Zone 4. This image is projected into UTM Zone 4 to comply with the State of Hawaii database design. Map area measurements and location control for this map are based on 32.0m x 32.0m cells. Mosaic of the four classification maps was produced in August 1996.

Base is adapted from USGS 1:24,000 topographic map of the Island of Hawaii. Clarke 1866, Old Hawaiian Datum. Latitude and Longitude grid indexes are at 15 minute intervals.

Field Survey using GPS, are by Roger Imoto, Ron Cannarella, Christine Hogan, Leo Ilsehara, John Hogan, Royce Jones, Lance Bookless, and Betsy Gagné.

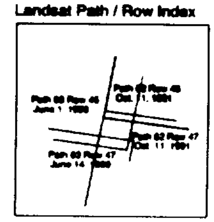
Dominant Hawaii Island plant communities are extracted from the vegetation classification schemes of Jim Jacobi, Linda Pratt and Wayne Gagné. The extent of non-native plant species is conservative on this map and shows the core area of concentration. Classifications are produced by Roger Imoto, Ron Cannarella, Christine Hogan, Lance Bookless, Leo Ilsehara, and Betsy Gagné. The confidence level of landcover classification map accuracy is generally high near the corresponding GPS and Non-GPS ground field site depending on data resolution.

Arc/Info GIS support by Leo Ilsehara, Royce Jones, Rod Low, Ron Cannarella, and Lance Bookless. GIS System Administration by Joan Esposo, Joy Toyama, Tammie Ilsehara, and Rob Kiessling.

Mosaic modeling with area of interest processing between scenes and map design by Leo Ilsehara and Christine Hogan.

Map produced: November 1996

Landsat Path / Row Index



Wet Plant Communities

- Burned Lowland Wet Open Mixed Forest-Grassland - with Molasses-Razor Grass, Pluchea, Lantana, Ohia-Hala (Puna); Molasses Grass, Firetree-Ohia (Kupaianaha)
- Lowland Wet Grassland - with dense Molasses Grass, Pluchea, Bamboo Orchid
- Lowland Wet Dense Koa-Ohia Forest - with Hapu'u Treefern, Mixed Shrub-Grass
- Lowland Wet and Mesic Dense Mixed Forest - with Ohia-Hala, Roseapple, Wiliwili, Kukui, Ironwood, Mango, Guava, Monkey Pod, Strawberry Guava, Guava, Java Plum; Loulu, Coconut, and Australian Palms, Christmasberry, Silk Oak, Hapu'u Treefern, Ulei, Pluchea; mixed sedges-grasses with Ohe-Uki, Naupaka, ferns Ama'u-Uluhe
- Lowland Wet Open Koa Forest - with Hapu'u Treefern, Banana Poka and other Lianas
- Montane Wet Ohia-Shrub - with Pukiawe, Ohelo, Orchid on weathered lava 1855 flow
- Montane Wet Open Ohia-Koa Forest - with Hapu'u Treefern, mixed shrub grass
- Montane Wet Grassland - with Gorse, mixed grasses
- Montane Wet Grazed Grassland - with Kikuyu, mixed grasses
- Montane Wet Open Shrubland-Lava - with Ama'u, Ohia-Deschampsia ecozone edge
- Montane Wet Lichen on 1984 Lava Flow - with Pioneer Ohia along road-ecozone edge

Mesic Plant Communities

- Lowland Mesic Dense Shrubland - with Melastomes
- Montane Mesic Open Grazed Koa Forest - with Kikuyu-mixed grasses, Rubus, trunks
- Montane Mesic Open Grazed Grassland - with Molasses Grass, Bush Beard Grass, Pili, Broomsedge, Bamboo Orchid on weathered Pahoehoe Lava
- Montane Mesic Open Ohia-Uluhe - with Bush Beard Grass, Bamboo Orchid
- Montane Mesic Mixed Forest - with Firetree-Ohia, Molasses Grass, mixed grasses
- Montane Mesic Dense Mixed Forest - with Silk Oak, Ohia-Koa, Beard Grass, Ulei
- Subalpine Mesic Open Shrubland - with Pukiawe, Ohelo, Lepo-nene on lava

Dry Plant Communities

- Coastal Dry Kiawe Forest - with Kiawe, Buffelgrass, Pluchea on weathered lava
- Coastal Dry Open Grass-Shrubland - with Buffelgrass, Pluchea, Lantana, Koa haole
- Lowland Dry Open Shrub-Grassland - with Koa haole, Pukiawe, Prickly Pear Cactus, Lantana, dense Fountain Grass
- Lowland Dry Dense Grassland - with Molasses, Pili, Bush Beard Grass, A'ali'i
- Lowland Dry Open Mixed Forest-Shrubland - with Molasses Grass, Firetree-Ohia,
- Montane Dry Open Mamane-Naio Woodland and Forest - with scattered Ohia, Koa, mixed grasses, mixed shrub, on weathered lava
- Montane Dry Open Koa-Mamane Forest - with A'ali'i, Pukiawe, Bush Beard Grass, Ulei, Deschampsia
- Montane Dry Open Grazed Grass-Shrubland - with Fountain Grass, mixed grasses, Mullein, Prickly Pear Cactus, Koa haole, Lantana, A'ali'i, Koa trunks
- Subalpine Dry Open Grass-Shrubland - with Dechampsia, Pukiawe, Ohelo on lava
- Subalpine Dry Native Shrubland - with Pukiawe, Ohelo, A'ali'i on lava
- Subalpine Dry Open Mamane Forest - with Pukiawe, Ohelo, Deschampsia on lava

Other Landcover

- Forest Plantation
- Sugar Cane - data from Hamakua and Kau Sugar Companies
- Macadamia Orchard and Coffee
- Bare Lava
- Bare Soil
- Cinder Fields-Ash
- Shadow, Water
- Cloud, Snow, Volcanic Gases, Urban
- Major Roads
- Publicly Owned Protected Areas
- Elevation Contour (in feet)
- Field Points - Global Positioning System (GPS) and non-GPS

Scale 1:250,000

Sources:

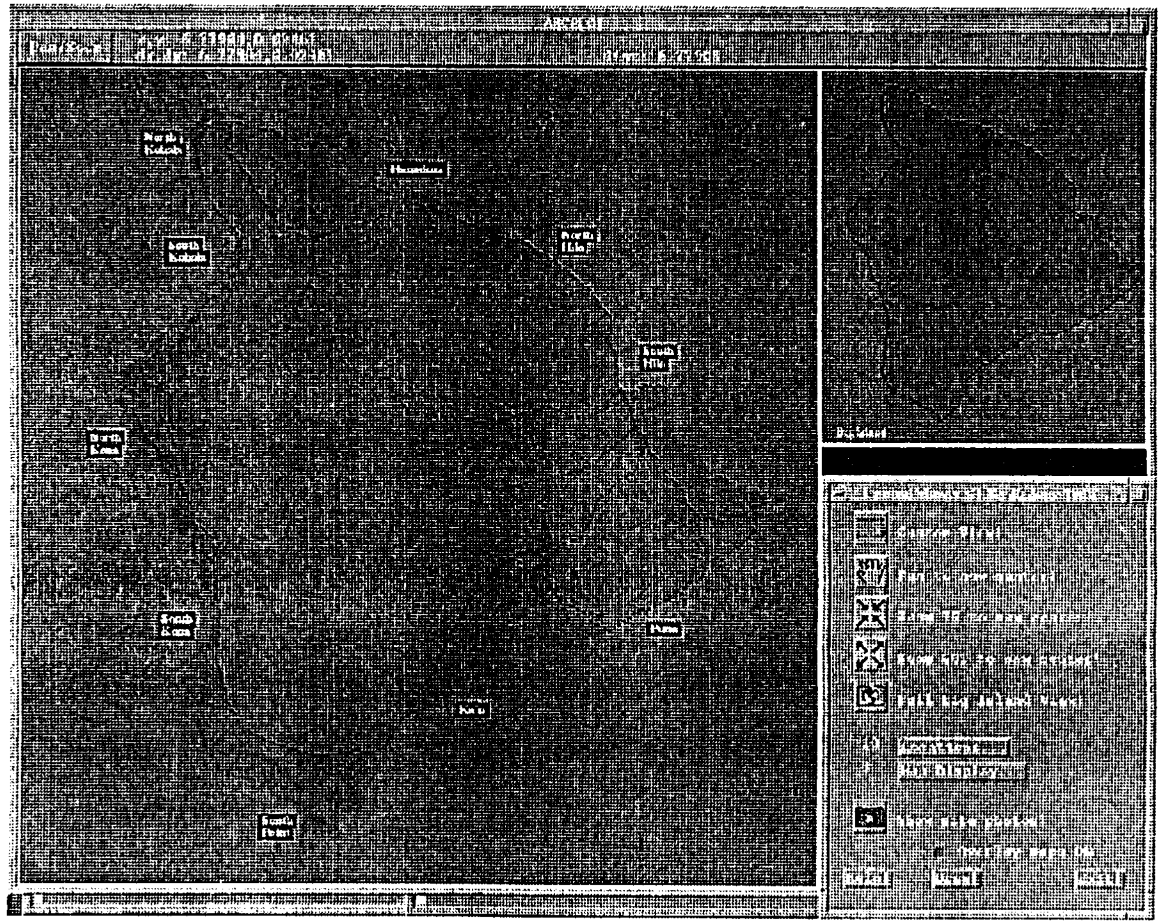
Major Roads - United States Geological Survey (USGS), Digital Line Graph (DLG) files, 1:24,000, 1983.
Managed Areas - Boundaries were primarily extracted from the USGS DLG files, 1:24,000, 1983, with more current boundaries digitized from a variety of sources provided by the Department of Land and Natural Resources (Division of Forestry and Wildlife), The Nature Conservancy, and other agencies.
Elevation Contours - USGS Digital Elevation Model (DEM) files, 1:100,000, 1983.
Note: All contours interpolated from digital point data, and are intended for general reference only. They are not to be used for analytical purposes.
Global Positioning System Field Points - GPS Field points recorded in August and December 1994, and October 1995 with Trimble Pathfinder Basic 16787-20.
Non GPS Field Data - Recorded in August and December 1994 and in 1995.

APPENDIX E - LSVIEW Quick Tour

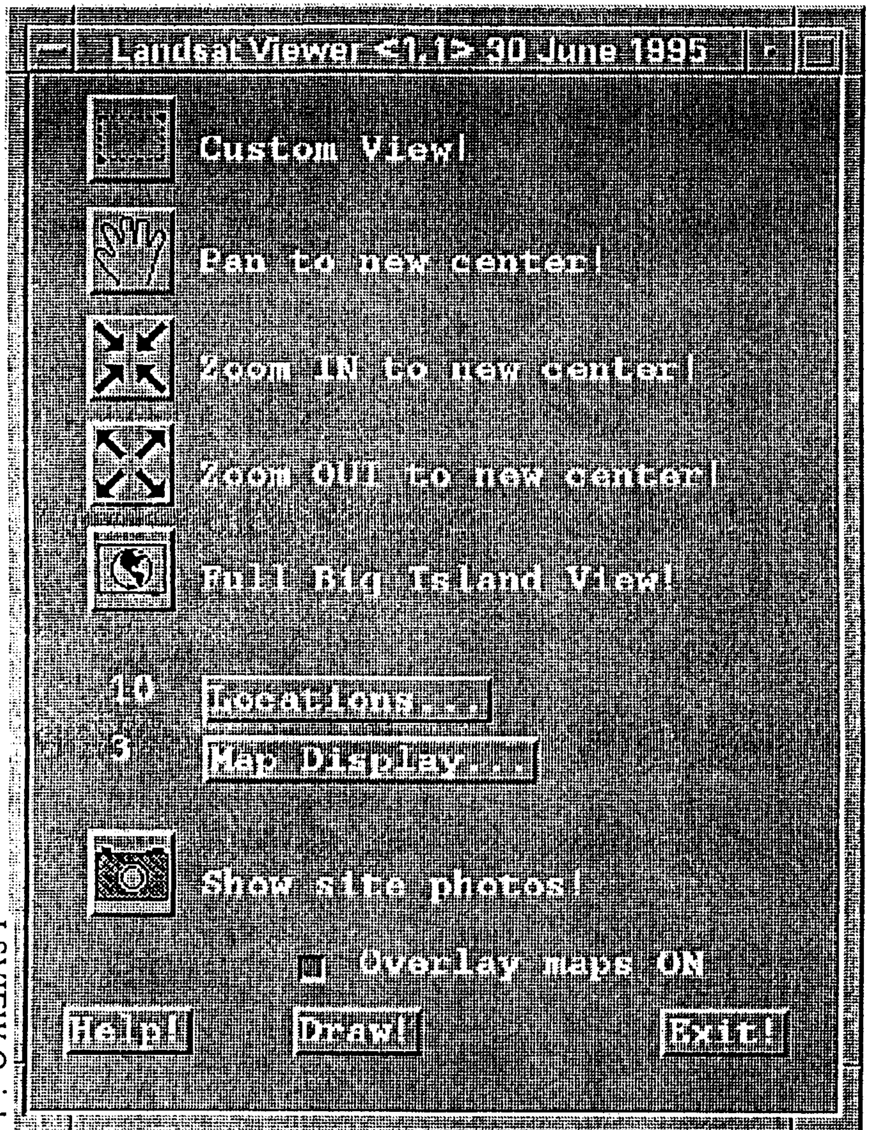
1) Sample Screens from LSVIEW with Explanations

1: LSVIEW Opening Full Screen Layout
2: LSVIEW Main Menu
3: LSVIEW Location Map Menu
4: LSVIEW Detail of Location Map for Mauna Kea
5: LSVIEW Full Screen Showing Mauna Kea Location
6: LSVIEW Map Display Menu
7: LSVIEW Map Display Menu with TM 7-5-3 Mosaic Active
8: LSVIEW Full Screen with TM 7-5-3 Mosaic of Mauna Kea Area
9) LSVIEW Main Menu to Show Site Photos
10: LSVIEW Full Screen Showing Site Photos Near Mauna Kea

LSVIEW QUICK TOUR

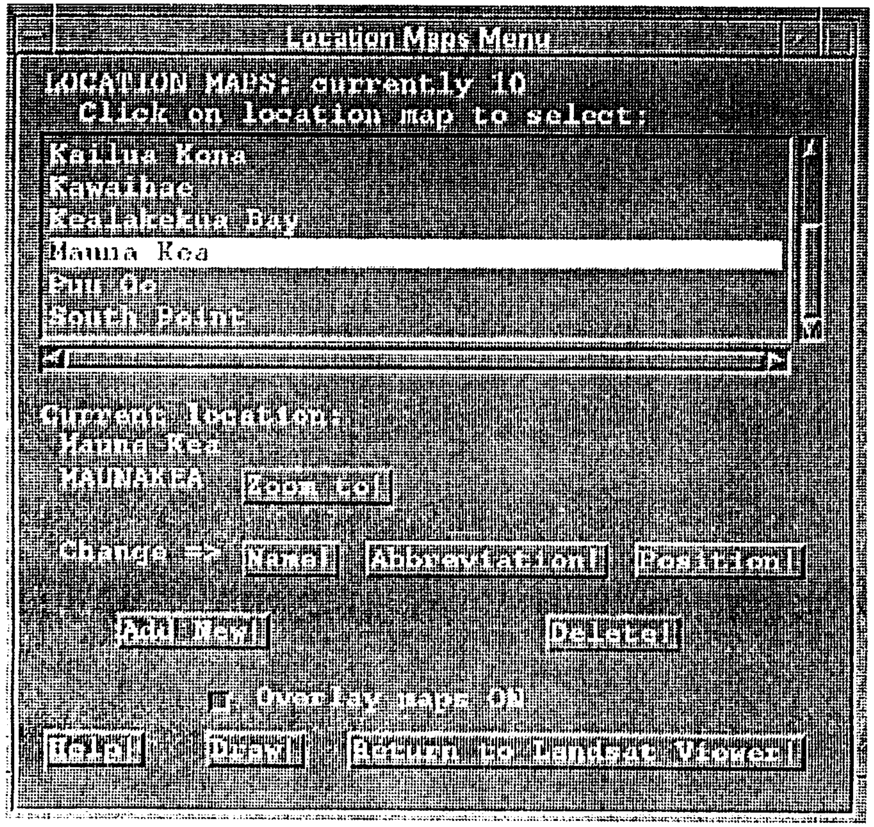


LSVIEW OPENING FULL SCREEN LAYOUT



Custom View!	User defines new window to zoom into on Detail Map.
Pan to new center!	User defines center for Detail Map, scale is unchanged.
Zoom IN to new...!	User defines center and Detail Map is zoomed in 2x.
Zoom OUT to new...!	User defines center and Detail Map is zoomed out 2x.
Full Big Island View!	Detail Map shows all of Big Island.
Locations...	Zoom Detail Map directly to user defined areas.
Map Display...	Select which data layers to show on Detail Map.
Show site photos!	Click on a site to see any scanned photos taken from that site.
Overlay maps ON	Click here to turn GIS layers on/off.
Help!	Display Help screen.
Draw!	Redraw Detail Map.
Exit!	Leave LSVIEW.

LSVIEW MAIN MENU



Clicking the Locations... button in the Main Menu brings up this Location Map Menu.

In this area are shown the available locations that have been previously identified. The user can scroll through the list and highlight a location to zoom into.

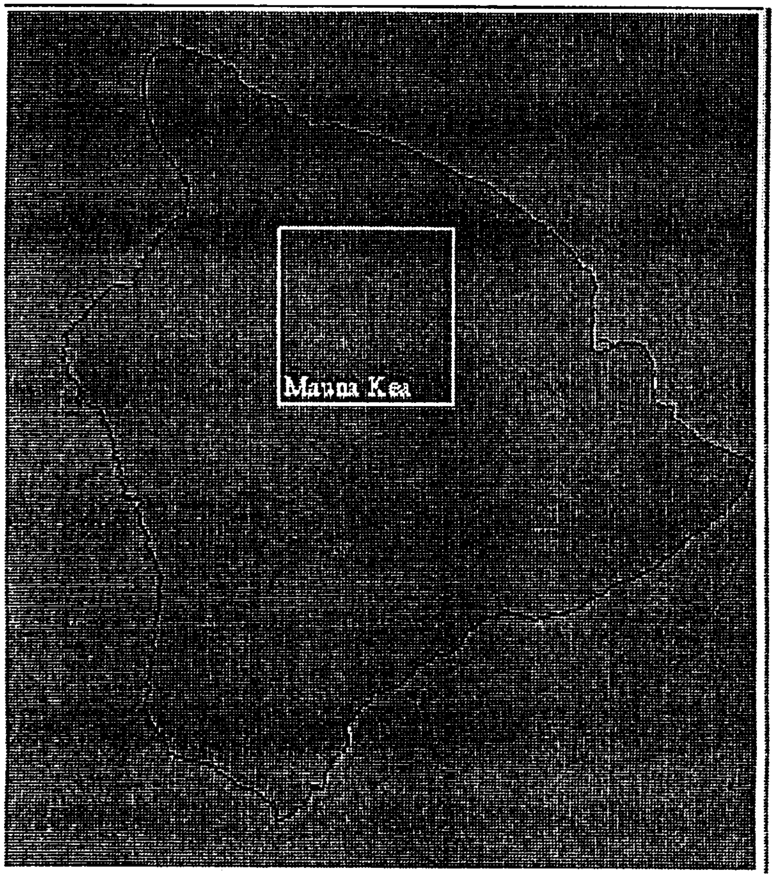
This is the location currently highlighted in the above scroll box. Click 'Zoom to!' and the Detail Map will show this location.

These buttons change the location name/position.

Use 'Add New!' to define a location within the current Detail Map and to save it as a new named location. 'Delete!' permanently deletes a named location.

Help! shows the Help screen.
Draw! redraws the Detail Map.
Return to Landsat Viewer brings back the Main Menu.

LSVIEW LOCATION MAP MENU

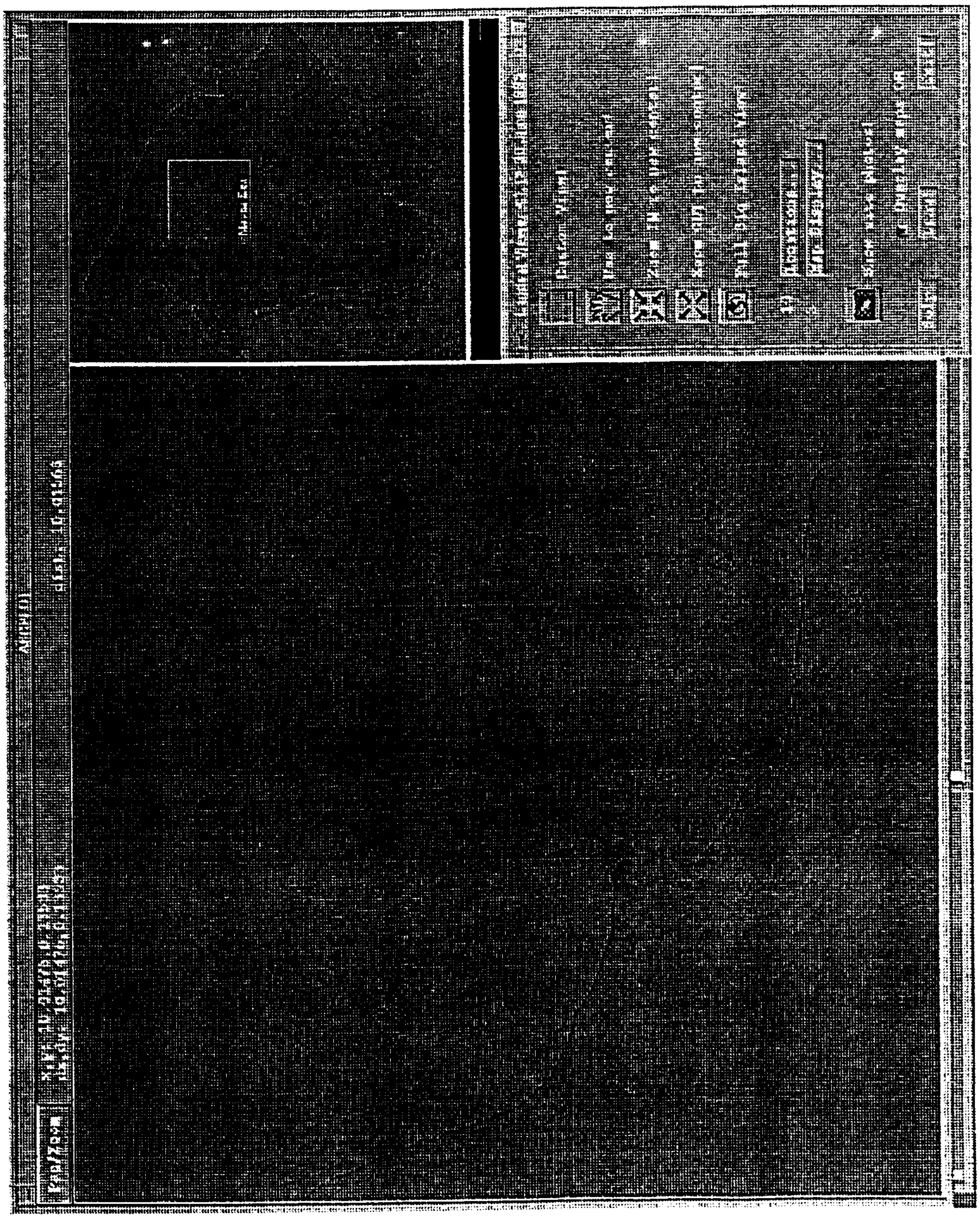


After clicking 'Zoom to' in the Location Map Menu, the Location Map part of the screen (upper right) will show the extent of the current location, in this case Mauna Kea, and the Detail Map will show the area within this extent.

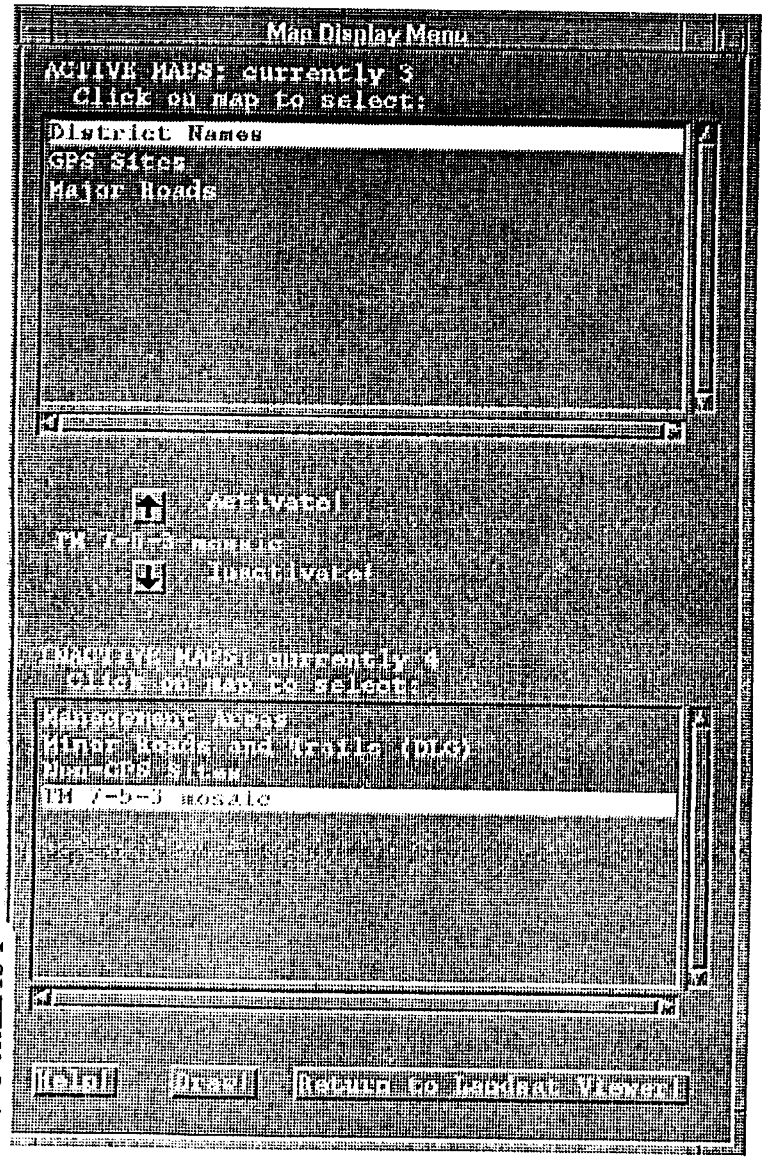
Clicking on 'Return to Landsat Viewer' will bring back the Main Menu as shown on the next page.

The Detail Map only shows roads and GPS sites as these are the only data layers currently turned on.

LSVIEW DETAIL OF LOCATION MAP FOR MAUNA KEA



LSVIEW FULL SCREEN SHOWING MAUNA KEA LOCATION



Clicking 'Map Display...' in the Main Menu brings up this Map Display Menu.

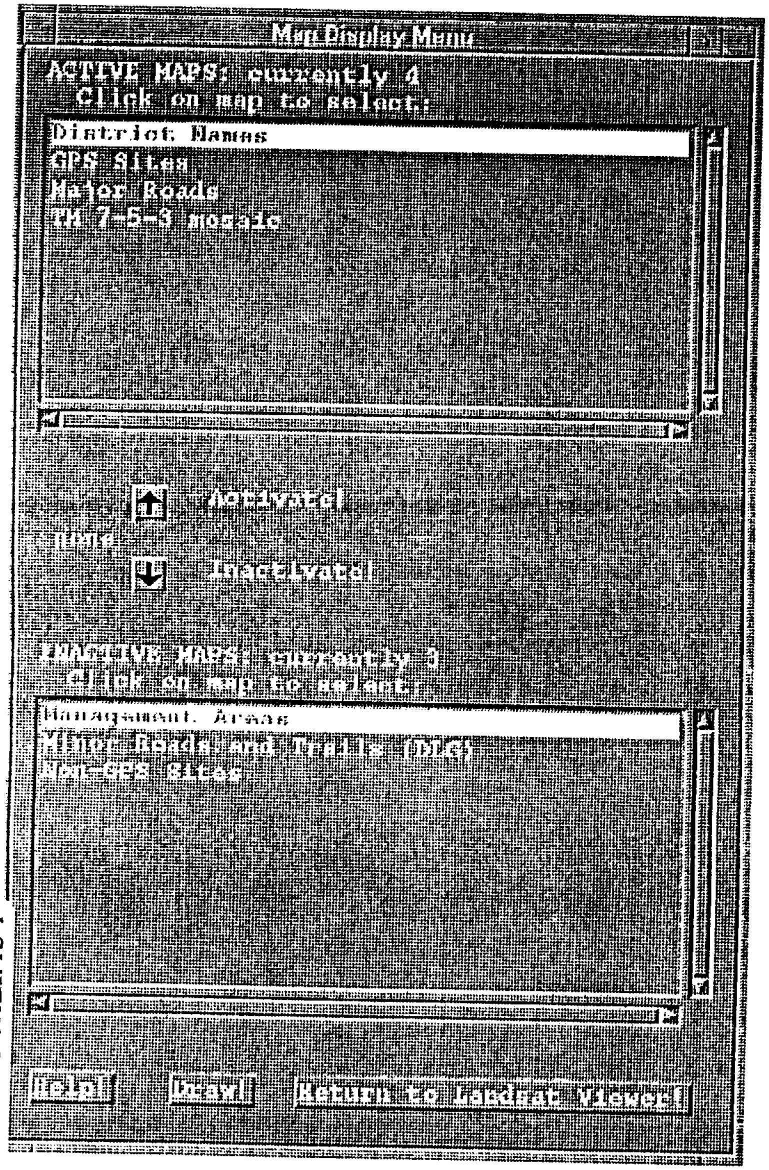
This scrolling box lists all of the data layers that will be drawn on the Detail Map.

Clicking on a data layer in either of the two scrolling boxes will display that data layer name here. Click on 'Activate' to make this data layer active (will display). Click on 'Inactivate' to make this data layer inactive (will not display).

This scrolling box lists all of the data layers that are available but not currently drawn on the Detail Map.

Help! shows Help screen.
Draw! redraws screen to show active data layers.
Return to Landsat Viewer! Brings back the Main Menu.

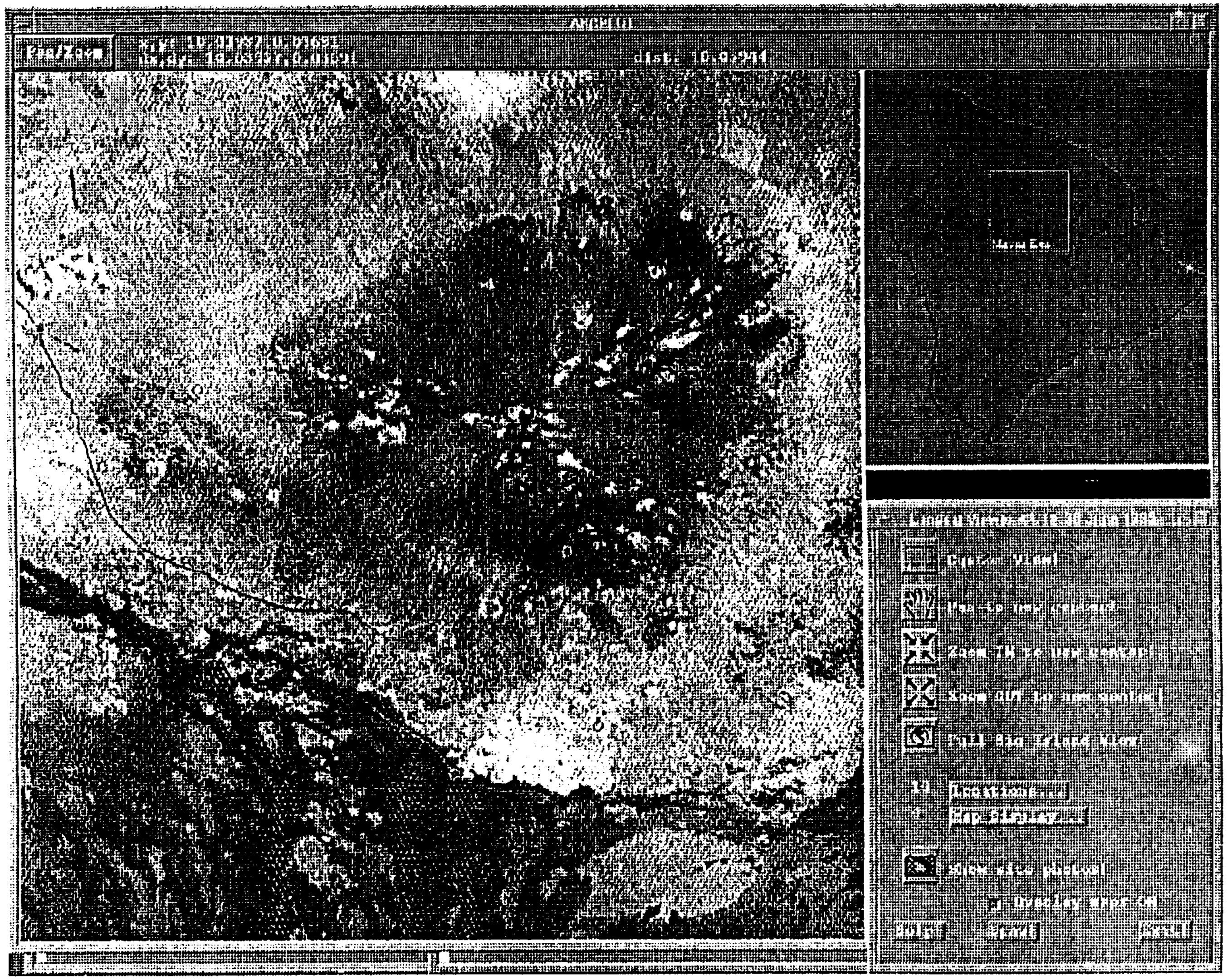
LSVIEW MAP DISPLAY MENU



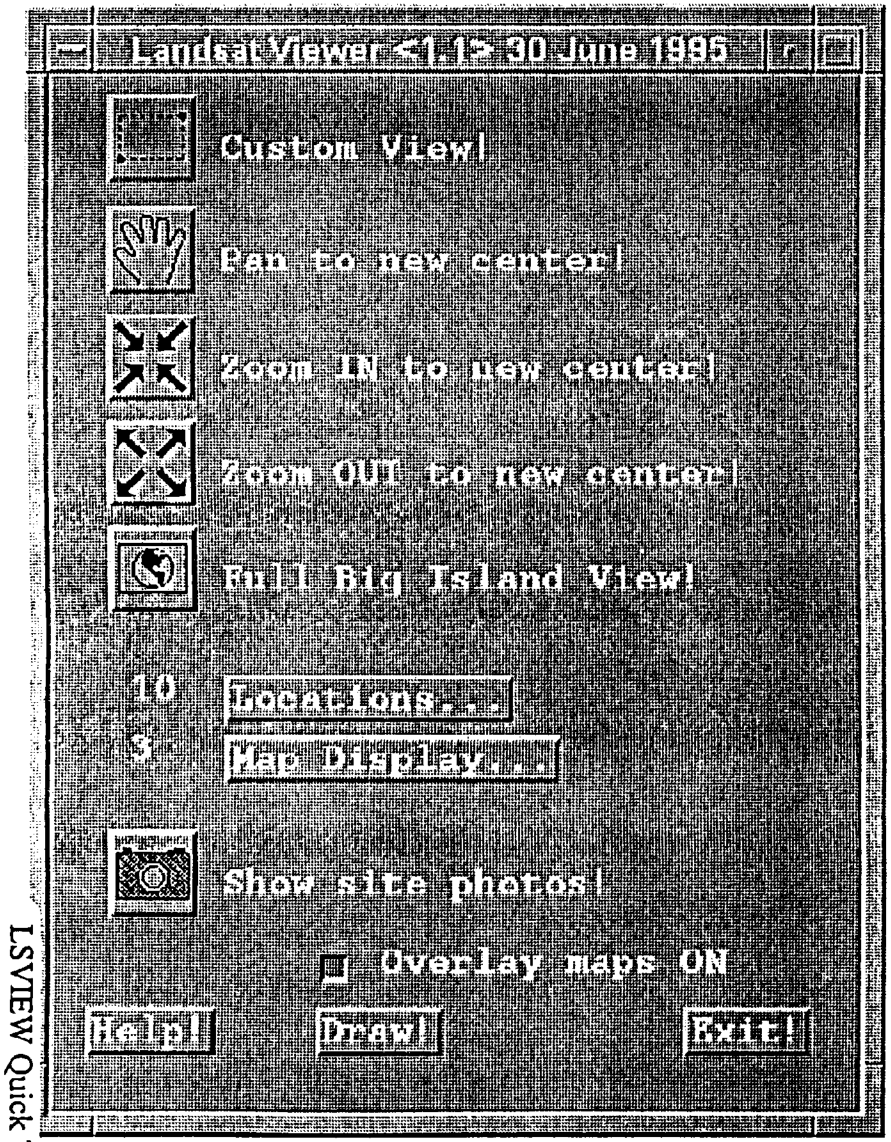
TM 7-5-3 Mosaic has been made active so it will be displayed on the Detail Map the next time the Draw! Button is clicked.

Click 'Draw!' to see all active layers on the Detail Map.

LSVIEW MAP DISPLAY MENU WITH TM 7-5-3 MOSAIC ACTIVE



LSVIEW FULL SCREEN WITH TM 7-5-3 MOSAIC OF MAUNA KEA AREA



The last button to illustrate is 'Show site photos!'

Clicking on this button brings up a graphics cursor with which the user can click on any of the GPS or non-GPS site circles shown on the Detail Map.

All photos taken at that site that have been scanned into a TIF format file will be displayed on the screen. Each photo will appear in its own popup window.

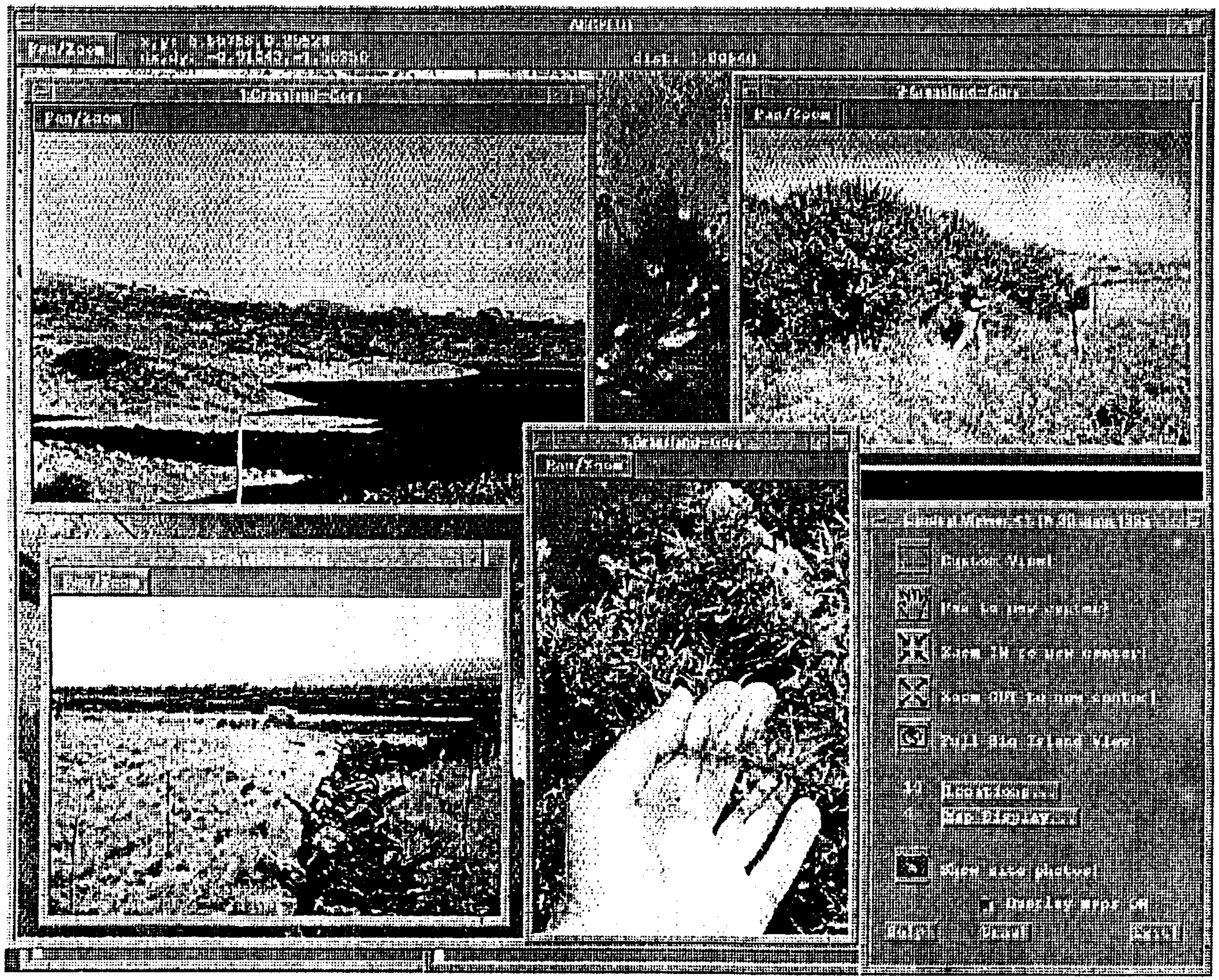
Each popup window can then be moved, re-sized, and zoomed in and out using the Pan/Zoom tools on the upper left corner of the window.

Each popup window can be removed independently of the others by closing the window.

The screen on the next page shows four photos from a single site in the Mauna Kea area. The plant shown in the closeup is gorse.

This completes the LSVIEW Quick Tour.

LSVIEW MAIN MENU TO SHOW SITE PHOTOS



LSVIEW FULL SCREEN SHOWING SITE PHOTOS NEAR MAUNA KEA

APPENDIX F - Change Detection

1) MSS 1977 Raw Data Mosaic

2) Change Detection from the University of Hawaii

    1: Lava Flows at Hawaii Volcanoes National Park

    2: Gorse and Koa-Banana Poka

    3: Eucalyptus Plantation Keyhole

    4: Change in Sugar Cane Cultivation

    5: New Golf Courses

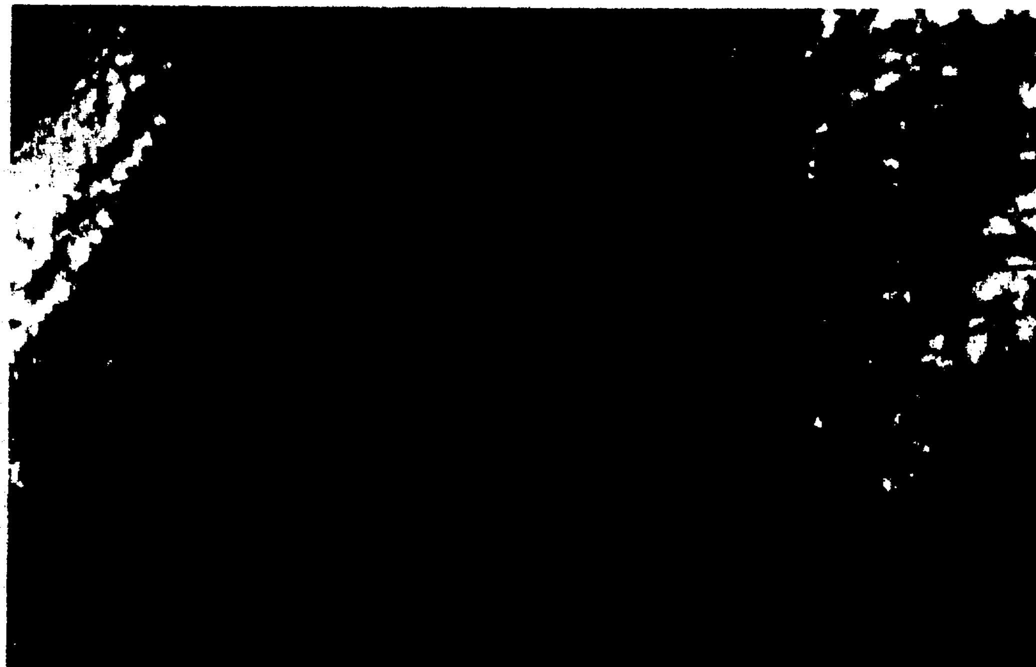
    6: Mauna Kea Forest Reserve Area

3) List of MSS and TM Band Combinations Revealing Significant Change

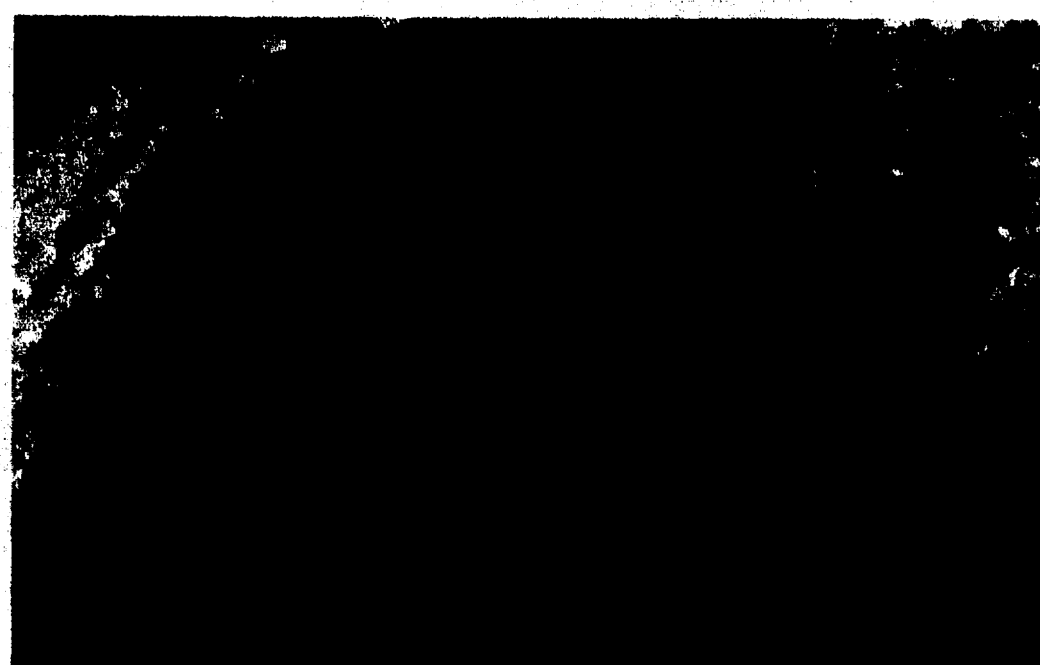
4) TM Raw Data Mosaic

MSS 1977 Raw Mosaic
Big Island
Acquired same day

Lava Flows



R (MSS4) G (MSS2) B (MSS1)



R (TM4) G (MSS4) B (MSS1)

Scale
1 : 350000

The top image is the 1977 MSS data. The bottom image is the 1991 TM data combined with the MSS data depicting the change in this land area. New lava flows are shown in green in the upper right portion of this image. Note: Landsat TM is currently the only satellite that provides shortwave bands 7 and 5 to detect active lava and provide maximum separation of lava, soil, and vegetation.

Digital data includes 4 scenes from Landsat TM (June 1989, June 1990, and Oct. 1991) registered with 2 scenes from Landsat MSS (Oct. 1977). All geographic databases of the State of Hawaii Geographic Information System are in UTM Zone 4, although the Island of Hawai`i is in UTM Zone 5. This image is projected into UTM Zone 4 to comply with the State of Hawai`i database design. Base is adapted from Hawai`i Island USGS 1:24,000 topographic maps. Old Hawaiian Datum is based on Clarke 1866. MSS processing by Ed Petteys, Chris Hogan, Pat Costales, Mike Buck, and Craig Tasaka. TM processing by Chris Hogan, Ron Cannarella, Leo Ikebara, and Roger Imoto.

This map was funded by NASA Grant NAGW-3812 and produced in concert by the following:
State of Hawai`i Office of State Planning,
DLNR Division of Forestry and Wildlife,
University of Hawai`i, Department of Geography
Geographic Decisions Systems Int`l, and Hogan Co.

Mosaic by Chris Hogan and Leo Ikehara.
Map design by Renee Louis and Eric Yamashita.
Thanks for contributions by Julio Polo, Steve Sakata, Matt McGranaghan, Rob Kiessling, and Harold Garbiel.

Lava Flows
Volcanoes N.P., Big Island
Change Detection 1 of 6
From U.H. Geography Dept.
Appendix F #2

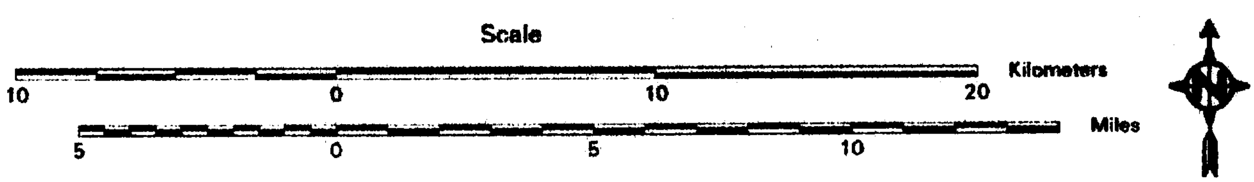
Gorse and Koa-Banana Poka

R (MSS4) G (MSS3) B (MSS2)

R (TM4) G (TM5) B (TM3)

Koa-Banana Poka

Gorse



The image on the left is comprised of 1977 MSS data only. Gorse and Banana Poka, two exotic plants invading the area, are hard to detect in this image. The image to the right is comprised of 1990 TM data only. Here, Gorse can be seen as a rust color within the yellowish area just below the center of the image extending upward toward the keyhole pattern at the top center of the image. Koa-Banana Poka is seen as an orange-red. The yellowish areas of the image are the high elevation pastures of Mauna Kea.

Digital data includes 4 scenes from Landsat TM (June 1989, June 1990, and Oct. 1991) registered with 2 scenes from Landsat MSS (Oct. 1977). All geographic databases of the State of Hawaii Geographic Information System are in UTM Zone 4, although the Island of Hawai`i is in UTM Zone 5. This image is projected into UTM Zone 4 to comply with the State of Hawai`i database design. Base is adapted from Hawai`i Island USGS 1:24,000 topographic maps. Old Hawaiian Datum is based on Clarke 1866. MSS processing by Ed Petteys, Chris Hogan, Pat Costales, Mike Buck, and Craig Tasaka. TM processing by Chris Hogan, Ron Cannarella, Leo Ikehara, and Roger Imoto.

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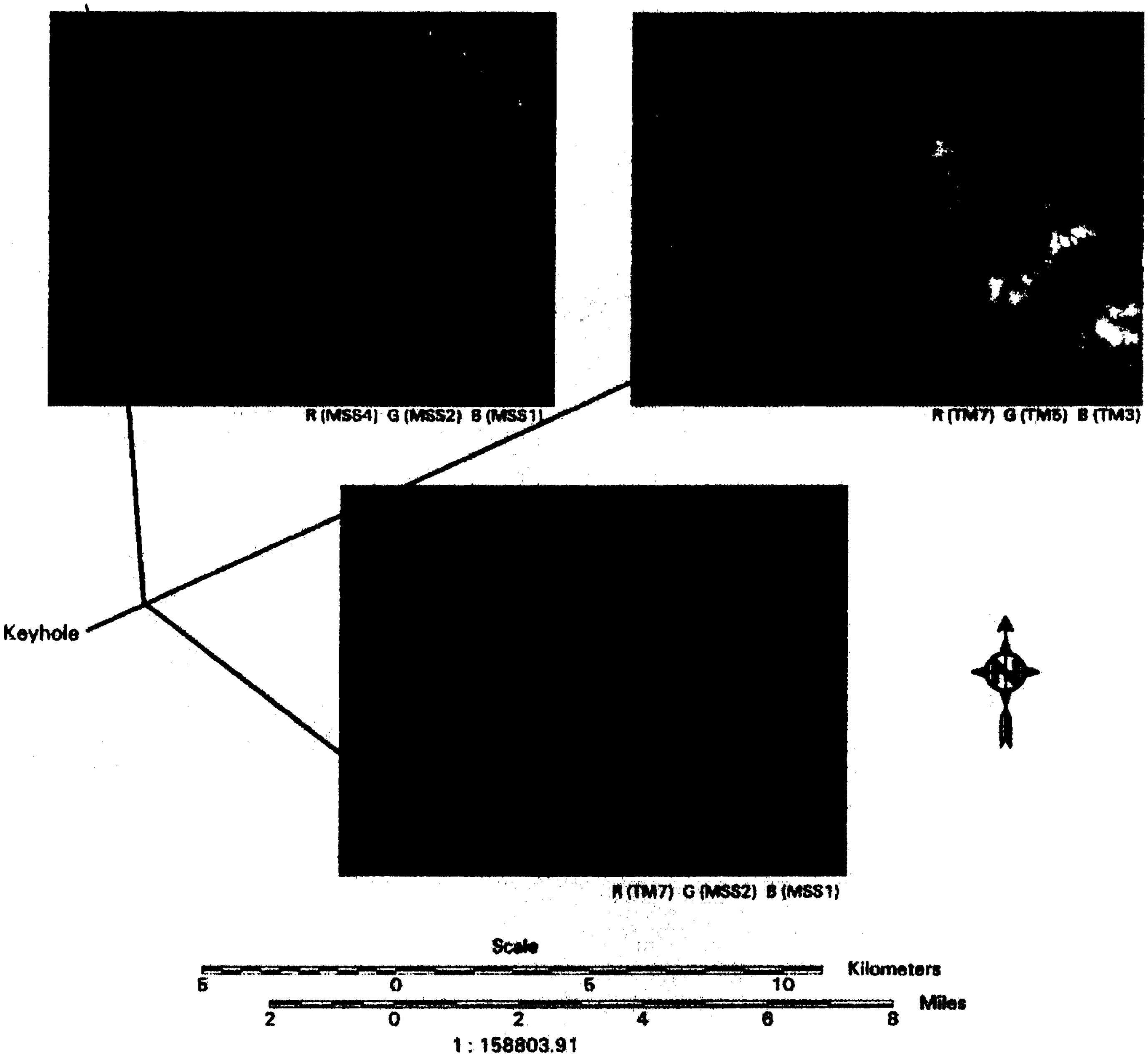
Keyhole



The keyhole pattern in the lower left corner of each image is a Eucalyptus Forest Plantation. The image in the upper left depicts 1977 MSS data of the keyhole. Since the Eucalyptus comprising the rectangular portion of the keyhole is not planted it shows up as a different color from the square portion which is planted. The image in the upper right depicts the 1990 TM data. Here, the entire keyhole is the same color since the entire region is planted. The lower center image depicts both the MSS and the TM data and shows the change between the two data as a bright green color.

Digital data includes 4 scenes from Landsat TM (June 1989, June 1990, and Oct. 1991) registered with 2 scenes from Landsat MSS (Oct. 1977). All geographic databases of the State of Hawaii Geographic Information System are in UTM Zone 4, although the Island of Hawai`i is in UTM Zone 5. This image is projected into UTM Zone 4 to comply with the State of Hawai`i database design. Base is adapted from Hawai`i Island USGS 1:24,000 topographic maps. Old Hawaiian Datum is based on Clarke 1866. MSS processing by Ed Petteys, Chris Hogan, Pat Costales, Mike Buck, and Craig Tasaka. TM processing by Chris Hogan, Ron Cannarella, Leo Ikehara, and Roger Imoto.

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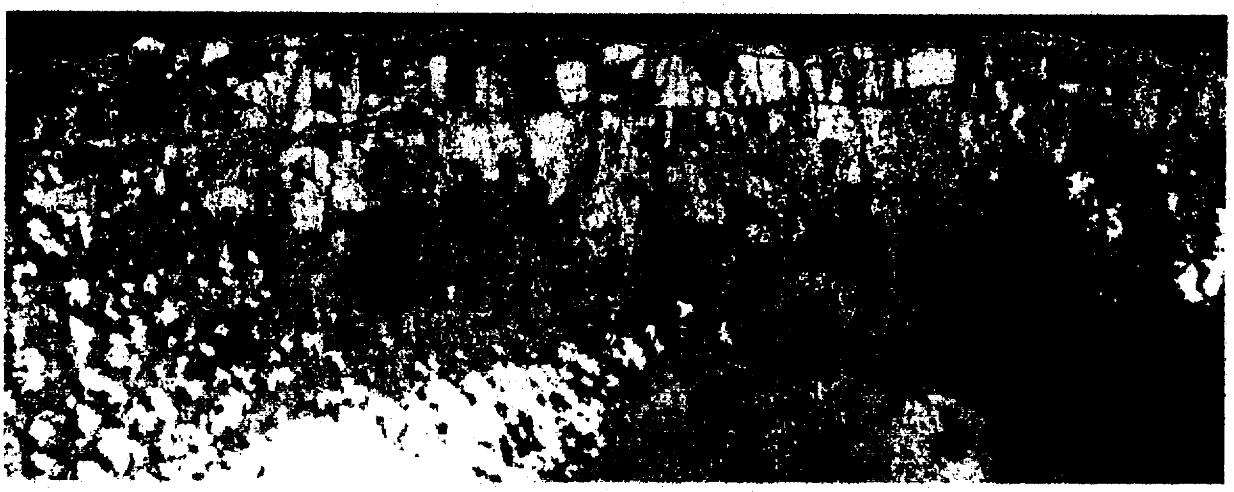
Thanks for contributions by Julio Polo, Steve Sakata, Matt McGranaghan, Rob Kiessling, and Harold Garbiel.

Hamakua, Hawai`i Island

R (TM7) G (TM5) B (MSS4)



TM Landcover Map

Legend

- Koa, Koa-Ohia, Ash, or Eucalyptus
- Wet Dense Mixed Forest
- Montane Wet Ohia-Shrb
- Bare Soil

Legend

- Shadow, Water
- Sugar Cane
- Dry Koa Community
- Montane Dry Koa with Banana Poka

Legend

- Montane Wet Exotic Grassland
- Cloud
- Firetree

Scale

10 — 0 — 10 Kilometers

5 — 0 — 5 Miles

1 : 190000

The top image shows both 1990 TM and 1977 MSS data, therefore it displays the land use/cover changes in this area. The green represents planted fields on both dates. The bright blue represents a change. The lower image is the classified map extracted from the TM image with its legend below it.

Digital data includes 4 scenes from Landsat TM (June 1989, June 1990, and Oct. 1991) registered with 2 scenes from Landsat MSS (Oct. 1977). All geographic databases of the State of Hawaii Geographic Information System are in UTM Zone 4, although the Island of Hawai`i is in UTM Zone 5. This image is projected into UTM Zone 4 to comply with the State of Hawai`i database design. Base is adapted from Hawai`i Island USGS 1:24,000 topographic maps. Old Hawaiian Datum is based on Clarke 1866. MSS processing by Ed Petteys, Chris Hogan, Pat Costales, Mike Buck, and Craig Tasaka. TM processing by Chris Hogan, Ron Cannarella, Leo Ikebara, and Roger Imoto.

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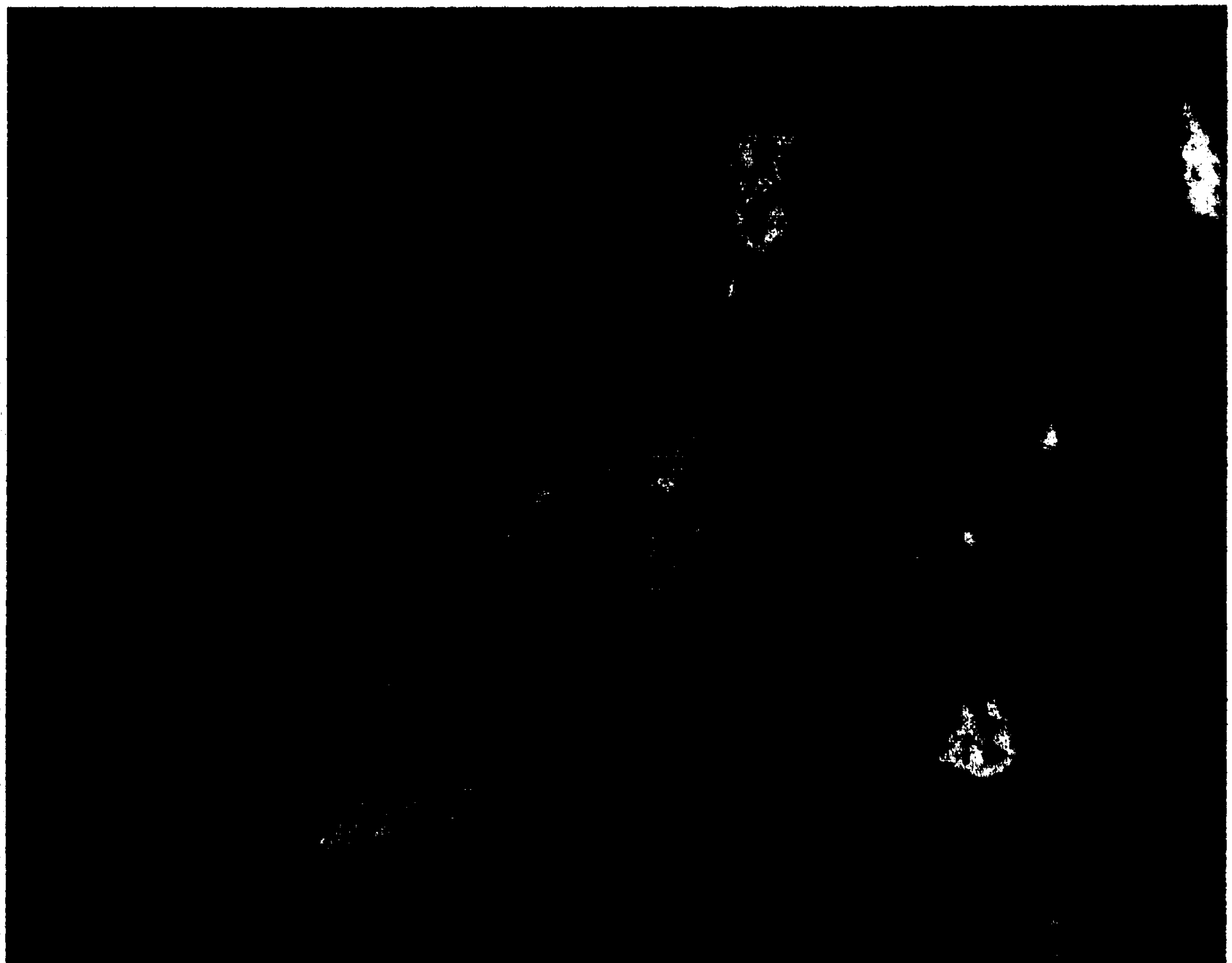
Thanks for contributions by Julio Polo, Steve Sakata, Matt McGranaghan, Rob Kiessling, and Harold Garbiel.

Change in Cane Cultivation
Hamakua, Big Island
Change Detection 4 of 6
From U.H. Geography Dept.
Appendix F #2

Northwest Hawai`i Golf Courses



R (TM7) G (TM4) B (MSS4)

Scale

Kilometers: 2 0 2 4 6 8 10

Miles: 2 0 2 4

1 : 100000

N

This image uses both 1990 TM and 1977 MSS data. A cyan or light blue color represents areas where little to no change has occured. The two cyan areas at the top and center of the image have traces of green and red which depicts some sort of change. The golf course at the bottom left of the image is completely new as it is entirely green and orange. Note the ability to see the golf course design and the cloud shadows. The rusty brown area near the cloud shadow is a Buffelgrass-Kiawe mix and the yellow brown area in the lower right is Fountain grass.

Digital data includes 4 scenes from Landsat TM (June 1989, June 1990, and Oct. 1991) registered with 2 scenes from Landsat MSS (Oct. 1977). All geographic databases of the State of Hawaii Geographic Information System are in UTM Zone 4, although the Island of Hawai`i is in UTM Zone 5. This image is projected into UTM Zone 4 to comply with the State of Hawai`i database design. Base is adapted from Hawai`i Island USGS 1:24,000 topographic maps. Old Hawaiian Datum is based on Clarke 1866. MSS processing by Ed Petteys, Chris Hogan, Pat Costales, Mike Buck, and Craig Tasaka. TM processing by Chris Hogan, Ron Cannarella, Leo Ikebara, and Roger Imoto.

This map was funded by NASA Grant NAGW-381
and produced in concert by the following:
State of Hawai`i Office of State Planning,
DLNR Division of Forestry and Wildlife,
University of Hawai`i, Department of Geography
Geographic Decisions Systems Int`l, and Hogan

Mosaic by Chris Hogan and Leo Ikehara.
Map design by Renee Louis and Eric Yamashita.
Thanks for contributions by Julio Polo, Steve Saka
Matt McGranaghan, Rob Kiessling, and Harold Gar

Golf Courses
Puako, Big Island
Change Detection 5 of 6
From U.H. Geography Dept.
Appendix F #2

Mauna Kea Area Reserve

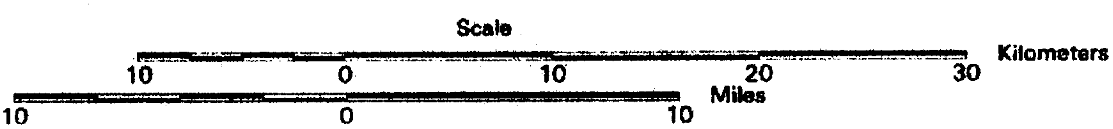
R (MSS4) G (MSS2) B (MSS1)

R (TM7) G (TM5) B (TM2)

TM Landcover Map

Legend

- Bare Lava
- Shadow
- Cinder-Ash
- Montane Mesic Exotic Eucalyyptus
- Montane Wet Exotic Grassland
- Montane Dry Open Koa-Mamane Forest
- Subalpine Dry Open Mamane Forest
- Montane Dry Open Mamane-Naio Forest
- Subalpine Dry Open Grassland
- Subalpine Mesic Open Shrubland



1 : 355777.28

The image at the top left shows only 1977 MSS data. The image at the top right shows only 1990 TM data. The lower image is the classified map extracted from the TM image with its legend to the right of it.

Digital data includes 4 scenes from Landsat TM (June 1989, June 1990, and Oct. 1991) registered with 2 scenes from Landsat MSS (Oct. 1977). All geographic databases of the State of Hawaii Geographic Information System are in UTM Zone 4, although the Island of Hawai`i is in UTM Zone 5. This image is projected into UTM Zone 4 to comply with the State of Hawai`i database design. Base is adapted from Hawai`i Island USGS 1:24,000 topographic maps. Old Hawaiian Datum is based on Clarke 1866. MSS processing by Ed Petteys, Chris Hogan, Pat Costales, Mike Buck, and Craig Tasaka. TM processing by Chris Hogan, Ron Cannarella, Leo Ikehara, and Roger Imoto.

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Mosaic by Chris Hogan and Leo Ikehara.
Map design by Renee Louis and Eric Yamashita.
Thanks for contributions by Julio Polo, Steve Sakata, Matt McGranaghan, Rob Kiessling, and Harold Garbiel.

Mauna Kea Area Reserve
Mauna Kea, Big Island
Change Detection 6 of 6
From U.H. Geography Dept.
Appendix F #2

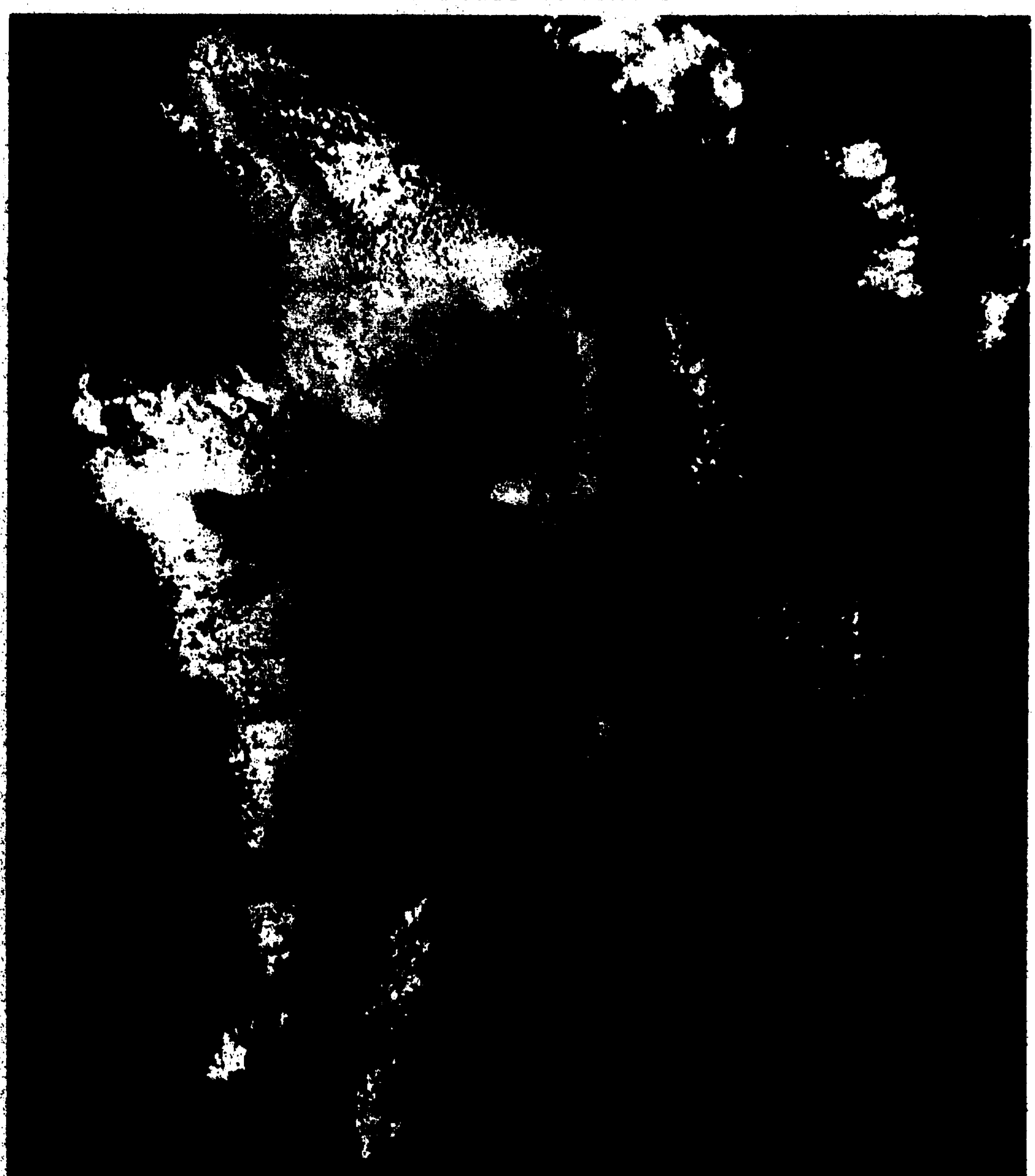
List of Band Combinations from Landsat MSS and MultidateTM Mosaic

The MSS mosaic from 1977 and multidate TM mosaic (6/1989, 6/90, 10/91) were registered together using DLG's in the State of Hawaii Database. The multidate mosaic is projected into UTM Zone 4, Clarke 1866, Old Hawaiian Datum, to comply with the state database design. Different spatial, spectral, and temporal resolutions are used to reveal change in landscape.

Bands:	TM	MSS	Viewer Layers:	TM	MSS
	7-5-4-3-2-1	4-3-2-1		10-9-8-7-6-5	4-3-2-1

Layer/Band:	Types of Vegetation / Land Cover Change
Layer Combinations: 10-2-1 Band Combinations: 7-2-1	Increase in Density of Gorse , Eucalyptus Keyhole
Layer Combinations: 9-8-4 Bands Combinations: 5-4-4	Mauna Loa Gardens-Mac nut; Hamakua sugar
Layer Combinations: 8-4-1 Band Combinations: 4-4-1	Laupahoehoe Open Forests - Banana Poka, Gulches, urban growth, Kupaianaha flow 1986-1992 and Kalapana, and cloud shadow
Layer Combinations: 10-9-4 Band Combinations: 7-5-4	Cloud - opaque, repeat burn area Puna (1977, 1983, June 1991); Kupaianaha flow 1986-1992 and Kalapana; sugar cane planted both dates, 1984 Lava flow from Mauna Loa, 1977 Lava Flow from Kilauea, dense biomass increase of Gorse, change in wet pasture grasses, and golf coarse and biomass increase of Kiawe forest near Mauna Lani Hotel
Layer Combinations: 10-4-2 Band Combinations: 7-4-2	Biomass increase in Coastal Kiawe Forest, and Open Kiawe Forest - Buffelgrass
Layer Combinations: 10-9-2 Band Combinations: 7-5-2	Moisture and biomass increase in Fountain Grass
Layer Combinations: 8-9-3 Band Combinations: 4-5-3	Separation of different forest types (i.e.. Myrica faya from Ohia, Ohia-Koa from Gorse, with Ohia-Koa appearing rusty brown, M. faya and Gorse appearing bright red; biomass change in HVNP forest west of Kipuka Ki, and separation of vegetation-lava from vegetation-soils.

The Application of Remote Sensing Data to a GIS Study of Land Use, Land Cover, and Vegetation Mapping in the State of Hawai`i



Big Island
Raw data mosaic

APPENDIX G - Map Composition

1) Map Composition Process ERDAS to ARC/ Info
2) Sample of Image Mask Process in ERDAS/Imagine
3) Large Format Negative Production

DESCRIPTION OF FILES UNDER /VG03/nasa/finmaps/amls

The two main AMLs in this directory:

finalmap.aml	This AML creates a map of the final supervised classification.
finalmapraw.aml	This AML creates a map of the raw Landsat image.

The other files under this directory include:

contour.aml	This AML draws the contour lines and is called by finalmap.aml and finalmapraw.aml.
geo.proj	Geographic projection file used to draw Lat/Long grid lines.
utm4.proj	UTM projection file used to draw Lat/Long grid lines.
imgcolor.aml	This AML was developed by Royce Jones. It creates shadeset, c.map file, and a key file to match a specified grid. A name of a grid must be specified in order to run AML.

DESCRIPTION OF FILES UNDER /VG03/nasa/finmaps/covers

oceanshd	This coverage is used to shade the ocean.
pathrow	This is the Satellite Path/Row Index coverage.
placenames	Annotation coverage for placenames.

DESCRIPTION OF FILES UNDER /VG03/nasa/finmaps/grids

finalgrid.shd	Shadeset for final supervised classification grid.
finalgrid.key	Keyshade for final supervised classification grid.
finalgrid	This is the final supervised classifcation grid that was created with ARC's imagegrid command. From this grid, the **finalgridclip** is created to clip out the data in the water.

finalgridclip	Final supervised classification grid. To view grid in arcplot: gridpaint /vg03/nasa/finmaps/grids/finalgridclip # identity ~ nowrap /vg03/nasa/finmaps/grids/finalgrid.cmap
bicstgrid	This grid was created by Royce in order to clip out data in the water.
hawcst	This is a copy of the Hawaii coastline coverage in /vg02/prime/basemap/final/@coast. Royce made a copy of it, and defined its coordinate system.

DESCRIPTION OF FILES UNDER /VG03/nasa/finmaps/keyfiles

contour.lkey	Contour keyline file.
finalinfo1.txt	Map information for final supervised classification map.
finalinfo2.txt	Map information for final supervised classification map.
gps.mkey	GPS marker file
rawinfo1.txt	Map information for Raw Landsat map
rawinfo2.txt	Map information for Raw Landsat map
rdmang.lkey	Major Roads, and Publicly Owned Protected Areas keyline file.
source.txt	Map source file.Map source file.

As of December 27, 1995 the final supervised classification is stored under:
/vg03/nasa/finmaps/grids/ and it is called **finalgridclip.**

As of December 27, 1995 the raw Landsat image is stored under:
/vg03/nasa/leo/makemaps and it is called **hawaiimosaic.lan.**

IMAGE MASKING

Example 1:

Water mask - make a copy unsupervised classification image file, select water classes and recode to 0, make all other land cover equal to 1.

Raw image input 1 X Cl water Mask = new raw image for classification.

Reclassify with water mask to classify only land.

Example 2:

Water in IR 7-5 or 4 subset into single channel and recode water-land boundary.

Separators 0-1; Image Interp>Util>Operators

Input original image, Input mask X = new raw image for classification.

Mask a land cover for classification:

Forest Vis3 or NIR4 same procedures as above.

Arc Info Polygrid with / without off shore island and new land buffer.

Island of Hawaii - Landsat Classification Project
Notes - Rod Low - 2/8/96

Production of 4" x 5" Film Negatives

1. Received graphics files from Leo's program.
2. Used Arc/Info's Postscript Command to produce Encapsulated Postscript files.
3. Used Alchemy version 1.7 to convert EPS to TIFF format
   a. Parameters for Raw Mosaic Map:
      alchemy /gis5/nasa/hawraw.eps /gis5/nasa/hawraw.tif -t1 -Zm 2 -Zi 29 40 -Zo 4i 5i -Zd 3400 3400 -Z+
      TIF file characteristics:
      Width x Height: 12325 x 17000
      Number of Colours: True Colour (24 bits)
      Dots per inch: 3400 x 3400
      Image size (inches): 3.62 x 5.00
      LZW Compressed file size: 111 Megabytes
   b. Parameters for Classification Map:
      alchemy /gis5/nasa/hawaii.eps /gis5/nasa/hawaii.tif -t1 -Zm 2 -Zi 40 34 -Zo 5i 4i -Zd 4000 4000 -Z+
      TIF file characteristics:
      Width x Height: 18824 x 16000
      Number of Colours: True Colour (24 bits)
      Dots per inch: 4000 x 4000
      Image size (inches): 4.71 x 4.00
      LZW Compressed file size: 38 Megabytes
4. Negatives created by SnapShot using Adobe Photoshop

Vectorization of Classified Image (in Arc/Info)

1. Erdas IMG file converted to Arc/Info Grid using IMAGEGRID command. Resulting grid named HAW_SCL.
2. Coastline vector coverage buffered 1 kilometer.
3. Buffered coastline converted to Grid using POLYGRID command. Resulting grid named COASTBUF. Grid cells out to 1 km from the coast received a value of 1, those outside the 1 km buffer were given a value of NODATA.
4. Each quad was processed in the GRID module as follows:
   a. For an area a little larger than each quad, the command SETWINDOW * HAW_SCL was given.
   b. QUAD = HAW_SCL * COASTBUF
   c. The GRIDPOLY command was used with a fuzzy tolerance of 1 meter.
   d. Each vectorized coverage was clipped to the boundaries of the quad. The item GRID-CODE in the PAT (Polygon Attribute Table) contains the value of the original Erdas Image's Class Code.

Still To do:
1. Create more generalized coverages. The proposed method is:
   a. Add a numeric item to each quad's PAT table that will signify each unique color code from the Erdas Image.
   b. Dissolve each original classified quad coverage using this new item.
2. Create Lookup Tables with class description text and color symbols.

APPENDIX H - Project Products

The following Products are either too large or on non-paper media to be bound in this report.

1) E-size Color Plot of Big Island Raw Data Mosaic
   - draft plot
   - final on large format 4X5 negative and CD

2) E-size Color Plot of Big Island Classified Mosaic
   - draft plot
   - final on large format 4X5 negative and CD

3) Raw Data Final Mosaic Map
   - on large format 4X4 Negative and CD

4) Vegetation and Other Land Cover Landsat TM Classification Map
   - on large format 4X5 negative

5) Sample 8X10 size Color Plots of Change Detection

6) Project CD containing final images and map products

7) A Pilot Land Cover Classification System for Remote Sensing Use in Subtropical Hawaii, based on Landsat TM data.