A Geographic Information System for Water Flow and Land Use in the Waimanalo Stream Drainage Basin

Final Report

by

David A. Krupp
Department of Natural Sciences
Windward Community College

for the

Department of Health
State of Hawai‘i

Student Project Team Members

Kimbery Andersen
Brian Gornet
Thomas Masaniai
Jennifer Olson

May 12, 2000

Introduction

Waimanalo Stream, located in the Ko'olaupoko district of the windward (southeastern) side of the island of O'ahu, Hawai'i, drains an area of approximately five square miles. The watershed is relatively narrow (approximately five miles), beginning with the steep cliffs of the Ko'olau Mountain Range, extending across a gently sloping lowlands, and draining into Waimanalo Bay. The average flow rate of Waimanalo Stream is about five cubic feet per second.

The watershed contains a mixture of land uses, including conservation, urban (includes military and residential uses), and agriculture. Of these uses, agriculture may exert the most significant effects upon the water quality of Waimanalo Stream (Thompson, 1993). However, other factors cited as possibly influencing water quality include golf course runoff, cesspool leakage, soil erosion, storm drain runoff, and litter (Wu, 1994). These sources of pollution may be responsible for the degradation of the water quality in Waimanalo Stream and the coastal waters into which it drains. However, there is a clear need to correlate specific land use activities, and their potential pollution sources, with the water quality characteristics of Waimanalo Stream (Stream Bioassessment Program, 1998). Further, since the existing maps are not accurate and do not clearly identify all perennial and intermittent drainages, there was a need to accurately map these drainages and their characteristics.

The first objective of this project was to use the Global Position System (GPS) to determine, with as much detail as possible, where the water flows, identifying tributary and other inlet points along the stream. The second objective was to identify and map features of the stream that may have an influence upon water quality. Finally, the third objective was to begin to map the details of land use features bordering the stream that could also influence water quality in the stream. The information collected was incorporated into a Geographic Information System (GIS) with relevant information from other sources.

Materials and Methods

Field Survey

The field work, begun in October 1999 and concluded in April 2000, was conducted using supervised, trained undergraduate students from Windward Community College (WCC). Location data was collected *in situ* using a Trimble ProXR differential GPS rover unit connected to a Trimble TCD1 datalogger loaded with Asset Surveyor software. This instrument may record geographic information as either point (e.g., a trash dumpsite or a stormdrain inlet), line (e.g., a stream, road, or sewer line), or area features (e.g., a nursery, a crop field, or a livestock enclosure). Specific information about these features (e.g., the physical characteristics of a streambed segment, or the use of a particular property parcel) were also be recorded in rover unit's datalogger while on site. To simplify the field data collection process, the datalogger was loaded with a menu-driven data dictionary appropriate for the type of data to be collected. The type of information collected with the GPS rover unit and incorporated into the GIS may be found in Appendices (II-XIII) of this report.

Differential correction of GPS location data was made in “realtime” mode using radio-transmitted information from a GPS base station (station was auto-selected by the rover unit). Under optimal conditions, differentially corrected data collected by the Trimble ProXR GPS rover unit exhibits a latitude-longitude accuracy of less than one meter. Altitude accuracy, on the other hand, is poorer at about 2-5 meters.

The field surveys were usually conducted by walking down the middle of the stream with the GPS rover unit which was set to collect position information at five-second intervals. Thus for line features, single points represented different locations along the stream or ditch. These points were later used by the instrument software (Pathfinder Office) to draw lines connecting the points. The plotting of area features (e.g., ponds or lakes) involved a similar procedure except that the final point was connected to the first point closing the line into a polygon. For point features (e.g., debris sites, or photo locations), at least five points were recorded at a single location and averaged to calculate a position. Unfortunately, obstructions in the stream (e.g., dense tall grass) or poor satellite reception because of dense forest canopy or deep and narrow ravine walls frequently forced pauses in data collection.

The antenna was set for a logged height of two meters above the ground (the Surveyor Asset software automatically takes this antenna height into account when reporting altitudes). However, the physical height of the antenna was frequently readjusted without changing the logged height (an unavoidable procedure when recording line and area features) while collecting data to optimize access to satellites when under forest canopies or in deep, narrow ravines. These adjustments reduced altitude accuracy by an additional 2-4 meters.

Occasionally, circumstances prevented the surveyors from being in a location where a position needed to be recorded. For example, the stream may have been too deep to walk through or a point location may have been inaccessible (e.g., a building on private property). At these times positions could still be recorded using offset information (horizontal offset, vertical offset, and azimuth from the actual antenna location) entered into the datalogger. Offset information was usually determined using a pulse laser rangefinder. Occasionally, a handheld compass and a measuring tape were used to determine the offset.

Field notes were also collected documenting survey team members, survey dates and times, general survey location, weather conditions, significant events, and other pertinent information not recorded in the datalogger of the GPS rover unit. This information, when appropriate, was incorporated into the GIS or used to enhance or correct information in the GIS.

Data Processing and GIS Development

Data recorded in the datalogger were uploaded onto a computer (Dell Pentium II Windows NT workstation in WCC's Hoaʻaina Remote Sensing and Geographic Information System Center for Environmental Monitoring) using the software (Trimble Pathfinder Office) supplied with the Trimble GPS instrument. Some initial processing of the data (e.g., deletion of extraneous or erroneous GPS points, or correction of attribute values based upon field notes, etc.) may have been done before combining individual data sets into larger data sets. The combined data sets were then exported as ESRI ArcView shape files in UTM 4 North Old Hawaiian (mean) with meters as the measurement unit. The GIS was then assembled using ESRI ArcView (version 3.2) GIS software.

Appendix I summarizes the all of the ArcView themes presented in the Waimanalo Drainage Basin Geographic Information System, including those imported from other sources (e.g., Honolulu City and County and Hawaiʻi State Department of Business and Economic Development). This appendix also presents the theme title (as designated in the WAIMNDRN.APR project file), the file path to the corresponding files on the CD-ROM, a brief description of the theme, location of the explanatory spreadsheet file for the theme (part of the metadata), and the number of records in the theme. These explanatory spreadsheet files (represented in Appendices II-XIII), in Microsoft Excel 2000 format, present information about the attributes (variables) and attribute values for each theme developed from the data collected for this GIS.

The Waimanalo Drainage Basin Geographic Information System is outlined and best reviewed from the ArcView project file WAIMNDRN.APR which may be found in the folder DOHPROJ on the CD-ROM. However, because this project file identifies a computer disk drive letter and file path where the included files occur, it will be necessary to do one of the following (see README text file in the project folder) to view the GIS through the WAIMNDRN project:

> (1) copy the entire DOHPROJ folder onto the "c" drive of the user's computer (do not place the project folder into any other folder), then load the WAIMNDRN project from this drive (note that the DOHPROJ folder uses nearly 200 mB storage memory); or
>
> (2) transfer only the WAIMNDRN.APR file to the user's drive and location on the computer and, using the find-replace function of a text editor (e.g., Wordpad), carry out a global text change on the WAIMNDRN.APR file that replaces the text string c:\ with a text string that substitutes the "c" in the string with the drive letter assigned to the CD-ROM drive of the computer (e.g., replace c:\ with d:\ if the letter "d" is assigned to the CD-ROM drive).

Note that all files on the CD-ROM, including WAIMNDRN.APR, on the CD-ROM have been write-protected. In order to make changes to a file, the user will need to unselect the "Read-only" box in the properties window for the file.

Types of Information (ArcView Themes) Collected by the Present Study and Incorporated into the Waimanalo Stream Drainage Basin GIS.

Waimanalo Stream and Tributaries

The locations of perennial stream channels and intermittent natural drainage channels were mapped using the GPS rover unit in the field (ArcView file = STREAMS). The kinds of information collected included the nature of the streambed itself (e.g., natural material bottom, realigned channel, hardened, culvert under road, etc.), the degree to which the streambed is filled or covered with vegetation, the characteristics of the land bordering the stream, its volume/flow characteristics, and its water quality (Appendix XI). The nature of the land bordering the stream (e.g., vegetation type within 50-100' of the stream) was recorded as occurring on either the south side (BORDERS) or north side (BORDERN) of the stream. Two other features, BUFFERS and BUFFERN, account for the stream segments where some kind of access road ran along side the stream (either the south or north side), separating the stream itself from the land bordering the stream. This data set consists of 174 stream segments.

Drawn Stream and Tributary Lines

Occasionally, the collection of stream data as linear features was impractical (usually because the vegetation in the stream was too thick for passage or the overhead canopy was too dense to acquire satellites). In these cases, lines representing the path of the stream were drawn (ArcView file = DRWSTREM) on the map using several types of information as a guide: individual GPS point locations taken where possible, 5' contour line data from the Honolulu City and County GIS data (see below), and orthorectified infrared aerial imagery (see below). The kind of information recorded in the GIS was the same as that for the Waimanalo Stream and Tributaries theme (Appendix VI), except that GPS parameters could not be presented. This data set consists of 19 stream segments.

Constructed Drainages

Irrigation ditches and other constructed drainages (ArcView file = CONSTDR), whether abandoned or still in use, were located and mapped using the GPS rover unit as described above for the natural drainages (Appendix III). Because many of these ditches ran perpendicular to the stream itself, land characteristics on either side of the ditch may have referred to either the ocean side (BORDERO) or the mountain side (BORDERM) of the ditch, as opposed to the south or north side (BORDERS and BORDERN respectively). A similar convention was used in recording access roads bordering the ditch (i.e., BUFFERO and BUFFERM, ocean and mountain sides respectively, as opposed to BUFFERS and BUFFERN). Golf course ditches were Included as constructed drainages even though many of these resembled natural, albeit altered, drainages. This data set consists of 92 drainage segments.

Drawn Constructed Drainages

As in the collection of stream data, the collection of ditch data as linear features was impractical at times. In these cases, lines representing the path of the drainage were drawn on the map (ArcView file = DRWDRAIN) using several types of information as a guide: individual GPS taken where possible, 5' contour line data from the Honolulu City and County GIS data (see below), and orthorectified infrared aerial imagery (see below). The kind of information recorded in the GIS (Appendix V) was the same as that for the Constructed Drainages theme, except that GPS parameters could not be presented. This data set consists of 6 drainage segments.

Hypothesized Drainages

Four lines representing hypothesized drainages (ArcView file = HYPOFLOW) were drawn in on the map in ArcView. Since these lines, based upon suspicions developed while collecting field data, were highly speculative, no information, other than the line itself, was entered into the GIS.

Inlets

The locations of stream and constructed drainage inlets (e.g., storm drains, field drains, feedlot drains, household drains, parking lot drains, etc.; ArcView file = INLET) were entered into the GPS datalogger as single point features when these inlets were encountered while mapping the stream and its tributaries (Appendix VII). In some cases the inlet location marked the entry point of a tributary or ditch that was mapped as a line feature later in the field study. A total of 34 inlets were recorded.

Significant Debris Sites

The locations of significant or conspicuous debris sites encountered while mapping the streams and ditches were determined and entered into the GPS datalogger (ArcView file = DEBRISSET). Information regarding the nature of the debris and the approximate amount were also recorded (Appendix IV). The data set includes 35 records.

Photo Locations

The locations of sites where 64 photographs were taken using an Epson digital camera were also included in the GIS (ArcView = PHOTOLOC). Some of these locations were located with the GPS while in the field. Others may have been entered on the map manually. These locations are “hotlinked” in the WAIMNDRN project. When the theme is made active, clicking on the locations with the ArcView “hotlink” tool will make the image visible in the view. Note that the hotlink file path is based on the project folder existing on the “c” drive of the user’s computer. Thus, in order to use the “hotlinks” established in the WAIMNDRN project, the DOHPROJ folder must reside on the “c” drive of the user’s computer.

Water Bodies

Bodies of water (ponds, lakes, and reservoirs) encountered in the study area were mapped as area features (polygons) by walking around the water body one meter out from its shoreline (ArcView file = WATERBOD). To account for the discrepancy between the path walked and the actual shoreline, the datalogger was set to account for the one meter offset. Information was recorded for a total of 8 water bodies (Appendix XIII).

Groundtruthed Land Use Points
The locations of 295 buildings and land use areas near the stream, its associated tributaries and drainages were determined as point features using the GPS rover unit in the field (ArcView file = LANDUSE; Appendix IX). Because of property access limitations, many of these points were determined remotely using a pulse laser rangefinder to calculate the position offset from the GPS antenna location. These points then served as references for the drawing of ArcView polygons (these polygons are represented in two ArcVIew files, see below) around corresponding features identified in the aerial imagery.

Land Use Types
Referring to the groundtruthed land use points laid over orthorectified infrared aerial images of the study area in the GIS (see below), polygons were drawn in ArcView around areas whose land use type (Appendix VIII) could be identified in the images (ArcVIew file = LANDTYPE). Because of the limited pixel resolution, in addition to cloud cover in the images, only 22 areas were identified and drawn in at the time this report was being compiled. Eventually, more polygons for this theme will be added to the data set, especially after incorporation of IKONOS satellite images of the study site (see below).

Buildings and Structures
Referring to the groundtruthed land use points laid over orthorectified infrared aerial images of the study area in the GIS (see below), polygons were drawn in ArcView around buildings and structures (Appendix XII) that could be could be identified in the image (ArcView file = USEAGE). Because of the limited pixel resolution, in addition to cloud cover in the images, only 150 buildings and structures were identified and drawn in at the time this report was being compiled. Eventually, more polygons for this theme will be added to the data set, especially after incorporation of IKONOS satellite images of the study site (see below).

Infrared Aerial Digital Images
Because the IKONOS satellite images (see below) of the study area were not available at the time the GIS was being prepared, georectified infrared aerial digital images were obtained from the Cartography Laboratory of the Geography Department of the University of Hawai‘i (courtesy of Dr. Matt McGranaghan). These images, taken during 1991-94 by Air Survey Hawai‘i for the State of Hawai‘i, were originally scanned at 200 dpi by the Cartography laboratory. Pixel resolution was approximately two meters. The images were “rubbersheeted” (orthorectified) using ArcView Image Analysis to correct for lens and camera angle distortions and to match the map projection/coordinate system of the GIS. The control points used to carry out this orthorectification were street intersections that were both visible in the images and the Hawai’i’ State Department of Business and Economic Development GIS layers illustrating roads in the study area. This photographic GIS layer permitted filling in the information gaps left in areas where field surveys could not be conducted because the landowners/tenants refused to provide access or because the environment made GPS data collection impractically difficult (e.g., a tall, thick forest canopy). In

order to bring these images into the view of the GIS, the user must turn on the Image Analysis extension in ArcView (ArcView files = NEW_031588, NEW_071581, NEW_ 081583, & NEW_094531; Appendix I).

Comments made About Field Locations

Occasionally it was useful to record a short comment into the GPS datalogger about a specific recorded location in the field (ArcView file = COMMENTS; Appendix I).

IKONOS Satellite Imagery

IKONOS satellite imagery of the study location was obtained (one meter pixel resolution), but, because of difficulties in achieving the appropriate weather conditions (i.e., less than 20% cloud cover in the study area when the satellite was overhead), the images were not available for incorporation into this GIS. Eventually, these images will be incorporated into an updated version of this GIS. These images will also be used to improve the interpretations made from the groundtruthed land use points.

Other Themes Incoporated into the GIS

Hawai‘i State Department of Business and Economic Development Themes

Several themes from the Hawai ‘i State Department of Business and Economic Development (DBEDT) GIS were incorporated after removing features outside of the study area (Appendix I): DBEDT Perennial Streams (ArcView file = PERSTRM), DBEDT Streams and Ditches (ArcView file = DBDTSTRM), DBEDT Major Roads (ArcView file = MAJORRD), and DBEDT Minor Roads (ArcView file = MINORRD). In addition, the entire outline of the island of O‘ahu is presented in DBEDT Oahu Outline (ArcView file = OAHCOAST).

Honolulu City and County Themes

Themes from the Honolulu City and County GIS were provided by Ken Schmidt. Unfortunately, these themes were projected into a different coordinate system (State Plane) from that of the DBEDT themes. Consequently, these layers were transformed into UTM 4 North Old Hawaiian (mean) in ArcView 3.2. After completing the transformation, selected themes were edited to remove features outside of the study area. The relevant themes incorporated into the GIS included the following (Appendix I): Honolulu C&C Wastewater Pipes (ArcView file = SEWER), Honolulu C&C Potable Water Main Facilities (ArcView file = PWMAIN), Honolulu C&C Wasterwater Facility Pump Station (ArcView file = PUMPS2), Honolulu C&C Parcel Data (ArcView file = PARCELS), Honolulu C&C 5’ Topographic Contours (based upon 1961 aerial photographs, ArcView file = 5FTTOPO), Honolulu C&C Water Bodies (ArcView file = WATBOD), Honolulu C&C Parks Layer (ArcView file = PARKS), Honolulu C&C Flood Zones (ArcView file = FLOOD), Honolulu C&C Soils Data (ArcView file = SOILS), and Honolulu C&C Zoning (ArcView file = ZONING2).

Results and Discussion

Nearly 11 km of Waimanalo Stream and its tributaries, as 193 linear segments, were mapped by this GIS (Table I). Of this value, nearly 5 km of stream data (174 linear segments) were collected by walking in or along the stream. In addition, nearly 5 km (ca. 4.5 km *in situ* data; 92 linear segments) of constructed drainages and ditches (98 linear segments) were mapped in the GIS (Table II). Point locations recorded included 295 groundtruthed land use points, 35 significant debris sites (Table V), 34 inlets, 64 photograph locations, and 31 comment locations. Eight water bodies were mapped as area features.

Table I
Streambed Characteristics of the Mapped Segments of
Waimanalo Stream and its Tributaries

STREAMBED TYPE	TOTAL LENGTH OF SEGMENTS COMBINED (m)	LENGTH PERCENT
channelized	3250	29.6
culvert under road	257	2.3
lined, one wall	612	5.6
lined, u-shaped	333	3.0
lined, v-shaped	5777	52.6
natural	153	1.4
road bridge	23	0.2
underground pipe	2	
Total	10974	100

Collection of stream and tributary data was very difficult and time-consuming because of the vegetation in or above the stream channel. Approximately 34% of the surveyed regions of the stream, and was choked with dense growths of tall grass (California grass usually; Table III, Fig. 4) Passage through these choked areas often required cutting our way through with a sickle or machete. Occasionally, we climbed up over the grass which was often thick enough to support our weight some 5+ feet above the streambed. Sometimes the thickness of the grass made it difficult to find the exact location of the stream below. Finally, the grass became tall and thick enough in some regions of the stream so as to make the stream impassible. The constructed drainages and ditches were generally clearer (Table IV).

Table II
Types of Constructed Drainages and Ditches Mapped in this Study

DRAINBED TYPE	TOTAL LENGTH OF SEGMENTS COMBINED (m)	LENGTH PERCENT
dam pipe	22	0.4
dam spillway	15	0.3
golf course ditch	2267	45.7
roadside ditch	747	15.1
small ditch	1572	31.7
underground pipe	339	6.8
Total	4962	100

Table III
Vegetation In or Above the Mapped Stream and Tributary Segments

TYPE OF GROWTH	TOTAL LENGTH OF SEGMENTS COMBINED (m)	LENGTH PERCENT
clear	2591	23.5
clear w/ orange sediment	13	0.1
choked short grass	476	4.3
choked tall grass	3713	33.8
canopy (clear)	1536	14.0
choked and canopy	497	4.5
some vegetation	1399	12.7
uncertainl	759	6.9
Total	10974	100

At other times, data collection was impaired by the deepness of the ravine containing the stream and the thickness of the tree canopy overhead. Determination of GPS locations required that the GPS rover receiver was able to communicate with at least four satellites spaced widely enough in the sky such that the position dilution of precision (PDOP) was six or less. Deep, narrow ravines, and thick canopies severely limited access to a clear sky, and, hence, to the satellites. There were many times during the survey when we had to wait a long time in one location before enough satellites (in the right locations overhead) could be accessed to acquire a reliable position.

Table IV
Vegetation In or Above the Mapped Constructed Drainages and Ditches

TYPE OF GROWTH	TOTAL LENGTH OF SEGMENTS COMBINED (m)	LENGTH PERCENT
clear	2164	48.3
choked short grass	541	12.1
choked tall grass	534	11.9
canopy (clear)	708	15.8
choked and canopy	311	6.9
dirt filled	76.4	1.7
some vegetation	266	5.0
thick bushes/shrubs	401	8.9
Total	4962	100

Table V
Types of Debris Sites Mapped in the GIS

TYPE OF DEBRIS	COUNT
auto batteries	
auto parts	
commercial debris	

construction waste	
fallen branches, logs	
household/commercial/construction combination	
household waste	
rugs	
yardwaste	
Total	

It was often difficult to determine the characteristics of the land 50-100’ on either side of the stream or ditch. Tall, steep walls to the stream or ditch made it difficult to observe these characteristics from within the stream. In addition, the vegetation bordering the stream was often so thick as to limit these interpretations to the 10-20’ nearest the stream.

Limited private property access also impaired comprehensive data collection. While most of the landowners and tenants encountered were very cooperative, a few viewed our activities with considerable suspicion. However, because of the number of properties in the study areas and difficulties in contacting landowners and tenants, it was impractical to attempt onsite surveys in every property bordering the stream. Fortunately, hostile domesticated animals (e.g., dogs) were only rarely encountered.

One approach to mapping locations in inaccessible areas involved determining the offset (horizontal distance and azimuth) between the GPS receiver antenna and the location. The offset was usually determined using a pulse laser range finder connected to the Trimble GPS unit. In this way, offset information recorded by the rangefinder was used to automatically incorporate the offset into the GPS location. This approach usually required a clear line-of-sight between the antenna and the location. While this approach, used mainly in acquiring the groundtruthed land use points, greatly enhanced our ability to plot locations in inaccessible areas, there were many locations in areas that could not be reasonably accessed. Hopefully, future evaluation of both the infrared aerial imagery and the IKONOS satellite imagery will permit more comprehensive mapping of locations in inaccessible areas.

An attempt was made to draw polygons representing land use types and buildings (Table I, Fig. 1) using the groundtruthed land use points in concert with infrared aerial imagery. Five factors significantly impaired the effectiveness of this approach: the pixel resolution of the image (ca. two meters), cloud cover in the imagery, the early dates the images were taken (1991-94), the inaccessibility of certain locations (see previous two paragraphs), and difficulties in determining the functions of specific locations (especially certain buildings). However, these interpretations may be improved by future evaluation of the IKONOS satellite images and future field studies.

Examples of the kinds of analyses that can be constructed from this GIS are illustrated in Tables I through VIII. Many more analyses investigating spatial relationships among the features of the GIS are possible, depending upon the questions asked by, and the creativity of, the GIS user.

Table VI
Types of Land Use Polygons Mapped in the GIS

TYPE OF USE	COUNT	AREA (m2)
auto batteries		
auto parts		
commercial debris		
construction waste		
fallen branches, logs		
household/commercial/construction combination		
household waste		
rugs		
yard waste		
Total		

Table VII
Types of Building and Structure Polygons Mapped in the GIS

TYPE OF USE	COUNT	AREA (m2)
auto batteries		
auto parts		
commercial debris		
construction waste		
fallen branches, logs		
household/commercial/construction combination		
household waste		
rugs		
yard waste		
Total		

Examples of the kinds of maps that can be constructed are illustrated in Figures 1 through 6. Figure 1 illustrates most of the information collected by this survey along with 5' topographic contours, DBEDT streams and ditches, roads, property parcels, wastewater facility pipes, and potable water mains. Figure 2 presents the soil types from the Honolulu City and County data behind the stream. Figure 3 identifies the streambed types of different stream segments. Figure 4 identifies the kind of overgrowth in different stream segments. Figure 5 identifies the different kinds of debris sites in or near the stream. Figure 6 shows the stream over a background of infrared aerial images. Other maps illustrating other relationships and features of the GIS may be prepared as well.

The existing Waimanalo Stream Drainage Basin GIS must be regarded as incomplete. The project, originally anticipated to require only about two months of field work, took a much longer period of time. Much of this additional time was required because of the difficulties cited above (impassible streams, dense canopies, narrow and deep ravines, private property access problems, and delays in acquiring the aerial imagery). Other factors contributing to delays in data collection and gaps in the data included occasional poor weather, safety concerns, and the need to schedule surveying expeditions for times when at least three people could work together in the field. Finally, the actual magnitude of the work involved in developing this GIS was not adequately anticipated from the beginning.

In spite of these problems, the GIS developed represents a substantial starting point for developing a more complete picture of the Waimanalo Stream Drainage Basin and the factors that may influence water quality in the stream. Future work can improve, add to, and build up the existing data set from this starting point. Since the watershed will inevitably change in its characteristics (some substantial changes have already occurred), these improvements and updates will be essential for a continued understanding of the health of this watershed.

Expenditures

DESCRIPTION	BUDGETED	EXPENDED
Salaries	2,500.00	2,000.07
Fringe Benefits	625.00	15.02
Materials and Supplies*	6,075.00	5,624.33
Travel	500.00	0.00
Stipends	4,000.00	4,800.00
TOTAL DIRECT COSTS	13,700.00	12,439.42
INDIRECT COSTS	1,300.00	1,023.68
TOTAL COSTS	15,000.00	13,463.10

*includes aerial imagery

Literature Cited

Ashizawa, D.J., and D.A. Krupp. 1999. Using GIS and the internet for watershed education and outreach. UCOWR Proceedings. Water: Lessons of World Development. pp. 151-162.

Hurn, J. 1989. GPS: a guide to the next utility. Trimble Navigation Ltd. Sunnyvale, CA. 76 pp
.
Stream Bioassessment Program. 1998. Land use patterns and potential polluted runoff sources in the Waimanalo watershed, Ko'olaupoko District, O'ahu, Hawai'i. Environmental Planning Office, Hawai'i Department of Health. 16 pp.

Thompson, J. 1993. Waimanalo preliminary water quality study: an assessment of non-point source water pollution in the hydrologic unit. University of Hawai'i at Mano'a School of Public Health Environmental & Occupational Health Program. 48 pp.

Wu, A.C. 1994. Assessing the water quality of the Waimanalo watershed by measuring indicator bacteria densities in Waimanalo Stream, Inoa'ole Stream, and in Waimanalo Bay. Masters Thesis. University of Hawai'i at Mano'a School of Public Health. 61 pp.