

AQUATIC STUDIES IN
KALOKO-HONOKOHAU NATIONAL HISTORICAL PART

FINAL REPORT

By

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1.0 INTRODUCTION.

This report describes techniques and results of a series of infrared video photography flights carried out along the Kona coast of the Big Island of Hawaii during the Fall of 1992. The purpose of these flights was to videotape the coastline in the 8---12 micrometer wavelength interval, so that images were created by the "light" of the earth's own radiation. It was expected that cold fresh water, leaking out to sea from the coastline, could be readily detected and discriminated from the warmer ocean waters. This expectation was successfully realized.

2.0 BACKGROUND.

The fishponds and coastline of Kaloko-Honokohau National Historical Park are locally famous for their intense flows of cold, relatively fresh water. Many of these flows have hardly any taste of salt. This is probably a major reason why Kaloko was a favorite residential area for Hawaii's alii in precontact days.

While the existence of this cold and nearly fresh water is common knowledge, the reasons for and the character of this existence are poorly understood. It is a clear exception to the behavior of Hawaii's fresh water resource, which follows the general pattern described below

- (1) Rain falling in the mountains percolates quickly and almost vertically downward through porous and permeable volcanic formations to sea level.
- (2) There, fresh water floats atop the denser seawater that underlies our islands, forming a "Ghyben-Herzberg Lens" whose upper surface lies slightly above sea level. The exact height of this surface is determined by the 2.5% density difference between fresh and seawater, and by the effective resistance of these deep strata to water flow.
- (3) Generally, the fresh water "free surface" will be found no more than a few feet above sea level, even at locations several miles inland. Wells drilled from altitudes of several thousand feet (e.g., 6000 feet at Waikii on the Saddle Road) must reach all the way to sea level in order to tap acceptably fresh water.

- (4) According to this hydrographic model the final passage of fresh water into the ocean from a young volcanic island such as Hawaii should be as a diffuse evanescence from the land into the sea. Discrete flows will be unlikely or at least should be extremely rare.

Along most of Hawaii Island's coastline, this model seems to adequately match observed hydrology. But there are exceptions, enough of them to indicate that the model ought to be modified or extended. Kaloko-Honokohau seems to be such an exception.

Two important factors may combine in causing the rather intense and concentrated flow of freshened water, via discrete exit portals, from the Kaloko coastline into the sea.

First, lava tubes and/or lava flow interfaces may combine to create a horizontal displacement in the path taken by high altitude water as it flows downward toward sea level. The Kaloko highlands are known to be riddled by such lava tubes, some of which extend for miles. My own 8 Kaloko acres at 2000 feet have at least three such well developed tubes, although none has been observed to serve as a water conduit.

Second, test wells have recently shown that a dike structure (a massive barrier of nearly impermeable rock) seems to follow closely along the route of the Upper Beltline Road from Kalaoa southward to at least the Papa Bay turnoff. This barrier has been postulated to explain why County and USGS test wells have discovered a free surface of fresh water standing well above sea level mauka of the Beltline road. The height of this surface is about 200 feet at Kalaoa and nearly 600 feet at Papa Bay Road.

These two factors---a dam to generate an upward lift to the free surface of fresh water only a few miles from the coastline coupled with direct conduits toward that shoreline---could easily account for the fact that the Kaloko-Honokohau shoreline is riddled with discrete fresh water portals that flow an enormous amount of fresh water into the sea.

The purpose of this study has been to employ aerial infrared photography to create clear video images of such flow, so that their spatial orientations can be studied in detail. Beyond this study---and following analysis of such images---chemical and physical "ground truth" should be established via instrumented sampling of water flow regions. Such sampling was to have been initiated as a part of this study if sufficient funds remained after infrared video flights were completed. There was no such excess.

Finally, it was hoped that an attempt could be made to follow the flows inland; that is, to establish a connection or continuity between coastline flows and highland sources of freshened water. This was far beyond the scope of the study described here.

3.0 TECHNICAL APPROACH

The Inframetrics Model IRTV-445* used for all flights is the same system employed in 1991 for a SEAGRANT-supported, infrared survey of the Kona coastline. This system uses two Mercury/Cadmium/Telluride detectors, thermoelectrically cooled to -196 C, and filtered for sensitivity only in the 8- to 12-micron wavelength interval. (This band contains the peak of the earth's blackbody radiation curve, and allows the earth to be photographed by the direct "light" of its own heat radiation.) The video output has a standard North American VHS format.

The two detectors race across camera image space in a lead/lag mode, in such a way that one of them determines the size of the image pixel while the two detector outputs are averaged to reduce system noise. In the wide angle viewing mode used at Kaloko, pixel resolution was 2.0 milliradians (about 1/8 degree), and the field of view was 21 high by 28 wide. The system's noise equivalent temperature difference (NET) was 0.2 C, and the field of view (FOV) width contained 400 resolution elements.

A single-engine high-wing aircraft was used, with the right door removed. The camera operator, rigged with a heavy duty safety belt restraint, could lean far enough outside the aircraft so that the camera FOV cleared the wheel- and wing struts. An instrumentation operator occupied the two rear seats to monitor and control system gain, FOV and focus.

A 12VDC/110VAC inverter was used to convert aircraft power into the voltage needed by the instrumentation. A second monitor was positioned so that the pilot could also see the infrared video. (This drastically improved agreement between the maneuvers requested by the flight director and those actually carried out by the pilot.)

Figure (1) shows the Kaloko-Honokohau coastline, and identifies the Park's three fishponds. It also shows Honokohau Harbor. Extensive blasting operations during construction of the harbor in the early 1970's converted a region well known for its fresh water springs into an incredibly copious source of fresh water. The seaward flow of this water from the harbor entrance is visible (in the infrared) for at least half a mile offshore.

The coastline mapped in Figure (1) was the main target for all flights. Infrared video of this area was normally recorded at both the beginning and end of each flight. At the same time, attempts were made to obtain sample video from the entire west coast---from Mahukona in the North to Honomalino Bay in the south. One flight was made to Volcano National Park to obtain infrared images of the lava tubes which lead from the volcanic cone Puu O'o to the sea, and to map water flows near South Point.

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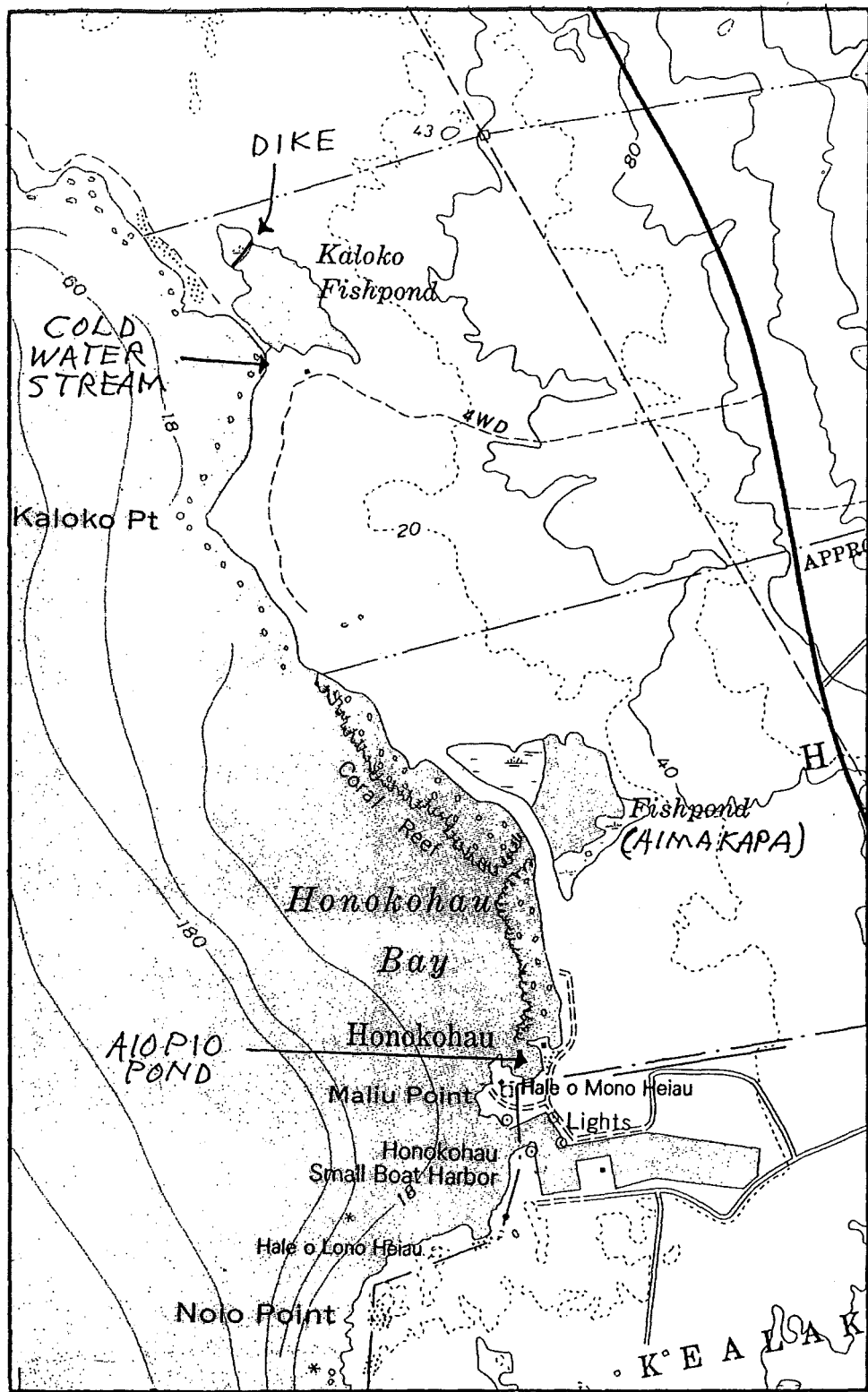


FIGURE (1). The coastline at Kaloko-Honokohau National Historical Park, showing Kaloko, Aimakapa and Aio Pio Fishponds. Note the dike across the NW corner of Kaloko Pond, and the "cold water stream" that enters the ocean SW of the pond.

4.0 RESULTS OF INFRARED VIDEO FLIGHTS

Table (1) is a log of flight dates and times for this study. The flight on November 2, 1992, was made 3 weeks before arrival of the infrared video system. Its purpose was to take color photos of likely study areas and to work out maneuvering procedures. All other flights were staged with infrared videography as the prime objective.

Flight intervals and destinations are recorded in Table (1), as are the times and magnitudes of low and high tides. Generally, the flights were initiated as close to dawn as possible, so that infrared images could be obtained before coastal rock formations were heated by the morning sun.

Detailed logs for all flights are attached as an Appendix to this report. The format for these logs is demonstrated in Table (2), an extract from the Flight Log for the first flight on December 18, 1992. Table (2) comments have been expanded as a result of more recent analysis of the videotape for that date.

The following observations are offered as a general synopsis of insights gained from the infrared videography flights.

- (1) The sensitivity of the Inframetrics IRTV445 allows a clear distinction between cold fresh(ened) water and seawater along the Kaloko-Honokohau coast of Hawaii.
- (2) This sensitivity is improved if the polarity of the image is reversed---ie., if white is used to denote cold backgrounds and black assigned for hotter targets. This is a uniquely valuable feature of the IRTV445 system.
- (3) The use of video allows a clear portrayal of spatial relationships between cold water flows and adjacent land masses or warmer sea water.
- (4) No attempt was made to quantitatively measure water temperature(s) for the cold water flows. To do this would have required complex and expensive calibration of the video camera, and would have required its modification in order to extract pulse height data from the video sweep.
- (5) Image contrast for cold water flows was much reduced when they were viewed at right angles to the plane of the sun---ie., at 90-degree solar scattering angles. The reason for this is not clear, since the infrared system showed no response to direct sunlight. It might have to do with wind direction and/or water surface roughness at these early morning hours.
- (6) Highly visible flows of cold water entered Kaloko Pond on the mauka side, and moved in rays across the pond to the seawall. The individuality of these rays was generally preserved during the pond crossing.

DATE	FLIGHT INTERVAL	DESCRIPTION OF FLIGHT
NOV 02	0800---0920	Orientation and photo flight from Kona Airport South to Hookena
NOV 25	0700---0800	IR video flight South to Hookena. 2.7' high tide at 0419. 0.3' low tide at 1144.
DEC 01	0640---0805	IR video flight S to Kailua, then N to Kawaihae Harbor. 0.8' low tide at 0134. 1.8' high tide at 0828.
DEC 04	0640---0800	S to Hookena. IR VCR malfunction..
IR video system returned to manufacturer for repair.		
DEC 18A	0640---0745	IR video S flight to Honaunau. 0.7' low tide at 0629. 1.2' high tide at 1033
DEC 18B	About 1000	IR video flight N to Mahukona. Time-of-flight log was lost.
DEC 19	0640---0810	IR video flight N to Mahukona. 2.2' high tide at 0045 0.6' low tide at 0748.
DEC 20	0705---0840	IR video flight S to Milolii. 2.4' high tide at 0130. 0.5' low tide at 0850.
DEC 21A	0700---0810	IR video of Puu O'O vent starting at 0748, then continue as DEC 21B.
DEC 21B	0815---0955	IR video along Kau/Kona coasts 2.6' high tide at 0209. 0.3' low tide at 0936.
DEC 22	0706---0824	IR video flight S to Milolii. 2.6' high tide at 0250. 0.3' low tide at 1015.
DEC 23	0640---N.A.	IR video failed. Made 2nd (PM) photo flight S to Hanomalino.

Table (1), Log of Infrared Video Flights. Times And Heights of Tides Are For Kailua-Kona.

DECEMBER 18, 1992 INFRARED VIDEO FLIGHT ALONG KONA COAST
 FLIGHT TIME 0640----0745
 2.2' HIGH TIDE AT 0045 AND 0.6' LOW TIDE AT 0748

VCR METER READING	DESCRIPTION	IMAGE QUALITY	WATER FLOWS?
0006	HEADING SOUTH FROM KONA AIRPORT.		
0110	"PINE TREES", JUST N OF KALOKO POND.	GOOD	NO
0180	CLEAR VIEW OF KALOKO POND, LOOKING TO NW ALONG SEAWALL. PLANE IS CIRCLING.	GOOD	YES
0230	LOOKING MAUKA (INLAND). NOTE INTENSE STREAM OF COLD WATER FLOWING SEAWARD FROM THE SHORELINE S OF KALOKO POND.	GOOD	YES
0255	LOOKING SE ACROSS POND. STREAMS OF COLD WATER ARE FLOWING SEAWARD ACROSS THE POND. NOTE THE RELATIVE COLDNESS OF THE WATER IN THE POND'S SE CORNER.	GOOD	YES
0265	TRAPPED RELATIVELY WARM WATER ON THE N SIDE OF KALOKO POND'S INTERIOR DIKE.	GOOD	YES
0275	LOOKING S ACROSS KALOKO POND. THE WATER STREAM NOTED BEFORE (0230) HAS MUCH LESS CONTRAST WHEN VIEWED FROM THIS DIRECTION. IS THIS DUE TO ANGLE DEPENDENT SCATTERING? POLARIZATION? WATER SURFACE ROUGHNESS?	GOOD	YES
0290	VIEW OF KALOKO POND'S COLD SE CORNER.	GOOD	YES
0330	AGAIN, THE SEAWARD JET OF COLD WATER FROM JUST S OF THE SEAWALL. THIS WATER IS DEFINITELY BYPASSING KALOKO POND.	GOOD	YES
0340	LOOKING MAUKA OVER KALOKO POND.	GOOD	YES
0445 TO 0670	CIRCLING AIMAKAPA POND. ITS WATER IS MUCH WARMER THAN KALOKO'S. SEAWARD FLOW THROUGH THE SEAWALL IS VERY DIFFUSE.	GOOD	DIFF.
0690 TO 0750	CIRCLING AIOPIO FISHPOND. NOTE SEVERAL COLD WATER INPUTS, PLUS A DISCRETE EXIT THROUGH A BREAK IN THE (AWASH) SEAWALL.	GOOD	YES

Table (2). Flight Video Log For DEC 18, 1992 (with annotations).
 Infrared Scenes Were Of Kaloko, Aimakapa and Aiopipo Fishponds.

- (7) The south/mauka corner of Kaloko Pond clearly contained the coldest surface water of the entire body of water. The northern section (N of an internal dike or wall) was clearly warmer than any other part of the pond.
- (8) Analysis of video data showed little or no day-to-day variation in temperature or magnitude of Kaloko Pond water flows. Little relationship to time, tide or recent rainfall was observed. The only obvious conclusions here are that:
- (a) The time constant for fresh water migrating seaward from upland rain forests may be quite long compared to the intervals between heavy upland rains.
 - (b) The fresh water flow may have such a great magnitude that a 1- or 2-foot variation in tide level will have only a minor influence in damming or retarding its seaward motions.
- (9) A major cold water flow enters the ocean just south of the southern end of the Kaloko Pond seawall, appearing much like a water jet that extends well out to sea. Water temperature for this flow appears to be clearly lower than that of water entering the coldest (south/mauka) corner of the pond. The only sensible interpretation of this coldness is that this flow bypasses Kaloko Pond and goes directly to the sea.
- (10) Aimakapa Pond is considerably warmer than Kaloko Pond, and does not show the surface temperature stream lines described above for Kaloko. Its seaward rock wall is well infiltrated with and covered by sand and, as a result, may have much greater impedance to water flow.
- (11) Aio Pio Pond is very close to Honokohau Harbor, and yet has a surprisingly high entry and exit rate of cold water flow. This is especially obvious at Aio Pio's only deep exit to the ocean. This exit has a flow much more intense than one would expect since the entire seawall is awash at high tide.
- (12) Honokohau Harbor overwhelmingly dominates all cold water flows in this area. Its surface waters are so cold and so fresh that normal marine life cannot survive there. To a diver, the harbor's upper 3 feet are bitterly cold, while the deeper waters feel almost like a sauna by comparison.
- (13) Repeated searches for cold water (or cold rock) mauka of the Kaloko-Honokau Park coastline were unsuccessful. Even small isolated pools (e.g., Queen's Bath near Aimakapa) did not show up in the infrared video.
- (14) Many cold water flows into the ocean were observed North and South of Kaloko-Honokau National Historical Park. None of these showed the magnitudes and tidal/seasonal independence of those described in this report.

18 DEC 1992 IR VIDEO FLIGHT (AS COPIED ONTO VCR TAPE)
 START FLIGHT AT 0640 HOURS
 2.2' HIGH TIDE AT 0045 AND 0.6' LOW TIDE AT 0748

PAGE (1) OF (3)

VCR METER	DESCRIPTION	IMAGE QUALITY	WATER FLOWS?
0006	BEGINNING OF TAPE ON MEMOREX VCR. HEADING SOUTH FROM NELHA ACCESS ROAD.		
0110	PINE TREES?	GOOD	NO
0180	FIRST CLEAR VIEW OF KALOKO POND, TO NW ALONG SEA WALL. CIRCLING.	GOOD	YES
0230	LOOKING MAUKA. FIRST CLEAR VIEW OF COLD WATER FLOWS S. OF KALOKO POND.	GOOD	YES
0255	LOOKING SE ACROSS POND. NOTICE COLD WATER FLOWS ACROSS POND AND RELATIVE COLDNESS OF WATER IN POND'S SE CORNER.	GOOD	YES
0265	NOTE RELATIVE WARMTH OF WATER ON THE N SJDE OF THE MAUKA/MAKAI POND WALL.	GOOD	YES
0275	LOOKING S ACROSS KALOKO POND. NOTE LOWER VISIBILITY FOR THE OCEAN FLOWS FLOWS JUST S OF THE POND.	GOOD	YES
0290	GOOD VIEW OF KALOKO POND'S COLD SE CORNER.	GOOD	YES
0330	NOTE SEAWARD JET OF COLD WATER FROM JUST S OF THE SEA WALL. THIS WATER SEEMS TO BE BYPASSING THE POND.	GOOD	YES
0340	LOOKING MAUKA OVER THE POND. THE WATER FLOWS ARE MUCH MORE PROMINENT FROM THIS PERSPECTIVE.	GOOD	YES
0410	LAST LOOK AT KALOKO POND.	GOOD	YES
0425	ISOLATED COLD WATER FLOW WELL S OF KALOKO. NOT YET IDENTIFIED.	GOOD	YES
0445 to 0670	CIRCLING AIMAKAPA POND. NOTE HOW MUCH WARMER ITS WATER IS. SEAWARD FLOW THROUGH THE SEAWALL IS DIFFUSE.	GOOD	DIFFUSE

18 DEC 1992 IR VIDEO FLIGHT (AS COPIED ONTO VCR TAPE)
 START FLIGHT AT 0640 HOURS
 2.2' HIGH TIDE AT 0045 AND 0.6' LOW TIDE AT 0748

PAGE (2) OF (3)

VCR METER	DESCRIPTION	IMAGE QUALITY	WATER FLOWS?
0690 to 0750	CIRCLING AIOPIO FISHPOND. POND HAS SEVERAL DISCRETE COLD WATER INPUTS, PLUS A DISCRETE EXIT THROUGH A BREAK IN THE SUBMERGED SEA WALL.	GOOD	YES
0755 to 0915	CIRCLING HONOKOHAU HARBOR. NOTE THAT SEAWARD FLOW HAS MAJOR N/S COMPONENTS. THIS VIEW IS BEFORE OUTBOUND FISHING BOATS HAVE CUT TRACKS THAT REPRESENT A MIXING OF COLD SURFACE WATER AND THE UNDERLYING WARMER SEA WATER.	GOOD	MAJOR
0965	CRUISE SHIP. NEGATIVE POLARITY MAKES THE SHIP'S HOT STACKS APPEAR DARK.	GOOD	-----
1015 to 1250	CIRCLING KAILUA PIER. NOTE HOW THE VISIBILITY OF THE WATER FLOWS CHANGES WITH VIEWING AZIMUTH ANGLE.	GOOD	MANY
1325	CASA DE EMDEKO (LANDMARK)	GOOD	NO
1520	KEAUHOU BAY. SHOWING ONLY DIFFUSE SOURCES OF COLD WATER.	GOOD	YES
1755	COOK MONUMENT WITH MUCH COLD WATER. LITTLE WATER FLOW WAS OBSERVED AT THE BASE OF THE KEALAKEKUA BAY PALI.	GOOD	YES
1795	NAPOOPOO. BROADLY DIFFUSE FLOWS.	GOOD	YES
1820	MAJOR FLOW FROM OLD LANDING BEACH IN MOKUOHAI BAY, JUST S OF PALEMANO PT.	GOOD	YES
1945	HONAUNAU WITH WATER FLOW FROM AREA OF CANOE LANDING.	GOOD	YES
2070	HOOKENA LANDING. FAINT DIFFUSE FLOWS.	FAIR	MINOR
2090	CLEFT JUST S OF HOOKENA PALI; SITE OF EARLIER INTENSE WATER FLOW. BEGINING TO TURN BACK TOWARD AIRPORT.	FAIR	MINOR
2145	HOOKENA LANDING VIEWED FROM THE SEA.	FAIR	MINOR

18 DEC 1992 IR VIDEO FLIGHT (AS COPIED ONTO VCR TAPE)
 START FLIGHT AT 0640 HOURS
 2.2' HIGH TIDE AT 0045 AND 0.6' LOW TIDE AT 0748

PAGE (3) OF (3)

VCR METER	DESCRIPTION	IMAGE QUALITY	WATER FLOWS?
2238	CRESCENT-SHAPED CRATER WALL FACING THE SEA AND SMALL STEEP-WALLED BAY. (LANDMARK).	FAIR	NO
2265	HONAUNAU AND PLACE OF REFUGE.	FAIR	DIFFUSE
2410.	MOKUOHAI BAY, VIEWED FROM SEA.	GOOD	MAJOR
2415	NAPOOPOO, VIEWED FROM SEA. GOOD VIEW OF SHORELINE UNDER KEALAKEKUA PALI.	GOOD	DIFFUSE
2445	CIRCLING COOK MONUMENT (TO 2500)	GOOD	MAJOR
2655	KAILUA PIER, VIEWED FROM THE SEA.	GOOD	DIFFUSE
2690	QUEEN'S BATH (?) NORTH OF THE NORTH END OF THE OLD AIRPORT.	GOOD	YES
2750 to 2765	HONOKOHAU HARBOR, VIEWED FROM THE SEA. NOTE BOAT WAKES CUTTING ACROSS THE COLD WATER SURFACE.	GOOD	MAJOR
2765	SHORT GLIMPSE OF AIOPIO FISHPOND.	FAIR	YES
2770	AIMAKAPA POND, VIEW FROM THE SEA.		
2790	GOOD VIEW OF INTENSE COLD WATER FLOW JUST SOUTH OF KALOKO POND.	FAIR	YES
2790	TWO CIRCLES OF KALOKO POND (TO 2940).	GOOD	YES
2940	CIRCLE (FREEZE FACE CAVE?). (TO 3010)	GOOD	YES
3018	END OF VIDEO TAPE.		

20 DEC 1992 IR VIDEO FLIGHT (AS COPIED ONTO VCR TAPE)
 START FLIGHT AT 0705 HOURS
 2.4' HIGH TIDE AT 0130 AND 0.5' LOW TIDE AT 0850

PAGE (1) OF (1)

VCR METER	DESCRIPTION	IMAGE QUALITY	WATER FLOWS?
9988	BEGINNING OF TAPE ON MEMOREX VCR. HEADING SOUTH FROM AIRPORT		
0120	FREEZE FACE CAVE, VIEWED FROM THE SEA.	FAIR	YES
0130 to 0440	CCW CIRCLING OF KALOKO POND. NOTE THE HIGH VISIBILITY OF THE SEAWARD COLD WATER FLOWS.	GOOD	YES
0460 to 0600	CIRCLING HONOKOHAI HARBOR. NOTE THE FISHING BOAT'S WARMER WAKE AS IT LEAVES THE HARBOR.	GOOD	MAJOR
0615	GLIMPSE OF AIOPIO FISHPOND. DIFFUSE COOL WATER FLOWS ARE VISIBLE BETWEEN AIOPIO FISHPOND AND AIMAKAPA POND.	GOOD	YES
0670 to 0780	CIRCLING AIMAKAPA POND. NOTE HOW MUCH WARMER THE SURFACE OF THIS POND IS THAN KALOKO POND.	GOOD	DIFFUSE
0800 to 0960	APPROACHING AND CIRCLING KAILUA PIER. NOTE HOW VISIBILITY OF THE COLD WATER FLOWS CHANGES WITH AZIMUTH ANGLE.	V. GOOD	YES
0980	CIRCLING COOK MONUMENT (TO 1140).	GOOD	MAJOR
1150	NAPOOPOO, VIEWED FROM THE SEA.	GOOD	YES
1170	VIEW FROM THE SEA OF MAKUOHAI BAY.	GOOD	MAJOR
1295	CIRCLING HOOKENA (TO 1420).	FAIR	FAINT
1695 to 1775	CIRCLING MILOLII. NOTE BOAT TRACKS THROUGH COLD WATER FLOW FROM THE BOAT LANDING.	GOOD	MAJOR
1780 to 1913	CIRCLING HANOMALINO BAY, THEN BACK TO MILOLII. NOTE MAJOR FLOWS INTO AN ALMOST-ENCLOSED BAY BETWEEN MILOLII AND HANOMALINO.	GOOD	MAJOR
1914	END OF VIDEO TAPE.		