CHAPTER 202

ENVIRONMENTAL IMPACTS ON AN

ISLAND COMMUNITY

Gordon A. Chapman[1]

INTRODUCTION

The environmental impacts of coastal engineering projects generally affect island communities to a greater degree than they would affect continental land mass communities. This occurs because of the smaller land area; close interdependence and interaction of land and sea communities, both natural and human; and relatively small projects having relatively large overall impacts on island ecosystems.

The natural flora and fauna of Pacific Islands have developed rather precariously unbalanced communities that are extremely fragile and susceptible to change, both natural and man induced. This susceptibility dictates that, where possible, man induced or proposed changes, such as coastal engineering projects, should be designed such that as little change as possible occurs to the natural environment. Additionally, the natural resources of island communities are generally limited and this too dictates that conservation practices be employed that assure the highest and best use of those limited resources.

The purpose of this paper is to indicate the environmental effects of a major coastal engineering project on an island community. This will be accomplished by describing the environmental quality control monitoring program that has been performed as an integral part of the Honolulu International Airport (HIA) Reef Runway construction project on Oahu, Hawaii, and presenting the initial findings of that environmental monitoring program.
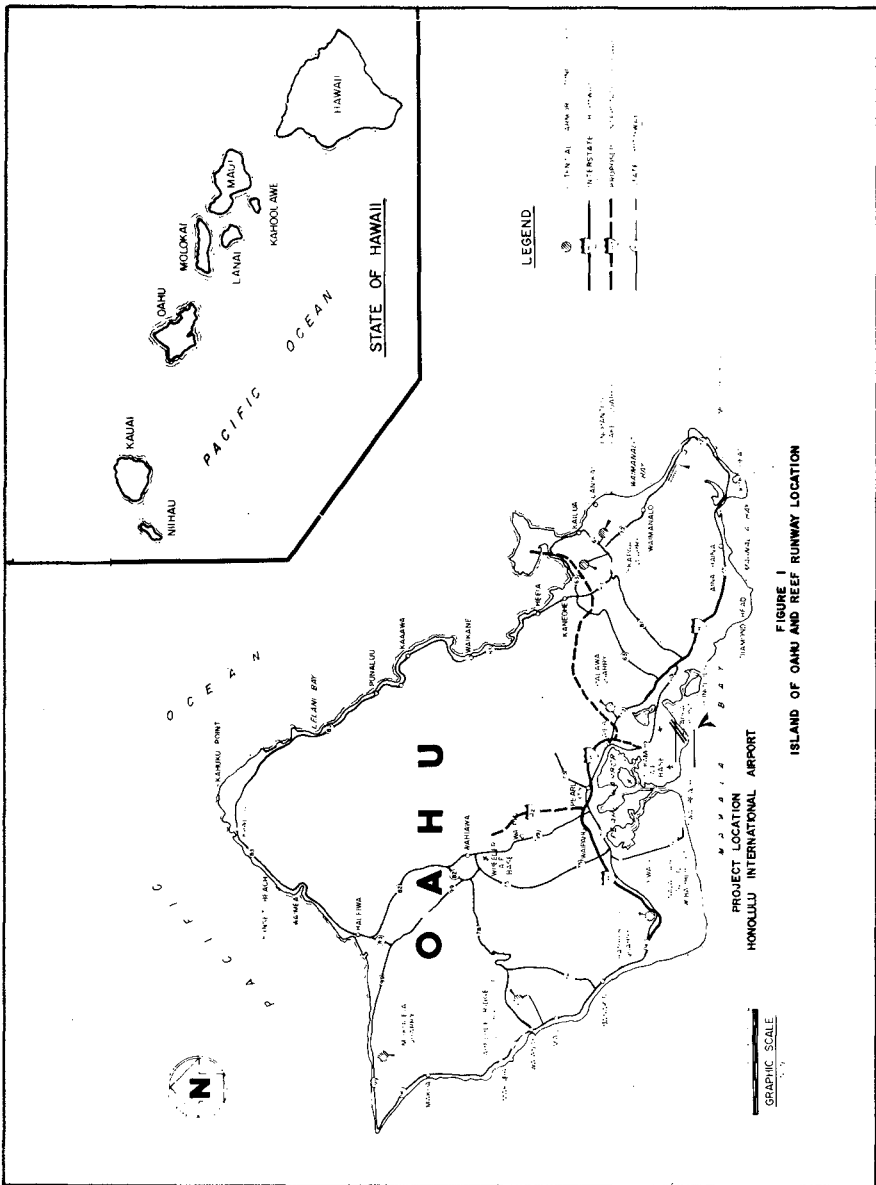
The Honolulu International Airport reef runway planning and design began in earnest in 1968 and 1969 with hydrographic and topographic surveys, foundation investigations, two- and three-dimensional hydraulic model studies, and environmental studies that were conducted (J. K. K. Look, 1970; Berger, 1971; Sunn, et al, 1969). These studies, and others, were utilized to determine the technical feasibility, and to gather the engineering and environmental data for final design and construction.

The Reef Runway, located south of the HIA runway system on the fringing coral reef, seaward of Keehi Lagoon, in Mamala Bay, is 12,000 feet long and 200 feet wide. The runway and taxiway complex is protected from the sea by a 16,000-foot long protective structure constructed of rock and dollose (Figure 1).

MATERIALS AND METHODS

The Reef Runway environmental monitoring program began during the 1970-1972 period when various oceanographic, marine biology and ecology, water quality, and avifauna baseline studies were conducted (J. K. K. Look, 1971; Berger, 1971; Harvey, et al, 1971; Sunn, et al, 1972a; Bathen, 1970). During the initial planning and design

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FIGURE 1
ISLAND OF OAHU AND REEF RUNWAY LOCATION

phases of the Reef Runway project, and during the preparation of the Environmental Impact Statement (Federal Aviation Administration, 1972), it was determined that extensive baseline studies as well as a construction period monitoring program were required. The baseline studies were needed to adequately describe existing conditions and to predict probable environmental impacts of the project, and the monitoring program to ensure compliance with all applicable State and Federal environmental protection regulations during construction activities.

The "during construction" water quality monitoring program was initiated in June, 1973, approximately one month prior to the start of construction and continued until August 30, 1976, approximately one month following major offshore and onshore construction activities. The program consisted of bimonthly water quality sampling, initially at 19 preselected stations, and finally at 13 of the original stations and one added station (Figure 2). Dissolved oxygen (D.O.) was measured using a Yellow Springs D.O. probe and turbidity measured with a standard 30 c.m. diameter Secchi disk. In-situ measurements of temperature and salinity were made utilizing a Beckman in-situ thermister probe and induction salinometer. Laboratory measurements of pH, total phosphorus, and total Kjeldahl nitrogen were made. Station depths varied from 6 feet to 45 feet, with most being 15 to 20 feet. All in-situ measurements and water samples were taken at mid-depths. Sampling was accomplished at different times of the day and at varying tidal, wind, and weather conditions.

Water quality sampling was conducted on 88 separate days during the 38-month period the reef runway environmental monitoring program existed. Over 1,300 samples were collected and 9,000 separate data entries have been recorded.

RESULTS

In order to assess the effects of the reef runway construction on Keehi Lagoon water quality, six water quality parameters have been analyzed in general and four in detail for five lagoon and two open ocean monitoring stations. Of the six parameters (temperature, salinity, turbidity, dissolved oxygen, total Kjeldahl nitrogen, and total phosphorus), the latter four have been analyzed in detail. Arithmetic means, standard deviations and geometric means of field and laboratory measurements have been calculated for annual, bi-annual, quarterly and seasonal periods. Quarterly arithmetic mean, standard deviation and geometric mean data for the stations analyzed are presented in Table 1.

Prior to regular monitoring activities, baseline data for most of the sampling stations shown on Figure 2 was assembled from various preconstruction studies. This baseline data and applicable State of Hawaii Water Quality Standards (State of Hawaii, 1974) formed the standards against which water quality readings during construction were measured. Keehi Lagoon, with the exception of the small boat marina areas along the eastern shoreline (Figure 2), is classified by the State Water Quality Standards as Class A waters. The small boat marina areas are Class B waters. Baseline data available for Stations 2, 2b, 3, 4, 6, 22 and 24 is presented in Table 2.

TEMPERATURE AND SALINITY

Temperature and salinity are two of the most potent physical factors in the life of marine organisms. They largely characterize the physicochemical properties of a given body of water (Kinne, 1963). There exists a complex correlation between the biological effects of temperature and salinity. Temperature can modify the effects

FIGURE 2

LAYOUT OF HONOLULU INTERNATIONAL AIRPORT
WITH REEF RUNWAY
AND WATER QUALITY MONITORING STATIONS

GRAPHIC SCALE
0   2000 FT   4000 FT

LEGEND

1 DISCONTINUED STATION

2 ACTIVE MONITORING STATION

RUNWAY AND TAXIWAY PAVEMENT

DREDGED FILL AREA

FUTURE TAXIWAY PAVEMENT

3 MARINE ECOLOGY SURVEY STATION
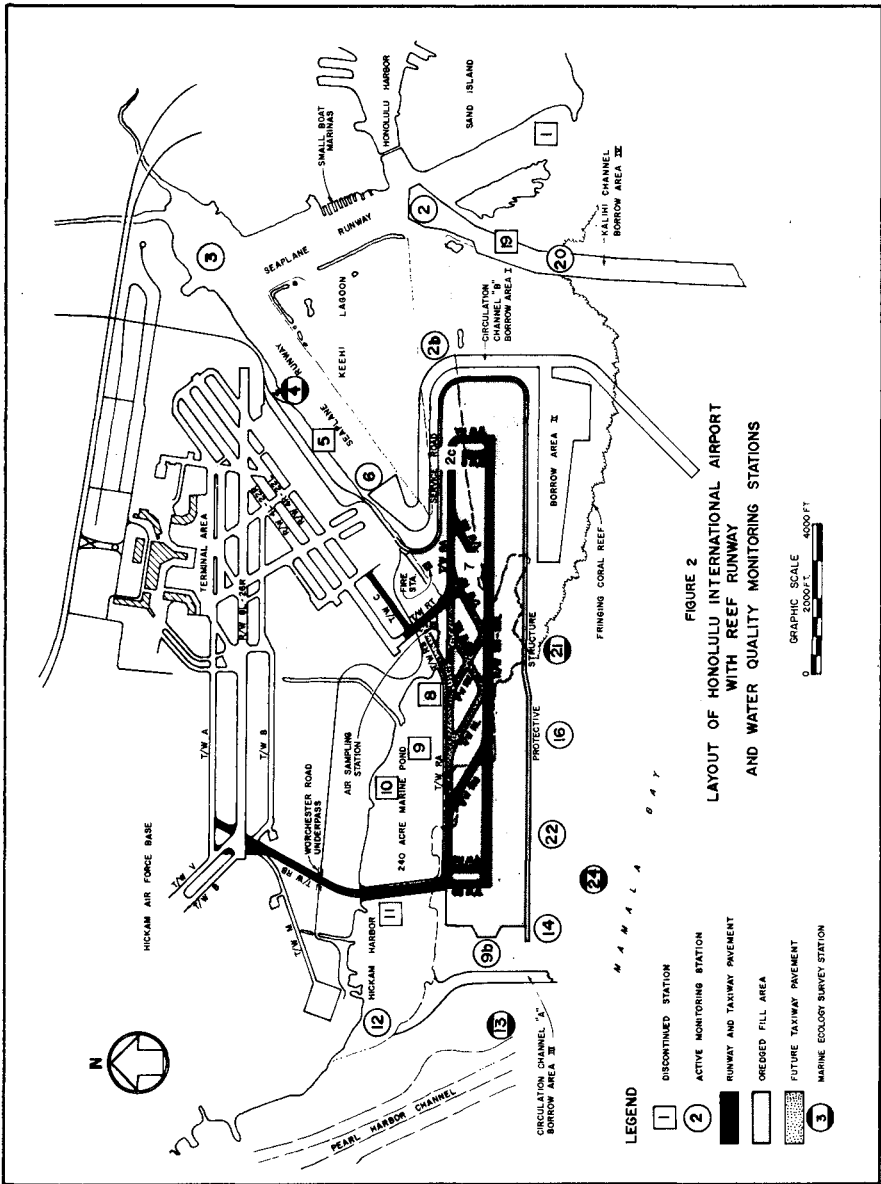
TABLE 1

REEF RUNWAY WATER QUALITY ANALYSIS
QUARTERLY ARITHMETIC MEAN, STANDARD DEVIATION AND GEOMETRIC MEAN
FOR STATIONS 2, 2b, 3, 4, 6, 22 and 24

STA.	QTR.	SECCHI DISK (ft.)			D.O. (mg/1)			TOTAL N (mg/1)			TOTAL P (mg/1)		
		ARITH. MEAN	STD. DEV.	GEOM. MEAN	ARITH. MEAN	STD. DEV.	GEOM. MEAN	ARITH. MEAN	STD. DEV.	GEOM. MEAN	ARITH. MEAN	STD. DEV.	GEOM. MEAN
2	1	7.04	1.30	6.93	5.94	0.50	5.92	0.226	0.11	0.198	0.022	0.01	0.01
	2	7.33	2.70	7.00	5.47	0.41	5.45	0.108	0.08	0.069	0.022	0.01	0.019
	3	7.11	1.52	6.97	6.16	0.32	6.15	0.143	0.12	0.068	0.022	0.01	0.019
	4	6.33	0.61	6.31	5.88	0.33	5.87	0.281	0.08	0.266	0.018	0.02	0.013
	5	6.67	1.75	6.50	6.17	0.42	6.15	0.253	0.19	0.190	0.021	0.02	0.007
	6	5.36	0.69	5.32	6.17	0.29	6.16	0.258	0.14	0.201	0.051	0.02	0.045
	7	5.67	1.72	5.42	6.55	0.39	6.54	0.257	0.08	0.246	0.029	0.02	0.024
	8	4.71	1.25	4.58	6.50	0.54	6.48	0.346	0.21	0.281	0.028	0.01	0.026
	9	6.38	1.49	6.24	6.48	0.23	6.47	0.386	0.19	0.336	0.041	0.02	0.038
	10	6.25	1.89	6.02	6.27	0.58	6.24	0.259	0.19	0.202	0.040	0.02	0.035
	11	8.67	1.60	8.51	6.94	0.28	6.93	0.481	0.25	0.418	0.033	0.01	0.032
	12	7.00	2.22	6.47	6.85	0.62	6.82	0.330	0.14	0.297	0.051	0.03	0.045
	13	11.00	2.92	10.59	6.27	0.34	6.26	0.344	0.19	0.288	0.071	0.02	0.068
2b	1	5.79	1.18	5.66	6.12	0.62	6.09	0.215	0.10	0.174	0.017	0.01	0.015
	2	5.00	1.53	4.78	5.52	0.18	5.52	0.117	0.11	0.061	0.024	0.01	0.023
	3	6.00	1.93	5.63	6.01	0.53	5.99	0.155	0.11	0.115	0.026	0.01	0.026
	4	6.08	2.26	5.69	5.67	0.24	5.66	0.327	0.25	0.249	0.024	0.01	0.021
	5	5.25	0.85	5.18	6.47	0.60	6.44	0.252	0.22	0.176	0.030	0.03	0.010
	6	5.93	0.86	5.87	5.90	0.42	5.88	0.244	0.13	0.202	0.047	0.03	0.040
	7	5.42	1.79	5.07	6.65	0.62	6.62	0.482	0.22	0.418	0.039	0.02	0.036
	8	4.79	1.22	4.64	6.53	0.35	6.52	0.304	0.06	0.297	0.028	0.01	0.025
	9	6.88	0.21	6.87	6.55	0.39	6.54	0.328	0.11	0.313	0.053	0.02	0.049
	10	5.25	1.11	5.14	6.22	0.31	6.21	0.233	0.15	0.163	0.050	0.01	0.048
	11	7.17	0.90	7.11	7.08	0.59	7.06	0.214	0.12	0.174	0.050	0.02	0.047
	12	6.50	1.26	6.39	7.00	0.48	6.98	0.349	0.24	0.276	0.059	0.02	0.052
	13	5.25	1.30	5.05	6.57	0.29	6.56	0.544	0.22	0.500	0.042	0.01	0.042
3	1	4.44	0.76	4.37	6.33	0.49	6.31	0.223	0.14	0.173	0.034	0.03	0.027
	2	4.83	1.75	4.53	6.38	0.51	6.36	0.169	0.09	0.145	0.026	0.01	0.025
	3	5.33	1.60	5.02	6.57	0.38	6.56	0.160	0.10	0.133	0.032	0.01	0.030
	4	4.17	0.47	4.14	6.85	0.68	6.82	0.352	0.13	0.313	0.028	0.04	0.014
	5	4.58	1.02	4.48	6.80	0.74	6.76	0.368	0.17	0.037	0.035	0.02	0.019
	6	4.50	0.89	4.41	5.91	0.35	5.90	0.348	0.24	0.238	0.052	0.03	0.046
	7	3.42	0.67	3.35	6.72	0.64	6.68	0.413	0.16	0.380	0.047	0.03	0.038
	8	3.64	0.52	3.61	6.53	0.37	6.52	0.343	0.33	0.255	0.032	0.01	0.032
	9	4.50	0.35	4.49	6.48	0.33	6.47	0.161	0.09	0.139	0.042	0.02	0.034
	10	3.92	0.67	3.85	6.63	0.24	6.63	0.388	0.22	0.317	0.045	0.01	0.043
	11	5.50	0.96	5.41	6.80	0.24	6.80	0.314	0.51	0.309	0.044	0.01	0.043
	12	5.08	0.61	5.05	6.88	0.55	6.86	0.390	0.16	0.352	0.062	0.02	0.054
	13	4.00	0.00	4.00	6.63	0.47	6.62	0.380	0.25	0.317	0.029	0.02	0.025
4	1	4.31	0.64	4.26	6.47	0.42	6.45	0.159	0.10	0.122	0.019	0.01	0.018
	2	4.78	1.47	4.60	6.56	0.41	6.54	0.155	0.12	0.121	0.026	0.01	0.024
	3	5.56	1.76	5.24	6.63	0.57	6.61	0.452	0.26	0.357	0.027	0.02	0.022
	4	4.67	0.80	4.60	6.70	0.71	6.66	0.574	0.13	0.558	0.037	0.02	0.032
	5	5.92	0.73	5.87	6.62	0.82	6.56	0.351	0.28	0.256	0.024	0.02	0.013
	6	5.29	1.16	5.16	6.41	0.70	6.38	0.230	0.14	0.196	0.034	0.01	0.030
	7	4.08	0.73	4.02	7.08	0.52	7.06	0.326	0.11	0.304	0.040	0.01	0.039
	8	3.93	0.62	3.88	6.77	0.27	6.77	0.387	0.18	0.354	0.026	0.01	0.022
	9	4.75	0.43	4.73	6.78	0.23	6.77	0.231	0.06	0.223	0.043	0.02	0.038
	10	4.25	0.38	4.23	6.63	0.24	6.63	0.407	0.33	0.302	0.023	0.01	0.021
	11	5.00	0.65	4.96	6.98	0.31	6.97	0.462	0.24	0.376	0.044	0.02	0.040
	12	5.08	0.61	5.05	7.15	0.77	7.11	0.417	0.16	0.385	0.062	0.03	0.057
	13	4.75	0.83	4.68	6.63	0.39	6.62	0.509	0.10	0.498	0.067	0.03	0.060

TABLE 1 (Continued)

STA.	QTR.	SEECHI DISK (ft.)			D.O. (mg/l)			TOTAL N (mg/l)			TOTAL P (mg/l)		
		ARITH. MEAN	STD. DEV.	GEOM. MEAN	ARITH. MEAN	STD. DEV.	GEOM. MEAN	ARITH. MEAN	STD. DEV.	GEOM. MEAN	ARITH. MEAN	STD. DEV.	GEOM. MEAN
6	1	4.21	0.83	4.13	6.59	0.44	6.58	0.175	0.11	0.129	0.017	0.01	0.016
	2	4.06	0.98	3.91	6.14	0.35	6.13	0.257	0.26	0.110	0.025	0.01	0.025
	3	5.44	1.54	5.25	6.42	0.41	6.41	0.450	0.28	0.356	0.031	0.01	0.026
	4	4.50	0.91	4.40	6.63	0.81	6.59	0.587	0.36	0.496	0.040	0.01	0.038
	5	5.25	0.99	5.15	6.50	0.66	6.47	0.523	0.32	0.433	0.018	0.02	0.012
	6	5.07	1.37	4.85	5.73	0.61	5.74	0.298	0.16	0.243	0.018	0.01	0.019
	7	3.83	0.75	3.76	6.65	0.64	6.62	0.285	0.08	0.272	0.039	0.01	0.036
	8	3.71	0.52	3.68	6.74	0.46	6.73	0.284	0.12	0.253	0.034	0.01	0.031
	9	4.25	0.43	4.23	6.48	0.13	6.47	0.253	0.10	0.223	0.132	0.17	0.059
	10	4.33	1.07	4.19	6.50	0.25	6.50	0.319	0.18	0.260	0.039	0.02	0.030
	11	5.50	0.91	5.42	6.82	0.47	6.80	0.348	0.22	0.261	0.034	0.02	0.031
	12	4.17	1.77	3.80	7.23	0.73	7.20	0.305	0.24	0.227	0.031	0.01	0.030
	13	6.25	2.28	5.89	6.57	0.25	6.56	0.390	0.19	0.324	0.047	0.01	0.045
22	1	15.92	3.36	15.50	5.48	0.48	5.46	0.216	0.11	0.163	0.023	0.02	0.021
	2	16.67	2.91	16.36	5.78	0.42	5.76	0.174	0.17	0.089	0.011	0.01	0.009
	3	17.44	1.95	17.32	6.39	0.35	6.38	0.185	0.21	0.081	0.024	0.02	0.017
	4	19.00	0.58	18.99	6.20	0.16	6.20	0.537	0.18	0.503	0.034	0.03	0.034
	5	18.50	3.40	18.10	5.93	0.36	5.92	0.257	0.14	0.168	0.019	0.01	0.014
	6	17.86	2.23	17.71	6.10	0.46	6.08	0.337	0.25	0.276	0.038	0.03	0.028
	7	15.67	4.50	14.88	6.62	0.27	6.61	0.447	0.48	0.259	0.040	0.04	0.036
	8	16.43	5.04	15.14	6.34	0.21	6.34	0.215	0.07	0.197	0.033	0.03	0.031
	9	12.50	5.72	13.54	6.65	0.22	6.65	0.284	0.06	0.278	0.019	0.02	0.017
	10	17.33	4.11	16.76	6.44	0.29	6.36	0.165	0.10	0.127	0.042	0.03	0.033
	11	18.00	1.73	17.91	7.04	0.42	7.03	0.493	0.23	0.448	0.045	0.04	0.042
	12	15.33	5.50	14.44	6.75	0.78	6.70	0.330	0.15	0.283	0.041	0.04	0.040
	13	16.67	4.71	15.87	6.15	0.05	6.15	0.354	0.20	0.308	0.053	0.05	0.051
24*	1	---	---	---	---	---	---	---	---	---	---	---	---
	2	40.00	0.00	40.00	5.86	0.28	5.85	0.087	0.06	0.074	0.018	0.01	0.017
	3	31.00	9.18	29.38	6.38	0.40	6.36	0.127	0.19	0.063	0.027	0.02	0.022
	4	31.83	7.90	30.76	6.20	0.25	6.19	0.283	0.18	0.189	0.036	0.04	0.020
	5	31.50	5.99	30.91	5.98	0.51	5.96	0.211	0.07	0.200	0.010	0.01	0.007
	6	35.00	7.07	34.11	6.11	0.38	6.10	0.243	0.14	0.155	0.029	0.01	0.026
	7	32.50	9.01	31.05	6.48	0.44	6.47	0.429	0.16	0.399	0.034	0.01	0.031
	8	35.14	10.01	32.63	6.25	0.34	6.16	0.259	0.08	0.245	0.034	0.02	0.030
	9	37.50	4.33	37.22	6.55	0.43	6.53	0.292	0.17	0.234	0.041	0.01	0.040
	10	35.83	6.07	35.25	6.48	0.19	6.48	0.235	0.17	0.128	0.024	0.01	0.020
	11	31.67	10.27	28.94	6.94	0.29	6.93	0.408	0.14	0.375	0.037	0.02	0.032
	12	34.50	8.14	33.17	7.07	0.58	7.04	0.304	0.11	0.284	0.051	0.02	0.046
	13	28.33	13.12	24.10	6.40	0.10	6.40	0.331	0.11	0.314	0.039	0.01	0.039

State of Hawaii Water Quality Standards for:

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        D.O.    = > 5.0 mg/l
     Total N  = < 0.150 mg/l
     Total P  = < 0.025 mg/l
 Secchi Disk  ± 10 percent from
                 natural conditions
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*Station 24 monitoring started in Oct 1973.

Qtrly. Periods:
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 1 = Jun 1973 to Sep 1973
 2 = Oct 1973 to Dec 1973
 3 = Jan 1974 to Mar 1974
 4 = Apr 1974 to Jun 1974
 5 = Jul 1974 to Sep 1974
 6 = Oct 1974 to Dec 1974
 7 = Jan 1975 ro Mar 1975
 8 = Apr 1975 ro Jun 1975
 9 = Jul 1975 to Sep 1975
10 = Oct 1975 to Dec 1975
11 = Jan 1976 to Mar 1976
12 = Apr 1976 to Jun 1976
13 = Jul 1976 to Aug 1976
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of salinity and change, either enlarge, narrow, or shift the salinity range of an organism; and salinity can modify the effects of temperature accordingly (Kinne, 1963; McLeese, 1956; Dehnel, 1960).

TABLE 2
BASELINE DATA
STATIONS 2, 2b, 3, 4, 6, 22 AND 24

	Water Quality Parameter					
Station	Temperature (°C)	Salinity (0/00)	Turbidity * (Lower Limit-Ft.)	D.O. (mg/1)	Total N (mg/1)	Total P (mg/1)
2	26.5	34.57	3.5	NA	NA	NA
2b	27.3	34.84	3.0	3.73	0.16	0.025
3	27.3	34.64	2.5	5.39	0.20	0.024
4	25.9	34.24	3.0	NA	NA	NA
6	25.6	34.69	2.5	5.35	NA	NA
22	27.2	NA	NA	5.62	0.09	0.030
24	NA	NA	NA	NA	NA	NA

NA - Not Available

*Turbidity lower limits were established by subtracting twice the standard deviation from mean Secchi disk readings taken during pre-construction studies (Sunn, et al, 1972).

Mid-depth temperature readings taken at Stations 2, 2b, 3, 4, 6, 22 and 24 demonstrate characteristics similar to those for open ocean conditions in the tropics. That is, fairly narrow variations (+5°C) between high and low readings, and normal variations between summer and winter months. Table 3 indicates high and low quarterly arithmetic means, standard deviation, and geometric means for temperature data collected.

TABLE 3
TEMPERATURE DATA
STATIONS 2, 2b, 3, 4, 6, 22 AND 24

	High (°C)				Low (°C)			
Station	Arith. Mean	Std. Dev.	Geom. Mean	Qtr.	Arith. Mean	Std. Dev.	Geom. Mean	Qtr.
2	27.33	0.68	27.33	5	23.10	0.51	23.09	11
2b	27.20	0.44	27.20	5	23.30	0.77	23.29	11
3	27.98	0.91	27.97	5	23.38	1.03	23.36	7
4	27.83	0.82	27.82	5	23.20	0.92	23.18	11
6	27.90	0.68	27.89	5	22.95	1.31	22.91	7
22	26.75	0.38	26.95	5	23.32	0.43	23.31	11
24	26.85	0.35	26.85	5	23.30	0.46	23.30	11

All high temperature readings were taken during the fifth quarter (July-September, 1974) and low readings were taken during the seventh quarter (January-March, 1975) and the eleventh quarter (January-March, 1976). The lowest average temperature was recorded at Station 6 and the highest average at Station 3. The temperature ranges and patterns indicated in Table 3 are comparable to those described in the literature for similar esturine water bodies (Ekman, 1953, Sverdrup, et al, 1942).

Salinity, like water temperature, is influenced by outside forces, primarily water temperature and wind. Salinity ranges for individual and/or all stations collectively varies only slightly, less than two parts per thousand (0/00 - Table 4). As with temperature, the highest salinity values are found in the spring and summer months (April-August, 1976) and generally, the lowest in the winter months (January-March, 1974).

TABLE 4
SALINITY DATA
STATIONS 2, 2b, 3, 4, 6, 22 AND 24

Station	High (0/00)				Low (0/00)			
	Arith. Mean	Std. Dev.	Geom. Mean	Qtr.	Arith. Mean	Std. Dev.	Geom. Mean	Qtr.
2	36.00	0.12	36.00	13	34.50	0.24	34.50	3
2b	35.93	0.08	35.92	13	34.46	0.25	34.25	3
3	36.17	0.36	36.16	12	34.00	0.45	33.99	3
4	35.88	0.11	35.87	13	33.83	0.44	33.83	3
6	36.03	0.13	36.02	13	33.76	0.40	33.76	3
22	36.00	0.16	36.00	13	34.73	0.52	34.73	1
24	36.10	0.28	36.10	13	34.82	0.04	34.82	3

The one exception occurred at Station 22 where the lowest average was recorded during the June-September, 1973 period. Higher ambient air temperatures and generally stronger tradewind conditions cause greater evaporation rates to occur in the summer months, resulting in higher salinity values. Conversely, lower ambient air temperatures, less tradewind activity, and greater inflows of fresh water, tend to cause lower salinities in the winter months.

TURBIDITY

The possibility of significantly decreasing water clarity as a result of dredging activities was believed to be potentially one of the most detrimental construction effects on the marine environment of Keehi Lagoon. High turbidity and associated suspended solids would reduce the amount of light available for photosynthesis, would smother bottom dwelling organisms, and if ingested, affect the vital life processes of marine organisms (Johannes, 1972). Although occasional violations of Seechi disk lower limits occurred, generally water clarity at all stations was not significantly different from baseline conditions.

High and low quarterly arithmetic mean, standard deviation, and geometric mean Secchi disk data are shown in Table 5. All low Secchi disk readings occurred during the April-September period and high readings occurred throughout the three-year program. Low readings can be expected during the summer months since the south coast of Oahu is subjected to fairly heavy southerly swell and wave action during those months.

DISSOLVED OXYGEN

Dissolved oxygen (D.O.) is an important environmental parameter since low levels, i.e., less than 5.0 milligrams per liter (mg/l) may significantly affect marine life. A complex set of factors, including organic decay, photosynthesis, and respiration affect D.O. values to range from less than 5.0 mg/l to over 8.5 mg/l or supersaturation on any given day. Oxygen saturation is dependent upon temperature and salinity, but roughly ranges from 6.8 to 7.1 mg/l for the temperature ranges generally recorded in the Keehi Lagoon area.

TABLE 5
SECCHI DISK DATA
STATIONS 2, 2b, 3, 4, 6, 22 AND 24

Station	High (Ft.)				Low (Ft.)			
	Arith. Mean	Std. Dev.	Geom. Mean	Qtr.	Arith. Mean	Std. Dev.	Geom. Mean	Qtr.
2	11.00	2.92	10.59	13	4.71	1.25	4.58	8
2b	7.17	0.90	7.11	11	4.79	1.22	4.64	8
3	5.50	0.96	5.41	11	4.17	0.47	4.14	4
4	5.92	0.73	5.87	5	3.93	0.62	3.88	8
6	6.25	2.28	5.89	13	3.71	0.52	3.68	8
22	19.00	0.58	18.99	4	12.50	5.72	13.54	9
24	40.00	0.00	40.00	2	28.33	13.12	24.10	13

State of Hawaii Class A Water Quality Standard for D.O. is values greater than 5.0 mg/l except from natural causes, e.g., heavy plytoplankton bloom and ensuing temporary depletion of dissolved oxygen. Table 6 indicates that all quarterly means for all stations fall within the generally accepted range of values, i.e., between 5.0 and 7.0 mg/l.

TABLE 6
DISSOLVED OXYGEN DATA
STATIONS 2, 2b, 3, 4, 6, 22 AND 24

Station	High (mg/l)				Low (mg/l)			
	Arith. Mean	Std. Dev.	Geom. Mean	Qtr.	Arith. Mean	Std. Dev.	Geom. Mean	Qtr.
2	6.94	0.28	6.93	11	5.47	0.41	5.45	2
2b	7.08	0.59	7.06	11	5.52	0.18	5.52	2
3	6.88	0.55	6.86	12	5.91	0.35	5.90	6
4	7.15	0.77	7.11	12	6.41	0.70	6.38	6
6	7.23	0.73	7.20	12	5.73	0.61	5.74	6
22	7.04	0.42	7.03	11	5.48	0.48	5.46	1
24	7.07	0.58	7.04	12	5.86	0.28	5.85	2

Table 6 also indicates that all high D.O. readings were recorded during the January-June, 1976 period and that all low readings, with the exception of Station 22, occurred during the October-December period. The low readings for Station 22 occurred during June-September, 1973 period.

All D.O. values are at acceptable levels, indicating adequate O_2 levels for marine biological processes. However, unrecorded bottom level readings, particularly at Stations 3 and 4, have, on occasion, indicated greatly depleted O_2 levels (less than 2.0 mg/l), indicating a lack of water mixing, overpopulation by planktonic organisms, or extreme putrefaction or eutrophication conditions.

NUTRIENTS

The significance of total Kjeldahl nitrogen and total phosphorus levels is difficult to assess due to the wide variation in natural conditions. For example, State of

Hawaii Standards for Class A waters are often exceeded in pristine open ocean waters
surrounding Hawaii (Tetra Tech, 1976). The measured levels of nitrogen and phos-
phorus in Keehi Lagoon vary widely. In some cases, it has been possible to determine
exact or definite probable causes of high nutrient readings. In other cases, the
causes of extremely high or low readings was not apparent even after investigating
several probable causes.

As an example of the wide range of nutrient levels recorded, nitrogen levels at
Station 4 have varied from less than 0.010 mg/l (August 20, 1973) to 1.080 mg/l
(December 4, 1975) and phosphorus readings have varied from less than 0.001 mg/l
(August 30, 1974) to 0.075 mg/l (September 11, 1975). Similar extreme high and low
readings have been recorded for all stations, inside and outside Keehi Lagoon.
Tables 7 and 8 indicate nutrient data collected.

TABLE 7
TOTAL KJELOAHL NITROGEN DATA
STATIONS 2, 2b, 3, 4, 6, 22 AND 24

	High (mg/l)				Low (mg/l)			
Station	Arith. Mean	Std. Dev.	Geom. Mean	Qtr.	Arith. Mean	Std. Oev.	Geom. Mean	Qtr.
2	0.481	0.247	0.418	11	0.108	0.075	0.069	2
2b	0.544	0.216	0.500	13	0.117	0.110	0.061	2
3	0.413	0.156	0.380	7	0.160	0.101	0.133	3
4	0.509	0.103	0.498	12	0.155	0.119	0.121	2
6	0.587	0.359	0.496	4	0.175	0.105	0.129	1
22	0.493	0.227	0.448	11	0.165	0.098	0.127	10
24	0.429	0.162	0.399	7	0.087	0.056	0.074	2

TABLE 8
TOTAL PHOSPHORUS
STATIONS 2, 2b, 3, 4, 6, 22 AND 24

	High (mg/l)				Low (mg/l)			
Station	Arith. Mean	Std. Oev.	Geom. Mean	Qtr.	Arith. Mean	Std. Dev.	Geom. Mean	Qtr.
2	0.071	0.021	0.068	13	0.018	0.016	0.013	4
2b	0.059	0.023	0.052	12	0.017	0.010	0.015	1
3	0.062	0.017	0.059	12	0.026	0.008	0.025	2
4	0.067	0.029	0.060	13	0.019	0.006	0.018	1
6	0.047	0.011	0.045	13	0.017	0.007	0.016	1
22	0.053	0.013	0.051	13	0.011	0.008	0.009	2
24	0.051	0.024	0.046	12	0.010	0.009	0.007	5

Low nitrogen readings occur generally during the fall (October-December) and winter
(January-March) months while high readings occur during the winter, spring (April-
June) and summer (July-September) months. All stations exceed Class A Standards
(0.15 mg/l). Generally, it can be expected that nitrogen readings will be highest
after the period of most rapid utilization of nitrate by plants in the spring and
summer, and then generally decrease. Also, it has been found that higher quantities
of nitrite are generally found in surface waters during the summer and autumn and

therefore definitely associated with the distribution of density and of water temperature (Sverdrup, 1942). These findings indicate that the low fall and winter month readings and high spring and summer month readings are fairly typical of naturally occurring situations. However, high winter readings for total nitrogen are atypical and may, in Keehi Lagoon, be caused by storm water runoff inflows.

Low phosphorus readings were found during the spring and summer months, except for Stations 3 and 22, and exceed Class A water standards. Generally, the values recorded are fairly atypical of natural conditions. Highest phosphorus values generally occur during the winter, and lowest values during the summer, when plytoplankton growth has been great.

It is known that in shallow water communities, e.g., Keehi Lagoon, bottom sediments may be a large reservoir of phosphorus. Even the release of a small part of this phosphorus could significantly increase the concentration in the water. When O_2 levels in bottom waters are reduced (e.g., from organic pollution) phosphate is released from the sediments. Dredging, with the consequent suspension of oxygen-consuming sediment particles, may increase total phosphorus concentrations (Ferguson Wood and Johannes, 1975).

As noted previously, bottom D.O. readings have indicated extremely low levels (less than 2.0 mg/l). This fact, acting in concert with the large amount of suspended sediment particles and disturbance of bottom conditions, may be the cause of high summer total phosphorus values recorded. However, also to be considered are the outside influences of drainage canals, streams, and sewer outfalls.

MARINE ECOLOGY SURVEYS

During the conduct of the water quality monitoring program, quarterly marine ecology surveys were being performed at four of the water quality stations (4, 13, 21 and 24 - Figure 2). Three of the stations (13, 21 and 24) are located seaward of the construction project on reef tops (15 to 40 feet below the surface. These reef tops have been exposed to little, if any, environmental stress (Bowers, 1976). Station 4 is located within Keehi Lagoon in an area that has been exposed to stress, including siltation, industrial pollution, and domestic sewage pollution (Bowers, 1976).

Live coral coverage of the substratum, numbers of sea urchins and fish, and zooplanton samples were recorded and collected. Coral coverage varied considerably from one quarterly monitoring period to the next. However, it appears that this variation represents an estimate of the natural variation inherent in the distribution of coral colonies throughout the station area.

The variations in numbers of sea urchins and fish that were observed were due, in part, to natural movements in and out of the station areas, requirements for irregular habitats, and mobility of the organisms.

Table 9 indicates yearly variations of coral coverage, numbers of urchins and fish, and total zooplankton types found at the four stations.

TABLE 9
YEARLY VARIATIONS OF MARINE ORGANISMS

Year Station	Percent Coral Coverage			Number Of Urchins Observed			Number Of Fish Observed			Number Of Zooplankton Types Observed		
	1	2	3	1	2	3	1	2	3	1	2	3
4	No Coral Observed			No Urchins Observed			Two Fish Observed During Three Years			15.5	15.7	17.0
13	34.3	45.0	47.3	11.2	46.0	47.0	475	620	476	20.2	17.0	19.0
21	21.5	20.5	20.3	2.0	2.2	2.7	592	710	442	17.7	16.5	16.5
24	26.3	25.5	25.8	7.2	7.5	14.0	557	418	416	18.0	14.7	16.7

CIRCULATION

Hawaii is located in an eastern central Pacific anti-cyclonic gyre. It is thought
that water approaches the island of Oahu from the northeast in the winter and from
the south to southeast in the spring and summer, depending on the position of the
gyre (Sverdrup, 1942; R. M. Towill Corp., 1975). The winds, waves, tides, config-
uration of the coastline, and the bathymetry strongly influence the flow of water
around the island at any given location. Flows in and out of major estuaries, e.g.,
Keehi Lagoon or Pearl Harbor, with each tide result in important local effects. The
circulation in the entire Mamala Bay area (Figure 1) is strongly influenced by winds
and tides, and therefore, varies seasonally (R. M. Towill Corp., 1975).
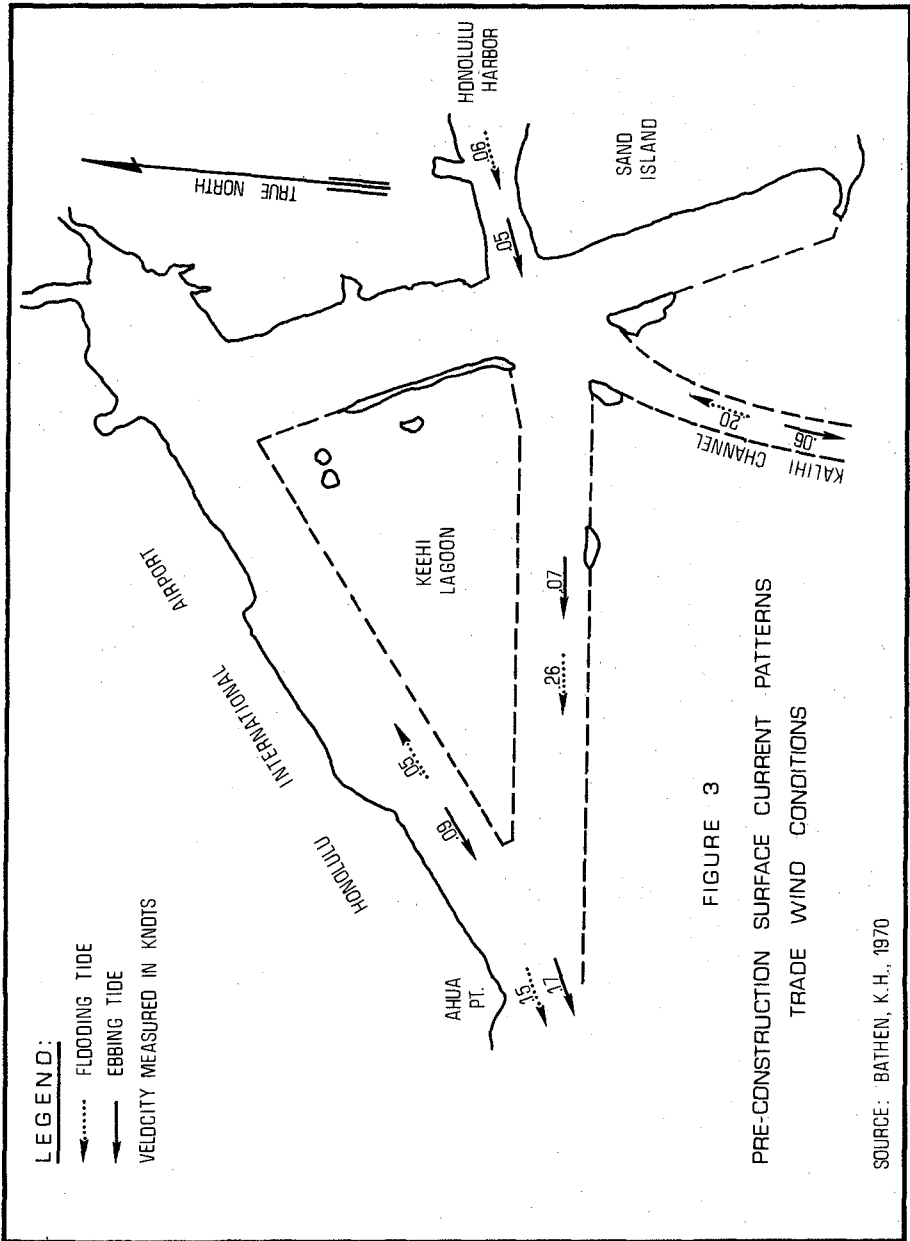
Circulation studies conducted prior to the construction of the reef runway (Bathen,
1970; Sunn, et al, 1969) indicated that there were weak but definite flows of water
inward over the barrier reef and westward around Ahua Point to the Hickam Harbor area
and on out to the open ocean (Figures 3 and 4). Since the reef runway has blocked
this flow, water entering Keehi Lagoon via Honolulu Harbor, Kalihi and Moanalua
Streams, Kalihi Channel, and over the reef, must now pass over the reef, back through
Kalihi Channel or out Circulation Channel "B" (Figure 2).

Prior to the dredging of Circulation Channel "B", a circulation study was performed
(R. M. Towill Corp., 1976a) that indicated most outward flow as occurring in Kalihi
Channel (Figure 5).

Recent post-construction aerial observations of Keehi Lagoon and the reef runway
project area indicate that there is now a definite outflow of water in Circulation
Channel "B". A portion of this outward flow can be seen on Figure 6. Circulation
Channel "B" is approximately 500 feet wide at the surface, with a bottom width of 300
feet. The channel is dredged to minus 45-50 feet.

DISCUSSION

The obvious environmental impact of the reef runway project has been the covering of
over 850 acres of coral reef flat with over 19 million cubic yards of dredged coral
materials. This has resulted in some changes to the water quality and circulation
patterns of Keehi Lagoon.

LEGEND:

FLOODING TIDE
EBBING TIDE
VELOCITY MEASURED IN KNOTS

FIGURE 3

PRE-CONSTRUCTION SURFACE CURRENT PATTERNS
TRADE WIND CONDITIONS

SOURCE: BATHEN, K.H., 1970

LEGEND:

········▶ FLOODING TIDE

————▶ EBBING TIDE

VELOCITY MEASURED IN KNOTS
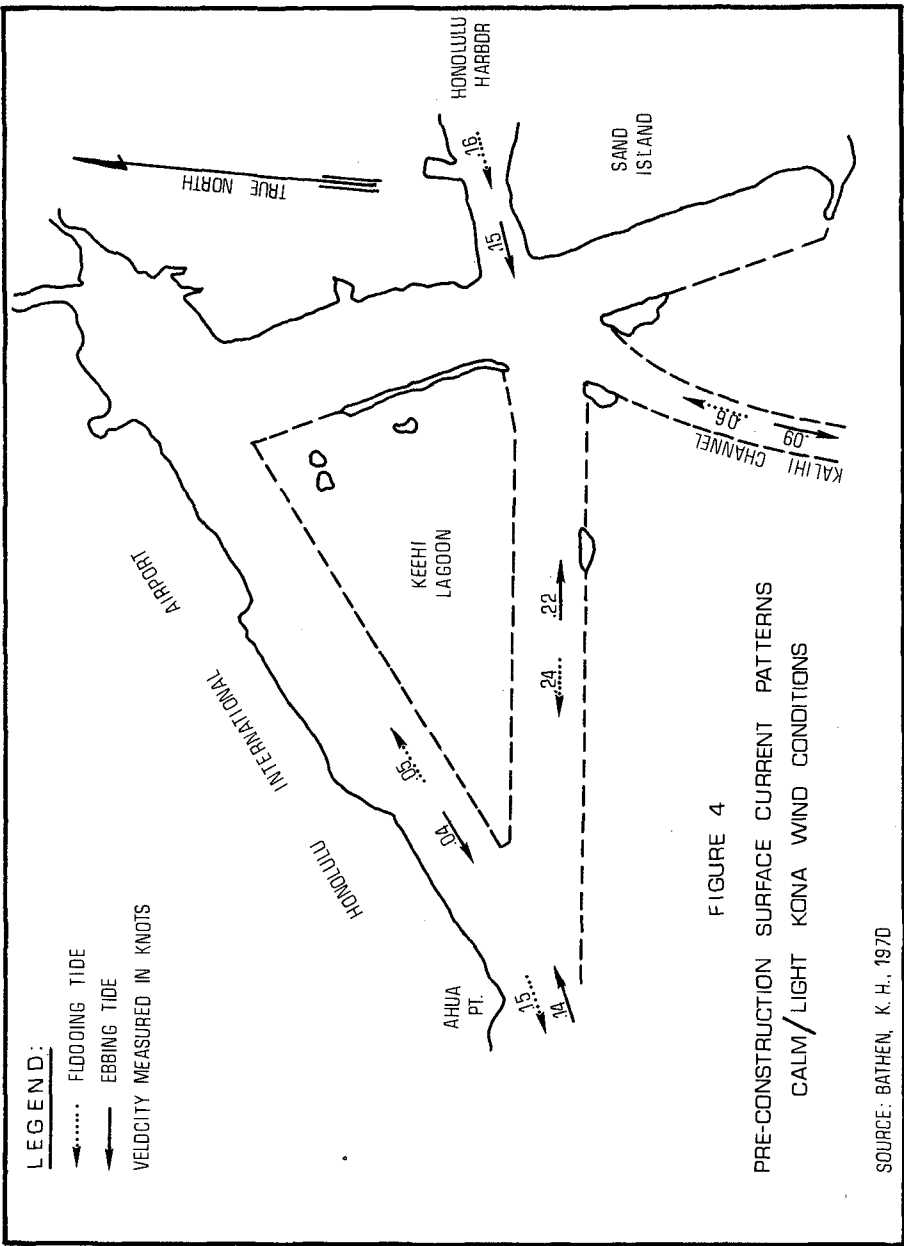
FIGURE 4

PRE-CONSTRUCTION SURFACE CURRENT PATTERNS

CALM/LIGHT KONA WIND CONDITIONS

SOURCE: BATHEN, K. H., 1970

FIGURE 5

DURING CONSTRUCTION SURFACE CURRENT PATTERNS
TRADE WIND CONDITIONS

LEGEND

28   VELOCITY IN KNOTS

— — →   FLOODING TIDE

——→   EBBING TIDE

RUNWAY AND TAXIWAY PAVEMENT

DREDGED FILL AREA

FUTURE TAXIWAY PAVEMENT

Source: R. M. TOWILL CORP. 1976s

GRAPHIC SCALE
0   2000 FT   4000 FT

Figure 6   Aerial View of Reef Runway, September, 1976.

Temperature and salinity levels at the seven stations analyzed (2, 2b, 3, 4, 6, 22 and 24) do not appear to indicate variations other than normal seasonal differences. That is, highest temperatures were found during the summer months and lowest during winter months. Highest salinity values were recorded during the spring and summer months and lowest values were recorded during the winter months, except at Station 22 where the lowest average was recorded during the summer. The reason for this anomoly is unclear, but it appears to be a local condition and not indicative of a long term situation.

Water clarity at all stations except two (3 and 24) is greater now than before the reef runway construction. It was apparent during the construction and dredging activities, that as dredging and filling approached any particular station, that water clarity decreased. However, as these activities proceeded by a given station and the area allowed to restabalize, water clarity increased. The exceptions to this are Stations 3 and 24. Station 3 is influenced by fresh water inflow from Kalihi and Moanalua streams. This inflow is generally silt laden and causes minor daily variations in water clarity. The effects of construction appear to have affected the water quality at Station 3 only to the degree that circulation patterns have been altered. Possibly resulting in decreased flow rates out of the area. However, until a detailed circulation study has been performed, definitive conclusions cannot be reached.

Station 24 is influenced by swell, wave, and offshore current action. It appears that dredging in Borrow Area II and Circulation Channel "B", plus the present outflow of water through Channel "B" may be causing some silt build-up along the 40- to 60-foot bottom contours. During the ecological surveys, a fine layer of silt was occassionally observed on corals at Station 24. However, it appears that this silt is naturally carried away by subsurface currents and is dispersed over a wide area. During spring and summer southerly swell conditions, this silt is placed into suspension and decreases water clarity. This condition is expected to continue for several years until the borrow areas and circulation channel have been cleansed of fine silts.

Dissolved oxygen levels at all stations indicate that construction activities have had little, if any, effect. As indicated previously, all sampling was performed at mid-depths and as such stratification of the various water quality parameters was not measured. However, unrecorded bottom D.O. measurements did indicate O_2 depleted conditions. These readings were made prior to completion of Circulation Channel "B" and it is, therefore, not possible at this time to indicate whether flushing or mixing within the lagoonal water column is occurring.

The general increases in nutrient levels (total Kjeldahl nitrogen and total phosphorus) that appear to be occurring are difficult to assess due to numerous outside influences. As noted above, Kalihi and Moanalua Streams and Honolulu Harbor enter Keehi Lagoon. The Sand Island Sewer Outfall, which presently disposes of over 55 million gallons of raw sewage daily, is less than two miles upwind the reef runway project area. Predominant currents flow towards the reef runway area. It is known (Ferguson Wood and Johannes, 1975) that dredging operations cause the release of nutrients stored in bottom sediments. It is also possible that if subsurface current flows through Keehi Lagoon have increased as a result of Circulation Channel "B", nutrients could be released from bottom sediments through increased scouring and the resultant suspension of silt particles in the water column.

An indication of the effects of changes in water quality that have occurred is provided by the marine ecology surveys. As noted previously, percent coral coverage variations that have occurred tend to indicate natural variation rather than one produced by construction activities or abrupt changes in water quality. Sea urchin and fish counts also tend to indicate variations due to natural causes rather than construction induced changes. Bowers (1976) reports that variations in numbers of sea urchins similar to those found at the reef runway have also been observed at other areas on Oahu, and that these variations may be natural cyclic occurrances.

The variations in the numbers of fish and fish species observed during the 3-year monitoring period can be generally explained by changes in the underwater visibility and natural fish movements.

The variations in the numbers and types of zooplankton observed does not indicate any general trend. The relatively small changes that have occurred, tend to imply that natural variation as opposed to environmental stress conditions, such as construction, are responsible for the variations in total plankton types noted.

CONCLUSIONS

As noted previously, a major purpose of the reef runway environmental monitoring program was the detection of non-compliance with State of Hawaii and construction project specification water quality standards.

Of major importance was the early detection of turbidity violations. Turbidity was controlled through the use of sea curtains and the requirement that all dredged spoil material be pumped into confined areas. Only in a few instances did turbidity levels go below allowable standards, and these situations were quickly and easily corrected. Violations of other water quality standards, e.g. nutrient levels, have also occurred. However, it appears that these violations have not been entirely due to construction efforts, but more likely, due to outside influences. As noted, when water quality, circulation, and marine biological factors are considered, it appears, at this time, that the reef runway construction project has not had any negative impacts. Definitive conclusions regarding the long-term effects of the reef runway project will not be possible until future water quality, circulation, and marine ecology studies have been conducted.

The analysis of water quality data collected during the reef runway project, and examinations of water quality data collected during other coastal engineering projects in Hawaii, suggests that present State Water Quality Standards require review and adjustment to reflect naturally occurring conditions. As noted previously, studies (Tetra Tech, 1976) have shown that pristine open ocean water, on the windward and leeward sides of Oahu and other islands, does not meet State Water Quality Standards. Studies performed at other construction sites on other Hawaiian islands also tend to indicate these findings (Sunn, et al, 1972b and 1975; Oceanic Foundation, 1975; J. K. K. Look, 1972; U.S. Army Engineers, 1976).

The long-term environmental effects of the reef runway construction can only be determined following additional data reduction analyses, and future water quality, circulation, and marine ecological studies. These studies, which should be conducted over at least a one-year period following major offshore construction efforts, will provide the data base upon which fairly definitive conclusions can be reached.

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