HYDRAULIC AND WATER QUALITY STUDIES, ERAKOR LAGOONS AND PORT VILA HARBOUR, VANUATU

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SUMMARY

An evaluation of the hydraulic characteristics of the marine channel linking Emten and Ekasuvat Lagoons shows that the major hindrance to tidal exchange is the causeway across the channel linking the Erakor community with the Port Vila area. The effect on the water quality of both lagoons of leaving the causeway intact or of restoring the original channel is discussed. A greater than three-fold increase in the tidal exchange within Emten Lagoon is anticipated with removal of the causeway and restoration of the connecting channel to its original condition. Restoration of the original channel and tidal prism to Emten Lagoon is recommended.

The data from water quality monitoring of Port Vila Harbour and the Erakor Lagoons between 1980 and 1990 show a decrease in the quality of these waters. Increased nutrients and reduced tidal flushing are cited for reduction in water quality within the Erakor Lagoons. The decrease in water quality of the Port Vila Harbour waters was found to be slower than that in the Erakor Lagoons. The water quality of the harbour was found to improve following major cyclones.

Future water quality monitoring is discussed and recommendations given. Some legislature to control ship discharges while within the harbour is indicated.

ACKNOWLEDGEMENTS

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Personnel Participating

The survey was directed by the Marine Scientist, Ralf Carter assisted by the Electronics Engineer, Ed Saphore of the ESCAP Project staff at SOPAC Techsec. Participants from Vanuatu included:

Cedric Mortimer, Director Geology, Mines, and Rural Water supplies
Jules S. Temakon, Applied Geologist
Siri Seoule, Field Assistant
Willie Harrison, Senior Geological Assistant
Sesule Siryl, Field Assistant
Martin Sokamanu, Hydrographer
Elison S. Bovu, Senior Environmental Health Officer

OBJECTIVES

The objectives of this study were to evaluate the effects of the causeway and bridge on the tidal exchange between Emten and Ekasuvat Lagoons, and to provide baseline data for estimation of the size of opening that might be required to re-establish adequate hydraulic exchange to improve the water quality within both lagoons. Other objectives were to collect additional water quality data on Port Vila Harbour and the Erakor Lagoons as part of a continuing water quality monitoring activity.

This study was undertaken as part of the SOPAC Coastal and Nearshore Programme and contributes to Vanuatu country projects VA.6 (Baseline studies of inshore areas in Vanuatu for Coastal Development Programmes). This work was requested by the Vanuatu Government to assist with management of Erakor and Ekasuvat lagoons and the continued development of those areas.

INTRODUCTION

The Vanuatu Government requested a survey of environmental conditions and pollution levels in the coastal waters around Port Vila. Tina Lam Yuen from the South Pacific Commission in Noumea, New Caledonia conducted a preliminary survey from 10-22 June 1979 (Yuen, 1980). The study indicted possible pollution problem areas, and the Vanuatu Government requested further investigations that centered upon Port Vila Harbour and the Erakor Lagoons.
SOPAC, in cooperation with SPREP, conducted a baseline study for those areas in 1983 (Carter, 1983) which drew attention to the reduced tidal exchange in Emten Lagoon and to the environmental impact resulting from several waste water sources in the area. These findings lead to a continuation of the water quality monitoring (Carter, 1985) and to the 1986 hydraulic study of the channel connecting Emten and Ekasuvat lagoons (Figure 1). Additional water quality surveys were carried out in 1986 and 1990 in the lagoons and in 1984, 1985, 1986, and 1990 in Port Vila.

STUDY METHODS

Tide and Current Study

The study was conducted between 22 and 24 July 1986. A recording water current meter was placed approximately mid-channel at the M. Michel property upstream from the bridge and causeway (Figure 1). The meter (Figure 2) was suspended from an anchored buoy with the sensor located 0.6 metre from the water surface. Recording began at 1434 hours on the 22nd and was terminated at 1436 hours on the 24th. The cross sectional area of the channel at mean tide level was 94 square metres. The tidal range was 0.2 metres. The current meter recorded depth, temperature, conductivity, and current speed and direction at five minute intervals. These data were averaged over 20 minute intervals.

A recording tide gauge was placed on the north shore of Emten Lagoon some distance from the entrance to the lagoon to record the water level within the lagoon. A second recording tide gauge was placed in an isolated cove within Ekasuvat Lagoon near the entrance to the channel to record the water level below the bridge during one-half of the study period. This gauge was moved to the Ross Winter property just above the bridge and causeway to record the water level there during the remaining half of the study. This meter was left running during the entire study period so the time sequence was not interrupted during the move.

The tide gauges at these three locations provided water level information below the bridge, just above the bridge in the 800 metre long channel, and in the upper lagoon. The hydraulic grade line could be estimated from this information. Using the current data, it was possible to determine the hydraulic characteristics of the channel and the head loss at the bridge section.

From the established elevation at the bridge and the tide gauge in Emten Lagoon it was possible to calculate the elevation of these two tide gauge locations relative to the Chart Datum. The elevation of the gauge location in Ekasuvat Lagoon was not established by leveling, but its relative elevation was estimated from the relative tide level when the current changed direction. The phase shift in the direction of flow due fresh water discharge would introduce a slight error in the estimated elevation. (Ordnance Datum + 0.674 metres = Chart Datum, and Ordnance Datum + 2.268 metres = Gauge Datum; the three datum employed at Port Vila. MTL is given as 0.75 metre above Chart Datum, and MHHW - MLLW = 1 metre).

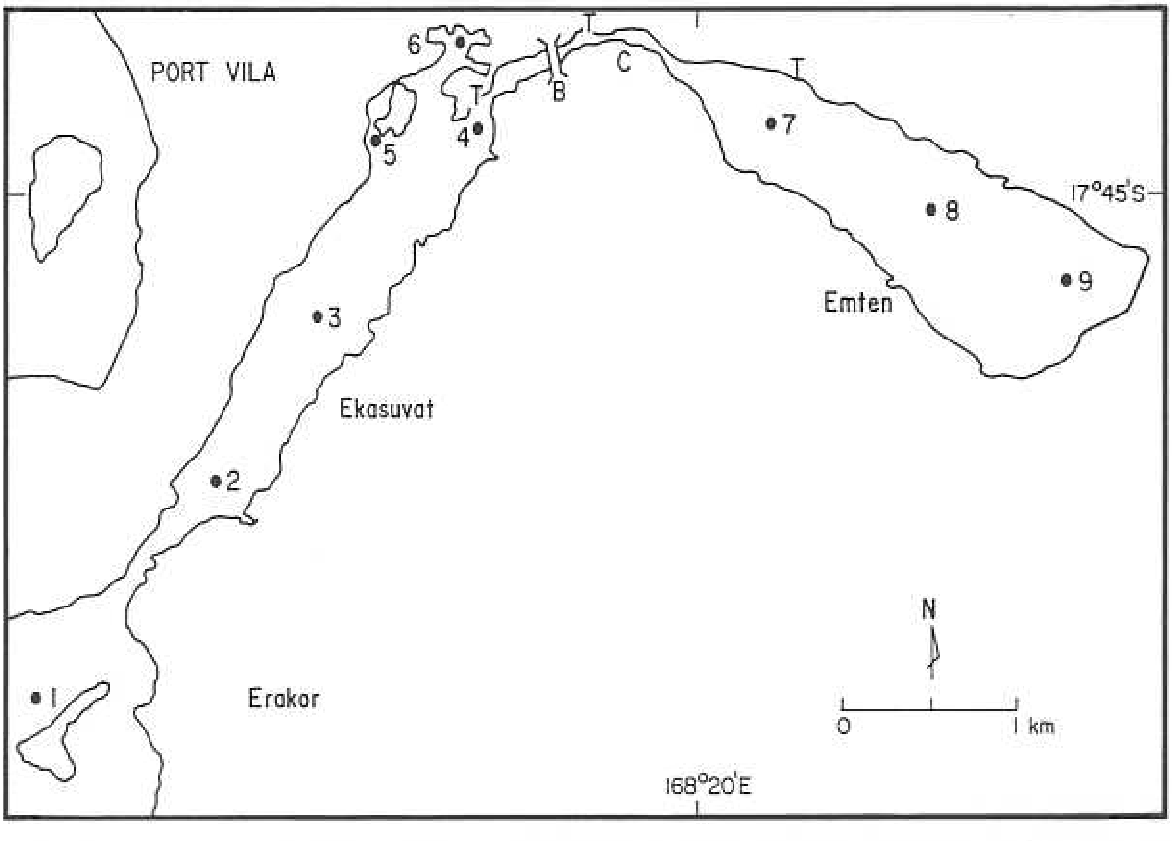

Figure 1. Location map of Ekasuvat and Emten lagoons showing the bridge, the three tide stations, and current station used for the 22-24 July 1986 tide and current study, and the nine water quality sampling stations established in the 1983 survey.

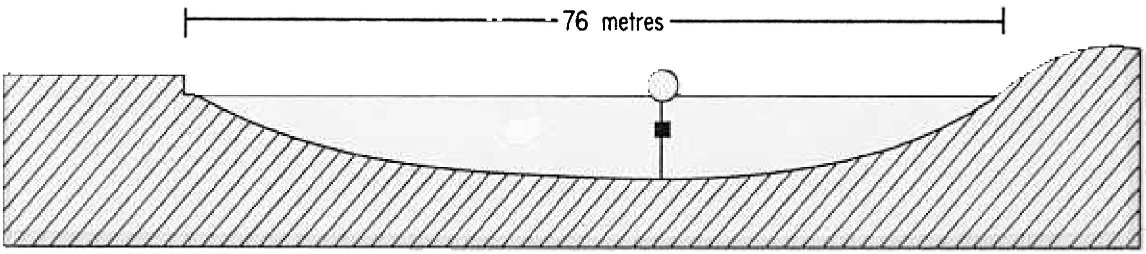

Figure 2. Cross section of the channel showing the current meter location. The cross section area is 94 square metres.

The change in water level and the surface area of Emten Lagoon was used to estimate the tidal prism. The amount of fresh water discharged was calculated from the relative duration of ebb and flood tide and from salinity changes. The tidal prism plus the fresh water discharge was used to estimate the factor to apply to the measured current to get the average current in the channel. The value of 1.38 was not applied due to uncertainty regarding the present area of Emten Lagoon. The surface current near the center of the channel would be expected to be approximately twice the average current in the channel.

Water Quality Monitoring

Nine sampling stations (Figure 1) were established in the 1983 survey (Carter, 1983) in Port Vila Harbour and Erakor Lagoons. These stations were sampled in 1985, 1986, and 1990. Particular attention was given to the transparency of the water that was determined using a secchi disk. There are no significant stream discharges into the water sampled. The shorelines do not erode rapidly from wave action, and the water depth is sufficient to reduce re-suspension of bottom material. Hence, changes in the water transparency are due almost entirely to suspended plankton; changes in this parameter are very sensitive, and it is an easily determined index of water quality. To determine water quality trends, it is necessary for the observations to be made under similar conditions at the same time of year.

Equipment and Facilities

The following equipment was provided by the Project and shipped from Suva to Vanuatu:

Aanderaa model RCM4 recording current meter
Aanderaa model WLR5 water level recorder, 2 each
Sounding equipment, calibrated line etc
Buoy and anchor
Secchi disk with calibrated line
Charts, maps and tools etc

The equipment and facilities supplied by the Vanuatu Government included the following:

Ground transport, field crew, and laboratory
Survey equipment; level, rod, tape etc
Laboratory and storage area
Survey vessel, engine, and crew

CURRENT AND TIDAL FINDINGS

Current Determined Tidal Prism

The twenty minute average currents are shown as points in Figure 3. Each set of points is a current vector where the vector at the origin is the last observation recorded. Ebb current is to the left and flood current is to the right. The shift in the loops down the figure are the result of Coriolis force, and the northwest to southeast alignment of the currents, except at slack water, is approximately along the center line of the channel. The gradual westward shift is due to fresh water spring discharge to Emten Lagoon, so the ebb tide lasts longer than the flood tide.

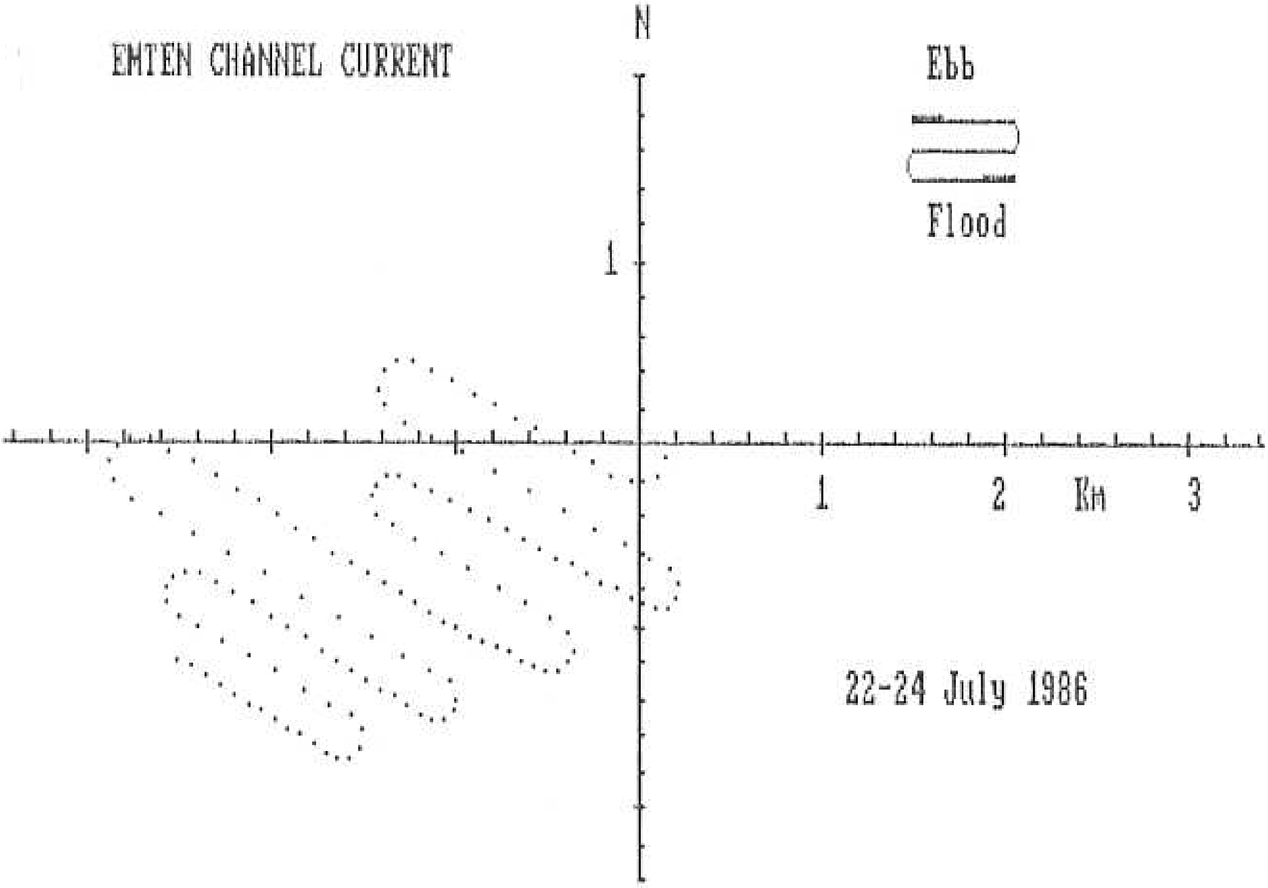

Figure 3. Twenty minute current vectors measured at mid-channel during the three day study period. Other than during slack water the currents were parallel with the direction of the channel.

The phase shift in the semi-diurnal components of tide result in diurnal inequalities in the tide levels in Ekasuvat Lagoon as shown in Figure 4. This inequality affects the duration and current speed in each tidal cycle. The alternate long and short ebb-flood cycles are evident in Figure 3 and Figure 5.

There is a phase shift in the tide levels between the two lagoons as seen in Figure 4. High water in Emten Lagoon was 2.9 hours after high water in Ekasuvat Lagoon, and the low water was 3.5 hours after low water in Ekasuvat Lagoon. The high-high shift was 1.8 hours between Emten Lagoon and just above the bridge, and the low-low shift was 1.1 hours between these points. The significant drop, 0.5 metres (Carter, 1983) in hydraulic head across the bridge section appears to be the principle cause for these phase shifts. The hydraulic head loss along the 800 metre channel above the bridge was 0.039 metres during flood tide and 0.099 metres during ebb tide.

The average ebb current was 0.076 mps, and the average flood current was 0.121 mps. The observed average duration of the ebb tide was 6.94 hours. With a cross section of 94 square metres a volume of 179,190 m would be discharged during the ebb. The observed average duration of the flood tide was 4.19 hours. The volume of flow during the flood tide would be 170,533 m. The net difference would be 8617 m. per ebb-flood cycle. On a daily basis it would be 16,900 m. or about 9.7 percent of the tidal prism.

Tidal Prism By Volume

The average change in water depth over several tidal cycles appears to be on the order of 0.11 metre. The area of Emten Lagoon was estimated at 219 hectares, although much of this area is covered with mangrove and the present area of the lagoon could be significantly less than when the map from which the area was estimated was produced. These values indicate a tidal exchange (119 x 10,000 x 0.11 = 240,900 m) that is much larger than that estimated from current velocities in the channel which average about 175,000 m. The factor 1.38 could be used to adjust the current, but as the area of the lagoon could be in error, no correction was applied.

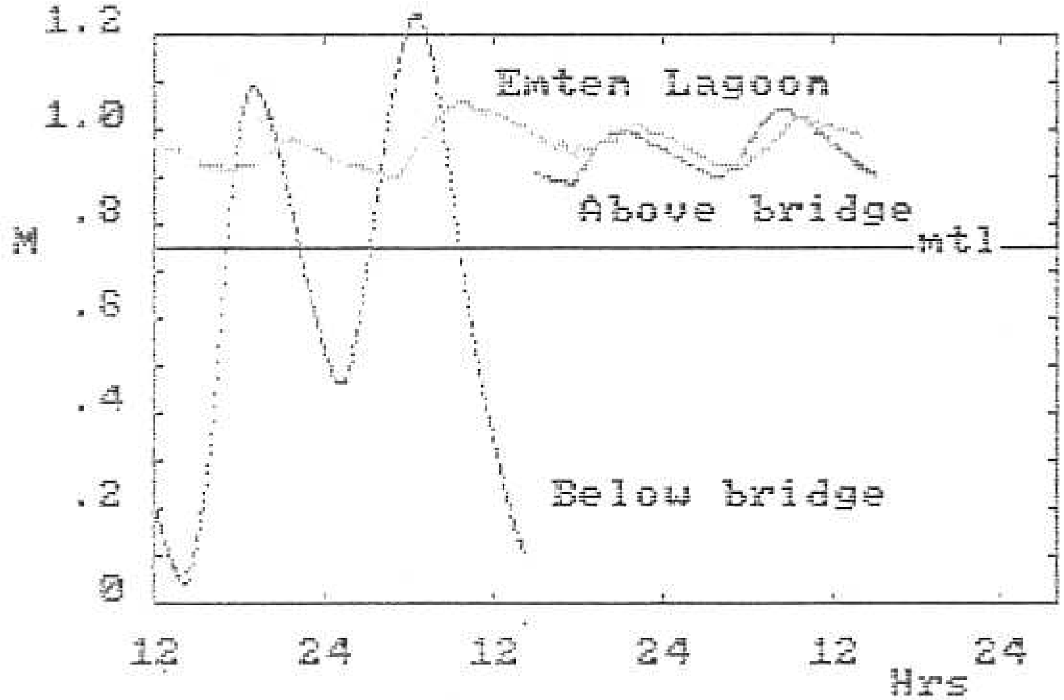

Figure 4. Tide level during the three day study period 22-24 July 1986.

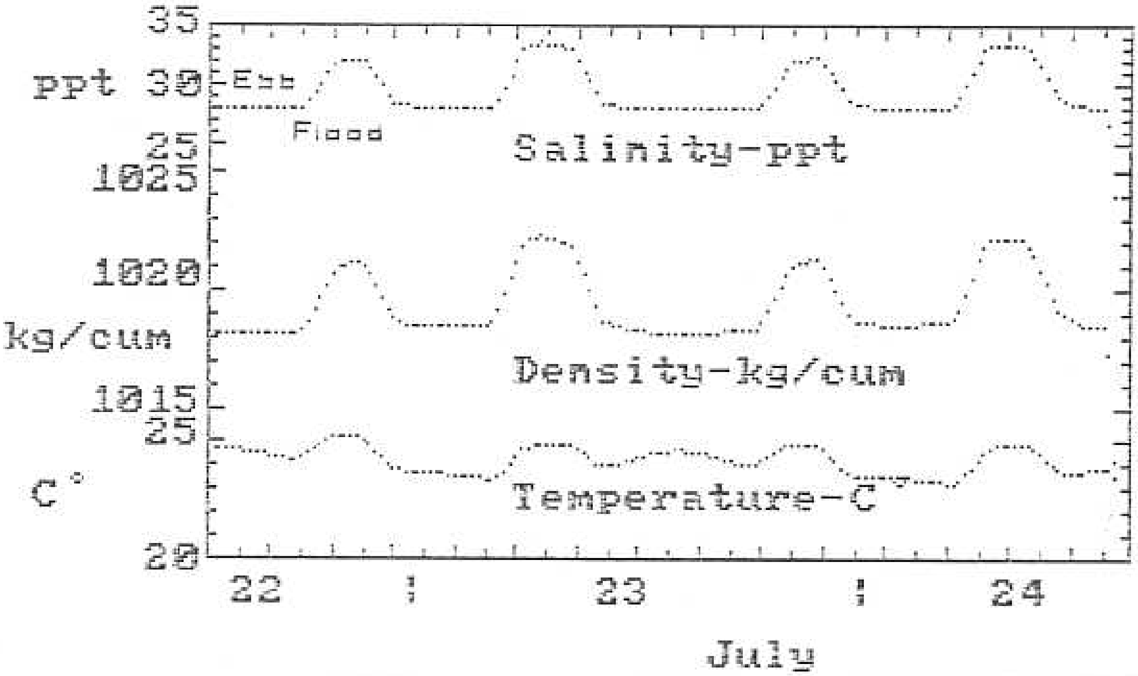

Figure 5. Water quality characteristics of the channel water during both ebb and flood tides in the 1986 current study.

Channel Hydraulic Characteristics

If we assume a Mannings n coefficient value of 0.05 for the channel and estimate the hydraulic radius to be 1.19 (both in Imperial units), an average ebb tide current of 0.076 mps (convert to fps with above hydraulic relationship) and an average flood current of 0.125 mps, the slope of the hydraulic grade line would be 0.0000561 1 metre/metre during ebb tide and 0.0001415 metre/metre during flood tide. The relative values for these slopes can be seen in Figure 4. There appears to be a greater change in water level or amplitude at the bridge than in Emten Lagoon. The observed slope values varied between 0.000056 and 0.0001 13 metre/metre during both ebb and flood tides. The hydraulic head loss at the bridge is about 0.5 metres as compared with about 0.1 metre in the 800 meter channel.

WATER QUALITY MONITORING

Lagoon Water Quality

Nine water quality sampling stations (Figure 1) were established in the lagoons during the 1983 survey. The significance of the station locations and findings are given in the discussion chapter of this report.

The transparency of the water in the lagoons was measured during three sampling periods over the past seven years. The results are given below and shown in Figure 6.

Station	Secchi Disk Transparency (metres)		
#	13 July 1983	23 July 1986	21 August 1990
2	6.10	5.5	4.50
3	5.18	5.5	3.20
4	2.90	3.5	1.68
5	2.29	2.5	2.74
6	1.52	2.5	1.52
7	3.51	5.5	2.44
8	3.72	4.5	2.13
9	2.44	3.25	2.44

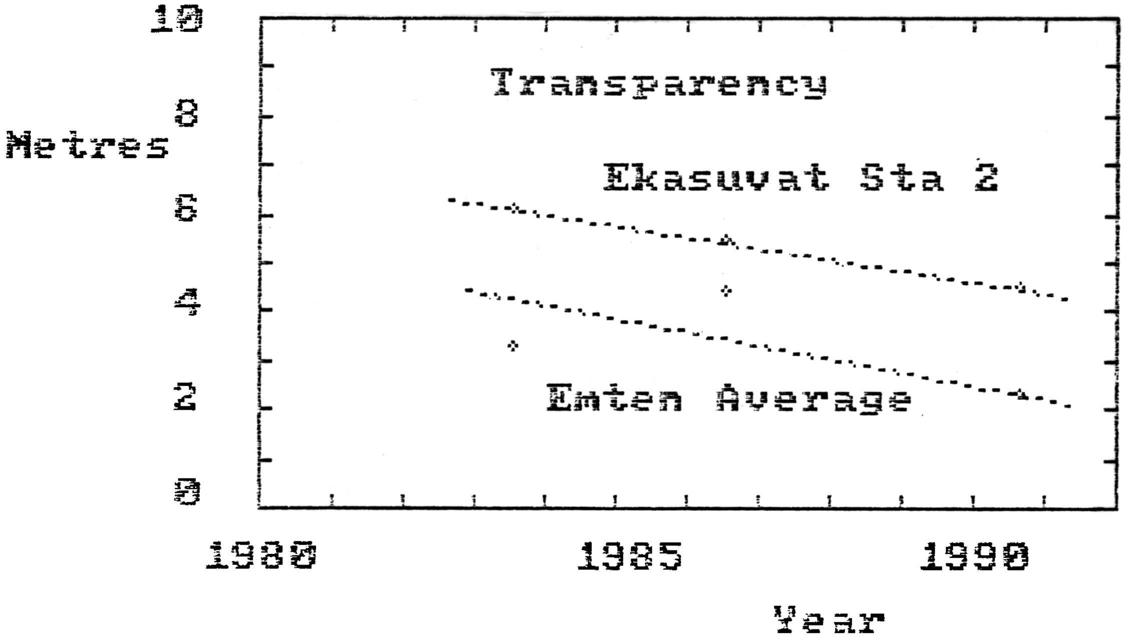

Figure 6. Secchi disk transparence of the Erakor Lagoon waters during the past 7 years.

Port Vila Harbour Water Quality

Seven water quality monitoring stations (Figure 7) were established in Port Vila Harbour during the 1983 survey. The significance of the station locations and the findings are given in the discussion chapter of this report.

The transparency of the water within the harbour was measured during five monitoring periods during the past seven years. The results of those monitoring are given below:

Station #	Jul Aug 1983	May 1984	Aug 1985	Jul 1986	Aug 1990
1	12.0	22.6	19.8	20.0	17.2
2	11.3	18.3	15.2	14.0	17.1
3	7.5	8.2	8.8	10.0	4.4
4	6.2	7.9	6.1	8.0	5.6
5	9.1	6.4	12.2	10.0	15.5
6	7.8	-	-	10.0	13.6
7	2.1	-	-	bottom	2.1

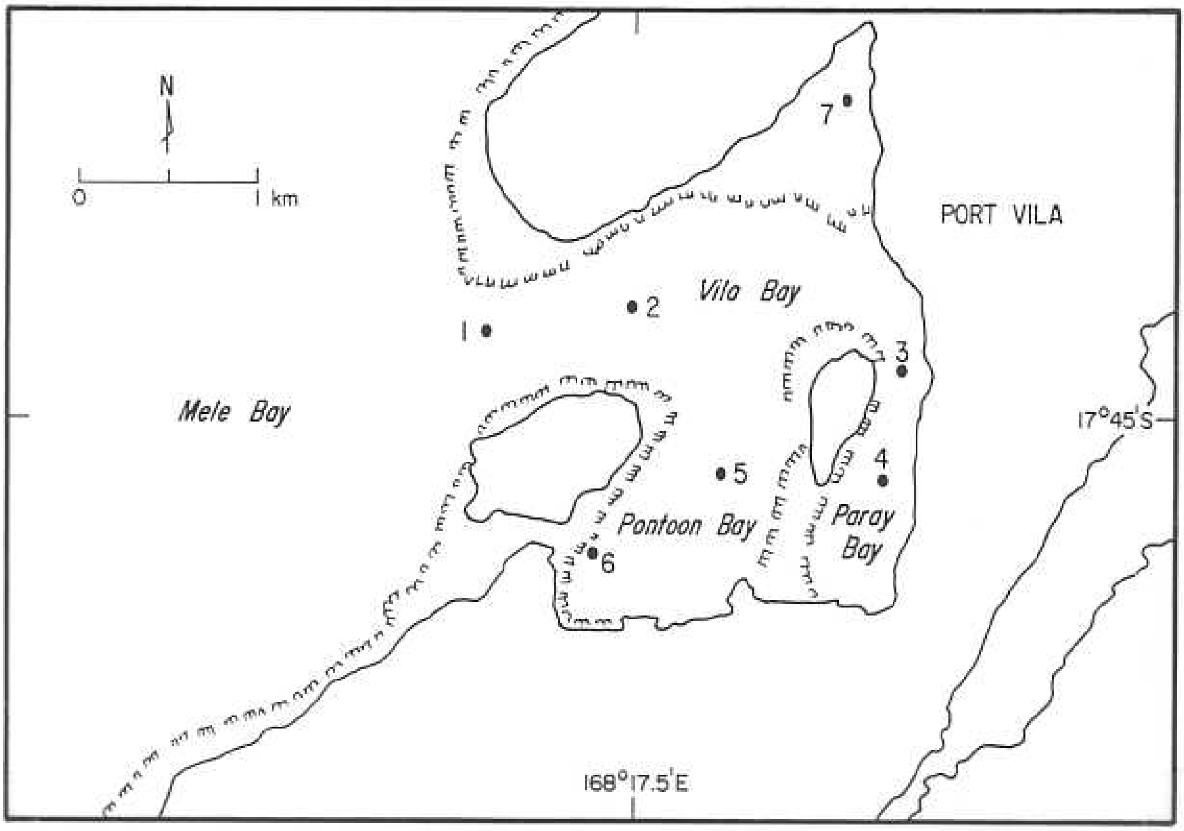

Figure 7. Water quality sampling stations used in Port Vila Harbour during the 1983, 1984, 1986, and 1990 observation periods.

During the 1990 survey a large cruise ship had been along side the main wharf for several days. Two slicks were observed during ebb tide within Pontoon Bay. Both slicks covered a very large area of 50,000 square metres or so. One was near Iririki Island and extended out to Station 5. The other extended from just aft of the bow of the cruise ship over to the Star of Russia marker buoy near Station 6. Both slicks were very similar in appearance, and neither had the characteristic odor of hydrocarbon products. The slicks were gray in appearance and contained many particulate which could have been vegetable fiber.

Other Monitoring

In September this year the Department of Geology, Mines and Rural Water Supply and the Health Department of Port Vila Central Hospital collaborated on a water quality monitoring of Vila Bay and Ekasuvat and Emten lagoons (Abbott, 1990). Their findings are attached as Appendix 1 of this report. In addition to the recommendations made in their report, it is recommended that transparency of the water also be monitored.

Between April 1987 and November 1988 several monitoring surveys of Vila Harbour and Erakor Lagoons were conducted by another study team (Naidu etal, 1990). The conclusions and recommendations are reproduced here as Appendix ll.

VANUATU CYCLONE HISTORY

The island of Efate' experiences tropical cyclones almost yearly, and there are periods of several month when significant rainfall may be not occur. These weather conditions have an effect on the water quality within Port Vila Harbour and the Erakor lagoons. Heavy rainfall following a dry period can result in the addition of a significant amount of nutrients from surface runoff that can produce an algal bloom in the receiving waters. The strong winds associated with a cyclone can exchange clean ocean water for the waters within Port Vila Harbour and Mele Bay, and cause a reduction in the suspended material of those waters. During the 1980's several cyclones have passed through the Vanuatu island group. Some of note are listed below:

Betty	03-06	February	1984
Eric	14-19	January	1985
Nigel	14-21	January	1985
Gavin	03-08	March	1985
Hina	10-18	March	1985
Keli	08-12	February	1986
Alfred	06-09	March	1986

Lusi	07-08	March	1986
Osea	21-25	November	1986
Patsy	13-17	December	1986
Uma	04-11	February	1987
Veli	06-11	February	1987
Yali	08-11	March	1987
Anna	07-14	January	1988
Bola	25-04	Feb/Mar	1988
Dovi	08-15	April	1988
Eseta	16-25	December	1988
Delilah	01-04	January	1989
Harry	07-19	February	1989
Ivy	23-02	Feb/Mar	1989

Following Cyclone Hina in March 1985 and Keli in February 1986 the water quality in Port Vila area was some improved over the 1983 condition. There is no direct proof that the cyclones were the cause for this improvement. Cyclone Keli produced some flooding.

Of all the above cyclones, Uma in February 1987 was the most destructive cyclone ever to have affected the capital of Vanuatu, Port Vila. It was estimated to have attained mean wind speeds of 90 knots and its center passed about 30 miles of Port Vila, where a pressure of 957 mb was recorded. Efate was battered by storm and hurricane winds for about 7 hours. Vila was declared a disaster area (Longworth, 1990). Uma was followed by Veli, also in February 1987. It attained only gale force winds, but produced a considerable rainfall at Port Vila.

DISCUSSION

Estimate Fresh Water Discharge

Using a mass balance relationship between the volume of water in the tidal prism and the observed ebb and flood tide flows, it is possible to show that the volume of spring water discharged from Emten Lagoon would be [(ebb discharge - flood volume)/2 = 4,308 m] over one-half of a tidal cycle. On a daily basis the volume is approximately 16,900 m. This volume of fresh water would be about 9.7 percent of the tidal prism which is the same volume of fresh water estimate in the tidal analysis. The amount of fresh water discharged would be expected to reflect recent rainfall, and to change from year to year.

The water quality data given in Figure 5 shows that the salinity of the ebb water was 28 ppt and the flood water was approximately 33 ppt. The salinity of the fresh water is assumed to be very low. As the flood water will be well mixed by turbulence during its passage by the bridge, the ebb water would have to be stratified when passing the current meter, as an average salinity around 31 ppt would be required to maintain salt balance in Emten Lagoon. It does not appear possible to estimate the fresh water discharge using a salt balance due as further information regarding the average composition of the ebb water would be required.

It is of interest to examine the temperature data recorded by the current meter that is shown in Figure 5. The temperature of the flood water from Ekasuvat Lagoon was relatively constant at 25 degrees centigrade. The temperature of the ebb water changed with the time of day, being coldest at daybreak, warming to a high at mid-afternoon then cooling. The night temperature was a degree or so colder than the daytime temperature. The density of the water is a function of the salinity and temperature. The combined effect is evident in the plot of density in Figure 5.

Hydraulic Exchange of Emten Lagoon

The hydraulic slope along the 800 metre channel was estimated to be 0.076 metre/metre during ebb tide and 0.121 metre/metre during flood tide. These slopes should result in currents of about 0.076 mps during ebb tide and 0.121 mps during flood tide.

If the channel is opened to full cross section of 94 square meters at the bridge, the slope along the 800 metre channel would be increased from around 0.00005 meter/meter to 0.00063 metre/metre. If we assume the hydraulic radius and the friction coefficient would remain constant, the velocity would increase less than 3.6 times. The entrance and exit losses to the channel would also increase and consume some of the one metre or so of available hydraulic head. The tidal exchange would increase significantly; however, the many years of reduced velocity may have cause several changes in the channel. The bar that has developed at the entrance to Emten Lagoon could now be cemented and not easily removed by increased current velocity, so it could restrict increased flow. The mangrove appears to have encroached into the channel area where it could have a significant effect on the friction factor, and restrict flow. Sedimentation and coral growth in the channel could have a similar effect. In order to regain the original tidal exchange, improvement work on the channel may be necessary in addition to removal of the hydraulic restriction at the bridge.

Increased tidal exchange in Emten Lagoon would also cause a greater volume of water to pass through the lower lagoon, and while this would improve the water quality in both lagoons, it would also increase the velocity of the currents in the connecting channels. Higher velocities could result in some bottom scour as well and some erosion along the shorelines. The higher currents could increase the risk for swimmers as well as bring some complaints from individuals experiencing property loss due to erosion. The higher currents did exist during earlier times, but present landholders have developed the shorelines for the slower currents.

If the present water quality within the Erakor lagoons is to be maintained and urban development continues in the drainage area tributary to the lagoons, additional hydraulic flushing must be achieved. If sufficient hydraulic flushing is provided then the water quality within the lagoons will improve with present nutrient loading.

Lagoon Water Quality

The sampling stations located in Ekasuvat Lagoon were selected to monitor the general condition of the lagoon and also to monitor specific areas of concern, in particular the quay development at the north end, the hospital outfall, and the Radison Royal Palms Hotel bathing area. The stations in Emten Lagoon were selected to represent the general water quality of the lagoon and were not directed toward any specific nutrient or pollution source.

There was a measured improvement in the transparency of Emten Lagoon water between 1983 and 1985 that appears to be associated with the low rainfall during that period. There was an algal boom in progress at Station 9 during the 1983 survey, and this lower value brought down the lagoon average. During the 1990 survey all three stations had lower transparency than previous, thus indicating a downward long-term trend. The transparency has decreased about 27 percent over the seven years of monitoring.

Ekasuvat Lagoon has a much greater tidal exchange than Emten Lagoon, and the water quality in the lagoon will be influenced by the quality of the incoming nearshore water as well as that of Emten lagoon discharge, the waste water discharges, and surface waters reaching the lagoon. The transparency of this lagoon has decreased 24 percent over the seven years of monitoring. The water quality of both lagoons is decreasing with time.

Harbour Water Quality

The sampling stations (Figure 7) were selected to represent the main water mass within each of the several sub-basins of water in the harbour area. Station 1 is located just outside of the harbour entrance within Mele Bay and is representative of Mele Bay water on flood tide during calm winds. During strong southeast winds, the surface water discharges from the entrance over most of the tidal cycle. Station 2 is located inside of Vila Bay and the water quality is generally determined by the tide and wind condition, much the same as Station 1. Station 3 is east of Iririki Island and as the waters of the harbour tend to circulate counter clockwise, this water is a good indication of conditions within Paray Bay. The water quality in this reach of the bay is influenced by many visiting yachts and small coastal ships. The industries located nearby in Port Vila will result in some surface pollution to this water. The plankton concentration is generally greater here than elsewhere in the harbour except at Station 7 in the norther reef flat area. At Station 7 surface drainage fertilizes the reef water causing a significant increase in the plankton concentration.

Station 4 is located in Paray Bay and the water in the southeast portion is often turbid due to a coral rock washing operation that can discharge 30,000 m per day of very turbid water when the coral rock is being washed. This turbidity appears to settle rapidly and does not appear to have much influence on the water in the central part of this bay. Station 5 is representative of water in Pontoon Bay which receives incoming water from Mele Bay before it reaches Paray Bay. Some gray water is discharged near the north end of Iririki Island that can diffuse over the reef area of Pontoon Bay, and the Main Wharf is located in this bay. Station 6 is located at Talimoru Passage entrance and this water is affected by the tide.

Cyclone Uma in 1987 may have resulted in an extensive exchange of Mele Bay water with Port Vila Harbour. The apparent improvement in the water quality at Station 3 between 1983 and 1986 could be related to rainfall. As shown in Figure 8, the water near the entrance of Port Vila Harbour is greatly influenced by the tide and water quality of Mele Bay. Station 3,4 and 7 are the only areas that show any significant water quality reduction during the seven years of observation. The water quality changes at Station 3 may indicate a long term water quality reduction in the inner part of the harbour.

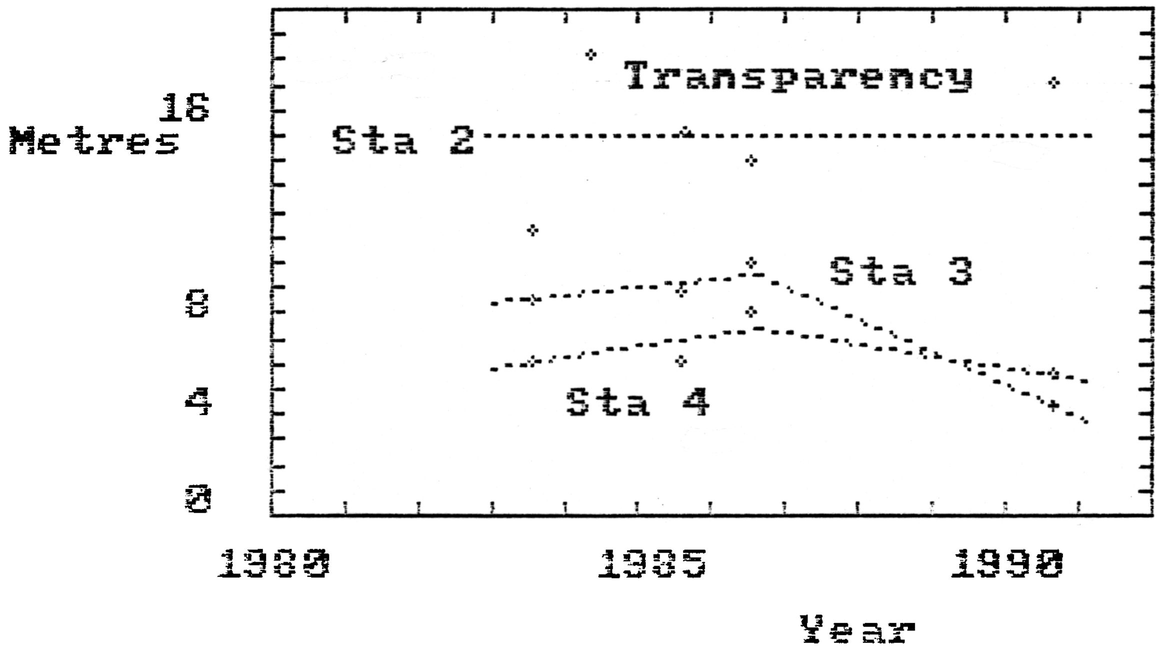

Figure 8. Secchi disk transparency of Port Vila waters during the study period from 1983 through 1990.

WATER QUALITY MONITORING PROCEDURES

To obtain maximum benefit from a water quality monitoring programme, a considerable amount of effort is required in its planning and standardization of procedures. The objectives must be examined carefully to ensure that data aquired will be useful. The monitoring programme for a specific application should be reviewed and updated as progress is made.

Some suggestions and guidelines are mentioned here to help in the development of a long range water quality programme for Port Vila Harbour and nearby lagoons. The comments are brief, and they do not include all aspects of monitoring. In particular they are directed toward the initial stages of programme development.

Bacteriological Monitoring

It is important that control cultures be prepared and tested each time field monitoring is done otherwise there is no assurance that the test results are meaningful. Sample handling is critical. For example, the bacterial-die-away of coliform type bacteria is rapid in sea water especially in surface samples in bright sun light. The T-90 for tropical waters is on the order of 90 minutes. With strong sunlight in surface sea water only 10 percent of the initial concentration of coliform bacteria would be expected to be viable after 90 minutes. The k value is approximately 0.0256 for the following relationship:

$$N = No \exp(-kt) \quad [1]$$

where N is the bacterial concentration after t minutes and No is the initial bacterial concentration. This means that for bacterial monitoring to be meaningful, the samples must be placed on test immediately upon collection. Adequate mixing with a pipette is necessary to break up clumps of organisms if a good count is to be obtained. Samples cannot be held and returned to the beach for testing.

Transparency of Water

The transparency of the water can be determined easily using a 30 cm or so diameter white disk (a dinner plate works well) held in a horizontal position by a calibrated line. This is probably one of the most useful parameters to measure, and requires the least effort.

Monitoring Schedule

The quality of monitoring is more important than the frequency of monitoring. Questionable data are often more of a liability than no data. Monitoring should be repeated under identical conditions asfar as possible. The tide phase and cycle should always be noted. Each sampling should be done the same time of year.

Plankton blooms should be noted, and when resources permit the net plankton concentration and volume should be determined. The impact of wind and rain should never be overlooked. Time since the last significant wind and rain should be noted as well at the present wind, and wave conditions.

Sampling once or twice a year can be very beneficial providing the work is done under comparable conditions. Monitoring at random times is of little value unless it is very frequent. The interpretation of monitoring results are generally quite dependent upon a developed pattern of values for a given location. If data are unusual it may be very important to repeat the sampling to confirm the results. Testing should be done using duplicate samples. Collection of bottom samples should be triplicated. The sampling method should prevent the presence of the vessel from affecting the sample.

Sample Station Location

Each sample station should be selected with a specific objective in mind. Some stations should be selected to represent the average water quality of the area without being influenced by a local discharge. Others should be placed to measure the maximum impact of the local discharges. The same stations should be used each sampling with special stations selected only for unusual situations. Control stations should always be used.

Observations

Any unusual condition should be noted. For example the presence of a large vessel in the immediate sampling area, very windy spell, surface slick, foam, or scum on the water, earth moving that could cause dust to be dispersed in the water, sudden increase in tourist and water contact sports etc should be recorded. Particular note should be made of any large surface slick, or widespread foam or bubbles. Its general appearance, size, odor, presence of particulate, type of particulate, color of surface, presence of color bands, tide and wind condition, direction of drift, lighting conditions, wave conditions etc should be recorded. Possible impacts such as yacht soiling, bird or fish kills, or fire hazard should be documented. Possible sources of the slick such as vessels, wharf activity, outfall etc should be described. The occurrence of a long dry or rainy period should be noted.

Data Review

The monitoring results should be reviewed and analysed to detect any new trends, and whether any changes in the monitoring are indicated. Procedures should not be altered unless the change is well documented. Any changes of personnel should be recorded. Where possible, simple procedures should be used. Data should be plotted so trends can be detected easily. The conclusions regarding a specific monitoring should be made as soon as adequate data are available and before important details are lost.

CONCLUSIONS

The conclusions reached in this study are based upon information developed herein. They are expected to be modified somewhat with time as additional information is recorded.

1. The water quality within both Emten and Ekasuvat Lagoons appears to be deteriorating with increased development in the watershed, and will continue to deteriorate unless the tidal exchange with the ocean is increased. Improvement of the lagoon water should receive higher priority than the harbour water.

2. The major cause of the reduced tidal prism within Emten Lagoon is the causeway across the Emten-Ekasuvat channel.

3. The water quality within the Erakor Lagoons does not appear to be improved with the passing of a cyclone.

4. Periods of low rainfall result in an increased water quality within the Erakor Lagoons.

5. Algae blooms can occur in the lagoons during July and August: however, the weather conditions are generally mild and constant during that time of year. It appears to be a good time of year for monitoring the water quality in the lagoons and in Port Vila Harbour.

6. Monitoring twice a year would be sufficient for the present in the Port Vila area. One monitoring should be scheduled during the July-August period, and one during January-February period.

7. Ship discharges within Port Vila Harbour reduce water quality there.

8. Hurricanes can result in a significant exchange of water between Mele Bay and Port Vila Harbour. The water quality within the harbour tends to deteriorate with time, but an occasional severe cyclone can improve it.

9. Increased development within the watershed will increase the nutrients within the waters. If the nutrient level increases, the water transparency will certainly decrease.

RECOMMENDATIONS

1. The Erakor bridge has been recently rebuilt, but further resources should not be invested in the present structure. It is recommended that plans be made to replace the existing bridge with another so that the causeway section can be removed.

2. The channel cross-section should be increased to approximately 94 square meters to restore the tidal exchange of Emten Lagoon back to its original volume.

3. Once the causeway has been removed, the current study should be repeated to determine if it is necessary to do additional work on the channel, bar, mangroves, coral, etc.

4. The water quality monitoring of Erakor Lagoons and Port Vila Harbour should be continued. It is recommended that water transparency be included in the programme. Bacteriological testing (MPM) should have a higher priority than chemical testing. Dissolved oxygen, heavy metals, bio-chemical oxygen demand (BOD), total and volatile suspended solids, net plankton, temperature, and salinity are important parameters to monitor; however, the monitoring should be kept simple for the present so not to overtax resources. The present programme should include: monitoring water transparency, MPM, general appearance of the water, phosphate and nitrate concentrations. It is essential that the tests should have controls, and the test methods be free of interferences.

5. Ship discharge within the Vila Harbour should be controlled with appropriate legislation and enforcement.

6. Future development within the area should be contingent upon paying for monitoring and testing. Development of a permit system could provide a tax for operation of the water quality control programme that is necessary due to that development. The cost of monitoring and operating the minimum practical water quality facility in Vanuatu should be investigated so that a future water quality programme can be defined, financed, and implemented.

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1. The views expressed in this report are those of the Author and do not necessarily reflect those of the United Nations.
2. Mention of any firm or license process does not imply endorsement by the United Nations.

APPENDIX 1

Hydrogeological Note No. 1/90/16a/5

Port Vila Bay and Erakor Lagoon
Water Quality Sampling -
September 1990

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HYDROGEOLOGICAL NOTE NO. 1/90/16A/5

Port Vila Bay and Erakor Lagoon Water Quality Sampling - September 1990

Mark A W Abbott
Hydrogeologist

1.0 Background

1.1 In the past water quality studies of Vila Bay and Erakor Lagoon (Ekasuvat and Emten) have shown the presence of relatively high levels of nutrients and faecal coliform bacteria (Yuen, 1980; Carter, 1983; Naidu et al., in press). Whilst within the safety limits set by the World Health Organization the presence of such contamination gives cause for concern and is an indication of pollution to the nearshore waters by sewage outfalls and septic tank effluent seepages.

1.2 No measurements of faecal coliform bacteria levels have been taken since April 1987, and of nutrient levels since November 1988. In view of the potential effects of pollution on health it was decided to undertake further monitoring of the level of pollution in these nearshore waters.

2.0 Sampling

2.1 This department in collaboration with the Health Department of Port Vila Central hospital sampled 22 sites at surface and 17 of these sites at depth in Vila Bay and the Ekasuvat and Emten lagoons on 18th and 19th September 1990 (Figure 1). The sites were chosen to incorporate many of those sampled in previous studies with additional sites in areas considered susceptible to pollution.

2.2 Surface samples were taken in sterilized glass bottles which were then sealed with screw caps. A borehole sampling device was used to obtain water samples from within a few metres of the sea bed where appropriate. Surface water temperature was also measured.

2.3 It was intended to measure salinities but this was outside the range of the instrumentation available within the department.

3.0 Analysis

3.1 The staff of the Health Department at Port Vila Central Hospital analyzed the samples for coliform bacteria within 24 hours of sampling. The results of these are expressed in terms of total coliform counts per 100ml of sample.

3.2 The samples were analyzed for Phosphate, Nitrate and Ammonium using this departments portable groundwater laboratory equipment.

3.3 Phosphate was determined as PO by the PhosVer3 method on the HACH spectrophotometer. Measurement range was 0 - 2.5 mg/L. No significant interferences should have been present.

3.4 Nitrate was determined as NO-N using the NitraVer5 method on the HACH spectrophotometer. Measurement range was 0 - 30 mg/L. It is likely that the concentration of Chloride was sufficiently high to produce interference which would reduce the measured levels of Nitrate.

3.5 Ammonium was determined as NH using Nessler's reagent on the AquaLytic spectrophotometer. the measurement range was 0 - 40 ppm. No significant interferences should have been present.

4.0 Results

4.1 The results of the analyses are given in Table 1. The faecal coliform counts were of a significant level in samples 3, 4, 6, 7, 15 and 22. The maximum count was 79 / 100ml (sample No. 15), which is well within the WHO standards for marine bathing waters which requires less than 350 faecal counts per 100ml (WHO 1983).

4.2 In Vila Bay sites 3 (65 /100ml) and 4 (52 /100ml) are located in an area of high seepage and minimal tidal flushing and showed high counts in previous studies. Site 6 (15 /100ml) is directly in front of the Rossi Hotel which discharges septic wastes into the Bay. Site 7 (25 /100ml) lies on the route of the Iririki Island ferry, at the time of sampling upwards of 30 sailing vessels were anchored in this area and were undoubtedly contributing to the level of pollution.

4.3 All other sites in Vila Bay showed less than 10 faecal coliform counts per100ml.

4.4 In the Ekasuvat and Emten Lagoons only samples 15 and 22 showed significant bacterial contamination. Sample 15 (79 /100ml) was the highest recorded and was taken in the lagoon in front of the Raddison Hotel. The water here was also noticeably less clear than in other places. Sample No. 22 (36 /100ml) was located at Tasiriki in an area of relatively enclosed water adjacent to a number of houses.

4.5 On the day of sampling the wind was southerly which may have resulted in an increase in the concentration of contamination in these areas.

4.6 The samples from depth showed consistently low measured values of faecal coliform contamination.

5.0 Recommendations

5.1 Future sampling should concentrate on surface samples to reduce the time required in sampling and the number of analyses required.

5.2 A measure of salinity and clarity should be included in future sampling. Appropriate equipment will need to be obtained for this purpose.

5.3 Sampling should be performed on a regular basis to obtain information on pollution trends and seasonal variations of pollution related to groundwater discharge to the nearshore areas. A sampling interval of 6 months should be attainable with present resources.

6.0 Staff Involved in sampling and analysis.

Richard Fechner, Bruce Hills and Mark Abbott - Geology Mines and Rural Water Supply.
Henry - Health Department, Vila Central Hospital.

7.0 References

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Dept. Geology Mines and Rural Water Supply.
Health Department, Vila Central Hospital.

Table 1: Port Vila Bay and Erakor Lagoon water quality sampling

Sample No.	sample depth m	Date	Temp. oC	Coliforms Per 100ml	PO4 mg/L	NO3 mg/L	NH4 ppm
1	-	18-SEP-90	25.00	0	-	-	-
1A	20	18-SEP-90		4	0.68	0.70	9.00
2	-	18-SEP-90	25.10	0	0.75	0.70	14.00
2A	4	18-SEP-90		0	0.59	0.00	0.00
3	-	18-SEP-90	25.10	65	1.15	0.00	11.00
3A	4	18-SEP-90		8	0.32	0.90	10.00
4	-	18-SEP-90	26.10	52	0.91	1.30	8.00
4A	5	18-SEP-90		3	0.23	0.00	6.00
5	-	18-SEP-90	26.00	5	-	2.00	7.00
6	-	18-SEP-90	25.30	15	–	0.40	10.00
6A	7	18-SEP-90		1	0.12	1.30	10.00
7	-	18-SEP-90	24.90	25	1.80	1.50	8.00
7A	10	18-SEP-90		3	0.38	1.10	5.00
8	-	18-SEP-90	24.80	6	0.37	1.10	8.00
8A	40	18-SEP-90		0	0.47	0.90	8.00
9	-	18-SEP-90	25.20	1	0.18	0.40	7.00
9A	50	18-SEP-90		3	0.70	0.80	10.00
10	-	18-SEP-90	25.20	7	0.68	0.90	9.00
10A	40	18-SEP-90		0	0.40	1.50	7.00
11	-	19-SEP-90	24.10	0	1.61	1.20	6.00
12	-	19-SEP-90	23.40	1	0.96	1.50	10.00
12A	6	19-SEP-90		0	0.43	1.30	7.00
13	-	19-SEP-90	23.20	0	0.28	0.40	7.00
14	-	19-SEP-90	23.40	0	0.95	1.20	7.00
14A	4	19-SEP-90		0	0.19	1.40	9.00
15	-	19-SEP-90	22.30	79	1.40	1.30	11.00
15A	4	19-SEP-90		0	0.14	1.30	8.00
16	-	19-SEP-90	24.30	2	1.93	1.50	17.00
16A	3	19-SEP-90		0	0.14	1.20	10.00
17	-	19-SEP-90		6	2.45	0.70	11.00
18	-	19-SEP-90	24.30	6	0.21	0.60	9.00
18A	6	19-SEP-90		2	1.08	0.10	-
19	-	19-SEP-90	24.40	0	2.14	0.90	8.00
19A	4	19-SEP-90		0	0.11	0.40	16.00
20	-	19-SEP-90	24.00	2	0.20	2.30	16.00
20A	5	19-SEP-90		0	0.22	0.90	12.00
21	-	19-SEP-90	23.90	2	0.18	0.80	12.00
22	-	19-SEP-90	25.6	36	0.39	1.50	13.00
22A	3	19-SEP-90		0	0.42	0.00	9.00

Notes :
Coliform analysis by Health department, Vila Central Hospital
PO4 and NO3 analysis by HACH spectrophotometer
NH4 analysis by Aqualitc spectrophotometer

APPENDIX II

Water Quality Studies on Selected South Pacific Lagoons:
Conclusions and Recommendations

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UNEP Regional Seas Report & Studies
(in press) 1990

4.4 CONCLUSIONS AND RECOMMENDATIONS

Based on the analytical results presented in Tables 4.2 to 4.17 it can be concluded that quality of water in the harbour was generally better than that in the lagoon. Nutrient levels in the lagoon were high and comparable to levels found in some polluted areas of Suva Harbour/Laucala Bay (Section 3.3). The situation is more critical in Erakor Lagoon because of the longer residence time of water compared to those studied in Fiji. Compared to other tropical coastal waters much of the lagoon area is already eutrophic. This means that eutrophication will be a major problem in the lagoon if nutrient inputs into the lagoon are not controlled. Treatment plants at the hotels and the hospital are reducing the BOD of the effluents but they are not removing the nutrients. Thus it is important to connect the hospital to a sewer system so that waste can be diverted from the lagoon. If nutrients from the hospital and the hotels continue to enter the lagoon, eutrophication will ultimately lead to fish kills, odour problems and general reduction in the suitability of the water for recreational purposes. The causeway across the lagoons is restricting the flow of water between the two lagoons and as suggested by the study of Carter (1983), an adequate channel is required: if major problems are to be avoided.

The population of Vila is increasing rapidly and so is the extent of industrial development. Many new industries are also being set up; thus it is very important thar an adequate sewerage system be installed as soon as possible. Feasibility studies have already been carried out and two sites have been selected as possible outfall area. The urgent priority must now be construction of the system.

During the construction and post construction, monitoring of the quality of waters in the harbour and lagoon mist continue so that the impact of the sewerage system can be quickly assessed.