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WATER QUALITY IN THE BA RIVER AND ESTUARY: ENVIRONMENTAL EFFECTS OF MULTIPLE RESOURCE USE

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by

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1 SUMMARY

Ba River is the site of an intense collision between competing water resource uses. The natural resource value of the river and estuary is high because of fisheries (especially the prized freshwater mussel *kai*), mangrove habitat and the value of the water itself for recreation and potential irrigation. Ba Town, small industries and the Fiji Sugar Corporation Rarawai sugar mill (FSC Rarawai) use the river mainly for waste disposal. The progression of agriculture up watershed slopes has undoubtedly contributed to increased flooding and excess sediment loads in the lower river. Department of Drainage and Irrigation are dredging a flood relief channel in the lower river. There have been fish-kills in the river, and the population nearby believe that the Rarawai mill is the main cause of these events as well as general degradation of the aquatic environment. Other potential sources of pollution have not been excluded. We sought to relate water quality in Ba River to the potential sources of pollution.

We made four water quality surveys of Ba River between 10 November 1994 and 26 January 1995. Two surveys were made before the mill ended its 1994 crushing season on 14 December, and two post-crushing. Measurements of salinity and temperature demonstrated that the Ba estuary is nearer to a well-mixed type than a salt wedge type circulation. A trace of salt penetrates upstream on the flood tide about 20km, to Nasolo. Between Nasolo and Nailaga, at about 9km from the river mouth, we observed an oxygen sag accompanied by high biochemical oxygen demand (BOD), mild temperature elevation, substantial contamination by faecal coliform bacteria (FC) and often reduced water clarity. The town of Ba is centered at about 15km upstream from the mouth, and FSC Rarawai at 16km from the mouth. *Kai* beds occur mostly in the region of the oxygen sag.

The oxygen sag was most pronounced during crushing season and dry weather, when oxygen approached zero at all depths for at least 5km of river centered on Ba/FSC Rarawai, when upstream and downstream reference stations had about 6mgO_2/L. The oxygen sag was partially relieved by increased river flow, but it persisted in a less dramatic form during post-crushing. Temperature elevation of about 1.5°C accompanies the oxygen effect. FSC Rarawai effluent is the major cause of the oxygen sag, but other sources contribute significant BOD loading.

Preliminary modeling showed that the BOD of FSC Rarawai effluent is competent to produce the observed oxygen sag only during extremes of low river flow and high BOD loading. Further work is required to reconcile the observed deep oxygen sag with the smaller calculated effect. FSC has installed an effluent treatment system to reduce BOD. The system was on line for the 1994 crushing season, but it was not operating at full efficiency. Operational improvements are expected to produce favorable results in the river environment.

Faecal coliform bacteria contamination is also greatest in mid-river. FC exceed world standard for primary water contact by factors of 5X to to 167X on average in the mid-river and tributary creeks. This represents a substantial health hazard, especially through eating partially-cooked *kai*. Ba Town is the likely cause of FC pollution. The population of about 11000 have no sewage collection and treatment system, other than pumping out downtown septic tanks for land disposal. Informal sewers and contaminated groundwater undoubtedly drain into the creeks. This situation is expected to improve with progressive connection of urban premises to a new sewage treatment plant, completed in 1995.

2 INTRODUCTION

2.1 GENERAL

The Ba River, while a small waterway by world standards, is the site of an intense collision between competing resource uses. The approximately 11000 people of the town of Ba, their industries and a sugar mill are concentrated along about 1 km of river near the Ba Bridge (Figures2,3). Town and industry use the river mainly for waste disposal; drinking water comes from boreholes, and transport by water, while once significant, has been largely replaced by roads. The mid river, estuary and nearby marine waters contain valuable natural resources - fish, *kai* and other shellfish, mangrove and other wetland, the water itself - whose quantity and quality are challenged by wastes from onshore development. Two major construction projects add further stress to the present situation: a new highway bridge about 0.5km downstream from the Ba town center, and dredging to reduce upland flooding.

There have been episodes of complaint about fish-kills, unusual taste and noxious smells in the Ba River (Tamata and Lloyd, 1994; Tomasi Tuibau, District Officer Ba, pers. comm. 1994; Anare Raiwalui, Fisheries Officer, Ba pers. comm. 1994), None have been unequivocally fixed to a cause. The river may be oxygen deficient (Watling and Chape, 1992). It receives drainage that is visibly polluted. We sought to disentangle the effects of the competing users on Ba River water quality. There are two obvious point sources of pollution stress: the Fiji Sugar Corporation mill at Rarawai, and the town of Ba itself. In addition, there are three riverside villages and diffuse sources in agricultural and industrial runoff.

2.2 GEOGRAPHICAL SETTING

Ba River discharges into a shallow lagoon on the northwest coast of Viti Levu, Fiji. It drains a watershed of 640km^2, rising in tributaries on the northern slopes of the Naloto range and exiting through a relatively large floodplain and delta composed of mud, clay-grade materials and an admixture of sand (Derek, 1946). Some of the gentler slopes of the watereshed, and most of the floodplain not occupied by human habitation or mangrove, are intensively cultivated for sugarcane.

Fiji has a maritime climate, with small diurnal and seasonal temperature changes (National State of the Environment report, 1992). The Ba watershed, on the lee side of Viti Levu with respect to the Southeast Tradewinds, experiences a dry environment during the months of June through to October, with nil rainfalls recorded in some years on the coastal plain. During the dry season, river flow in maintained by highland precipitation and goundwater flow. During the wet season, October to March, precipitation regularly exceeds 400mm per month. Daily average temperatures at Ba vary from 27°C in February to 23°C in July. Maximum recorded temperature is 38°C and minimum, 10°C (PWD, 1988).

Most rain falls at higher elevations in the Ba watershed. In the decade 1985-1995, annual rainfall at the five PWD meterological stations in the Ba watershed (Figure 2) was as follows:

Station	Waiwai	Navala	Nanoko	Koro	Nadrugu
Elevation, m	70	70	580	80	330
Precipitation					
Annual average, mm		2000	2200	2300	4800

The river's total length is 67 kilometres. The lower river is navigable by small boat to Irish Crossing, approximately 23km upstream. There are both shallow and deep reaches in the navigable portion of the river. Maximum depth is 8.2m below mean sea level about 1.6km from the mouth. Minimum controlling depth is 1.8m about 1km downriver from Nasolo bend. River flow is gauged at Toge (Figure 2), where discharge minimum is $2m^3/s$, average $7m^3/s$ in the dry season and $38m^3/s$ in the wet season (Divisional Engineer Western, pers. comm. 1994; PWD 1996). Tributaries below Toge may raise the minimum to $3m^3/s$ at the river mouth, wet and dry season averages 10 and $58m^3/s$.

Tides at the river mouth are mixed, mainly semidiurnal, with mean range about 1.2m. During most river stages, tidal currents reverse the flow at least as far upstream as Irish Crossing. In the lower river, currents are relatively sluggush, with an average speed of approximately 0.2m/s (D & I, 1994).

Delta and flood-plain extend some 16km inland from the coast. The delta exhibits the largest aggregation of mangrove forest in Viti Levu (Derek, 1946). The river banks are lined with mangrove as far upstream as Nailaga village. Cane fields abut the banks of the lower river; mixed farming and livestock are characteristic of the mid-section. The banks mostly lack forest cover.

The river meanders through the flood plain. Active erosion is evident on the outer banks of bends in the lower river. Floods during the wet season from November to April affect primarily industrial and commercial areas on the east banks.

2.3 POTENTIAL SOURCES OF ENVIRONMENTAL STRESS

Sugar Industry

Of the five major river systems in Fiji, the Ba has ranked high in economic importance for many years (Derek, 1946). Sugar is the principal industry. The Rarawai mill was established by the Colonial Sugar Corporation in 1886. This mill and its surrounding cane farms are the economic reason for Ba's development.

Fiji Sugar Corporation now owns the Rarawai mill. It crushes about $1.1X10^6$ tonnes of cane annually to produce about 135,000 tonnes of raw sugar, plus 38,000 tonnes of molasses. The mill operates seasonally from about June through December, and is idle from about January through May. Cane is crushed during the dry season because sugar content is highest at this time, and transportation easiest. In addition to a large volume of water used in cooling, the mill discharges an organic rich mixture of general mill washings and waste sugars. At approximately two week intervals, the process equipment is washed down with a caustic solution, bringing the possibility of high pH discharge to the environment.

FSC Rarawai has constructed new effluent treatment facilities, which were brought into operation in June, 1994. Cooling waters are discharged directly to the river, but all other wastewaters, including caustic washwaters, are processed in an aerated pond system with a retention time of 26 days. Based on industry standards (Meade and Chen, 1977) we estimate that the Rarawai mill produces 5 -10m^3/hr of organic rich effluent at BOD 3000 - 7000mgO_2/L. The smell and appearance of the effluent indicated that treatment was not fully effective in the ponds' first season of operation. The mill discharges about 4000m^3L/hr of relatively clean cooling water at at about 14°C above river ambient temperature (Tamata and Lloyd, 1994).

Human population

The population of Ba will be about 11,380 in 1996, increasing at 2.0% to 2.5% per year (PWD, 1988). Of this population, about 7640 are in the town, and 3920 in the periurban area. The town of Ba has no formal sewerage system. Individual households have septic tanks and disposal fields. Downtown Ba is a small urban centre, with one or two stories of apartments above many of the main street shops, and other dense habitation on side streets. Sewage from these premises drains into holding tanks, which must be pumped out regularly so that the effluent can be transported to land disposal. The groundwater below Ba town is undoubtedly contaminated. Informal drainage can be seen along creeks running through the town. Elevuka creek (Figure 3) is visibly polluted.

Fiji Department of Public Works is installing sewers and building a sewage treatment system for the town of Ba, with discharge through mangrove wetland in the north delta, outside the Ba River. The sewage lagoons have been built, but complete reticulation of sewers to all downtown premises is expected to take several years.

Three river-side villages, Nasolo, Nailaga, and Votua, may contribute to the contamination of the Ba river.

Additional contaminants

Additional contamination can be expected from smaller industrial inputs and from non-point sources such as agricultural runoff, which may also vary seasonally. Light industries, primarily related to the sugar industry, have developed in Ba. These industries include motor vehicle servicing and repair; machine shops; electroplating; wire nail manufacture. A sweet factory with its own waste treatment plant is located in the eastern suburbs. Ba is a regional transportation centre and produce market. The town centre, market, bus station and most industries are concentrated on the east bank of the Ba river, in the Elevuka creek drainage. Elevuka creek may receive some direct discharges (PWD, 1988). Nailaga Creek, on the west bank, is also suspect.

In January 1993, floods from Cyclone Kina washed away the Ba bridge. The present one-lane steel truss bridge on columns is a temporary structure. A new bridge is under construcion about 0.5km downstream (north) from the present bridge. Temporary increases in siltation or erosion are likely during construction phase. The Department of Drainage and Irrigation (D&I) are dredging the lower Ba River, to reduce flooding and restore land lost to erosion at Votua village. The suction dredge deposits spoil, mostly sand, along the banks of the river in diked ponds.

2.4 RESOURCES OF THE BA RIVER AND ESTUARY

The *kai* fishery (freshwater mussel, *Batissa violacea*) is the most important aquatic resource in the lower Ba River. *Kai* beds occur from approximately 100 m upriver fron Nailaga to Nasolo. They are harvested by breath-hold divers. Swamy (1994) estimated the catch from the Ba River at over 130,00 tonnes, of which 100,000 tonnes over $84000 were sold commercially.

A few finfish are taken along the river by hook and line, but most commercial fishermen work in the outer estuary using gill nets.

2.5 CONFLICTS

Previous investigations in the Ba river responded to complaints by local villages that the sugar mill effluent discharged into the river had caused occasional fishkills (Tamata and Llyod, 1994; K. Swamy, Fiji Department of Fisheries pers. comm. 1994). The events were poorly documented. The Ba Fisheries Officer felt that more events would be reported if fishermen and villagers were confident that corrective action would follow.

Neither Ba District Officer nor Ba Fisheries Officer were aware of any fishkills during the period of our field investigation, but during the writeup period, a further fishkill occurred near the end of June 1995, just after crushing resumed (pers. comm. Turaga-ni-koro, Natutu village).

Many people along the river believe that fishkills coincide with mill washdowns, which occur at approximately two week intervals through the season. The most serious spill was an accidental discharge of 26 tonnes of caustic soda ($NaOH$) on 16-17 January 1992. No other direct connection to mill effluent has been established, and it is possible that toxic inputs from other sources are deliberately timed to coincide with scheduled FSC Rarawai washdowns. Normal mill practice is to recycle the most caustic washdown liquids. The end-of-season washdown is particularly thorough, and is the most likely occasion for toxic discharge. We planned our third field trip to occur soon after the final washdown for 1994.

The river is not used for drinking water, but all of the villages along the river use it recreation and for *kai* diving. In Fiji, *kai* are often eaten raw or partially cooked. Contamination of the waters and shellfish with human and animal faeces brings risk of water-borne diseases such as hepatitus A, typhoid, cholera and dysentery. The Ba District Health Office does not recall incidence of these serious diseases. This office would not necessarily be aware of the occurrence of lower grade diseases, such as diarrhea and skin infections, among river people.

Kai occur in the estuary from near Nailaga upstream at least to the limit of salt penetration near Nasolo. This is also the region where pollutants are most likely to compromise the ability of the river to support living resources. *Kai* and associated fishing activities may also contribute to oxygen demand and sediment disturbance.

There is as yet no tourist development of the lower Ba River. Towns people make little use of the river for recreation.

2.6 STUDY OBJECTIVES

The two obvious major sources of environmental stress to the Ba River are the FSC mill at Rarawai and the population of the town of Ba. The two water quality parameters of highest concern are therefore faecal coliform bacteria (FC), which indicates the presence of faeces of humans or other warm-blooded vertebrate animals; and dissolved oxygen, which will be depleted by wastes with high biochemical oxygen demand (BOD). Untreated sewage and sugar mill effluents are high BOD wastes. Other pollution concerns include pH changes caused by the discharge of caustic washwaters; industrial contaminants, such as heavy metals and organic chemicals from industry; and effects of agriculture, such as eroded soil and pesticides.

Our plan to separate the effects of these two major sources was to sample along the river and near the potential pollutant discharge points during crushing and non-crushing seasons. The seasonally variable part of the river effect should be attributable to sugar milling; the invariant part, human and other animal input. Consistently high values near sources would indicate the important contributors. Elevated river flow during the wet season, from October through March would complicate the pattern by reducing effects through dilution and downstream transport. We cannot exclude the possible occurrence of other significant pollution loads that would not be expressed as FC or BOD.

Our measurments will serve as a baseline against which to measure expected improvements in water quality resulting from the new waste treatment facilities for the town of Ba and FSC Rarawai can be measured.

We undertook four water quality surveys in the Ba River: two during crushing season and two post-crushing. Many of the stations coincide with those of Tamata and Lloyd (1994) to maintain comparability. We sought and received valuable information and insights from the Ba District Officer, Votua Village, Nailaga Village, Ba Town Council, Fiji Sugar Cooporation (FSC), Department of Drainage and Irrigation (DI) of the Ministry of Agriculture, Forests and Fisheries (MAFF).

3 METHODS

3.1 SAMPLING

We collected field data in Ba River during the crushing season on November 10-11 and November 30 to December 1. FSC Rarawai shut down the 1994 season on 14 December. Post-crushing sampling was done on December 19-20, 1994 and January 24-26 1995. We sampled mostly from outboard motorboats provided by FSC or D&I.

We visited two series of stations (Figure 3; Table 1). One was a series of Depth Profile stations, taken at seven mid-river positions from the mouth of the river upstream to Irish Crossing at Vaqia Road (Figure 3, Stations A-G). On the first trip, we extended this further upstream to the washed out railway crossing at Nabatolu Road (Station H); but when Irish Crossing proved adequate as an upstream reference Station H. Most sites were selected to coincide with those of previous surveys (Tamata and Lloyd, 1994; D&I work in progress). Depth Profile samples were taken at 1 m intervals from surface to bottom, with measurements of salinity, temperature, dissolved oxygen, pH and water clarity (Secchi depth). Where possible, we repeated the series on ebb and flood tides on the same day. The purpose of the Depth Profile series was to describe the estuarine circulation pattern and river water quality.

The Surface series was designed to discriminate among sources of contamination (Figure 3, Stations 1 - 8). We sampled just below the surface, taking care to exclude both surface and bottom materials, at nearshore river locations (Votua, Nasolo, Irish Crossing) and at sites of likely pollutant inputs (Nailaga Creek, Elevuka Creek, FSC Rarawai). Creek samples were taken well upstream from the main river when possible; but at Nailaga Creek low tides forced several surface samples to be taken at the mouth.

Measurements were the same as for the Depth Profile Series, with the addition of faecal coliform bacteria (FC) and biochemical oxygen demand (BOD). FC and BOD analyses must be started as soon as possible after capture. Therefore, Surface Series samples were taken on the morning of the second day of a field trip, iced immediately, and returned within 6 hours to the laboratory at the Institute of Applied Sciences, University of the South Pacific, Suva.

The chance of detecting pollution that occurred periodically, rather than randomly, was increased by taking samples at different times of the day during ebb and flood times and on different days of the week. All sampling methods followed the American Public Health Association (APHA, 1992) procedures except for *in situ* pH, temperature, salinity and dissolved oxygen where the instrument manufacturers manuals were followed. Methods of sampling and laboratory analysis were similar to those of Tamata and Lloyd (1994).

3.2 FIELD MEASUREMENTS

Salinity

We used a Yellow Springs Intruments model 33A conductivity meter to measure salinity *in situ* at all stations. Depth was determined by reference to marks on the probe cable. Temperature corrections were dialed in to the meter, and salinity read directly. The main use of salinity measurements was to determine the upstream salt penetration and mixing type of the estuary.

Temperature

The DO meter (next section) was used to determine temperature *in situ* for all samples. Temperature measurements were taken because they are useful in determining estuarine circulation patterns (Carpenter & Margos, 1989), and to evaluate the possible effect of FSC Rarawai cooling water discharge. Temperature is the most important factor in controlling persistence of many microorganisms in natural waters (WHO, 1993).

Dissolved Oxygen

Dissolved oxygen was measured using a portable Yellow Springs Instruments Series 51B meter calibrated against air standard. The DO meter was calibrated at the beginning of each run and checked several times during the run and at the end of sampling. Instrument drift, never greater than 0.1mg/L, was corrected by recalibration when necessary. Temperature and salinity corrections were made. Dissolved oxygen content is the most important parameter for the survival of fish and aquatic biota (Hutton, 1983)

pH

We measured pH *in situ* at the surface at each station with an Orion Model 290A glass electrode meter. The instrument was calibrated against buffers at pH 4 and pH 7. Calibration was checked at least twice during sampling. Instrument drift was never significant. The pH of most raw water sources is between 6.5 and 8.5 (UNESCPA, 1992). PH is a primary indicator of water quality, and could be affected by caustic mill washdown water.

Clarity

Water clarity was estimated with a Secchi disc. This measurement is the least depth at which a 20cm white-and-black disc is visible from the surface. This depends to some degree on light and wave conditions at the surface, and yields only a "greater than" value in shallow, clear water. Water clarity is determined by the absorbance of the water itself, by suspended particles and by dissolved substances (Goldberg, 1972). In this work, Secchi depth is a function of suspended matter.

3.3 LABORATORY ANALYSES

Faecal Coliform Bacteria

Concentrations of fecal coliform bacteria (*Escherichia coli*) were determined at all seven surface sampling sites. Samples were collected in 500mL autoclaved glass bottles and transported on ice to the laboratory for analysis within 6 hours. FC presence indicates contamination by feces of warm-blooded animals. FC is the most sensitive and specific routine measure of the hygienic status of water (WHO, 1993).

Biochemical Oxygen Demand

BOD is the amount of oxygen used by biological organisms in five days at 20°C, to consume dissolved or suspended biodegradable organic waste materials (APHA 1992). Water samples for BOD were collected in 2.0L plastic bottles rinsed with the water that was to be sampled and immediately filled to the top without entraining air. Samples were kept in the dark to prevent production of oxygen by algae and microorganisms in the sample, and kept on ice during transport to Suva. Samples were analyzed within approximately 12 hours of capture. Initial and final DO was measured in each sample with a YSI Model 57 meter with self-stirring electrode, following a standard method (APHA 1992, Method 5210A). Dilutions of 1:1 and 1:3 were performed to ensure that DO declined by at least 1mg/L, but left at least 1mg/L in the test solution. Biochemical oxygen demand is an important indicator of water quality (UNESCPA, 1992; Carpenter & Maragos, 1989). High BOD indicates a source loading with organic waste.

3.4 HYDROLOGY

Precipitation

Fiji Department of Meteorology maintains five weather recording stations in the Ba watershed (Figure 2). The station at Waiwai is most useful for correlation with contaminant loading by land drainage from Ba town, but it is in the drier lowland region and does not represent the pattern of river flow. We chose Navala station, on the upper Ba River, as a better representative of watershed precipitation.

River flow

River flow in the Ba and tributaries is gauged at Toge (Figure 2). The river receives tributaries and groundwater below Toge. We have multiplied gauged flow by an arbitrary 1.5X to estimate flow at Ba Town.

PWD maintains a continuous automatic record of stream height (stage) at Toge. Once per month, stream flow is measured directly with a hand current meter at ten or more positions. Velocity and depth are integrated to calculate river flow. The relationship between stream height and river flow is used to estimate daily average river flow from the continuous record of river stage.

4 RESULTS

4.1 SAMPLING DATES AND HYDROLOGICAL CONDITIONS

We performed two sampling trips during the crushing season, and two post-crushing:

Field survey	Dates	River flow at Toge on sampling days, cm/s	River flow at Toge average for previous week, cm/s
1	10 - 11 Nov94	6,6	5
2	30 Nov - 1 Dec94	6,6	5
(last day of crushing 14 Dec94)			
3	19 - 20 Dec94	4,4	4
4	24 - 26 Jan95	7,6,5	26

During the study period, from November 1994 through January 1995, rainfall was generally light at Navala, a typical station in the upper Ba valley for which we have the most complete information. Rain is expressed as increased river flow about one day later (Figure 5). Hydrological conditions were similar during the first three field trips: dry, with low river flow. River flow was also near minimum during the fourth field trip (24-26 January 1996), but this was preceded by a period of significantly increased river flow (16-21 January 1995).

4.2 WATER QUALITY: DEPTH PROFILE SERIES

Tables 3 to 6 and Figures 6 to 9 present the results of the Depth Profile Series.

Salinity

Salinity at the mouth of the river on flood tide ranged from 13.3‰ to 28.8‰. Measureable salt penetrated upstream as far as Station F (Nasolo) on one occasion, but usually only a small mixture of salt passed Station E (FSC/Namosau, max 1.8‰). Freshwater usually passed Station D, and on one occasion, almost excluded salt at Station 1 (Nailaga). The range of salinities at each Depth Profile station was as follows:

STATION	MINIMUM S, ‰	MAXIMUM S, ‰
A1, Mouth	11.5	21.8
B, Votua	2.0	15.8
C, Nailaga	0.5	13.7
D, Bridge	0	3.2
E, Namosau/FSC	0	1.8
F, Nasolo	0	0
G, Irish Crossing	0	0

Salinity increased with depth but the difference was seldom dramatic. At Nailaga, in mid estuary, the greatest depth variation occurred on the flood tide of Survey 4, when the range was from 2.4‰ at surface to 9.6‰ at 7.0m.

Temperature

Surface temperatures were confined to the range 28.5°C to 31.6 °C for all Depth Profile samples. The maximum change with depth was 1.4 °C over 6 m at Station C, Survey 4 flood tide. Average river temperature was 29.4°C. Maximum temperature was usually found at Site D (Bridge) or Site E (FSC/Namosau). Maximum longitudinal temperature difference was 1.8 °C.

Although the range of temperatures was small, there is a difference in the temperature distributions for crushing and post-crushing seasons (Figure 11). Temperature was elevated by about 1.5 °C in the Ba/FSC Rarawai area, relative to upstream and downstream reference sites. This pattern did not appear in post-crushing results.

Dissolved Oxygen

Dissolved oxygen (DO) measurements showed the largest variation of any of the physico-chemical measurements, from a general high of 6.0 to 6.5mg/L to lows often of 0.0mg/L. The pattern was always similar, with lowest oxygen at either C, D or E (Nailaga, Bridge or FSC/Namosau), and higher values both upstream and downstream from this section. There was a significant and persistent oxygen sag.

The oxygen sag was displaced upstream on the flood tide, and downstream on the ebb. On the flood tide during Survey 1, the oxygen sag affected the river as far upstream as Nasolo; on the ebb, at least to Votua and perhaps as far as the river mouth.

The oxygen sag was much more intense during crushing than during post-crushing (Figure 10). During crushing (Surveys 1 and 2), dissolved oxygen approached 0.0mg/L at all depths at Sites D,E and F in Survey 1 and Site E in Survey 2. During the two post-crushing surveys, was depressed at stations D and E, and perhaps also at stations B,C and F in Survey 3, but the post-crushing depression wasreduced to about 2mg/L, compared to a depression of about 4 to 6mg/L during crushing.

SURVEY	STATIONS	DISSOLVED OXYGEN, mg/L AVERAGE	DIFFERENCE (A,G)-(D,E)
CRUSHING			
1 flood	D,E	6.28	
	A,G	0.06	- 6.22
2 ebb	D,E	4.96	
	A,G	0.91	- 4.07
POST-CRUSHING			
3 ebb	D,E	5.40	
	A,G	3.92	- 1.48
3 flood	D,E	6.52	
	A,G	4.70	- 1.82
4 flood	D,E	6.47	
	A,G	4.30	- 2.17

For reference, Table 7 shows the solubility of oxygen in water at standard pressure. Warm, salt water can hold much less oxygen than cold, fresh water. Daytime oxygen values in Ba River are normally near saturation. In the mid reaches during the 1994 crushing season, dissolved oxygen approached zero. In the months after crushing, dissolved oxygen in the mid reaches rebounded, but remained below that at the reference stations.

pH

The pH of the river ranged from 7.2 to 9.1. The highest readings occurred at the reference site; the lowest coincide with low oxygen sites near Ba Town and Rarawai. Excluding three extreme high values, the general range of pH was from 7.2 to 7.8.

Clarity

Clarity was generally low during surveys one, two and four. Greatest average secchi depth was observed at the reference site; lowest, at sites surrounding Ba township, from FSC to Nailaga. The second survey had lower secchi readings. Rain fell the day before sampling. Clarity readings were also affected by floating materials recognizable as mill effluent, tree cuttings and rubbish.

4.3 ESTUARINE CIRCULATION

An estuary is a body of water in which seawater is measurably diluted by freshwater from land drainage (Officer, 1983). Using this definition, the Ba estuary extends from some distance seaward of the mouth to approximately Station 6 at Nasolo. In dry weather, tidal effects extend further upstream, at least to the reach above Irish Crossing: water pours upstream through the culverts in the crossing at high tide. In wet weather, river flow overcomes tidal effects at Irish Crossing.

The Ba is a well-mixed estuary, not a salt wedge type. Because the estuary is shallow, and freshwater flow is small relative to the tidal currents, the river is mixed from bottom to top, and approaches the vertically homogenous type.

4.4 WATER QUALITY: SURFACE SOURCE SERIES

Table 8 and Figure 12 present the results of all four sampling trips in the Surface Source Series.

Salinity, Temperature

The patterns of temperature and salinity in the surface series followed those of the depth profile series. There was nothing remarkable in either.

Dissolved Oxygen (DO)

DO range was similar to that for depth profile samples. On three of the four samplings , the lowest value was found in Elevuka Creek (range 0.1 to 1.4 mgO_2/L). FSC showed the second lowest DO during crushing season. During post crushing DO at FSC rose first to 2.2mgO_2/L on 20 Dec 94 and then to 5.10mgO_2/L on 26 Jan 95, which was in conformity with the mid-river general average. Namosau replaced FSC as second lowest DO during post-crushing.

pH

There was little variation in pH among surface series samples. Most determinations fell in the range 7.10 to 7.50 pH units. The high values (8.68, 7.77, 7.98) occurred at Irish Crossing. Low values (7.03, 7.10, 6.80) occurred in Elevuka Creek.

Clarity

River stations gave greater secchi depths than creek stations (range 0.3 to 1.5m versus 0.2 to 0.6m). The general average indicates moderately turbid river water, but it does not discriminate among the possible sources of turbidity, which include suspended sediments, plankton and contaminants. There was nothing remarkable in the pattern of secchi depths.

Faecal Coliform Bacteria

The range of FC counts was from 0 to 230,000 colonies/100 mL, or 50 to 52000 colonies/100 mL excluding the highest and lowest counts. The two extreme values are not included in the following statistics. FC were usually lowest at Votua or Irish Crossing, and considerably higher at Elevuka and Namosau Creeks. The average FC count for each surface station was as follows:

1. Votua	265	5. FSC	1230
2. Nailaga	1950	6. Nasolo	850
3. Elevuka	17800	7. Irish Crossing	1154
4. Namosau	8620		

Of the river's tributaries, Elevuka creek had the highest counts during all four surveys. The appearance of the water was also unusual: it was often very turbid, with surface scums or slicks. The anomalous high value, 230000FC/100mL, at FSC on 1 Dec 94 probably represents a small, highly contaminated parcel of water, perhaps from Elevuka carried upstream on the rising tide.

For reference, here are some guidelines for primary contact waters (McNeill, 1991; WHO, 1983):

	maximum FC/100mL	qualification
USEPA 1968	200, logarithmic mean	90% <400 FC/100mL
Australia 1990	150, median	80% <600 FC/100mL
WHO 1983,	350	

Biochemical oxygen demand

BOD values ranged from 0.72 to 8.70 mgO_2/L. The pattern of variation was negatively correlated with that for DO (Figure 13, Table 8). Votua village and Irish Crossing gave the lowest BOD readings. BOD was always highest in the creeks and in the river at FSC Rarawai. Station 5 (FSC) had the highest BOD on Surveys One and Three. Elevuka Creek dominated Surveys Two and Four. The transition from crushing season to post-crushing produced a marginal reduction in BOD (comparison of 01 Dec 94 with 20 Dec 94), and a further improvement by 26 Jan 95. The station averages were as follows:

	BOD, mg/L		BOD, mg/L
1. Votua	1.52	5. FSC	5.22
2. Nailaga	2.87	6. Nasolo	1.58
3. Elevuka	5.20	7. Irish Crossing	1.69
4. Namosau	4.03		

In temperate waters, BOD of less than 2 mgO_2/L may be considered unpolluted; above 10 mgO_2/L, grossly polluted (Clark, 1992). This standard is not directly applicable to tropical waters because the solubility of oxygen in warm water is substantially lower than in cold.

5 DISCUSSION

Pollution occurs when additions of substances (contaminants) to the environment cause harmful effects. The discharge of untreated or inadequately treated waste waters from industry, agriculture and sewers is the usual cause of pollution (UNESCAP, 1992). The harmful effects may be undesireable changes to ecosystems, reductions in the economic value of natural resources, aesthetic damage and human health risks. Our limited study shows that Ba River is polluted in all of these ways. Our problem in this study is to attribute the pollution in correct proportion to the many possible sources of contaminants. We hope that clear identification of the sources will lead to corrective action.

Faecal coliform bacteria contamination exceeds international standards for primary water contact throughout the mid-river, and exceeds standards for shellfish harvest at all stations. This is a significant health risk. Dissolved oxygen is significantly depleted throughout the mid-river, from Nailaga to Nasolo, often to near zero. This must affect aquatic resources. At times the oxygen depletion results in anoxic conditions accompanied by noxious odours. Aesthetic amenity is further damaged by the common practice of discarding rubbish in the river or on the river banks.

5.1 OVERVIEW OF MEASUREMENTS

Salinity

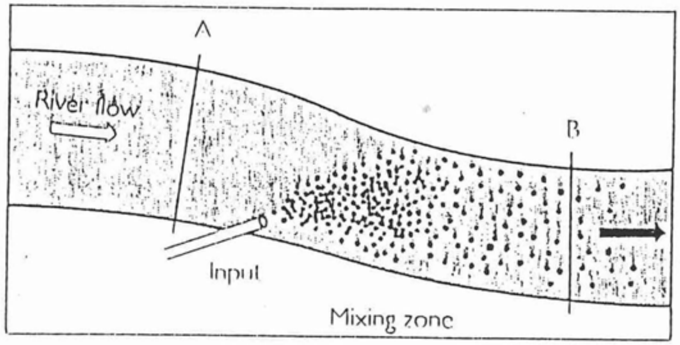
The significance of salinity in this study is that it is the marker for mixture of seawater with freshwater. There is some suggestion that coliform bacteria may survive longer in salt water than in freshwater (MacNeill, 1991), but in our case bacterial contamination is associated with the fresh water.

Temperature

The major potential source of thermal pollution at Ba is FSC coooling water, which delivers a flow of about $1000L^3$s, at about 14°C above river ambient temperature. This must produce localised heating of the river, which at low flow carries $3000L^3$/s. During crushing season, the temperature in the Ba/FSC Rarawai was about 1.5°C higher than at the upstream and downstream reference stations. This pattern did not occur after the suspension of crushing. It is likely that FSC Rarawai caused the temperature elevation.

Dissolved Oxygen

In streams, the dissolved oxygen concentration is controlled by the balance between oxygen sinks and sources. The sinks, that is the biochemical and biological processes that use oxygen, include: respiration of plants and animals; bacterial oxidation of biodegradable organic materials; sediment oxygen demand including both oxidation



Diluting effect of effluent (or cooling water) discharged into a river.

of reduced surface sediments and respiration of benthos; and downstream transport (Novotny & Olem, 1994). Sources include photosynthesis, reaeration through gas exchange with the atmosphere and input from upstream. In natural running waters, these factors usually combine to produce oxygen concentrations near or slightly above saturation in daylight and slightly below saturation in darkness.

When excess biodegradable organic material is added to a natural system, bacterial respiration and chemical oxidation may tip the balance in favor of the sinks, depleting oxygen in the water. This has happened at Ba. In the extreme case, oxygen may be depleted to zero and anaerobic processes may take over. In this case, sulfate and nitrate may be used as alternate oxidants, fermentation may occur, and new chemical products such as hydrogen sulfide and methane may be produced.

During crushing, the average DO at stations D,E was 5.14 mgO_2/L lower than at the reference stations A,F. The comparable difference during post-crushing was 1.82 mgO2/L. Because the end of crushing coincides with increasing rainfall in most years, it might be thought that the reduction in oxygen sag is attributable to increased river flow rather than the cessation of crushing. We reject this hypothesis. Following the closedown of the mill on 14 December 1994, rainfall was light, and river flow near minimum before our first post-crushing sampling on 18-19 December 1994. Oxygen concentrations rebounded promptly after the cessation of crushing. FSC Rarawai effluent was plainly the major cause of oxygen depletion in the mid reaches of the Ba River.

pH

Most aquatic biota are sensitive to pH variations, and prefer a pH near neutral but can tolerate pH in the range 6 to 8.5 (Novotny and Olem, 1994). Rivers with a pH of less than 6.0 tend to be less biologically diverse than those with a pH more than 6.0 (WHO,1993). When pH falls below 5, it causes death in many species. Our results indicate that Ba river pH usually remains in the range 7.2 to 7.8 and thus should not adversely affect fauna. In shallow waters subject to intense sunlight, dissolved carbon dioxide is consumed during photosynthesis so much that the pH value may rise above 9.5. This may be the reason for the high values seen at Station 7, Irish Crossing. The observed high pH excursions were not caused by caustic effluent.

Clarity

Low clarity may be caused by the presence of suspended matter such as clay, silt, finely divided organic matter, plankton and other microscopic organisms. The lowest average clarity occurred in Survey Two, following a day of rain. Low clarity (high turbidity) limits light penetration and thus photosynthesis. The shallowest Secchi depths were always found in the creeks (Elevuka, Namosau, Nailaga). In the river, the upstream reference station was usually clearest. Some indications of reduced clarity at the FSC site were likely caused by mill effluent. The presence of black scum on the water surface during survey three reinforces this conclusion. Tidal currents may also contribute to turbidity by scouring and suspending sediments.

Faecal coliform bacteria

Recreation that includes swimming and other water contact requires water quality almost as high as that for drinking water (Carpenter & Maragos, 1989). Bacterial contamination in Ba River exceeded WHO and USEPA guidelines for primary contact, such as diving and swimming, at all sites except possibly Votua. Elevuka Creek is the strongest source of sewage contamination. By international standards, no place in the lower Ba River would be considered safe for shellfish harvest.

Sewage from FSC Rarawai is directed to the effluent treatment system. This fact, and the relatively low loading from workers, relative to the town of Ba, indicate that the major source of sewage contamination is not FSC Rarawai. . Shores near the villages are not highly contaminated. The most likely dominant source is the town of Ba, especially the drainage through Elevuka Creek.

Faecal coliform bacteria in water may not be a major health risk. Their presence indicates contamination by faeces of warm-blooded vertebrate animals. The usual dominant source is sewage and groundwater contaminated with human wastes, but other animals may contribute.

Serious water-borne diseases are reported sporadically in Fiji. Typhoid and hepatitis A are endemic throughout the Pacific island region (Brodie *et al.* 1990). In some places, these diseases are quite common (Kelly 1994). Diarrhea from unsanitary water is common but often unreported, although it is a major cause of infant mortality (Bryant 1993). Lethal outbreaks of cholera have occurred in South Tarawa, Kiribati; Guam; and Truk, Federated States of Micronesia (Kelly 1994). The enabling factors for these diseases, such as poor sanitation, contamination of drinking water supplies, and eating raw or partially cooked seafood, are present and can be expected to produce further epidemics. The fact that Ba Health Inspector has no record of recent serious water-borne disease in the district does not guarantee this happy result for the future, nor does it indicate absence of chronic lower-grade diseases.

Biochemical Oxygen Demand

We have argued that effluent from FSC Rarawai is the most significant cause of the oxygen depletion observed in the Ba River during crushing season. Is the BOD of this effluent sufficient to cause the observed depletion in the mid-river?

We can make a first approximation to answering this question by comparing the dominant source and sink terms in the oxygen balance equation. The dominant source is oxygen carried downriver in solution. This can be estimated as average river flow times oxygen concentration:

	River flow, L/s	X DO, g/L	= Oxygen supply, g/s
low estimate	2.0×10^{3}	5.0×10^{-3}	10
mid-range	5.0×10^{3}	6.0×10^{-3}	30
high estimate	10.0×10^{3}	7.0×10^{-3}	70

Based on data from other mills (Meade and Chen 1977), we believe that Rarawai effluent, exclusive of cooling water, should have a flow of 5 to $10m^3/hr$ (1.4 to 2.8L/s) at BOD 3000 to 7000 mgO_2/L. Our estimate of the oxygen demand of untreated Rarawai effluent is therefore:

	Effluent flow, L/s	X BOD, g/L	= Oxygen demand, g/s
low estimate	1.4	3.0	0.5
mid-range	2.1	5.0	10
high estimate	2.8	7.0	19

These rough calculations suggest that only during times of low river flow and high BOD effluent would the oxygen demand of the raw effluent be able to overcome the supply provided by flow from upstream. Treatment of the effluent to remove 90% of the BOD would make the river supply greater than effluent demand at all times. Removal of 99% of BOD, which is a reasonble objective for the Rarawai treatment system, would reduce effluent demand to minor significance.

These calculations oppose our argument that FSC Rarawai effluent is the major cause of the oxygen sag in the Ba River. Further investigation is required to verify the estimates of river flow and effluent characterisatics.

5.2 SOURCES OF POLLUTION

Industry

Sugar mill effluent contains potential pollutants such as raw sugars, phosphates, oil, floor washings, caustic soda used to clean equipment and other process chemicals. Solid wastes, particularly mill mud and bagasse, can contribute further pollutant loads if they are poorly managed. All industrial processes have some potential for accidental spills.

Routine effluents from the sugar cane process are characterized by high BOD (table 18, Naidu & Morrison, 1988). This can cause prompt depression in the DO of receiving waters. If solid wastes escape or leach into receiving waters they may introduce substantial amounts of nutrients, particularly phosphate. Eutrophication (overgrowth of undesireable plant and animal species) may result from the addition of nutrients.

FSC has installed an effluent treatment system at Rarawai. The aerated lagoon system was on line for the 1994 crushing season. Nevertheless, our study shows that the mill causes a substantial part of the oxygen depression in the middle reaches of the Ba River. It is not the only source of excess oxygen demand.

FSC Rarawai does not appear to have significant problems with solid waste disposal. Mill mud and fly ash are disposed off site: they are valued substances. Bagasse is used for fuel. We observed no obvious signs of eutrophication.

Urban Sewage

Ba Town and surrounding areas lack a proper sewage treatment system. At present, industries and households have individual septic tanks. Sewage is pumped out and transported to land disposal. Some sewage is apparently discharged directly or through groundwater into Elevuka Creek and perhaps Namosau and Nailaga creeks. The middle reaches of Ba River contain unacceptable sewage contamination.

With progressive connection of the premises in the Ba Town to the new sewage treatment plant, this situation should improve.

Kai Fishery

One of the major sedentary species found in the Ba river is the freshwater mussel, or *kai*. In Fiji an annual catch of around 1,000 tonnes (including shell) is fished from the major rivers (Watling & Chape, 1992). Divers harvest *kai* from about 100m above Nailaga to Nasolo village. Anoxic conditions occur in this area. The abundant supply of *kai* in the mid-river is puzzling: they are apparently able to survive anoxic conditions for at least several days.

Oxygen concentrations may be affected significantly by the estuarine fauna (Perkins, 1974). *Kai* respiration may be a factor contributing to the oxygen depletion in certain areas of the river.

Additional Contaminants

We have investigated oxygen depletion and bacterial contamination in the Ba River, against a background of measurements designed to show the estuarine circulation. Light industry and agriculture may produce significant pollutants that were not measured. Of the industries present, electroplating stands out as the most likely to cause environmental harm, for heavy metals and acids can be released in significant quantities, even from small operations. Agriculture probably causes pollution from excess erosion, pesticides and fertilizers. Some of these pollutants and their effects are easy to measure; but some, such as pesticides, are difficult to measure and may have subtle chronic effects on both aquatic biota and humans.

6 CONCLUSIONS & RECOMMENDATIONS

- These results show that the waters of the Ba River and its estuary are polluted. The lower reaches of the river, from Nailaga to Nasolo and centered on Ba Town and FSC Rarawai, are depleted in oxygen needed by aquatic organisms. High levels of faecal coliform bacteria indicate contamination by sewage, bringing significant health risks through direct water contact and eating *kai* (freshwater mussels) from the river.

- There are numerous sources of both oxygen depleting pollutants and faecal contamination in the Ba watershed. Among these, sugar mill effluent from FSC Rarawai and untreated sewage from Ba Town are clearly the most significant.

- *Kai* survive throughout the polluted area even in areas where oxygen is apparently near zero for months at a time. Fish are caught within 2km of FSC Rarawai, both upstream and downstream. Aquatic resources, although certainly challenged, are not extinguished. This is an indication that recovery can be expected in prompt response to improved conditions.

- New waste treatment plants for both major sources of pollution are expected to improve water quality in the Ba River. These expensive projects deserve recognition especially because they are proceeding in advance of legal requirement.
To ensure this improvement, consistent water quality monitoring and effluent source control are required. At present there is no effective legislation governing discharges to the rivers and marine waters of Fiji, apart from the mandate of the Ports Authority of Fiji to protect harbour waters. The introduction of such legislation is a declared priority of the Government of Fiji. With its passage, it will be possible to enforce environmental protection measures.

- This study has had a narrow focus on present conditions in the Ba River. Future developments, such as dredging, bank protection works, industrial development and population growth require assessment in a broader context. In the absence of comprehensive assessment and planning, the benefits of treating FSC Rarawai and Ba Town effluents may be cancelled by harmful effects of inappropriate development. Ba River is a significant natural resource, with unexploited potential; but it is also vulnerable because, especially in dry weather, the lower reaches are poorly flushed.

- With the reduction in pollution from FSC Rarawai and Ba Town, other causes of environmental degradation will become more prominent. These include industrial discharges, urban drainage, agricultural sources including siltation from poor land management, and the unfortunate practice of discarding rubbish on the river banks. In order to realise the full value of the river, these inputs must be controlled.

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District Officer Ba, Tomasi Tuibau, Assistant District Officer Shiu Jittan and Turaga ni Koro of the villages of Votua and Nailaga graciously welcomed us and provided much information and insight in discussion. It is the villagers of the lower Ba River who are most directly affected by water quality in the river. We hope this work will serve them in their progress toward a cleaner, healthier and more productive environment.

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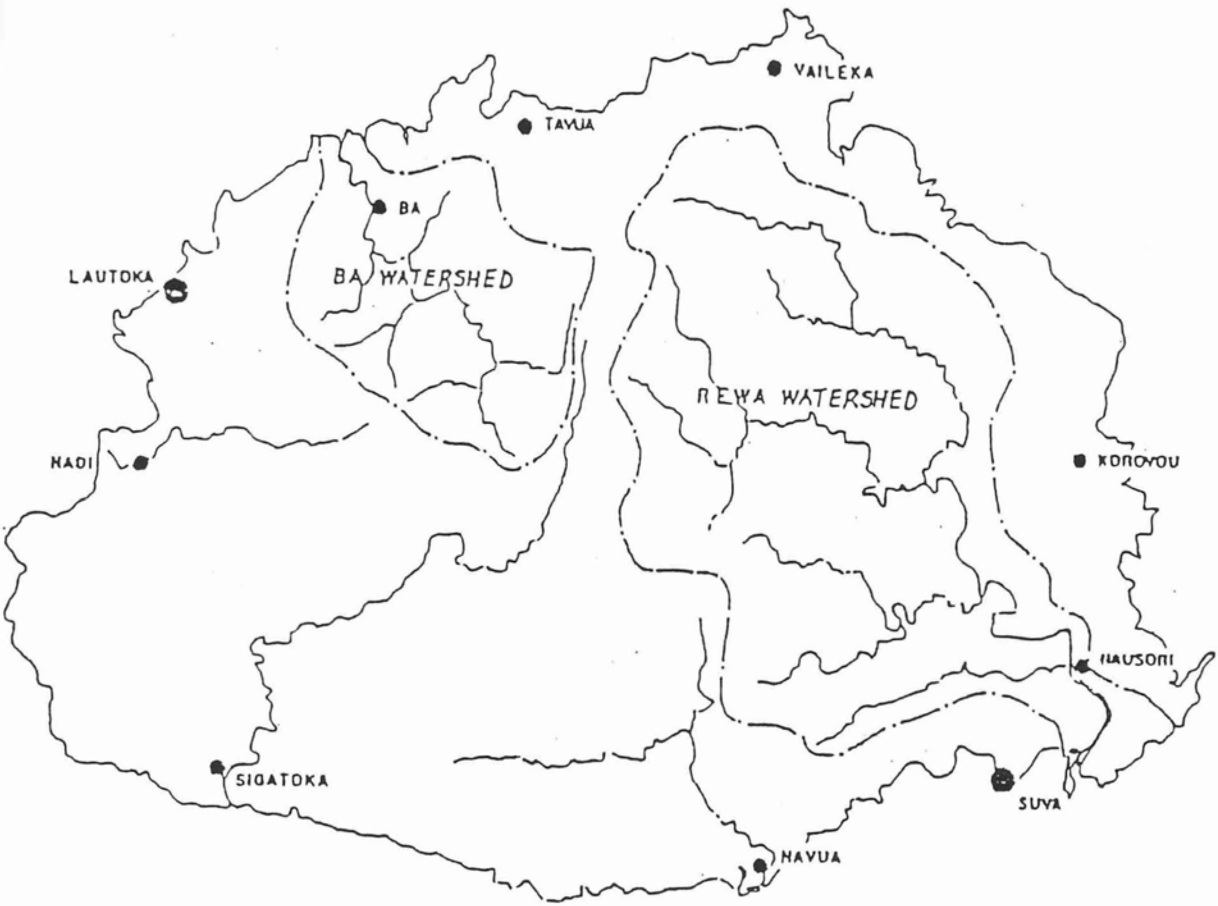
FIGURES



Ref. Clarke, 1989

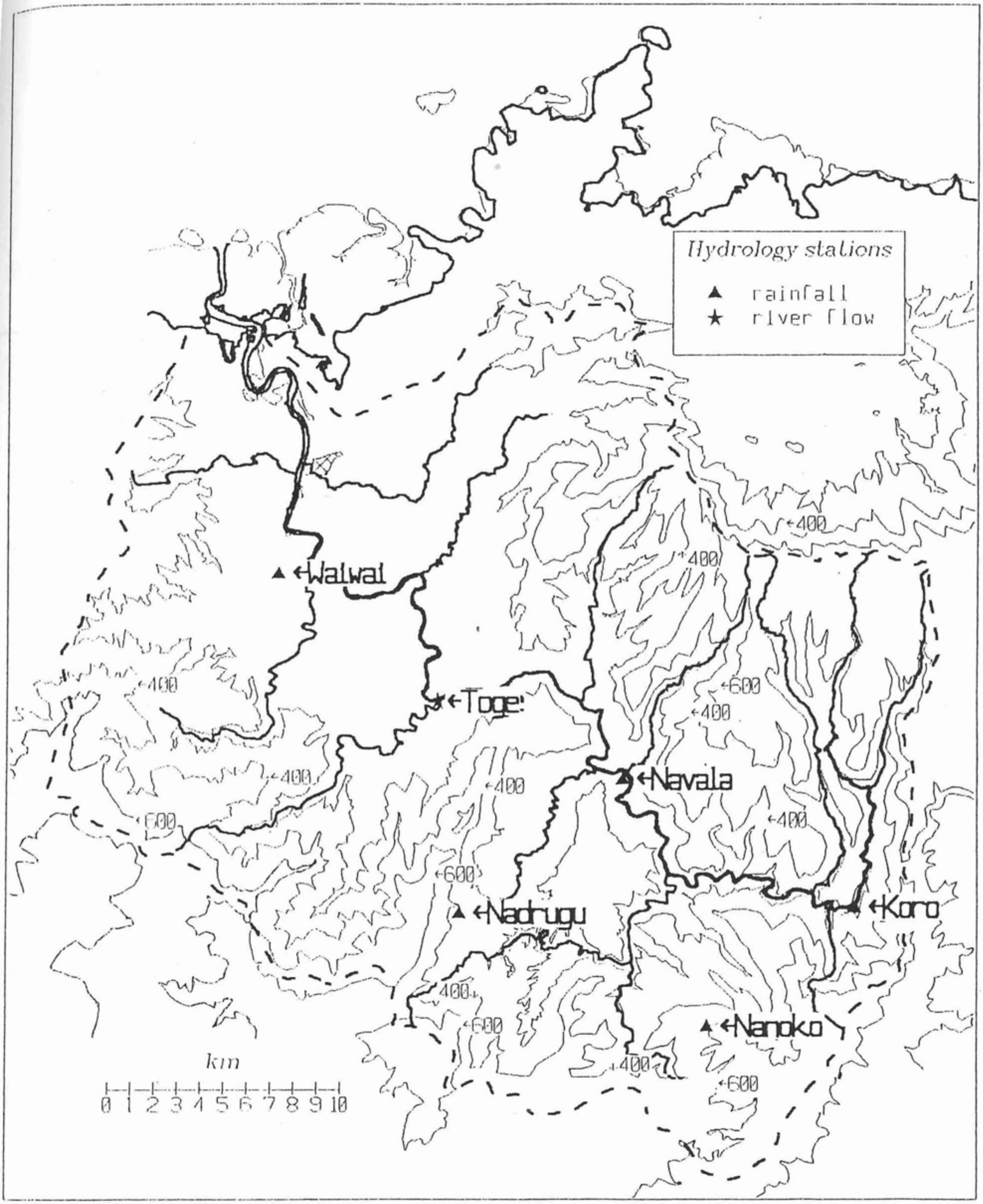


Figure 2. Hydrological recording stations in the Ba River watershed.

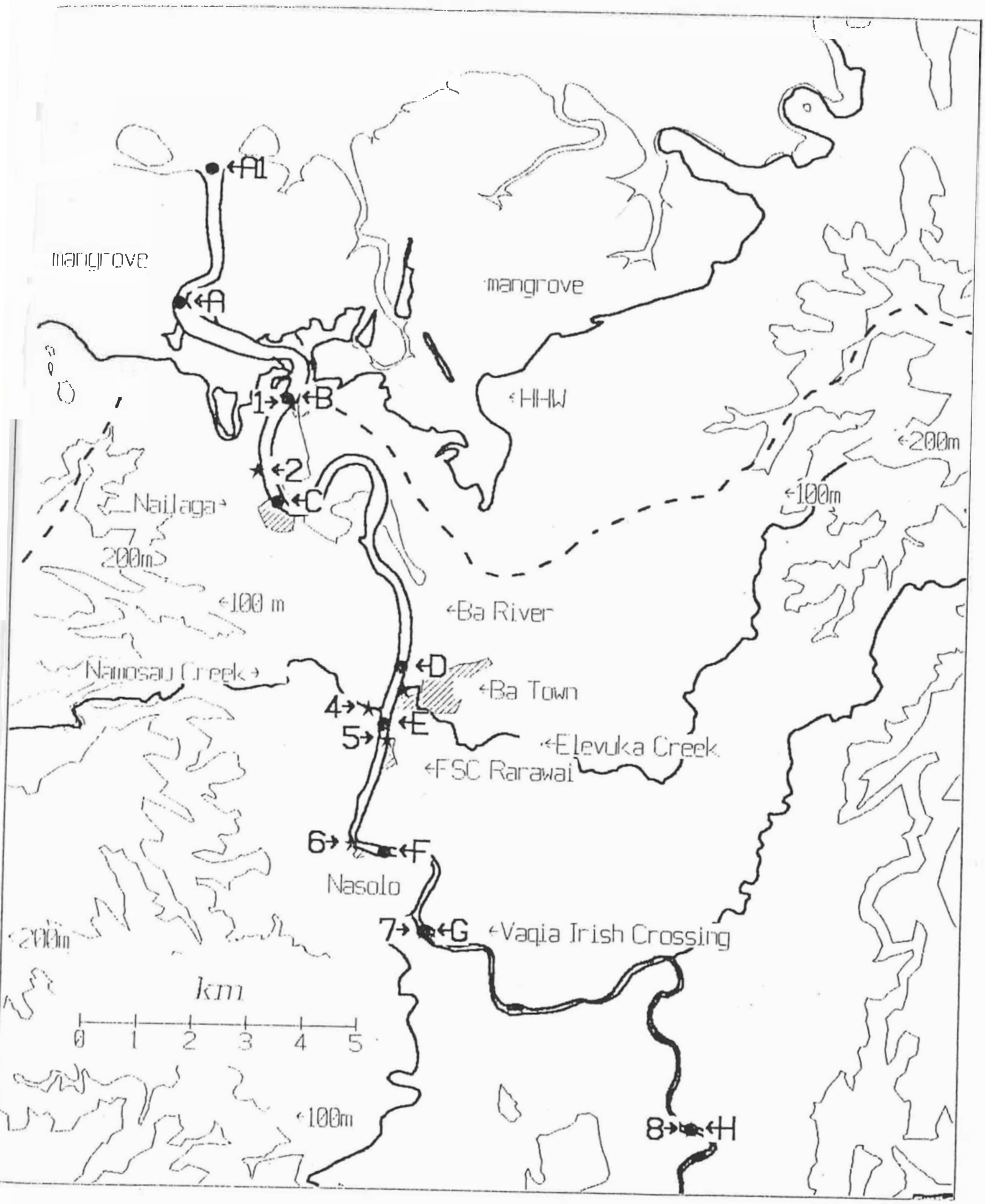


Figure 3. Sampling stations and other features of lower Ba River.

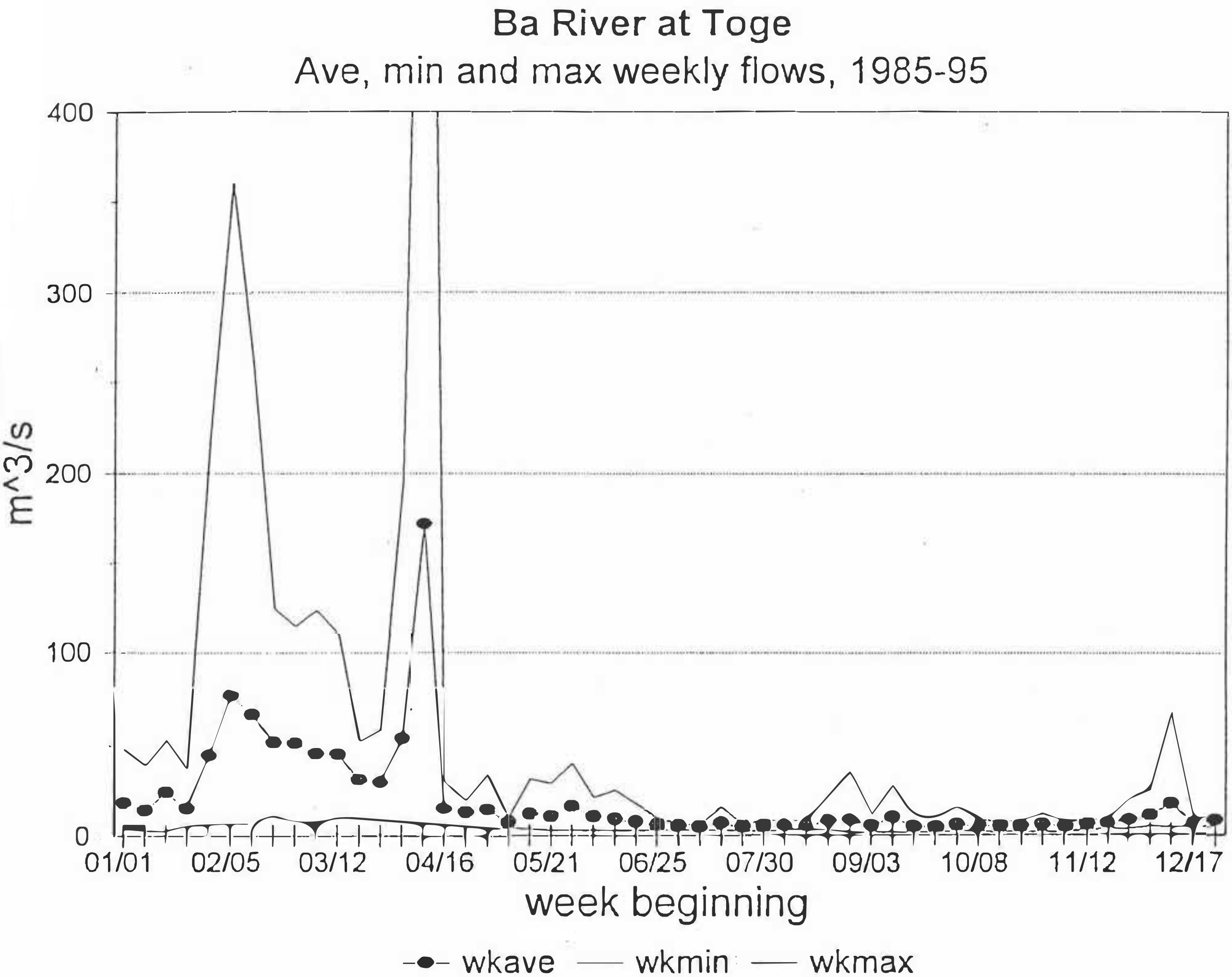


Figure 4. Weekly discharge of Ba River at Toge, 1985 - 1995.

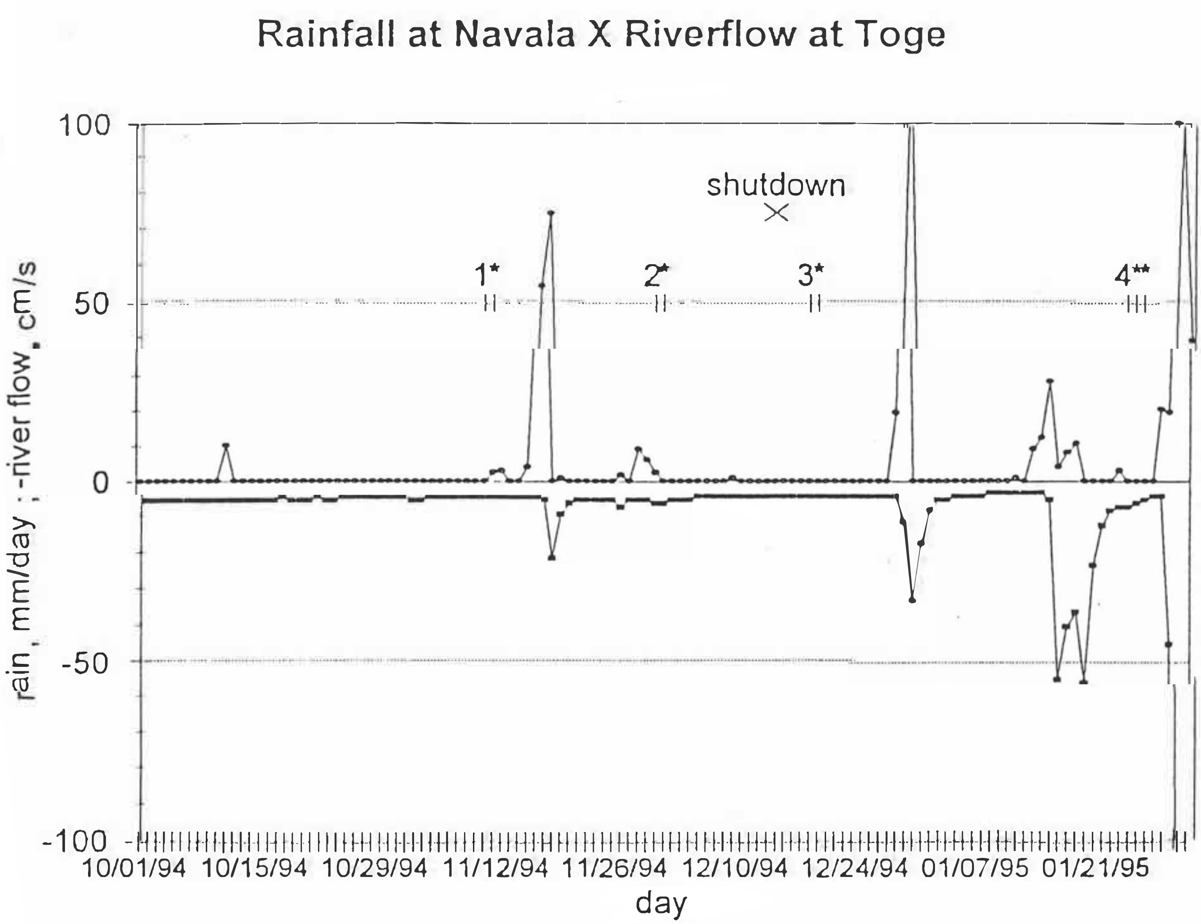
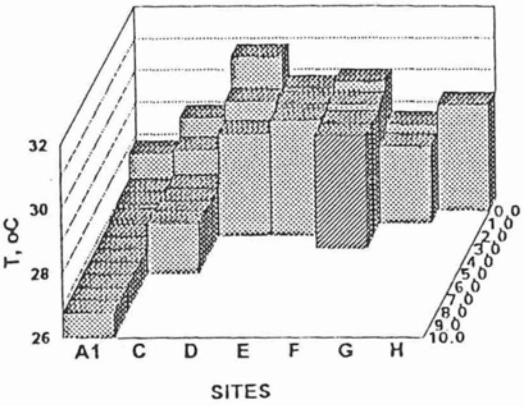


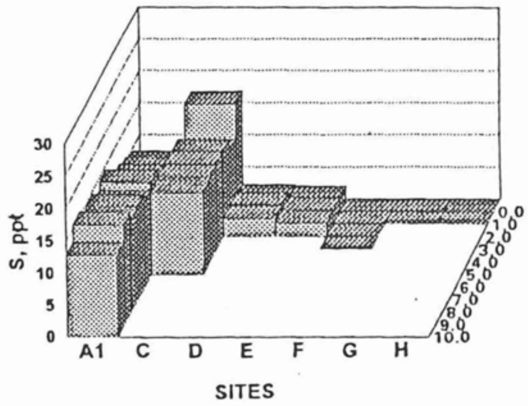
Figure 5. Rainfall at Navala versus river flow at Toge.

CRUSHING SEASON

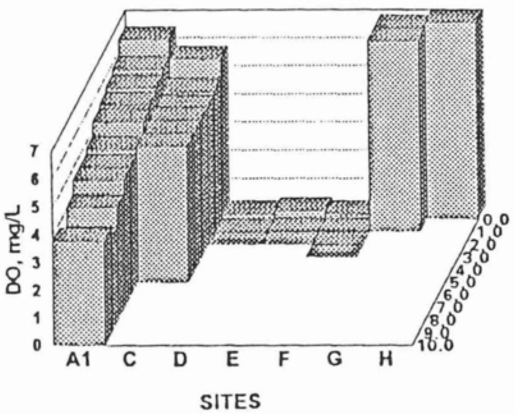
Temperature 10 Nov 94
FLOOD



Salinity 10 Nov 94
FLOOD



Dissolved Oxygen 10 Nov 94
FLOOD



pH 10 Nov 94
FLOOD

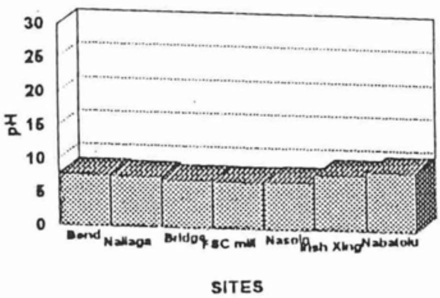
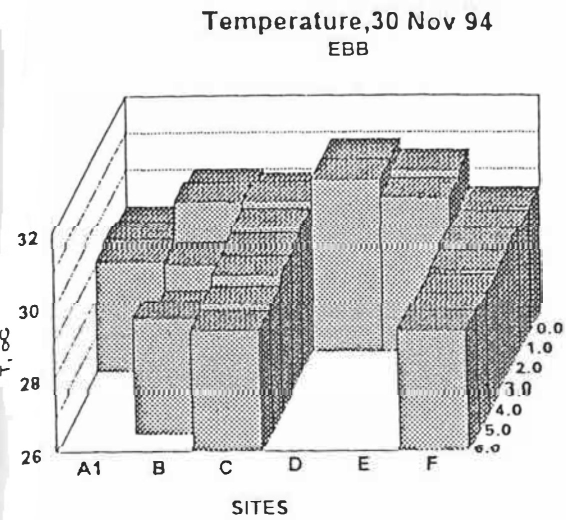
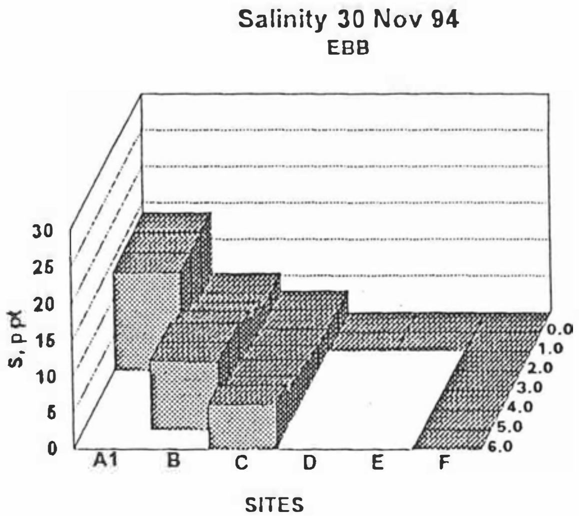
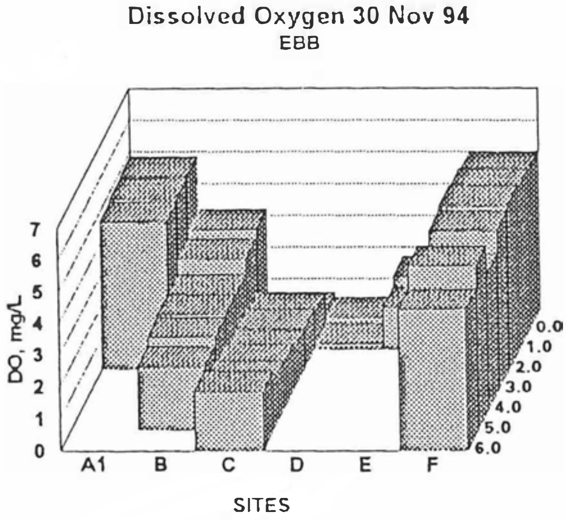


Figure 6. Water quality, depth profile series 1.

CRUSHING SEASON







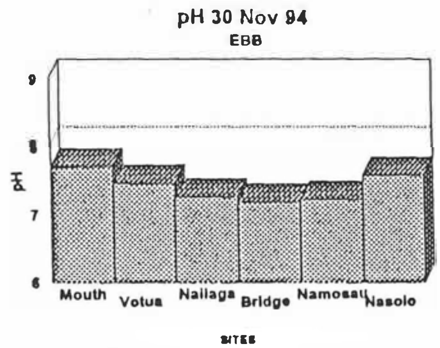


Figure 7. Water quality, depth profile series 2.

POST CRUSHING SEASON

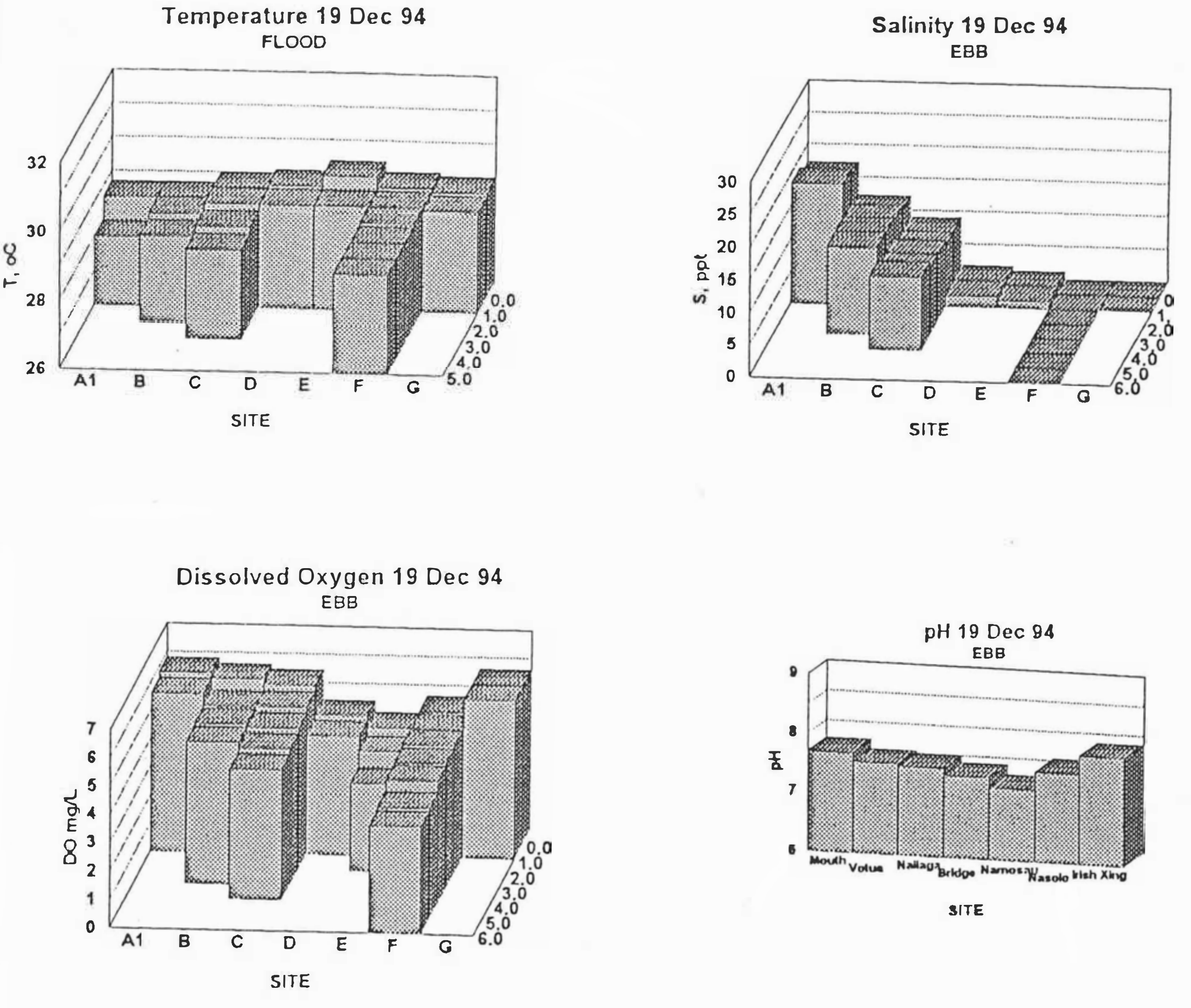
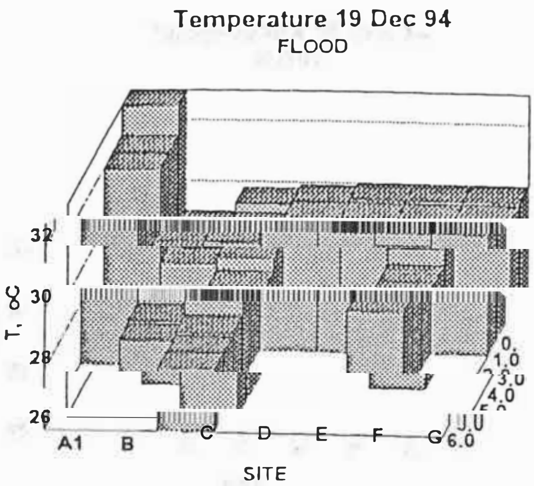
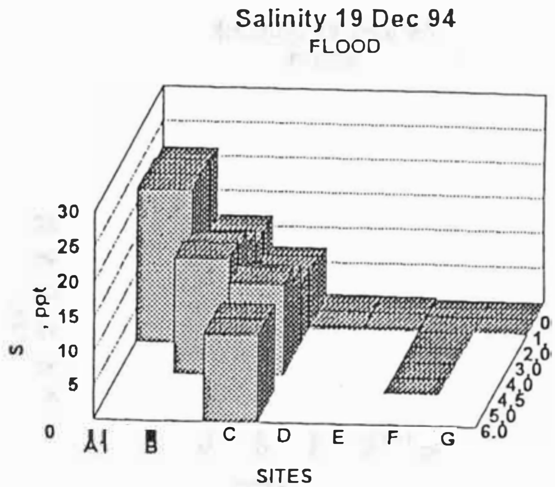
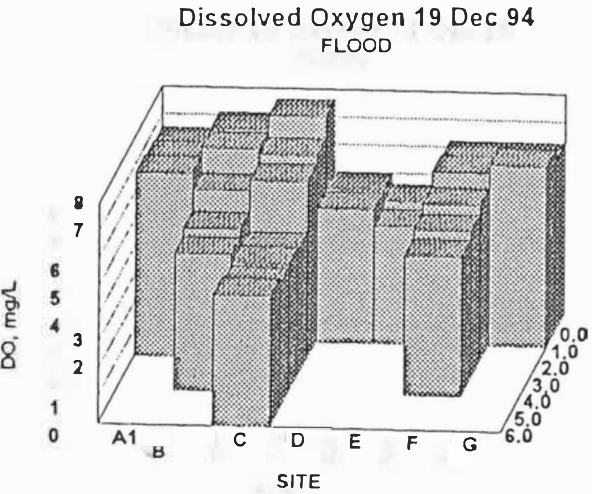


Figure 8. Water quality, depth profile series 3.

POST CRUSHING SEASON







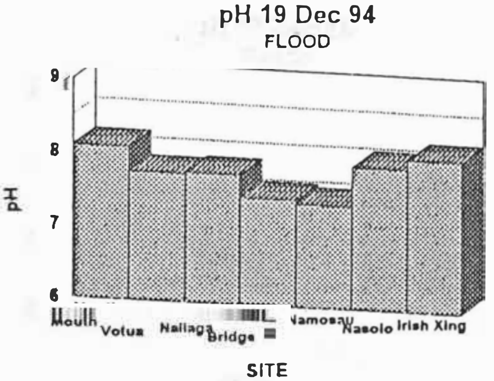


Figure 8. (continued).

POST CRUSHING SEASON

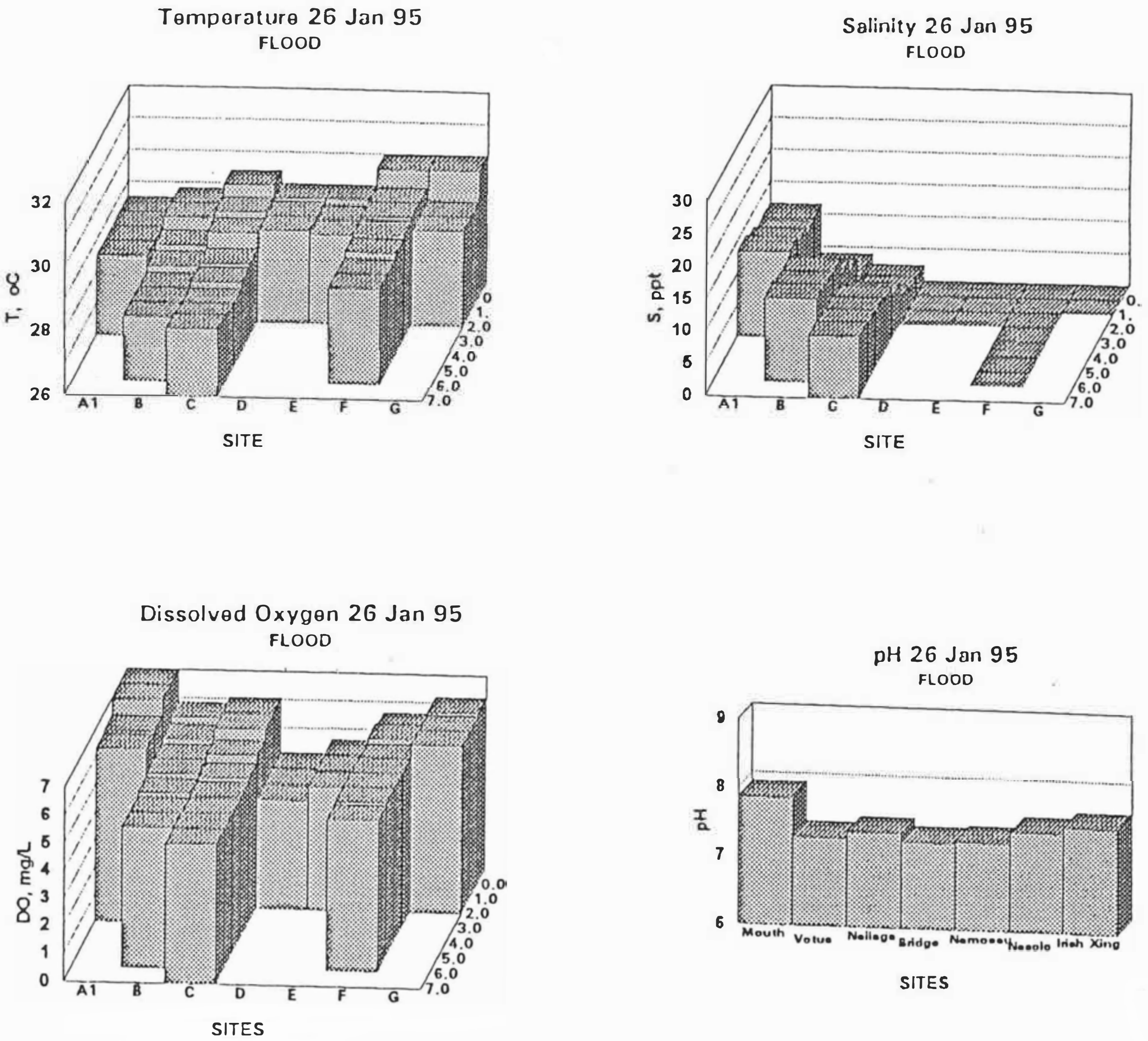


Figure 9. Water quality, depth profile series 4.

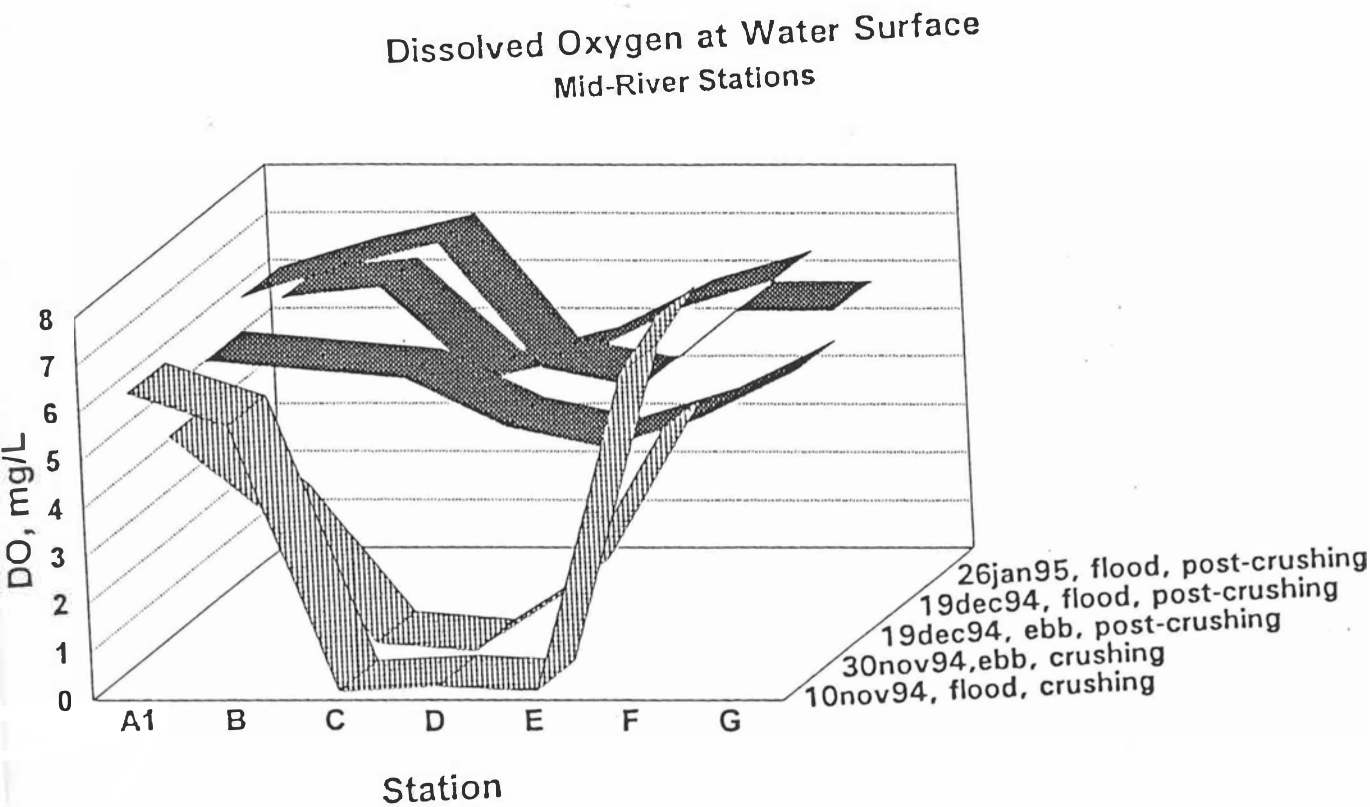


Figure 10. Dissolved oxygen at 0 m in Ba River during and after crushing season.

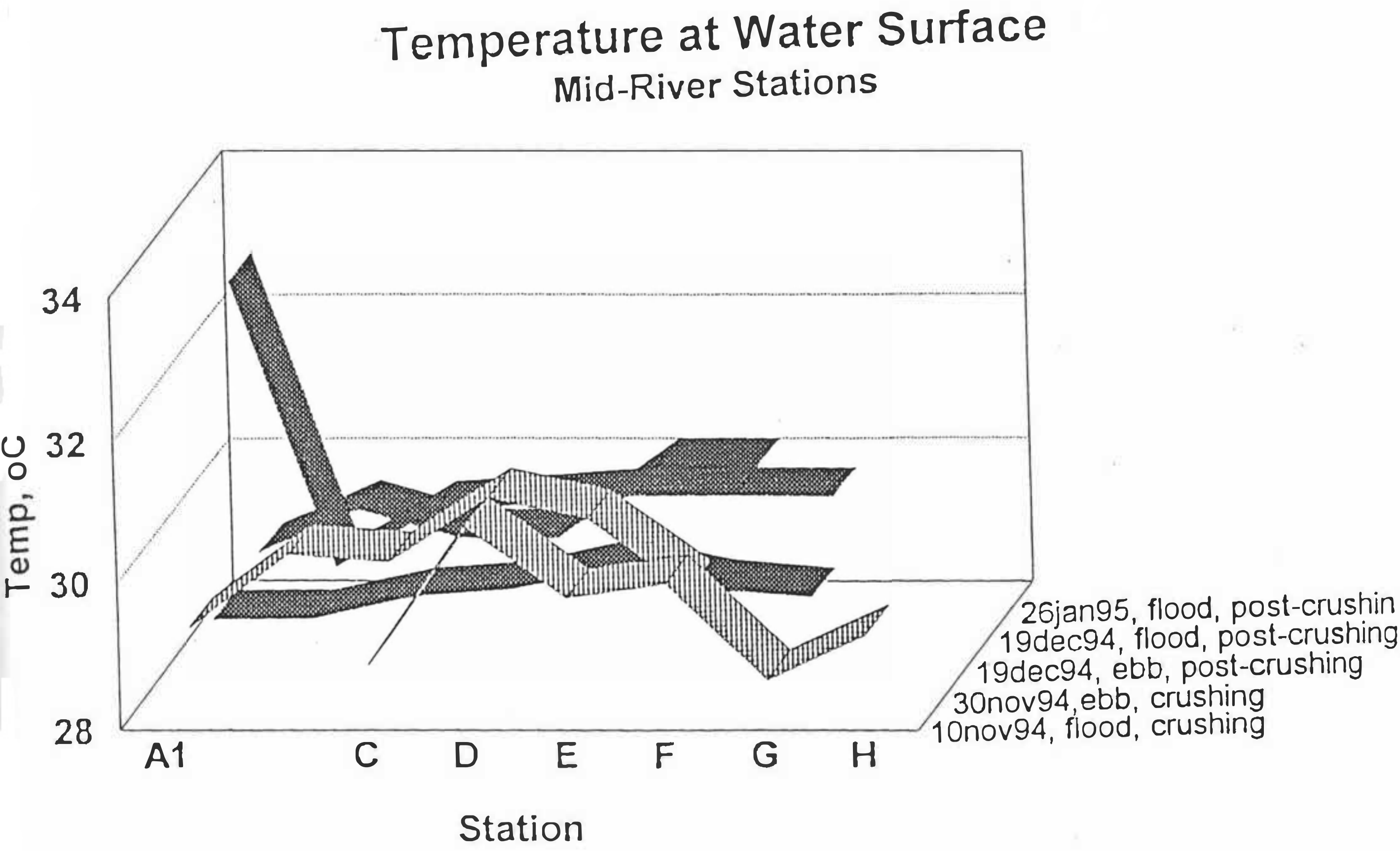
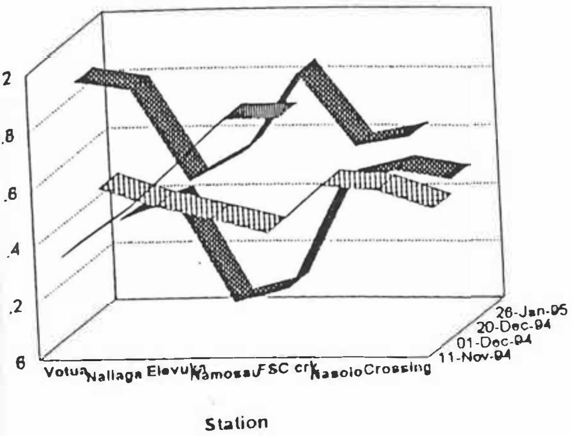
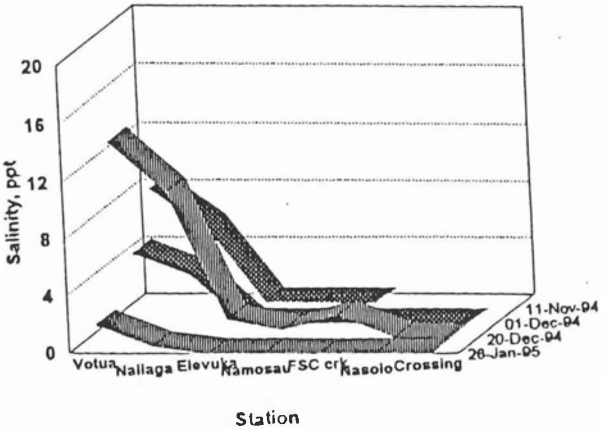


Figure 11. Temperature at 0 m in Ba River during and after crushing season.

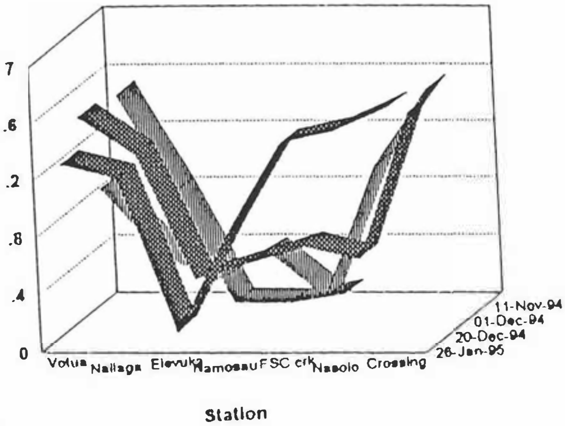
Surface Temperature



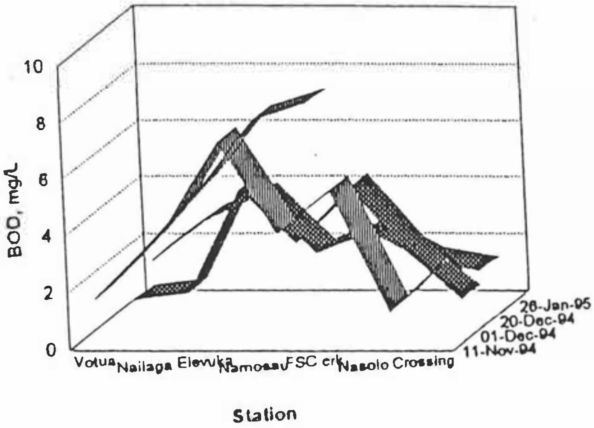
Surface Salinity



Disolved Oxygen



Biochemical Oxygen Demand



Faecal Coliform Bacteria

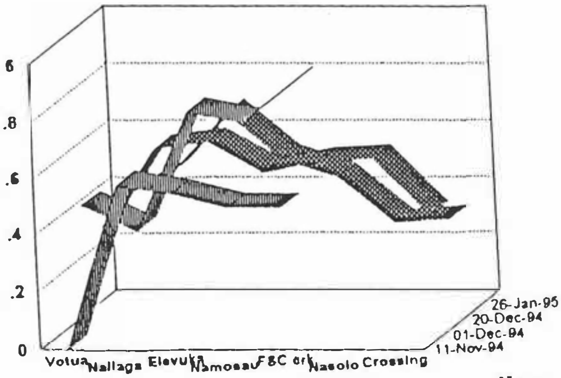


Figure 12. Water quality, surface source series 1 - 4.

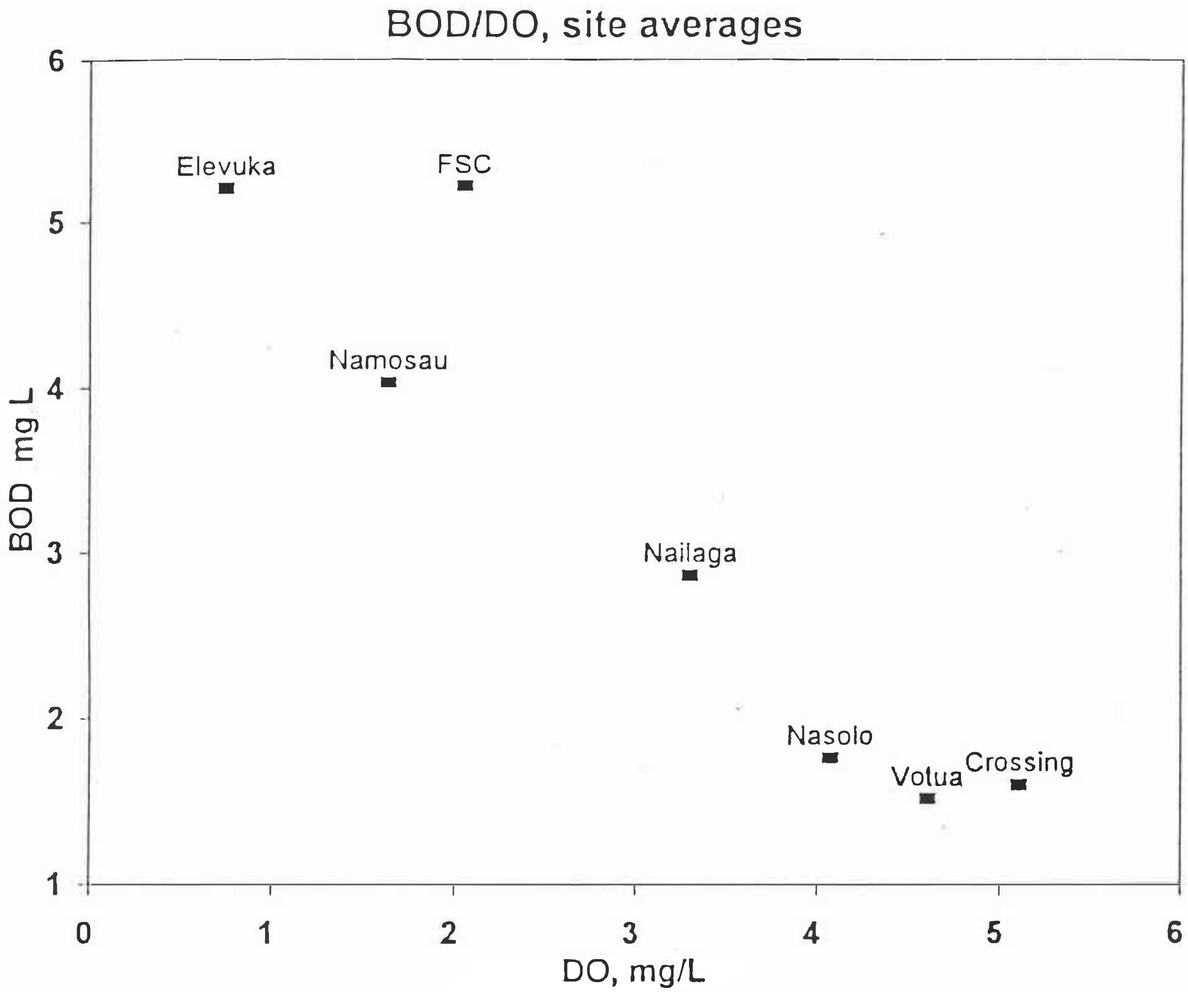


Figure 13. Correlation diagram for DO and BOD, suface source series.

9 TABLES

Station	Fiji Lands and Surveys 1:50,000, 1991	Drainage and Irrigation coordinates		Distance from river mouth, km
DEPTH PROFILE SERIES[1]				
A1 Mouth	M26 832 498	0.0L	0.5R	-0.5
A Mouth (10 Nov only)	M26 826 474			
B Votua	M26 847 456	13.3L	0.2R	6.2
C Nailaga	M26 845 438	17.5L	0.3R	8.5
D New Bridge	M26 868 941	28.6L	0.5R	15.0
E Namosau/FSC	M27 865 398	30.9L	0.5R	16.0
F Nasolo	M27 866 374	35.5L	0.6R	19.3
G Vaqia Irish Crossing	M27 873 360	na	na	21.6
H Nabatolu	M27 922 325	na	na	
SURFACE SERIES[2]				
1 Votua shore	M26 847 455	13.0L	0.8R	6.0
2 Nailaga Creek	M26 841 443	17.2L	0.0R	8.4
3 Elevuka Creek	M26 869 404	28.9L	1.0R	15.0
4 Namosau Creek	M27 864 399	30.3L	0.0R	15.7
5 FSC treatment pond[3]	M27 866 395	30.5L	0.9R	15.8
6 Nasolo shore	M27 860 376	34.5L	0.1R	18.8
7 Vaqia Irish Crossing	M27 873 360	na	na	21.6

[1] Depth profile series samples were taken at the deepest part of the river cross section.

[2] Surface series river samples were taken from a boat a few meters from shore, and downstream from the potential pollution source (for example, 50m downstream from Votua Village or FSC Rarawai treatment pond outfall. Creek samples were taken about 50m up each creek, or as far into the creek as the boat could be poled.

[3] The FSC Rarawai treatment pond effluent exits through an inconspicuous pile of rubble on the river bank about 0.5 km north of the main mill structures. The conspicuous outfall nearer the mill is cooling water.

Table 1. Sampling stations.

Date	TONGE river flow m^3/s	NAVALA precipitation mm/day
11/01/94	6	0
11/02/94	6	0
11/03/94	5	0
11/04/94	5	0
11/05/94	5	0
11/06/94	5	0
11/07/94	5	0
11/08/94	5	0
11/09/94	5	0
11/10/94	5	0
11/11/94	5	2.5
11/12/94	5	3
11/13/94	5	0
11/14/94	5	0
11/15/94	5	4
11/16/94	5	54
11/17/94	5	74
11/18/94	21	0
11/19/94	9	1
11/20/94	6	0
11/21/94	5	0
11/22/94	5	0
11/23/94	5	0
11/24/94	5	0
11/25/94	5	0
11/26/94	7	2
11/27/94	5	0
11/28/94	5	9
11/29/94	5	6
11/30/94	6	2.5
12/01/94	6	0
12/02/94	5	0
12/03/94	5	0
12/04/94	5	0
12/05/94	4	0
12/06/94	4	0
12/07/94	4	0
12/08/94	4	0
12/09/94	4	1
12/10/94	4	0
12/11/94	4	0
12/12/94	4	0
12/13/94	4	0
12/14/94	4	0
12/15/94	4	0
12/16/94	4	0
12/17/94	4	0
12/18/94	4	0
12/19/94	4	0
12/20/94	4	0
12/21/94	4	0
12/22/94	4	0

Date	TONGE river flow m^3/s	NAVALA precipitation mm/day
12/23/94	4	0
12/24/94	4	0
12/25/94	4	0
12/26/94	4	0
12/27/94	4	0
12/28/94	4	19
12/29/94	11	123
12/30/94	33	0
12/31/94	17	0
01/01/95	8	0
01/02/95	5	0
01/03/95	5	0
01/04/95	4	0
01/05/95	4	0
01/06/95	4	0
01/07/95	4	0
01/08/95	3	0
01/09/95	3	0
01/10/95	3	0
01/11/95	3	1
01/12/95	3	0
01/13/95	3	9
01/14/95	3	12
01/15/95	5	28
01/16/95	55	4
01/17/95	40	8
01/18/95	36	10.5
01/19/95	56	0
01/20/95	23	0
01/21/95	12	0
01/22/95	8	0
01/23/95	7	3
01/24/95	7	0
01/25/95	6	0
01/26/95	5	0
01/27/95	4	0
01/28/95	4	20
01/29/95	45	19
01/30/95	733	100
01/31/95	276	39

CRUSHING SEASON

BA RIVER DEPTH SERIES FLOOD TIDE
10-Nov-94

TEMPERATURE, oC

Depth(m)	A1 Bend	C Nailaga	D Bridge	E FSC mill	F Nasolo	G Irish Xing	H Nabatolu
	TEMPERATURE, oC						
0.0	27.8	28.9	30.8	29.8	30.0	28.7	29.3
1.0	27.0	28.3	29.8	29.7	29.7	28.4	
2.0	27.0	27.5	29.2	29.6	29.5		
3.0	***26.9***	27.5			29.5		
4.0	26.8	27.5					
5.0	26.8	27.6					
6.0	26.8						
7.0	26.8						
8.0	26.8						
9.0	26.8						
10.0	26.8						
	SALINITY, ppt						
0.0	6.90	16.70	2.30	2.00	0.00	0.00	0.00
1.0	9.40	11.10	3.00	2.20	0.15	0.00	0.00
2.0	10.40	13.10	2.90	2.20	0.08		
3.0	***11.30***	13.30			0.15		
4.0	12.20	13.20					
5.0	14.40	12.80					
6.0	13.10						
7.0	14.50						
8.0	14.10						
9.0	15.60						
10.0	12.90						
	DISSOLVED OXYGEN, mg/L						
0.0	6.40	5.70	0.20	0.30	0.20	6.80	9.80
1.0	5.80	5.00	0.00	0.05	0.05	6.80	
2.0	5.60	4.90	0.00	0.00	0.00		
3.0	***5.45***	4.90			0.00		
4.0	5.30	4.90					
5.0	4.80	4.90					
6.0	4.60			0-3m			
7.0	4.60			ave A,G	6.14		
8.0	4.10			ave D,E	0.06		
9.0	3.40						
10.0	3.80						
	pH						
0.0	7.82	7.66	7.26	7.21	7.27	8.56	9.14

No secchi taken

Table 3. Water quality depth profile series 1.

CRUSHING SEASON

BA RIVER DEPTH SERIES, EBB TIDE
30-Nov-94

Depth(m)	A1 Mouth	B Votua	C Nailaga	D Bridge	E Namosau	F Nasolo
	TEMPERATURE, oC					
0.0	29.0	30.0	29.9	30.8	30.5	29.5
1.0	29.1	30.2	30.2	30.8	30.3	29.4
2.0	29.1	29.0	30.0			29.4
3.0		28.3	29.8			29.4
4.0		28.1	29.8			29.3
5.0		29.1	29.5			29.3
6.0			29.3			29.3
	SALINITY, ppt					
0.0	13.60	5.30	2.90	0.00	0.00	0.00
1.0	13.50	5.30	3.10	0.00	0.00	0.00
2.0	13.50	6.80	3.20			0.00
3.0		8.40	3.60			0.00
4.0		9.40	4.30			0.00
5.0		9.50	4.70			0.00
6.0			6.20			0.00
	DISSOLVED OXYGEN, mg/L					
0.0	4.85	3.20	0.55	0.40	1.70	5.00
1.0	4.80	2.90	1.15	0.20	1.35	5.10
2.0	4.70	2.40	1.30			5.20
3.0		2.40	1.25			5.05
4.0		2.30	1.45			4.30
5.0		2.00	1.55			5.20
6.0			1.85			4.45
	pH					
0.00	7.72	7.48	7.28	7.20	7.24	7.60
	SECCHI Depth, m					
	0.70	0.40	0.50	0.80	0.90	1.60

Table 4. Water quality depth profile series 2.

POST CRUSHING SEASON

BA RIVER SURVEY EBB TIDE

19-Dec-94

Depth (m)	A1 Mouth	B Votua	C Nailaga	D Bridge	E Namosau	F Nasolo	G Irish Xing
	TEMPERATURE, oC						
0.0	28.7	28.7	29.0	29.1	29.4	29.1	29.0
1.0	28.0	28.7	29.0	29.0	29.0	29.0	28.9
1.3				29.0			28.9
1.6	27.0						
2.0		28.5	28.9		29.0	29.0	
3.0		28.5	28.8			29.0	
3.3		28.2					
4.0			28.6			28.9	
5.0						28.9	
6.0						28.9	
6.7						28.9	
	SALINITY, ppt						
0.0	17.10	12.10	8.90	1.76	1.10	0.00	0.00
1.0	18.40	12.90	9.10	1.76	1.20	0.00	0.00
1.3				1.76	1.70		0.00
1.6	19.40						
2.0		13.30	10.10			0.00	
3.0		13.40	10.40			0.00	
3.3		14.30					
4.0			11.40			0.00	
5.0						0.00	
6.0						0.00	
6.7						0.00	
	DISSOLVED OXYGEN, mg/L						
0.0	5.80	5.60	5.42	4.40	4.00	4.60	5.59
1.0	5.60	5.19	5.20	4.20	3.70	4.50	5.60
1.3				4.10			4.40
1.6	5.40						
2.0		5.10	4.99		3.10	4.50	
3.0		5.00	4.80			4.40	
3.3		5.00					0-3m
4.0			4.60			4.30	avg A,G
5.0						3.90	avg D,E
6.0						3.80	
6.7						0.20	
	pH						
0.0	7.70	7.55	7.51	7.39	7.22	7.53	7.84
	SECCHI DEPTH, m						
0.0	0.52	0.37	0.42	0.43	0.55	1.20	1.30

Table 5. Water quality depth profile series 3.

POST CRUSHING SEASON

BA RIVER SURVEY FLOOD TIDE
19-Dec-94

Depth(m)	A1 Bend	B Nailaga	C Bridge	D FSC mill	E Nasolo	F Irish Xing	G Nabatolu
	TEMPERATURE, oC						
0.0	33.0	29.0	29.8	29.9	30.0	30.0	30.0
1.0	32.0	29.0	29.5	29.9	29.9	29.9	29.9
2.0	32.0	28.9	29.1			29.5	
3.0		28.0	28.7			29.0	
4.0		27.9	28.2			29.0	
4.5						29.0	
5.0			28.1				
6.0			28.1				
	SALINITY, ppt						
0.0	21.10	11.40	7.00	0.44	0.35	0.00	0.00
1.0	21.80	11.50	8.10	0.44	0.35	0.00	0.00
2.0	21.90	13.70	8.50			0.00	
3.0		15.80	11.40			0.00	
4.0		16.70	13.30			0.00	
4.5						0.00	
5.0			12.80				
6.0			12.90				
	DISSOLVED OXYGEN, mg/L						
0.0	6.50	7.10	7.60	5.00	4.60	6.20	6.20
1.0	6.60	7.00	6.81	4.90	4.30	6.30	6.60
2.0	6.70	6.10	6.50			5.75	
3.0		5.30	4.60			5.40	
4.0		5.00	4.70			5.10	
4.5						4.10	
5.0			4.60				
6.0			4.80				
	pH						
0.0	8.10	7.76	7.78	7.47	7.42	7.96	8.10
	SECCHI DEPTH, m						
	0.50	0.60	0.70	0.50	0.40	0.80	0.71

Table 5. (continued).

POST CRUSHING SEASON

BA RIVER DEPTH SERIES, FLOOD TIDE
26-Jan-95

Depth(m)	A1 Mouth	B Votua	C Nailaga	D Bridge	E Namosau	F Nasolo	G Irish Xing
	TEMPERATURE, oC						
0.0	28.5	28.8	29.4	29.0	29.0	30.0	30.0
1.0	28.5	28.8	29.0	28.9	28.8	29.4	29.0
2.0	28.5	28.4	28.8	28.9	28.8	29.4	29.0
3.0	28.5	28.2	28.3			29.3	
4.0		28.0	28.2			29.2	
5.0		28.0	28.0			29.0	
6.0		28.0	28.0			29.0	
7.0			28.1				
	SALINITY, ppt						
0.0	11.50	3.90	2.40	0.00	0.00	0.00	0.00
1.0	11.20	3.90	2.90	0.00	0.00	0.00	0.00
2.0	12.30	7.80	3.90	0.00	0.00	0.00	
3.0	13.30	9.70	6.60			0.00	
4.0		12.50	8.30			0.00	
5.0		12.70	8.90			0.00	
6.0		13.20	9.20			0.00	
7.0			9.60				
	DISSOLVED OXYGEN, mg/L						
0.0	7.15	5.85	6.05	4.10	4.60	5.60	6.20
1.0	7.05	5.60	6.00	4.05	4.55	5.75	6.10
2.0	6.40	5.40	5.60	4.00	4.50	5.55	6.10
3.0	6.30	5.40	5.30			5.60	
4.0		5.25	5.15			5.60	
5.0		5.10	5.10			5.60	
6.0		5.10	5.10			5.50	
7.0			5.05				
	pH						
0.0	7.87	7.30	7.39	7.27	7.29	7.46	7.55
	SECCHI DEPTH, m						
	1.0	1.0	0.7	0.4	0.6	0.9	0.9

Table 6. Water quality depth profile series 4.

OXYGEN SATURATION IN WATER IN EQUILIBRIUM WITH MOIST AIR
AT 760 mmHg, mgO2/L: Parsons et al 1984
conversion factor mlO2/L time 1.43

TEMPERATURE, oC	SALINITY, ppt									
	0	4	8	12	16	20	24	28	32	34
0	14.61	14.21	13.83	13.46	13.10	12.74	12.40	12.07	11.74	11.58
10	11.28	11.00	10.73	10.45	10.20	9.94	9.70	9.45	9.21	9.09
20	9.08	8.87	8.67	8.47	8.37	8.07	7.88	7.69	7.52	7.44
24	8.41	8.21	8.02	7.85	7.66	7.49	7.32	7.16	6.99	6.92
26	8.09	7.92	7.74	7.56	7.39	7.24	7.08	6.91	6.76	6.68
28	7.81	7.64	7.48	7.31	7.15	6.99	6.84	6.68	6.54	6.46
30	7.55	7.38	7.22	7.06	6.91	6.76	6.61	6.46	6.33	6.26

BA RIVER SURFACE SERIES

11-Nov-94	flood		CRUSHING				
	1	2	3	4	5		7
	Votua	Nailaga	Elevuka	Namosau	FSC crk		Crossing
salinity	8.40	5.60	0.40	0.40	0.40		0.00
temp.	28.2	29.0	30.0	31.0	31.0		28.9
D.O.	5.20	2.80	0.10	0.10	0.30		5.20
pH	7.6	7.34	7.25	7.29	7.31		8.68
secchi	0.80	0.40	0.50	0.40	0.10		1.50
FC	0	3000	2000	1000	1000		2400
BOD	1.80	3.70	5.70	8.10	8.70		2.30
begin	end	Suva tides		time	height, m		
1026	1210			701	0.3		
				1328	1.5		

01-Dec-94	low tide		CRUSHING				
	1	2	3	4	5	6	7
	Votua	Nailaga	Elevuka	Namosau	FSC	Nasolo	Crossing
salinity	4.90	3.40	0.00	0.00	0.00	0.00	0.00
temp.	31.5	31.3	29.4	30.0	31.6	30.1	30.3
D.O.	3.25	1.70	0.99	1.70	0.60	3.8	5.70
pH	7.39	7.34	7.03	7.06	7.18	7.47	7.77
secchi	0.30	0.20	0.33	0.40	0.85	0.70	0.40
FC	530	150	52000	31000	230000		2000
BOD	1.93	3.85	6.80	3.55	5.05	0.82	2.52
begin	end	Suva tides		time	height, m		
910	1042			1029	0.3		
				1647	1.8		

20-Dec-94	ebb		POST CRUSHING				
	1	2	3	4	5	6	7
	Votua	Nailaga	Elevuka	Namosau	FSC	Nasolo	Crossing
salinity	13.80	10.30	1.30	0.60	1.60	0.10	0.00
temp.	29.0	28.6	28.3	28.0	29.0	28.9	28.5
DO	5.39	4.45	1.40	1.80	2.20	1.90	5.50
pH	7.67	7.36	7.10	7.17	7.17	7.19	7.98
secchi	0.70	0.60	0.50	0.64	0.70	0.70	1.40
FC	85	4000	5800	1300	2200	2500	154
BOD	0.72	0.95	4.55	2.67	4.61	2.40	0.74
begin	end	Suva tides		time	height, m		
910	1032			803	1.5		
				1349	0.6		

26-Jan-95	low to flood		POST CRUSHING				
	1	2	3	4	5	6	7
	Votua	Nailaga	Elevuka	Namosau	FSC	Nasolo	Crossing
salinity	2.00	0.50	0.00	0.00	0.00	0.00	0.00
temp.	28.0	28.4	26.2	26.5	28.7	29.0	28.8
DO	4.60	4.25	0.50	2.95	5.10	5.40	6.00
pH	7.30	7.29	6.8	6.94	7.38	7.48	7.20
secchi	0.80	0.20	0.20	0.20	0.87	1.06	
FC	180	650	11400	1180	490	50	60
BOD	1.61	2.96	3.76	1.81	2.53	1.53	1.21
begin	end	Suva tides		time	height, m		
730	925			743	0.5		
				1415	1.7		

10 APPENDICES

Appendix 1. Weekly average discharge at Toge, 1985-1995.

Ba River at Tonge: weekly average discharge, cms

wkbeg	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
01/01	14.4	8.7	4.0	18.1	40.6		48.3	5.0			4.9
01/08	6.3	5.0	3.0	12.4	39.0			28.0			3.0
01/15	53.0	10.0	2.6	8.7	49.4			9.6			32.4
01/22	18.0	15.3	5.7	16.4	36.7			6.0			5.9
01/29	14.7	6.3	14.3	27.5	44.7	9.7		19.0			220.3
02/05	10.7		28.4		360.1	7.1	38.8				17.7
02/12	26.2		23.9	95.0	260.1	6.8	37.0				16.1
02/19	26.9		26.4	124.0	72.4	11.4	63.7	20.4			66.7
02/26	66.0	30.0	7.4		114.1	17.3	54.0	94.4			23.6
03/05		123.1	6.6		45.4	18.2	59.2	17.4			47.3
03/12		19.1	37.7		41.9	10.7	72.0	23.1			110.1
03/19		23.9	37.4		30.9			9.0			52.4
03/26		58.7	25.6		26.0			7.0			
04/02		51.9	17.4		195.6	13.0	17.8	8.1			72.0
04/09		797.5	8.9			13.0	30.8	6.6			
04/16			6.3	30.0				7.5			
04/23			4.9	19.1	14.4						
04/30			4.0	11.7	11.2	9.8	34.0				
05/07			4.0	9.4		9.0					
05/14			3.9				31.0	5.7			6.3
05/21			3.0	8.0			28.7	5.0			7.4
05/28			3.0	6.6	40.0		27.3	9.6			8.7
06/04			3.0	6.0	20.9	20.8	8.1	7.7			5.6
06/11			3.0	6.6	12.7	24.9	7.0	5.0			4.4
06/18			3.0	7.0	10.4	17.3	6.9	5.3			4.3
06/25			3.0	5.0	9.2	7.0	6.0	5.6			4.0
07/02			3.0	4.9		6.6	6.9	5.0			4.0
07/09			3.0	4.6		6.0	6.0	4.0			4.9
07/16			3.0	15.3		7.7	6.0	4.6			4.7
07/23			2.9	5.3		6.0	5.9	4.0			4.0
07/30			2.0	4.9	6.0	6.0	5.1	4.3		8.0	3.7
08/06				5.0	6.0	6.0	5.0	4.0		8.0	3.0
08/13				5.0	6.4	5.7	5.6	4.0		8.0	3.0
08/20				4.0	6.9	21.1	7.7	4.0		7.3	3.0
08/27			2.0	3.6	5.1	34.9	5.0	5.9		7.0	3.0
09/03			2.0	3.0	5.0	10.7	5.6	4.0		7.0	4.7
09/10			2.0	3.0		27.3	19.0	4.0		7.0	3.7
09/17		3.2	2.0	3.3		9.9		3.9		7.3	3.0
09/24		3.0	2.0	3.3		9.4		3.0		6.9	3.1
10/01		3.0	2.6	4.6		15.1	5.0	3.0		6.0	3.5
10/08		3.0	2.3	5.3		8.4	5.7	3.0		6.0	
10/15		3.0	2.0	6.9		6.9	5.6	3.0		5.7	
10/22		4.1	2.0	3.7		6.0	8.0	3.0		5.3	
10/29		4.7	2.0			5.4	11.6	3.0		5.3	
11/05		4.4	2.0			5.1	7.4	3.4		5.0	
11/12		3.0	2.7		8.5	6.0	5.7	4.4		7.3	
11/19		3.0	8.0			8.5	6.9	5.0		5.7	
11/26		3.0	3.7		8.5	20.0	9.0	5.3		5.6	
12/03			4.4		24.7	11.1	8.0	9.0		4.3	
12/10			4.4		12.5	7.7	5.7	67.0		4.0	
12/17			4.3		9.0	7.0	5.0			4.0	
12/24			9.7			9.0	4.4			9.1	

Ba River at Tonge: weekly average discharge, cms

wkbeg	wkbeg	observati	avewk	minwk	maxwk
01/01	01/01	8	18.0	4.0	48.3
01/08	01/08	7	13.8	3.0	39.0
01/15	01/15	7	23.7	2.6	53.0
01/22	01/22	7	14.9	5.7	36.7
01/29	01/29	8	44.6	6.3	220.3
02/05	02/05	6	77.1	7.1	360.1
02/12	02/12	7	66.4	6.8	260.1
02/19	02/19	8	51.5	11.4	124.0
02/26	02/26	8	50.9	7.4	114.1
03/05	03/05	7	45.3	6.6	123.1
03/12	03/12	7	45.0	10.7	110.1
03/19	03/19	5	30.7	9.0	52.4
03/26	03/26	4	29.3	7.0	58.7
04/02	04/02	7	53.7	8.1	195.6
04/09	04/09	5	171.3	6.6	797.5
04/16	04/16	3	14.6	6.3	30.0
04/23	04/23	3	12.8	4.9	19.1
04/30	04/30	5	14.1	4.0	34.0
05/07	05/07	3	7.5	4.0	9.4
05/14	05/14	4	11.7	3.9	31.0
05/21	05/21	5	10.4	3.0	28.7
05/28	05/28	6	15.9	3.0	40.0
06/04	06/04	7	10.3	3.0	20.9
06/11	06/11	7	9.1	3.0	24.9
06/18	06/18	7	7.7	3.0	17.3
06/25	06/25	7	5.7	3.0	9.2
07/02	07/02	6	5.0	3.0	6.9
07/09	07/09	6	4.7	3.0	6.0
07/16	07/16	6	6.9	3.0	15.3
07/23	07/23	6	4.7	2.9	6.0
07/30	07/30	8	5.0	2.0	8.0
08/06	08/06	7	5.3	3.0	8.0
08/13	08/13	7	5.4	3.0	8.0
08/20	08/20	7	7.7	3.0	21.1
08/27	08/27	8	8.3	2.0	34.9
09/03	09/03	8	5.3	2.0	10.7
09/10	09/10	7	9.4	2.0	27.3
09/17	09/17	7	4.6	2.0	9.9
09/24	09/24	7	4.4	2.0	9.4
10/01	10/01	8	5.3	2.6	15.1
10/08	10/08	7	4.8	2.3	8.4
10/15	10/15	7	4.7	2.0	6.9
10/22	10/22	7	4.6	2.0	8.0
10/29	10/29	6	5.3	2.0	11.6
11/05	11/05	6	4.6	2.0	7.4
11/12	11/12	7	5.4	2.7	8.5
11/19	11/19	6	6.2	3.0	8.5
11/26	11/26	7	7.9	3.0	20.0
12/03	12/03	6	10.3	4.3	24.7
12/10	12/10	6	16.9	4.0	67.0
12/17	12/17	5	5.9	4.0	9.0
12/24	12/24	4	8.1	4.4	9.7
	Tonge		19.7	2.0	
	Dry season, May-		7.0		
	Wet season, Dec-		38.3		
	Ba mouth (1.5 X)		29.5	3.0	
	Dry season, May-		10.5		