The effect of dredging on light penetration in the Boro River, Okavango Delta, Botswana, from 1972 to 1975

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Abstract

This paper presents data on the effects of dredging on light penetration along the lower 4.5 km of the Boro and Thamalakane Rivers, between 1972 and 1975. The short-term effects of dredging were a decrease in light penetration by 25 to 50% for a river distance of 12 km. This effect was evident up to 18 months after the dredging had ceased. This could be ascribed to wash-in of silt and clay colloids from unvegetated spoil heaps.

Introduction

In 1971, the former De Beers Consolidated Mines Limited (now Debswana Diamond Company Limited) opened a diamond mine at Orapa in Botswana. In order to provide a regular supply of fresh-water to the mine, an attempt was made to canalise the Boro River, which is the main drainage channel of the Okavango Delta (Fig. 1), by deepening the channel bed to a depth of between 2 and 5 m, straightening river meanders, and preventing water loss to surrounding flood plains ("melapos") (Dye, 1975; Dye et al., 1976; Lubke et al., 1984).

A suction dredge and Poclain digger were installed at the junction of the Boro and Thamalakane Rivers in June 1971 (Lubke et al., 1984). In 1972 four bunds were constructed in order to confine the flow to the Boro channel (Fig. 2). This engineering operation was intended to supply 45.5 x 10^3 m^3·yr to Mopipi Reservoir at the Orapa Mine 193 km below the Boro River mouth (Dye et al., 1976; Lubke et al., 1981; Lubke et al., 1984). The dredge which had a capacity of ± 40 $m^3 \cdot h^{-1}$, moved from the Boro River mouth to a point 4.5 km up-channel between January 1972 and January 1973, after which it was decommissioned (Dye et al., 1976), due to technical problems. The Poclain excavator cut a channel down the Boro River, then the channel was deepened from 4 to 5 m in April 1972 (Dye, 1975). The dredger dispersed large amounts of clay and silt into the water, due to a suction and dispersal system which homogenised the water, silt and clay (White et al., 1973a, Reavell et al., 1973). The major source of the silt and clay was the effluent from the sludge disposal system (White et al., 1973a), which was deposited in spoil heaps along the banks of the Boro River. These were levelled off by bulldozer in June 1972 (Raynham, 1979). The suspensoids were also released by the dredger from excavation of the channel sediments, as well as wash-in from spoil heaps of the floodplains. Between February 1972 and September 1975, water quality, sediment particle size and phytoplankton ecology were studied to assess the impact of dredging on the Boro River. The water quality and phytoplankton studies were presented in published (Reavell, 1978) and in unpublished form (Reavell et al., 1972; Reavell, 1973; Reavell, 1981 and Reavell et al., 1976). Much information on the effects of dredging on the submerged and floodplain macrophytes is available in published form (Reavell, et al., 1973; Dye, 1975; Dye et al., 1976; Lubke et al., 1981; 1984; and Reavell, 1984).

There has been a recent recommendation for further dredging of the Boro River, which was not supported by the World Wildlife Fund (IUCN) (Williamson, 1994). However, it is expected that there may be future attempts to abstract the water resources from the Okavango Delta for development in this semi-arid country.

Although this study was done between March 1972 and August 1974, this paper presents data on the effect of dredging on water clarity, as few such studies have been documented for Southern Africa (Dallas and Day, 1993), and provides useful archival data.

Study area

The Okavango Delta lies between 18°45'S, 22°10'E and 20°15'S, 23°40'E (Fig. 1). It is an alluvial fan which was instigated by tectonic activity about one million years ago and lies in a graben (McCarthy et al., 1988). The inflowing rivers, Cuito and Cubango, drain the Angolan highlands with the out-flowing Boro River carrying 45% of the total inflow. The Thamalakane fault impedes the flow of the Boro at the toe of the Delta. Downstream of the Boro junction the Thamalakane River bifurcates into the two rivers which end as endorheic outflows to Lake Ngami and the Makgadikgadi pans (Figs. 1 and 2).

The study area is situated in the seasonally inundated lower region of the Delta along the lower Boro and upper Thamalakane Rivers, between the Kunyere and Thamalakane fault lines (Fig. 2). The terrain between the floodplains represents ancient dunes which were active during periods of extreme aridity (Stanistreet and McCarthy, 1993).

Thirty-one sites were established to study the effect of dredging; fifteen above the dredge, one at the dredge and fifteen below the dredge. some of the sites chosen were from Thokatsebe village in the Xaraxlau flats 20 km down to the Boro mouth and the rest were located along the Thamalakane River down to its divergence (Fig. 2). The study period was from March 1972 until August 1974 and consisted of nine sampling periods; three in 1972, four in 1973 and two in 1974. During 1973, two sampling periods were omitted from this study as they fell during a severe drought when the channel water dried up into a series of residual channel bed pools.

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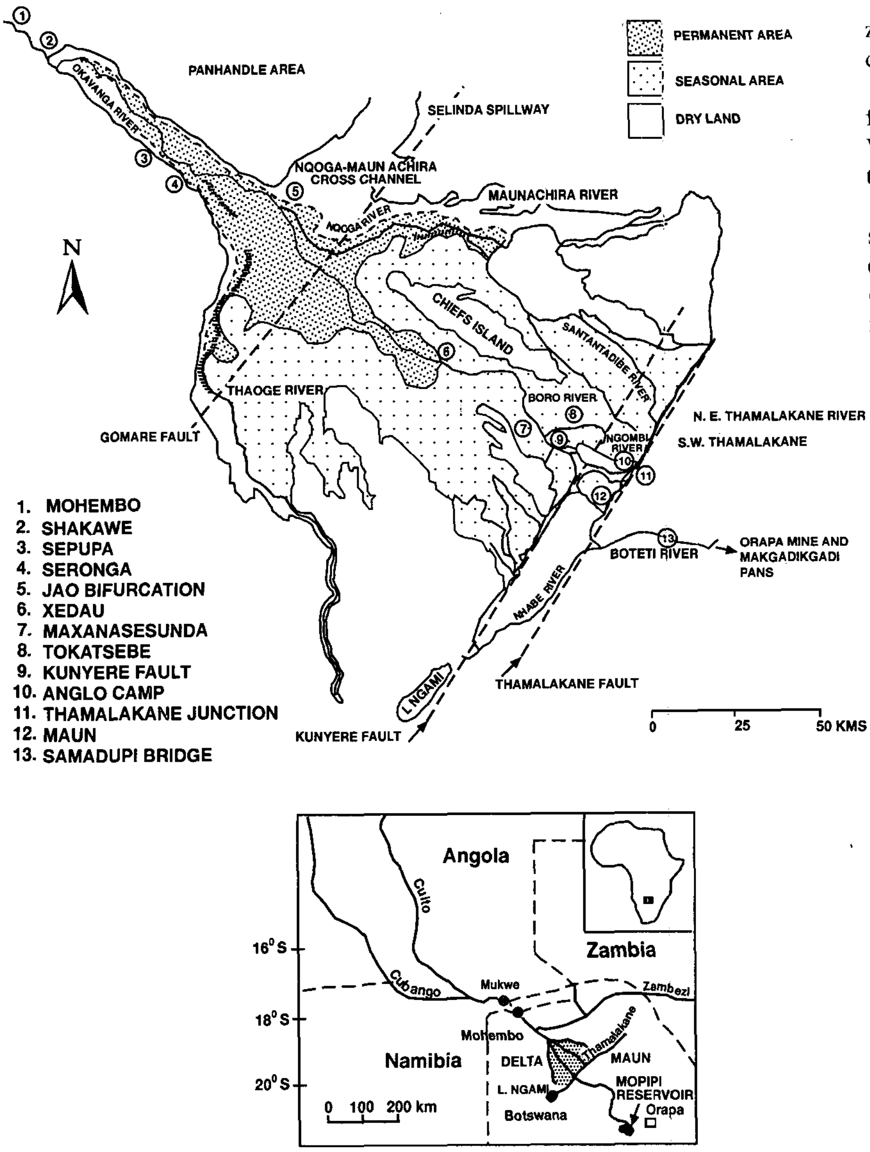

Figure 1

The Okavango Delta catchment, major rivers and sample sites

Materials and methods

Maximum channel depths were measured at each site with a graduated rod held vertically at each site.

The mean mid-channel velocity was measured at 60% of the channel depth, using the mean of three readings (Chow, 1964) with an Ott universal current meter, type 10.002. When the channel velocity was below the level of detection a float was constructed. A polystyrene block was attached to a nylon thread with an open tin can adjusted to hang 60% below the surface. The velocity was averaged for three runs. Channel discharge was calculated at selected sites as the product of channel area and velocity at each meter across the channel (Chow, 1964).

Light penetration was measured in two ways; as Secchi depth and percentage light absorption-depth profiles. Secchi depth was calculated from the average depth of disappearance and reappearance of a weighted 25 cm Secchi disc. Percentage light absorption-depth profiles were measured with a Hydrobios model 203/11 luxmeter lowered on a graduated rod. The luxmeter was zeroed each week in a closed box in a darkroom.

Total suspended solids were measured by filtering 1 ℓ of channel water through a tared Whatman filter paper No. 10 and weighing the residue after drying at 100°C .

Turbidity was measured on a few water samples taken below the surface. It was expressed in nephelometric turbidity units (NTU) using a Hach model 16800 turbidimeter.

Sediment samples were removed from mid-channel, using a soil auger inserted to a depth of 9 cm into the channel bottom.

They were drained and placed in sealed tins, air dried in the laboratory for two days and stored back in the tins. Mechanical particle size analyses were carried out as follows. The sand fraction was removed by sieving through a 0.25 and 0.50 mm Endecotts test sieve. The silt and clay fractions were dispersed by adding 10 mℓ of 5% sodium hexametaphosphate to each boycos cylinder. The viscosity changes were measured at 4 min, 16 min and 7 h using a hydrometer (Black, 1965). The sand fraction was 2 to 0.02 mm, the silt fraction was 0.02 to 0.002 mm and the clay fraction <0.002 mm diameter.

Results and discussion

Suspensoid concentrations and sedimentation

The main source of suspended matter (suspensoids) in the channels is probably particulate detritus. Clay and silt concentrations were very low (McCarthy et al., 1991), as were plankton concentrations. The phytoplankton concentrations were 7 to 14 x 10^3 cells·ℓ^{-1} and mesozooplankton concentrations only 10 individuals·ℓ^{-1} (Reavell, 1981).

The relationship between down Delta channel distance, discharge and suspended loads is shown in Table 1. Although there is a 16 year difference in sampling between the Panhandle and seasonal areas, there was probably little change in suspended loads in the Okavango River between these periods. During dredging periods, the suspensoid concentration rose from 14 to 20 mg.ℓ^{-1} at sites above the dredger, to 32 mg.ℓ^{-1} below the dredge (Table 1). Total suspended loads were 2 to 6 times higher in the Okavango River channel between December 1987 and January 1988, than in the Boro River channel during August 1972 (Table 1). This is due to the filtering action of papyrus roots and peat in the permanent swamp (McCarthy et al., 1992 and 1993), which removes the clay and silt from the Okavango River channel thus lowering the suspensoid concentrations when the water reaches the Boro River. Although the total suspended load decreased down the Okavango-Jao-Boro Rivers, the suspended load increased 3- to 4-fold due to the decrease in discharge (Table 1).

The sedimentation rate of fines below the dredge was probably very low due to channel velocities which exceeded the settling

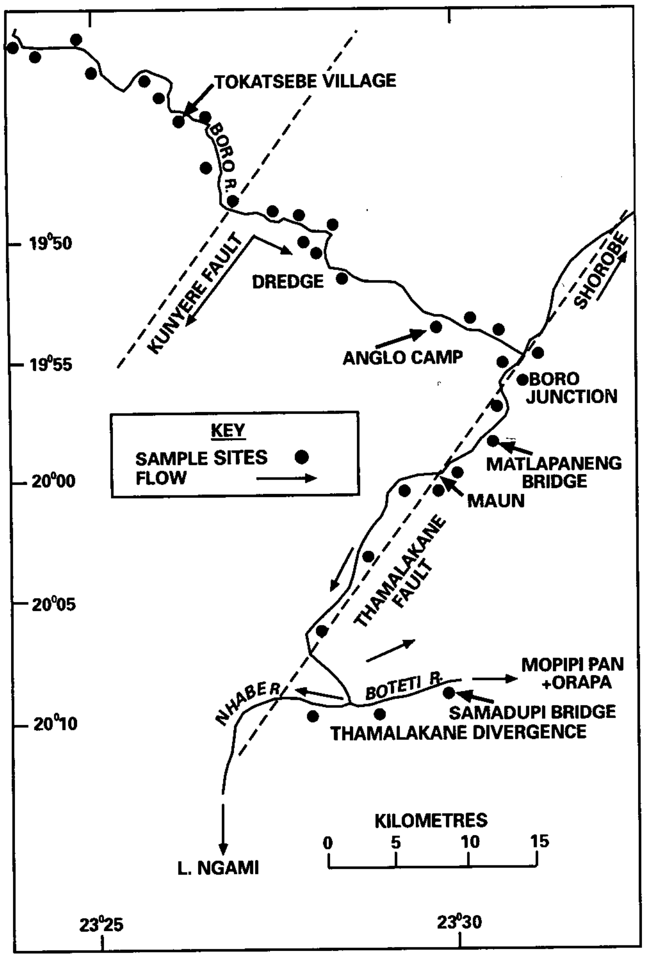

Figure 2 (left)
The Boro and Thamalakane Rivers showing sample sites

velocity of clay colloids and silt (Selley 1988). During low water periods they ranged from 0.03 to 0.06 m·s^{-1} and during peak flood from 0.4 to 0.5 m·s^{-1} (Reavell 1981). The base cation concentrations were below the flocculations of clay colloids (White et al., 1973b). During flowing water periods they were Ca^{2+} 5.9 to 10.1 mg·ℓ^{-1}, Na^{+} 3.9 to 10.1 mg·ℓ^{-1}, Mg^{2+} 2.6 to 6.7 mg·ℓ^{-1} and K^{+} 2.6 to 6.7 mg·ℓ^{-1} (Reavell and Weinert, 1997).

The sediments of the Boro and Thamalakane River channels were predominantly sandy (fines only 7 to 20%) (Table 2). No increase in silt and clay percentage was detected below the dredger. Any fines which were deposited may have been masked by the inherent variability of the mechanical composition of the channel bed. Probably the fines disturbed by 12 months of dredger activity were swept away by the current and deposited in the sediments of the Boteti and Nhabe Rivers, 35 km below the dredger.

Effect of dredging on light penetration

The maximum channel depths and Secchi depths were plotted at selected sites along the Boro and Thamalakane Rivers (Fig. 3). The dredger was active from March 1972 to January 1973, with a quiet period in June. Secchi depths always exceeded the channel depth at all sites above the dredger as light reached the bottom. When the dredger was inactive, Secchi depth always exceeded 3 m below the dredger. In March 1972, when it was active, Secchi depth gradually increased from 0.2 m to 1.5 m during the rising flood. In August 1972 it rose from 0.5 to 2.0 m as the flood water

TABLE 1
SUSPENDED SOLIDS IN THE CHANNELS OF THE OKAVANGO DELTA DURING THE PEAK FLOOD OF 1972 AND THE RISING FLOOD OF 1987/88 (REAVELL, 1981 AND McCARTHY ET AL., 1991)

River	Site	Date	Distance below Mohembo km	Mean velocity m·s^{-1}	Discharge m^3·s^{-1}	Total suspended load kg·s^{-1}	Suspended load kg·m^{-3}	Turbidity NTU	Dredge
Okavango	Below Shakawe	12.87-1.88	20.6	0.74	129.9	1.10	0.00848	7.8	
Okavango	Below Sepupa	12.87-1.88	133.6	0.61	117.9	1.12	0.00947	8.7	
Okavango	Seronga	12.87-1.88	152.3	0.51	117.6	1.13	0.00957	8.8	
Okavango	Jao Bifurcation	12.87-1.88	158.3	0.64	81.9	1.01	0.0123	11.3	
Boro	Xedau	9.72	270.6	0.67	19.2	0.27	0.0140	-	
Boro	Maxanasesunda	9.72	345.1	0.20	2.3	0.49	0.0210	0.7-0.9	Up-channel of dredge
Boro	Anglo Camp	8.72	380.5	0.23	12.5	0.21	0.0170	-	Down-channel of dredge
Thamala-kane	Matlapaneng Bridge	8.72	387.5	0.22	14.1	0.45	0.0320	-	
Boteti	Samadupi Bridge	9.72	414.6	0.71	7.9	0.21	0.0270	0.9	

TABLE 2
MEAN SEDIMENT COMPOSITION OF THE OUTLET CHANNELS IN THE OKAVANGO DELTA (MEANS ± 1 STANDARD DEVIATION)

River sand	Per cent silt	Per cent clay	Per cent	n
Boro above dredger	79.0 ± 21.6	9.5 ± 15.4	11.5 ± 14.1	23
Boro below dredger	75.0 ± 18.8	10.5 ± 8.5	14.3 ± 11.9	9
Thamalakane	81.5 ± 13.1	8.0 ± 9.6	10.5 ± 7.8	36
Nhabe	82.2 ± 17.1	11.3 ± 10.7	6.5 ± 6.5	4
Boteti	92.5 ± 5.3	2.5 ± 1.9	5.0 ± 4.4	4

peaked, although it never reached the channel bed. In June 1972 when the dredger was inactive, the Secchi depth reached the channel bottom on both sides of the dredger.

The light penetration was highest at peak floods, due to dilution of dissolved and particulate organic matter by the fresh flood water. During low-flow periods, organic and inorganic suspensoids drained into the channel (Merron, 1991), probably from the floodplains.

The irregular depths of light penetration were probably due to down-channel transport of varying loads of suspended solids generated by the suction of the excavator (Reavell et al., 1973). As the fines gradually settled out from the water column, there was an increase in Secchi depth. This light penetration may have been augmented by inflow of clean groundwater into the excavated channel bottom. During the rainy season (November to March), clay and silt may have been washed in from spoil heaps along the floodplains. Backwash from motorboats eroded the marginal spoil heaps and steep excavated river banks which collapsed into the channel (Reavell et al., 1973; Dye, 1975).

Secchi depths down-channel of the dredger (Fig. 3) show that suspended solids were released in "pulses", even up to 8 months after dredging had ceased. Turbidity reduced light penetration by 20 to 40%. It is not clear whether these turbidity pulses were correlated with the phases of the flooding cycle or with seasonal rainfall. For example, in October and December 1973 there was little rain when Secchi depth reached the channel bottom. However, in February and March 1974 during rising flood, although there was little rain during the rising flood, there were turbidity pulses which may indicate that the major source of turbidity was from spoil heaps washed by the flood water.

These spoil heaps became vegetated by 1976 (Dye et al., 1976) and were still covered with vegetation by 1980 (Lubke et al., 1984). These pulses occurred during rising flood periods. The Boro floodplain is rapidly constricted above the position of the dredge (Lubke et al., 1984) from 80 to 130 m wide (Dye et al., 1976). This created a "bottleneck effect" for the rising floodwave, which spread out over the wide floodplain and washed over the spoil heaps and through the meanders of the original channel bed, returning the fine sediments into the channel water. The spoil heaps above the dredger originated from straightening of the Boro River channel and the erection of floodplain bunds (Dye et al., 1976). However, the Secchi depth in the Thamalakane River was only 1.0 m during the low flood of December 1980 (Reavell, 1984).

Light penetration

The light depth profiles are shown for three periods (Fig. 4). When the dredger was active during the peak flood of August/September 1972, light reached 3 to 4 m depth at sites above the dredger and only 2 m depth at sites below the dredger. The depth of 50% light absorption was 0.25 m on both sides of the dredger and increased to 0.5 m 36 km down-channel of the dredger. During the low-flow period of December 1973, there was a slightly higher light attenuation below the dredger during the rising flood of February/March 1974, when light penetrated to the channel bottom on both sides of the dredger. 50% light absorption was 0.45 m above the dredger and 0.37 m at sites below the dredger.

Conclusions

Excavation of the Boro River channel bed and wash-in of fines from spoil heaps increased the turbidity of channel water for about 12 km down-channel. The suspensoids were released in pulses while the dredger was active and during the rising flood of 1974, while the dredger was inactive. The increase in turbidity below the dredger reduced light penetration depths during March 1972 to January 1973. At the Nhabe-Boteti divergence, water clarity had returned. There was no evidence of an increase in % fines in the sediments below the dredger until the divergence. Suspensoids were released in pulses due to the excavation and wash-in of clay and silt from spoil heaps. These spoil heaps were only covered by vegetation by 1976 (Dye et al., 1976).

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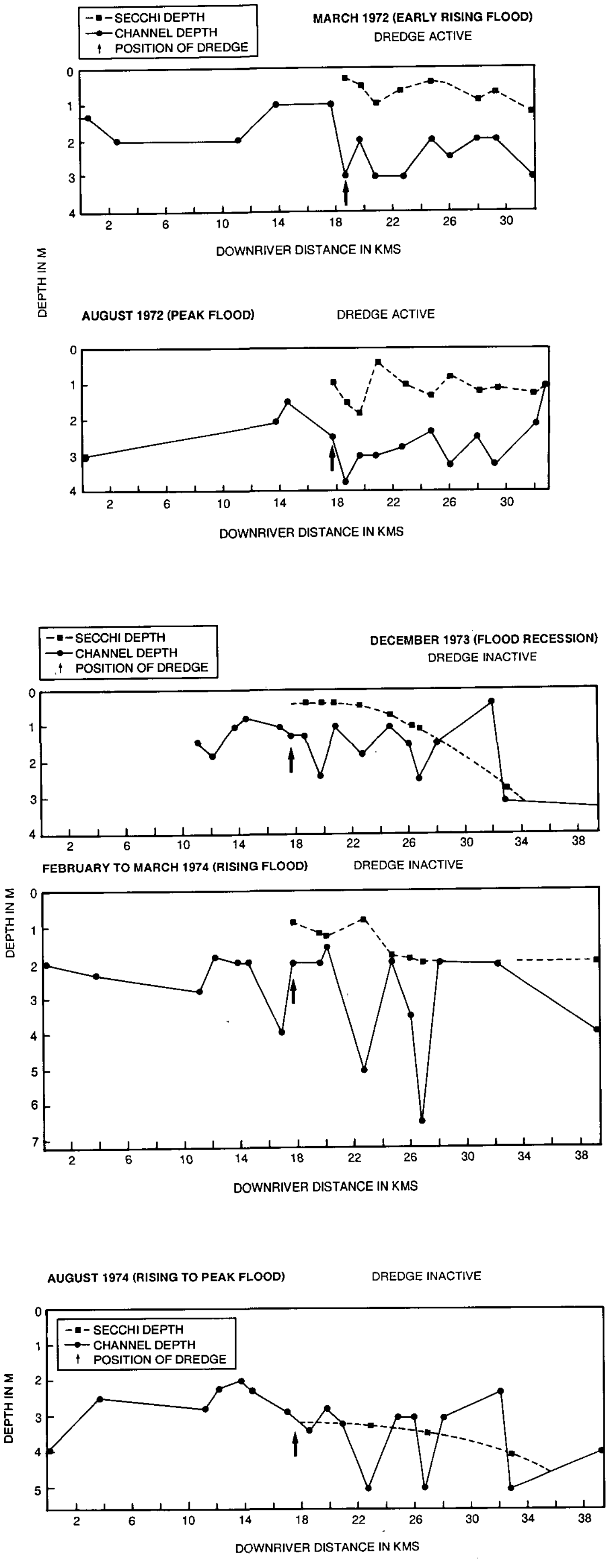

Figure 3
Secchi depth from Tokatsebe to Thamalakane divergence during five periods

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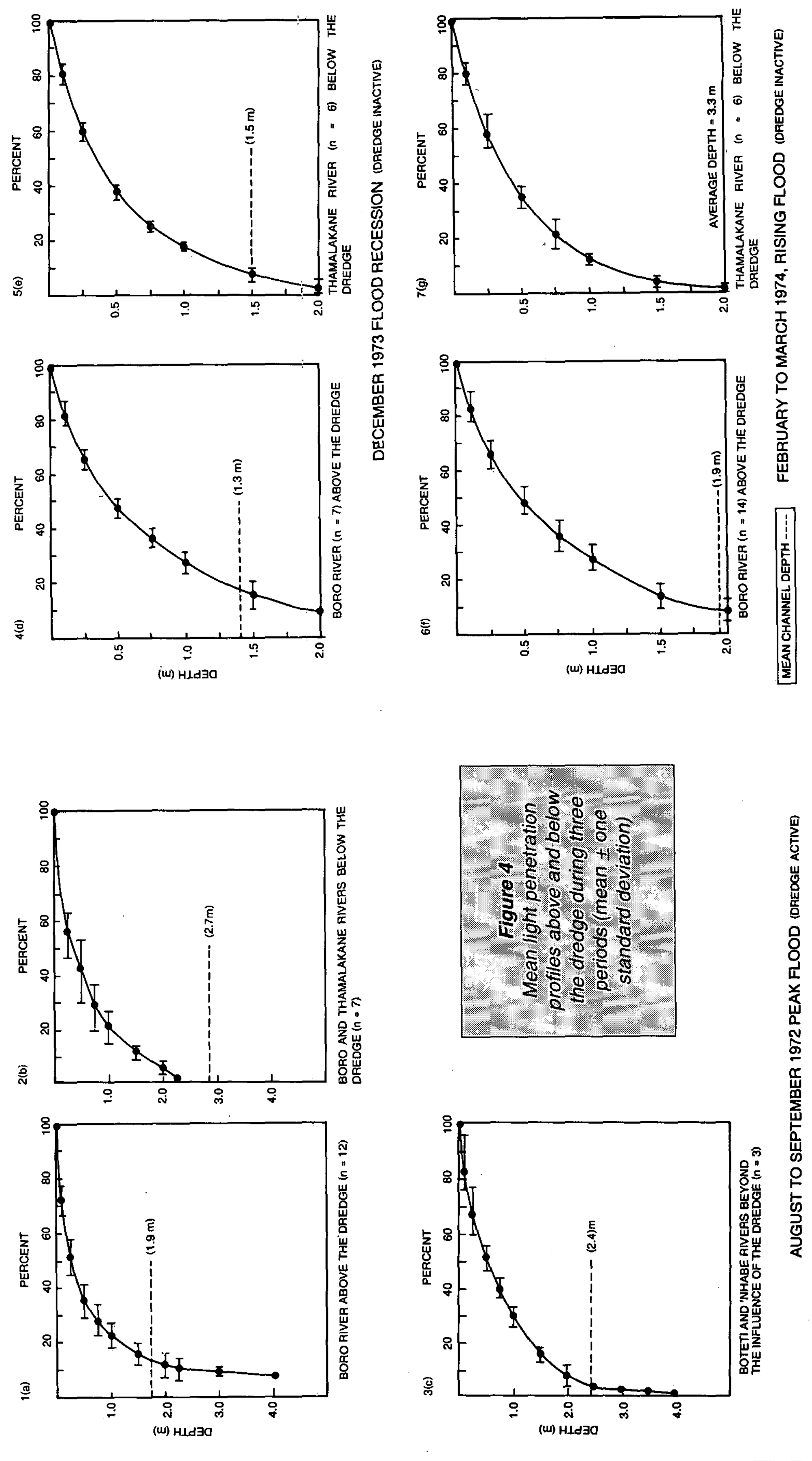

Figure 4
Mean light penetration profiles above and below the dredge during three periods (mean ± one standard deviation)