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POSSIBLE GROUND WATER POLLUTION BY SEWAGE EFFLUENT AT CAMPS IN THE OKAVANGO DELTA: SUGGESTIONS FOR ITS PREVENTION

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Abstract

Many camps in the Okavango Delta rely on borehole water to supply camp needs, and moreover discharge waste water and sewage effluent into the ground water. This situation creates the potential for contamination of drinking water supplies. General guidelines are described for the siting of boreholes and waste water disposal points which reduce this risk, based on results of studies of groundwater movement beneath islands.

Introduction

Many tourist camps in the Okavango Delta, especially those located in the seasonal swamps, rely on borehole water to supply the camp and staff quarters. Most of these camps employ some form of septic tank system for sewage and waste water disposal. There are potential pollution problems associated with this combination. Under normal circumstances, effluent is discharged into a dry soil above the water table, in which it is believed that bacteria and chemical pollutants rarely travel more than 3m (Carroll, 1982). However, in cases where soils are sandy and the permeability is high, pollutants may travel much greater distances. This problem is further exacerbated by the presence of a high water table, as found in the Okavango Delta.

Our studies of surface and groundwater hydrology in both the permanent and seasonal swamps of the Okavango Delta make it possible to provide general guidelines for borehole location and waste water disposal in the Delta which could substantially reduce the risk of pollution of drinking water.

Generally Established Guidelines for Sewage Water Disposal and Their Applicability to the Okavango

A wide variety of sewage systems are available for use in remote areas (NBRI, 1977; 1981; de Villiers, 1984; 1987; Heap, 1984), and many depend on discharge of waste water into the ground either directly from a sewage pit or via a French drain system. General guidelines have been suggested for the location of final disposal points in relation to points where water is drawn (Carroll, 1982):

i) disposal points should always be above the maximum elevation of the water table;

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ii) in high permeability soils, disposal points should be at least 30m away from water points, and on the downslope side, as groundwater flow is generally downslope;

iii) in low permeability soils, the discharge points should be at least 8m away if on the downslope side of water points, or else 30m away if on the upslope side;

iv) on level ground, discharge points should be at least 30m away from the water draw point.

In the case of the Okavango Delta, the water table is usually less than 1m below surface during the flood season, so that discharge of effluent directly into the groundwater is unavoidable. The soils are often sandy, with very low clay contents, and thus very permeable. Moreover, the clay is usually kaolinite, which has very low exchange capacity, and therefore a low potential to absorb chemical pollutants. Islands on which camps are built are often small, limiting the distance between effluent disposal points and water sources. There is no significant slope so that the direction of ground water movement cannot be easily predicted. For these reasons, the applicability of the general guidelines is questionable, and the potential for pollution of water sources is high.

Groundwater Movement Beneath Islands

Several studies on the hydrology of islands and the surrounding swamps have been carried out by the authors in the permanent and the seasonal swamps (McCarthy, McIver & Verhagen 1991; Ellery, Ellery & McCarthy 1993; McCarthy, Ellery & Ellery, 1993; McCarthy & Ellery 1994), and have provided some insight into the groundwater movement beneath islands and the way in which this water interacts with surface water. The hydrology of surface and ground water of islands in the seasonal swamps differs somewhat from that in the permanent swamps, and these will therefore be discussed separately.

a) Permanent swamps

Studies in the permanent swamps were carried out at sites along the lower Nqoga and Maunachira channel systems, where seasonal water level fluctuations in the swamps, as well as of the ground water table beneath islands, are generally less than 20cm. At these sites, the water table beneath islands is always at a lower elevation than water level in the surrounding swamp, in some cases by as much as 50cm (Fig.1). The ground water beneath the centres of the islands is generally very saline, containing up to several percent of dissolved sodium bicarbonate, whereas swamp water contains only a few parts per million (Table 1). The water under the centres of the islands is not potable, and generally exceeds the limits for domestic water use (Table 2), with pH often exceeding 10. A simple measure of dissolved solids is the electrical conductivity of the water, usually measured in mS/cm (milliSiemens per centimetre), which increases with increasing dissolved solids.

The islands generally have a raised rim with a flat or slightly depressed interior which may sometimes contain a small saline pan. Vegetation is usually most dense around the island fringe, and species are strongly zoned within this fringe. The vegetation fringe may encircle the island, or it may form a crescent around a portion of the island margin. The outer fringe usually has wild date palms (*Phoenix reclinata*) and the water berry (*Syzygium cordatum*),

Cross section of an island in the Okavango Delta showing the distribution of vegetation (top) in relation to the topography (middle) and the electrical conductivity (in mS/cm) of the ground water beneath the island (bottom).

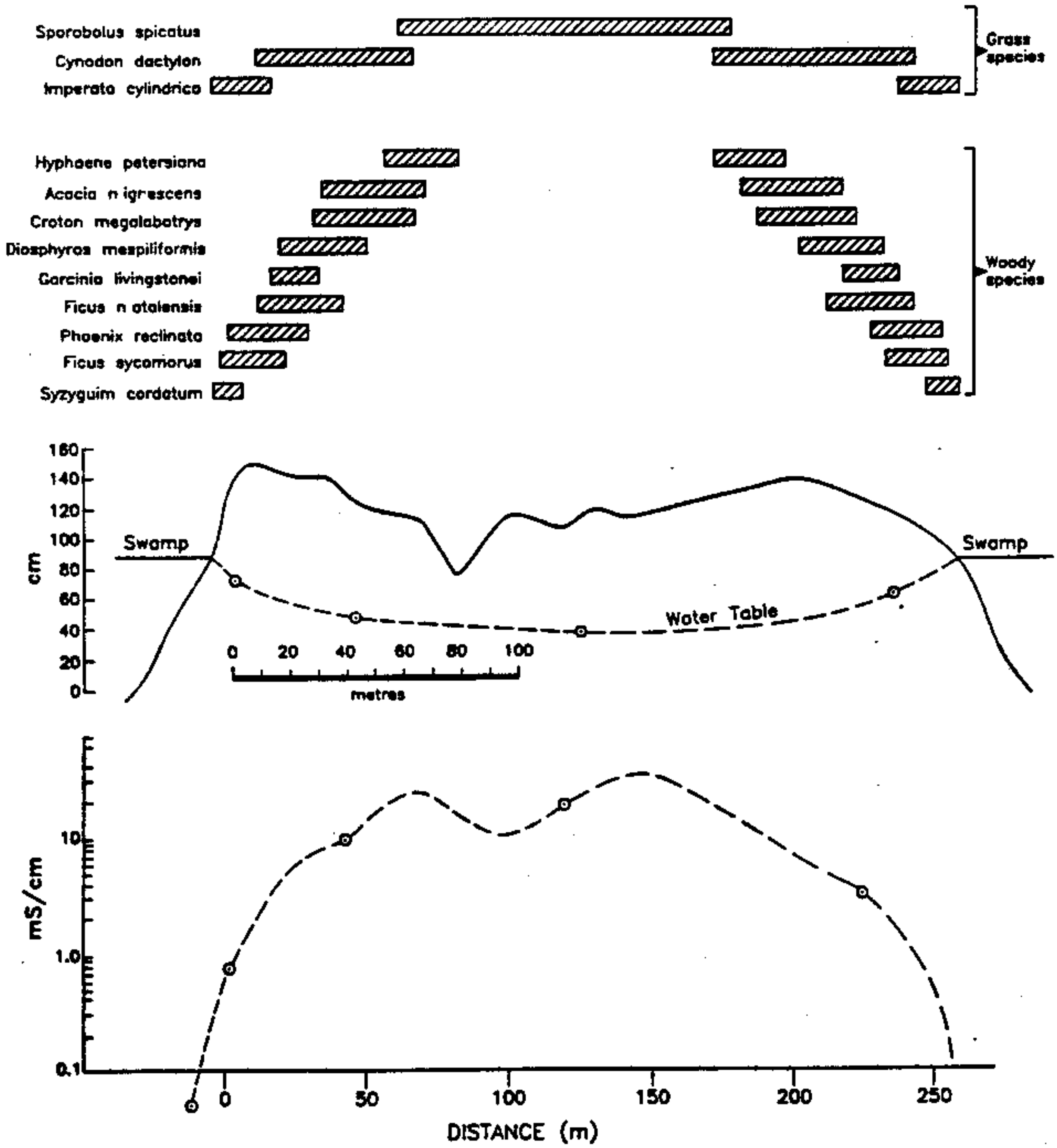

Figure 1

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rading inwards to a zone of broadleaved evergreen trees, including the sycamore fig (*Ficus sycomorus*), strangler fig (*F. natalensis*), jackal berry (*Diospyros mespiliformis*) and the mangosteen (*Garcinia livingstonei*). These give way to deciduous species such as the marula (*Sclerocarya birrea*), fever berry (*Croton megalobotrys*), and species of acacia, particularly the knobthorn (*Acacia nigrescens*). Inwards of this the vegetation is typically dominated by the ivory palm (*Hyphaene petersiana*). The island interiors are generally devoid of trees.

Table 1: Surface and ground water analyses for the Okavango Delta

	1	2	3
Magnesium mg/l)	1.3	30	10
Sodium (mg/l)	3.9	1650	4000
Chloride (mg/l)	1.0	13	62
Sulphate (mg/l)	<5	<5	8
Calcium (mg/l)	4.8	19	5
Electrical Conductivity (mS/cm)	0.1	5.1	10.4

1 Swamp water (Sawula *et al* 1992)
2,3 Ground water beneath island (McCarthy *et al* 1992)

Table 2: Quality specification for potable water (SABS, 1984)

	Recommended limit	Maximum allowable limit
Magnesium (mg/l)	70	100
Sodium (mg/l)	100	400
Chloride (mg/l)	250	600
Sulphate (mg/l)	200	600
Calcium (mg/l)	120	-
Electrical conductivity (mS/cm)	0.7	3

This zonation of trees is paralleled by zonation of grasses, sedges and other herbs. The outer fringe where permanent surface water is present is characterized by sedges such as papyrus (*Cyperus papyrus*) or grasses such as (*Miscanthus junceus*), or the bulrush (*Typha capensis*). On the island edges, grasses tend to be sparse due to shading by tall evergreen species, but *Imperata cylindrica* may occur. The bristle grass *Setaria verticillata* is generally common. In the zone dominated by deciduous trees, the couch grass (*Cynodon dactylon*) is dominant, and it gives way to *Sporobolus spicatus* towards the island interiors. Occasionally the central portions of the islands may be completely devoid of vegetation. These barren areas and the fringing *Sporobolus* grassland are frequently encrusted with a white salt called trona, which is a mixed sodium bicarbonate - sodium carbonate salt. It is locally known as *n'tsonga*, and is especially prevalent in the dry season.

The trees are rooted in the ground water and are very sensitive to salinity levels, so much so that the trees provide a good indication of salinity levels in the ground water. The maximum and mean salinity levels, and the number of individuals sampled to compile the results, are provided in Table 3.

Table 3: **The mean and maximum values of ground water electrical conductivity associated with different woody species on islands of the Okavango Delta. The number of individuals sampled provides some indication of the reliability of values in each of the columns.**

Species	Mean conductivity (mS/cm)	Maximum conductivity (mS/cm)	Number of individuals sampled
Ficus verruculosa	0.05	0.07	7
Syzygium cordatum	0.22	0.78	18
Ficus sycomorus	0.53	1.44	17
Phoenix reclinata	0.74	3.06	44
Ficus natalensis	1.15	6.53	19
Garcinia livingstonei	1.29	4.66	28
Diospyros mespiliformis	1.36	7.63	31
Croton megalobotrys	1.82	12.34	38
Acacia nigrescens	1.94	12.58	35
Combretum imberbe	4.04	7.39	7
Hyphaene petersiana	5.72	16.48	48
Pechuel-loeschea lubnitziae	6.04	12.58	4
Lonchocarpus capassa	6.49	12.58	3

The hydrology of a typical island is illustrated diagrammatically in the cross-section shown in Figure 2. Islands are areas where major water loss to the atmosphere takes place by a combination of transpiration and evaporation. The trees around the island fringe transpire large quantities of water and cause the drawdown of the water table beneath the island. Water thus lost is replaced by inflow from the surrounding swamp. The loss of water results in an increase in the concentration of dissolved solids in the water, and hence the salinity increases as the ground water migrates beneath the vegetation fringe. In the central portion of the island, evaporation of water drawn to the surface by capillary action causes the accumulation of sodium bicarbonate on the soil surface. Seasonal rains flush this very soluble material downwards, and over time there is a gradual accumulation of dissolved salts beneath this region of the island. Other salts precipitate in the soil as discussed by McCarthy, McIver & Verhagen (1992). The end result is a marked gradient in salinity of the ground water and soils across the island, which induces the distinct zonation of the vegetation.

Diagrammatic cross section of an island in the permanent swamps illustrating ground water flow, transpiration and evaporation.

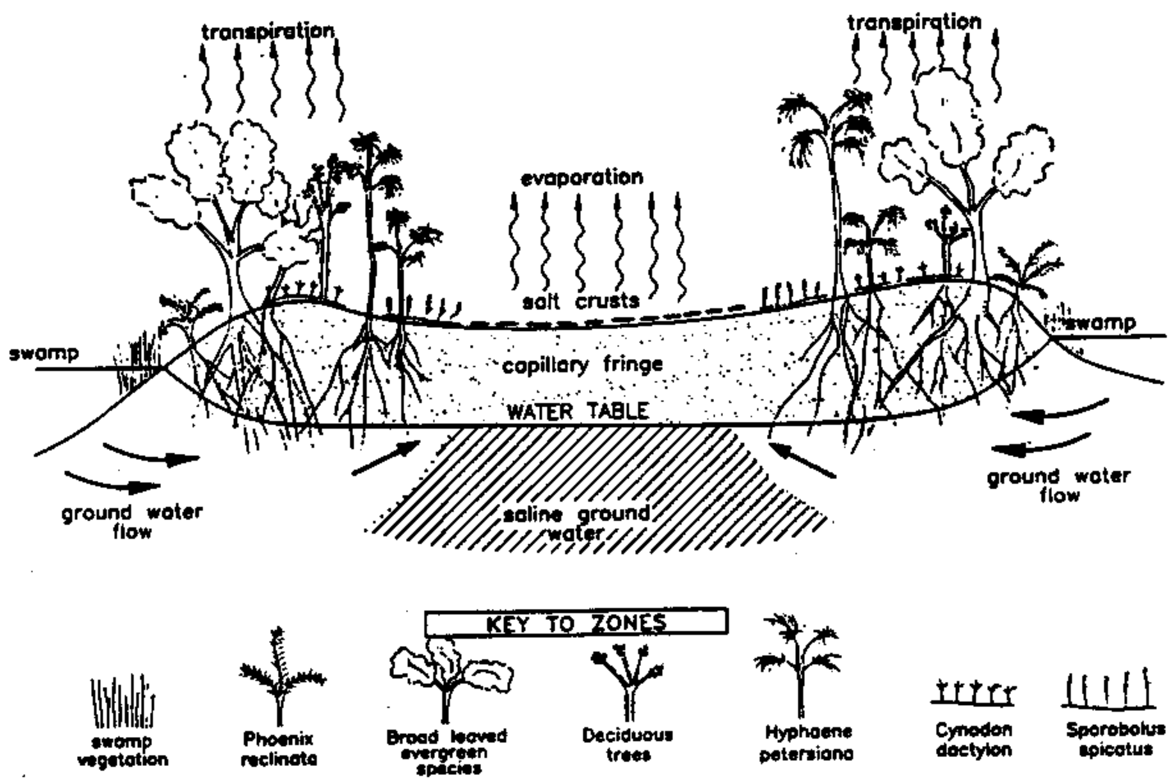

Figure 2

b) Seasonal swamps

Studies of islands in the seasonal swamps were carried out at Xaxaba and Thokatsebe. In these areas the seasonal fluctuations in swamp water level are greater than in the permanent swamps, generally exceeding a metre. Surprisingly, our studies have shown that the hydrology of islands is similar to that in the permanent swamps, in spite of the large fluctuations in surface and ground water levels, and that there is very little mixing of swamp and ground water.

The vegetation on islands in the seasonal swamps shows a similar zonation to that described above, although the abundances of several species differ. Generally, *Phoenix reclinata* is less abundant, while *Hyphaene petersiana* is superabundant, reflecting a generally higher level of salinity in the groundwater. In the lowermost reaches of the Delta, even the broadleaved evergreen species disappear. In these areas, floodplain grasses and sedges provide an indication of flooding regimes rather than of soil salinity. Areas flooded for the longest period are characterized by submerged and floating leaved species. Less prolonged flooding is indicated by the sedges *Cyperus articulatus* and *Scirpus corymbosus*. Higher lying ground supports *Sorghastrum friesii* and *Panicum repens*, with the sedge *Eliocharis* dulcis quite common. This gives way to dense *Imperata cylindrica* grasslands on the island edges. On the islands themselves, the zonation of grasses and trees is similar to that described for the permanent swamps, with *Sporobolus spicatus* dominating the interiors.

The hydrology of an island in the seasonal swamps is illustrated schematically in Figure 3. During the flood stage, the island behaves in much the same way as islands in the permanent swamps, producing saline ground water beneath the islands. This saline ground water does not disperse during the fall of the water table as the flood recedes, but remains centred beneath the island, although it expands slightly. With the arrival of the flood, recharge of the ground water occurs in low lying areas, and this has the effect of lifting the saline ground water beneath islands without any mixing or dispersion taking place.

It is evident from these studies that the ground water beneath islands is a sink for salts which accumulate as a result of high evapotranspiration over the Delta. It is likely that there is a slow downward migration of this saline water to deeper levels because of its higher density, but this has not yet been verified. The localization of saline groundwater beneath islands has important implications for the disposal of effluent at camps in the Okavango Delta.

Implications for Siting of Water Boreholes and Effluent Disposal Points

a) Effluent disposal

It is evident from the above that the most suitable location for disposing of septic tank effluent is in the interior regions of islands where salinity levels are significantly elevated. The reasons for this are:

- i) islands have depressed water tables and are characterized by inward flow of ground water;
- ii) there is no mixing of the saline ground water which occurs beneath islands with the fresh surrounding ground water or with swamp water, even in the seasonal swamps;
- iii) there is probably long-term downward flow of saline ground water beneath islands which would entrain and remove effluent from the environment.

Diagrammatic cross section of an island in the seasonal swamps showing the variation in water level between high flood (A) and low flood (B), and the localised distribution of the saline ground water.

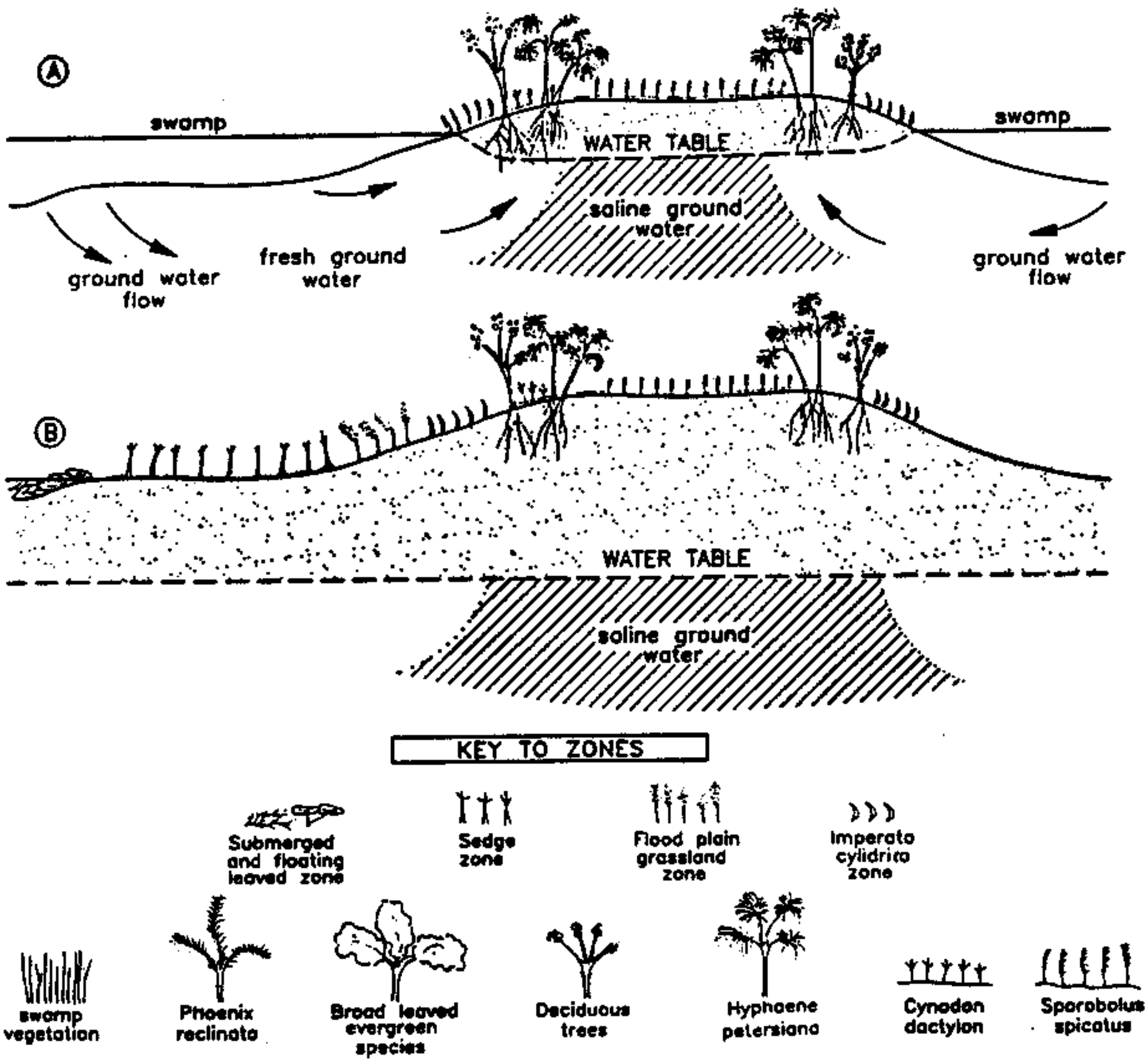

Figure 3

iv) effluent water will always be associated with highly saline, unpotable ground water, providing an opportunity for early warning should excessive pumping of boreholes cause effluent to discharge into a borehole;

v) the high pH and salinity of the ground water may destroy some pathogens, and will greatly reduce the solubility of most heavy metal pollutants.

b) Boreholes

Boreholes should be located on the outer fringes of islands, where there is continual recharge by fresh water. Trees should be used as a guide to the siting of boreholes, which should be placed on the outer edge of the widest wooded fringe as this will ensure maximum protection from the saline ground water of the island interior. It is probable that much of the deep ground water beneath the Delta is saline, even where the surface water is fresh, and care should be taken not to drill too deep as this may result in inflow of saline water. While a borehole is being drilled, it is therefore advisable to monitor the conductivity of the water with increasing depth.

Conclusions and Recommendations

Studies of the pattern of ground water movement and chemistry beneath islands in the Okavango Delta have provided useful guidelines for locating effluent disposal points and water boreholes in both the seasonal and permanent swamps. It has been found that the interiors of islands act as groundwater sinks and that recharge takes place from the swamp around the outer edge of the vegetation fringe. The sensitivity of vegetation to ground water salinity provides a ready means of assessing the salinity distribution in ground water, and hence the location of effluent discharge and borehole sites.

The following guidelines are suggested:

i) effluent discharge should be above the highest level of the water table;

ii) discharge points should be placed in the zone of high ground water salinity which can be identified by means of the zonation of vegetation;

iii) discharge points should be placed on the opposite side of the island from which water is abstracted, and the distance between these 2 points should be as large as possible, at least 30m;

iv) boreholes should be located just beyond the outer edge of the most densely wooded fringe, once again using vegetation as a guide to their siting;

v) care should be exercised when drilling boreholes so as not to intersect deep saline water in areas where surface water is fresh;

vi) borehole water should be regularly monitored for increases in salinity, as excessive pumping may cause inflow of saline water.

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