Hydrological modelling of the Sudd and Jonglei Canal

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ABSTRACT The water balance of the Sudd is represented by a hydrological model which uses measured inflows and outflows and estimates of rainfall and evaporation to reproduce volumes and areas of flooding over the historical period 1905-1980. Predicted outflows based on inflows are then substituted for measured outflows so that the proposed diversions through the Jonglei Canal can be incorporated in the model in order to predict the effects of the canal on areas of flooding.

INTRODUCTION

The swamps of the Sudd are responsible for the loss of much of the Nile outflow from Lake Victoria. At present only half the inflow of the Bahr el Jebel or White Nile at Mongalla emerges from the tail of the swamps (Fig.1); the remainder spills from the river into permanent and seasonal swamps and subsequently evaporates. The Jonglei Canal, when completed, is planned to carry about $20 \times 10^5$ m$^3$day$^{-1}$ past the Sudd and thus save about $4.7 \times 10^9$ m$^3$year$^{-1}$ of water currently evaporated in the swamps. Because the volume evaporated is proportional to the areas flooded, the swamp area must decrease if water is to be saved. However, there is an important distinction between the permanent swamp and the areas seasonally flooded and uncovered which provide dry season grazing.

A hydrological study was carried out to analyse the historical behaviour of the swamps and then to estimate the effect of the canal on the areas of permanent and seasonal flooding. The analysis was

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Open for discussion until 1 December 1987.
based on a simple reservoir model, using measured values of hydrological inputs and outputs wherever possible. The study covered the period 1905-1980, when variations in outflow from Lake Victoria (Piper et al., 1986) have caused considerable natural variations in the areas of flooding.

Fig. 1 Location map of the Sudd area.
THE HYDROLOGICAL BACKGROUND

The inflow to the swamps combines the damped outflow from the East African lakes, which respond slowly to periods of high and low rainfall, and the seasonal and variable flows of the rain-fed torrents above Mongalla. Thus for half the year the flow at Mongalla depends on lake levels while the high flows between May and October derive from local rainfall.

Longer-term variations in East African lake levels and outflows have an important effect on the Mongalla flow. Because the average rainfall over Lake Victoria is almost equal to the evaporation, the lake system is sensitive to changes in rainfall and tributary inflow. An increase in rainfall of about 20% over the average in 1961-1964 led to a 2.5 m rise in lake level and a doubling of the outflow. Thus the average annual discharge at Mongalla was $50.3 \times 10^9$ m$^3$ for 1961-1980, compared with $26.8 \times 10^9$ m$^3$ for 1905-1960; the average for 1905-1980 was $33.0 \times 10^9$ m$^3$. There is evidence from rainfall records, lake levels and Nile records (Piper et al., 1986) that this period was preceded by high outflows around 1875-1895 and earlier by alternating periods of high and low outflows.

Below Mongalla the channel capacities are less than the flood flows and the alluvial channels themselves are above the flood plain. Thus excess flows leave the river through spill channels and inundate wide areas on either side of the river; this inundation is limited by higher ground only in the south of the swamps. The high flows coincide with the rainfall season within the swamps, when evaporation is comparatively low. The outflow from the swamps is relatively constant, with a very damped seasonal cycle, and totals only half the inflow (Fig.2).

The combined effect of these processes is that varying areas are inundated permanently or seasonally, with the uncovering of the seasonal swamp coinciding with the dry season. The areas of permanent swamp reflect the longer term variations in flow from the East African lakes, while the seasonal swamps depend on the torrent inflows and the annual cycle of balance between rainfall and evaporation within the swamps.

Sutcliffe (1974) has described the reach between Juba and Bor, where the flood plain is incised and is divided into a number of basins which act as reservoirs in series, storing water when the river rises and returning water to the river downstream when it falls. Further north, the channel system becomes even more complex, with a number of channels parallel to the main river. However, there is no topographic limit to the flooding which extends further from the river in periods of high flow, especially to the northeast where there is a lack of defined channels, and it is doubtful whether much of the spill returns to the main river. The flooding pattern is complex but may be described by a water balance model, where the swamp storage is represented by a reservoir.

A detailed study of a surveyed sample reach between Juba and Bor (Sutcliffe, 1974) has shown that it is possible, given inflow and outflow records, to reconstruct volumes and levels of flooding over a number of years. In order to develop a simple hydrological model to monitor the behaviour of the Sudd over the historical period,
Fig. 2 Measured monthly Mongalla inflows and outflows from the Sudd ($\times 10^9$ m$^3$ month$^{-1}$).
inflow and outflow records are required together with estimates of rainfall and evaporation.

**AVAILABLE RECORDS**

**River flows**

The river flows required are the inflows at Mongalla, where the Bahr el Jebel flows in a single channel, and the outflows from the tail of the swamps, deduced from the differences between the White Nile at Malakal and the Sobat at Hillet Doleib. These flows are available from 1905 to 1980. The flow from the Bahr el Ghazal at Lake No was not taken into account, as most of this is spill from the Bahr el Jebel.

It is interesting to compare rating curves at Mongalla over the period of record. For a given river flow there was a continuous rise in water level from 1905 to 1960, but during the high flows of 1963-1964 the rating changed abruptly and the water level and bed level fell by about a metre. There were a number of changes in river channel and spill channels during this period, in response to the high flows, and the areas of flooding and the swamp vegetation changed markedly.

**Rainfall**

Ten rainfall stations near the swamps were available for different periods at Mongalla, Terakeka, Pap, Bor, Shambe, Kongor, Ler, Fangak, Tonga and Malakal. Monthly means for 1941-1970 were averaged to give the overall estimates in Table 1, with an annual average for the swamps of 871 mm. Individual monthly swamp rainfall estimates, \( \bar{R}_i \), were calculated from:

\[
\bar{R}_i = \left( \frac{1}{n} \sum_{j=1}^{n} \frac{R_{ij}}{R_j} \right) \times \bar{R}
\]  

where \( R_{ij} \) is the rainfall in month \( i \) at station \( j \), \( \bar{R}_j \) is the long-term average at station \( j \), and \( \bar{R} \) is the long-term areal average (871 mm). The monthly series was calculated for the period 1905-1980.

The rainfall records at Fangak were rejected after inspection and double mass curves revealed anomalies; the successive decade means were halved over nearly 60 years of record. This is significant
because most isohyetal maps of the Sudd show a locally high rainfall over the swamps based on this station record.

Evaporation

Realistic modelling of the swamps depends on a reasonable estimate of this factor; early experiments were carried out to measure evaporation from papyrus grown in tanks, but it was difficult to maintain vigorous growth (Hurst & Phillips, 1938). Penman (1963), discussing experiments by Migahid (1952) using tanks filled with papyrus and with open water, notes that the evaporation rates are about the same, and suggests that with the increased daytime wind speed observed, transpiration from the papyrus and evaporation from the open lagoon will be nearly equal. Open water evaporation has been estimated by the Penman method for Bor (ILACO, 1981) at 2150 mm year\(^{-1}\) and the monthly averages (Table 1) were used to estimate the evaporation from flooded areas. The seasonal cycle of rainfall and evaporation is illustrated by Table 1.

Flooded areas

The areas flooded on specific dates can be used to test the model. Areas cannot be measured directly but can be estimated from air photography, satellite imagery or indirectly from vegetation maps. Measurements were found for four separate dates. Maps based on air photography in 1930-1931 were planimetered (Hurst & Phillips, 1938) to give a mean flooded area of 8300 km\(^2\) at that period; a map based on satellite imagery of February 1973 gave a flooded area of 22 000 km\(^2\) on that date, reflecting the increased Mongalla flows after 1961.

The areas of permanent and seasonal swamp may be deduced from vegetation, which responds to flooding over a few years. A vegetation map based on aerial survey, satellite imagery of 1979-1980 and field observation (Mefit-Babtie, 1980) gave estimates of permanent swamp of 16 600 km\(^2\) and seasonal swamp of 14 000 km\(^2\). A map based on reconnaissance in 1950-1952 (Jonglei Investigation Team, 1954, Map 7) gave permanent swamp of 2800 km\(^2\) and seasonal swamp of 11 200 km\(^2\); the permanent swamp was probably underestimated by comparison with the seasonal swamp. The approximate limits of the seasonal swamp at these two dates are indicated on Fig.1. These estimates are summarized in Table 2.

DEVELOPMENT AND TESTING OF A HYDROLOGICAL MODEL

Given inflows to and outflows from an area of swamp plus rainfall and evaporation data, the swamp can be treated as a reservoir whose storage volume is cumulative inflow less outflow. To estimate direct rainfall and evaporation volumes for this reservoir, the area flooded for a given volume of storage is required; this corresponds to the area-capacity curve of the reservoir. Because no flow measurements below Mongalla are completely representative of the total flow down the river and flood plain, the whole Sudd below Mongalla is the only area which can be modelled over a long period.
Table 2  Measured areas of flooding (km²)

<table>
<thead>
<tr>
<th>Source of information</th>
<th>Date</th>
<th>Areas of permanent (P), seasonal (S) and total (T) swamp below Mongalla:</th>
<th>Areas of permanent (P), seasonal (S) and total (T) swamp below Bor:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planimetered air survey maps</td>
<td>1930-1931</td>
<td>8 300</td>
<td>7 500</td>
</tr>
<tr>
<td>Vegetation map</td>
<td>1950-1952</td>
<td>2 800</td>
<td>2 700 (P)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11 200</td>
<td>10 400 (S)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14 000</td>
<td>13 100 (T)</td>
</tr>
<tr>
<td>Flooding map from Landsat</td>
<td>Feb. 1973</td>
<td>22 100</td>
<td>21 300</td>
</tr>
<tr>
<td>Vegetation map</td>
<td>1979-1980</td>
<td>16 600</td>
<td>16 200 (P)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14 000</td>
<td>13 600 (S)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30 600</td>
<td>29 800 (T)</td>
</tr>
</tbody>
</table>

using directly measured flows.

The equation of continuity for a time interval δt is:

\[ \delta V = (Q - q + A(R - E))\delta t - r\delta A \]  \( (2) \)

where \( V \) is volume of flooding, \( Q \) is inflow, \( q \) is outflow, \( R \) is rainfall, \( E \) is evaporation, \( A \) is flooded area and \( r \) is soil moisture recharge, which is positive when \( \delta A \) is positive and zero when \( \delta A \) is negative. Deep recharge may be neglected.

With \( \delta t \) taken as a month, the inflows and outflows, \( Q \) and \( q \), are known for the period 1905-1980, the rainfall depths, \( R \), are known, and the evaporation, \( E \), may be taken as the mean open water evaporation for the calendar month. The soil moisture recharge, \( r \), may be estimated as 200 mm at the beginning of the wet season, and decreased by \( \bar{E}(R - E) \) to allow for preceding months when rainfall exceeded evaporation. Thus the series of records provides for each month an equation in which, given the initial values of area, \( A \), and volume, \( V \), there are two unknowns, \( \delta A \) and \( \delta V \). Moreover, there must exist a relationship between storage volume and flooded area which may be expressed as \( A = f(V) \).

This relationship could be determined only by detailed topographical survey over the whole area, but it is possible to deduce and test a reasonable form of such a relationship. In three reaches where survey and hydrological records exist on the While Nile (Wright, 1954) and the Bahr el Jebel (Sutcliffe, 1957), the relationship between area and volume of flooding can be deduced and in each case is linear within the range of information. Although the evidence is from the fringes of the swamp, it seems reasonable to use a linear relationship for the whole Sudd and to express it as \( A = kV \) bearing in mind that \( V = 0 \) when \( A = 0 \). The relationship \( A = kV \) leads to expressions for \( V \) and \( A \) in terms of level, \( h \), of the form:

\[ V = a e^{kh} \]  \( (3) \)
with a constant average flooding depth of the swamp of $1/k$ m. This is not unreasonable and permits an estimate of $k$ as 1.0, though other values were tested. Indeed, other forms of the expression were also tested.

Starting the analysis at the beginning of month $i$, with an initial storage, $V_i$, and area, $A_i = kV_i$, and taking the net evaporation as $(E - R)A_i$ over the initial area, the equation of continuity leads to:

$$V_{i+1} = V_i + Q_i - q_i - A_i(E_i - R_i) - r(A_{i+1} - A_i)$$

$$= V_i + Q_i - q_i - kV_i(E_i - R_i) - rk(V_{i+1} - V_i)$$

Hence:

$$V_{i+1}(1 + rk) = V_i(1 + rk) + Q_i - q_i - kV_i(E_i - R_i)$$

where $Q_i$, $q_i$, $E_i$ and $R_i$ are tabulated and $r$ varies with net rainfall from an initial value of 0.2 m.

This equation provides an initial estimate of $V_{i+1}$ and thus $A_{i+1}$. Because the evaporating surface is strictly the mean of the initial and final values for the month, these estimates were used to adjust the evaporation estimate to the mean flooded area to give:

$$\left(\frac{A_{i+1} + A_i}{2}\right)(E_i - R_i)$$

in a second iteration, which was considered sufficient.

**APPLICATION OF THE MODEL**

Starting from a reasonable initial storage of 8000 x 10$^6$ m$^3$ on 1 January 1905, the storage and flooded area were estimated at monthly intervals to the end of 1980. The predictions of flooded area are plotted in Fig.3, and are compared with monthly gauge levels at Shambe lagoon near the centre of the swamps up to 1966; after about 1964 the relation of the channel to the lagoon changed and the levels are not a reliable index. The comparison shows that the seasonal variations are reasonably well reproduced.

The six measurements of flooded areas on specific dates are compared with the predictions in Fig.4. The areas of permanent and total swamp measured from vegetation maps were assumed to correspond with the minimum and maximum over a three year period. This comparison suggests that the analysis represents the physical situation within acceptable limits.

**DISCUSSION OF MODEL**

The analysis is simply based on the equation of continuity, with
Fig. 3  Estimated areas of flooding 1905-1980 ($10^3$ km$^2$) and monthly mean Shambe gauge level (m).
Most of the elements directly measured. The analysis confirms that the Penman open water evaporation estimates totalling 2150 mm year\(^{-1}\) are reasonable and applicable to the whole Sudd as predicted areas of flooding are proportional to net evaporation. The initial soil moisture recharge is estimated as 200 mm, but sensitivity analyses showed that the predictions of flooded area were little affected by varying this value; a 25% change gave only a 1% change in mean area. The form of the relationship, \(A = kV\), was derived from survey data and the mean depth, \(1/k\), was estimated as 1.0 m; changing \(k\) by 25% also altered the mean area by 1%. It is interesting to note that a similar relationship and mean depth were used for the Okavango swamp (Hutton & Dincer, 1979).

It could be argued that the predictions, especially of the effects of the canal, would be sensitive to the form of the \(A:V\) relationship. This relationship was tested by substituting \(A = kV^x\), while maintaining realistic values with \(x\) from 1.0 to 0.5 and varying \(k\) and \(x\) together to fit the mean values of \(A\) and \(V\) from the previous trial. The effect (Table 3) is to reduce the predicted

<table>
<thead>
<tr>
<th>(x)</th>
<th>1.0</th>
<th>0.9</th>
<th>0.8</th>
<th>0.7</th>
<th>0.6</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>(k)</td>
<td>1.0</td>
<td>2.59</td>
<td>6.71</td>
<td>17.4</td>
<td>45.1</td>
<td>116.8</td>
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<tr>
<td>Mean area (km(^2))</td>
<td>13640</td>
<td>13530</td>
<td>13430</td>
<td>13340</td>
<td>13260</td>
<td>13180</td>
</tr>
<tr>
<td>Mean minimum (km(^2))</td>
<td>10280</td>
<td>10450</td>
<td>10630</td>
<td>10820</td>
<td>11000</td>
<td>11150</td>
</tr>
<tr>
<td>Mean range (km(^2))</td>
<td>7440</td>
<td>6700</td>
<td>5980</td>
<td>5300</td>
<td>4650</td>
<td>4080</td>
</tr>
</tbody>
</table>

mean area of seasonal swamp from 7400 to 4100 km\(^2\), while the fit between observed and predicted areas of flooding deteriorates. Thus a value of \(x\) of 1.0 provides the best fit as well as corresponding
to the available survey data.

Thus although the model is shown to be sensitive to the form of the equation linking area and volume, which should be borne in mind as more data become available, the linear relationship derived from physical evidence gives a reasonable fit to measured areas of flooding. Thus one may deduce that the model gives an acceptable representation of the flooding regime within the limits of historical experience.

The monthly series of flooded areas predicted by the model may be summarized in histogram form as in Fig. 5. The number of years with

![Histogram of flooded areas below Mongalla 1905-1980 (estimated from measured inflows and outflows).](image)

maximum, minimum and range of flooded areas of different values is shown; these correspond to the total, permanent and seasonal swamp. The monthly series and the histograms demonstrate the fluctuations of the swamps and the dominant effect of the increased outflows from Lake Victoria after 1961-1964. This effect is most marked on the permanent swamps; the seasonal swamps, which depend on the torrents above Mongalla, have varied less than the permanent swamps.

**ADAPTATION OF ANALYSIS FROM MEASURED TO PREDICTED OUTFLOWS**

The analysis has thus far been based on measured outflows as well as inflows. It is necessary to adapt the model to predict what the effects of the Jonglei Canal would have been during the historical period; the river inflows to the swamp would be reduced by the canal diversion and the swamp outflows would have been altered. The benefits of the canal have been estimated in previous studies (el Zein, 1974) by deriving a relationship between inflows and outflows and then assuming that this relationship will link river inflows and outflows when part of the inflows are diverted. The model can be adapted similarly and tested for use without measurements of outflow. This adaptation is based first on the whole swamp area below
Mongalla.
Inflows at Mongalla and outflows at the tail of the swamps were correlated with various lags and in both linear and logarithmic form, using records from 1916-1972 but omitting 1963-1966 when the Mongalla rating was uncertain. The variance explained increased from 41 to 55% as the lag was increased to three months. The equation

\[ q_t = 50.8(Q_{t-3})^{0.411} \]  

was selected to predict outflows from inflows with a three month lag. However, this equation implies that outflow, \( q \), exceeds inflow, \( Q \), at low flows, whereas \( q \to Q \) as \( Q \to 0 \). A simple equation with these properties is

\[ q = Q + cQ^2 \]

and the value of \( c \) can be derived to fit the prediction equation without discontinuity of gradient. Thus:

\[ q_t = Q_{t-3} - 0.000214Q_{t-3}^2 \quad \text{for } Q < 1730 \]  

\[ q_t = 50.8(Q_{t-3})^{0.411} \quad \text{for } Q > 1730 \]

(9)
(10)

together provide the curve in Fig. 6, from which monthly outflows can be deduced from monthly inflows with a three month lag. For compari-

Fig. 6 Inflow at Mongalla and outflow at tail of swamps (Malakal–Sobat) (X 10^6 m^3 month^{-1}).
son, annual inflows and outflows have been reduced to the same units and plotted on the same graph.

Equations (9) and (10) were used with Mongalla inflows to predict lagged outflows for the period 1905–1980, and these outflows were used in the reservoir model to provide a second series of estimated areas of flooding. The timing of the seasonal fluctuations, the magnitudes of the maxima and minima, and the comparison of estimated and measured areas on specific dates were little changed from those obtained with measured outflows. Thus the reservoir model has been adapted to make reasonable predictions of flooded areas using measured inflows but deduced outflows, and could be used, after subtracting canal diversions from the inflows, to estimate the effects of the Jonglei Canal.

However, there is a complication because river inflows were measured completely only at Mongalla, and the canal offtake will be at Bor where flows spill over the left bank and down the Aliab valley. The relationship between flows at Mongalla and the total flow at Bor latitude was derived by multiplying the flooded area in this reach, which was related to Mongalla flow after detailed survey (Jonglei Investigation Team, 1954, Table 192), by average evaporation less rainfall to estimate the loss. This provides a relationship:

\[ Q_B = 1.1017 Q_M^{0.985} \times 10^6 \text{ m}^3\text{month}^{-1} \]  

(11)

between flow at Bor, \( Q_B \), and at Mongalla, \( Q_M \). The difference is only about 2% at average flows.

The relationship between flows at Bor latitude and swamp outflow can be deduced as:

\[ q_t = Q_{B,t-3} - 0.000213 Q_{B,t-3}^2 \quad \text{for } Q_B < 1730 \]  

(12)

\[ q_t = 48.8(Q_{B,t-3})^{0.417} \quad \text{for } Q_B > 1730 \]  

(13)

Equation (11) may be used to predict Bor flows from Mongalla flows, and equations (12) and (13) can be used to predict swamp outflows from Bor flows. The reservoir model was again repeated using these equations to give estimates of areas flooded below Bor under natural conditions which again correspond with measured areas.

PREDICTION OF THE EFFECTS OF THE JONGLEI CANAL

The reservoir model has been adapted to use measured inflows and predicted outflows, and tested by its ability to reproduce historical areas of flooding over the range experienced. It can be used to estimate what the effect of the Jonglei Canal would have been during the period 1905–1980 by using the measured Mongalla inflows and rainfall series to model the flooded areas with and without the canal. The canal diversions are subtracted from Bor flows to give residual river inflows, and swamp outflows were estimated from
these; the flooded areas are then recalculated and compared with estimates without diversion.

Different canal regimes were tested. Constant flows of $20 \times 10^6$ and $25 \times 10^6 \text{ m}^3\text{day}^{-1}$ were assumed to be diverted, which were also reduced in periods of low natural flows as shown in Table 4. To indicate the effect of varying canal flows, diversions were tested of $15 \times 10^6 \text{ m}^3\text{day}^{-1}$ during the dry season (November-April) and $25 \times 10^6 \text{ m}^3\text{day}^{-1}$ during May-October, and the reverse; as these rules occasionally implied very low river flows, the outflow was not allowed to exceed simultaneous inflow when the flooded area was less than 500 km$^2$.

Each trial provided monthly flooded areas for 1905-1980 which may be compared with natural conditions. One example (Fig.7) shows that the timing of seasonal fluctuations would remain with the amplitude reduced. Presentation of results requires a choice of the important features. The effects of the canal could be presented in terms of averages (Table 4). A reduction in average permanent swamps of 32-43% and in seasonal swamps of 11-32% is estimated, with reductions increasing with higher canal flows. Seasonal variations in canal diversions could weigh the reduction to permanent or seasonal swamps.

However, histogram presentation of the natural regime shows that areas of flooding have varied greatly with river regime, with the permanent swamps varying more than the seasonal swamps (Fig.8). Similar diagrams for different canal rules show that natural variations remain important and put the effects of the canal into perspective. The estimated effects of the canal are summarized in Table 4 for 1905-1961 and 1961-1980 as well as the whole period. The effects would be relatively greater in the early years of low inflows than in the recent years of high flows; indeed, the effect of the canal on the areas of maximum flooding would be less than the changes which occurred when Lake Victoria rose in 1961-1964.

The simplicity of the analysis implies that undue precision

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Table 4 Estimated effects of canal on average areas of flooding (km$^2$), Bor to Malakal, and percentage reductions

<table>
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<tbody>
<tr>
<td></td>
<td>6,700</td>
<td>6,200</td>
<td>12,900</td>
<td>17,900</td>
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<td>28,900</td>
</tr>
<tr>
<td>20*</td>
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<tr>
<td>25*</td>
<td>3,600</td>
<td>4,600</td>
<td>8,200</td>
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<td>26</td>
<td>37</td>
<td>21</td>
<td>17</td>
<td>20</td>
</tr>
<tr>
<td>25 Nov.-April</td>
<td>3,000</td>
<td>4,200</td>
<td>7,200</td>
<td>13,100</td>
<td>8,700</td>
<td>21,800</td>
</tr>
<tr>
<td>15 May-Oct.</td>
<td>56</td>
<td>32</td>
<td>44</td>
<td>27</td>
<td>21</td>
<td>24</td>
</tr>
<tr>
<td>25 May-Oct.</td>
<td>3,300</td>
<td>5,400</td>
<td>8,700</td>
<td>13,700</td>
<td>9,900</td>
<td>23,600</td>
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<tr>
<td>15 Nov.-April</td>
<td>51</td>
<td>12</td>
<td>32</td>
<td>23</td>
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<td>18</td>
</tr>
<tr>
<td></td>
<td>3,800</td>
<td>3,900</td>
<td>7,700</td>
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<td>8,400</td>
<td>22,800</td>
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<td>24</td>
<td>21</td>
</tr>
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<td></td>
<td>5900</td>
<td>7,400</td>
<td>16,900 km$^2$</td>
<td>6,000</td>
<td>5,000</td>
<td>11,500 km$^2$</td>
</tr>
</tbody>
</table>

*Flow down canal was reduced at low flows according to PJTC rules defined as follows. If river flow at Bor is $Q$ and canal flow $Q_c$, in $x \times 10^6$ m$^3$ day$^{-1}$, then if $33 < Q < 45$, $Q_c = 15$ and if $Q < 33$, $Q_c = Q - 18$.  

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The simplicity of the analysis implies that undue precision
should not be attributed to the results, but physical measurements have been used wherever possible and the predicted outflows from the swamps are in accordance with previous estimates of the net yield of the canal. It is doubtful whether enough survey information is available at present for detailed modelling of the whole swamp area, but monitoring of the hydrology with simultaneous satellite imagery could provide more information on, for example, the relation between areas and volumes of flooding. However, it is suggested that the results give a reasonable indication of the degree to which the permanent and seasonal swamps will be affected by the operation of the canal.
ACKNOWLEDGEMENTS  This paper is based on an investigation carried out for the Food & Agriculture Organization of the United Nations (Sutcliffe & Parks, 1982) and on data kindly provided by the Sudan authorities.

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Received 21 March 1986; accepted 14 October 1986.