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WATER BUDGETS FOR IRRIGATED REGIONS IN EGYPT

By:

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EGYPT WATER USE AND MANAGEMENT PROJECT

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Abstract

Water budgets were compiled for three small irrigated regions in Egypt: Abyuha in Middle Egypt, Beni Magdul near Cairo, and Om-Sen in the North Delta. Water deliveries during winter seasons ranged from 4419 m^3/*feddan* to 4440 m^3/*feddan* in Abyuha, from 2685 m^3/*feddan* to 3174 m^3/*feddan* in Beni Magdul, and were 4887 m^3/*feddan* in Om-Sen. Summer season values ranged from 7175 m^3/*feddan* to 10419 m^3/*feddan* in Abyuha, from 3601 m^3/*feddan* to 4217 m^3/*feddan* in Beni Magdul, and were 6810 m^3/*feddan* in Om-Sen. Average winter season crop consumptive use was estimated as 1527 m^3/*feddan* in Abyuha, 1754 m^3/*feddan* in Beni Magdul, and 1425 m^3/*feddan* in Om-Sen. Average summer consumptive use was 3478 m^3/*feddan* in Abyuha, 2977 m^3/*feddan* in Beni Magdul and 2298 m^3/*feddan* in Om-Sen. Seasonal irrigation efficiency ranged from 32 to 49% in Abyuha, from 50 to 76% in Beni Magdul, and from 26 to 43% in Om-Sen. Control of canal deliveries to Beni Magdul is the reason for the better efficiency there. Inadequate control of deliveries during periods of low consumptive use resulted in excess water released to drains in Abyuha and Om-Sen. The ratio of crop consumptive use to total water infiltrated was typically high for each region. Monthly average depth to water table ranged from 1.20 to 1.91 m at Abyuha, from 0.65 to 0.90 m at Beni Magdul, and from 0.20 to 0.80 m at Om-Sen.

mh/

ملخـــــــــص

لقد تم عمل الميزانية المائية لثلاث مناطق صغيرة من مناطق الـــــرى بمصر وهى منطقة أبيوها فى مصر الوسطى ومنطقة بنى مجدول بالقرب مـــــن القاهرة ومنطقة أم سن بالدلتا . وقد كانت كمية المياه المخصصة للـــرى فى فصول الشتاء تتراوح بين ٤٤١٩ و ٤٤٤٠ م^{3} للفدان الواحد فى ابيوهـــا وبين ٢٦٨٥ و ٣١٧٤ م^{3} للفدان الواحد فى بنى مجدول ، أما فى أم ســـــن فقد كانت ٤٨٨٧ م^{3} للفدان الواحد . وبالنسبة لفصول الصيف فقد وجد انهـــا تتراوح بين ٧١٧٥ و ١٠٤١٩ م^{3} للفدان الواحد فى أبيوها وبين ٣٦٠١ و ٤٢١٧ م^{3} للفدان الواحد فى بنى مجدول ، أما فـــى أم سن فقد كانت ٦٨١٠ م^{3} للفدان الواحد .

هذا وقد تم تقدير متوسط الاستهلاك المائى للمحصول فى فصل الشتاء بأنه ١٥٢٧ م^{3} للفدان الواحد فى ابيوها و ١٧٥٤ م^{3} للفدان الواحد فى بنى مجدول و ١٤٢٥ م^{3} للفدان الواحد فى أم سن . أما الاستهلاك المائى فى فصل الصيـــف فقد كان ٣٤٧٨ م^{3} للفدان الواحد فى ابيوها و ٢٩٧٧ م^{3} للفدان الواحـــــد فى بنى مجدول و ٢٢٩٨ م^{3} للفدان الواحد فى أم سن .

وتراوحت كفاءة الرى الموسمية بين ٣٢ و ٤٩ ٪ لمنطقة ابيوها وبيـــن ٥٠ و ٧٦ ٪ لمنطقة بنى مجدول وبين ٢٦ و ٤٣ ٪ لمنطقة أم سن . أن التحكم المنظم لتصرفات مياه الرى بمنطقة بنى مجدول كان سببا لرفع كفاءة الـــرى. وعدم التحكم الكافى فى تصرفات المياه فى فترات الاستهلاك أدى الى زيـــادة فقدان المياه الى المصارف فى كل من منطقتى ابيوها وأم سن . أن نسبـــــة الاحتياج المائى للمحصول لكمية المياه المنصرفة كانت مرتفعة ارتفاعـــــا ملحوظا فى معظم الاحيان فى كل من المنطقتين المذكورتين . وقد تراوحـــت متوسطات اعماق الماء الأرضى شهريا من ٢٠ر١ م الى ٩١ر١ م فى أبيوهـــا ومن ٦٥ر٠ م الى ٩٥ر٠ م فى بنى مجدول ومن ٢٠ر٠ الى ٨٠ر٠ م فى أم سن .

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INTRODUCTION

A water budget is an account of all water that enters, exits, and is stored in a region with defined boundaries during a specific period of time. Water budget studies were conducted by the Egypt Water Use and Management Project (EWUP) at each of three project sites where irrigated agriculture was studied at the farm level. This report presents the rationale, procedures, and results of these studies and draws conclusions related to irrigation water management in Egypt.

OBJECTIVES

There are several reasons for conducting water budget studies in irrigated regions. A water budget reveals how much of the water diverted to a region is being used beneficially; thus, an idea of the overall water use efficiency may be gained. Since salts move in and out of a region with the water, salinity problems associated with the hydrologic characteristics of the region can be evaluated. The interaction between surface water and groundwater and the behavior of the water table may also be determined from water budget data. When all of this information is studied, implications may be seen for redesigning watercourses and hydraulic control structures, improving water management practices, and planning for better water allocation and distribution. After any such changes have been implemented in a region, water budget studies may again be conducted to help evaluate their effect.

SITE DESCRIPTIONS

Water budget studies were conducted for three small irrigated regions (Figure 1): Abyuha, near El-Minya in Middle Egypt; Beni Magdul, near Cairo; and Om Sen, near Kafr El-Sheikh in the northern Delta. These sites were selected because they seemed representative of irrigated agriculture in Egypt and because their features allowed relatively well defined boundaries.

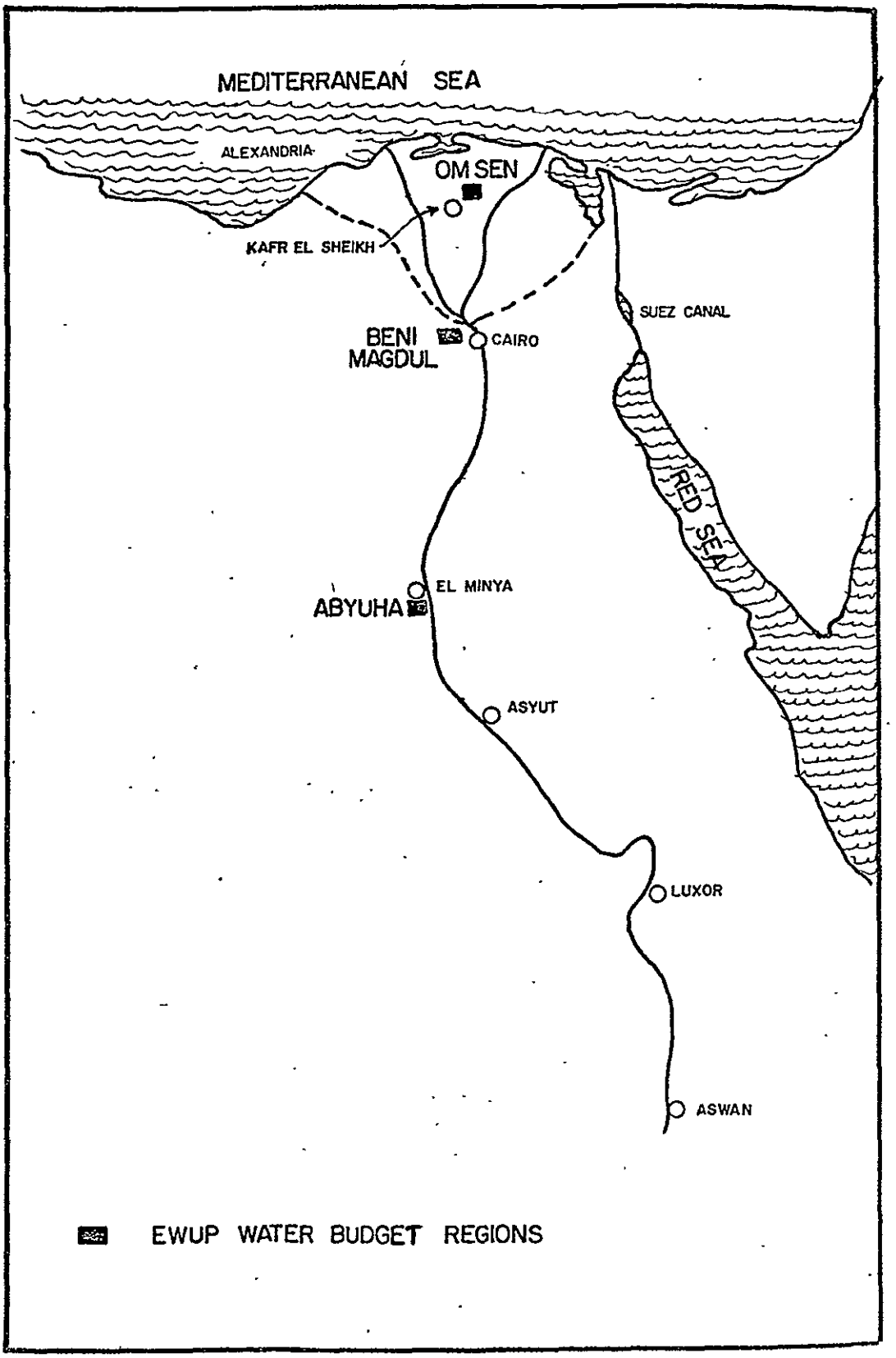

Figure 1. Location map for EWUP water budget regions

Abyuha

Located in Middle Egypt about 17 km south of El-Minya, the Abyuha region encompasses a total hydrologic area of approximately 1200 *feddans* (504 ha). The total cropped area is about 1100 *feddans* (462 ha). The defined boundaries enclosing the water budget region are formed by the Abyuha canal, *mesqa* 5, Kom El Zoheir-El Mustaged drain, *mesqa* 24, the private drain, and Kom El Zoheir-El Qadim drain as shown in Figure 2.

The total thickness of the clay-silt layer in this region is about 10 to 15 m (Warner, et al, 1984; Barber and Carr, 1981; Water Master Plan, 1981). The soil profile to a depth of 12 m was determined from drilling 29 shallow wells and 4 deep wells and is given in Table 1. The surface soils have been characterized as Typic-Torrerts of the vertisol soil order (Selim, et al., 1983). Though a little lighter in texture than the soils of the Delta region the soil at Abyuha is a relatively heavy clay that characteristically swells and cracks upon wetting and drying.

Table 1. Soil Profile From Well Logs in Abyuha.

Depth (meters)	Classification
0-4	clay
4-6	silty clay loam/sandy loam
6-8	silt loam/sandy loam
8-10	silt loam/sandy clay loam
10-12	sandy loam/loamy sand

As is characteristic of the Nile valley, the clay-silt layer supports a water table aquifer and forms a semi-confining cap over an underlying sand aquifer. The sand aquifer is reported by Barber and Carr (1981) to be about 16.5 m thick in this region. Data from a battery of 41 observation wells in the area showed over a period of two years that the monthly average water table depth fluctuated between 1.20 m and 1.92 m below ground surface (Figure 3). A vertical gradient of piezometric head exists between the water table in the clay-silt layer and the semi-confined sand aquifer creating a downward vertical leakage estimated to be about 0.0005 m/day (Warner et al, 1984).

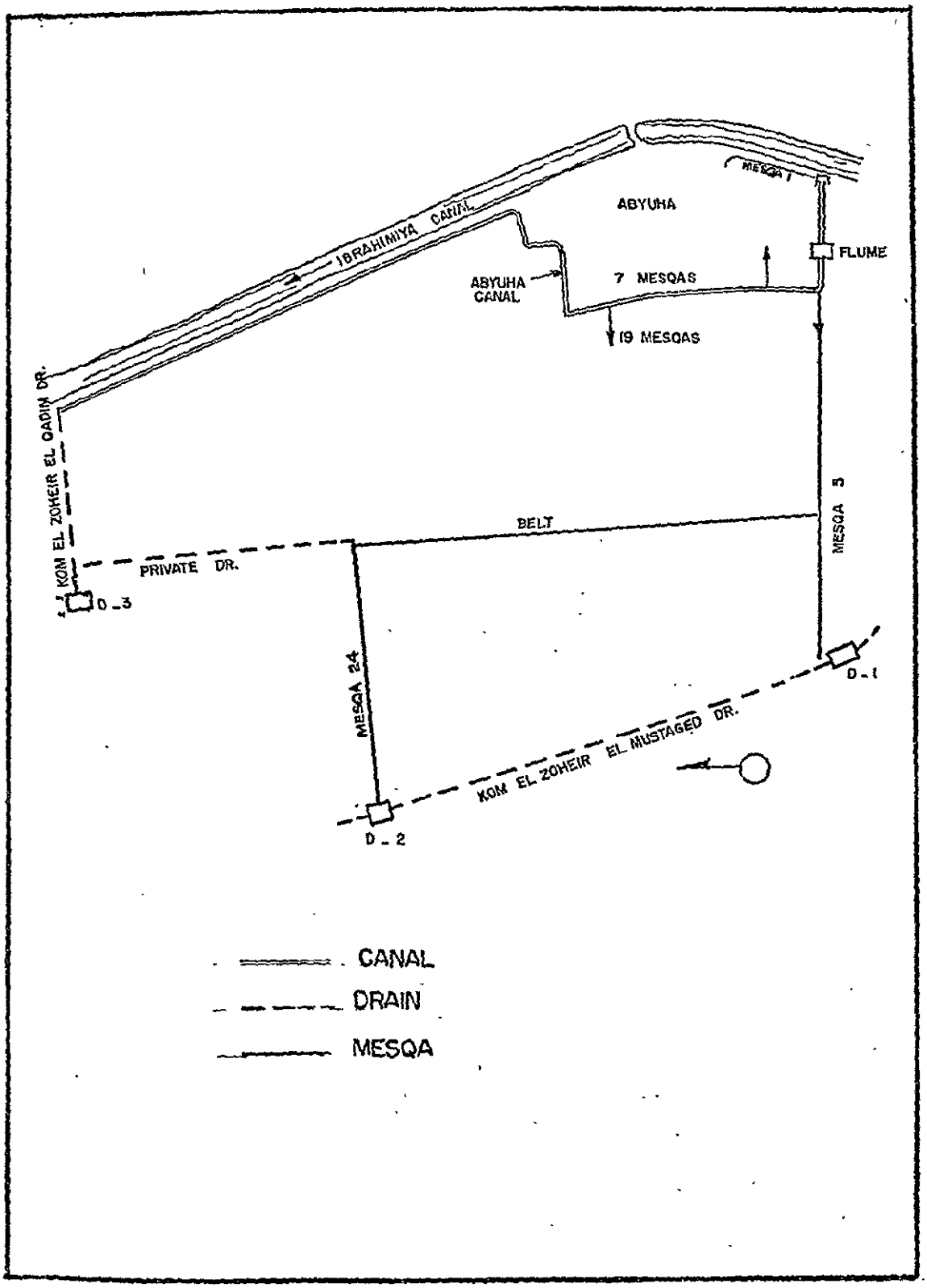

Figure 2. Abyuha water budget region

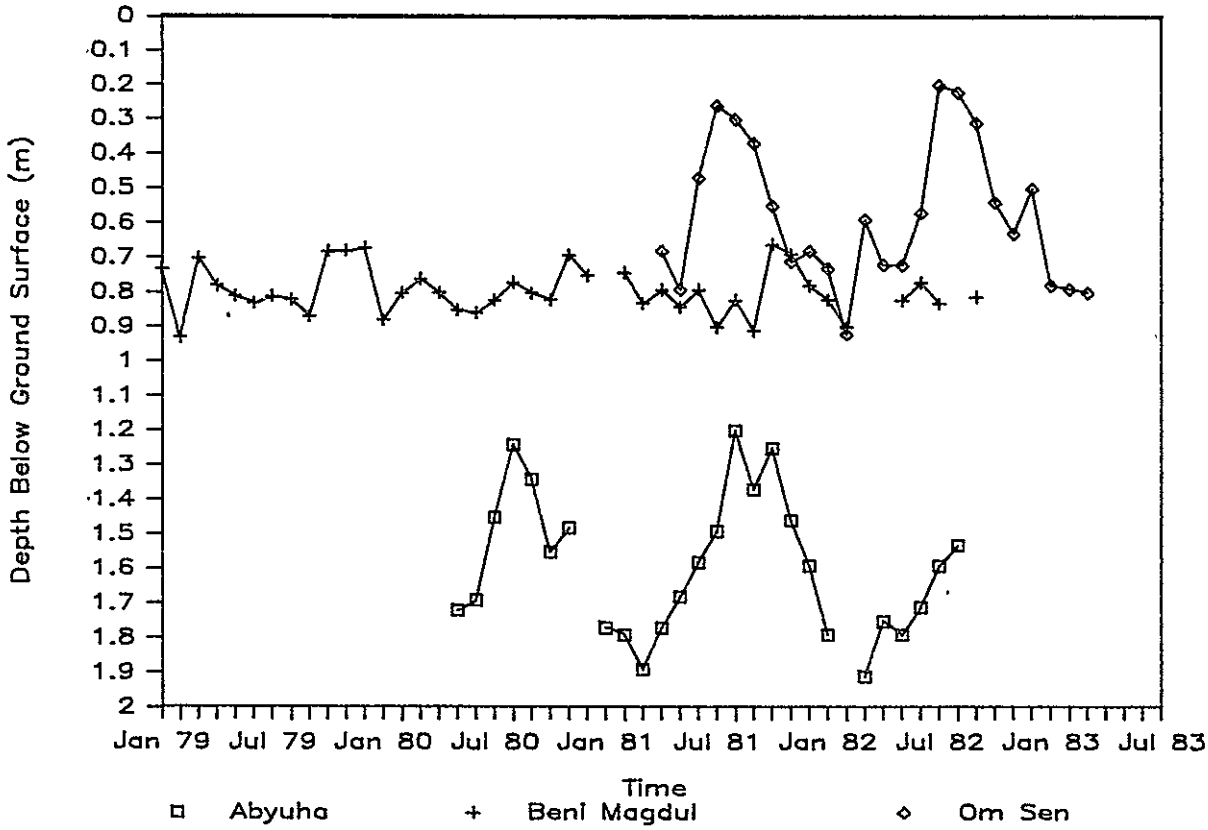

Figure 3. Monthly average water table depth at Abyuha, Beni Magdul, and Om Sen

Berseem (a fodder crop similar to alfalfa), beans, wheat, and sugar cane are the major crops grown in the winter season (approximately October 1 to April 1) at Abyuha. Winter season crop area surveys for 1980-1981 and 1981-1982 are given in Tables A-1 and A-2 in Appendix A respectively. In the summer (approximately April 1 to October 1) corn, cotton, and sugar cane are the primary crops grown. Crop area surveys for the 1980 and 1981 summer seasons are given in Tables A-3 and A-4 in Appendix A respectively.

Abyuha canal took water from the Ibrahimiya canal on a rotation schedule and delivered it to the region's 30 farm channels, called *mesqas*. The Abyuha was on a 7 day on/7 day off schedule in the summer and a 5 day on/10 day off schedule in the winter. Since the *mesqas* were open directly to the drains and the canal headgate was never completely closed, water continued to flow through the system at night and during off periods.

About 800 *feddans* (336 ha) in the area were irrigated during most of the year by force of low head gravity without the need for lifting. On the remaining 300 *feddans* (126 ha) farmers lifted water from the *mesqa* by *tambour* (Archimedes screw) or diesel-powered pump.

Beni Magdul

The Beni Magdul site is located in the southern portion of the Mansuriya Irrigation District about 20 km west of Cairo. The site comprises approximately 842 *feddans* (354 ha) of which about 810 *feddans* (340 ha) are under cultivation. The area is enclosed by the Beni Magdul, Lebini, and Nahia drains as shown in Figure 4. These drains formed boundaries for water budget studies.

The surface soils of the area consist primarily of sandy clay, sandy clay loam, and sandy loam (Dotzenko, et al., 1979). These soils have a characteristic angular, blocky structure and form deep cracks upon drying. The soil profile to a depth of 40 m was determined by combining logs taken during drilling of a pumping well with logs of several observation wells and test holes in the region. A summary descripton of the soil profile is given in Table 2 . The well logs revealed a relatively tight clay layer in the upper two to four meters of the profile with layers of clay and fine sand mix extending to a depth of about 14 m. Similar observations were made during drilling of the domestic water supply for Beni Magdul village and in a preliminary exploration hole drilled beside Nahia Drain about 300 m east of the Mansuriya canal.

Table 2. Soil Profile From Well Logs in Beni Magdul

Depth (meters)	Classification
0- 2	Clay
2- 4	Clay or Sandy Clay or Clayey Sand
4-14	Clay with fine sand
14-15	Fine sand
15-20	Medium sand
20-26	Sand with gravel
26-27	Coarse sand and large gravel
27-34	Coarse sand
34-40	Fine sand

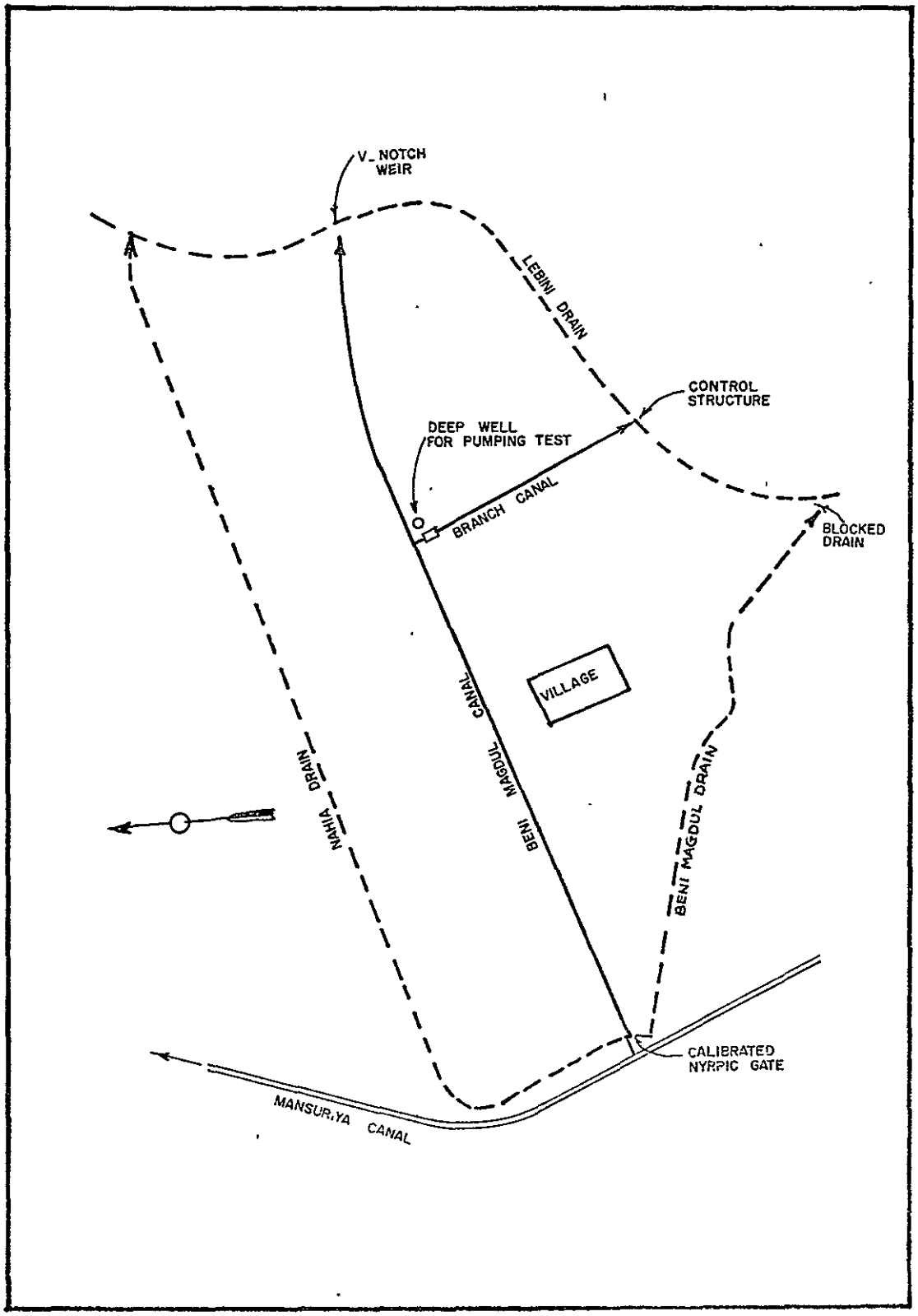

Figure 4. Beni Magdul water budget region

Observations over the past four years showed that the monthly average depth below ground surface to the shallow water table ranged from about 0.65 m to 0.90 m (Figure 3). It is suggested by Barber and Carr (1981) that the underlying sand aquifer extends to a depth of 30 to 50 m below ground surface in this area. Deep observation wells in this aquifer revealed that its peizometric surface fluctuated from 0.1 m to 2.4 m below the water table (Figure 5). Vertical leakage from the water table to the underlying sand aquifer was estimated to be about 0.0003 m/day (Warner et al, 1984).

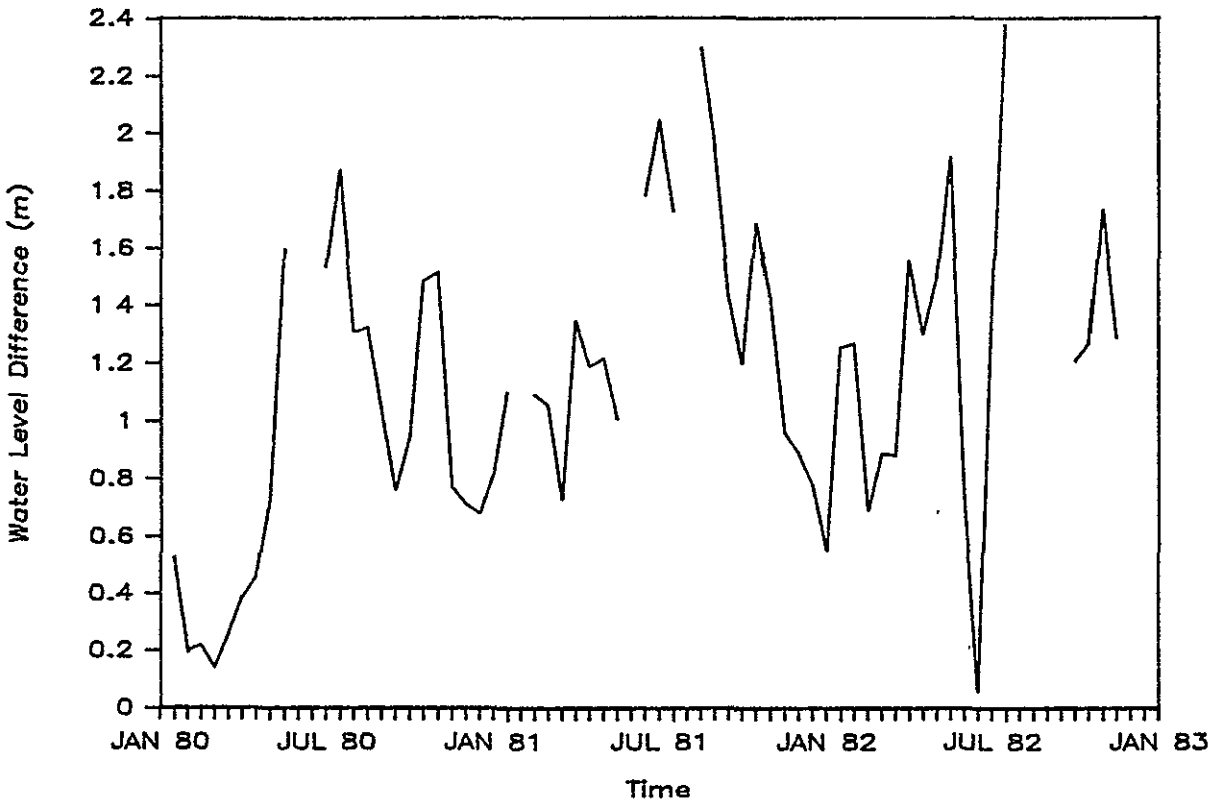

Figure 5. Difference between water table level and piezometric level of deep aquifer in Beni Magdul

Major crops grown in the winter season are berseem and wheat. Total cropped areas during the 1979-1980, 1980-1981, and 1981-1982 winter seasons are given in Tables A-5 through A-7 in Appendix A respectively. Corn is the major crop in the summer. Total cropped areas during summer seasons 1980, 1981, and 1982 are given in Tables A-8 through A-10 in Appendix A.

The Beni Magdul canal, a branch of the Mansuriya canal supplied almost all of the area's irrigation water. A very small amount was supplied by flow from adjacent areas, from deep aquifer pumping, and from pumping out of Nahia drain. Continuous flow (there was flow in the canal approximately 12 hrs/day every day) in the Beni Magdul canal supplied a total of eleven *mesqas* on the north side and fifteen *mesqas* on the south side. A small branch canal was also supplied on the south side.

Irrigation of small level basins with small streams is the method traditionally used in the area. Water was lifted by animal powered *saqias*, or Persian wheels, from the *mesqas* in a stream size of 20 to 30 lps which was used to irrigate several *feddans*.

Om-Sen

The Om-Sen site is located near the village of Abu Raya in the Kafr El-Sheikh governorate of the northern Delta. Enclosed by the boundaries of the Daqalt canal, the Gadalla Drain, the Om-Sen Drain, and the Hamad *mesqa* (Figure 6), the region is composed of about 260 *feddans* (109 ha) of which about 235 *feddans* (99 ha) are cultivated.

As is typical of the Delta region, the surface soil in the Om-Sen area is a heavy clay vertisol which expands upon wetting and contracts forming deep cracks upon drying. Seven deep soil core samples taken in the area revealed a heavy clay to a depth of about 3.4 m followed by heavy clay with fine sand to a depth of 5 m. Samples were not taken below 5 m. Studies by the Water Master Plan (1981) indicate that the clay-silt layer extends to a depth of about 35 m in the Kafr El-Sheikh region.

Data collected over a period of two years from 35 observation wells in the region showed a shallow water table that fluctuated on the monthly average between 0.20 m and 0.80 m below ground surface (Figure 3). Studies by Warner, et al (1984) showed that the downward vertical leakage from the water table could be considered negligible.

In the winter season berseem, wheat, and sugar beets are the primary crops grown in the area. Total areas of each crop grown are given in Tables A-11 and A-12 in Appendix A for the winter seasons 1981-1982 and 1982-1983 respectively. The major summer crops are rice, cotton, and corn. Crop areas for the summer seasons of 1981 and 1982 are given in Tables A-13 and A-14 in Appendix A.

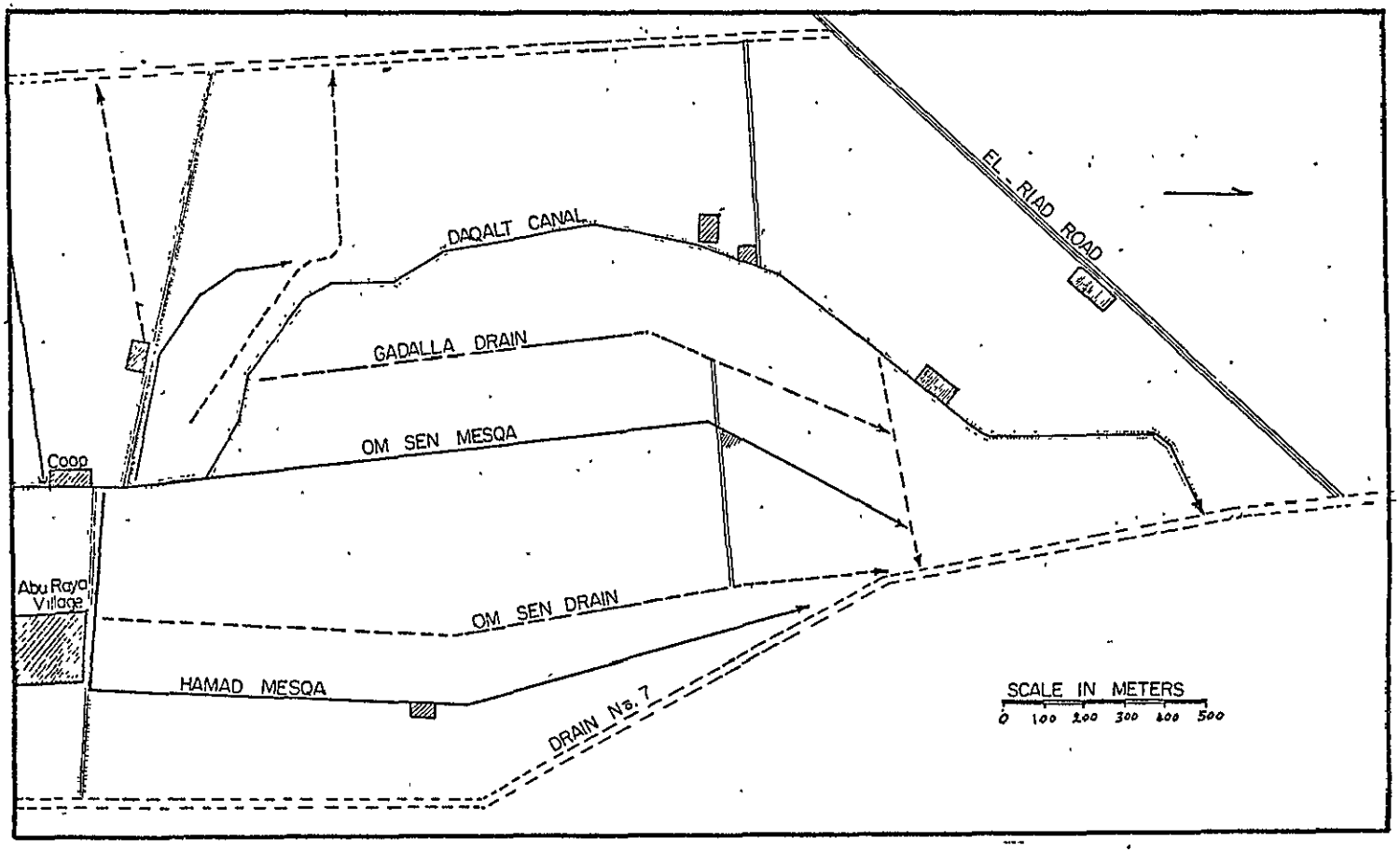

Figure 6. The Om Sen Water Budget Region

The Om-Sen *mesqa* which delivers water to the region is served by the Daqalt canal, a branch of the Meet Yazid canal. A typical rotation schedule of water delivery for Daqalt canal is summarized in Table 3. There was no headgate on the Om-Sen *mesqa* and downstream conditions were such that water continued to flow into the *mesqa* at night and during the off periods.

Table 3. A Typical Water Rotation Schedule for Daqalt Canal.

Dates From	Dates To	Type of Rotation [a]
Middle of Oct.	First week of Jan.	Triple water rotation [b]
First week of Jan.	Middle of Jan.	10 days general irrigation.
Middle of Jan.	Jan. 20	4 days partial closure.
Jan. 20	Feb. 9	20 days winter-closure period.
Feb. 10	Feb. 14	4 days partial opening.
Feb. 14	Feb. 24	10 days general irrigation.
Feb. 25	Middle of March	Triple water rotation.
Middle of March	Middle of April	Double water rotation[c] for the purposes of cotton preplanting irrigation.
Middle of April	May 20	Triple water rotation.
May 20	Middle of Oct.	Double water rotation for the summer crops (cotton, maize).

[a] All rotations could be changed with a 48-hour notice
[b] Triple water rotation means 4 days "on " followed by 8 days "off" or 5 on/10 off
[c] Double water rotation means 4 days "on" followed by 4 days "off"

Typically, farmers irrigated by means of one of the 34 *saqias* located on the Om-Sen *mesqa*. However, during limited periods of high water level several farms were irrigated by gravity flow from the *mesqa*. The time of day in which farmers in the region preferred to irrigate was between 0500 and 1200 hours.

WATER BUDGET MODEL

General Case

When appropriate vertical and horizontal boundaries have been specified, an irrigated region may be defined as a hydrologic control volume for purpose of water budget studies. A control volume is a volume in space having specified boundaries across which mass may flow. In an irrigated region, the surrounding drains and canals locate the vertical boundaries. The horizontal boundaries are the bottom of clay-silt layer and the top of the crop canopy. Water flowing across the boundaries of the region and the resulting change in the volume stored within the region are subjects of a water budget study.

The basic principle for any water budget study is the general equation of continuity for a fluid which is presented in standard texts of fluid dynamics (Daily and Harleman, 1966; Daugherty and Franzini, 1977). For hydrologic studies, a simplified form of the equation for a fixed control volume and a specific period of time may be used:

$$I_T - O_T = \Delta S_T \qquad (1)$$

where,

I_T = total inflow volume of water into the control volume during time period T, (m^3)

O_T = total outflow volume of water from the control volume during time period T, (m^3)

ΔS_T = total change in volume of water stored within the control volume during time period T, (m^3)

The inflow volume, I_T, to an irrigated hydrologic unit may be made up of several components.

$$I_T = (I_A)_T + (I_B)_T + (I_C)_T \qquad (2)$$

where,

$(I_A)_T$ = total volume of surface inflow during time period T, (m^3)

$(I_B)_T$ = total volume of subsurface inflow during time period T, (m^3)

$(I_C)_T$ = total volume of precipitation during time period T, (m^3)

The components of equation (2) (with the subscript T dropped from the notation) may take many forms in the field. For example, surface inflow, I_A, often enters a region by a canal. Subsurface inflow, I_B, may enter in underground pipelines, by pumping from deep wells penetrating the lower boundary to bring water from a lower aquifer, by seepage from the boundaries, or by lateral and vertical flow due to hydraulic gradients in the groundwater aquifer. Precipitation, I_C, enters through the control surface at the top of the crop canopy.

There are also many components making up the outflow volume, O_T.

$$O_T = (O_{A1})_T + (O_{A2})_T + (O_{B1})_T + (O_{B2})_T + (O_C)_T + (O_D)_T \qquad (3)$$

where,

$(O_{A1})_T$ = total volume of surface outflow as drainage during time period T, (m^3)

$(O_{A2})_T$ = total volume of surface outflow to irrigate adjacent areas during time period T, (m^3)

$(O_{B1})_T$ = total volume of vertical subsurface outflow during time period T, (m^3)

$(O_{B2})_T$ = total volume of horizontal subsurface outflow during time period T, (m^3)

$(O_C)_T$ = total volume of crop consumptive use during time period T, (m^3)

$(O_D)_T$ = total volume of evaporation from free water surfaces during time period T, (m^3)

The components of equation (3) (subscript T dropped) may take many forms in a region. For example, surface outflow leaves a region to the drains as O_{A1}. Outflow from a *mesqa* in a region may cross a drain in an aquaduct to irrigate an adjacent area as an example of O_{A2}. Vertical subsurface outflow, O_{B1}, occurs as deep percolation from the water table aquifer to a deeper underlying aquifer. Horizontal subsurface outflow, O_{B2}, may leave in subsurface drains intersecting the region, in an underground pipe line, or as lateral groundwater flow due to a

hydraulic gradient. The crop consumptive use outflow volume, O_C, is composed of the water vapor that leaves above the crop canopy in the form of transpiration from the crop and evaporation from the crop and field surface. The water vapor leaving a region by evaporation from free water surfaces and wet non-cultivated areas makes up O_D.

Since I_T and O_T usually are not equal, a change must occur in the total volume of water stored within a hydrologic control volume over the time period, T. The total storage change, ΔS_T, is composed of two significant components.

$$\Delta S_T = (\Delta S_A)_T + (\Delta S_B)_T \tag{4}$$

where,

$(\Delta S_A)_T$ = total storage change in surface water volume during the time period T, (m^3)

$(\Delta S_B)_T$ = total storage change in subsurface water volume during the time period T, (m^3)

Changes in surface water storage, ΔS_A, take place as water levels rise and fall in canals, drains and ponds. Application and drainage of water from fields also cause surface storage changes, particularly in the case of rice flooding. Changes in subsurface storage, ΔS_B, occur as water tables rise and fall and as the water content varies within the region of negative soil-water potential above the water table.

The time period, T, over which a water budget study may be conducted will vary with the objectives. Usually, T will be a period of one month, one agricultural season, or one year.

Abyuha Case

The vertical boundaries of the water budget region for the Abyuha region were the Abyuha canal on the east; the Abyuha canal and *mesqa* 5 on the south; the Kom El Zoheir -El Mustaged drain and the private drain on the west; and *mesqa* 24 and the Kom El Zoheir - El Qadim drain on the north. The horizontal boundaries were the bottom of the clay-silt layer and the top of the crop canopy.

Each of the inflow components of equation (2) was identified specifically for the Abyuha region and is shown in Figure 7. Surface inflow, I_A, entered the region from the Abyuha canal. A relatively small volume of subsurface inflow, I_B, entered the region as seepage from the large Ibrahimiya canal along the east boundary. Precipitation, I_C, seldom occurred in Abyuha and was negligible.

The outflow components of equation (3) are also identified in Figure 7. Surface drainage outflow, O_{A1}, occurred as water exited the ends of the *mesqas* directly to Kom El Zoheir - El Mustaged drain, as it flowed from other *mesqas* via the private drain to Kom El Zoheir -El Qadim drain, and as it periodically flowed through the tail escape at the end of Abyuha canal to the Kom El Zoheir - El Qadim drain. Water also flowed out of the region in *mesqas* 24 and 25 and via the private drain as O_{A2} to irrigate the area adjacent to the northwest quadrant. Vertical subsurface outflow, O_{B1}, occurred as leakage from the water table aquifer in the clay- silt layer to the underlying semi-confined aquifer. Horizontal subsurface outflow, O_{B2}, was negligible. Consumptive use, O_C, was the largest component of outflow for the area. Evaporation outflow, O_D, occurred from the watercourses.

The seasonal storage change in surface water, ΔS_A, in the region was negligible. Subsurface storage change, ΔS_B, occurred as the water table rose and fell.

Water budgets for the Abyuha region were determined for these agricultural seasons: summer 1980, winter 1980-1981, summer 1981, and winter 1981-1982. The time period, T, for the winter season was from October 1 to March 30, and for the summer season, April 1 to September 30. Water budget components were determined for semi-monthly subperiods within each season.

Beni Magdul Case

The vertical boundaries of the Beni Magdul water budget region were the Lebini drain on the east; the Lebini and Beni Magdul drains on the south; and the Nahia drain on the west and north. The horizontal boundaries were the bottom of the clay-silt layer and the top of the crop canopy.

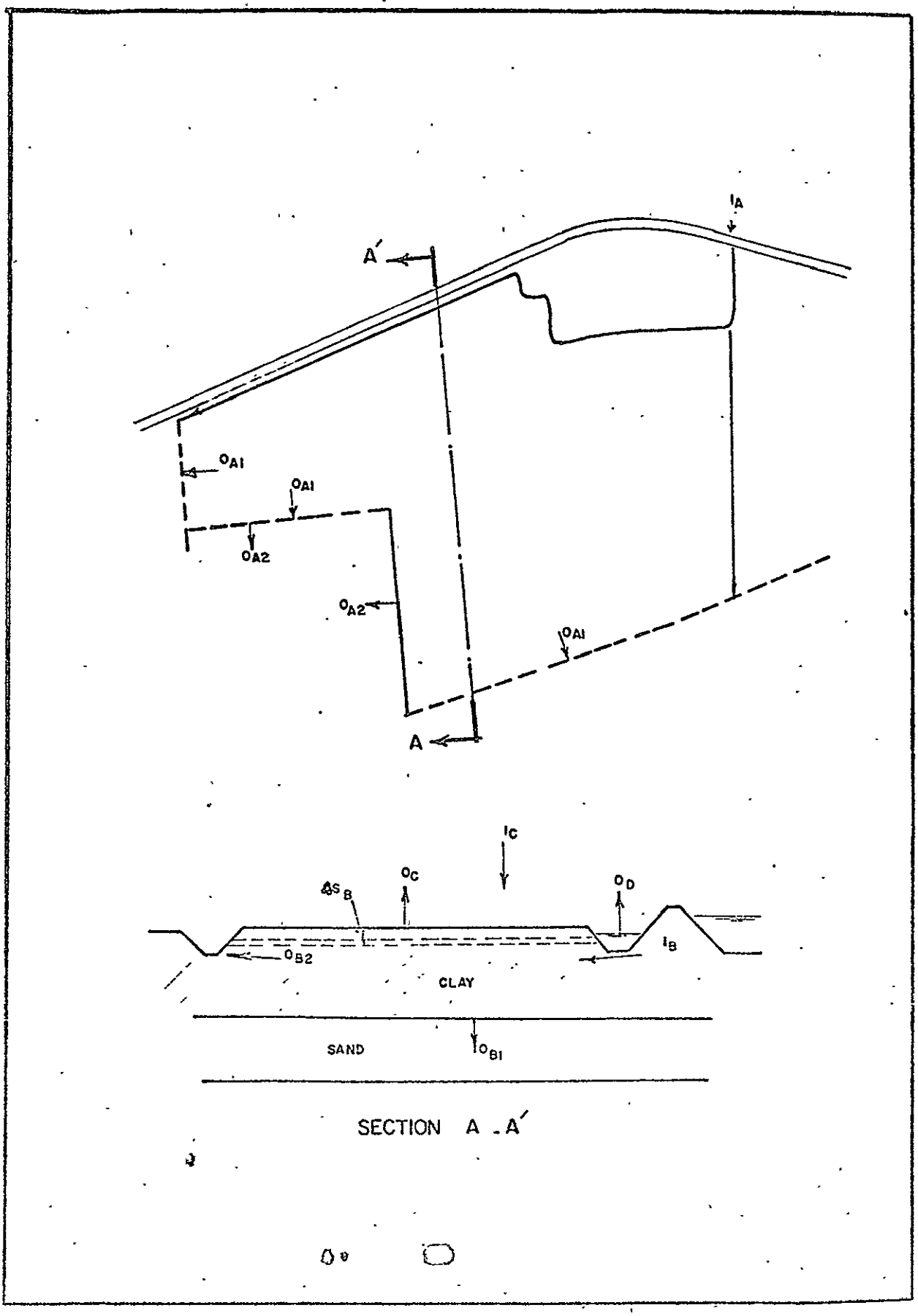

Figure 7. Components of water budget at Abyuha

Figure 8 shows each of the inflow components of equation (2) as it occurred in the Beni Magdul site. Surface inflow, I_A, largely entered the area through the Beni Magdul canal. Small volumes of surface inflow also entered the northwest quadrant from a *mesqa* supplied by the Nahia canal (just north of the region) and entered the region in the form of pumping of drain water at various locations along the Nahia, Lebini and Beni Magdul drains. Subsurface inflow, I_B, occurred in the form of pumping from three deep aquifer wells. Inflow due to seepage from or flow beneath the drain was negligible. Precipitation, I_C, was also negligible.

The outflow components of equation (3) also are illustrated in Figure 8. A relatively small volume of water flowed directly to the drains out of the ends of some *mesqas* in the region as surface drainage outflow, O_{A1}. Flow that left in a *mesqa* transporting water south of Beni Magdul drain to irrigate about 16 feddans outside the region was designated as O_{A2}. Vertical subsurface outflow, O_{B1}, occurred as leakage from the water table aquifer in the clay-silt layer to the semi-confined aquifer in the underlying sand. Horizontal subsurface outflow, O_{B2}, occurred in the form of horizontal flow to or under the drains. Crop consumptive use, O_C, was the largest component of outflow. Evaporation, O_D, occurred from the watercourses in the region.

The seasonal storage change in surface water, ΔS_A, was negligible in the region. Subsurface storage change, ΔS_B, occurred as the water table fluctuated in level.

Water budgets for the Beni Magdul region were determined for these agricultural seasons: winter 1979-1980, summer 1980, winter 1980-1981, summer 1981, winter 1981-1982, and summer 1982. Water budget components were determined for semi-monthly sub-periods within each season.

Om-Sen Case

Om-Sen drain on the east; Hamad *mesqa* and Daqalt canal on the south; Daqalt canal and Gadalla drain on the west; and Gadalla drain on the north formed the vertical boundaries for Om-Sen region. The horizontal boundaries were the bottom of the clay-silt layer and the top of the crop canopy.

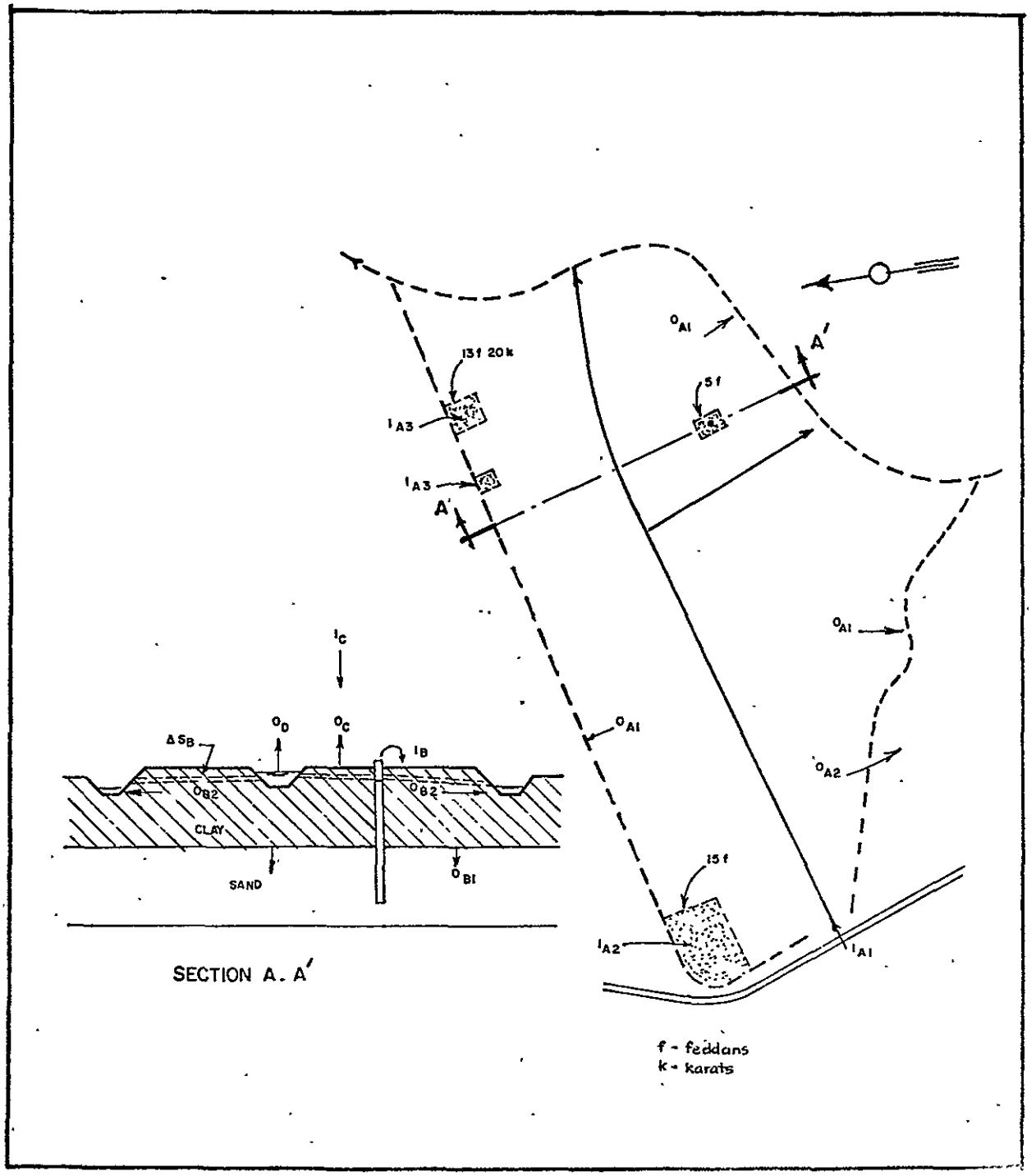

Figure 8. Components of water budget at Beni Magdul

The inflow components of equation (2) are illustrated in Figure 9 for the Om-Sen region. The Om-Sen *mesqa* carried the surface inflow, I_A, from the Daqalt canal to the region. Subsurface inflow, I_B, was negligible. Precipitation, I_C, was not insignificant and occurred primarily in the winter months.

The outflow components of equation (3) are also indicated in Figure 9. Surface drainage outflow, O_{A1}, occurred as water flowed through *marwas* (field ditches) and from field drains (for collecting irrigation surface runoff) to the Gadalla and Om-Sen drains. No water left the region as O_{A2} to irrigate adjacent areas. Vertical subsurface outflow, O_{B1}, as leakage from the water table aquifer in the clay-silt layer to the semi-confined aquifer in the underlying sand was negligible. A small amount of horizontal subsurface outflow, O_{B2}, occurred along the eastern boundary as flow to the large collector drain, No. 7. Crop consumptive use, O_C, and evaporation, O_D, from watercourses and uncultivated land also occurred in the region.

The storage change in surface water, ΔS_A, was significant only for short periods of time during the time rice was flooded. Subsurface storage change, ΔS_B, occurred as the water table fluctuated in level.

A water budget for the Om-Sen region was determined for summer 1982 and winter 1982-1983. Water budget components were determined for semi-monthly sub-periods within the season.

DATA COLLECTION AND ANALYSIS

Summary descriptions of how data were collected and analyzed to determine the values of the water budget components are given in Tables B1, B2, and B3 in Appendix B.

RESULTS

Complete seasonal water budgets for Abyuha, Beni Magdul, and Om-Sen are summarized in Tables C1 through C11. Figure 10 presents scaled illustrations of each winter season water budget components as a fraction of total inflow for Abyuha and Beni Magdul. Similar scaled illustrations are given in Figure 11 for the summer season for each region.

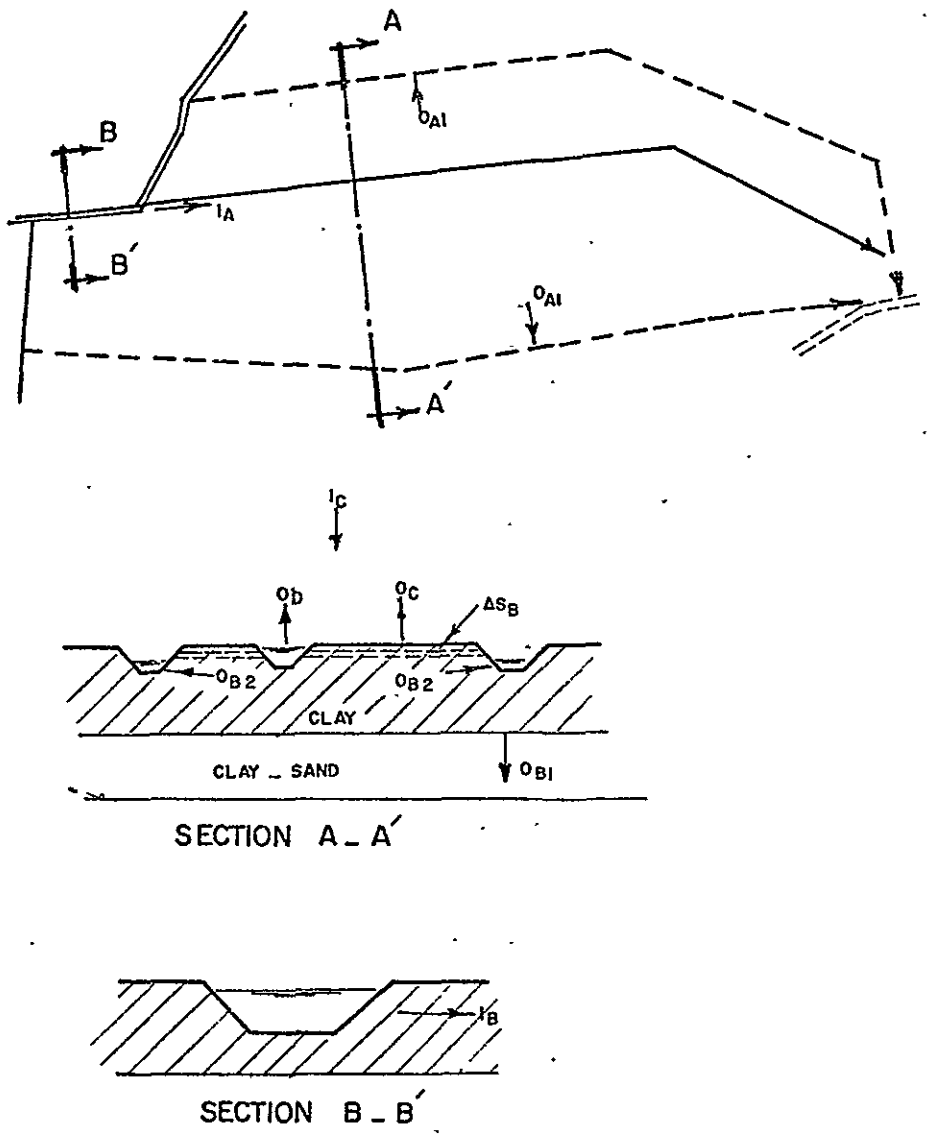

Figure 9. Components of water budget at Om Sen

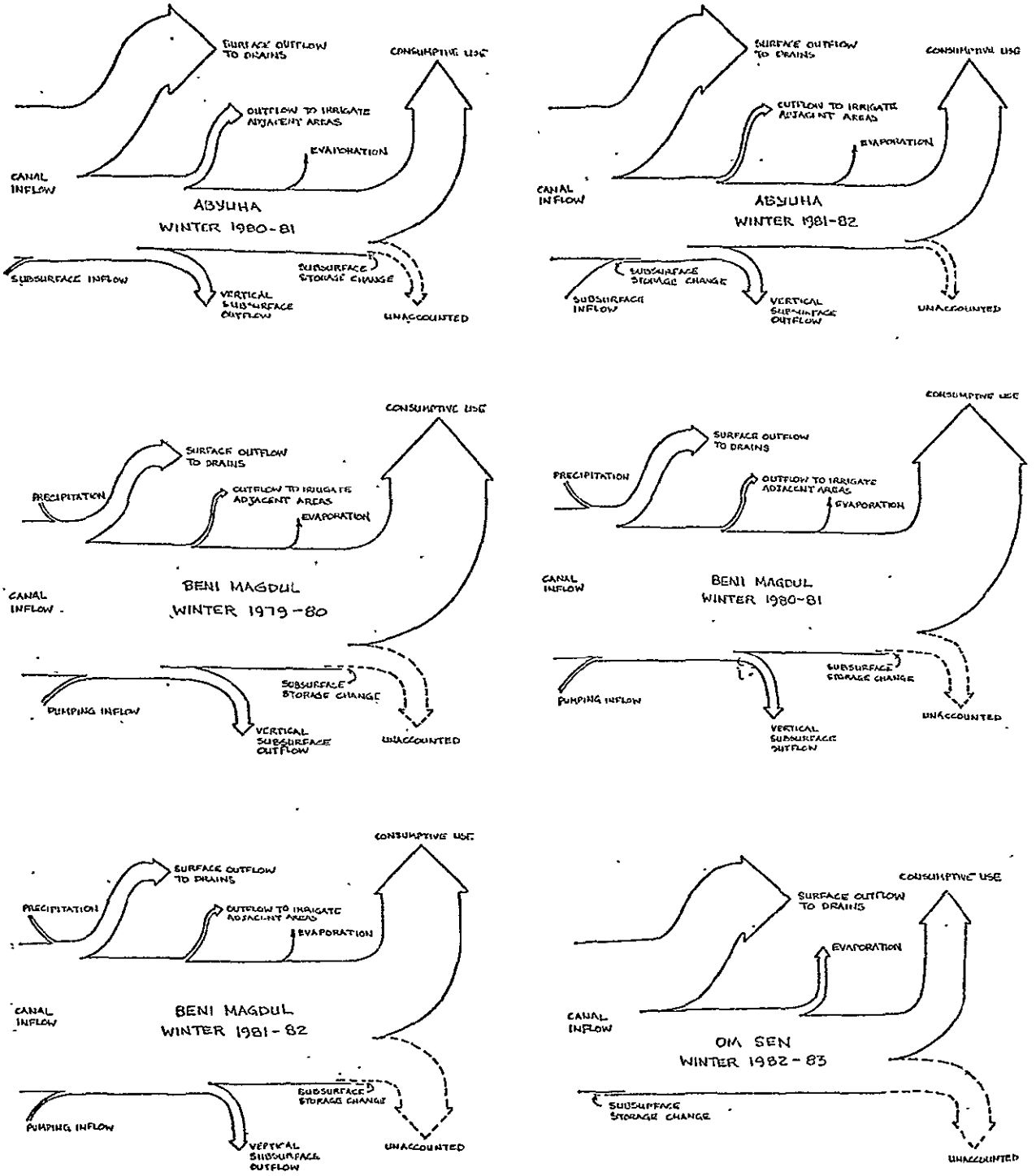

Figure 10. Schematics of winter season water budgets for Abyuha, Beni Magdul, and Om Sen regions.

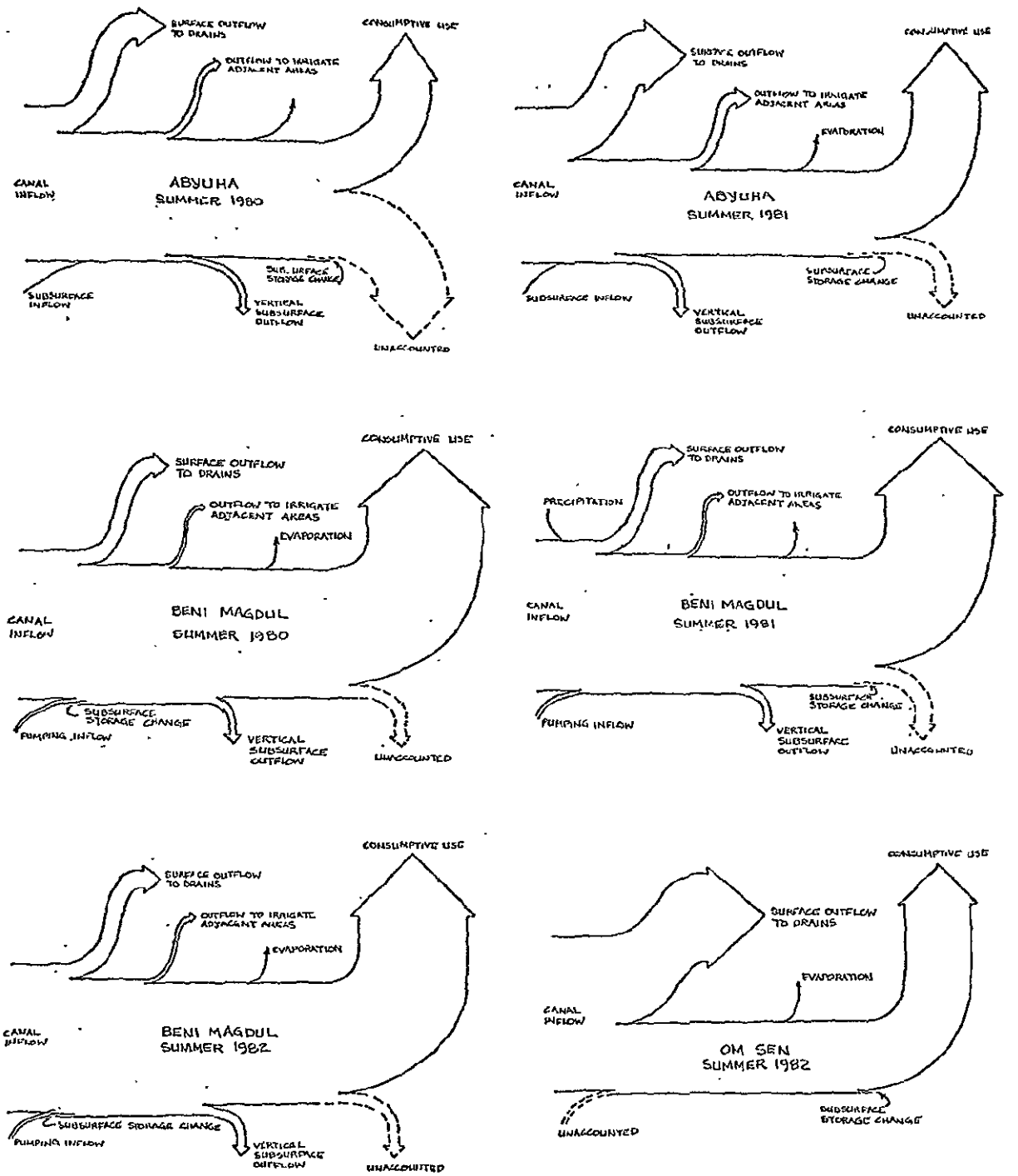

Figure 11. Schematics of summer season water budgets for Abyuha, Beni Magdul and Om Sen regions.

The amount of water lost to surface drainage, O_{A1}, was typically high in Abyuha and in Om-Sen -- 30 to 45% of the total water diverted for irrigation (I_A) in Abyuha and 46 to 58% in Om-Sen. Only 10 to 13% of the total water diverted (I_A+I_B) was released as surface drainage in Beni Magdul. These results were to be expected since in both Abyuha and Om-Sen there was very little control at the inlets to the supply canals and downstream conditions allowed free outfall to surface drains. In contrast, the water entering the Beni Magdul canal was carefully regulated by a project technician under engineering supervision.

Vertical subsurface outflow, O_{B1}, in the form of downward leakage was a small but significant component of the water budget in Abyuha and in Beni Magdul. It made up 8% to 18% of the total inflow (I_A+I_B+I_C) in Abyuha. In Beni Magdul it was 9% to 14% of the total inflow (I_A+I_B+I_C). Vertical leakage in Om-Sen was negligible due to the thick, relatively impermeable clay layer and the very small hydraulic gradient. Salts are transported out of the water table aquifer in the drainage water; hence, it would be expected that for a similar quality of irrigation water the salinity of the groundwater would be significantly greater in Om-Sen where vertical drainage is smaller than in Abyuha or Beni Magdul. Project data on salinity in observation wells, however, does not confirm this expectation. Apparently, salts rise from the water table to the surface layers of the soil where they are flushed away by overland flow to surface drains during irrigation. The large volume of flow in surface drains at Om-Sen may be due in part to the need for such flushing of salts.

The component designated as "unaccounted" indicates the cumulative error in the measurement or estimation of each water budget component. These errors may be due to the inherent limitations of methods and equipment used, inadequate precision and replication of measurements due to limited manpower and financial resources, and human mistakes.

Monthly volumes of total water diverted for irrigation and total crop consumptive use are illustrated in the bar graphs shown in Figures 12, 13, and 14 for each of the three sites. In Beni Magdul where canal inflow is closely regulated according to crop need, the pattern of inflow closely follows that of consumptive use. The patterns are not as clearly matched in Abyuha and Om-Sen. Total water diverted during winter seasons ranged from 4419 m^3/*feddan* to 4440 m^3/*feddan* in Abyuha and 2685 m^3/*feddan* to 3174 m^3/*feddan* in Beni Magdul. In Om-Sen the

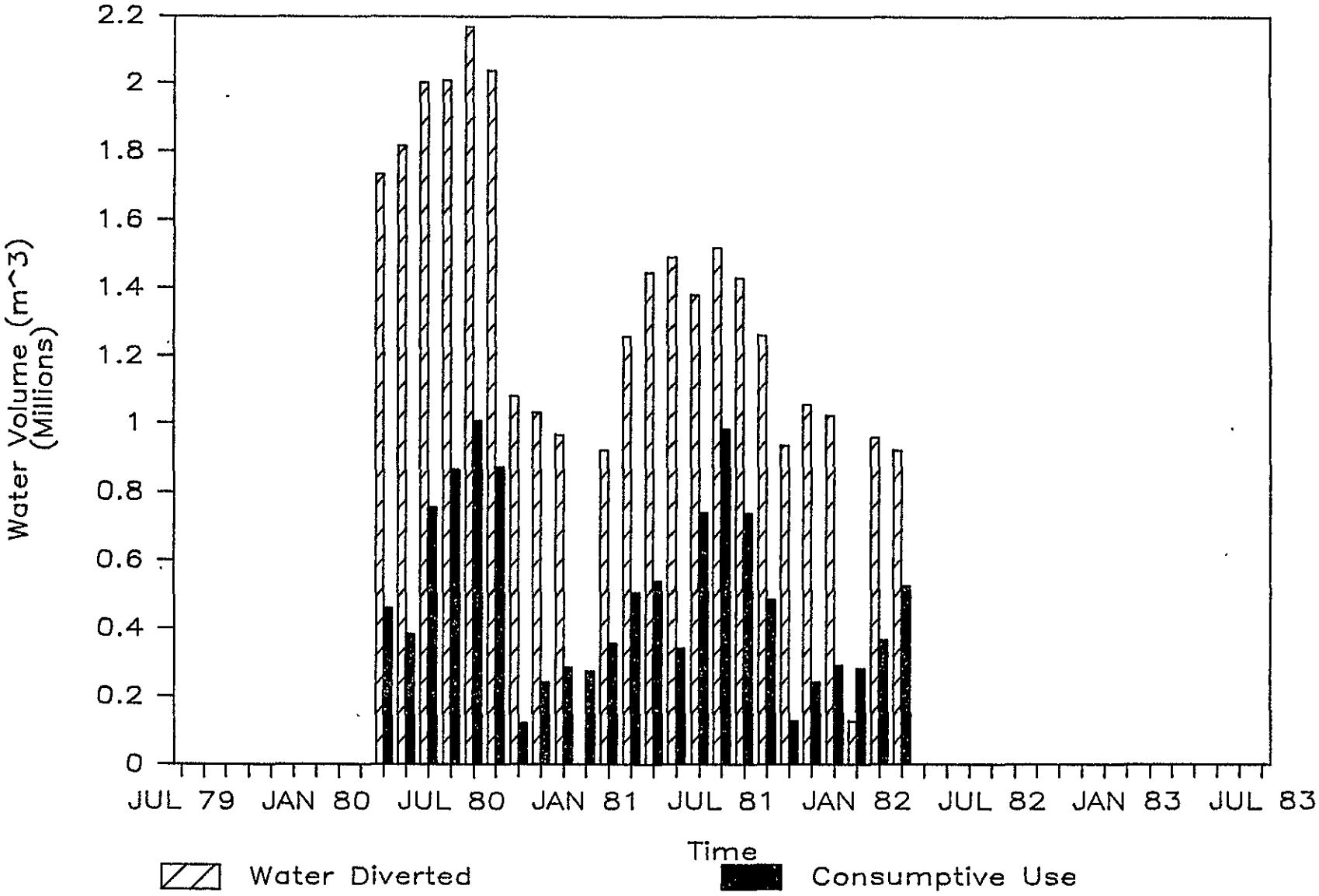

Figure 12. Water diverted and crop consumptive use at Abyuha

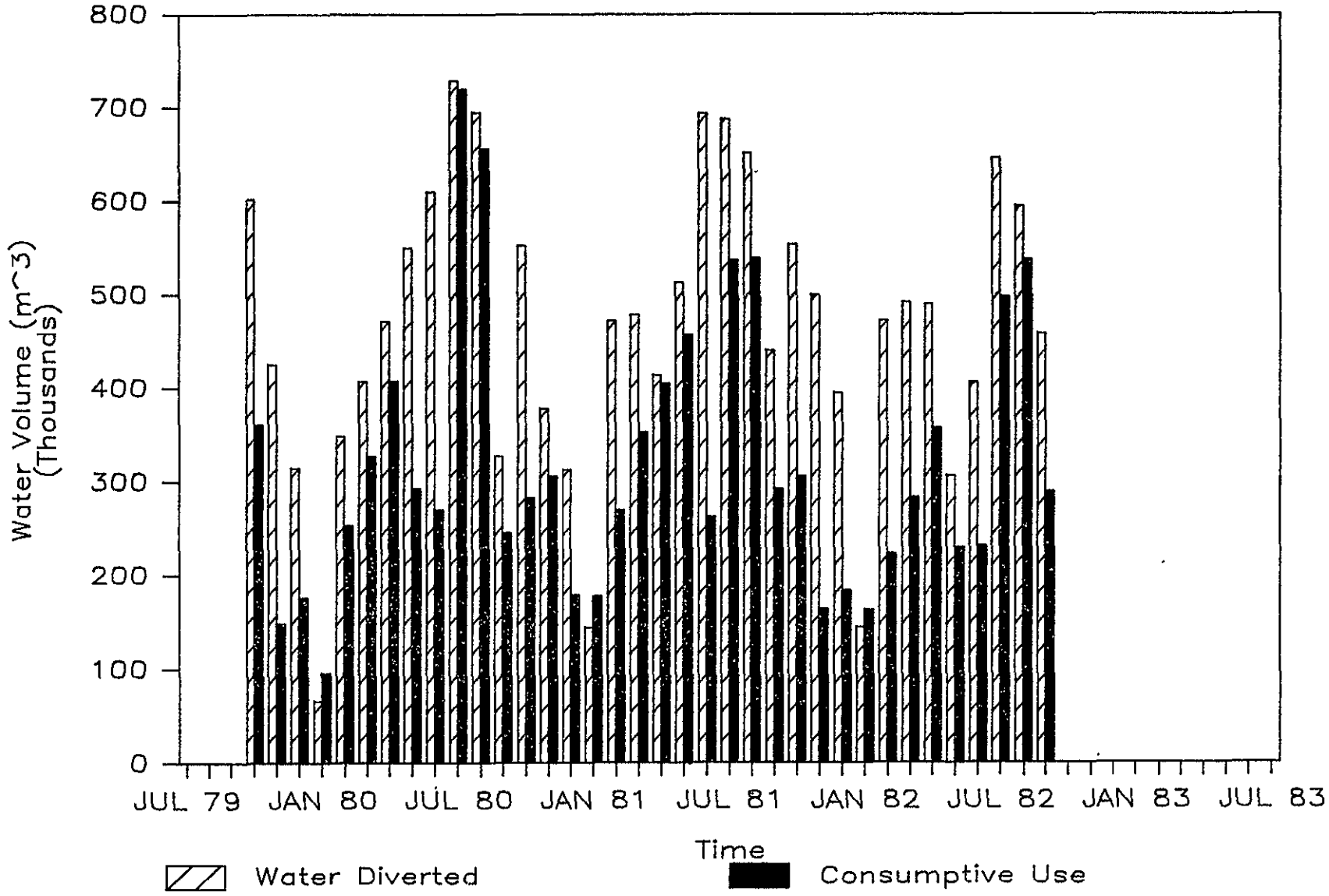

Figure 13. Water diverted and crop consumptive use at Beni Magdul

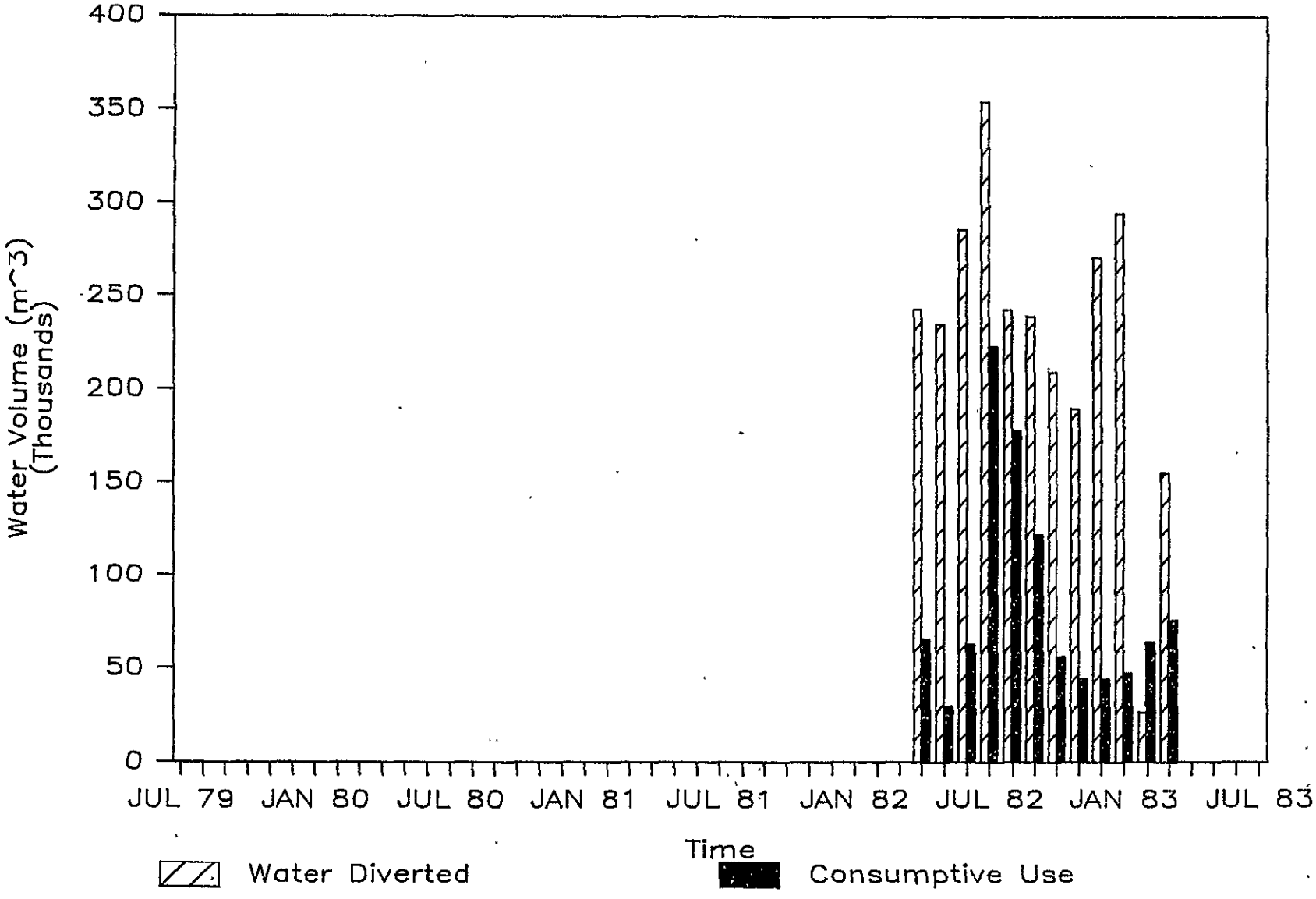

Figure 14. Water diverted and crop consumptive use at Om Sen

value was 4887 m^3/*feddan*. Summer season values ranged from 7175 m^3/*feddan* to 10419 m^3/feddan in Abyuha, from 3601 m^3/*feddan* to 4217 m^3/*feddan* in Beni Magdul, and were 6810 m^3/*feddan* in Om-Sen. Average winter season crop consumptive use was estimated as 1527 m^3/*feddan* in Abyuha, 1754 m^3/*feddan* in Beni Magdul, and 1425 m^3/*feddan* in Om-Sen. Average summer consumptive use was estimated as 3478 m^3/*feddan* in Abyuha, 2977 m^3/*feddan* in Beni Magdul and 2298 m^3/*feddan* in Om-Sen.

Irrigation efficiency as defined by Israelsen (1950) is the ratio of the total crop consumptive use in a region to the total water diverted to the region for irrigation. Tables C1 through C11 give the seasonal irrigation efficiencies for each of the sites. Seasonal irrigation efficiency ranged from 33 to 49% in Abyuha, from 52 to 78% in Beni Magdul, and from 26 to 43% in Om-Sen. Figure 15 illustrates how the irrigation efficiency varied throughout the year at each of the three sites. In each case the pattern was similar: peak efficiencies occurred during periods of peak crop consumptive use.

The ratio of the total seasonal consumptive use demand (crop consumptive use minus effective precipitation) to the total seasonal volume infiltrated (total surface inflow minus total surface outflow and evaporation) was typically high for each region (Figure 16). At Abyuha and Beni Magdul, where surface runoff from irrigated fields was negligible, this ratio indicates that the field application efficiency (ratio of consumptive use to amount applied, Bos and Nugteren, 1974) was high. Though significant amounts of deep percolation from the root zone were measured in each of these regions, the high ratio of consumptive use to infiltrated water indicates a significant contribution from the water table to plant water use.

The results presented here are indicative of water use and irrigation efficiency at the farm distribution system level only. They are not necessarily representive of water management on individual farms in the respective regions. Rather, they must be considered as composite or average indicators of regional farm water use and management.

CONCLUSIONS

The following conclusions were drawn from these studies:

1) The water table was consistently high for each site studied. Considerable seasonal fluctuation was noted at each site with the

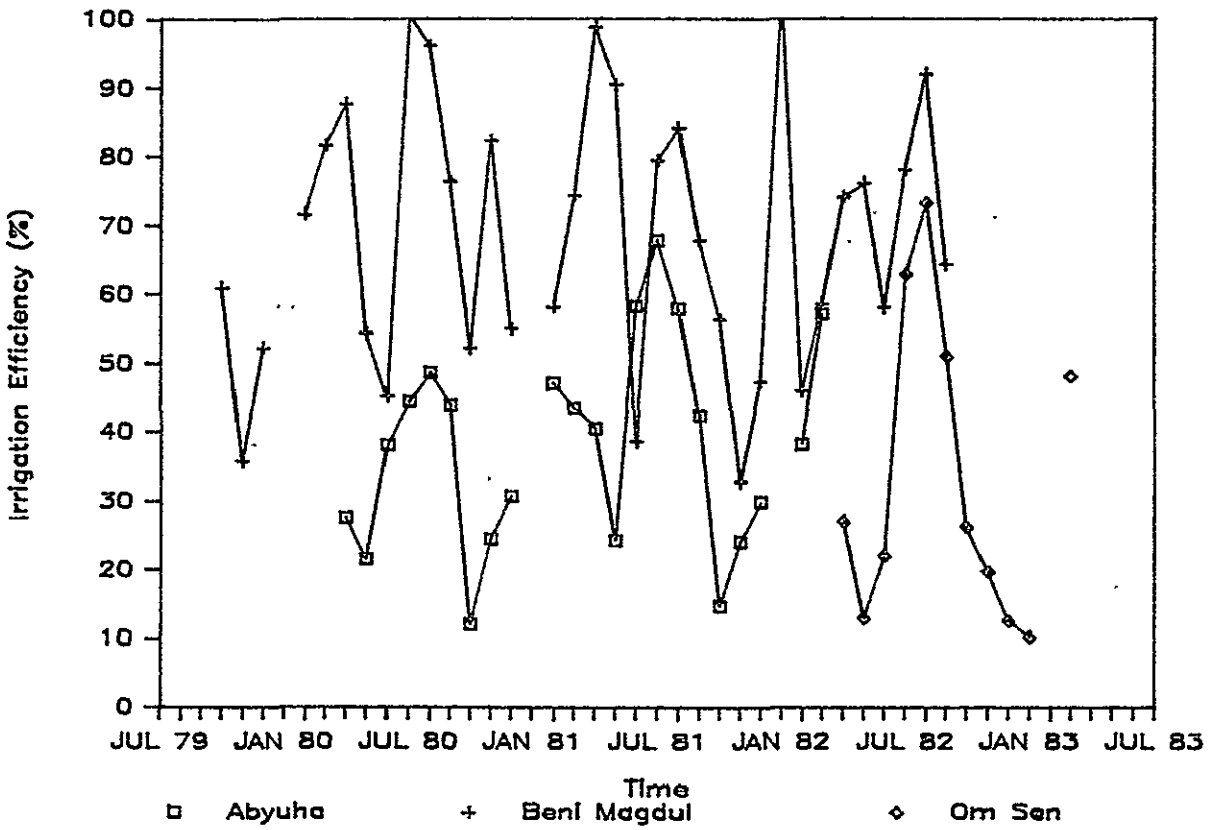

Figure 15. Irrigation efficiency at Abyuha, Beni Magdul and Om Sen.

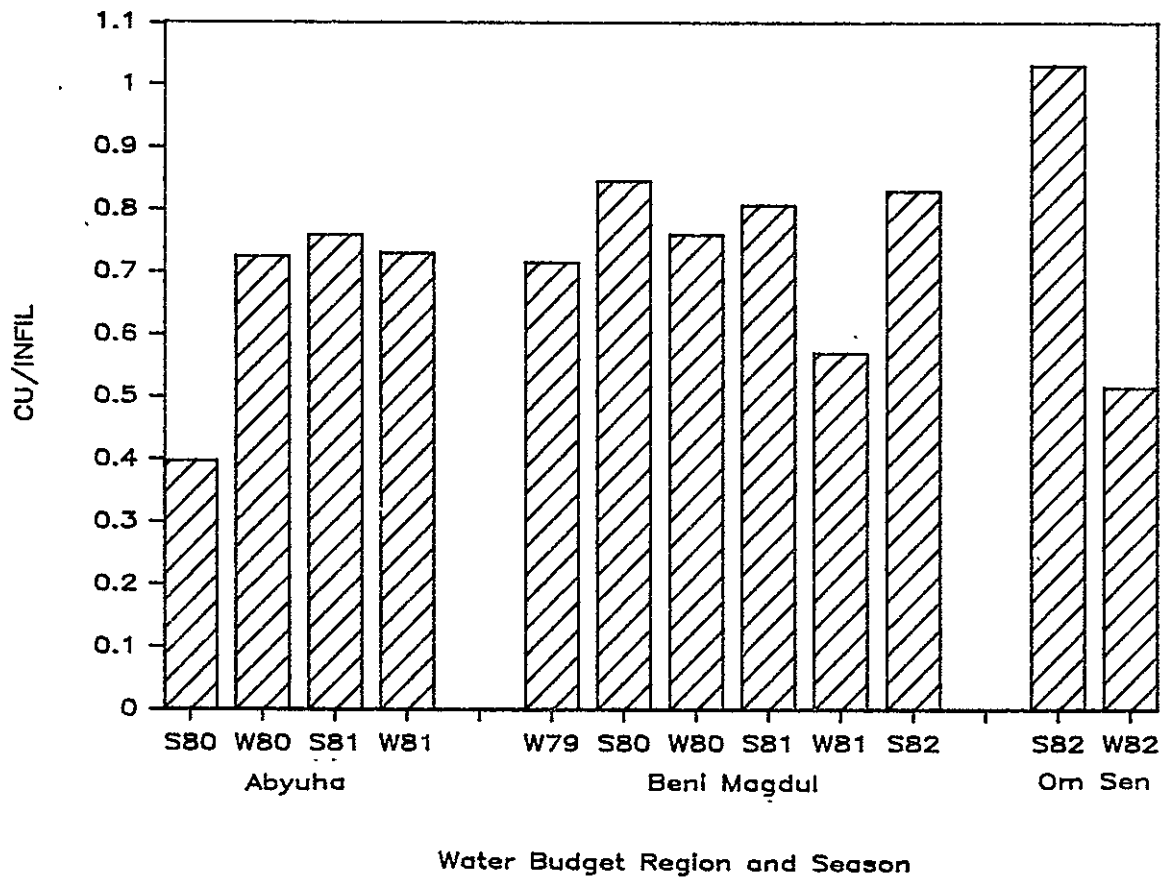

Figure 16. Ratio of total crop consumptive use demand volume to total infiltrated volume (CU/INFIL) for each season at Abyuha, Beni Magdul and Om Sen.

indication being that the water table was highest during periods of highest inflow and lowest following the period of canal closure. Changes in groundwater storage associated with this fluctuation were very small.

2) Vertical drainage was a small, though significant, component of the water budget at Abyuha and Beni Magdul. However, it was negligible in Om-Sen where the thick, relatively impermeable clay layer and small hydraulic gradient impede downward flow.

3) Horizontal movement of groundwater was negligible at all three sites due to very small horizontal gradients in head and low horizontal permeabilities.

4) In Beni Magdul careful regulation of canal headgates to control inflow resulted in a relatively high value of regional irrigation efficiency and only a small amount of water released as surface drainage. However, in Abyuha and Om-Sen inadequate control resulted in high losses as surface drainage and low irrigation efficiencies.

5) Ratios of total crop consumptive use demand to total volume infiltrated in each region were typically high. This indicates high field application efficiency in Abyuha and Beni Magdul where surface runoff from irrigated fields was negligible.

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APPENDICES

Table A-1. 1980-1981 Winter Season Crops in Abyuha.

Crop	Area	
	Feddans	hectares
Berseem	381	160.0
Green Beans	191	80.2
Dry Beans	159	66.8
Wheat	209	87.8
Sugar Cane	151	63.4
Group including: Onion, Garlic, Potatoes and Carrots	9	3.8
TOTAL	1100	462.0

Table A-2. 1981-1982 Winter Season Crops in Abyuha.

Crop	Area	
	Feddans	hectares
Berseem	350	147
Wheat	263	110.5
Beans	350	147
Potatoes	15	6.3
Group including: Onion, Garlic, Carrots and Fenugreak	9	3.8
Sugar Cane	151	63.4
TOTAL	1138	477.9

Table A-3. 1980 Summer Season Crops in Abyuha.

Crop	Area	
	Feddans	hectares
Tomatoes	15	6.3
Cotton	234	98.3
Corn	634	266.3
Soya Bean	11	4.6
Sugar Cane	140	58.8
Sunflowers	73	30.7
TOTAL	1107	464.9

Table A-4. 1981 Summer Season Crops in Abyuha.

Crop	Area	
	Feddans	hectares
Cotton	249	104.6
Sugar Cane	151	63.4
Corn	577	242
Soy Bean	105	44
Tomatoes	15	6.3
Sunflowers	10	4.2
TOTAL	1107	464.9

Table A-5. 1979-1980 Winter Season Crops in Beni Magdul.

Crop	Area	
	Feddans	hectares
Berseem	578	242.8
Wheat	42	17.6
Onion	18	7.6
Green Pepper	3	1.26
Artichoke	16	6.7
Lupine	4	1.7
Flax	9	3.8
Tomato	1	.4
Cabbage	1	.4
Carrots	12	5
Group including: Spinach, Dill, Parsley, Leeks, Chard	39	16.4
Citrus Trees	18	7.6
Date Palm	65	27.3
TOTAL	806	338.5

Table A-6. 1980-1981 Winter Season Crops in Beni Magdul.

Crop	Area	
	Feddans	hectares
Berseem	526	220.9
Wheat	81	34
Onion	27	11.3
Parsley	25	10.5
Citrus Trees	18	7.6
Date Palms	65	27.3
Leeks	20	8.4
Garden Rocket	15	6.3
Carrots	12	5.0
Artichokes	9	3.8
Cabbage	8	3.4
Chard	5	2.1
Tomatoes	4	1.7
Flax	4	1.7
Dill	2	.8
Peppers	1	.4
TOTAL	822	345.2

Table A-7. 1981-1982 Winter Season Crops in Beni Magdul.

Crop	Area	
	Feddans	hectares
Berseem	416	174.7
Wheat	65	27.3
Onion	125	52.5
Artichokes	14	5.9
Leek	24	10.1
Parsley	24	10.1
Garden Rocket	17	7.1
Squash	1	.42
Cabbage	3	1.3
Chard	8	3.36
Dill	5	2.1
Lupine	7	2.9
Tomatoes	19	8
Citrus Trees	18	7.6
Date Palms	65	27.3
Eggplant	.5	.2
Flax	4	1.68
Okra	.3	.1
TOTAL	816	342.6

Table A-8. 1980 Summer Season Crops in Beni Magdul.

Crop	Area	
	Feddans	hectares
Corn	651	273.4
Onion	27	11.3
Parsley	25	10.5
Citrus Trees	18	7.6
Date Palms	65	27.0
Leeks	20	8.4
Garden Rocket	15	6.3
Chard	5	2.1
Sweet Potatoes	3	1.3
Eggplant	2	.8
Peppers	1	.4
Tomatoes	4	1.7
TOTAL	836	351.1

Table A-9. 1981 Summer Season Crops in Beni Magdul.

Crop	Area	
	Feddans	hectares
Corn	461	193.6
Green Corn	29	12.2
Tomatoes	42	17.6
Parsley	17	7.1
Leek	21	8.8
Garden Rocket	12	5
Sunflower	52	21.8
Eggplant	33	13.9
Pepper	16	6.7
Potatoes	9	3.8
Okra	18	7.6
Chard	2	.8
Dill	8	3.4
Cabbage	12	5
Date Palms	65	27.3
Citrus Trees	18	7.2
TOTAL	815	342.3

Table A-10. 1982 summer Season Crops in Beni Magdul.

Crop	Area	
	Feddans	hectares
Corn	414	173.9
Green Corn	52	21.8
Tomatoes	19	8
Parsley	29	12.2
Leek	22	9.2
Garden Rocket	26	10.9
Sunflower	70	29.4
Eggplant	17	7.1
Pepper	13	5.5
Potatoes	8	3.4
Okra	7	2.9
Coriander	6	2.5
Rice	2	.8
Cabbage	18	7.6
Palm Tree	65	27.3
Onion	13	5.5
Citrus Tree	18	7.6
Dill	5	2.1
TOTAL	804	337.7

Table A-11. 1981-1982 Winter Season Crops in Om-Sen.

Crop	Area	
	Feddans	hectares
Wheat	75	31.5
Berseem	112	47
Suger Beets	32	13.4
Beans	13	5.5
Onion	2	.8
Barley	1	.4
TOTAL	235	98.7

Table A-12. 1982-1983 Winter Season Crops in Om-Sen.

Crop	Area	
	Feddans	hectares
Wheat	106	44.5
Berseem	115	48.3
Suger Beets	17	7.1
Beans	3	1.3
Oniom	--	---
Barley	--	---
TOTAL	241	101.2

Table A-13. 1981 Summer Season Crops in Om-Sen.

Crop	Area	
	Feddans	hectares
Cotton	79	33.2
Rice	113	47.5
Corn	37	15.5
Watermellon	4	1.7
Cucumber	2	.8
TOTAL	235	98.7

Table A-14. 1982 Summer Season Crops in Om-Sen.

Crop	Area	
	Feddans	hectares
Rice	134	56.3
Corn	72	30.2
Cotton	24	10.1
Tomatoes	5	2.1
TOTAL	235	98.7

Appendix B

Table B1. Summary Description of the Methods Used for Determining Each of the Water Budget Components at Abyuha.

Water Budget Component	Location	Method of Determination
Surface Inflow, I_A	Abyuha Canal downstream of *Mesqa* 4	Measured with cutthroat flume (3.30 m length, 1.43 m throat width) with upstream and downstream continuous water level recorders; periodic current meter flow measurements immediately downstream. (References: Skogerboe et al, 1973; Bos, 1978; USBR, 1967; Rantz, et al 1982).
	Mesqa 1, upstream of the flume	Estimated as proportional to flow measured in flume by the ratio of the area served by *mesqa* 1 to the area served by the canal downstream of the flume.
	Mesqa 4, beside Kom El-Zoheir- El Mustagad Drain	Measured periodically by current meter and extrapolated over time.
Subsurface Inflow, I_B	Along the east boundary of the hydrologic region beside the Ibrahimiya Canal	Calculated from Darcy. Equation for groundwater flow using measured values of piezometric head from boundary observation wells and average measured value of horizontal hydraulic conductivity from auger hole tests. (References: McWhorter and Sunada, 1977; Bouwer, 1978; Bear, 1979; Warner, et al 1984).
Precipitation, I_C	Entire hydrologic region	Measured in rain gauge at Mellawi weather station, about 30 km south of the site.
Surface Drainage Outflow, O_{A1}	Kom El-Zoheir - El Mustagad Drain	Measured from current meter, rated gauging stations (D-1 and D-2 on Figure 3) with continuous water level recorders; measured periodically by current meter and extrapolated over time prior to June, 1981. (Reference: Rantz, et al, 1982).
	Kom El-Zoheir - El Qadim Drain	Measured periodically by current meter at gauging station (D-3 on Figure 3) and extrapolated over time.

Table B1 (Cont.). Summary Description of the Methods Used for Determining Each of the Water Budget Components at Abyuha.

Water Budget Component	Location	Method of Determination
Surface Outflow to Irrigate Adjacent Areas, O_{A2}	*Mesqa* 24 where it exits the hydrologic region	Measured periodically by current meter and extrapolated over time.
	Mesqa 25 where it exits the hydrologic region	Measured periodically by current meter and extrapolated over time.
	Private Drain along northwest boundary	Estimated as proportional to consumptive use in the Abyuha region by the ratio of the area irrigated out of the private drain to the area of the Abyuha region and adjusted by irrigation application efficiency.
Vertical Subsurface Outflow, O_{B1}	Entire hydrologic region	Calculated from Darcy Equation for groundwater flow using values of piezometric gradient and vertical hydraulic conductivity measured in a nearby region by the Groundwater Institute of the Ministry of Irrigation.
Horizontal Subsurface Outflow, O_{B2}	Along hydrologic boundary	Calculated from Darcy Equation for groundwater flow using measured values of piezometric head from boundary wells and average measured value of hydraulic conductivity from auger hole tests.
Crop Consumptive Use Outflow, O_C	Entire crop area	Calculated using values of crop consumptive use for Middle Egypt reported by the Ministry of Irrigation (1981b) and crop surveys in the region for each agricultural season.
Evaporation Outflow, O_D	Abyuha Canal and *mesqa* water surface	Calculated from Piche evaporimeter data collected at Mellawie weather station and water surface area of channels.
Surface Storage Change, ΔS_A	Entire hydrologic region	Estimated negligible by observation.
Subsurface Storage Change, ΔS_B	Entire hydrologic region	Calculated using observations of the fluctuation of the water table in a battery of 41 observation wells in the region and a value of aquifer storativity determined from the literature and from soil pressure-saturation data. (References: CcWorter and Sunada, 1977; Moustafa and Tinsley, 1984).

Table B2. Summary Description of the Methods Used for Determining Each of the Water Budget Components at Beni Magdul.

Water Budget Component	Location	Method of Determination
Surface Inflow, I_A	Inlet to Beni Magdul Canal from El-Mansuriya Canal	Measured with calibrated Nyrpic gate and upstream continuous water level recorder. (references: Bos, 1978; Rantz, et al, 1982)
	Mesqa from Nahia Canal to northwest quadrant of region	Estimated as proportional to flow measured at inlet of Beni Magdul Canal by the ratio of the area served by the *mesqa* to the total area served by Beni Magdul Canal; occasionally measured by current meter.
	Pumps located on Nahia, Lebini, and Beni Magdul Drains	Estimated as proportional to flow measured at inlet of Beni Magdul Canal by the ratio of the area served by the pumps to the total area served by Beni Magdul Canal.
Subsurface Inflow, I_B	Pumps taking from the lower sand aquifer	Estimated as proportional to flow measured at inlet of Beni Magdul Canal by the ratio of the area served by the pumps to the total area served by the Beni Magdul Canal; occasionally measured by Sparling meter.
Precipitation, I_C	Entire hydrologic region	Measured in rain gauge at Mansuriya weather staton about 2 km north of Beni Magdul.
Surface Drainage Outflow, O_{A1}	Along Nahia, Lebini, and Beni Magdul Drains	Estimated from observation and occasional measurement by current meter.
Surface Outflow to Irrigate Adjacent Areas, O_{A2}	*Mesqa* 4 where it exits the region to irrigate an area across Beni Magdul drain	Estimated as proportional to flow measured at inlet of Beni Magdul Canal by the ratio of the area served by the *mesqa* to the total area served by the Beni Magdul Canal.

Table B2 (Cont.). Summary Description of the Methods Used for Determining Each of the Water Budget Components at Beni Magdul

Water Budget Component	Location	Method of Determination
Vertical Subsurface Outflow, O_{B1}	Entire hydrologic region	Calculated from Darcy Equation for groundwater flow using measured values of piezometric head in the clay-silt aquifer and sand aquifer and using value of vertical hydraulic conductivity determined from aquifer pumping test and consolidation/permeameter tests. (Reference: Warner, et al 1984).
Horizontal Subsurface Outflow, O_{B2}	Along Nahia, Lebini, and Beni Magdul Drains	Calculated from Darcy Equation for groundwater flow using measured values of piezometric head from boundary observation wells and measured values of horizontal hydraulic conductivity from auger hole tests.
Crop Consumptive Use Outflow, O_C	Entire crop area	Calculated by means of FAO modified form of the Blaney-Criddle equation using climatic data from the Mansuriya weather station and crop surveys in the region for each agricultural season. (Reference: Doorenbos and Pruitt, 1977).
Evaporation Outflow, O_D	Beni Magdul Canal and *meaqa* water surfaces	Calculated from Class A Pan evaporation data from Mansuriya weather station.
Surface Storage Change, ΔS_A	Entire hydrologic region	Estimated negligible by observation.
Subsurface Storage Change, ΔS_B	Entire hydrologic region	Calculated using observations of the fluctuation of the water table in a battery of 30 observation wells in the region and a value of aquifer storativity determined from the literature and from soil pressure-saturation data. (References: McWhorter and Sunada, 1977; Moustafa and Tinsley, 1984).

Table B3. Summary Description of the Methods Used for Determining Each of the Water Budget Components at Om-Sen.

Water Budget Component	Location	Method of Determination
Surface Inflow, I_A	Inlet to Om-Sen *mesqa* from Daqalt Canal	Measured with cutthroat flume (1.8 m length, 0.3 m throat width) and reinforced concrete pipe calibrated for submerged flow by current meter with continuous water level recorders upstream and downstream of each structure. (References: Skogerboe et al, 1973; Bos, 1978; USBR, 1967; Rantz et al,1982).
	Three *saqias* on Daqalt canal upstream of Om-Sen *mesqa* inlet	Estimated as proportional to consumptive use in the Om-Sen region by the ratio of the area irrigated by the three *saqias* to the area of the Om-Sen region and adjusted by irrigation application efficiency. Flow periodically measured with small cutthroat flumes.
Subsurface Inflow, I_B	Along hydrologic boundaries	Calculated from Darcy Equation for groundwater flow using measured values of piezometric head from boundary observation wells and values of horizontal hydraulic conductivity measured nearby (References: McWhorter and Sunada, 1977; Bouwer, 1978; Bear, 1979; Warner et al, 1984)
Precipitation, I_C	Entire hydrologic region	Measured in rain gauge at Karada weather station, 20 km south of Om-Sen.
Surface Drainge Outflow, O_{A1}	Om-Sen Drain and Gad Alla Drain	Estimated using measurements of total flow developed from cutthroat flumes and continuous water level data and estimates of proportion of total drain flow contributed by hydrologic region.
Vertical Subsurface Outflow, O_{B1}	Entire hydrologic region	Not yet independently determined but estimated as very small.
Horizontal Subsurface Outflow, O_{B2}	Along hydrologic boundaries	Calculated from Darcy Equation for groundwater flow using measured values of piezometeric head from boundary observation wells and values of horizontal hydraulic conductivity measured nearby. (References; McWhorter and Sunada, 1977; Warner, et al 1984).

Table B3. (Cont.) Summary Description of the Methods Used for Determining Each of the Water Budget Components at Om-Sen.

Water Budget Component	Location	Method of Determination
Crop Consumptive Use Outflow, O_C	Entire crop area	Calculated by means of FAO modified from of the Blaney-Criddle equation using climatic data from the Karada weather station and crop surveys in the region for each agricultural season. (Reference: Doorenbos and Pruitt, 1977).
Evaporation Outflow, O_D	Om-Sen *mesqa* water surface	Calculated from Class A Pan evaporation data from Karada weather station.
Surface Storage Change, ΔS_A	Entire hydrologic region	Estimated negligible by observation.
Subsurface Storage Change, ΔS_B	Entire hydrologic region	Calculated using observations of the fluctuation of the water table in a battery of 35 observation wells in the region and a value of aquifer storativity determined from the literature and from soil pressure saturation data. (References: McWhorter and Sunada, 1977; El Mouelhi and Van Schilfgaarde, 1982; Warner, et al 1984).

Appendix C

Table C1

ABYUHA WATER BUDGET FOR SUMMER 1980

	INFLOW (M3)			OUTFLOW (M3)						STORAGE CHANGE (M3)		UNACCOUNTED (M3)
PERIOD	I(A)	I(B)	I(C)	O(A1)	O(A2)	O(B1)	O(B2)	O(C)	O(D)	dS(A)	dS(B)	SUM(I)-SUM(O)+dS
A80a	1011448	523	0	359495	33927	37800	0	235728	3014	0	-37000	305007
A80b	725537	524	0	152680	32773	37800	0	226505	3820	0	-1900	270583
M80a	808026	659	0	163892	25993	37800	0	186849	3469	0	84641	475323
M80b	1009987	702	0	100584	2274	40320	0	199907	4880	0	114583	777307
J80a	1121641	10866	0	103136	14847	37800	0	378744	4672	0	-39805	553503
J80b	882712	10867	0	85898	3100	37800	0	379826	3640	0	76459	459774
J80a	1128026	8143	0	134364	60817	37800	0	487939	3525	0	42795	454519
J80b	1041058	8686	0	82145	37420	40320	0	521738	3249	0	30239	395111
A80a	998540	8911	0	152220	12524	37800	0	353668	3097	0	-152	447990
A80b	1228623	9506	0	199196	35755	40320	0	378000	3110	0	-22713	559035
S80a	956463	5865	0	171706	49233	37800	0	237570	2499	0	-2813	460707
S80b	893014	5866	0	168865	35426	40320	0	222676	2062	0	-73649	355882
TOTAL	11805075	71118	0	1874181	344089	463680	0	3809150	41037	0	170685	5514741

TOTAL HYDROLOGIC AREA (FEDDANS) = 1200
TOTAL CROPPED AREA (FEDDANS) = 1100
TOTAL WATER DIVERTED (M^3/FEDDAN) = 10419
IRRIGATION EFFICIENCY (EI) FOR HYDROLOGIC AREA = [O(C)-I(C)]/[I(A)-O(A2)] = 0.33

'a' indicates the 1st day through the 15th day of the month
'b'indicates the 16th day through the end of the month

I(A) = total volume of surface inflow
I(B) = total volume of subsurface inflow
I(C) = total volume of precipitation
O(A1) = total volume of surface outflow in drains
O(A2) = total volume of surface outflow to irrigate adjacent areas
O(B1) = total volume of vertical subsurface outflow
O(B2) = total volume of horizontal subsurface outflow
O(C) = total volume of crop consumptive use
O(D) = total volume of outflow as evaporation from free water surfaces
dS(A) = total volume of storage change in surface water
dS(B) = total volume of storage change in subsurface water

Table C2

ABYUHA WATER BUDGET FOR WINTER 1980-81

	INFLOW (M3)			OUTFLOW (M3)						STORAGE CHANGE (M3)		UNACCOUNTED (M3)
PERIOD	I(A)	I(B)	I(C)	O(A1)	O(A2)	O(B1)	O(B2)	O(C)	O(D)	dS(A)	dS(B)	SUM(I)-SUM(O)+dS
O80a	528239	9950	0	100184	27074	37800	0	59180	2006	0	-42034	269911
O80b	553338	10614	0	192259	37886	40320	0	63125	1994	0	55529	283897
N80a	631146	8962	0	133569	24497	37800	0	121873	1493	0	-16030	304846
N80b	402455	8963	0	143058	16463	37800	0	122061	1104	0	-21113	69819
D80a	299809	6307	0	305595	10377	37800	0	138864	1125	0	-50427	-238072
D80b	667670	6727	0	514584	28202	40320	0	147844	1035	0	155743	98155
J81a	0	6097	0	5795	473	37800	0	133787	976	0	-274760	-447494
J81b	0	6304	0	8191	450	40320	0	142209	1175	0	105340	-80701
F81a	614121	7107	0	245421	104289	37800	0	191773	1178	0	105340	146107
F81b	310957	6160	0	153479	62734	35280	0	166162	1556	0	-7271	-109365
M81a	674840	7159	0	331488	60472	37800	0	245456	1796	0	30789	35776
M81b	584436	7637	0	240616	33695	40320	0	261820	2369	0	23596	36849
TOTAL	5267011	91987	0	2374239	406612	461160	0	1794154	17807	0	64702	369728

TOTAL HYDROLOGIC AREA (FEDDANS) = 1200
TOTAL CROPPED AREA (FEDDANS) = 1100
TOTAL WATER DIVERTED (M^3/FEDDAN) = 4419
IRRIGATION EFFICIENCY (EI) FOR HYDROLOGIC AREA = [O(C)-I(C)]/[I(A)-O(A2)] = 0.37

'a' indicates the 1st day through the 15th day of the month
'b'indicates the 16th day through the end of the month

I(A) = total volume of surface inflow.
I(B) = total volume of subsurface inflow
I(C) = total volume of precipitation
O(A1) = total volume of surface outflow in drains
O(A2) = total volume of surface outflow to irrigate adjacent areas
O(B1) = total volume of vertical subsurface outflow
O(B2) = total volume of horizontal subsurface outflow
O(C) = total volume of crop consumptive use
O(D) = total volume of outflow as evaporation from free water surfaces
dS(A) = total volume of storage change in surface water
dS(B) = total volume of storage change in subsurface water

Table C3

ABYUHA WATER BUDGET FOR SUMMER 1981

	INFLOW (M3)			OUTFLOW (M3)						STORAGE CHANGE (M3)		UNACCOUNTED (M3)
PERIOD	I(A)	I(B)	I(C)	O(A1)	O(A2)	O(B1)	O(B2)	O(C)	O(D)	dS(A)	dS(B)	SUM(I)-SUM(O)+dS
A81a	725985	523	0	827516	60809	37800	0	284886	2955	0	-36880	-524338
A81b	722986	524	0	406608	54207	37800	0	255984	4019	0	-1919	-37027
M81a	674666	659	0	203376	38629	37800	0	179170	3744	0	18427	231033
M81b	818771	702	0	276027	47943	40320	0	164076	3964	0	60524	347667
J81a	616753	10866	0	146789	42523	37800	0	366304	4672	0	9157	38688
J81b	764824	10867	0	86564	66559	37800	0	375928	3640	0	-12531	192669
J81a	799607	8143	0	126292	32302	37800	0	473319	3525	0	50052	184564
J81b	721896	8686	0	174208	37056	40320	0	513137	3249	0	-11515	-48903
A81a	681668	10875	0	127653	53469	37800	0	359972	3097	0	207	110759
A81b	749444	11601	0	272788	98488	40320	0	381555	3110	0	32727	-2489
S81a	741074	7316	0	106806	96433	37800	0	247503	2499	0	-615	256734
S81b	520334	7317	0	48293	16657	37800	0	239705	2062	0	57264	240398
TOTAL	8538008	78079	0	2802920	645075	461160	0	3841539	40536	0	164898	989755

TOTAL HYDROLOGIC AREA (FEDDANS) = 1200
TOTAL CROPPED AREA (FEDDANS) = 1100
TOTAL WATER DIVERTED (M^3/FEDDAN) = 7175
IRRIGATION EFFICIENCY (EI) FOR HYDROLOGIC AREA = [O(C)-I(C)]/[I(A)-O(A2)] = 0.49

'a' indicates the 1st day through the 15th day of the month
'b'indicates the 16th day through the end of the month

I(A) = total volume of surface inflow
I(B) = total volume of subsurface inflow
I(C) = total volume of precipitation
O(A1) = total volume of surface outflow in drains
O(A2) = total volume of surface outflow to irrigate adjacent areas
O(B1) = total volume of vertical subsurface outflow
O(B2) = total volume of horizontal subsurface outflow
O(C) = total volume of crop consumptive use
O(D) = total volume of outflow as evaporation from free water surfaces
dS(A) = total volume of storage change in surface water
dS(B) = total volume of storage change in subsurface water

Table C4

ABYUHA WATER BUDGET FOR WINTER 1981-82

	INFLOW (M3)			OUTFLOW (M3)						STORAGE CHANGE (M3)		UNACCOUNTED (M3)
PERIOD	I(A)	I(B)	I(C)	O(A1)	O(A2)	O(B1)	O(B2)	O(C)	O(D)	dS(A)	dS(B)	SUM(I)-SUM(O)+dS
O81a	442869	9950	0	275048	32128	37800	0	62463	2006	0	143307	186681
O81b	494960	10614	0	344366	29070	40320	0	66627	1994	0	-100608	-77411
N81a	720607	8962	0	220311	21666	37800	0	120937	1280	0	-22507	305068
N81b	337100	8963	0	87579	23801	37800	0	123557	946	0	-62914	9466
D81a	317747	6307	0	145329	25840	37800	0	142752	965	0	-26230	-54862
D81b	708390	6727	0	264723	16369	40320	0	152004	887	0	82019	322833
J82a	90887	6097	0	95807	343	37800	0	137636	336	0	-178085	-353023
J82b	37686	6304	0	45514	780	40320	0	146338	1007	0	-84267	-274236
F82a	525061	7107	0	220131	478	37800	0	197053	1010	0	49548	125244
F82b	436414	6160	0	225130	415	32760	0	170835	1333	0	49548	61649
M82a	392471	7159	0	187141	582	37800	0	254940	1539	0	15590	-66782
M82b	531468	7637	0	230530	623	40320	0	273017	2031	0	96369	88953
TOTAL	5035660	91987	0	2341609	152095	458640	0	1848159	15334	0	-38230	273580

TOTAL HYDROLOGIC AREA (FEDDANS) = 1200
TOTAL CROPPED AREA (FEDDANS) = 1100
TOTAL WATER DIVERTED (M^3/FEDDAN) = 4440
IRRIGATION EFFICIENCY (EI) FOR HYDROLOGIC AREA = [O(C)-I(C)]/[I(A)-O(A2)] = 0.38

'a' indicates the 1st day through the 15th day of the month
'b'indicates the 16th day through the end of the month

I(A) = total volume of surface inflow
I(B) = total volume of subsurface inflow
I(C) = total volume of precipitation
O(A1) = total volume of surface outflow in drains
O(A2) = total volume of surface outflow to irrigate adjacent areas
O(B1) = total volume of vertical subsurface outflow
O(B2) = total volume of horizontal subsurface outflow
O(C) = total volume of crop consumptive use
O(D) = total volume of outflow as evaporation from free water surfaces
dS(A) = total volume of storage change in surface water
dS(B) = total volume of storage change in subsurface water

Table C5

BENI MAGDUL WATER BUDGET FOR WINTER 1979-80

	INFLOW (M3)			OUTFLOW (M3)						STORAGE CHANGE (M3)		UNACCOUNTED (M3)
PERIOD	I(A)	I(B)	I(C)	O(A1)	O(A2)	O(B1)	O(B2)	O(C)	O(D)	dS(A)	dS(B)	SUM(I)-SUM(O)+dS
O79a	307094	6914	0	26520	5531	15914	0	176011	750	0	13570	102852
O79b	294954	6641	0	28288	5313	16975	0	185503	661	0	-17808	47047
N79a	259097	5834	0	26520	4667	15914	0	39437	454	0	21833	199772
N79b	166257	4483	0	28288	3587	15914	0	109563	372	0	-12643	373
D79a	144146	3245	2829	26520	2596	15914	0	84375	334	0	5743	26224
D79b	170847	3847	11493	28288	3077	16975	0	92053	321	0	5161	50634
J80a	0	0	0	13260	0	15914	0	74361	323	0	-30936	-134794
J80b	65889	1483	2122	14144	1187	16975	0	21812	397	0	-34121	-19142
F80a	176152	3966	4422	26520	3173	15914	0	131097	433	0	44633	52036
F80b	172840	3891	2564	24752	3113	14853	0	122182	449	0	-5584	8362
M80a	174461	3928	0	26520	3142	15914	0	163477	570	0	-12856	-44090
M80b	232934	5244	0	28288	4196	16975	0	163974	747	0	37024	61022
TOTAL	2164671	49476	23430	297908	39582	194148	0	1363845	5811	0	14016	350299

TOTAL HYDROLOGIC AREA (FEDDANS) = 842
TOTAL CROPPED AREA (FEDDANS) = 810
TOTAL WATER DIVERTED (M^3/FEDDAN) = 2624
IRRIGATION EFFICIENCY (EI) FOR HYDROLOGIC AREA = [O(C)-I(C)]/[I(A)-O(A2)] = 0.63

'a' indicates the 1st day through the 15th day of the month
'b' indicates the 16th day through the end of the month

I(A) = total volume of surface inflow
I(B) = total volume of subsurface inflow
I(C) = total volume of precipitation
O(A1) = total volume of surface outflow in drains
O(A2) = total volume of surface outflow to irrigate adjacent areas
O(B1) = total volume of vertical subsurface outflow
O(B2) = total volume of horizontal subsurface outflow
O(C) = total volume of crop consumptive use
O(D) = total volume of outflow as evaporation from free water surfaces
dS(A) = total volume of storage change in surface water
dS(B) = total volume of storage change in subsurface water

Table C6

BENI MAGDUL WATER BUDGET FOR SUMMER 1980

	INFLOW (M3)			OUTFLOW (M3)						STORAGE CHANGE (M3)		UNACCOUNTED (M3)
PERIOD	I(A)	I(B)	I(C)	O(A1)	O(A2)	O(B1)	O(B2)	O(C)	O(D)	dS(A)	dS(B)	SUM(I)-SUM(O)+dS
A80a	205543	4628	0	26520	3702	15914	0	207983	905	0	-29419	-74272
A80b	266411	5998	0	26520	4799	15914	0	199490	1011	0	18027	42702
M80a	245345	5524	0	26520	4419	15914	0	243097	1035	0	-31987	-72103
M80b	304821	6863	0	28288	5490	16975	0	50381	1297	0	9862	219115
J80a	297102	6689	0	26520	5351	15914	0	123230	1218	0	8302	139860
J80b	312851	7044	0	26520	5635	15914	0	147781	1182	0	17362	140225
J80a	337282	7594	0	26520	6075	15914	0	309458	1163	0	-17045	-31299
J80b	391576	8816	0	28288	7053	16975	0	410394	1004	0	12041	-51281
A80a	360669	8120	0	26520	6496	15914	0	342018	965	0	-10998	-34122
A80b	334803	7538	0	28288	6030	16975	0	314648	977	0	11387	-13190
S80a	182606	4111	0	26520	3289	15914	0	208036	900	0	-10192	-78134
S80b	145063	3266	0	26520	2613	15914	0	37875	868	0	-18481	46058
TOTAL	3384072	76191	0	323544	60952	194148	0	2594391	12525	0	-41141	233562

TOTAL HYDROLOGIC AREA (FEDDANS) = 842
TOTAL CROPPED AREA (FEDDANS) = 810
TOTAL WATER DIVERTED (M^3/FEDDAN) = 4103
IRRIGATION EFFICIENCY (EI) FOR HYDROLOGIC AREA = [O(C)-I(C)]/[I(A)-O(A2)] = 0.78

'a' indicates the 1st day through the 15th day of the month
'b'indicates the 16th day through the end of the month

I(A) = total volume of surface inflow
I(B) = total volume of subsurface inflow
I(C) = total volume of precipitation
O(A1) = total volume of surface outflow in drains
O(A2) = total volume of surface outflow to irrigate adjacent areas
O(B1) = total volume of vertical subsurface outflow
O(B2) = total volume of horizontal subsurface outflow
O(C) = total volume of crop consumptive use
O(D) = total volume of outflow as evaporation from free water surfaces
dS(A) = total volume of storage change in surface water
dS(B) = total volume of storage change in subsurface water

Table C7

BENI MAGDUL WATER BUDGET FOR WINTER 1980-81

	INFLOW (M3)			OUTFLOW (M3)						STORAGE CHANGE (M3)		UNACCOUNTED (M3)
PERIOD	I(A)	I(B)	I(C)	O(A1)	O(A2)	O(B1)	O(B2)	O(C)	O(D)	dS(A)	dS(B)	SUM(I)-SUM(O)+dS
O80a	322458	7260	0	26520	5808	15914	0	138266	694	0	20948	163464
O80b	230352	5186	0	26520	4149	16975	0	145188	608	0	13923	56021
N80a	202489	4559	0	26520	3647	15914	0	190254	471	0	-1384	-31142
N80b	175822	3959	0	28288	3167	15914	0	116235	351	0	-12383	3443
D80a	149950	3376	3572	26520	2701	15914	0	85778	288	0	18758	44455
D80b	163229	3722	7179	28288	2978	16975	0	94169	254	0	-8456	23010
J81a	62136	1399	2688	13260	1119	15914	0	85888	376	0	-5141	-55475
J81b	82836	1865	3607	14144	1492	16975	0	92720	566	0	-5141	-42730
F81a	248669	5599	0	26520	4479	15914	0	138703	434	0	7518	75736
F81b	224117	5046	0	34752	4037	13792	0	131760	521	0	-803	43498
M81a	228478	5144	2263	26520	4115	15914	0	171809	598	0	-4833	12096
M81b	250654	5643	0	28288	4515	16975	0	181461	718	0	1005	25345
TOTAL	2341190	52758	19309	306140	42207	193087	0	1572231	5879	0	24011	317724

TOTAL HYDROLOGIC AREA (FEDDANS) = 842
TOTAL CROPPED AREA (FEDDANS) = 810
TOTAL WATER DIVERTED (M^3/FEDDAN) = 2838
IRRIGATION EFFICIENCY (EI) FOR HYDROLOGIC AREA = [O(C)-I(C)]/[I(A)-O(A2)] = 0.68

'a' indicates the 1st day through the 15th day of the month
'b'indicates the 16th day through the end of the month

I(A) = total volume of surface inflow
I(B) = total volume of subsurface inflow
I(C) = total volume of precipitation
O(A1) = total volume of surface outflow in drains
O(A2) = total volume of surface outflow to irrigate adjacent areas
O(B1) = total volume of vertical subsurface outflow
O(B2) = total volume of horizontal subsurface outflow
O(C) = total volume of crop consumptive use
O(D) = total volume of outflow as evaporation from free water surfaces
dS(A) = total volume of storage change in surface water
dS(B) = total volume of storage change in subsurface water

Table C8

BENI MAGDUL WATER BUDGET FOR SUMMER 1981

	INFLOW (M3)			OUTFLOW (M3)						STORAGE CHANGE (M3)		UNACCOUNTED (M3)
PERIOD	I(A)	I(B)	I(C)	O(A1)	O(A2)	O(B1)	O(B2)	O(C)	O(D)	dS(A)	dS(B)	SUM(I)-SUM(O)+dS
A81a	136573	3075	3147	26520	2460	15914	0	211586	804	0	-6583	-121072
A81b	277554	6249	0	26520	4999	15914	0	193880	809	0	8537	50218
M81a	215756	4858	0	26520	3886	15914	0	256815	908	0	-16904	-100333
M81b	298126	6712	0	28288	5370	16975	0	200105	1272	0	24890	77718
J81a	388564	8748	0	26520	6999	15914	0	124437	1242	0	-37494	184706
J81b	305498	6878	0	26520	5503	15914	0	138710	1237	0	-1191	123301
J81a	322704	7266	0	26520	5813	15914	0	236279	1155	0	1990	46279
J81b	364862	8215	0	28288	6572	16975	0	300812	1092	0	35618	54956
A81a	347113	7815	0	26520	6252	15914	0	273654	1111	0	-18554	12923
A81b	303991	6844	0	28288	5475	16975	0	265467	965	0	1011	-5324
S81a	164787	3710	0	26520	2968	15914	0	214203	1027	0	-21750	-113885
S81b	275111	6194	0	26520	4955	15914	0	78684	957	0	42276	196551
TOTAL	3400639	76564	3147	323544	61252	194148	0	2494632	12579	0	11846	406041

TOTAL HYDROLOGIC AREA (FEDDANS) = 842
TOTAL CROPPED AREA (FEDDANS) = 810
TOTAL WATER DIVERTED (M^3/FEDDAN) = 4123
IRRIGATION EFFICIENCY (EI) FOR HYDROLOGIC AREA = [O(C)-I(C)]/[I(A)-O(A2)] = 0.75

'a' indicates the 1st day through the 15th day of the month
'b'indicates the 16th day through the end of the month

I(A) = total volume of surface inflow
I(B) = total volume of subsurface inflow
I(C) = total volume of precipitation
O(A1) = total volume of surface outflow in drains
O(A2) = total volume of surface outflow to irrigate adjacent areas
O(B1) = total volume of vertical subsurface outflow
O(B2) = total volume of horizontal subsurface outflow
O(C) = total volume of crop consumptive use
O(D) = total volume of outflow as evaporation from free water surfaces
dS(A) = total volume of storage change in surface water
dS(B) = total volume of storage change in subsurface water

Table C9

BENI HAGDUL WATER BUDGET FOR WINTER 1981-82

	INFLOW (M3)			OUTFLOW (M3)						STORAGE CHANGE (M3)		UNACCOUNTED (M3)
PERIOD	I(A)	I(B)	I(C)	O(A1)	O(A2)	O(B1)	O(B2)	O(C)	O(D)	dS(A)	dS(B)	SUM(I)-SUM(O)+dS
O81a	283977	6394	0	26520	5115	15914	0	152860	805	0	-4770	84387
O81b	270033	6080	0	26570	4864	16975	0	153518	714	0	9721	83193
N81a	262826	5918	0	26520	4734	15914	0	83741	518	0	-31942	105375
N81b	237505	5347	3607	28288	4278	15914	0	80712	392	0	11060	127935
D81a	226060	5090	0	26520	4072	15914	0	107878	379	0	-4757	71630
D81b	169035	3806	0	28288	3045	16975	0	76265	389	0	24245	72124
J82a	62136	1399	8593	13260	1119	15914	0	80874	280	0	-33938	-73257
J82b	82836	1865	5835	14144	1492	16975	0	82721	348	0	-51252	-76396
F82a	248669	5599	6719	26520	4479	15914	0	116131	438	0	71212	168717
F82b	224117	5046	3147	24752	4037	13792	0	107307	435	0	15528	97515
M82a	287947	6483	0	26520	5186	15914	0	138152	661	0	6124	114121
M82b	204333	4601	0	28288	3680	16975	0	145685	753	0	5504	19057
TOTAL	2559474	57628	27901	296190	46101	193087	0	1325844	6112	0	16735	794404

TOTAL HYDROLOGIC AREA (FEDDANS) = 842
TOTAL CROPPED AREA (FEDDANS) = 810
TOTAL WATER DIVERTED (M^3/FEDDAN) = 3103
IRRIGATION EFFICIENCY (EI) FOR HYDROLOGIC AREA = [O(C)-I(C)]/[I(A)-O(A2)] = 0.52

'a' indicates the 1st day through the 15th day of the month
'b'indicates the 16th day through the end of the month

I(A) = total volume of surface inflow
I(B) = total volume of subsurface inflow
I(C) = total volume of precipitation
O(A1) = total volume of surface outflow in drains
O(A2) = total volume of surface outflow to irrigate adjacent areas
O(B1) = total volume of vertical subsurface outflow
O(B2) = total volume of horizontal subsurface outflow
O(C) = total volume of crop consumptive use
O(D) = total volume of outflow as evaporation from free water surfaces
dS(A) = total volume of storage change in surface water
dS(B) = total volume of storage change in subsurface water

Table C10

BENI MAGDUL WATER BUDGET FOR SUMMER 1982

	INFLOW (M3)			OUTFLOW (M3)						STORAGE CHANGE (M3)		UNACCOUNTED (M3)
PERIOD	I(A)	I(B)	I(C)	O(A1)	O(A2)	O(B1)	O(B2)	O(C)	O(D)	dS(A)	dS(B)	SUM(I)-SUM(O)+dS
A82a	260079	5856	0	26520	4685	15914	0	142688	864	0	-19194	56070
A82b	230066	5180	0	26520	4144	15914	0	214985	937	0	-14979	-42233
M82a	136355	3070	0	26520	2456	15914	0	172045	1012	0	-15244	-93766
M82b	170550	3840	0	28288	3072	16975	0	58045	1302	0	26198	92906
J82a	229109	5158	0	26520	4127	15914	0	105425	1223	0	-10017	71041
J82b	176625	3977	0	26520	3181	15914	0	125867	1344	0	7803	15579
J82a	316486	7126	0	26520	5701	15914	0	206192	1260	0	-15322	52703
J82b	328985	7407	0	28288	2926	16975	0	291915	1119	0	17631	12800
A82a	327495	7374	0	26520	5899	15914	0	258500	980	0	-5730	21326
A82b	266754	6006	0	28288	4805	16975	0	279614	1121	0	-9722	-67765
S82a	229195	5160	0	26520	4128	15914	0	200367	935	0	667	-12842
S82b	229447	5166	0	26520	4133	15914	0	89304	831	0	16786	114697
TOTAL	2901146	65320	0	323544	49257	194148	0	2144947	12928	0	-21123	220519

TOTAL HYDROLOGIC AREA (FEDDANS) = 842
TOTAL CROPPED AREA (FEDDANS) = 810
TOTAL WATER DIVERTED (M^3/FEDDAN) = 3521
IRRIGATION EFFICIENCY (EI) FOR HYDROLOGIC AREA = [O(C)-I(C)]/[I(A)-O(A2)] = 0.75

'a' indicates the 1st day through the 15th day of the month
'b'indicates the 16th day through the end of the month

I(A) = total volume of surface inflow
I(B) = total volume of subsurface inflow
I(C) = total volume of precipitation
O(A1) = total volume of surface outflow in drains
O(A2) = total volume of surface outflow to irrigate adjacent areas
O(B1) = total volume of vertical subsurface outflow
O(B2) = total volume of horizontal subsurface outflow
O(C) = total volume of crop consumptive use
O(D) = total volume of outflow as evaporation from free water surfaces
dS(A) = total volume of storage change in surface water
dS(B) = total volume of storage change in subsurface water

Table C11

OM SEN WATER BUDGET FOR SUMMER 1982

	INFLOW (M3)			OUTFLOW (M3)						STORAGE CHANGE (M3)		UNACCOUNTED (M3)
PERIOD	I(A)	I(B)	I(C)	O(A1)	O(A2)	O(B1)	O(B2)	O(C)	O(D)	dS(A)	dS(B)	SUM(I)-SUM(O)+dS
AB2a	139428	0	0	61389	0	0	0	37141	639	0	-8156	32103
AB2b	103523	0	0	69560	0	0	0	28688	639	0	-8909	-4273
MB2a	82209	0	0	52862	0	0	0	19874	944	0	2615	11144
MB2b	152740	0	0	72978	0	0	0	10526	944	0	6940	75232
JB2a	124768	0	0	69530	0	0	0	15976	981	0	1286	39567
JB2b	161165	0	0	115670	0	0	0	47077	981	0	14798	12235
JB2a	168914	0	0	158946	0	0	0	105251	1037	0	5095	-91225
JB2b	185675	0	0	55278	0	0	0	118107	1037	0	-587	10666
AB2a	130730	0	0	74162	0	0	0	89718	862	0	382	-33630
AB2b	111927	0	0	99970	0	0	0	88661	862	0	-6016	-83582
SB2a	131703	0	0	60914	0	0	0	70627	749	0	3413	2826
SB2b	107578	0	0	36919	0	0	0	51554	749	0	-2203	16153
TOTAL	1600360	0	0	928178	0	0	0	683200	10424	0	8658	-12784

TOTAL HYDROLOGIC AREA (FEDDANS) = 260
TOTAL CROPPED AREA (FEDDANS) = 235
TOTAL WATER DIVERTED (M^3/FEDDAN) = 6810
IRRIGATION EFFICIENCY (EI) FOR HYDROLOGIC AREA = [O(C)-I(C)]/[I(A)-O(A2)] = 0.43

'a' indicates the 1st day through the 15th day of the month
'b' indicates the 16th day through the end of the month

I(A) = total volume of surface inflow
I(B) = total volume of subsurface inflow
I(C) = total volume of precipitation
O(A1) = total volume of surface outflow in drains
O(A2) = total volume of surface outflow to irrigate adjacent areas
O(B1) = total volume of vertical subsurface outflow
O(B2) = total volume of horizontal subsurface outflow
O(C) = total volume of crop consumptive use
O(D) = total volume of outflow as evaporation from free water surfaces
dS(A) = total volume of storage change in surface water
dS(B) = total volume of storage change in subsurface water

Table C12

OM SEN WATER BUDGET FOR WINTER 1982-83

	INFLOW (M3)			OUTFLOW (M3)						STORAGE CHANGE (M3)		UNACCOUNTED (M3)
PERIOD	I(A)	I(B)	I(C)	O(A1)	O(A2)	O(B1)	O(B2)	O(C)	O(D)	dS(A)	dS(B)	SUM(I)-SUM(O)+dS
O82a	151599	0	624	99268	0	0	0	29237	5040	0	-6317	12361
O82b	58058	0	936	29154	0	0	0	27477	4704	0	-17710	-20051
N82a	89571	0	6777	28416	0	0	0	19300	4460	0	8261	52433
N82b	100570	0	624	39276	0	0	0	25726	2772	0	8956	42376
D82a	128265	0	4243	33511	0	0	0	19410	2184	0	2784	80187
D82b	142717	0	6739	55401	0	0	0	25499	2604	0	-11048	54904
J83a	176377	0	8237	136532	0	0	0	22801	2033	0	-768	22480
J83b	118521	0	9485	38382	0	0	0	25051	2974	0	-5658	55941
F83a	15559	0	624	2651	0	0	0	33546	2520	0	-2859	-25393
F83b	11703	0	549	14868	0	0	0	30699	1999	0	-1058	-36372
M83a	77980	0	624	22638	0	0	0	37118	9912	0	6772	15708
M83b	77552	0	499	30407	0	0	0	38948	5796	0	-6495	-3595
TOTAL	1148472	0	39961	530504	0	0	0	334812	46998	0	-25140	250979

TOTAL HYDROLOGIC AREA (FEDDANS) = 260
TOTAL CROPPED AREA (FEDDANS) = 235
TOTAL WATER DIVERTED (M^3/FEDDAN) = 4887
IRRIGATION EFFICIENCY (EI) FOR HYDROLOGIC AREA = [O(C)-I(C)]/[I(A)-O(A2)] = 0.26

'a' indicates the 1st day through the 15th day of the month
'b'indicates the 16th day through the end of the month

I(A) = total volume of surface inflow
I(B) = total volume of subsurface inflow
I(C) = total volume of precipitation
O(A1) = total volume of surface outflow in drains
O(A2) = total volume of surface outflow to irrigate adjacent areas
O(B1) = total volume of vertical subsurface outflow
O(B2) = total volume of horizontal subsurface outflow
O(C) = total volume of crop consumptive use
O(D) = total volume of outflow as evaporation from free water surfaces
dS(A) = total volume of storage change in surface water
dS(B) = total volume of storage change in subsurface water

APPENDIX D

AMERICAN EQUIVALENTS OF EGYPTIAN ARABIC TERMS AND MEASURES COMMONLY USED IN IRRIGATION WORK

Land Area	in *sq meters*	in *acres*	in *feddans*	in *hectares*
1 acre	4,046.856	1.000	0.963	0.405
1 *feddan*	4,200.833	1.038	1.000	0.420
1 hectare(ha)	10,000.000	2.471	2.380	1.000
1 *sq* kilometer	100×10^4	247.105	238,048	100.000
1 *sq* mile	259×10^6	640.000	616.400	259.000

Water Measures	*feddan*-cm	*Acre*-feet	*Acre*-inches
1 billion m^3	23,809,000.000	810,710.000	
1,000 m^3	23.809	0.811	9.728
1,000 m^3/*feddan* (= 238 mm of rainfall)	23.809	0.781	9.372
420 m^3/*feddan* (= 100 mm of rainfall)	10.00	0.328	3.936

Other Conversions

1 *ardeb* = 198 liters = 5.62 bushels (U.S)
1 *ardeb/feddan* = 5.41 bushels/acre
1 kg/*feddan* = 2.12 lb/acre
1 donkey load = 100 kg
1 camel load = 250 kg
1 donkey load of manure = 0.1 m^3
1 camel load of manure = 0.25 m^3

Egyptian Units for Field Crops

Crop	Eg. Unit	in kg	in lbs	in bushels
Lentils	*ardeb*	160.0	352.42	5.87
Clover	*ardeb*	157.0	345.81	5.76
Broad beans	*ardeb*	155.0	341.41	6.10
Wheat	*ardeb*	150.0	330.40	5.51
Maize,Sorghum	*ardeb*	140.0	308.37	5.51
Barley	*ardeb*	120.0	264.32	5.51
Cottonseed	*ardeb*	120.0	264.32	8.26
Sesame	*ardeb*	120.0	264.32	
Groundnut	*ardeb*	75.0	165.20	7.51
Rice	*dariba*	945.0	2081.50	46.26
Chick-peas	*ardeb*	150.0	330.40	
Lupine	*ardeb*	150.0	330.40	
Linseed	*ardeb*	122.0	268.72	
Fenugreek	*ardeb*	155.0	341.41	
Cotton(unginned)	*metric qintar*	157.5	346.92	
Cotton(lint or ginned)	*metric qintar*	50.0	110.13	

Egyptian Farming and Irrigation Terms

fara = branch
marwa = small distributer, irrigation ditch
zawariq = small open field drain
mesqa = small canal feeding from 10 to 40 farms
qirat = cf. English "karat," A land measure of 1/24 *feddan*, 175.03 m^2
qaria = village
sahm = 1/24th of a *qirat*, 7.29 m^2
saqia = animal powered water wheel
sarf = drain (vb.), or drainage. See also *masraf*, (n.)