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Managing the water balance of The Fayoum Depression, Egypt

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Abstract. A study of the water balances of The Fayoum irrigated lands and Lake Qarun was made to investigate the management of the irrigation system and the efficiency of irrigation water use. The two water balances are strongly interrelated. The drainage flow to Lake Qarun and the water level of the Lake are in delicate balance. A rise in Lake level causes the inundation of adjacent land. Management of The Fayoum water balance assumes control over irrigation water flows, but this control has technical and organizational limitations.

Also discussed is the influence of irrigation practices in The Fayoum on the water balance (e.g., the autumn flushing of fields and farmers' preference for not irrigating at night in winter).

Notwithstanding a high overall efficiency, irrigation efficiency during the winter is low. The reasons for this are given, together with the constraints against improving system management.

Improved uniformity of the division and application of irrigation water will enable a better technical control of flows and will result in better water management in The Fayoum.

Abbreviations: FID – Fayoum Irrigation Department, 1 feddan (fe) – 0.4 ha, 1 mcm – 1 million cubic metres: an average annual flow of 3.17 m^3/s gives 100 mcm, m^3/fe.year – supplied volume (m^3) per surface area (fe) per year: 1000 m^3/fe.year equals 240 mm/year, MSL – Mean Sea Level

Introduction

The Fayoum Depression, some 90 km south-west of Cairo, is one of the depressions in the limestone plateau of the Egyptian Western Desert (Fig. 1). It is connected to the Nile Valley by a natural channel, the Bahr Yusuf. The topographic and hydrological boundaries are sharp. The desert rises from the irrigated land, except in the north-west where Lake Qarun fills the bottom of the Depression. Land slopes from El Lahun, 25 m above MSL, to Lake Qarun, 43.40 m below MSL. The Lake has no natural outlet and water only leaves it through evaporation.

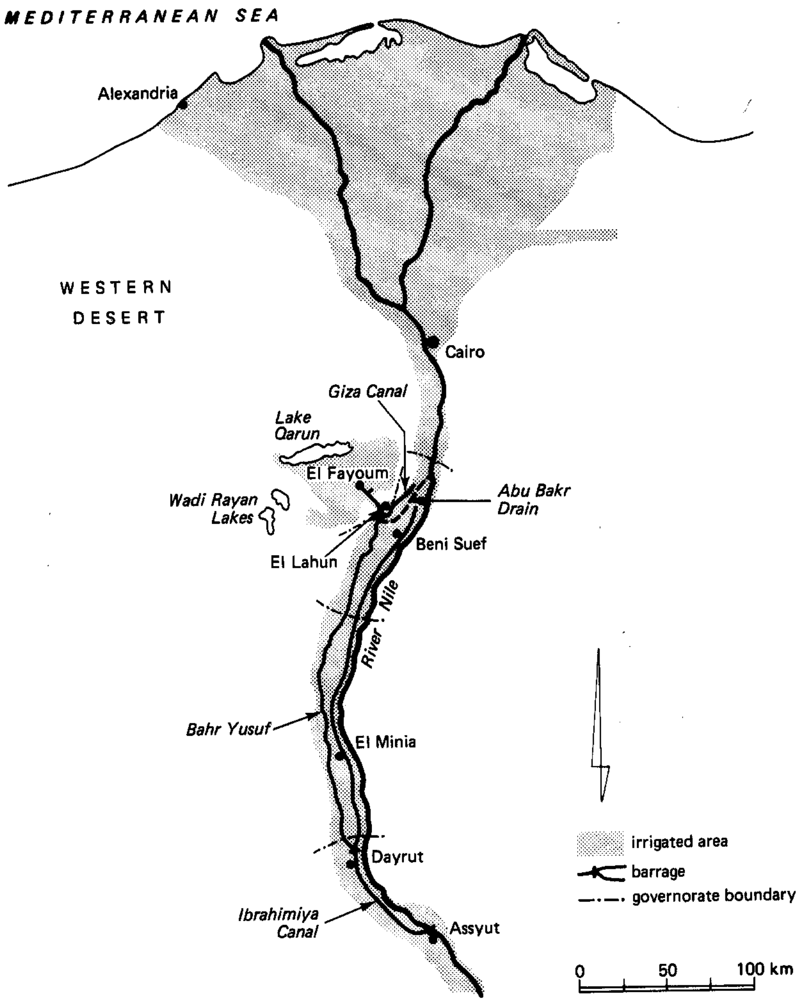

Fig. 1. **The Fayoum Depression.**

The Fayoum Irrigation Department/FID is responsible for the management of the irrigation system. The performance of the Department is evaluated in three ways:

Water level of Lake Qarun. The steady and uncontrolled rise of the Lake level in recent decades has caused a loss of land. It has also necessitated the construction of a dike along part of the southern shore. Approximately 4000 ha suffer from drainage and/or salinity problems. For low-lying areas near the shore, gravity drainage has ceased to be possible and formerly productive land is annually inundated with Lake water, which has a salinity of about 38 g/l. The

Egyptian Government, bearing in mind that its population is increasing, that it is already importing food, and that 96% of its territory is desert, is unable to accept any loss of agricultural land.

Agricultural production. Unfortunately, no reliable figures on crop production can be presented here. That it is a measure for the performance of the system is demonstrated by a message from the Minister of Agriculture to the Governor of The Fayoum in the spring of 1987: he commended the authorities in The Fayoum for the increase in production.

Farmers' complaints. Compaints by farmers are taken seriously in The Fayoum. Every individual or group can resort to the irrigation or political authorities to ask for an increased supply of water. The supply of water, free of charge, is considered a basic right. The irrigation authorities can be forced to increase supplies, even if "technically" not feasible.

The rise in Lake Qarun's water level alerted the authorities of the Ministry of Public Works and Water Resources in Cairo and the Governor of The Fayoum. In 1983, this led to the establishment of The Fayoum Water and Salt Balance Model Project. The overall Project objective was to aid in optimizing the use of water resources in The Fayoum. To investigate the management of the irrigation system and the efficiency of irrigation water use, the Project included a study of the water balances of The Fayoum irrigated lands and Lake Qarun.

This paper describes The Fayoum Depression and Lake Qarun. It then discusses the control over water flows by the FID, with its organizational and technical limitations. In "Materials and methods", it describes the investigations, and then presents and discusses the results. In its final section, it summarizes the conclusions.

General information

The Fayoum Depression

The Fayoum Depression has a long and varied history of irrigation, which started before 2000 B.C. The first major irrigation works were related to the legendary Lake Moeris. An interesting review of this history was recently published (Garbrecht 1987). The present irrigation system was constructed in the first two decades of this century. It supplies irrigation water to a gross irrigable area of 150 000 ha, of which about 132 000 ha are irrigated each year. The Fayoum irrigation system has been described by Wolters et al. (1987a).

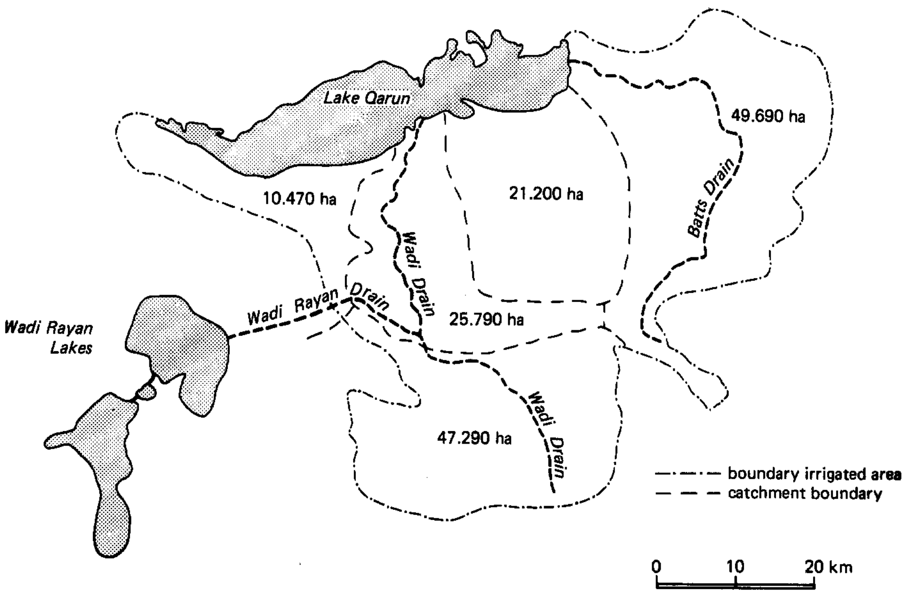

Fig. 2. Drainage catchments of The Fayoum.

The irrigation water for The Fayoum is released to the River Nile from the Aswan High Dam – as is the total water supply for Egypt. The water for The Fayoum is diverted from the Nile into the Ibrahimiya Canal at Assiut. At Dairut, 284 km upstream of El Lahun, flow is diverted from the Ibrahimiya Canal to Bahr Yusuf (see Fig. 1).

Until 1973–1974, all drainage water from The Fayoum Depression used to end up in Lake Qarun. At that time, a drainage diversion to the Wadi Rayan Depression became operational. Construction works included a 9-km-long open channel and an 8-km-long tunnel through the desert ridges between The Fayoum and Wadi Rayan. At present, drainage to Lake Qarun comes from the two main drains, Batts and Wadi, and from the catchment of several minor drains. About 69% of The Fayoum drains discharge into Lake Qarun. The Wadi Rayan Depression is now the drainage base for the remaining 31% of the area (Fig. 2).

The climate of The Fayoum is arid. It is characterized by a long dry summer and a short winter with an average annual rainfall of 10 mm. The average annual evaporation of open water is 1950 mm for the years 1960 to 1976. Prior to the irrigation season, the cropping pattern is decided upon by the Ministry of Agriculture. The actual cropping pattern is known to differ from the "theoretical" one, but to an unknown extent. The Ministry of Public Works and Water Resources calculates the water requirements for a whole year in advance and the FID demands the water it needs accordingly. Winter crops include berseem,

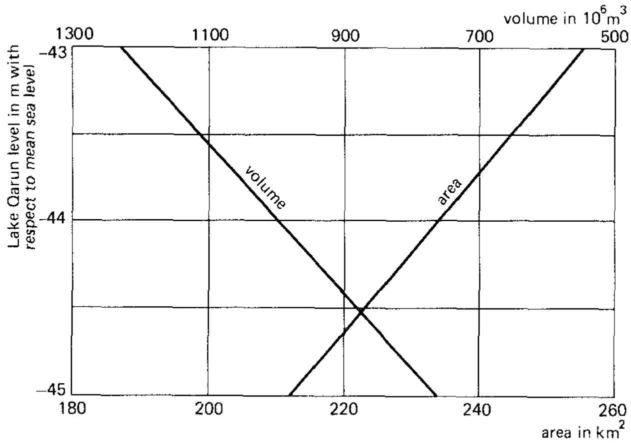

Fig. 3. Level-area-volume characteristics of Lake Qarun.

wheat, beans, and vegetables. Summer crops are cotton, rice, maize, sorghum, and vegetables, especially tomatoes and water melons.

Lake Qarun

Lake Qarun fills the bottom of The Fayoum Depression. The area of the Lake depends on its water level, and averages 247 sq km at present. Its average water level is 43.4 m below Mean Sea Level (MSL) at Alexandria. Figure 3 shows the level-area-volume relationships, which are taken linearly over the ranges used. Since the Lake has no natural outlet, a delicate balance exists between inflow and evaporation. There is a seasonal variation in water level: the difference between the annual high in April and the low in September is 45 to 60 cm. The reason for this variation is that when evaporation is high in summer, Lake inflow is limited. Water is used efficiently and some drainage water is re-used for irrigation. In winter, however, evaporation and thus crop water requirements are lower but supplies are generous, resulting in Lake inflow exceeding evaporation.

The evaporation from the Lake depends not only on its surface area, but also on the salinity of its water. This salinity is increasing with time because salts do not evaporate. Annually, the drainage water carries roughly 500 000 tons of salt to the Lake. In 1979, the Nasr Salines Company measured the salinity of the Lake water. The 650 samples showed an average salinity of 37.6 g/l.

Evaporation from saline water bodies is lower than that from the same water bodies without salinity because dissolved salts reduce the free energy of water molecules and thus the saturation vapour pressure over a saline surface. Man-

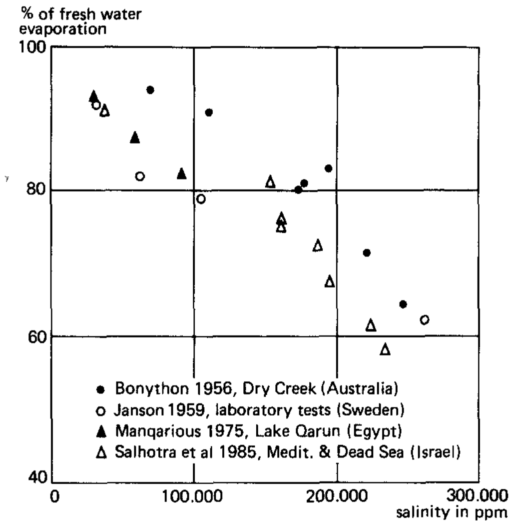

Fig. 4. Reduction in evaporation due to salinity of water.

qarious (1979) measured the influence of the salinity of Lake Qarun on the evaporation. Figure 4 shows that these measurements agree with measurements elsewhere (Janson 1959; Bonython 1956; Salhotra et al. 1985). Expressing the evaporation of saline water as a percentage of the evaporation of fresh water, depending only on salinity, is not entirely correct because the ionic composition of the water has an effect on the reduction of the saturation vapour pressure (Salhotra et al. 1985). Available data, however, do not allow such detail to be taken into account. More detailed research in the future, including measurements of saturated vapour pressure over the Lake and tests to indicate the influence of the ionic composition of Lake water, might improve the accuracy of the reduction percentage chosen to be 91.5%.

Figure 5 shows the average annual water level of Lake Qarun from 1885 onward, with only the years 1892 to 1899 missing. The water levels before 1900 were derived from Brown (1892). Three observations can be made from Fig. 5:

A marked fall in Lake level before the turn of the century. This fall might be related to the famous breach in the dikes of Bahr Yusuf in 1819 or 1820, which Mohamad Ali's people only succeeded in closing six months after its occurrence (Brown 1892). In this period, the Nile flood had uninterrupted access to The Fayoum, and the Lake Qarun level must have risen considerably. We will probably never know whether there were more dike breaches in the period between 1820 and 1885. All of them – some more, some less – will have contributed to a Lake level so high that it was still falling after 1885.

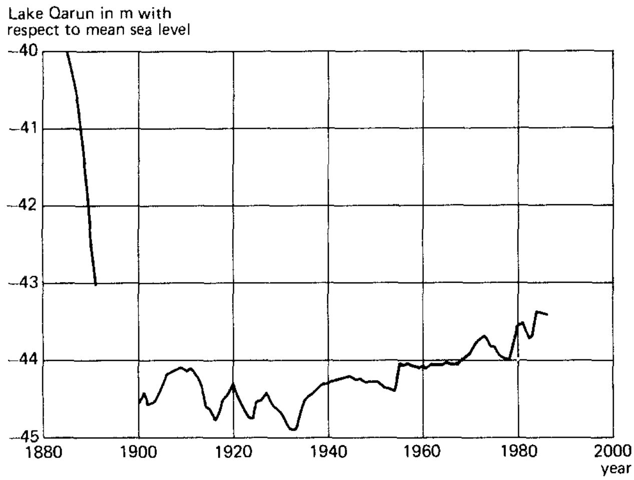

Fig. 5. Average annual water levels of Lake Qarun, 1885–1986.

The rise in Lake levels since the early 1950s, the years in which the Revolution took place in Egypt. Larger irrigation supplies enabled an intensification of land use, resulting in more drainage water and a rise in the Lake level.

The fall in Lake level just after 1973. In that year, the drainage diversion to the Wadi Rayan Depression became operational. Later on, following the reduction of Lake Qarun inflow, falling levels opened possibilities for again increasing the irrigation supplies to The Fayoum. In 1983 and 1984, the trashracks upstream of the tunnel diverting drainage water to the Wadi Rayan Depression became clogged; discharges to the Depression decreased and went to Lake Qarun instead. In those years, Lake inflow far exceeded Lake evaporation, causing a rise in Lake water level.

Salts do not evaporate from the Lake, neither does sediment. At present, the annual rate of sedimentation of the Lake bed is 0.004 m. And, although in the beginning of this century the sediment load of the drainage water was higher, the total irrigation supplies were much lower than they are today. Sedimentation accounts for only a 0.4 m rise in 100 years of observation, so is only of little significance.

Organizational limitations of control over water flow

The FID demands water on the basis of an assumed average climate and an annually presumed cropping pattern. In reality, these conditions will seldom be met. In a "hot" year, crops evapotranspirate more water than under average conditions, and in a "cold" year they evapotranspirate less water. Delays in planting, due to shortage of labour, the untimely availability of seeds and fertilizer, or over-irrigation (EWUP 1984), influence the deviations from the assumed conditions. Also the coincidence of a planting period with the fasting month Ramadan has been observed to delay planting. A delay in planting is a difficulty for the system management because water for The Fayoum is demanded one week in advance and with an uncertainty of planting dates, it is impossible to give a correct forecast of the water needs for every week. Once the water is released upstream, it will flow – by gravity and continuously – whether it is going to be used by crops or not.

Moreover, if the released flow at Dayrut differs from the demanded flow, the FID cannot be held responsible for that. Tail-end problems are universal in irrigation, and The Fayoum happens to be at the tail of Bahr Yusuf. The upstream Governorates of Minia and Beni Suef are supplied with water first, then comes The Fayoum. The location at the tail is not only unfavourable in summer, but also in winter. The measures taken to counteract this in winter are worth mentioning. Excess winter water from upstream governorates had to be swallowed at Lahun. This especially occurred at the start of the annual closure period, fixed at one date for all of Upper Egypt. The irrigation systems of Minia and Beni Suef were emptied within a few days, and this resulted in a surplus discharge in Bahr Yusuf at Lahun. There, because the Abu Bakr drain – the drainage spill from the days of the ancient flood irrigation – was out of use, the only spill capacity for the tail of Bahr Yusuf was The Fayoum itself and the Giza Canal. The solution to these spill problems has been a shift in the start of the closure period for The Fayoum. Since 1975, it has started one week later than for the upstream governorates. Also, the Abu Bakr Drain has been rehabilitated and is ready to dispose of any excess winter supply.

The irrigation system receives water from the Nile and supplies water continuously to rotational units. What happens downstream of these points of supply is not the responsibility of the FID. Sometimes, farmers illegally increase their supply through the unauthorized modification of structures. Any discharge a farmer takes from the system in excess of his regular supply is "stolen" from another farmer. FID district engineers are responsible for having any damage to the offtakes repaired and, in summertime, inspect structures at least daily. An experiment with irrigation police was started in The Fayoum some years ago to counteract any illegal action in the irrigation system. Violators can be found but mostly get away with their practices because it is considered unacceptable to resort to punishment. Still, the experiment has been reported to be beneficial, but budget considerations prevent the appointment of irrigation police throughout the country. Unauthorized "modifications" of structures actually prove that irrigation officials have no absolute control over the process of irrigation. In striving for a just division of flow over The Fayoum, the FID has in recent years been using a "destruction-proof" outlet from main canals. The outlet is made of reinforced concrete with a steel crest and very long wingwalls. Another solution, which would prevent irrigators from having direct access to the main canals, would be to construct "ganabias", canals that have an offtake from the main and serve several laterals previously in direct connection with the main. This solution is not considered feasible because of higher costs and loss of land.

Irrigation management in many places over the world has two regimes: the formal, visible, operation of some eight hours of the day and the informal, invisible, operation of the night (Chambers 1986). Inspections by district engineers and flow measurements, for example, always take place during daytime. Water levels, formally, are observed by FID staff at 8.00 and 16.00 hrs every day. What happens is between these times is not recorded. In The Fayoum, the only round-the-clock observations are performed by automatic, rotating drum, water level recorders at the head of main canals and the outfalls of main drains. These register the overall flows.

Technical limitations of control over water flow

For an effective control of the irrigation system, it must be possible to measure and monitor flows accurately, and the system should not be sensitive to inaccuracies of measurement. The accuracy of flow measurement in The Fayoum can be high because of the presence of weirs. Weirs are used to divide flow and to dissipate head. Hydraulic ratings of weirs in their original condition are still valid and, for weirs with a widened crest or with pipes through their sill, hydraulic theory will yield ratings with an error of less than 5% (Wolters et al. 1987b). At regulators, the accuracy of measurement is less favourable and although they are not many, they are at key points. Wolters et al. (1987a) show that Bahr Wahby (shown in Fig. 6), which serves an area of 30 000 ha, receives 10 to 20% less water than required, mainly because the rating of the head regulator is not known and changes regularly because of silting and channel maintenance. In the same paper, the sensitivity of the system to inaccuracies in monitoring and regulation are discussed. It can safely be estimated that the total annual flow supplied to The Fayoum, 2304 mcm, is known with an error of about 5%; 2304 mcm plus or minus about 115 mcm.

The level of Lake Qarun can be read accurately. But, for two reasons, it cannot be predicted with an accuracy better than 0.1 m. Firstly, there is the climate, the standard deviation of the evaporation in the years 1960 to 1976 being 7%. On an average of 1800 mm (evaporating from the salt lake), this is more than 0.1 m. Secondly, there is the accuracy of measurement of drainage flows.

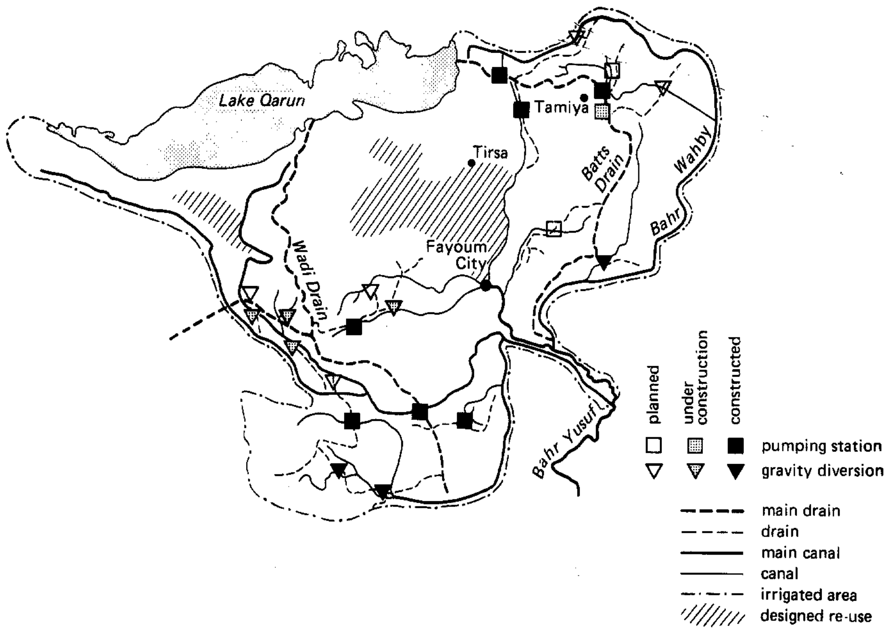

Fig. 6. Re-use stations in The Fayoum.

This error exceeds 5% because not all drain flows are measured with weirs. Accordingly, the drainage to Lake Qarun is known with an error of about 21 mcm per year. This volume equals a change in Lake level of 0.09 m.

Owing to the technical limitations, the FID, even if nothing else were to interfere with the operation of the system, can never accurately predict what will be the result of one year's operation in terms of Lake Qarun's water level.

Management of the system in practice

In practice, complaints by farmers and the water level of Lake Qarun are "the thermometer" for managing the irrigation system. Complaints stem from lack of irrigation water. Weeds in canals obstruct flow and are part of the cause of under-irrigated tail-ends. Maintenance of the canals, often referred to as weed cleaning, is important because the conveyance capacity increases and more water will reach the tail-ends. During the last few years, the public companies for canal maintenance have been re-organized and are better supervised by the FID. The companies' performance is monitored and has improved greatly with a minimum input of new equipment. At present, all main canals and the majority of main drains are maintained once a year, and although there is still room for improvement, complaints are less serious and fewer in number.

The Governor of The Fayoum chairs a meeting every two weeks to discuss complaints by farmers. Present at this meeting are the Chief of Security, the Chief of the Governorate Council, the Undersecretary of the Governorate, the Undersecretary of State for the Ministry of Public Works and Water Resources, the Directors General of the Departments of Irrigation and Agriculture, the Chief of the Irrigation and Agriculture Commission of the Governorate, the Heads of The Fayoum districts, and some members of the Governorate Council. Moreover, experts (e.g., farmers or inspectors) are invited if required. After a justified claim, immediate action is taken. If the problem happens to be a low supply at the Lahun regulators, a notice can be sent directly to the Minister to request adjustment, if possible, of the division of flow over the three Governorates served by Bahr Yusuf. This demonstrates that the FID cannot ignore complaints. On the other hand, complaints are used to manage the system: if there are none, supply is anticipated to be too generous and flow at Lahun can be reduced.

The level of Lake Qarun is also used in managing the system. If the flow supplied to The Fayoum should be sufficient in total, the FID, before being able to give in to the general request for some more water, consults the staff gauge of the last weir in the Batts Drain flowing to Lake Qarun. If drainage flows are high, water is being wasted and there is neither scope nor reason to increase supplies.

Materials and methods

The management of irrigation water and the efficiency of its use in The Fayoum have been evaluated with the water balances of The Fayoum irrigated land and Lake Qarun. The water balance of The Fayoum irrigated lands reads:

$$IRR + RAIN = ETC + DR + EL + CSMS + REST$$

with the following terms:

IRR : Irrigation intake at Lahun
RAIN : Rainfall
ETC : Evapotranspiration by crops
DR : Drainage flow to Lake Qarun and the Wadi Rayan lakes
EL : Evaporation losses
CSMS : Change in soil moisture storage
REST : Rest-term or closing error

Calculation or measurement of part of the terms of the water balance and subsequent substitution into the equation, yields a remaining term. Here, irrigation flows are measured and evapotranspiration and evaporation losses are calculated from the cropping pattern, climatological data, and area of open water. The theoretical crop water use is calculated, assuming well-watered conditions for the crop. When the calculated evapotranspiration exceeds the water supply to the crop, soil moisture will be depleted and potential evapotranspiration will be reduced to actual. Evaporation losses include evaporation from canal water surfaces and from fallow lands. Soil moisture changes are negative for depletion and positive for recharge, but are assumed to be nil over a period of years. Drainage is then a result of the calculation.

The water balance calculations, for 1983–1986, were made with the aid of a computer. Calibration of the model was done for 1985. Calculated drainage outflow was compared with measured values and the closing error ("rest term") of the water balance appeared to be small: summation of the closing error and the annual change in soil moisture is 29.4 mcm or 1.3% of the average annual intake of 2304 mcm in 1983–1986 (Table 1; this table will be discussed in "Results"). This is clearly within the overall accuracy of measurement of irrigation and drainage flows, estimated at not better than 5%. Such considerations are also the reason why the average annual rainfall of 10 mm is neglected. Besides evaporation being about twenty times more than the rainfall depth, the annual rain volume is only 15 mcm or 0.7% of the annual irrigation intake.

For the calculations, it is assumed that there is no significant groundwater flow into or out of The Fayoum because the measured drainage flows are, within limits of measurement accuracy, equal to the drainage water inflow into the Lake as determined from the water balance of Lake Qarun. The water balance of Lake Qarun reads:

$$\text{INDR} + \text{RAIN} + \text{SEEP} = \text{EVAP}$$

with the following terms:

INDR : Inflow of drainage water
RAIN : Rainfall
SEEP : Inflow of seepage water
EVAP : Evaporation from the lake surface

The wâter balance was studied for 1970–1986 and is derived from measured Lake levels and calculated average annual evaporation. Measured drainage flows were not available for the complete period, but as far as drainage was measured, it confirmed what the water balance found.

Main Lake inflow is from drainage water. The other inflow terms such as rainfall, seepage, and inflow from a freshwater well (where fishermen drink) are negligible in terms of volume. The average depth of the Lake at −43.40 MSL is 4.7 m and the average annual evaporation from it is 1800 mm, which corresponds to almost 40% of the Lake depth. For the water balance of Lake Qarun, a constant evaporation of 91.5% of freshwater evaporation was used, solely based on the actual measurements of Manqarious (1979, see Fig. 4). The bottom of the Lake consists of a layer of heavy clay with an average thickness of 8 m.

The two main drains discharging into the Lake are measured at weirs, as close as possible to their outfalls into the Lake. Full measurement of the drainage from the other, minor drains is impractical because of their number and the backwater effect at their outfalls into the Lake. Also, seasonal flow variations are high. In summer, almost all drainage water from the minor drains is re-used before it can flow to the Lake. In winter, sometimes large quantities of water are observed discharging into the Lake.

Results

The water balances for The Fayoum irrigated lands and Lake Qarun are given in Table 1 and 2, respectively. Table 1 shows that in 1983–1986 an average an-

Table 1. Average monthly water balances for The Fayoum, 1983–1986. (Terms are expressed in mcm and percentage of monthly irrigation water supply.)

	Irrigation water supply	Evapo-transpiration				Total drainage		Evapo-ration losses		Changes in soil moisture		Rest-term	
		Poten-tial		Actual									
	mcm	mcm	%	mcm	%	mcm	%	mcm	%	mcm	%	mcm	%
Jan	70.0	58.1	83	55.3	80	49.6	71	4.6	7	−28.3	−42	−11.2	−16
Feb	144.9	79.9	55	78.3	54	54.4	38	5.7	4	−4.6	−3	11.2	8
Mar	195.9	126.1	64	118.6	61	65.2	33	7.5	4	4.7	2	0	0
Apr	197.1	107.5	55	107.5	55	61.8	31	10.4	6	14.4	7	3	2
May	201.2	159.6	79	140.1	70	49.6	25	39.4	20	−27.9	−14	0	0
Jun	215.2	199.8	93	175.8	82	39.1	18	32.9	15	−32.5	−15	0	0
Jul	250.0	224.8	90	201.3	81	44.0	18	20.9	9	−16.2	−7	0	0
Aug	245.4	223.7	91	197.8	81	50.0	21	10.6	5	−13.0	−5	0	0
Sep	217.4	152.8	70	150.8	69	52.3	24	11.4	5	2.9	1	0	0
Oct	211.5	98.6	47	98.6	47	70.4	33	21.2	10	4.4	10	0	0
Nov	191.6	71.7	37	71.7	38	84.3	44	4.3	2	31.3	16	0	0
Dec	163.7	56.4	34	56.4	34	84.7	52	4.4	3	18.3	11	0	0
Year	2304	1559	68	1452	63	705	31	173	8	−29.5	−1.3	3	0.1

nual volume of 2304 mcm irrigation water was supplied to The Fayoum. For the same period, the annual average drainage amounted to 705 mcm and evaporation losses were 173 mcm. Evapotranspiration was 1452 mcm. From the total drainage flow of 705 mcm, 246 mcm was diverted to the Wadi Rayan Depression and 459 mcm was discharged into Lake Qarun.

In the summer months – June, July and August – the water supplied is used very efficiently, more than 80% being used by the crops. And although in winter this value is less favourable, the annual average of 63% is high. The results show that in the months May through August the average actual evapotranspiration is 12% lower than the potential because of water shortage. Theoretical crop water use is calculated, assuming well-watered conditions for the crop, but when the calculated evapotranspiration exceeds the water supply to the crop, soil moisture is depleted and evapotranspiration is reduced.

In the winter months, it is the other way around: the water balance does not show a lack of water. The ratio Drainage/Irrigation is not low as in summer. In the last quarter of the year, crop water requirements are at a minimum. In October, November, and December, the irrigation supply is 567 mcm, almost 25% of the annual supply, but this results in 239 mcm drainage, 34% of the annual drainage, a ratio of Drainage/Irrigation of 0.42. (This ratio

Table 2. Water balance of Lake Qarun in mcm, for the years 1970–1986.

Year	Total annual inflow	Annual volume of evaporation	Annual change in storage	Average volume in storage
1970	437	415	21	1007
1971	422	420	1	1035
1972	479	423	56	1052
1973	378	424	−46	1063
1974	410	419	−10	1031
1975	378	419	−40	1024
1976	426	414	12	999
1977	364	416	−53	1008
1978	461	411	50	978
1979	499	420	79	1035
1980	447	430	17	1095
1981	393	431	−38	1100
1982	409	422	−13	1049
1983	486	426	61	1068
1984	484	436	47	1137
1985	409	435	−26	1130
1986	442	434	8	1122
Average	431	423	8	1055

Drainage/Irrigation, with values from Table 1, is shown monthly in Table 3.)

The water balance of Lake Qarun is given in Table 2. The average Lake inflow is 431 mcm a year. This means a long-term rise in Lake level because this inflow exceeds the average evaporation of 423 mcm by 8 mcm.

The water balances of The Fayoum irrigated lands and Lake Qarun are strongly interrelated and the drainage flow to Lake Qarun and the water level of the Lake are in delicate balance; the rise in Lake level is caused by a relatively small quantity of water. The water balance of the cultivated lands showed a total drainage from The Fayoum of 239 mcm in October, November, and December (Table 1). In the last quarter of the year, supply is generous and drainage high. If, in that period, the volume of drainage to Lake Qarun (69% of the total drainage) could be decreased by about 5% (8 mcm), there would be no average excess of Lake inflow over evaporation.

Discussion

Table 1 shows that, in general, the performance of The Fayoum irrigation system is good. A large percentage of the irrigation water supplied is used by the crops. The project or overall efficiency (Bos 1979) is 63%. This high overall efficiency has its origin in some summer shortage and in the re-use of drainage water within the system.

Shortage

The results show that in the months May through August the average actual evapotranspiration is 12% lower than the potential because of water shortage. The theoretical crop water use is calculated under the assumption of well-watered conditions for the crop. When the calculated evapotranspiration exceeds the water supply to the crop, soil moisture will be depleted and evapotranspiration will be reduced. The summer shortage is first felt at the tail-ends of the canals and is partly structural, because The Fayoum has always been supplied with less water than the Delta (in this century, at least) although The Fayoum climate is hotter. The supply used to be 5900 m^3/fe.year; now it is about 7000, but the Delta receives 8000 me^3/fe.year.

Re-use of drainage water

The re-use of drainage water has a positive effect on the water balances of The Fayoum irrigated lands and Lake Qarun because water used excessively upstream in the system can still be beneficial downstream and because the re-use of drainage water reduces the flow to Lake Qarun, preventing a rise in Lake level. There are three types of re-use in The Fayoum:

"Designed" re-use. Besides the two main valleys, now occupied by the Batts and Wadi Drains, several smaller valleys intersect the first terrace sloping from Fayoum City to the level of + 15 m MSL. Bahr Tirsa flows at the bottom of one of these valleys (Fig. 7). For the first 11 km of its length, Bahr Tirsa acts as a drain. Flow-rates at the intake are lower than the crop water requirement for the area because the canal actually gains water from the drainage of lands bordering the valley. Here, drainage water re-use is incorporated in the design because of the Fayoum topography, and is referred to as "designed" re-use. Figure 6 shows the occurrence of this type of re-use.

Re-use from minor drains. The re-use of water from the minor drains is easier than that from the main drains because of The Fayoum topography. Figure 7 shows a cross-section from Fayoum City to Lake Qarun, via the village of Tirsa. From Tirsa onward, water flows in the direction of Lake Qarun in a dense network of canals and drains in a gradually sloping area. Sometimes even farmers cannot distinguish between a drain and a canal. Ditches might act as a drain for an upstream field and a downstream farmer irrigates from it. Not much drainage water reaches Lake Qarun from this area in summer because a farmer can easily divert any water flow to his field if he wants to irrigate.

Re-use by pumping stations. The FID plans and constructs pumping stations to lift drainage water to be mixed with the normal irrigation supply. This is mostly done for tail-ends suffering shortages due to the unofficial use of extra water upstream. These stations are shown in Fig. 6 (see p. 112). The largest one is planned at Tamiya, where a maximum of 4.5 m^3/s from the Batts Drain will be lifted to the tail-end of Bahr Wahby. The criterion used by the FID to decide on the mixing ratio is that the salt content after mixing should be less than

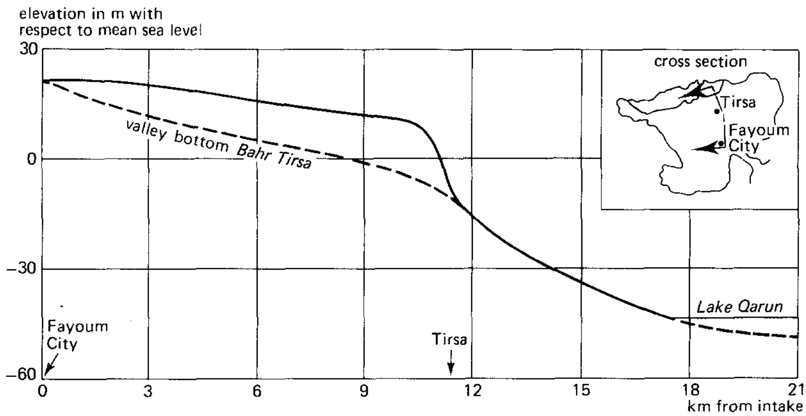

Fig. 7. A cross-section from Fayoum City to Lake Qarun.

800–1000 ppm. This limit is considered to be conservative, but nevertheless shows that the general quality of irrigation water in The Fayoum is good.

The re-use of drainage water from the Batts Drain will result in a lower Lake Qarun level. To illustrate this fall, the Lake level after the installation of the pumping station at Tamiya was simulated. The assumed pumping scenario is given in Table 3. In January, the pumps are not used because there is not enough water in the Batts Drain to pump out. The net reduction (i.e., withdrawal minus return drainage) of the Batts Drain flow to Lake Qarun will be 56.2 mcm in five years. This means a reduction in Lake level of −43.63 m, or a fall of 0.23 m in five years if we only consider volumes. A falling Lake level is accompanied by a reduction in evaporating volume because of a decreasing surface. The Lake Qarun level will thus stabilize at a lower level because of the reduced inflow. If continued extraction of drainage water from the Batts Drain results in too low levels of Lake Qarun, water presently flowing to Wadi Rayan can be re-directed to Lake Qarun. Also, re-use from the Wadi Rayan drainage diversion canal will result in more drainage to Lake Qarun.

The excess winter drainage is partly a result of the lack of irrigation at night in winter. Because of the shortage in summer, not much irrigation water is

Table 3. Estimated net reduction of Batts Drain flow to Lake Qarun after installation of the Tamiya pumping station.

	Units in operation	Design Q	Estim. pump effic.	Hours pumped /day	Gross with-drawal	*) Ratio DR/IR	Net re-duction
	Number	m^3/s	%		1000 m^3		1000 m^3
Jan	0	0	–	0	0	0.71	0
Feb	1	1.5	80	12	1451.5	0.38	551.6
Mar	1	1.5	80	12	1607.0	0.33	530.3
Apr	1	1.5	80	12	1555.2	0.31	482.1
May	3	4.5	80	12	4821.1	0.25	1205.3
Jun	3	4.5	80	12	4665.6	0.18	839.8
Jul	3	4.5	80	12	4821.1	0.18	867.8
Aug	3	4.5	80	12	4821.1	0.21	1012.4
Sep	3	4.5	80	12	4665.6	0.24	1119.7
Oct	3	4.5	80	12	4821.1	0.33	1591.0
Nov	2	3.0	80	12	3110.4	0.44	1368.6
Dec	2	3.0	80	12	3214.1	0.52	1671.3
Year							11239.9

* Values from Table 1

wasted then. Crop water requirements are high and irrigation at night is not considered a problem. The irrigation system was designed for 24 hours of irrigation a day, and in summertime farmers do irrigate at night and water is used carefully. Chambers (1986) cites a Fayoum farmer who said that, in summer, the worst time for an irrigation turn was midday, because of the heat. In the farmer's view, a turn at night was preferable. In winter, however, nights are cold: minimum temperatures can be as low as 1 to 2°C (in summer 24°C). Farmers on upstream reaches of canals benefit from their situation close to the water source, and try to prevent the need to irrigate at night by illegally increasing their daytime supply. This has another advantage to the farmers: a larger supply reduces the time needed to irrigate. Irrigation water available at night, but not used, flows directly to the drains. This flow of unused water has an especially negative effect on the water balance if it discharges directly into the Batts and Wadi main drains since these drains flow at the bottom of natural depressions at least 15 m below the land surface. Once at the valley bottom, water can only be re-used if lifted over a considerable head.

The night irrigation problems in The Fayoum should be solved by improving conditions for irrigation at night. An example of improved conditions is a water-course-lining and reconstruction project in Pakistan. Authorities viewed the project as a means of reducing losses and improving head-tail water distribution, but farmers mentioned additional benefits in the form of greater ease of movement at night. Paths along the bunds were less narrow and were free of obstacles such as trees, bushes, and weeds, thus making night irrigation easier (Merrey 1985).

The FID, in an attempt to lower Lake Qarun levels, tries to decrease the water supply to The Fayoum in the last quarter of the year. When it does so, however, it is confronted by protesting farmers. Although winter supplies are in excess of calculated crop water requirements, it is difficult to give less water in the period from October through December for the following reasons:

- Farmers want a lot of water to flush the surface of their fields, expecting to remove salts that accumulated in the hot summer. Following this flushing, new crops are planted. For the germination of the young plants, a wet topsoil is necessary. It remains to be determined whether the flushing practice, irrigating a field at one end and draining it at the other end at the same time, can be replaced by a less water-consuming activity.

- The irrigation supply is level-dependent but not uniform. This means that a decreased water supply in winter, proportional to the calculated (theoretical) decrease in water requirement, would further deprive tail-end farmers of their share. Many complaints would be the result. In the same way as an increase in supply to The Fayoum at El Lahun does not lead to an evenly distributed increase to all farmers (Wolters et al. 1987a), so too is a decrease in supply not evenly shared by all farmers.

- Farmers want a lot of water before the closure period starts; crops will not be irrigated for a period of more than three weeks. Moreover, if a contractor, working in an irrigation canal during the closure, fails to meet his time schedule, crops will have to wait even longer. Table 1 indeed shows that soil moisture is recharged in winter and depleted first in January and later in summer.

The loss of some water in January cannot be prevented because in this month there is the annual closure period. Starting on the 10th or 11th day of the month, no irrigation water is supplied to The Fayoum for a period of three to four weeks. This period is used for maintenance. The influence on the water balance comes from the fact that the whole system is emptied. Some water present in the system at the start of the closure period can be used for irrigation, but most is lost to the drainage base, Lake Qarun and the Wadi Rayan Depression.

Improvements in the irrigation system must be sought in decreasing irrigation supplies in winter in favour of the summer months. Water supplied in winter should not be wasted. Only then will the FID be able to decrease the winter intake. To reach this situation, the uniformity of supply must be improved so that water does indeed arrive at the field it is intended to irrigate. Flushing of fields and night irrigation should be studied for their potential to save additional water in winter.

Conclusions

1. The performance of The Fayoum irrigation system management is evaluated in three ways: the water level of Lake Qarun, the agricultural production in the area, and the number of farmers' complaints. The FID has no absolute control over all factors involved and is subject to several boundary conditions: technical, political, socio-economic, and even religious. In practice, the complaints of farmers and the water level of Lake Qarun are "the thermometer" for managing the irrigation system.

2. The water balance shows that in general the performance of The Fayoum irrigation system is good. A large percentage of the irrigation water supplied is evapotranspirated by the crops. The project or overall irrigation efficiency is 63%. This high overall efficiency has its origin in summer water shortage and in the re-use of drainage water within the system.

3. The water balances of The Fayoum irrigated lands and Lake Qarun are strongly interrelated and the drainage flow to Lake Qarun and the water level of Lake Qarun is in delicate balance. The rise in the water level of Lake Qarun,

causing the inundation of adjacent land, follows from a relatively small excess of inflow over evaporation. If, in the last quarter of the year, the volume of drainage water could be decreased by about 5%, there would be no average excess of Lake inflow over evaporation and hence no rising Lake level.

4. The re-use of drainage water in The Fayoum has a favourable effect on the water balance. Re-use from the drainage catchment of Lake Qarun results in a lower Lake Qarun level. The irrigation system incorporates features that can be classified as re-use. Re-use from the main drain valleys can only be done with considerable lift and cost. Re-use in winter is no solution to the drainage excess because crop requirements are low compared with supplies.

5. Improvement of overall irrigation efficiency in winter can only be attained when water is used carefully and when the supply is more uniform than at present. Only then can the FID start decreasing winter supplies by some percentage without having to expect farmers' protests. Priority for engineering improvement of the performance of The Fayoum irrigation system is improving the division of flow, both over the area and between seasons. This will enable the system management to decrease or increase supply equally to all farmers by some percentage if necessary. A decrease of supply in winter is a prerequisite for an increase in summer. Flushing of fields and night irrigation should be studied for their potential to save water in winter.

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