The Performance of a Low Pressure Irrigation Pipeline, El Hammami, Egypt

Implications for Design and Management

R D Hinton, D E D El Quosy, W F Mankarious,
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(TDR Project R 5830)

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Summary

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Low pressure pipelines for irrigation are widely used in countries such as the United States, the Peoples Republic of China, India and Pakistan to reduce water loss in conveyance and improve areal coverage. While the details of the design and operation vary widely, it is common to limit the operating pressure to around two to six metres. Water is supplied through risers to controlled outlets.

This report describes an investigation into the performance of a low pressure pipeline system, the first introduced into Egypt to serve some 330 ha (780 feddans) at El Hammami, near Cairo. General lessons and implications for the design and management of similar systems are drawn.

The El Hammami area was originally supplied by a traditional open channel system serving landholdings of around 0.6 ha on average. Increasing urbanization threatens the area, as land is taken out of production for housing and other enterprises.

Low pressure pipelines have rarely been used to serve large numbers of small farmers growing dry-foot crops under traditional practices. Design and construction difficulties delayed implementation for many years. The pipeline was originally designed with 9 outlets, but was subsequently adapted, under pressure from farmers, to include 32 outlets serving the original field channels (mesquas). The area served by the outlets varies from less than 1 ha to over 38 ha. Owing to the vastly different size of outlet commands and uncoordinated demand from individual farmers, it was hard to maintain line pressure and difficult to operate the pipeline effectively.

Initially the farmers were allowed unhindered access to the system and a performance monitoring programme was initiated. As the deficiencies in water distribution became apparent, the management of the system was successively tightened up. At first a system of rigid scheduling, allocating equal opportunity time to all outlets regardless of area, was introduced and later a more flexible schedule, under which outlet operations were linked to the command area, was brought in.

The introduction of the pipeline system to replace the open channel system, along with improved management, brought about a marked improvement in the equity of water distribution between head and tail areas. However, many of the anticipated benefits were not realised. Pumping-capacity constraints, power shortages and restricted operating hours limited the maximum output of the

system so that the full required supply could not be delivered. The choice of asbestos cement for the pipeline also led to unanticipated leakages. The volume supplied to the system was similar to that released under the original canal operations as farmers continued to practice surface irrigation on sandy soils. Farmers holding land at some distance form the pipeline had to continue pumping water from small, private wells. No measurable lowering of the ground water was achieved as the water table level is determined by the surrounding canals and drains. In fact the high ground water table contributed towards crop water requirement. Despite these constraints, farmers reacted very positively to the pipeline once it was fully operational, and the project continues to serve as a market garden for Greater Cairo. However, farmers also chose to grow lower value crops such as berseem (clover) and wheat.

Under Egypt's current policies, strong emphasis is now placed on farmer group formation. To function effectively, groups must be limited in size to no more than fifteen farmers and systems should be designed to facilitate group formation.

The report summarises the findings of the hydraulic investigation (Section 4) and operational practice (Section 5) before discussing the implications for design (Section 6). Conclusions and recommendations are presented in Section 7. Appendix 2 sets out guidelines for the design of smaller pipeline systems at tertiary level.

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1 Introduction

This report describes collaborative applied research involving the Overseas Development Unit (ODU) of HR Wallingford and the Water Management Research Institute (WMRI) of the Egyptian Water Research Centre (WRC), to quantify the performance of a low pressure irrigation pipeline. The work took place at Mansouria, near Cairo between 1990 and 1994. The aim of the project was to make recommendations with a wider relevance for the design and management of pipeline systems in arid and semi-arid regions.

The work in Egypt was undertaken as part of the ODU's programme of investigations into the performance of small schemes supported by Technology Development and Research (TDR) funding from the British Overseas Development Administration (ODA).

1.1 Background details of the project

1.1.1 General

In 1990 the Egyptian Government requested assistance from ODU to quantify the performance of an irrigation pipeline constructed in the previous decade but not put into service.

Pipelines potentially offer advantages over conventional open channel systems, particularly in sandier soils. Benefits frequently cited include savings in water which would otherwise be lost in conveyance through open channels, and in land taken up by the works. A number of less tangible benefits are also attributed to pipeline systems. At El Hammami it was anticipated that the pipeline would:

- improve the adequacy and equity of water distribution;
- lower the watertable level as a result of reduced conveyance loss and better water management;
- reduce O&M costs;
- reduce problems of water-borne disease, principally schistosomiasis;
- release extra land for cultivation.

Primary attention under the present project was directed to examining the first two aspects, including the constraints affecting operation and the way in which farmers responded to the system.

1.1.2 Activities

The El Hammami research area is managed by WMRI. The Ministry of Public Works in Egypt has overall responsibility for operation and maintenance on irrigation and drainage projects. Negotiations with the Ministry concerning the allocation and funding of pump operators took until mid April 1991. Thereafter, regular operation of the system commenced.

In order to achieve the objectives of the project it was necessary to undertake a number of activities additional to the nominal scope of the work. In the first place, assistance was given with commissioning the system. Four of the six pumps had seized up because of lack of use and had to be repaired. The automatic pump control system did not function because the backup batteries had failed for want of charging and the control programme had been lost. The depth and pressure sensors in the pump stands and Venturi meters were also damaged. As spares for these items were not available in Egypt it was decided to operate the system under manual control.

Since the pipeline was completely new and the changes involved to traditional practices were considerable, it was agreed to treat the first operational season as an introductory period. Farmers would be permitted to draw water as they wished without constraint by staff, other than to ensure that the infrastructure was safeguarded. In the event a form of rotation was introduced quite soon as farmers understood the difficulties of uncontrolled withdrawals.

Once users had become familiar with the characteristics of the pipeline, and in particular with the restrictions imposed by limited conveyance and pumping capacity, a more formal operational pattern was introduced.

During the first year activity centred on setting up a measurement programme, familiarizing farmers with the pipeline, learning how to operate the system, and monitoring progress. In the second and third years, fairly rigid operating schedules were introduced, with the approval of, but without detailed discussion with farmers. In the event the introduction of the system to farmers took longer than planned. It was only with the completion of lined field channels in the middle of 1993 that piped water became available in areas more remote from the system. A more realistic schedule was evolved and tested in a six month extension to the original project.

The present report makes reference to a previous report (Hinton and Mankarious, 1993), summarizing the situation in the El Hammami area before the construction of the pipeline.

1.2 Low pressure pipelines

Early development of low pressure pipeline systems took place on large farms owned and managed by individuals. Operational control and distribution of water is relatively straightforward in such circumstances since both demand and supply are controlled by a few users, and systems operate on demand.

Low pressure pipelines for irrigation are now widely used in the United States, in PR China and in the Indian sub-continent. In the USA and to some extent in PRC, farming practices, particularly field and land sizes are in many respects different from smallholder agriculture in the developing world. In Pakistan, India and Bangladesh, where pipelines are commonly specified on tubewell projects, they are generally used at tertiary level, serving areas of up to 50 ha. Large numbers of small farmers are involved in developments even at that scale, since 1 ha or less is a typical landholding size in many developing countries. As it is not economic to design systems capable of supplying water to all users simultaneously, limited on-demand operation must be practised.

Design and construction guidelines have been produced by a number of authors, most recently by Van Bentum and Smout (1994). To date, very limited information on the longer term performance of pipelines in developing nations has been available to permit comparisons to be made with design assumptions and to guide further developments.

2 El Hammami area and the pipeline system

2.1 Description of the area

The El Hammami area lies some 15 km west of Cairo in the Giza Governorate on the Mansouria branch canal of the Giza main canal system (Figures 1,2). The scheme falls within the extent of the "old lands", the fertile areas which were traditionally cultivated after the annual flood of the River Nile.

The land slopes generally towards the east and north from the Mansouria canal. The study area is approximately rectangular, totalling 780 feddans (330 ha), bounded by the Mansouria canal to the west, and by large open drains on its other three sides, respectively the Talb drain to the south, the Kafr Hakim drain to the east and the Rimal drain in the north. The entire drainage system discharges into the El Moheit main drain which flows northwards towards the delta.

Under the original system of supply, the entire area was supplied by El Hammami canal from its offtake on the Mansouria canal at Km 25.85 and by a minor branch off El Hammami, the El Shimi canal.

2.2 Soils and water table

A comprehensive soils testing programme was carried out under the EWUP project in the late 1970s.

The soil is a sandy loam, mainly uniform in texture though somewhat sandier towards the middle of the area. Soil bulk density ranges from 1.6 g/cm^3 in the top 30 cm of the soil to 1.75 g/cm^3 at a depth of 60 to 90 cm below the surface. Soil porosity varies from 40% in the top 30 cm to 34% at a depth of 60 to 90 cms. Infiltration was found to average 27 cm per hour.

The surrounding drains are poorly maintained. They are used for urban rubbish disposal where they pass through villages. As a result the surrounding land cannot drain freely. Within the El Hammami area the ground water table lies on average 50 to 60 cms below the land surface except during January, at the time of annual canal closure, when it drops noticeably. Sub-surface drainage was installed over part of the El Hammami area in the 1980s, without obvious effect. The high water table restricts crop root development.

The low intrinsic moisture-holding capacity and shallow depth of the soil strongly influence irrigation practices (section 4.2.2).

2.3 Land holdings and cropping

Owing to its position close to the Cairo markets and the extensive growth of vegetables, farming at El Hammami is termed "garden" agriculture.

There are a number of relatively large farms in the area, but the average land holding size, at about 1.5 feddan (0.63 ha), is small by Egyptian standards. The land owned by a single farmer is fragmented and scattered owing to traditional inheritance customs. Individual land parcels are divided into fields, the size of which depend on the crop, the soil type and the slope of the land. Crops are grown in small ridged basins typically varying in size between 20 and 120 square meters.

Government does not restrict the crops which may be grown in the area apart from a prohibition on rice. A wide variety of vegetables including cabbage, spinach, peppers, tomatoes, onions, broad beans, squash, lettuce and eggplant are grown all year round for sale in the nearby markets of Cairo. During the winter season the area planted to vegetables is cropped twice. Additionally, berseem (clover) is grown as a fodder crop, together with a small area of wheat in the winter months. In summer the main crop is maize.

As a result of increasing urban encroachment, land values are very high. There appear to be no Government constraints on residential and industrial development in the area. Since 1990 a sizeable part of the area has been given over to enterprises such as charcoal-making and intensive poultry farming. It is apparent that if the present rate of development continues, within ten to fifteen years farming is likely to have disappeared from the EL Hammami area.

2.4 Traditional irrigation supply practice

It is necessary to define the context in which the pipeline has to operate in order to identify constraints and draw conclusions which are applicable to implementations elsewhere.

Typically an Egyptian irrigation system consists of a major canal taking off from the River Nile serving main and secondary branch canals. The area served by the main branch canal is divided into either two or three nominally equal parts which are served in rotation. Water was supplied for 24 hours per day during the time when supply was “on” for any given area. The duration of supply could vary depending on season, type of crops and, in some cases, the soil type..

A triple rotation pattern is practised in the Mansouria canal, involving a twelve day irrigation cycle during which four days are "on" and eight days "off". At Mansouria the basic pattern was modified in part due to variations in soil type, but in the main due to inequity of the reach. The area of the middle reach is more than double that of the other two. In compensation the middle reach takes some water during the last two days of the first reach rotation, then receives four days of full supply. Supply is also received at a reduced level from the first two days of the third reach rotation. As a consequence the El Hammami canal which took off from the middle reach, received extra supply, though at a reduced command level.

During "on" periods, water was formerly diverted from the El Hammami canal into field channels (mesqua) via pipe outlets set into the canal banks. The pipe was theoretically set with its invert about 25 cms below full supply level. The pipe size was governed by the area to be irrigated and the length of the mesqua. Water duty was established at 25 cubic meters/feddan/day. It was found during the EWUP project that over 70% of the pipes in the El Hammami canal were either larger than designed or had been illicitly introduced by farmers. Water level in the mesqua was typically 50-70 cm below ground. Farmers were required to lift the water into a field ditch (marwa) or directly onto their fields, using the animal-powered Sakia (water wheels) or small diesel pumps.

There are a number of disadvantages to the traditional pattern of supply. Firstly, farmers are reluctant to irrigate at night, so they will not use water continuously over a 24 hour period. In consequence, a high proportion of the total supply, estimated at the time to be 30%, was lost to the tail drains. Secondly, the canal system in Egypt is operated by maintaining defined water surface levels at control structures rather than by scheduling required discharges. As the canal deteriorates, owing for example to the growth of weeds, its conveyance capacity for a given supply level decreases. Downstream users will therefore experience water shortages.

A shallow aquifer underlies the El Hammami area at a depth of less than 35 metres. By the time of the EWUP project, wells were already being exploited, particularly at the downstream end of the mesqua, to supplement an unreliable surface supply. In consequence, crops such as vegetables which are drought-sensitive, particularly in the early growth stages, could be successfully cultivated.

Since the pipeline is served by pumped supply from the Mansouria canal, it was found that operations could continue even though the level in the reach was insufficient for gravity irrigation. The system could function for up to eight days, thus effectively reducing the "off" periods in El Hammami to around four days.

2.5 Background and description of the El Hammami pipeline

The Egyptian Water Use Programme (EWUP) funded by USAID, was executed in the late 1970s and early 1980s to improve the conditions of small farmers. The project aimed to implement improved irrigation water management and agricultural practices so as to save water, decrease drainage problems and increase agricultural production.

WMRI, formerly the Water Distribution and Irrigation Systems Research Institute, in conjunction with American counterparts studied irrigation practices in several pilot areas in Egypt. Amongst recommendations for improvement was the construction of an experimental pipeline to replace an existing open channel system serving some 780 feddans (330 ha) at El Hammami. Both high and low pressure piped systems were considered before the low pressure option was selected. Construction of the pipeline started in 1980 and was finally completed in 1989 after severe difficulties in implementation, in part connected with the high groundwater level.

The system designed to replace the El Hammami canal and its branch, El Shimi consists of two main pipelines Nos 1 and 2 (Figure 3). Pipeline 1, 1.67 km long, was aligned along the north bank of the El Hammami canal. At its end a stand allowed for drainage to the main drainage system. A spur taking off at a corner stand 780 m from the head of pipeline 1 follows the line of the old El Shimi branch north for 580 m to a gate stand. Flow into the main and spur lines can be controlled by gates in the corner stand.

Pipeline 2 located further north on the Mansouria canal is L shaped. It parallels El Rimal Drain before turning south along the line of the El Shimi branch to connect with pipeline 1 at the gate stand. All the farm outlets on pipeline 2 are located on the line of the El Shimi branch.

The gate stand connecting pipelines 1 and 2 was designed to allow the whole area to be served by either pumping station in the event that one should suffer complete breakdown. The gate stand also allows pipeline 2 to be drained via pipeline 1 during maintenance. In normal operation the gate is closed and the pipelines operate independently.

Pipes are of asbestos cement. The upper part of each line is 600 mm in diameter, decreasing to 500 mm towards the tail of the system. Each line is served by a pump station containing 3 electrically-driven turbine pumps, one 12" and the other two of 10" diameter. A pump stand some 6 metres high is located just downstream of the pumps to provide the necessary line operating head. A Venturi meter is installed on each line to measure pump discharge.

All the stands are open to the air and are intended to:

- accommodate surges arising from sudden shutdown of outlets
- permit the escape of air trapped within the system.

Sixteen outlets in total were provided on the two pipelines in the original design. However, farmers were accustomed to operating a large number of small outlets and the design proved unacceptable to them. Instead, a total of 62 outlets were constructed, of which 32 were located on pipeline 1, including the El Shimi branch. The siting of the outlets corresponded roughly to the former offtakes from the canal so farmers continued to view the outlet points as within their control. Outlets are equipped with alfalfa valves either 10" or 14" in diameter set in a concrete outlet box some 2 m by 2 m square (Figure 4). The outlet boxes were originally designed with a Fayoum-type weir at exit to the Mesquas.

Table 1 gives details of outlets on pipeline 1. Outlet numbers 28 to 32 are on the EL Shimi branch canal.

Severe problems were encountered with a high ground watertable during construction. When first constructed and tested the pipeline was found to leak excessively. Dewatering equipment was used in reconstructing the line. During early operation in 1991, the capping on a stub pipe from the end stand on pipeline 1 failed, causing heavy leakage locally. The leak was repaired with mass concrete. During 1993 leakage was observed in the first reach, but the problem appeared to cease after some time had elapsed.

Extra wells were installed by the EWUP project to compensate farmers for the loss of surface supply during the construction period. Farmers already accustomed to irrigating from wells became totally dependant on well supply during the period of seven to eight years until the pipeline was commissioned, but they complained of salinity in the ground water. Advantages, however, lay in the freedom to irrigate when they chose. The cost of pumping was considered by farmers to be less than with the traditional lift methods.

Table 1 Outlets on pipeline no. 1

Outlet no.	Distance along pipeline (km)	Weir reduced level (m)	Command area (ha)	Mesqua (M) or direct outlet (D)	Total no. of farmers
1	0.134	18.91	1.0	D	1
2	0.360	18.62	2.4	D	5
3	0.455	18.30	1.4	D	7
4	0.533	18.44	11.8	M	31
5	0.570	18.63	3.8	M	11
6	0.618	18.54	1.8	D	7
7	0.708	18.73	6.5	M	29
8	0.752	18.80	2.9	D	8
9	0.847	18.80	1.6	D	4
10	0.900	18.73	10.7	M	22
11	0.901	18.55	0.8	D	1
12	0.957	18.63	1.7	M	8
13	0.962	18.70	4.8	M	7
14	1.052	18.56	1.0	M	6
15	1.111	18.33	1.5	M	5
16	1.122	18.29	0.7	M	2
17	1.287	18.50	1.1	D	4
18	1.333	18.39	1.2	D	6
19	1.352	18.23	15.9	D	47
20	1.358	18.26	11.5	M	21
21	1.457	18.10	4.8	M	9
22	1.482	18.34	5.6	M	17
23	1.541	18.18	0.3	D	7
24	1.562	18.35	0.2	D	2
25	1.604	17.76	1.1	D	3
26	1.667	17.98	38.4	M	78
27	1.670	18.11	3.4	M	12
28	0.176	18.47	4.1	M	4
29	0.318	18.55	3.4	M	5
30	0.330	18.59	1.4	D	8
31	0.380	18.54	2.4	D	4
32	0.510	18.65	3.6	D	1
Totals	-	-	152.8	-	382

3 Preliminary investigations

It was decided from the outset that the study would concentrate on pipeline 1, and that pipeline 2 would show how farmers managed without outside help. In the event, farmers from each pipeline naturally interacted, so a true learning process occurred. Staff numbers were insufficient to allow both sites to be monitored so full attention was given to pipeline 1.

The levels of the weirs are plotted in Appendix Figure A.1. Weirs were set to command the maximum area of land rather than at a constant height above the average hydraulic gradient. Section 5 discusses the resulting constraints imposed on the operational patterns.

The outlet boxes include a weir based on the Fayoum pattern. The outlet rises within 1.5 meters of the weir so the water surface was invariably unsettled. To improve accuracy of measurement a sharp edged metal plate was installed on each weir. Water level was measured on a staff gauge within the box. Munro water level recorders were installed at four of the weirs so as to provide a check on the manual data. A fifth recorder was installed on the corner stand so as to monitor the head loss within the first reach. A number of Stevens recorders from the EWUP project were installed on other outlets and at the pump stand.

A manometer was installed to measure the head difference across the Venturi meter. The pump operators found it tedious to bleed air from the system so the data are of uncertain accuracy. Discharges were based on pump performance curves.

The following data from pipeline 1 were recorded:

- Area and crop details, recorded from farmers served by the pipeline.
- Daily climatic data from a nearby metrological site.
- Daily ground water levels in 15 wells.
- On-farm data taken from six selected farms, including:-
  soil moisture before and after irrigation;
  discharge within the field ditch;
  length of time of irrigation;
  area irrigated;
  crop details.
- Pumping hours, number of pumps in operation, electricity usage and the water surface level in the supply canal. Differences in head across the pumps from 1993 onwards.
- Hourly water levels and the time of opening and closing of the outlets on each day of pipeline operation. Chart records from outlets with automatic recorders.
- Water levels in the stands at either end of the head reach.

3.1 Evapotranspiration

Penman reference evapotranspiration (Eto) was calculated for a local agroclimatic station. Average sunshine hours were assumed from previous measurements. Table 2 gives monthly reference evapotranspiration over the period of the project.

Table 2 Reference evapotranspiration

Month	Eto (mm/day)				
	1990	1991	1992	1993	1994
Jan	N/a	2.22	2.33	2.53	3.02
Feb	N/a	3.11	3.28	3.38	3.69
Mar	N/a	4.64	3.90	4.67	4.38
Apr	N/a	5.85	4.69	5.59	6.28
May	N/a	6.92	6.05	6.75	N/a
Jun	N/a	7.33	6.92	7.55	N/a
Jul	6.21	6.95	6.68	7.47	N/a
Aug	6.15	6.38	6.50	6.58	N/a
Sep	5.33	5.58	5.43	5.85	N/a
Oct	N/a	4.51	4.28	4.86	N/a
Nov	2.63	2.94	3.08	3.12	N/a
Dec	2.23	2.29	2.30	2.46	N/a

The theoretical water requirements for each outlet for each season were calculated on the basis of actual crops grown, using the FAO Cropwat program. In practice, in the delta area of Egypt, groundwater makes a significant contribution towards crop needs. The analyses in Section 4 take account of this fact.

Minimal rainfall occurs in December and January. Its contribution to crop water needs is negligible.

3.2 Groundwater

A number of 2 metre long observation wells were installed at various localities either side of the pipeline to monitor the effect of the pipeline on groundwater levels in the area. Figure 4 shows water depth below ground averaged for all wells. The level falls during January, when the canal system is shut down for maintenance, and during June/July when crop water demand is greatest and power cuts are common. Otherwise, there is little variation over the year.

3.3 Outlet commanded areas

Figure 5 shows the proportion of land irrigated by the pipeline over the duration of the project. At the outset, about 30% of the potential command was served. In the winter of 1992/93 some 38% was covered. By summer 1993, 50% was irrigated. During the last winter season, 60% was served. Section 5 discusses the reasons for the steadily increased coverage.

Table 3 gives the area commanded by each outlet and the percentage of area under cultivation in each season. Small outlets were cultivated intensively throughout the project period. The proportion of land cultivated on larger outlets increased steadily over the course of the project. Intercropping caused the proportion of area cropped to exceed 100% in some instances.

Table 3 Areas irrigated by each outlet on pipeline no. 1

Outlet No	Comm Area (ha)	Percentage of Area Under Cultivation					
		Sum91	Win91	Sum92	Win92	Sum93	Win93
1	1.0	101.9	88.4	88.4	54.4	81.6	95.2
2	2.4	31.8	74.4	59.5	65.3	82.6	85.9
3	1.4	90	60	12.9	67.9	70	55.0
4	11.8	20.8	24.7	20.4	36.9	32.7	56.1
5	3.8	0	11.1	5.5	18.4	50.8	74.2
6	1.8	89.3	117.1	132.8	84.2	90.4	93.8
7	6.5	3.9	3.6	4.3	56.5	102.6	108.0
8	2.9	114.6	117.1	101.7	111.5	96.9	111.5
9	1.6	67.7	77.2	89.9	60.1	86.7	94.9
10	10.7	21.9	9.8	0	10.0	32.6	36.6
11	0.8	66.2	27.3	72.7	54.6	41.6	81.8
12	1.7	84.9	83.0	83.0	87.3	72.1	66.1
13	4.8	23.2	28.6	26.1	19.3	42.9	30.0
14	1.0	61.2	100	94.9	96.9	78.6	104.1
15	1.5	42.3	98.7	89.3	98.7	104.7	106.0
16	0.7	100.0	100.0	92.7	108.8	105.9	119.1
17	1.1	30.5	100	70.5	86.7	100.0	93.3
18	1.2	99.2	99.2	87.2	88.0	28.2	111.9
19	15.9	6.5	10.1	10.0	15.3	29.9	56.3
20	11.5	28.1	29.2	20.5	45.1	47.4	57.3
21	4.8	14.6	15.0	18.3	11.0	86.3	95.0
22	5.6	72.4	75.4	58.5	102.2	100.9	117.8
23	0.3	87.5	100	87.5	115.6	78.1	121.9
25	1.1	103.8	70.5	103.8	106.7	106.7	97.1
26	38.4	6.2	6.2	7.1	13.3	26.8	25.3
27	3.4	19.7	44.6	23.8	47.2	54.0	40.2
28	4.1	59.8	56.3	28.3	56.3	40.5	100
29	3.4	79.0	33.8	45.5	40.8	87.8	100
30	1.4	53.3	71.1	96.3	111.9	97.0	75.6
31	2.4	42.6	91.3	94.2	107.0	117.4	123.6
32	3.6	76.5	62.8	70.6	44.3	80.9	61.9

Average dates of planting and harvesting were estimated from survey records and previous investigations. Summer crops, maize and peanuts, were taken to start on May 1 and to conclude on September 30. Winter cropping, berseem and wheat, was assumed from October 1, concluding on April 30.

Vegetables are grown all year round. Two vegetable crops were assumed in the winter and one in the summer. There is a small area planted with oranges, limes and dates which are intercropped with field crops but were not assumed to affect the averaged water need. The following table gives the proportion of annual cropped area devoted to the major crops. The cropping pattern prior to the construction of the project is included for the sake of comparison. Overall, there appears to be little difference between the years prior to 1981 and 1993.

Table 4 Proportion of different crops in annual cropping pattern

Crop	1991	1992	1993	pre 1981
Berseem (Winter)	49 %	47 %	37 %	32 %
Maize (Summer)	50 %	45 %	41 %	45 %
Vegetables (Summer) (Winter)	43 % 47 %	45 % 48 %	52 % 58 %	50 % 50 %
Peanuts (Summer)	5.5 %	7 %	6.5 %	N/a
Wheat (Winter)	2.7 %	3.9 %	3.8 %	1.5 %

3.4 Pump deliveries

The output of the pumps at the design head was nominally 90 l/s for each of the 10 inch pumps and 180 l/s for the 12 inch pump. Hourly records of water levels, pump operations and electricity used were kept. Average daily operating hours are shown in Figure 6.

The level in the pump stand, and thus the pressure in the pipeline, was dependent on: the number of pumps operating; the level in the sump; the number and location of outlets being operated. It was noted that debris sometimes accumulated on the trash racks in front of the inlets causing the sump water level to drop and the operator to shut down the pumps.

Pump deliveries were limited by the water available in the Mansouria canal. On average, the level was sufficient to operate on 8 days out of 12. In some instances, 9 or 10 days operation were possible. The supply lines to the pump house only allowed a maximum of 2 pumps to be operated. The electricity company eventually installed extra lines during the last part of the project which enabled 3 pumps to be run together. However the maintenance department stipulated that 3 pump operation was not desirable so it was rarely practised. Therefore total pumping capacity was nominally 270 l/s. Power cuts in the summer months were a problem, especially in the summer of 92. On average, one day's pumping a week would be lost for lack of power.

Section 4.1 discusses the results of the flow analysis and the constraints affecting the deliveries to the system.

3.5 Outlet deliveries

Calibration of a typical structure equipped with thin-plate weir was carried out. The following empirical formula was obtained:

$$Q_{(l/s)} = 1.580 \times h_{(cm)}^{1.5}$$

Measuring points were set inside each of the boxes away from the weir edge so that the effects of drawdown and turbulence were minimised.

The total delivery per day was calculated for each outlet, based on regular readings of head and information and the time for which the outlet was open. Where possible, the results were checked against the output from the automatic water level recorders.

The daily releases were accumulated for the season. Sections 4.4.2 and 4.5.2 discuss the results.

3.6 Field irrigation practice

Six farms were investigated by agreement with farmers. Irrigation inflow at the head of the farm, soil moisture content before and after the irrigation, crop type and area were recorded.

The flows into each farm were measured by portable flumes installed in the mesqua or field channel. Initial measurement of soil moisture was carried out on the day preceding an irrigation. Follow-up measurements were made when the field was considered to have reached field capacity some 2 days after irrigation.

The moisture content was averaged from gravimetric measurements at 5 levels down to 90 cms at each of four locations in the field. The efficiency of application was calculated from the depths of water applied and retained during an irrigation. The number of irrigations applied during a season were also recorded.

3.7 Losses from the pipeline

Measurements were carried out at intervals to determine the leakage from the pipeline. Water was ponded in the system and levels in the corner stand were recorded at regular intervals. Leakage varied from 8 to 32 l/s at different times.

The first ponding test, in February 1992, took place just after maintenance had been carried out on the pipeline and returned a loss of 8 l/s.

The losses of 32 l/s in December 1992 are considered to have been particularly high because one of the alfalfa outlet valves was broken, and the test followed the earthquake.

The flap valves sealing the outlets of the pump delivery mains in the pumpstand were not completely effective. Some return flow to the sump at this point was believed to have contributed to the losses from the system.

Section 4.2.4 deals with the losses in more detail.

3.8 Pipe friction

Estimates of pipe friction in the first reach of pipeline 1 between the pumpstand and El Shimi branch were made just before the start of the project . Tests were run with a series of combinations of pumps, and discharges varying between 90 l/sec and 270 l/sec. The resulting values for C, the Hazen Williams coefficient, lay in the range 110 to 135, averaging around 122. Published values for C (asbestos cement pipe) are:- 150 (brand new) and 140 (partially degraded condition). Only very limited inspections of the pipe were possible at its junctions with the stand tanks. No major blockages were visible, its condition appeared reasonable. The result of the tests suggest that the pipe had deteriorated significantly, but they must be set in the context of the method of measurement. In particular, flow was measured by a manometer which proved somewhat unreliable in subsequent seasons. A 10% error in the flow estimate could account for the difference between observed and published values. No allowance was made for losses from the line, a further possible, though minor, source of error.

4 Performance of pipeline no. 1

At an early stage of the project it was decided that interventions would be restricted to pipeline 1 whilst the response of farmers on pipeline 2 would be observed. The performance of pipeline 1 was quantified. In practice, resources were not available to monitor the performance of the second line.

The following sections examine the water distribution performance on pipeline 1 during the years 1991-1994. Overall deliveries at system level are described in Section 4.1. Efficiency of supply is covered in Section 4.2. Adequacy of supply at scheme, reach and outlet levels is included in Section 4.3. Equity of supply is discussed in Section 4.4.

4.1 Overall water deliveries

Figure 7 summarizes the volumes of water pumped daily into pipeline 1 during the period May 1991 to April 1994. Volumes were estimated from the manufacturer's pump performance curves.

Checks on pump performance carried out in 1990 (Ruff, 1990) indicated that the pumps on average were delivering some 10% less than their rated capacity. In view of the long delay between pump installation and commissioning, the reduced discharge seems, if anything, to be on the high side.

The daily pumped volumes increased steadily throughout the period. Nominal (unadjusted) values were 2,500 cubic meters (average) and 4,500 cubic meters (maximum) in 1991 rising to 6000 m^3 (average) and 11,500 m^3 (maximum) in September 1993.

Two pumps with a total nominal capacity of 0.270 m^3/sec were normally used. In 1993, all three pumps with a total nominal capacity of 0.360 m^3/sec were used on occasion. Inadequate transformer capacity severely limited the potential for use of all pumps simultaneously. The main reason for the increase in pumped volume was an increase in pump operating hours. Figure 6 shows the number of daily operating hours in each season. Six hours of operation per day were typical in the years up to 1993. In the summer season of 1993 permission was obtained to extend the operating hours. The pumps operated over 7 hours per day on average and 10 hours at times of peak demand, as compared with 14 hours assumed in the original design. Other factors limiting system output are discussed in Section 5.

4.2 Efficiency of water use

4.2.1 General

During the period of the project there was no season in which major shortfalls in yield resulted from water shortage. It can therefore be concluded that the hydraulic system as a whole, including groundwater and pumping from private wells, at least matched the need of the crops.

Previous work at El Hammami (EWUP, 1984) showed that farmers were typically applying more water than could be held in the half meter or so of unsubmerged sandy soil typical of the area. Excess water enters the water table, to be taken up in due course by the plant roots within the surrounding area in an informal type of sub-irrigation. The water table acts as a reserve which is automatically exploited by the plants when the surface supply is erratic. It appears that the practice has grown up over time. Adequate sub-surface drainage is needed to ensure that the watertable does not rise to the point where crop yields are reduced and soil salinity sets in. The irrigation interval for satisfactory growth at peak time in summer is 3-4 days, potentially a problem if, under the traditional delivery system, water was only available in the canal for 4 days in every 12 day cycle.

Section 2.2 referred to the high water table which occurs throughout the delta area. In El Hammami area the water table fluctuates over a limited range in response to irrigations and water standing in adjacent drains. Soil at a depth of 60 cms is normally at, or close to, saturation.

The moisture-holding capacity of the unsubmerged soil is so low that a surface irrigation regime aimed at just replenishing moisture in the upper 60 cm is impractical. The stream sizes which are needed by farmers to complete irrigation in a reasonable period without major distribution losses will inevitably result in considerable application losses. However, it is well-established in Egypt that crops draw a significant proportion of their need from the groundwater table. The amount will vary according to crop, growth stage and water table level; a general figure of some 33% is commonly used. In circumstances where surface water is unavailable, the proportion drawn from groundwater can be much higher as roots develop to follow the water level. Farmers effectively exploit the fact in their everyday irrigation practices.

In the circumstances, conventional concepts of field application efficiency are of less obvious significance. They can serve, however, to indicate trends in water use over time. At design stage a figure of 50% field application efficiency was assumed to be attainable (EWUP 1982), a value which agrees with data from Bos and Nugteren (1974) for small farms under basin irrigation.

4.2.2 Field application efficiency

In order to determine how the construction of the pipeline was affecting water use, measurements of field application efficiency, which were first made in 1979/82 were repeated on five farms in 1991/1992. The results of the two sets of measurements are compared in the following section.

For the present purposes the field application efficiency has been taken to be the depth of water retained in the soil compared with the depth delivered at the field edge. The calculation is complicated by the fact that the water table fluctuates in response to irrigation and surrounding drain water levels. A standard profile depth is needed for the determination. The earlier estimates were based on determining differences between the moisture held within a depth of 90 cm before and after irrigation. In practice, part of the profile was always submerged so that the weight of moisture in the lower part was constant. For the sake of consistency, the same procedure was followed in the present analysis.

Investigations under the EWUP project at the time when the open channel system was operating showed that farmers' unit water use varied widely. Typically, water considerably in excess of the volume which could usefully be stored in the soil was applied. For example, it was found (EWUP no 74, 1984) that a total depth of 1790 mm of water was applied to berseem throughout winter and spring on a farm at the head end of the system. Only 225 mm were retained in a soil depth of 90 cm. On the other hand, at the tail of the system, 275 mm were applied and 53 mm were retained: supplementary well irrigation was certainly practised at this location. Elsewhere, 885 mm were applied to the same crop, of which 280 mm were retained. Further data are available for other crops, but these figures serve to emphasize that:

- water application depth varies widely between farmers, being in the main part related to the availability or otherwise of supply

- the depth of water which can be retained in the soil is very small

- frequent light irrigations are necessary. Large applications mostly find their way to the water table.

The results for moisture retained in the soil compare with estimates for total available soil moisture-holding capacity of 100 mm per meter, equivalent to 50 mm in the region above the water table. Under optimal conditions it would be desirable to irrigate when 50% of available moisture, equalling 25 mm, had been withdrawn. The water supply, however, was unreliable. In practice, farmers' averaged unit applications were 180 mm, 69 mm and 75 mm at the above three locations. Overall, individual applications varied between 27 mm and 200 mm.

It is clear that large volumes of water went to the ground water table, particularly at the head of the system. Berseem seemed to encourage excess water use at all locations. At times of peak demand in summer, crops may be transpiring at 7 mm per day. Under the former system of water scheduling, farmers could irrigate for 4 days out of 12. Crops would have needed up to some 56 mm during the interval. Farmers will have been accustomed to overwatering so that the crop could draw the balance of its need from the water table. Average values of application efficiency ranged from 33% (berseem) to 55% (beans).

Investigations under the present project suggest that field irrigation practices have remained similar over the years. Table 5 shows the results.

Table 5 Irrigation water use for different crops

Crop	Average Water App. Efficiency (%)	Average Depth of Application (mm)	No. of Irrigations Per Season
Berseem	31	137	10
Egg Plant	51	93	11
Cabbage	51	69	7
Maize	43	88	8
Wheat	72	66	4

On these sites up to 50 mm was retained in the soil during irrigation.

The field application efficiencies compare with a figure of 50% assumed by the system designers. The efficiency for wheat appears misleadingly high. The total volume of water applied was small, comparison of supply with potential crop need may not be valid in these circumstances. Supplementary irrigation would have taken place using the deep aquifer and this plus the groundwater contribution would certainly have supplied most of the crop need and thus have kept the plants alive.

4.2.3 Losses in distribution

Distribution losses were taken to consist of seepage from the mesquas and field ditches between the outlet and the farm boundary. Mesquas were assumed to lose water in proportion to their length.

Estimates were made at the time of the EWUP project. Based on that work and experience from elsewhere (Bos and Nugteren, 1974), unlined mesquas were assumed to be 80% efficient and lined mesquas 90% efficient. No losses were assumed at direct outlets discharging directly onto the fields.

4.2.4 Losses in conveyance

Section 3.7 described the measurement of pipe losses. Table 6 shows the outcome of tests on pipeline 1.

Table 6 Losses from the head reach of pipeline no. 1

Date	Rate of loss
13 February 1992	8 l/s
16 December 1992	32 l/s
15 December 1993	18.6 l/s

The initial result was obtained soon after the pipeline had been maintained, in early 1992. The major increase in loss in late 1992 followed an earthquake which caused some damage in the Cairo area. Several of the alfalfa valves also needed maintenance. The final result, after a further year's operation, was taken to be reasonably representative of overall conditions during the period.

Factors contributing to the loss were identified as:

- backflow from the pumpstand to the sump via flap valves which were thought not to seal properly;

- leakage from alfalfa valves;

- leakage from the pipeline.

On the basis that the pipeline normally operated at a nominal discharge of 270 l/sec, the average loss was equivalent to some 7% of the discharge. Short-term losses caused by overflow from the end stand at the tail of the line have not been calculated but were relatively small.

The inflow to the line and the outflow from it were also compared. It is noted that in general inflow-outflow analyses are strongly affected by the accuracy with which measurements are made, since the resulting difference between two large numbers may, in some circumstances, be of the same order as the possible error in measurements.

The volume pumped over six full seasons was estimated from the number of operating hours and the nominal design discharge. Outflows were obtained from daily field measurements and records of outlet operating periods as described in Section 3. Figure 7 compares nominal inflows and outflows for the period of the project. It is evident that in the early years, inflows exceeded outlet flows by a small margin, of the order of 14%. By the end of the project the difference appeared to be around 27%.

A number of factors are thought to be involved:-

- farmers took water out of turn
- pump performance declined
- line losses increased
- outlet weirs were reset

There is no doubt that as the pressure for water increased with the lining of the mesquas, farmers operated outlets out of turn. The practice was not always corrected by the linemen and may partially account for the evidence of Figure 8 that a significant increase in apparent shortfall occurred in the summer of 1993 when the lining of the mesquas had been completed. Operation was still on the basis of two days per outlet. On the improved mesquas there was pressure for longer time allocations. Volume supplied and delivered were a better match at the end of the summer 1993 as the farmers and operators became used to the extended system.

As indicated in section 4.1, tests of pump performance before the start of the project showed that two of the three units on pipeline 1 were delivering some 10% less than the specified output for the design head. The pumps had remained idle for several years since installation and had doubtless suffered some deterioration. During pipeline operation the 12 inch unit was used virtually all the time whilst the two 10 inch pumps were used alternately. The pumps were maintained only once during the project period, so a further reduction in performance could be expected.

In the summer of 1993, a leak causing water to bubble up through the ground was observed in the head reach of the pipeline. After several months leakage was no longer evident on the surface. The large increase in mismatch between supply and delivery seen in April/May 1993 and the subsequent drop later in the season may thus be partially accounted for.

The outlet weirs were calibrated at the start of the project over a range of flows typical of daily operation. Errors in field measurement were unlikely to be greater than 10% and would be distributed randomly about the correct value. In some cases farmers lowered the metal plate weirs so as to increase discharge. Line staff were aware of the practice and were instructed to reset the measurement points.

In summary, deterioration in pump performance and undisciplined behaviour by farmers were primarily responsible for the discrepancy between recorded deliveries and supply. During 1993, localized leakage from the line, which appeared to diminish later in the season, was also a factor.

4.2.5 Block and overall efficiency

Field and distributary efficiencies were combined to estimate the efficiency of supply between the outlet and crop root zone.

An overall block figure of 40% was assumed for areas served by mesquas, and 45% for direct outlets, during the initial seasons. A combined figure of 45% was applied generally after the lining of mesquas. Outlet no 19, nominally classed as a direct outlet, has a large command area. Efficiency was assumed to be 40% throughout the project since no channel improvement was made.

Field, distributary and conveyance efficiencies were combined to arrive at an estimate of the overall project efficiency. Before the lining of mesquas it was some 35 %, and afterwards around 38 %.

The figures need to be set in the context of Egypt's overall water use. Overall, the national use of Nile water is highly efficient owing to reuse and exploitation of the aquifer which is linked to the river system. Water lost to the groundwater table at El Hammami, will to a large extent, be reused, either locally by the crop, or elsewhere. The disadvantages are that:

- overall the quality of water will decline;
- capital expenditure on systems is wasted.

4.3 Adequacy of supply

Field level supply and requirement were compared for:

- the scheme as a whole;
- individual outlets;
- head, middle, tail and El Shimi reaches.

Potential evapotranspiration needs for the particular crop mix on each outlet were calculated by the Penman method (Section 3.1). It was assumed that actual and potential evapotranspiration were similar since harvests were reasonable.

4.3.1 Scheme average

Figure 8 shows averaged field level supply and requirements for the years 1991-1994.

The in-field supply has been calculated by factoring the measured outlet volume by the outlet efficiency, allowing for application and distribution losses as deduced above. The supply has been represented in two ways, firstly as the depth supplied to the nominal command area, and secondly as a depth on the area actually irrigated. The irrigated area was invariably less than the nominal area, although the difference between the two decreased steadily over the course of the project. The depth actually supplied to the growing crop was considered a more meaningful measure of how the system was meeting crop needs.

In the early seasons, when the system was serving around 33% of the area, the supply corresponded to some 60% of crop need. By the end of the project period, the system was covering some 60% of the area, and supplying around 30% of crop need, at first sight a surprising result since crop yields were reasonable. Considerable care was taken to distinguish between areas benefitting from the system and from wells. However, farmers in some areas were supplementing the surface supply with pumped groundwater.

The water table at El Hammami always lay between 60cms and 0cms below the crop root zone, depending on the crop and its stage of growth.

FAO Irrigation and Drainage Paper No. 24 indicates that under such circumstances groundwater can contribute between 2mm and 6mm per day to crop water needs. In-field plant requirements were some 3.5mm/day on average in winter and 7mm/day in summer. In theory, groundwater might then supply between 33% and 66% of crop needs if the plant could not draw its supply from surface irrigation. In other words, crops at El Hammami were effectively sub-irrigated. The water “losses” at block level, (55% or 60% of supply, see 4.2.5) would have been directly recycled to meet shortfalls in supply obtained from the surface. There was no contribution from rainfall; the efficiency assumed is, if anything, optimistic. A high proportion of crop need was therefore obtained from groundwater, and some supplementary irrigation from farm wells.

4.3.2 Individual outlets

Only part of the potential command area below most outlets was actually irrigated. The exceptions were a number of direct outlets (those serving a single landowner). Table 3 shows the proportion of area served in each season. Generally, the area commanded rose steadily over the period of the project. As there are many wells supplying areas within the project boundaries, a given location was taken to be dependent on the system for its supply if at least 2 irrigations in one season were received from the pipeline. Areas receiving less than two irrigations were not considered.

The volume of water supplied in-field from a given outlet is affected by many factors, both technical and social. Physical constraints include: the level of the outlet weir relative to the hydraulic gradient line; the position of the outlet in the system and the operation of other outlets in alternative rotation groupings; losses in mesquas and field channels. Social determinants include: the number of farmers required to share the supply amongst themselves; the ability of the mesqua leader to coordinate and impose cooperative water use patterns; individual farmer's judgements as to the relative worth of competing for the piped water or settling for an existing well supply.

Clearly, it is not possible to identify the effect on outlet supply of each of these variables, given a limited data set. The aim of analysis was to try to detect trends in supply and to determine whether the pipeline promoted reasonable equity in supply between farmers at the head, middle and tail of the system.

As indicated above, the normal operating head differed considerably between outlets, since the outlet weirs were not set relative to the hydraulic gradient line. In particular nos 8, 17, 22, 30 and 32 suffered from a relatively poor supply. Direct and mesqua outlets were also likely to perform differently.

All the available outlet discharge information was therefore reviewed so as to generalize conclusions concerning system performance. Cumulative seasonal in-field water requirement and supply for direct and mesqua outlets considered representative of the head and tail of the system are presented in Figures 9-12. Outlets 7 and 21 are mesqua outlets at the head and tail of the system serving respectively 6.5 ha and 4.8 ha. Outlets 3 and 18 are direct outlets serving 1.4 ha and 1.2 ha.

The supply depth was calculated on the basis of the area actually irrigated by the system. The depth averaged over the total nominal command area is also shown in the figures. In the case of direct outlets, the two areas were normally similar. For mesqua outlets, particularly in the early years of operation, there was considerable difference.

Direct outlets 3 and 18 (Figures 9 & 10) received between 20% and 40% of their requirement from the system, depending on season. The balance would have been supplied from the ground, mainly deriving from seepage and percolation losses within the immediate area. There was no consistent difference between the supply to the two outlets. Figures 11 & 12 for mesqua outlets 7 and 21 show a pattern of supply similar to that at the direct outlets. Deliveries from the system were particularly limited in the later seasons.

4.3.3 Reaches

To reduce the variability in results based on individual outlets, the in-field supply and requirements at different reaches of the system were also calculated. The analysis followed the same pattern as for the system and for the outlets (above). The area actually served within the reach was totalled from the different outlets falling within its boundaries.

Outlets were grouped into four reaches as follows:

- Head reach. An area of 28.9 ha between the pumphouse and the Shimi branch corner stand supplied from outlets 1 to 8.

- Middle reach. 24.8 ha served by outlets 9 to 18.

- Tail reach. 81.4 ha supplied by outlets 19 to 27 including several of the mesquas with the largest command areas.

- El Shimi. Outlets 28 to 32 on the Shimi branch serving 14.8 ha. Outlets were normally supplied at the same time as the head reach via the corner stand.

The selection of the boundary between middle and tail reaches may appear somewhat arbitrary, given that the nominally-commanded area at the tail is much bigger than on the other reaches. In a spatial and operational sense the division is logical insofar as the number of outlets is around a third of those on the main limb of the pipeline. In practice, the pipeline as implemented is not capable of irrigating the full nominal area. The nominal command areas of individual outlets at the tail, in particular nos 19, 20 and 26 are too large for cooperative control of water. Outlet nos 17 and 22 suffer from low operational pressure as the outlet weirs are high. It is realistic to exclude some of the area at the tail. In 1993 the area actually irrigated at the tail, as defined above, was about half of the nominal command of 81.4 ha. The disparity in size between the effective areas served by the various reaches is therefore much less than first appears.

Table 7 gives the total area in each reach and the area under command for each of the six seasons of the project. The increase in command area in 1993 was due to the construction of lined raised mesquas which allowed water to reach land remote from the pipeline.

Table 7 Seasonally commanded area by reach

Reach Name	Area Under Command (ha & %)						
	Total	Sum91	Win91	Sum92	Win92	Sum93	Win93
Head	28.9	11.6 40%	12.434 43%	9.35 32%	17.45 60%	18.41 64%	24.47 85%
Middle	24.8	11.97 48%	10.66 43%	10.52 42%	12.46 50%	10.9 44%	12.74 51%
Tail	81.4	15.1 19%	14.67 18%	12.81 16%	21.84 27%	31.76 39%	37.52 46%
Shimi	14.8	12.3 83%	8.45 57%	8.38 57%	8.96 61%	11.39 77%	14.53 98%

By the end of the project period the head reach and El Shimi branches were effectively fully served. The middle and tail reaches were around 50% covered. There was little change in the area served in the middle reach in response to improved water distribution and mesqua construction. It appears that the farmers' demand for irrigation was being met. As noted elsewhere, constraints imposed by limited system capacity and the layout of the project area meant that it was not realistic to attempt to serve the full area.

Figures 13-16 show in-field supply and demand in head, middle, tail and El Shimi reaches respectively. The figures were prepared on the same basis as those for individual outlets. There is evidently no indication of a worsening of supply in the tail reach. The presence of the groundwater reservoir clearly helps to overcome shortages which would otherwise become acute. Section 4.3.4 examines the relative supply to different reaches in more detail.

Table 8 Seasonal supply depth, by reach, related to areal mean supply

	SEASONAL SUPPLY DEPTH S (mm)											
Reach	Sum 91	S/S_m	Win 91	S/S_m	Sum 92	S/S_m	Win 92	S/S_m	Sum 93	S/S_m	Win 93	S/S_m
Head	437	0.96	337	0.88	454	0.90	289	0.97	331	0.93	224	1.07
Middle	483	1.06	414	1.08	439	0.95	386	1.30	482	1.35	233	1.11
Tail	466	1.02	412	1.08	504	1.09	254	0.85	339	0.95	186	0.89
El Shimi	440	0.96	366	0.96	444	0.96	297	1.00	335	0.94	227	1.09
Reach Mean (S_m)	457	___	383	___	463	___	297	___	357	___	209	___

Table 9 Seasonal supply depth, by outlet command, related to mean supply, S(mm)

	SEASONAL SUPPLY DEPTH S(mm)											
Command	Sum 91	S/S_m	Win 91	S/S_m	Sum 92	S/S_m	Win 92	S/S_m	Sum 93	S/S_m	Win 93	S/S_m
0-1 ha	578	1.26	433	1.13	514	1.11	375	1.26	509	1.43	393	1.88
1-2 ha	468	1.02	428	1.12	500	1.08	331	1.11	372	1.04	230	1.10
2-5 ha	392	0.85	326	0.85	426	0.92	259	0.87	304	0.85	186	0.89
5+ ha	--	--	--	--	--	--	229	0.77	311	0.87	179	0.86
Mean (S_m)	457	___	383	___	463	___	297	___	357	___	209	___

4.3.4 Equity of supply - Reaches

Equity between reaches was calculated using the basic information shown in Figures 14-17. The data are too few to allow statistical analysis by a method such as the Coefficient of Variation. However, the results were compared with the mean supply for the project as a whole, to give a measure of relative supply.

The supply depth was calculated on the basis of the area actually served from the system, rather than the area nominally under command in each reach. Therefore, the results are considered in conjunction with the proportion of the area actually served, as set out in Table 7 above.

Table 8 shows that the supply depth was fairly uniform over the different reaches. The tail reach was slightly disadvantaged, but still received some 80% of the supply to the better-served areas at the end of the project period. The middle reach appeared to be favoured, particularly in the summer of 1993. Overall, the equity of supply appears good.

When the area commanded in each reach is considered in conjunction with the supply data it appears that the pipeline was distributing the available water remarkably fairly. Although only 50% of the tail area was served, the absolute area served, some 38 ha, equalled the total area of the head and middle reaches combined.

4.3.5 Equity of supply - Outlets

Owing to the in-built variability between the outlets it was considered that any attempt to assess equity of supply between individual outlets would have limited meaning. However, it was felt that there might be trends in the supply to outlets of a certain size. Outlets were therefore grouped in terms of irrigated command area, in ranges of 0-1 ha, 1-2 ha, 2-5 ha, and above 5 ha.

Table 9 presents the results of the analysis. It is apparent that the smallest outlets, those commanding less than 1 ha, were consistently better-served than larger ones. The trend was consistent, and in fact became more marked, throughout the period of the project. Furthermore, there appears to be an inverse relationship between the size of the outlet and its supply. Outlets serving between 1 and 2 ha consistently received a supply about average for all outlets, whereas outlets commanding more than 5 ha were significantly worse off, receiving only around 50-60% of the supply to the smallest outlets per unit area.

4.4 Water delivery in canal and pipeline systems compared

The two systems were compared on the basis of:

- the volume of water used
- the distribution of the available water
- farmers' views.

The discharge measurements in the original canal system were made during daylight hours in reach 1 just downstream of the head gates. Overnight losses to the drains were estimated at the time to be between 20 and 40% of the total discharge. The average irrigation release in the summer calculated from the measured flow at the canal head, divided by the total command area was 2.9 mm/day assuming the flow continued unchanged over 24 hours. Allowing for the fact that the flow into the canal would decrease during the night as the canal filled up to command level, an average flow of say 2.5 mm/day may be assumed. Table 10 below gives the average depth supplied by the pumps on pipeline 1 over the six seasons relative to the total command area and that area actually considered to be under irrigation from the system. It should be noted that the calculations are based on nominal pumped volume and do not allow for losses from the system or during application.

Table 10 Water supplied by the pipeline (mm/day) for the six seasons of the project

Season	Depth of supply over total area (mm/day)	Depth of supply over irrigated area (mm/day)
Summer 91	1.88	5.52
Winter 91/92	1.50	4.87
Summer 92	2.16	7.92
Winter 92/93	1.77	4.38
Summer 93	3.43	7.09
Winter 93/94	1.84	3.09

It can be seen that the pipeline supplied substantially more water as the area under command increased after completion of the raised mesquas in the summer of 1993. Relative to the nominal command area, supply increased from 1.88 mm/day in summer 1991 to 3.43 mm/day in the summer of 1993, an increase of 82%. During the winter seasons supply increased by 23% to 1.84 mm/day in 1993. Considering the supply in summer 1993, it appears that releases were somewhat greater than with the canal system, however it is not known how effectively the former system was operating. Overall, if the releases from summer and winter are combined then the releases are comparable.

In terms of the area actually irrigated it can be seen that the unit depth of water supplied decreases over the duration of the project as the irrigated area increased. The total quantity of water increased but proportionally less than the rate of increase in area. Setting aside the results in the first summer season, considered atypical, the unit supply decreased by 10% over the last two summer seasons. On the same basis, the winter supplies dropped by 36% per unit area.

The pipeline improved distribution along its length and removed the head/tail inequity that existed with the canal system (Hinton and Mankarious 1993). The size of the command and the number of farmers being served from an outlet primarily determined the supply to different areas. The situation was improved by the construction of the lined mesquas. Then the capacity and pumping hours of the system became the limiting factors. As would be expected, the further the farm from the outlet, the less dependable the supply of water.

Farmers were in favour of the pipeline system because the water was free and they considered it to be of better quality than well water. Those farmers whose land was served by a direct outlet or was close to the head of a mesqua, were strongly in favour of the pipeline. Those farmers who did not have access to the water because of problems of command continued to use their well pumps, but they would have preferred to use water from the system.

In the absence of a high water table and private wells, the pipeline would have had to supply a minimum of 6 mm/day at field level equivalent to 13.3 mm/day at the pumps during the summer. This is almost four times the amount supplied to the total area in the summer of 93.

The separate contribution of the water table and wells to the total water supply were not quantified either before or after the pipeline construction. It is clear that wells were the primary source of supply in some 40% of the command not served by pipeline 1. Plots taken to be served by the system, but receiving less than five irrigations were obviously also receiving supplementary irrigation from wells.

Having grown accustomed to well irrigation during the long period before commissioning, farmers were not unduly concerned if they were not supplied from the pipeline. They were cautious about using the system until it had proved to be reliable. The early mode of operation, two days for each outlet regardless of area, and the problems with power cuts and low water level in the Mansouria canal during the summer of 1992, did not engender confidence. Greater reliability, and correspondingly greater confidence amongst farmers, was achieved in subsequent seasons. During the duration of the project only one farmer, on a direct outlet, decommissioned his pump whilst several others used theirs rarely but made sure they retained the capability.

4.5 Review of findings

Water application efficiency appears low, however the results must be seen in the context of the practice of irrigating a soil with a very low moisture-holding capacity by surface methods. The water demand and water use figures indicate that farmers have been accustomed to managing by making full use of the high water table. The results support the assumption made at the design stage that the design capacity of outlets should be based on peak crop evapotranspiration needs, without allowing for losses in distribution and conveyance. It is apparent that the groundwater table, constantly recharged by losses from the surface supply, plays a major role in supplying crop needs. In addition it functions as a buffer in the intervals between irrigation applications, compensating for the fact that there is no in-built storage capacity in either the pipeline design or the original canal system. However, there are some disadvantages to the system: good drainage is needed to ensure that the water table does not rise too high. It is also inevitable that the quality of the water supply to the crop is reduced by passage through the ground. Quantitatively the results for water supply and demand appear similar for the system as a whole, for reaches and for outlets.

The results for equity appear to have considerable significance for the planning of pipeline schemes. Section 4.41 indicates that a pipeline offers potential for spreading supply fairly across an area and reducing problems of head-tail inequity which invariably occur on open channel systems. However, section 4.4.2 shows that water was not equally spread at outlets commanding larger areas, despite efforts to improve distribution by lining mesquas.

Small outlets are under the control of a few farmers. Direct outlets serve between 1 and 8 farmers. Complex, cooperative decisions about when, and where, water will be used are not involved. Outlets of above 5 ha involve cooperative working between a larger number of farmers, up to 39 on outlet 26 in Winter 1993. The results show that at present, efficient sharing of water between different users on a large mesqua decreases the further away from the outlet the farm is sited.

In the face of decline in the quantity and quality of available water, improved water management is essential. However, Governments throughout the world have increasingly limited resources to devote to water management. It is neither possible nor desirable for agencies to control water at tertiary level and it should be sought to simplify system design to reduce operational involvement at the system level as well. The direct consequence is that significant improvement in control is needed at, and below, tertiary level. If the design and layout demand that large numbers of farmers must organize to share water it is unrealistic to expect major improvement. Particular care is needed at the planning stage to devise distribution systems which allow farmers control over their supply but which keep the water use units small enough for cooperative management. Section 5 discusses the management of the pipeline at El Hammami and identifies desirable features of possible future designs.

5 Operations

5.1 General

Pipeline 1 was selected for operational improvements. Pipeline 2, which is very similar in all respects, was seen as a benchmark against which to compare farmers' response to formalized operations.

The project strategy for gradual introduction of improved operations was shaped by the fact that the farmers were unaccustomed to the new system. In the long period during construction of the pipeline they had grown used to irrigating from wells.

WMRI agreed with farmers that they would be permitted to draw water as they wished during the first season of operation, provided no damage to the system would result. In the event, this lasted about six weeks. An overall recommendation was issued that no more than six outlets should be operated at one time. The purpose of establishing such a loose regime on a system with many inbuilt capacity restrictions, refer Section 5.2, was to allow farmers to experience for themselves the limits on supply resulting from unsynchronized demand.

At the farmers' request, WMRI introduced a formalized rotation pattern after about six weeks of the first season. It was agreed to provide two days supply per outlet per rotation, insofar as that was possible. No attempt was made at that stage to link outlet operating time with the command area. Outlets were under the direct control of a lineman. Later on, farmers from pipeline 2, having observed operations on the first pipeline, requested similar assistance from WMRI. The project authorities responded by advising farmers to look and learn for themselves; direct assistance was refused.

In the summer of the third year, progress was made on the introduction of a schedule linking outlet operating time with command area. Full implementation of the practice was not possible in the time available. Outlets were handed over to the control of a single farmer within each command area, but the linemen were responsible to ensure that the farmers kept to the agreed schedule.

The gradual evolution of a viable operating pattern is apparent from daily records of the outlet opening times throughout the period of the project. Certain outlets, particularly nos 8, 9, 10, 17, 22, 30 and 32 consistently suffered a poor supply as the weirs on the outlet boxes were set high relative to the hydraulic gradient. Some extra time was made available by the operators to help with this problem. The fact was also held in mind when the operating records were analysed.

5.2 Constraints on operation of the system

5.2.1 System constraints

Early development of low pressure pipelines was linked to large farms owned and managed by a few individuals. Operational control and distribution of water under such conditions is relatively straightforward since both demand and supply are determined and managed by users. The pipeline operates on demand, irrigating defined areas according to a relatively simple roster.

The EL Hammami pipeline design, as implemented, involves a large number of outlets, great variation in the command areas of individual outlets (0.3 - 38 ha) and a large number of farmers with small landholdings. Both scheduling of water and its subsequent distribution become complex issues. The system as constructed was subject to external constraints as detailed in Section 5.2.2, but even had these been removed, it would inevitably have had to operate on the basis of limited demand because of the exceptionally large number of outlets and different users. It is not economic to provide capacity for the extreme situation in which every farmer wishes to irrigate simultaneously. Overall control must therefore reside with a managing authority, whether appointed by Government or by farmers. The fact was clearly recognized by farmers on both pipelines after the initial 6 weeks of informal operation.

It is widely recognized that effective cooperation between individuals is difficult when large numbers are included in a group. Chambers (1988) suggests that, as a maximum, 15-18 members can operate effectively as a group. Table 11 below lists outlets which include more than 10 farmers within the mesqua command area. For the sake of comparison, the numbers of farmers taking water from the system by the end of the project period are also shown.

Table 11 Outlet commands serving more than 10 farmers

Outlet No.	No. of Farmers in Command Area	No. of Farmers Served
4	31	21
5	11	10
7	29	22
10	22	12
19	47	27
20	21	21
22	17	17
26	78	27
27	12	7

Several outlets, nos 5, 20 and 22, appear to serve all farmers within the command. On the larger outlets, some 60 - 70% of framers appear to benefit. The exception is outlet no 26, nominally serving 78 farmers. In practice only 25 farmers within the command receive benefit. The original design assumed some 46 ha of the area was excluded from supply. Under the project it has been recognized that full command of the area under outlet 26 is impossible. Continuous supply would be needed to meet crop needs in the peak period.

The as-built levels of the weirs on the outlet boxes impose a further constraint on operations. In order to maximize the irrigated area, the weirs were apparently set to provide command over the highest land below the outlet rather than to maintain a reasonably consistent level relative to the hydraulic gradient. The result is that, quite apart from variations in available outlet head under different combinations of valve openings, there are considerable in-built variations in the pressure-flow characteristics of individual outlets. Certain outlets, notably numbers 8, 9, 10, 17, 22, 30 and 32, suffered from poor operational pressure.

In theory, there would appear to be an almost unlimited number of combinations of 6 outlets operating simultaneously. In practice, there is a very strong logic to grouping together outlets within the same area as far as possible. It is also desirable to group together outlets serving similar command areas so that they will be operated for a similar length of time. In practice, the latter aim cannot be achieved at El Hammami since the command areas of the outlets differ so greatly, sometimes by an order of magnitude.

Until and unless farmers limit their abstractions to defined periods on defined dates, operators will have difficulty in maintaining line pressure and preventing surges and overflows at the tail stand since delivery cannot be regulated except by stopping or starting one of the pumps.

5.2.2 Supply constraints

The level in the Mansouria supply canal was low for part of each operating cycle. The pumps could also only be operated for a limited period, averaging 7.2 hours each day during the 1993 summer season, see Section 4.1 (Figure 6) . By contrast, up to fourteen hours daily operation were assumed in the design.

The capacity of the transformers installed initially at the pump stations was insufficient to allow all three pumps to operate together. In the last two seasons this problem was rectified, but then no more than two hours operation under these circumstances was sanctioned by the MPWWR. The electricity power supply was also rationed during the summer months: one day per week was typically lost for power cuts. Figure 7 showed that, despite constraints, the total pumped volume during the summer of 1993 was 58% greater than in the previous summer. The number of operating days was increased as were the operating hours in peak periods. It may be noted that in the following winter season, deliveries were only marginally greater than in the previous year, but in practice crop production did not suffer.

Records of power consumption mirror the trend in monthly water deliveries. Although peak reference evapotranspiration occurs in June, power demand in 1993 was at a maximum in August and September. Demand throughout 1993 was higher than in the previous year; the August figure was 70% up on the equivalent month in 1992, mainly because of the completion of the long mesquas.

5.2.3 Constraints resulting from system condition

Maintenance in Egypt normally takes place over a period of 4 to 6 weeks in January and February during the winter canal closure period. The Ministry has an extensive programme of work at that time over the whole of the Egyptian system. It was therefore difficult to obtain staff and resources to maintain the pipeline. The system was checked and the pumps maintained only once, in February 1992. Some work was done on the control gates in the stand tanks. During the course of the project a number of damaged or missing alfalfa valves were replaced and the outlets later padlocked. An annual maintenance programme is essential to rectify problems before they become severe.

5.3 Yearly operations

The following observations were based on analysis of selected parts of the seasonal outlet operating records.

5.3.1 Operations in 1991

The initial operation as has been explained earlier was a on free for all basis, shadowing the old method of operation whereby if there was water in a mesqua then it was available for any farmer to take. The farmers were very loath to give up this way of thinking even though it rapidly became apparent that a rotational system had to be adopted. after six weeks of the free for all system, the WMRI staff and farmers met to agree a system of two days opening per outlet in an irrigation period. This was not based on any area basis, but meant that the farmers were not tied to an absolute times of opening and closure. A further problem that occurred was that individual farmers on an outlet did not always work in an efficient manner. One farmer would want to water his crops so the outlet if in turn would be opened. Once he had finished, and no other farmer was taking water then the outlet would be closed. Another farmer would then come later in the day and demand that the outlet be opened again. During the first two seasons when the system was being introduced to farmers, the upper part of Pipeline 1, including the El Shimi branch, received disproportionate access to water compared with the tail.

The fact is reflected in the proportion of the potential command area which was served by the system (Table 7): some 45% in head and middle reaches, 70% on El Shimi and only 18% of the large area at the tail. Overall, only around 34% of the area of pipeline 1 was served by the system.

Outlets in the top and middle reaches normally received water on the same day. In addition, some outlets in the middle reaches received water on the day when the tail outlets received supply. The tail reach rarely received the entire supply for a full day despite the fact that the nominal command area of 81 ha represented over 50% of the area on the pipeline.

Certain outlets were clearly not using the system efficiently. For example, in the winter of 1991, based on the intervals between outlet operation, the irrigation interval was only 3-4 days. Evapotranspiration demand would have been low and an interval of at least a week could have been adopted.

However, the system being operated was two days per outlet and water was plentiful due to the restricted area. On occasions as many as 20 outlets were open within a single day, though not at the same time.

5.3.2 Operations in 1992

Summer. During the summer of 1992, power shortages and low levels in the supply canal reduced the total volume of water pumped. The area irrigated accordingly decreased. In particular, the area in the tail was smaller than in 1991. Despite the overall constraints, certain outlets used an excessive proportion of the available total. For example, outlet no 27 (command area 3.4 ha, actually irrigating about 1 ha) regularly received water for some 2 hours on more than the two days per period, whereas no 26 (commanding 38.4 ha, but only irrigating 3 ha because the mesqua was in poor condition), received supply at a more reasonable interval of around 4 days but only for a very limited period. At both outlets the as-built levels of the weirs allowed a good supply. It should be noted that a large part of Outlet 27 in fact was laid to nursery plants and therefore required light and frequent waterings.

Over a typical period of 8 days in June, the time of peak water use, the head reach received water on 5 days out of eight, and the middle reach on 4 days. The area commanded at the head actually decreased over the previous year, so it is clear that a few outlets, serving 9 ha, were consuming a large share of the water.

As in previous seasons, the middle reach and Shimi branch benefitted by inclusion in rotas common with adjacent reaches. During this season, unlike the previous year, supply was routed to the middle reach only on certain days. It is clear that certain outlets on the middle reach were benefitting at the expense of all other areas.

The constraints on the system had not been yet recognized by farmers. On occasions, up to 20 outlets were open within a single day, a situation which would have produced poor operating pressure throughout the system. However it should be noted, farmers were under no pressure to work together. The design flow of 50 l/s from 6 outlets would have been too much for individual farmers to handle.

The ad-hoc manner in which the outlets were being operated is apparent from the records of operating times for the period. For example, outlet no 10 in the middle reach (commanding 11 ha but probably irrigating only 2 ha), received water for 6 hours on 24th June; for 2 hours on 25th June and for 2.5 hours on 27th June. A rational schedule related to the soil moisture-holding capacity and crop needs would have involved a light application of say 25 mm, applied within half a day. It is clear that individual farmers were acting independently. As another example, outlet no 4 in the head reach, commanding 12 ha but irrigating only 2.5 ha, was open for: 6 hours on 23rd June; for 2 hours on 25th June; 5 hours on 26th June; 1.5 hours on 29th June and 1.5 hours on 30th June.

Winter. By the winter season, the construction of lined mesquas had started. The area irrigated in each reach increased over the previous year. In particular, 27% of the tail area could be irrigated. However, the organization of supply was still visibly biased to the middle reach because of outlet size and the 2 day schedule. In a given 8 day period in December, the middle reach received sole access to water on 3 days. The head reach and El Shimi branch shared water on two days and the tail received sole supply on 3 days, an improvement over the previous year which also reflects increasing demand.

The irrigation interval was around three days on average. Individual outlets were still open more frequently than necessary, for example outlets 12, 13 and 15, all in the middle reach, were open on at least three separate days during an 8 day period.

It was noticeable that a maximum of only 11 outlets were open in a single day compared with 20 earlier in the year. The system would have been under lower demand than during the summer, but It is also likely that the experience of the previous season had caused farmers to adopt better operating discipline.

5.3.3 Operations in 1993

Summer. By July 1993, the programme of mesqua lining was effectively complete. A substantial benefit was observable in the tail reach, where the irrigated area was 40% of potential. Very minor overall increases were recorded on the other reaches.

The increasing focus on irrigation needs at the tail end was reflected in the fact that water was supplied to the tail reach on 3 days out of eight, in addition to half day when supply was shared with the head. Outlet 26 was open on four days, a substantial improvement over the situation previously. Outlet 27 was still relatively favoured, receiving supply on three days, it was still being used for seed beds.

Relative to the size of command area, the head reach still received better access to water mainly because there only two of the outlets had large commands. Typically the reach was irrigated twice during the period, a few outlets also received water at other times. The middle reach received water twice with the irrigation interval being about four days. There were some variations in the grouping of outlets. The head reach was sometimes irrigated together with the tail and sometimes with the Shimi branch. Certain outlets were still favoured notably outlet 8. No more than 12 outlets received water within any particular day.

Winter. By the winter of 1993, further improvements in command area had been achieved. A new system of outlet rotation had been implemented based more on the area under an outlet command. Of the tail reach 46% of the area was being irrigated from the pipeline compared with 85% of the head reach and 98% of the El Shimi branch. The area irrigated in the middle reach was little changed from the previous seasons. The total area of the middle reach in fact only represents 16% of the total command area of the system. As it had been relatively favoured in previous seasons, it seems probable that the land in the reach was satisfactorily served.

No more than 9 outlets were open in any one day during the sample periods in early December and during April. The irrigation interval remained on average about 4 days which given the low crop evapotranspiration demand during the Winter period was shorter than necessary. However it should be remembered that an outlet being open did not necessarily mean that the same plots were being watered The farmers still did not always work together, there was no official water users association which controlled the distribution of water within the mesqua.

Outlet no 27 received water on a smaller number of days during the two irrigation periods, once in the December period and twice during the April period. Again it was still being used as seed beds which would account for the apparent overwatering. Outlet no 26 how ever was receiving a more plentiful supply in regard to the large potential command area. It obtained water for 7 and three days respectively in December and April periods. It should be remembered that though the data indicated that some 10 ha of outlet 26 was receiving water from the pipeline by this season, this was calculated on the basis that the areas received water on a regular basis. Farms further downstream on the mesqua did take water on occasions though not on enough to be included officially in the area. An area of some 5 to 10 ha can be included in this category.

Instances of excess discharge were quite few. Outlet 7 appeared to receive more water than needed, however it was difficult to precisely define the area served by 7 as the supply was shared by farmers drawing from outlets 7 and 8. Outlets 2, 4 and 8, which had previously taken more water than necessary, no longer did so.

The discharge from mesqua outlets was larger than from direct outlets. More than six direct outlets could be operated at a time, supplying a stream which could be handled by a single farmer. System operators complained of problems, particularly in 1993, when outlets were shut down without notice, often in mid to late afternoon, causing overtopping of the end stand. At times when direct outlets were being served the problems were reduced, as the closure of a single outlet had less effect on the line pressure.

On the majority of days, water was allocated to adjacent outlets on a given reach or within adjacent reaches. Because the rotation took greater account of the area to be served, rather than, providing, as formerly, equal time per outlet, more water and time was allocated to the much larger command areas at the tail.

5.4 Summary of seasonal operations

The 3 years (6 x seasons) of outlet operating data illustrate the evolution of a pragmatic operating pattern responding to the needs of farmers.

In the early part of the first season, farmers clearly did not understood the limitations imposed on supply by uncoordinated demand for water. Large numbers of outlets tended to be open at the same time, no doubt producing a poor supply in most areas. Farmers responded with a request to WMRI to take control of the pipeline, a practice which took effect in 1991. Each outlet was fitted with padlock and chain, the key which initially was operated by the lineman and then subsequently was held by a farmer within the adjacent mesqua command area, who operated the outlet under the rotation agreed with the lineman.

Introduction of formal operations was difficult at the outset, since farmers wanted to reserve to themselves the decision as to when to take water. However, once regular operations had been introduced the practice was followed for four seasons, largely because of low demand for water. When the raised mesquas were constructed, it became extremely difficult to extend the schedule because extra working hours were required. Improvements were achieved during the last winter season when demands on the system were less than the summer maxima. By the end of the project period, the tail reach was receiving a fair proportion of available water. The other reaches were already reasonably served by that stage. Notwithstanding the severe constraints on system capacity, the pipeline obviously encouraged an equitable distribution of supply, compared with general problems of inequity on open channel systems. Further improvements will require longer pumping hours as well as a more formal system of operation within mesquas.

The analysis of system operations confirms that the introduction of radically different practices into traditional agriculture requires time and adjustment on the part of operators and farmers. Future projects should emphasize the vital need for training in bringing new technology to irrigators. Traditional social patterns in Egypt are strong but farmers are likely to adapt their practices if they recognize that their interests will be served.

5.5 Water user associations

In order for the project to be sustainable it is recommended that farmers be involved far more in the operational decision making processes at El Hammami. At present they appear to feel that O&M is the responsibility of Government. Without any sort of model to follow, farmers did not display interest in the idea of Water User Associations.

Traditionally, given water in the canal system, farmers decide when to irrigate from mesqua or turnout based on the condition of the crop and the availability of labour. As their farms are so small, cultivators mostly have other sources of income. They value flexibility in the time of watering so that they can undertake other tasks. The unpredictable nature of their demand, even when made on the advised day, and the number of independent outlets made operation of the pipeline extremely difficult.

Farmers were not good at cooperating amongst themselves so WMRI staff had to spend a great deal of time in responding to requests and resolving disputes which could, and should, have been settled internally. Typically, on the longer mesquas, farmers claimed that they had missed their turn and requested compensatory supply. The system operators tried to accommodate such requests after the scheduled irrigation for the day had been completed. However, extra power and water would be involved in filling a long mesqua so as to supply a single farmer. Under the old system of canal irrigation, farmers at the end of the mesqua would normally have received water during the night when demand was low. That option was not possible with the pipeline. Distribution of water along the length of the pipeline was more equitable than with the old canal system. However, farmers close to the run of the pipeline were the prime beneficiaries; those further away received less or no water.

The only workable solution over the long term is a system of rotation between outlets which is agreed and enforced by strong outlet leaders. At the time of the project, Water User Associations had no status in law and were not encouraged. Subsequently, under the Irrigation Improvement Project (IIP), funded by USAID and later by World Bank loan, Water User Associations received the backing of senior ministers within the Egyptian Government.

In Egypt the development of WUAs is considered to consist of the following steps:

- **Entry.** Identify problems. Establish relationships.

- **Initial organization.** Introduce aims and objectives. Agree on formation. Elect WUA leaders. Establish roles and responsibilities. Train leaders.

- **Participation in planning for mesqua improvement.** Develop plans for improvement. Train WUA councils. Turnover mesquas.

- **Mesqua improvement.** Implement WUA roles and responsibilities. Develop water use plans.

- **WUA Operations.** Implement water use plans.

- **Branch WUA Federation.** Individual WUA leaders elect/agree federation leader and council members. Implement federation responsibilities.

The formation of effective associations is a slow process, requiring the skills of experienced motivators and support over a number of years, financial trust and training are the key components of any such groups.

5.6 Discussion - operations

The El Hammami pipeline can only operate effectively under a command style of management because of the various constraints identified in sections 5.2 and 5.4. In the short term, the Government must remain involved as a managing agent. However, now that the system is operating, farmers need to be made aware that Government will gradually withdraw financial and material support. In the long term, farmers should be pressed to employ their own trained linesman.

5.6.1 Farmers' response to the system

When informed of the details of the original design, farmers demanded more outlets - one for each existing mesqua. The design flow rate remained unchanged. Apart from extra cost, the main consequence was that system operation became much more complex. The problem of grouping outlets together for simultaneous operation was complicated by considerable variation in area served and in the head available at individual outlets.

Under the open channel system, water was in theory available to farmers for 4 days out of 12. In the interim period of pipeline operation, intended to apply for a maximum of two seasons but in fact in place for four seasons, water was supplied to each outlet for two days in the 12 day period, irrespective of the outlet command area. The pumps could operate for 8 days, sometimes 9, out of the 12 day period. Farmers were reasonably content with the system, but it did not encourage best use of available water. It was clear that individual farmers did not cooperate because the outlets were constantly being adjusted. WMRI required that farmers come to them to open the valves. Locks were fitted to the alfalfa valves when it became apparent that farmers habitually took water outside their turn. Field staff held the keys.

Once the idea of rotation had been introduced, the key was handed over to the mesqua leader. The changeover to a pattern of supply based on outlet operating time proportionate to area served met with fierce resistance initially. The practice was being introduced gradually by the end of the project. Table 12 shows the target outlet operating schedule at that stage.

Various attempts to involve farmers in the decision-making process failed because they did not want to incur cost or take responsibility for running the system. Initially some farmers did not use the system because of general fears that they would have to pay. WMRI made no attempt to introduce charges in order to gain farmers' confidence in the system. Increasingly, the limited water supply in Egypt has caused Government to reconsider the question of farmers paying for water, though this has great ramifications with Islamic Law. It is more likely that some form of service charge may be implemented.

Mesqua leaders had been appointed, rather than elected, under the EWUP project. Leaders tended to be farmers whose land was nearest the pipeline. Under the traditional supply system those upstream had first right to water and controlled the supply to downstream users. Some farmers at the head of the pipeline, feeling that they had not received enough water, complained when water was released to downstream users on their "off" days. Their reaction reflected the fact that under the canal system, farmers could draw supply at will whenever there was water in the canal. No formal pattern of rotation amongst users had existed, under the canal system, though there would probably have been informal arrangements.

Table 12 Supply schedule - winter season 1993/94

Outlet No.	Hours of operation								
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9
1	2.5				2.5				
2	6				6				
3	5				5				
4	ALL		ALL		ALL		ALL		
5	7				7				
6	4				4				
7	ALL		ALL		ALL		ALL		
8	5				6				
9	4				2.5				
10		7	7	6		7	7		
11	2				2				
12			3				3		
13			4				4		
14			3				3		
15			2.5				2.5		
16			1.5				1.5		
17			2				2		
18			2.5				2.5		
19		ALL	ALL	ALL	ALL	ALL	ALL	ALL	
20		4		6		7		7	7
21		2.5		6		ALL		7	7
22		ALL				ALL			ALL
23		1.5				1.5			
24									
25		2.5				2.5			
26	ALL	ALL	ALL	4	ALL	ALL	ALL	4	
27		7				7			
28				7				6	5
29				4.5				4.5	
30				4.5				4.5	
31				4.5				4.5	
32				8					

Note: Part of the water from No. 7 went to land nominally watered from 8

5.6.2 Improved operations

Given the project's success in achieving a working system, despite severe constraints, future management initiatives should focus on improving coordination between farmers and reducing the managerial input of Government officials. WUA members will need educating in basic principles. Most important from the point of view of water management, the mesqua leader must effectively control and time the operation of the outlet to match the size of the outlet command. Secondly, water should be distributed to individuals within the command on the basis of their land holding size. Technical help is still needed on both these aspects.

Water distribution within the outlet command would be much easier if the full stream could be directed to a single farmer. Unfortunately, such a practice is not possible as the nominal stream size of 50 l/sec is too large for a single farmer to manage efficiently. Apart from a complete redesign and reorganization of the field channel network, there is no alternative but to divide the flow below the outlet, a practice which is inherently less efficient than directing the full stream from a smaller mesqua to one farmer. Three farmers could be served by a stream of 50 l/sec. The date and time of rotations need to be prominently displayed, for example on the pumphouse and corner stands, so that no farmer can plead ignorance of the schedule. Also, depending on crop, farmers don't always wish to be on hand to supervise watering - berseem, once established, is normally just left whilst basins are filled.

The schedule should be established with the full involvement of farmers and their leaders. Each outlet needs to select a leader to sit on the distributary committee. Special arrangements are needed for outlets both larger and smaller than average. Group action and decision-making become problematic when more than 10 to 15 people are required to cooperate closely so head, middle and tail groups might be needed on the largest mesqua commands. Direct outlets, probably each under the control of a single farmer, should not wield disproportionate influence on the distributary committee. Therefore, an agreed formula for grouping direct outlets under one or more representatives on the committee would be needed.

In summary, further improvements to operational efficiency require:

- outlets operated to a formal plan agreed with, and between, farmers. The details of the schedule should be prominently displayed.

- an agreed internal rotation pattern specific to each mesqua. WUAs should be pressed to work out plans so that each farmer knows when to expect water. The rotation would be supervised by farmers with the active support of the authority.

- motivated and responsible WUA leaders capable of checking that their outlets receive the due amount of water. For this purpose, they would need to know the planned time of supply and the water level required on the outlet weir. They would also be expected to check that other outlets were operating according to plan. In the event of problems, they should have right of appeal to the distributary committee.

6 Design for operations

6.1 Water management-general

Low pressure piped irrigation systems appear similar in many respects to water supply networks. However, in practice there are substantial differences in the way demand is imposed and managed within the two types of system.

In a water supply network the consumer registers a demand and the system is required to respond. Unadvised and uncoordinated demands can be met from storage. The operating pressure is comparatively high; moderate changes in outflow do not radically alter the pressure and flows throughout the network. The system is designed to accommodate high static pressures. Pressure-relieving devices are provided to accommodate dynamic loads resulting from sudden changes in demand. Cooperation between users is neither required nor expected.

In a piped irrigation network on flat terrain it is physically and economically impractical to include a meaningful volume of storage to cope with sudden demands on the system. Land is scarce and individual landholdings are small. Systems are commonly powered by constant-speed electrically-driven pumps.

Sudden changes in demand can only be met by switching individual pumps in or out, so fine adjustments to the discharge are not possible. The individual components of the network are not designed to resist a large range of pressures. The system is inherently less capable of responding to sudden changes in demand and associated pressure fluctuations than a water supply network. Good water management therefore becomes very important.

Water must be managed at a number of levels in an irrigation system. Cooperative working is required. If, at a given level of the system, the design is insufficiently flexible to provide the necessary water control, then correspondingly tighter control must be exercised at some other level in the system if the overall efficiency of water use is not to suffer.

Direct abstractions from mains and branch canals in open channel systems are discouraged as far as possible because they affect water levels and the deliveries to lower-order channels. The higher-order channels are expected to carry a relatively steady and constant discharge. Checks are made on the distributary canal designs to ensure that acceptable head can be maintained in the system when operating at discharges less than design. Much greater variation is expected in the discharge in lower order canals. Similar practice should be adopted on low pressure pipelines. Outlets imposing direct and variable demands on the main conveyance system should be avoided wherever possible. Operational problems at the system level at El Hammami would have been reduced by constructing a few large group outlets. However, the result would clearly have been major problems in water sharing below the outlet.

It is clear that designers must adopt realistic assumptions about how the system is to operate, must identify the nature and location of the possible constraints to good operational control, and must design, specify and cost the accompanying social and technical measures needed to achieve the assumed level of performance. Project feasibility and detailing studies tend to focus on physical aspects of the system. Early consideration must be given to operational aspects. Investigations of prevailing irrigation practices in the region may be required.

Irrigation systems can only be designed to supply, within available operating hours, the full averaged demands of an area at time of peak evapotranspirative needs. It is uneconomic to attempt to build in excess pump and pipeline capacity, which will be underutilized for long periods of time, to meet unsynchronized short-term demands. Such over-design will also probably impose unnecessary burdens upon the water supply and electricity networks. It is, however, necessary to provide standby capacity to cover for plant breakdown.

Appendix 2 sets out guidelines for sizing schemes serving small farmers. Small, independent units sized so as to offer the best chance for farmers to cooperate are to be preferred. If topography and the water supply infrastructure dictate that schemes considerably in excess of 10 ha like El Hammami, must be developed as a single unit, then special arrangements are needed to avoid the problem of unregulated demand on the pipe distributary network. An attractive technical option would be to provide group outlets with proportional division structures, to subdivide the flow and direct it in equitable amounts via channels or pipes to different groups of farmers. Operational problems in the pipeline system would be reduced by limiting the number of outlets and the difficulties of water division below the outlet would be simplified. Farmers' representatives would need to check the division weirs frequently to ensure that there was no illicit interference with their proper functioning. Experience at El Hammami has shown that patient discussion, explanation and agreement with farmers would be needed before such a solution could be introduced.

6.2 Water management - El Hammami

The system design, as summarized in EWUP report no 21, assumed that a maximum of 4/5 of the total 9 outlets would be operated at a time (modified demand) on pipeline 1. Operations would have been straightforward. In the design case, supply would have been directed alternately between two sets of similar outlets operated by farmers. Since the command area, the cropping and the operating pressure would have been similar, the required time of outlet operation would generally have been comparable. System capacity was based on the crop water needs at peak time, assuming three pumps were to operate for 14 hours per day. Under the design assumptions the task of imposing a pattern of rotational supply was principally assigned to the tertiary level, a logical procedure if it could be implemented in practice. It was recognized that the design stream size was likely to be too large for a single farmer. The outlet discharge was to be shared between a number of individuals.

When farmers rejected the design until 32 outlets were promised, the clear limits on system demand were removed at a stroke. In place of a demand pattern imposed evenly over the available operating hours, uncoordinated operation of outlets could now result in sudden demands far in excess of the available system capacity. In some irrigating nations where peak demands exceed system capacity, cooperative social water use patterns to limit and stagger demand, such as the Golongan system in Indonesia, are part of rural culture. Such behaviour requires considerable change in a society where farmers were formerly accustomed to drawing water whenever it was available in the distributary channel. Supply at El Hammami was hitherto regulated only in the sense that downstream farmers were unable to draw supply when most upstream users were irrigating.

Unless self-limiting patterns are accepted by farmers, regulation must be imposed at a higher level of the system. Direct evidence for the need was the request by farmers on pipeline 2 for WMRI to take over operational control. It should be pointed out that such dependency is directly counter to the move by Governments to devolve O&M responsibilities to farmers. However, when new systems and ideas are introduced, training and initial help from authority is vital to the success of the project.

Despite the difficulties, continuing Government support has permitted the gradual introduction of a workable operational pattern, to the point where the project can be considered reasonably successful. However, to achieve further improvements in water management at El Hammami, some 300 farmers have to coordinate their activities better and pumping hours have to be extended, see Sections 5.4 and 5.52. Without the formal structure offered by WUAs, the prospects for improvement look remote.

The practice of water sharing is complex, since variation in outlet command area and operating pressure mean that each outlet is unique. Water distribution must be based on generalized rules and guidelines:

- The area which can be irrigated will depend on the season and the number of hours for which the pumps are operated. In the summer season, the two pumps on pipeline 1 could irrigate

Operating hours	Area (ha)	Area (fed)
10	80	200
12	96	240

- No more than 6 outlets are to operate simultaneously.

- A discharge of 56 l/sec corresponds to a head of some 11 cms on the weir crest.

- At outlets where the head on the weir is rarely or never more than 6 cms, the entire flow should be taken by one farmer for a time related to his holding size and the unit time. Where the head is usually between 7 and 11 cms two farmers should share the flow

- Each feddan should receive water for no longer than 2½ hours, allowing time extra for changing the stream between fields.

- Each outlet is to prepare a rotational schedule for participating members.

Farmers will need continuing technical help whilst evolving sharing arrangements appropriate to the available discharge and operating pressure.

Appendix 2 sets out some basic requirements of small pipe systems designed to take account of water sharing arrangements between small farmers.

7 Conclusions and recommendations

General conclusions and recommendations concerning the El Hammami pipeline are set out in the following section. Appendix 2 includes guidance for developing new systems.

- Introduction of pipeline 1, operating under the overall control of WMRI, improved the distribution of water between head and tail of the system. The area commanded increased steadily over the period of the project, whilst unit releases declined.

- On average the irrigation supply to unit area was similar to that provided by the original open channel system. Between 30% and 60% of crop needs, depending on the season, was supplied by groundwater and supplementary irrigation from deep well pumps. The reserve meant that the timing of irrigation was not so critical as it would otherwise have been. The concept of adequacy of supply has limited meaning in such circumstances. Harvests were reasonable indicating that the system as a whole was supplying crop needs.

- As the pipeline aged, transit losses increased to some 7% of total supply. Losses are attributed to difficulties with a high ground water table during construction and the pipeline material (asbestos cement). The total loss between system head and crop root zone was estimated at 55%.

  It is clear that the lost water passed directly to the groundwater to be drawn upon by the crops in an informal system of sub-irrigation.

- In response to farmers' demands, the number of outlets on pipeline 1 was increased from 9 in the original design to 32. The conditions at each outlet are unique since the area served and the available head on the weir crest varied widely. The original assumption that the outlets could be operated by farmers under a system of modified demand was no longer relevant. Rotational patterns involving a maximum of 6 outlets operating simultaneously were devised by a process of trial and error. Initially the outlets were under the control of a lineman. Later in the project period locks were fitted to the outlets, the key initially being under the control of the lineman and latterly held by a single farmer within each outlet command. However, lack of cooperative working amongst farmers and inability of the system to provide enough water meant that the average supply to large outlet areas was poorer than to small areas farmed by a few individuals.

- Outlets imposing variable demands on the main conveyance system should be avoided wherever possible. It is generally not feasible to include meaningful storage where individual landholdings are small and land scarce. The pipeline therefore lacks flexibility to respond to uncoordinated demands. To achieve a stable operational pattern at system level, demand must be regulated at tertiary level.

  To improve efficiency in the system as constructed, there is little option but to promote greater involvement of farmers. Farmers are currently content to leave all operational matters to Government. Formal Water User Associations as now being introduced in Egypt represent a way forward. They will need continuing support, training and technical assistance from Government in order to become self-sustaining.

- Improved distribution arrangements would have involved few outlets provided with proportional division structures to split a relatively large flow into manageable discharges, allowing each group to manage water independently of others, given overall coordination by group leaders at outlet level.

- The average level of the groundwater, though high, has remained fairly stable over recent years indicating it was unaffected by the construction of the pipeline. The water levels in the Mansouria canal and the peripheral open drains primarily affect groundwater conditions in the area.

- Whenever possible, topography and supply system permitting, pipeline schemes should be sized according to the average land holding. Cooperative water management breaks down when too many individuals must work together. An upper limit of 15 farmers leads to a maximum scheme size of 7.5 ha in the case of holdings of 0.5 ha and 60 ha when holdings are 4 ha. If schemes are to be linked by distributary pipeline then the comments made above concerning demand regulation apply. Designers need to include the costs of social measures and institutional support if smallholder farmers are to benefit from pipeline schemes.

- Supposed benefits of such schemes are not always realised. Little land was reclaimed at El Hammami as the old canal was used as a drain. Part was filled in but was not used for agriculture. Potential improvements to health could not be established. Children were still seen bathing in the mesquas at risk of contracting schistosomiasis, and the outlets were often used as toilets.

8 Acknowledgements

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Figures

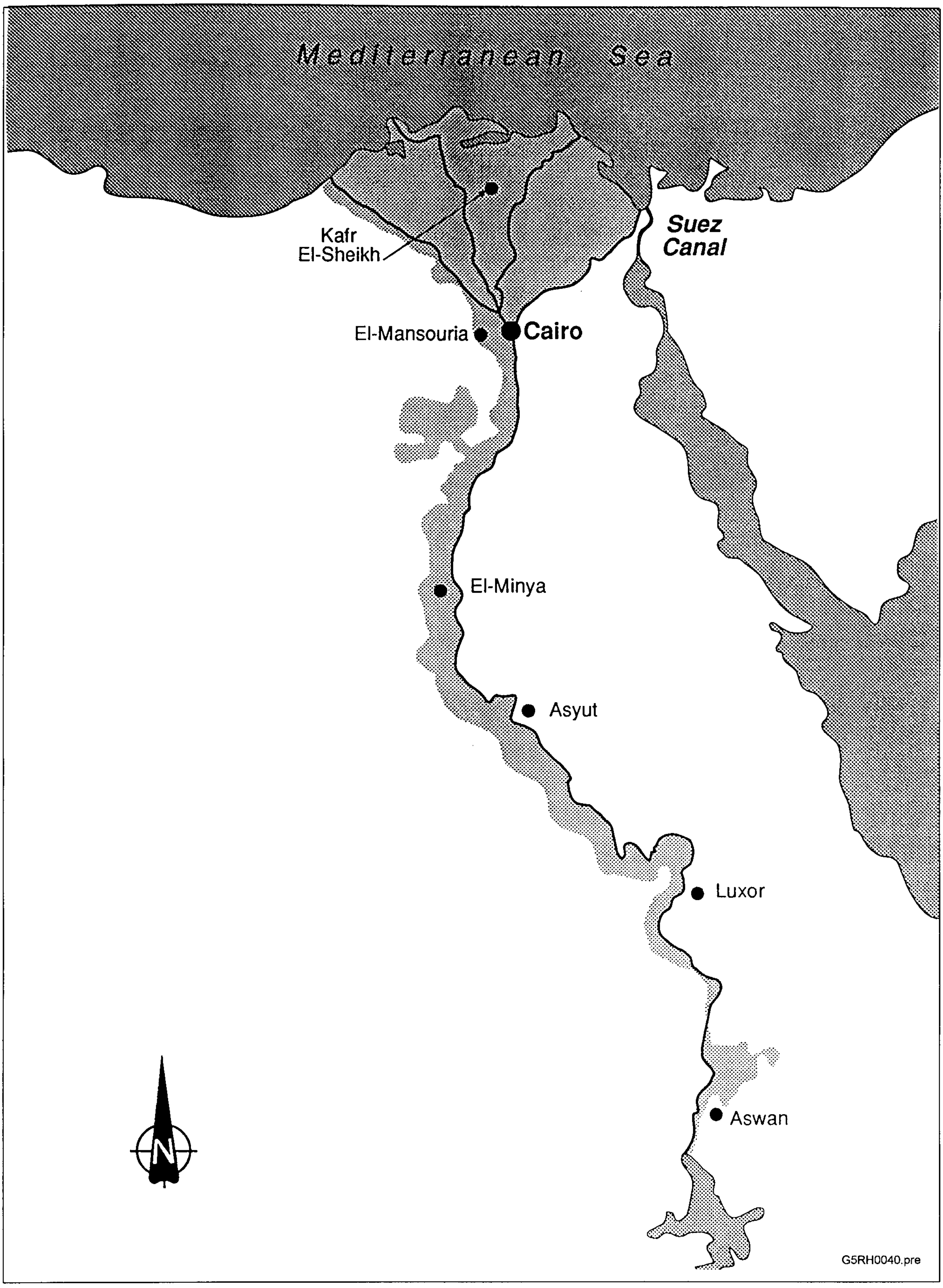

Figure 1 Map of Egypt Showing Location of Project Area

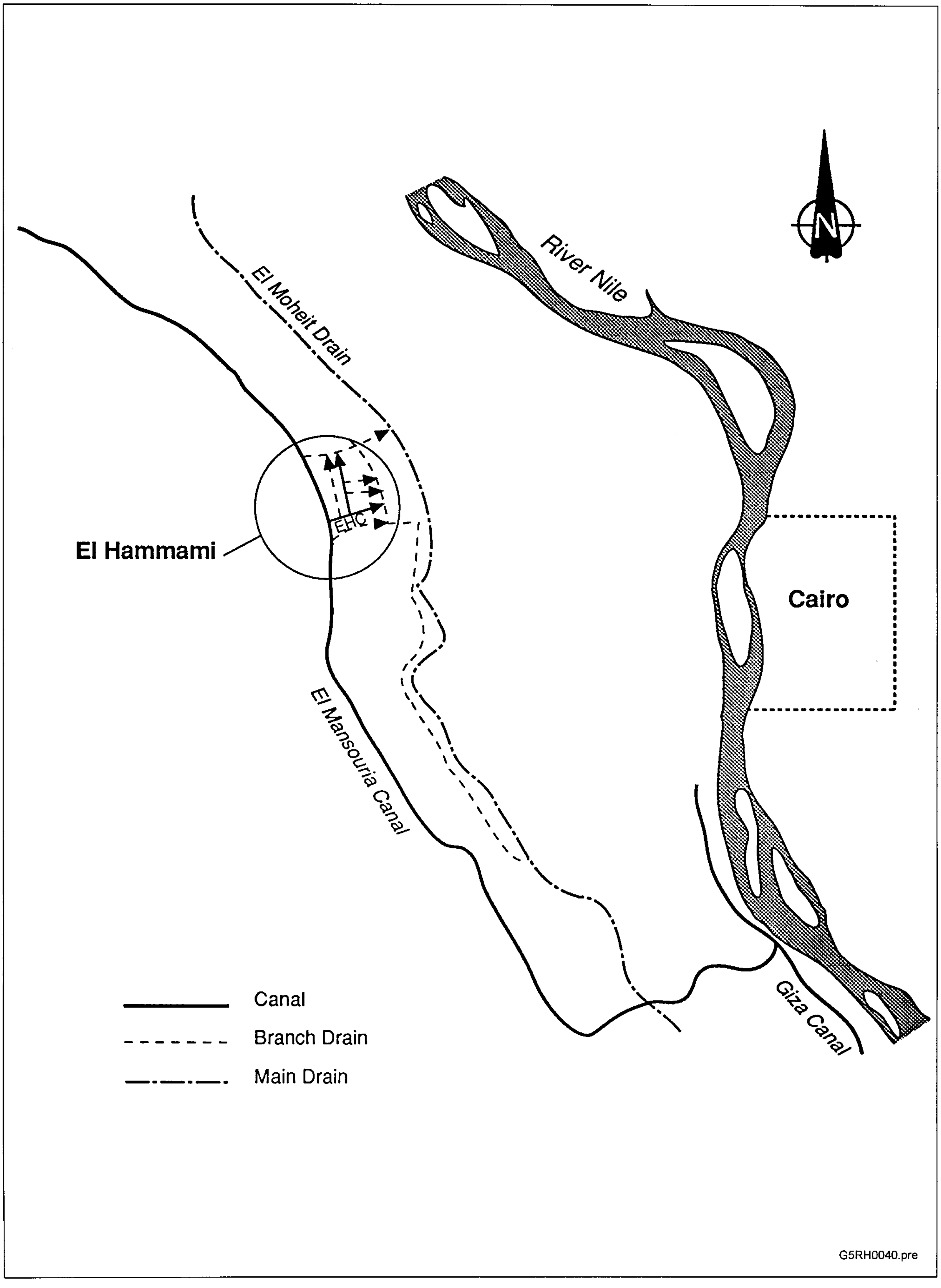

Figure 2 **Map of Mansouria Irrigation District showing the El Hammami study area**

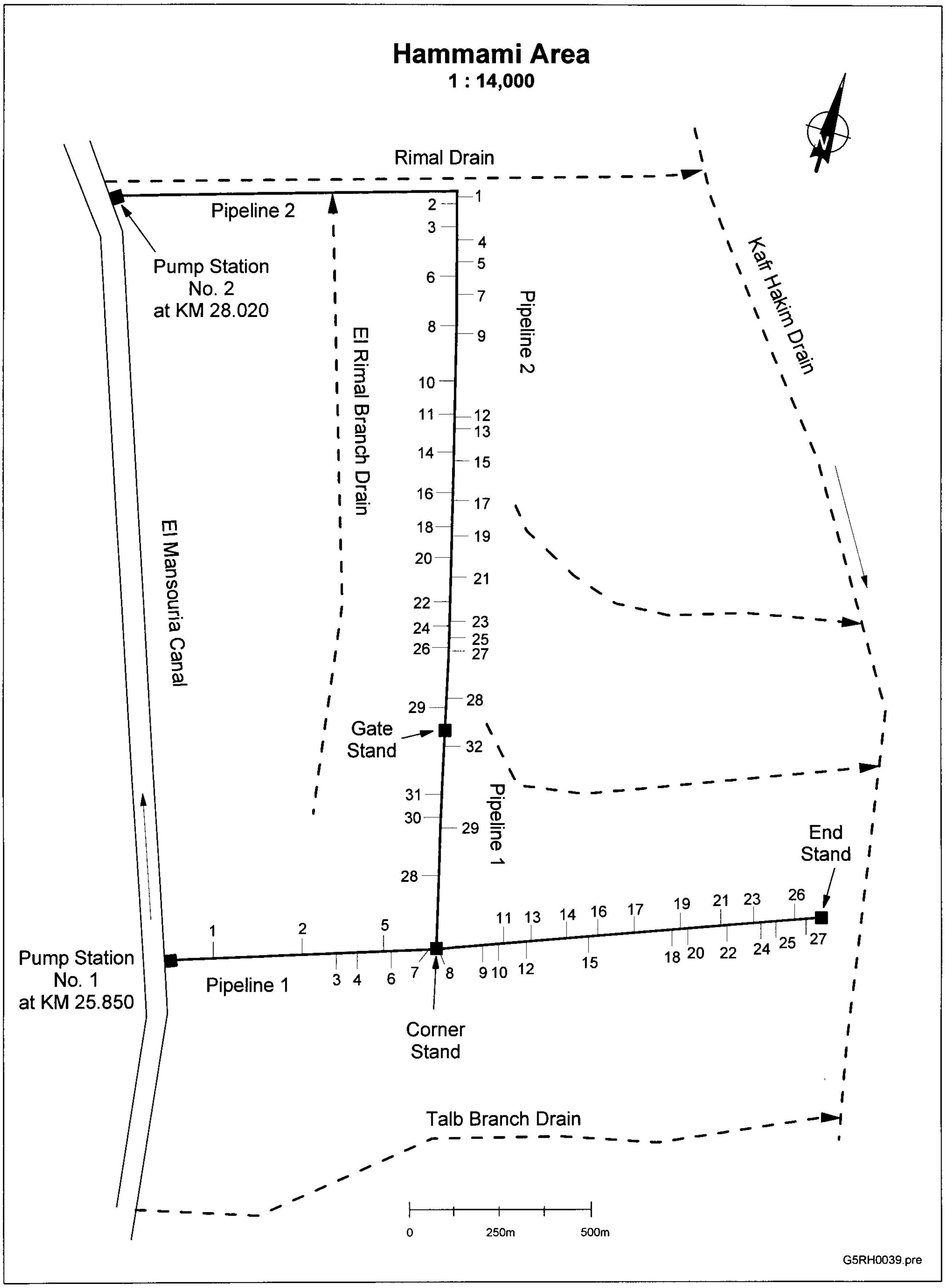

Figure 3 Map of El Hammami Pipeline Showing Outlets

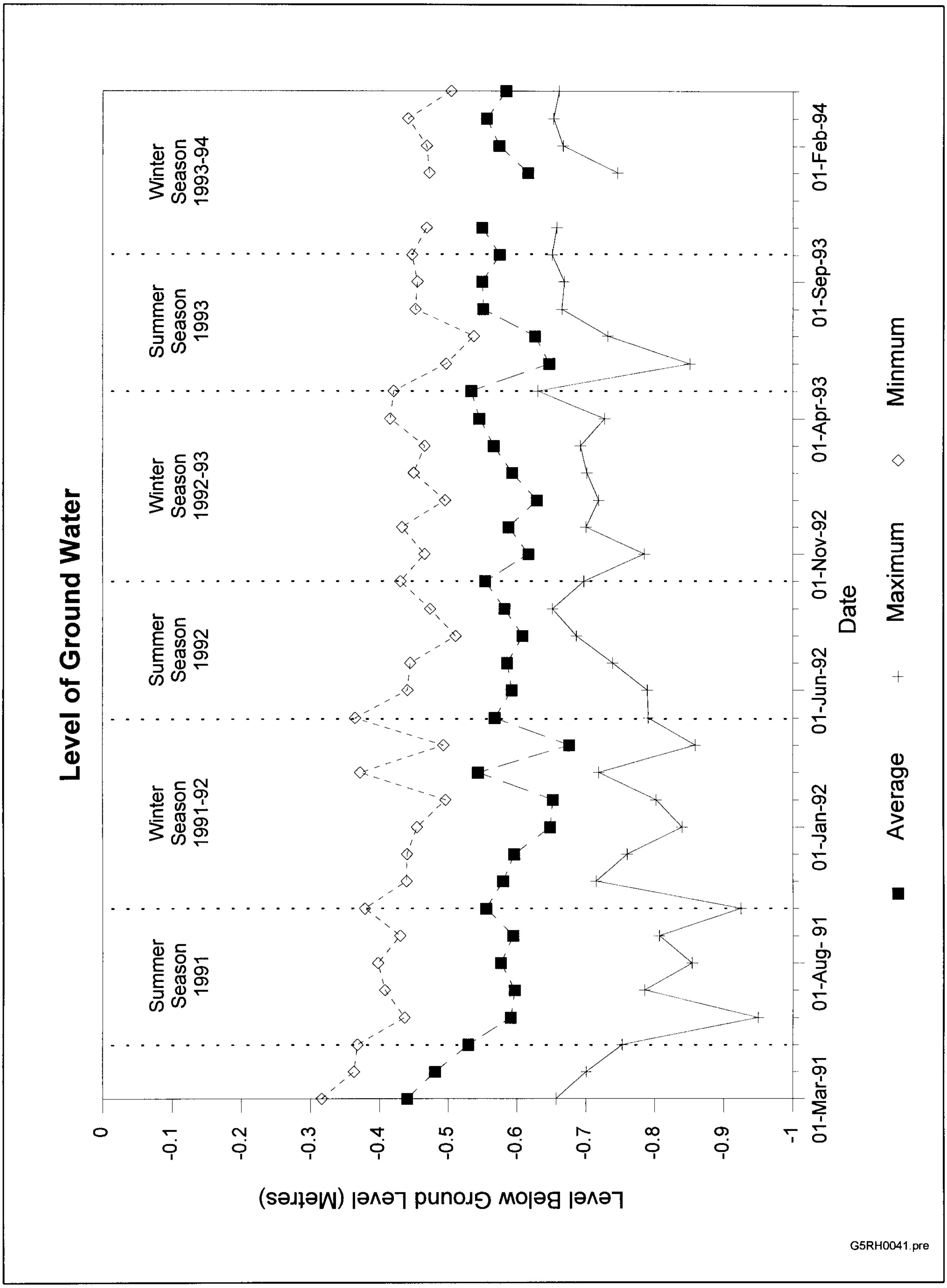

Figure 4 Average Depth of Water Table

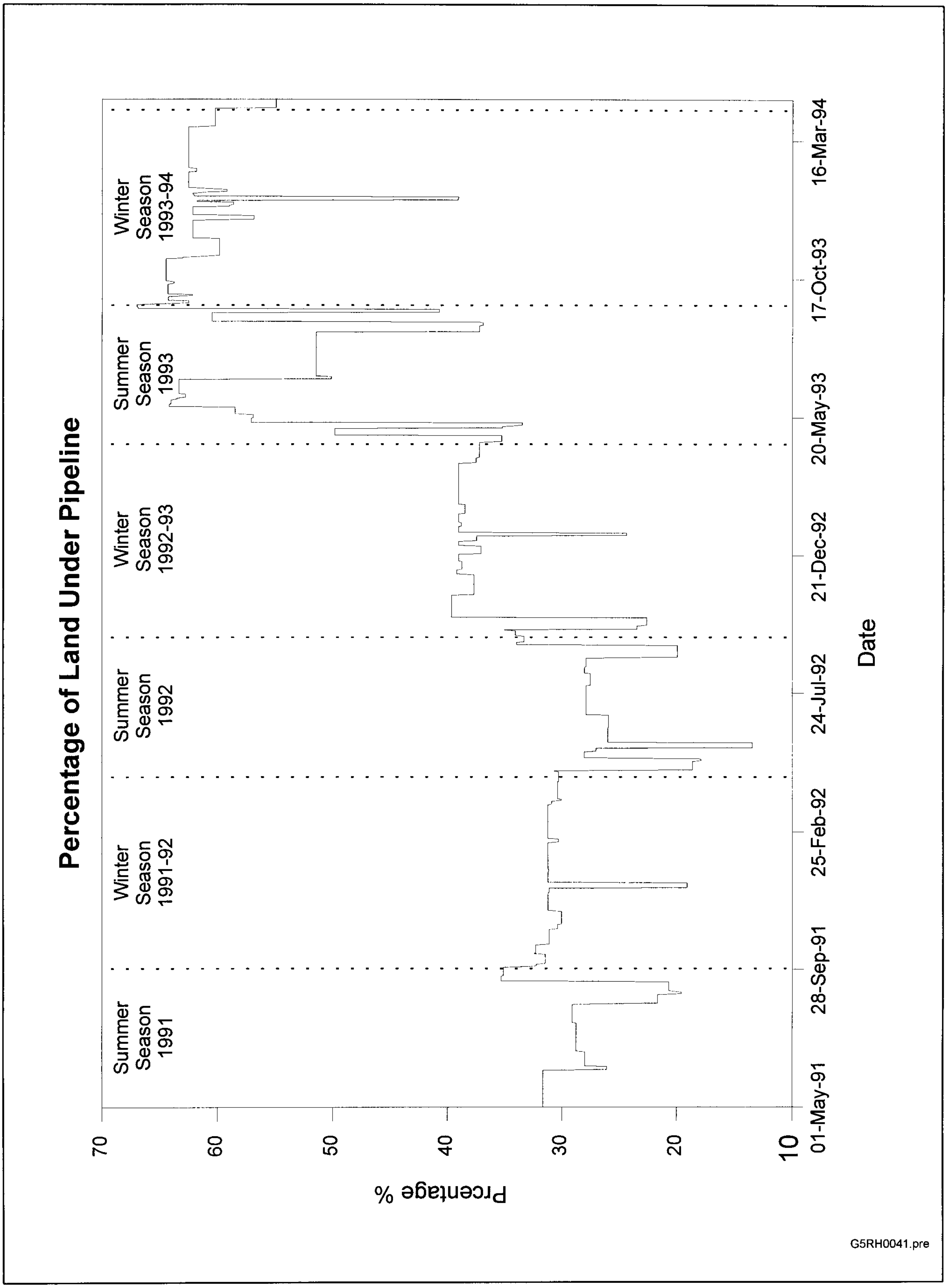

Figure 5 Percentage of Command Area Irrigated by Pipeline

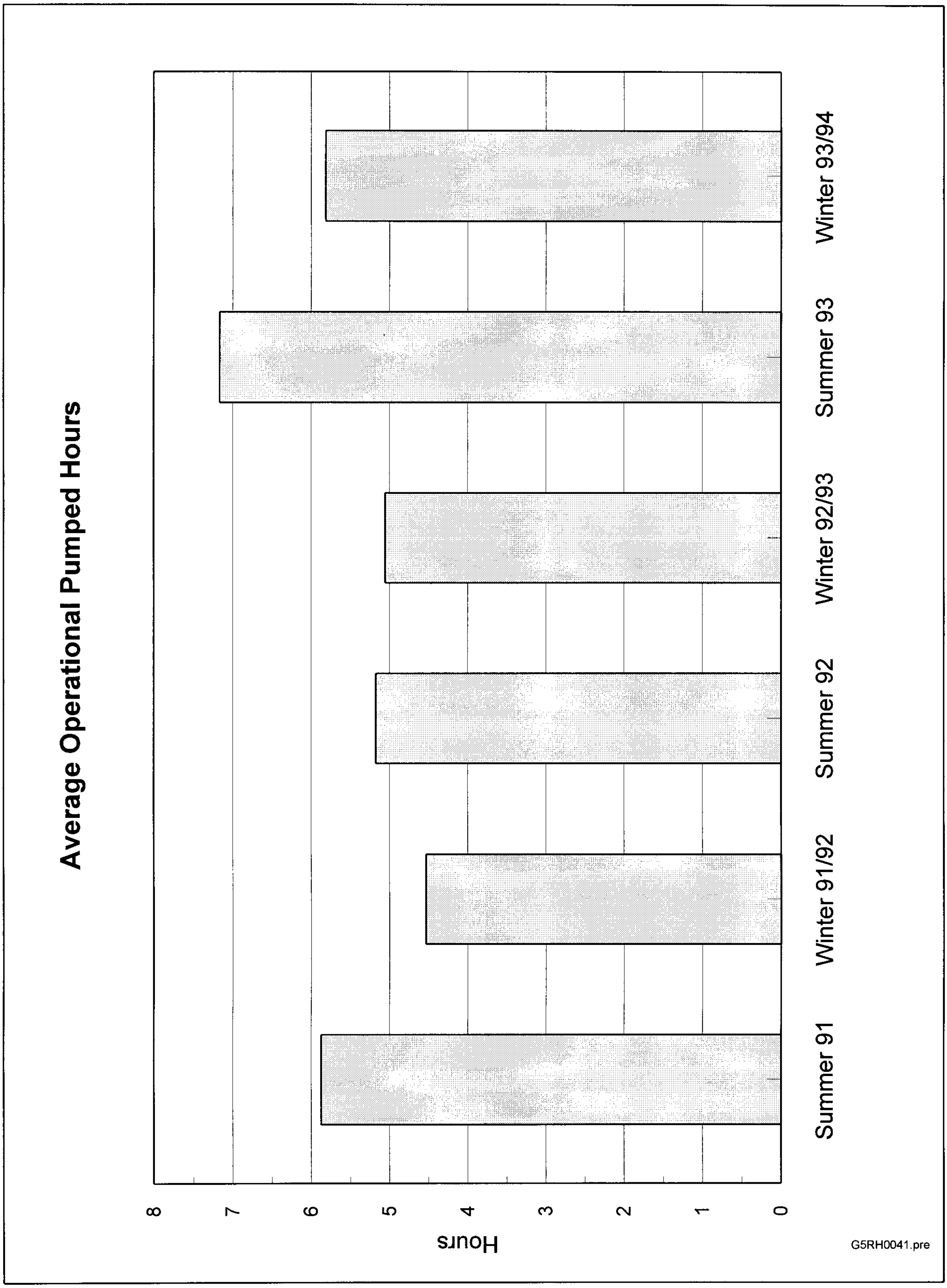

Figure 6 Average Hours of Pump Operation (per Season)

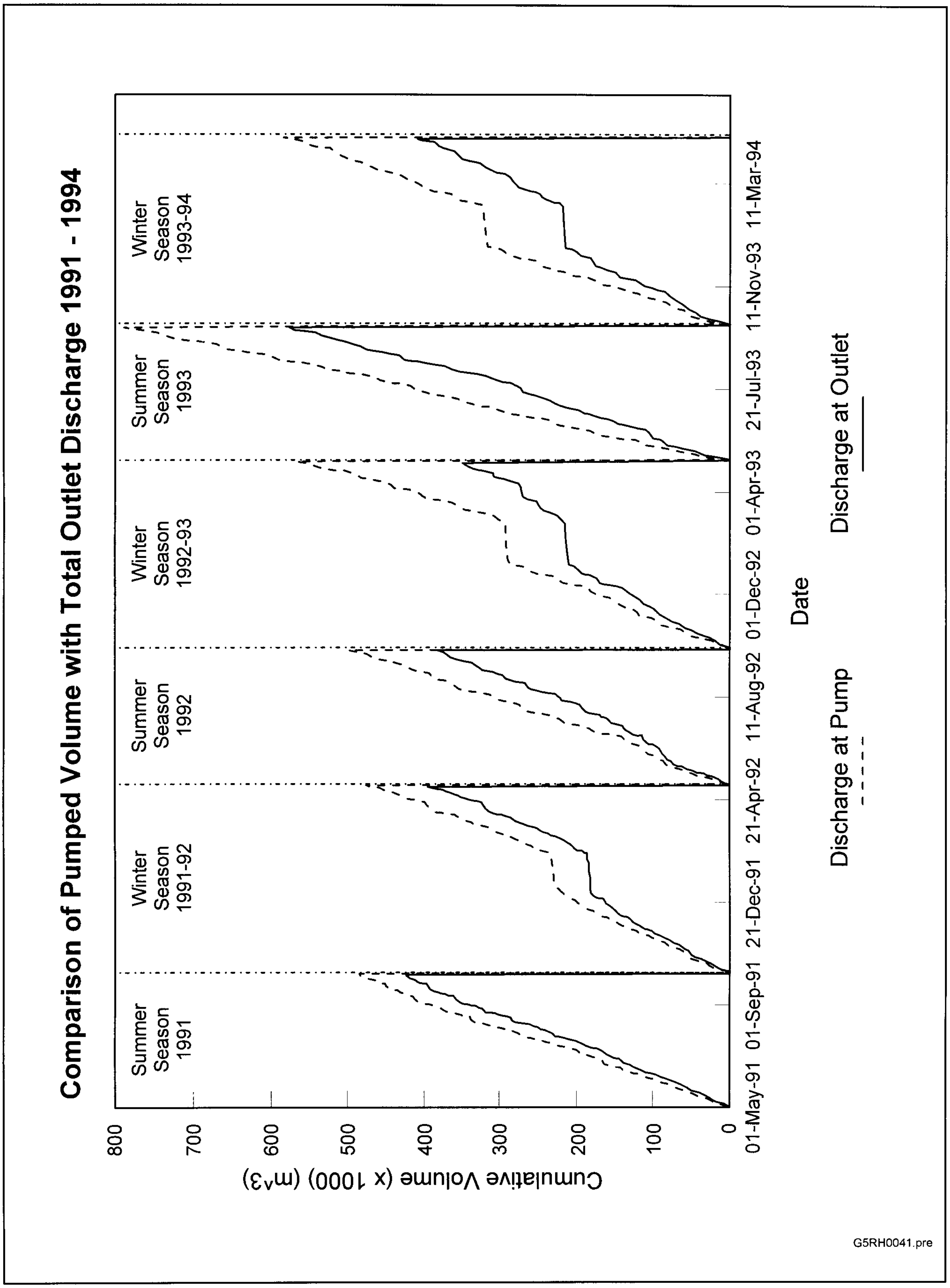

Figure 7 Comparison of Discharge of Pumps with Discharges at Outlets

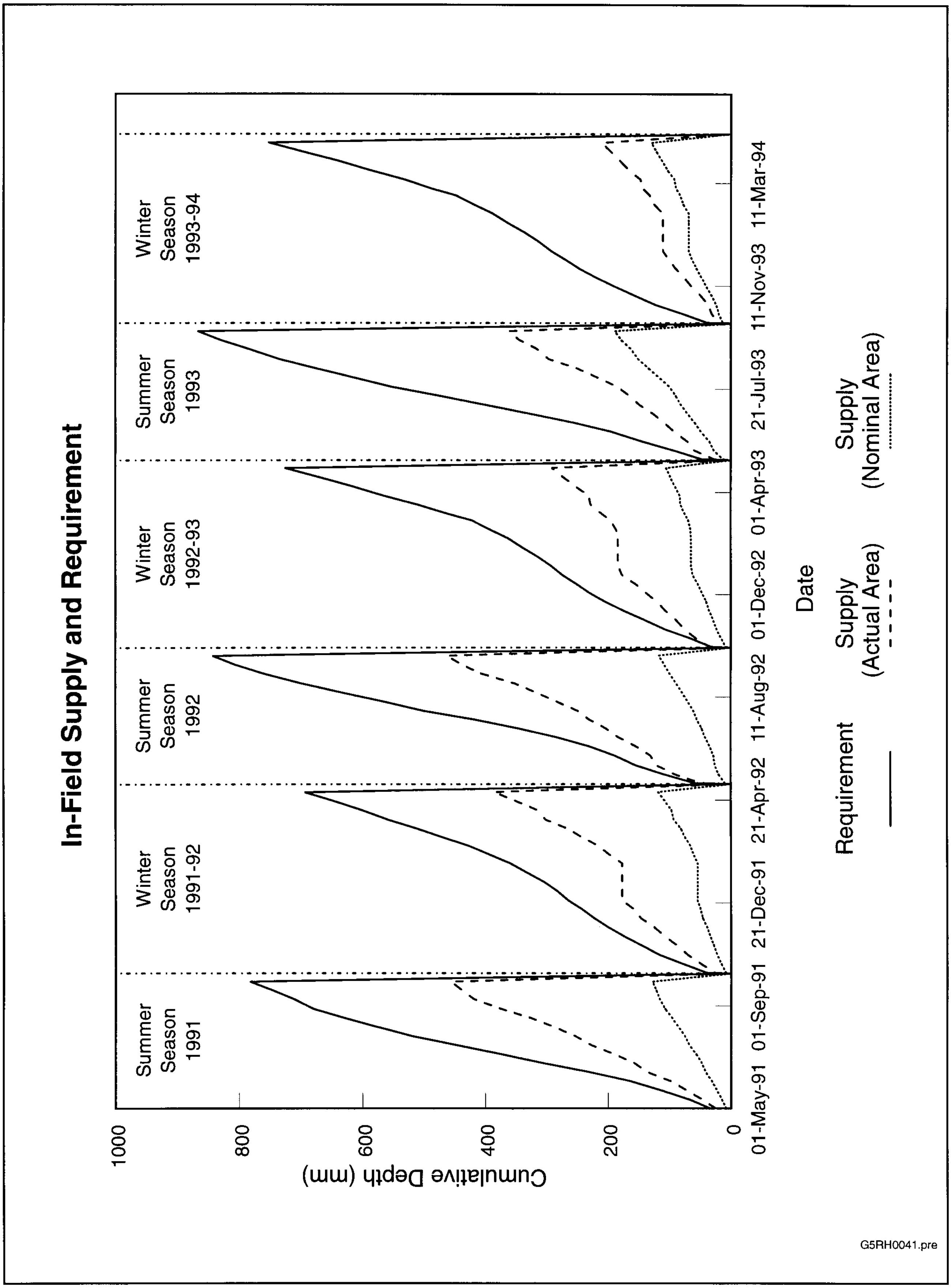

Figure 8 Cumulative Field Level Supply & Requirements (mm). Scheme Average 1991 - 1994

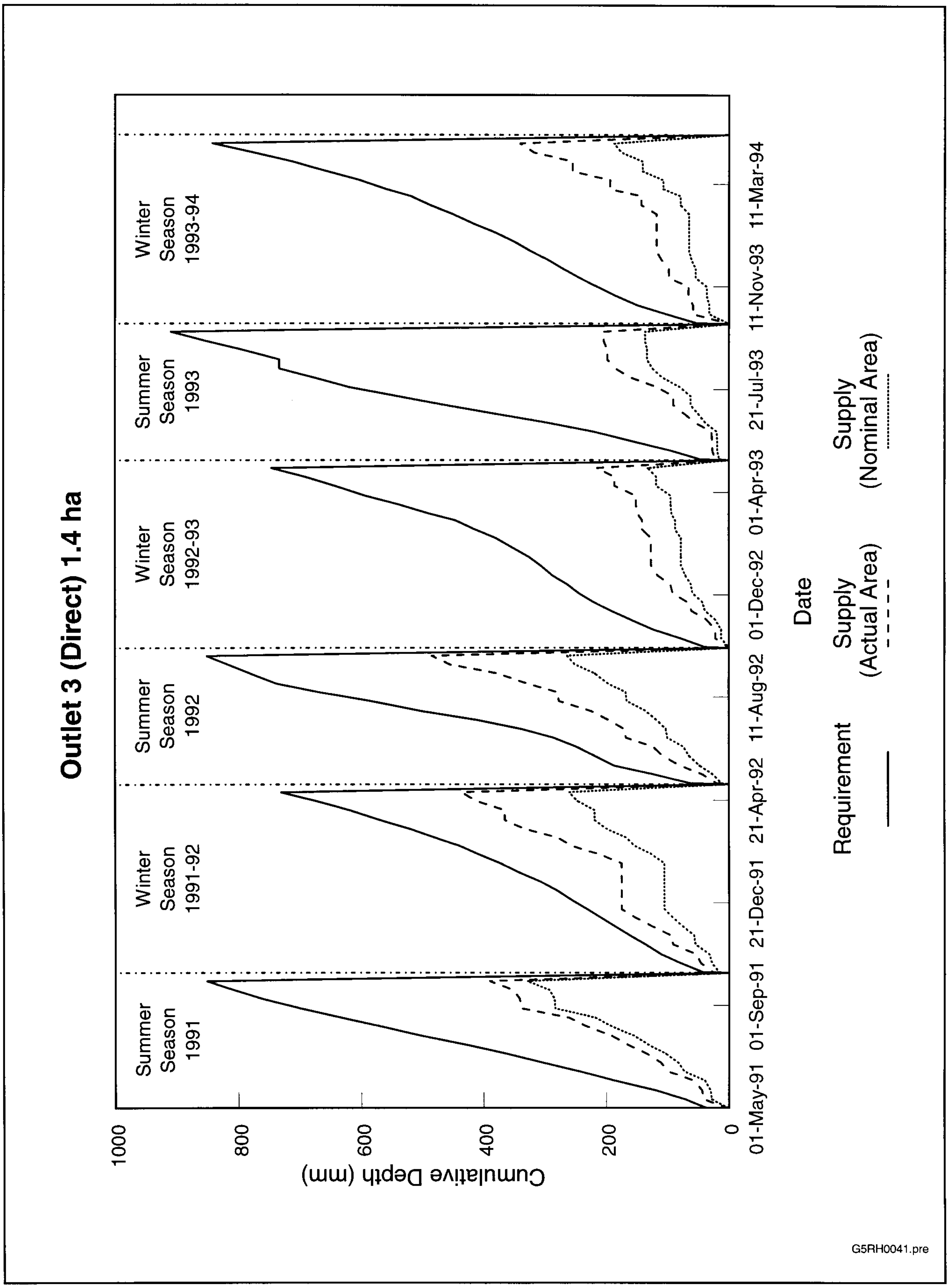

Figure 9 Cumulative Field Level Supply & Requirements (mm). Outlet 3 1991 - 1994

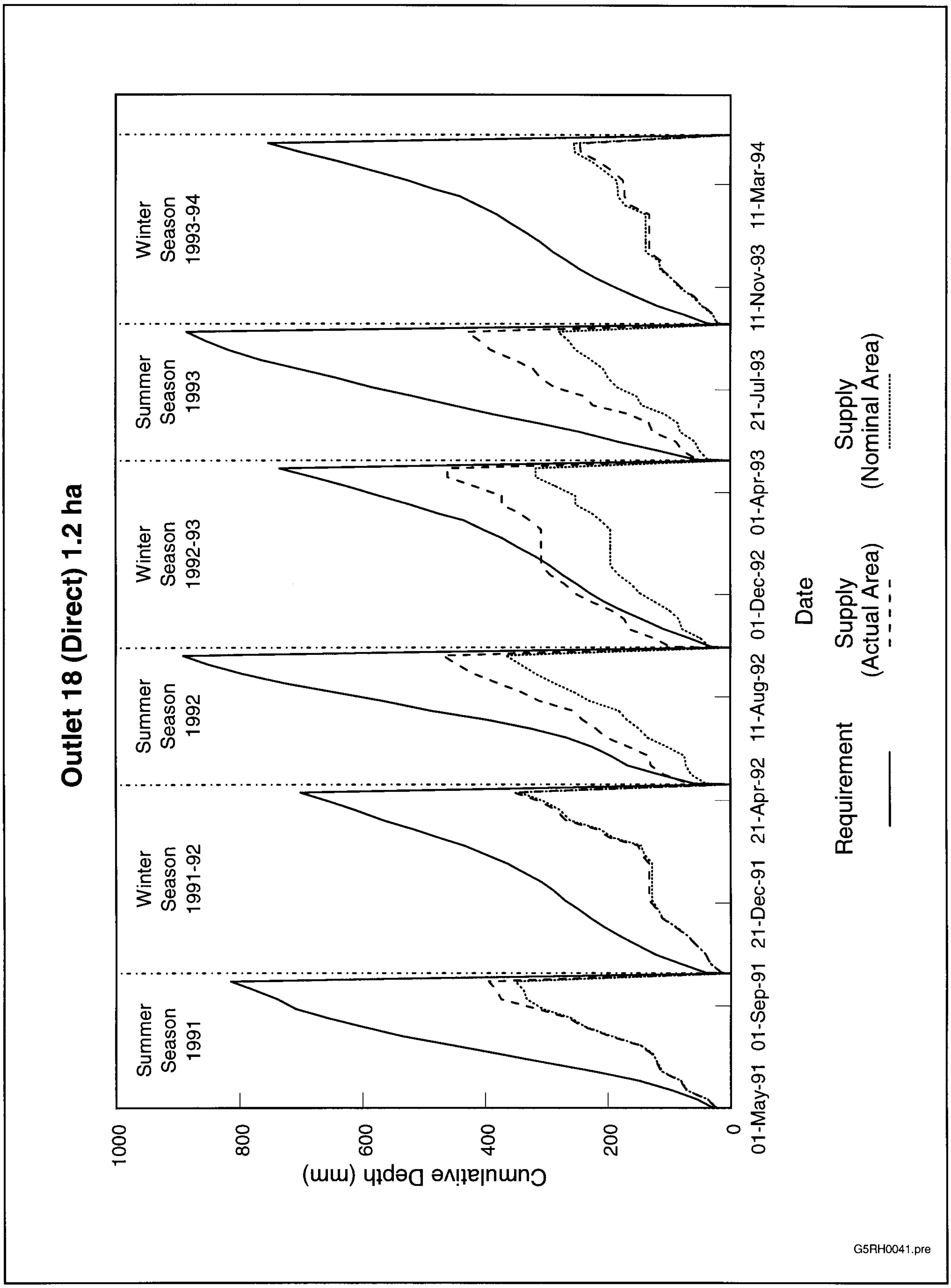

Figure 10 Cumulative Field Level Supply & Requirements (mm). Outlet 18 1991 - 1994

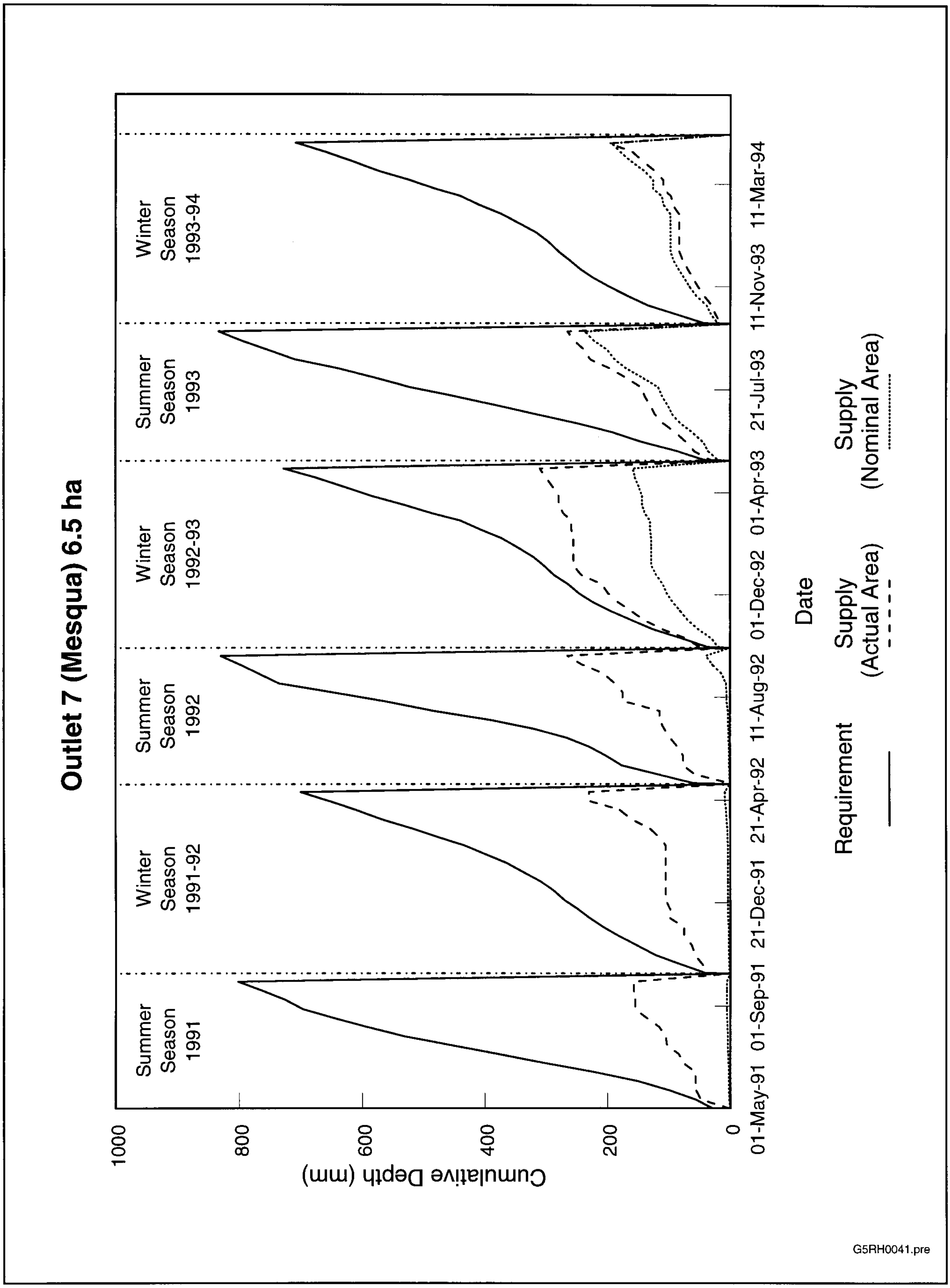

Figure 11 Cumulative Field Level Supply & Requirements (mm). Outlet 7 1991 - 1994

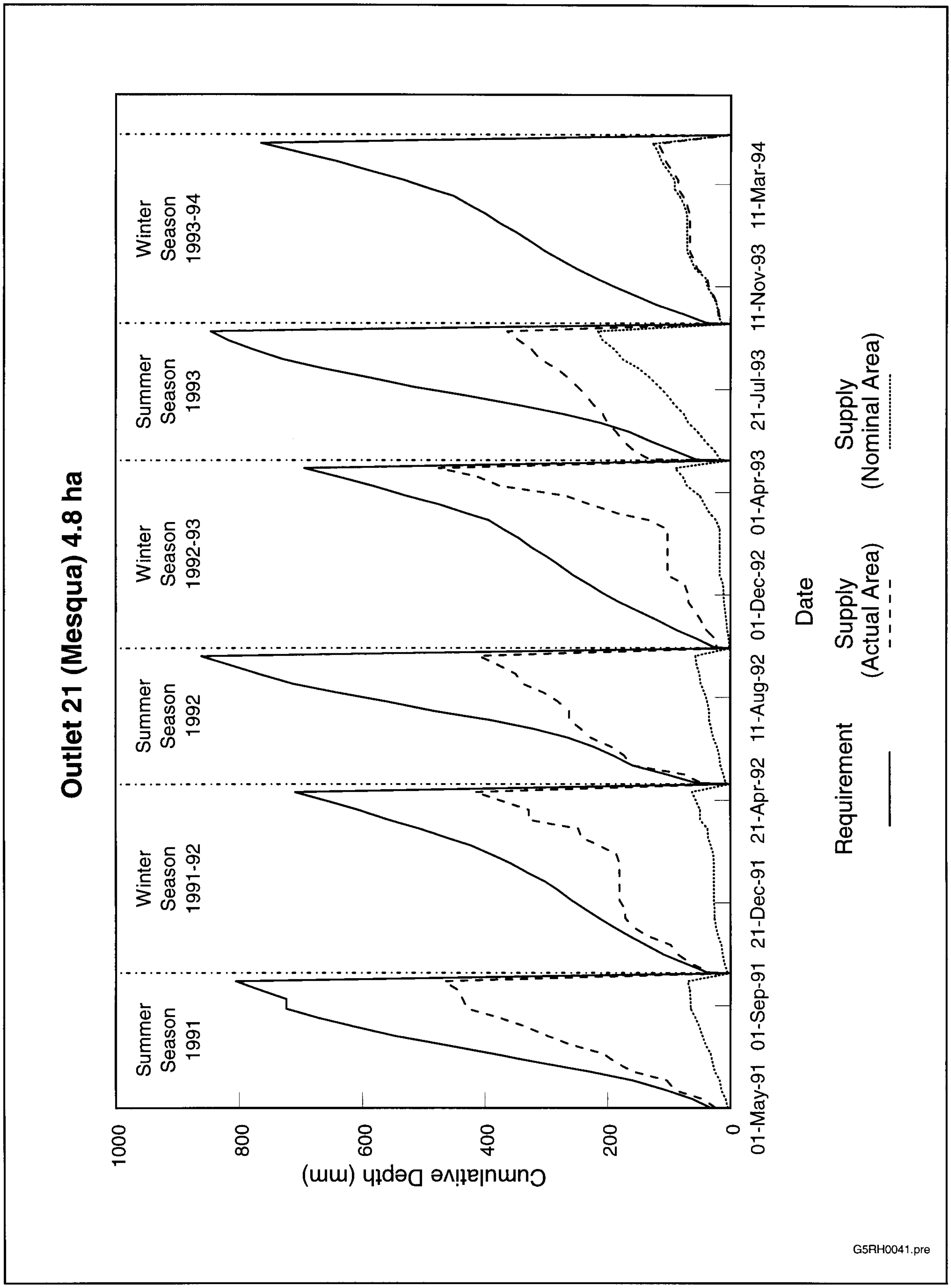

Figure 12 Cumulative Field Level Supply & Requirements (mm). Outlet 21 1991 - 1994

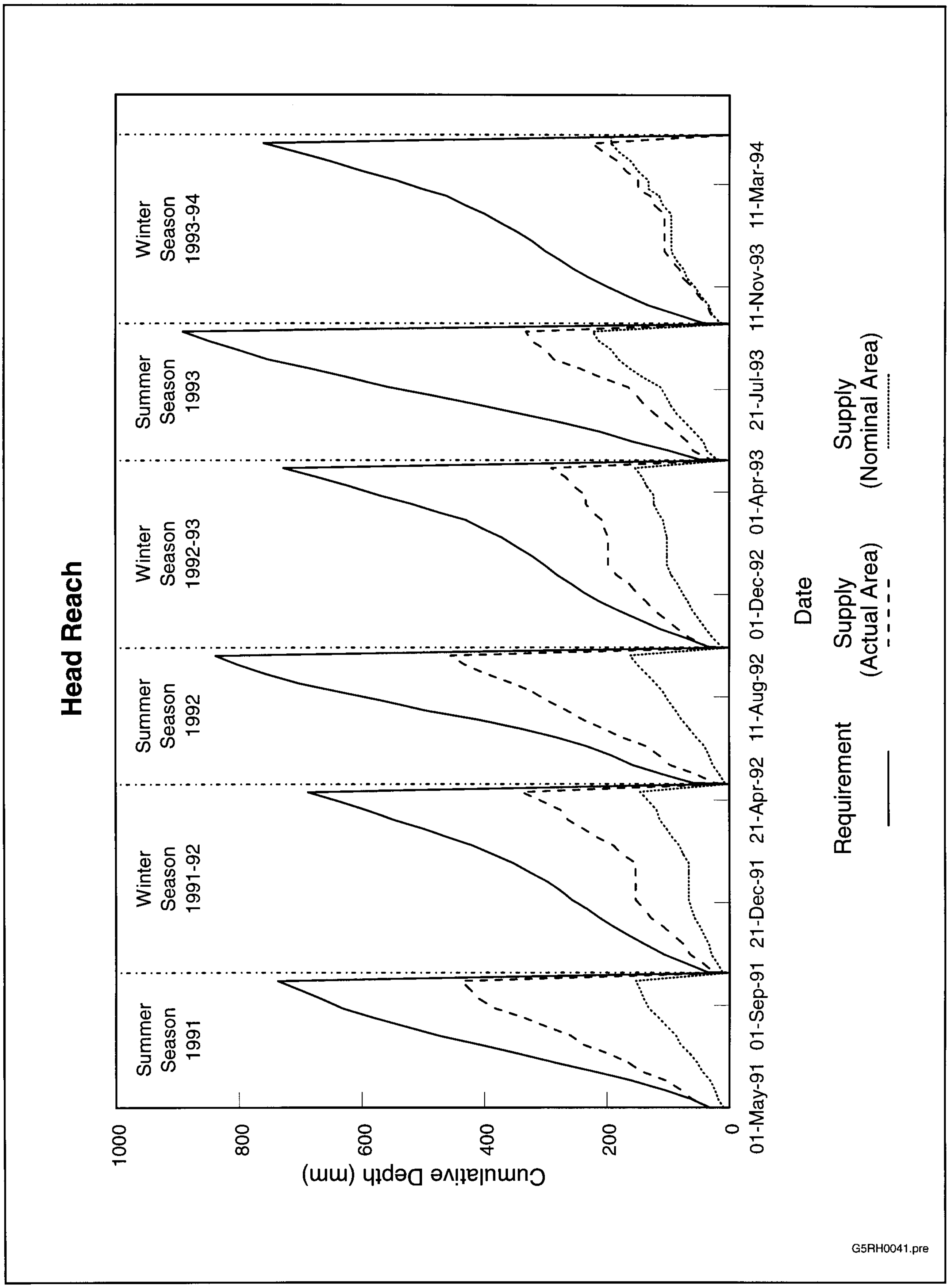

Figure 13 Cumulative Field Level Supply & Requirements (mm). Head Reach 1991 - 1994

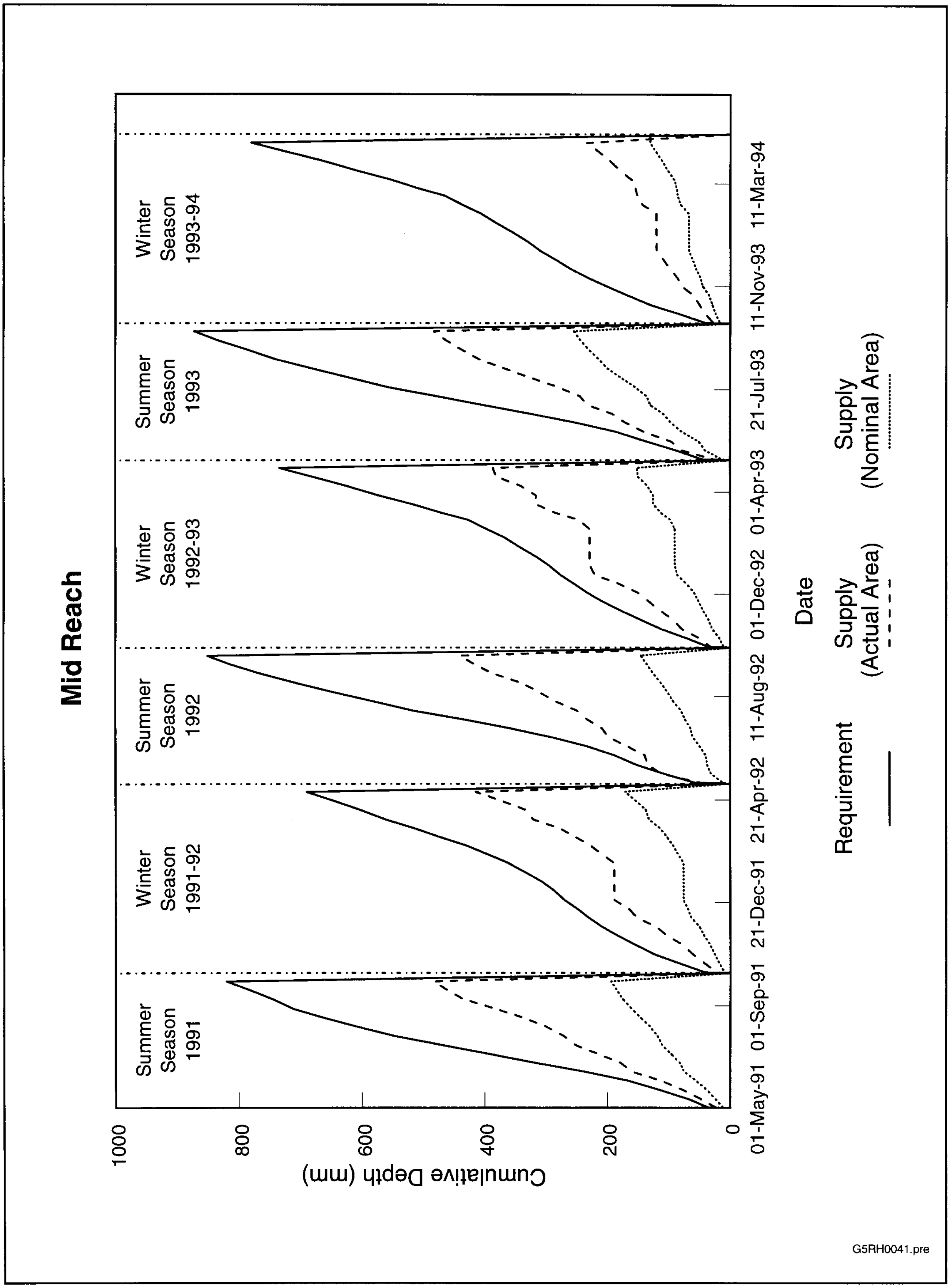

Figure 14 Cumulative Field Level Supply & Requirements (mm). Mid Reach 1991 - 1994

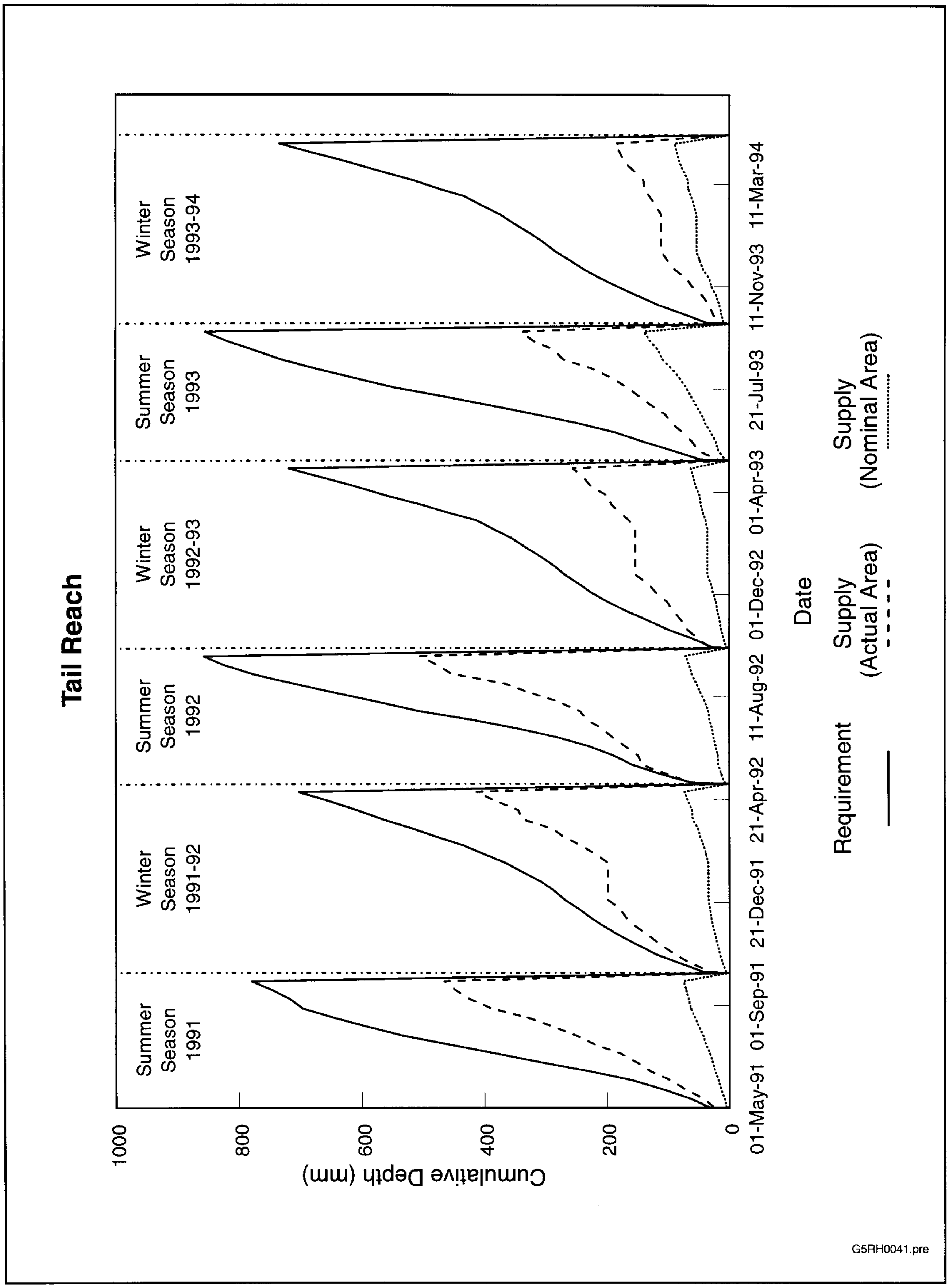

Figure 15 Cumulative Field Level Supply & Requirements (mm). Tail Reach 1991 - 1994

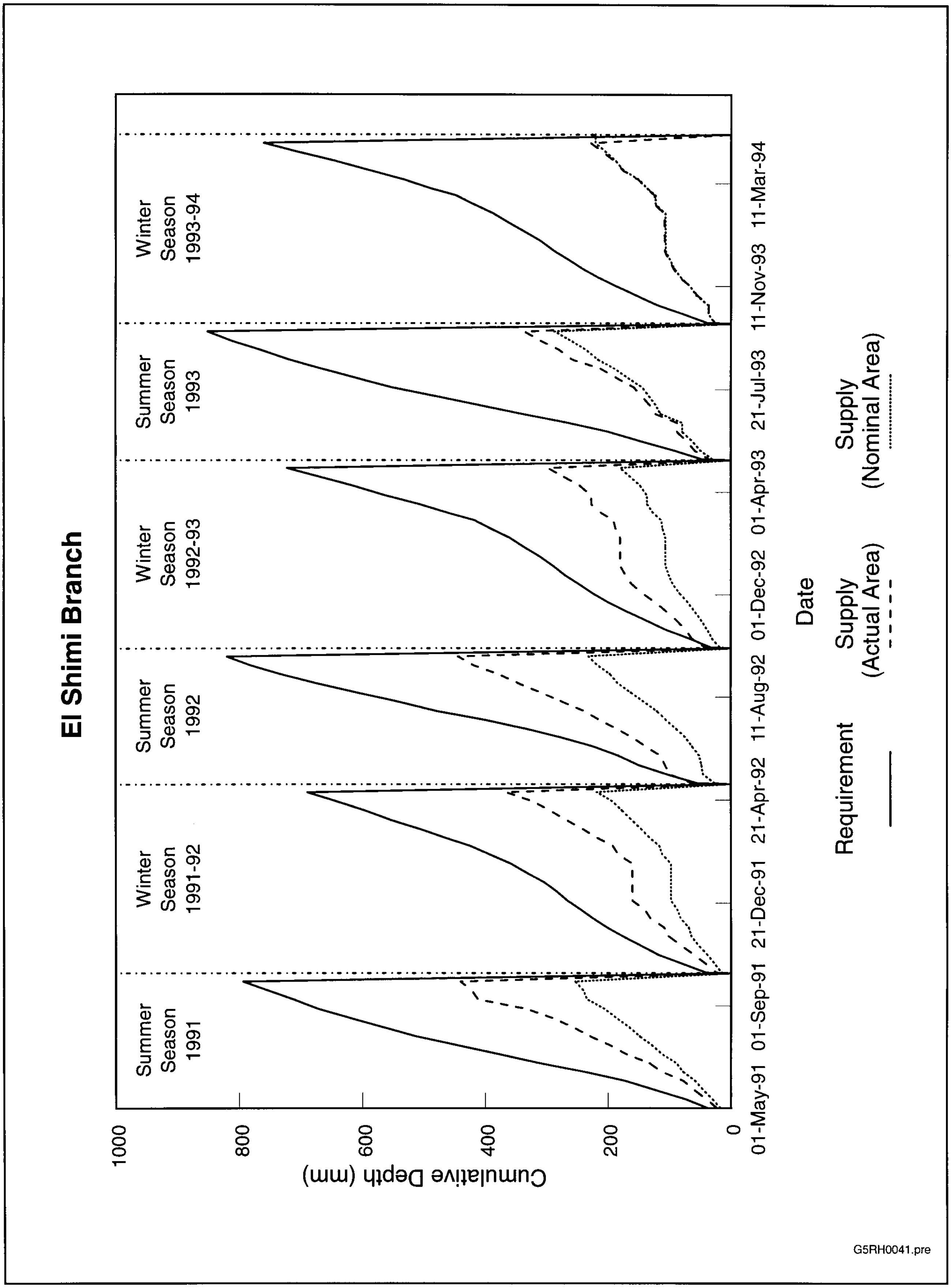

Figure 16 Cumulative Field Level Supply & Requirements (mm). El Shimi Branch 1991 - 1994

Appendices

Appendix 1

Design details - El Hammami pipeline

Appendix 1 Design details - El Hammami pipeline

A1.1 Background details

Both high and low pressure systems were considered at the design stage. A low pressure system was ultimately selected. Principal assumptions:

- the design discharge capacity of the pipeline was initially to be based on a peak consumptive rate of 10 mm per day, later reduced to 8 mm per day

- sub-irrigation from the ground water table was assumed to offset conveyance and irrigation losses. No separate allowance was made for such losses

- three pumps would be required to operate for 14 hours per day, seven days a week, at times of peak crop demand

- farmers would be eventually become responsible for the operation of the system.

A number of design requirements and system attributes were specified in EWUP Report no 21, 1983:

1) A buried pipeline was to replace existing canals.

2) The system was to operate on a system of modified demand. No more than half of the outlets to be open at any one time. Outlets operated according to demand and available supply.

3) The full set of three pumps would be required to operate for the assumed maximum period of 14 hours per day, when the crop demand was at its peak.

4) Rotation between mesquas assumed.

5) Rotation between farmers on individual mesquas assumed. The full stream to be used by a single farmer or by several farmers sharing.

6) The minimum capacity of an outlet to be 56 l/sec (2 cusecs)

7) Water to flow by gravity below the outlet.

8) Losses to the groundwater table become available to the plant roots.

9) Farmers should eventually take control of the pipeline.

10) No irrigation at night, unless required to make up for water needs after mechanical breakdown or power outage during the day.

11) Pumps to be powered by electricity.

12) Connections to drains to be provided to permit flushing and wastage of excess flow.

13) Robust and simple construction to be adopted.

14) A minimum cover of one meter over the pipe to be provided.

15) Design to be adequate (not optimal) and transferable.

16) Back-up equipment to be kept in storage.

17) The main pipeline to be of asbestos-cement.

18) Each pumping station to be equipped with three pumps.

19) Flexible design to allow the farmers to improve the mesqua whenever they wished after the installation of the pipeline.

20) Flow measuring devices required at each pipe outlet.

21) A Venturi meter to be provided on each pipeline near the pumping plant.

22) The pipe velocity to be maintained above 2.0 ft per sec (0.61 m/s) to reduce possible problems of sedimentation.

23) Overflow weir to be provided in the tail stand on pipeline 1.

24) An area of 110 feddans in the north east corner of the project area to be excluded from supply.

25) Pipelines nos 1 and 2 to be connected by a gate stand.

26) Pipelines to follow the north side of the El Hammami canal, the east side of the El Shimi Branch Canal and the south side of the Rimal Hakim drain.

27) Pump stands to be substantial.

28) Washing water to be provided for the adjacent village.

29) To ensure proper bedding for the pipe, the contractor might install tile drains in the trench below the pipe.

30) The number of different alfalfa valve sizes to be kept to a minimum.

31) Extra alfalfa valves to be kept as spares.

32) One spare pump and motor of each installed size to be held.

33) At outlet 26 on pipeline 1, the mesqua might be replaced by a pipeline. Automatic control of outlets to be considered. (option not adopted).

34) Total head to be less than 16 feet at the pump station and less than 12 feet at the mid point of the pipeline.

35) Turbine or submersible pumps to be specified so as to avoid priming problems.

36) The equipment in the two pumphouses should be similar.

A1.2 Design-general

The system was designed for limited demand with four outlets open on each pipeline (half of the total outlets then anticipated). On pipeline 1, the design case consisted of four adjacent outlets located towards the tail of the system. Individual outlets would have received between 30 and 150 l/sec. Subsequently, owing to pressure from farmers, the number of outlets on pipeline 1 was increased to 32.

In its as-built form the pipeline is not easy to operate. The problems posed by large numbers of outlets each with a variable mean operating head have already been referred to.

It was found that once the operators had gained experience of the system characteristics, the pipeline was operated competently, though spillage from the tail stand was a continuing problem at the end of the day as farmers shut down the outlets.

A1.3 Size of outlets

In the early stages of the project, attention was focused on the outlets because it appeared that they were vulnerable to damage by farmers.

The original outlets were designed for a minimum discharge of 56 l/sec, a maximum of 167 l/sec and a maximum head loss of 0.44 m. The minimum size was determined by a requirement for high uniformity of irrigation on a border of 0.2 ha (0.5 acres). In practice, individual basin size at Mansouria is much smaller: basins vary between 20 and 120 square meters. Field trials (EWUP, 1979) suggested farmers were familiar with a stream size between 20-30 l/sec which permits good efficiency. Smaller streams of 10-15 l/sec are appropriate to the smallest basins with young crops.

Mesquas up to 800 m long are needed to command parts of the designated command area. It is not practical to design mesquas for discharges as small as 15 l/sec because a high percentage of the flow will be lost in conveyance. Farmers must therefore split the outlet flow.

Alfalfa valves of diameter 10" (0.225 m) and 14" (0.35 m) are used. They incorporate a lockable cast iron disk sealing on a bevelled edge to the cast body. Rubber seals tend to perish and are relatively difficult to replace. The basic design is rugged and well-proven but there were one or two isolated cases of damage done to the valves by disgruntled farmers in the period before the system began regular operations. Once regular operations were established and farmers accepted the system the valves were operated successfully, initially by water management staff and later by farmers, with checks by linesmen.

The flow must be rotated at field level. For good water management the outlet size and the area commanded should be limited. Appendix 2 contains more details. At Mansouria individual outlet command areas for the 32 outlets on pipeline 1 vary from less than 1 ha up to 38 ha. Areas larger than 10 ha were not well covered by supply from the system.

At peak irrigation time the soil moisture-holding capacity is so low that crops, particularly during the early growth stage, would need irrigation every 2-3 days if it were not for the reserve represented by the water table. If the outlet were sized to deliver 25 l/sec, assuming 10 hours operations per day and six working days per week, the maximum area which could be commanded would be 7.5 ha.

Two irrigations of 30 mm net each, say 40 mm gross, could be applied per week. A smaller outlet, say 8 "in diameter, would have been suitable. The head loss would be 0.15 m for a discharge of 40 l/sec.

Alternative outlet designs ranging from orchard valves to pot valves and various types of sophisticated automatic, and pressure-operated devices are available. Provided replacement valves can be obtained on the local market, the alfalfa valve was shown to be a practical and appropriate device.

A1.4 Mesqua operations

Farmers have needed to adopt different water use practices with the coming of the pipeline. It is generally accepted that efficiency of water use declines when more complex patterns of cooperative water use are involved. At Mansouria, some farmers are involved in supplementary employments. Quite heavy demands would therefore be placed on mesqua leaders to organize the farmers within their jurisdiction. Experience on the IIP project in the Delta area indicates that considerable effort and time may be needed by system operators to put over necessary messages to farmers groups. In the IIP, Water User Associations have been established and it is understood that national legislation will be enacted to formalize their status. At Mansouria, the loose groupings which still exist on the mesquas will be based on the pattern prevailing before the construction of the pipeline.

A1.5 Pumps

The design delivery required of the pumps was 360 l/sec,

Each pumphouse contains 1 no 12" (300 mm) and 2 no 10" (225 mm) centrifugal pumps. At an average static head difference of 6 m, the rated discharges are respectively 185 l/sec and 85 l/sec. The pump bowls are submerged to avoid priming problems. A trashrack prevents floating debris from the canal from being drawn into the system.

Limitations on electric power meant that, except for brief periods it was only possible to operate two out of three pumps in each pumphouse. The nominal available capacity was thus reduced from 360 l/sec to 270 l/sec.

Pumps were stripped, checked and reassembled at the start of the project. Checks by an independent consultant on pump performance at the start of the project (Ruff, 1990) showed that the pumps were delivering somewhat less than the rated discharge. Subsequent checks were inconclusive. Approximate balances between supply and deliveries suggest that the pumps were delivering less than their nominal capacity. Since they were first installed in the mid 1980s, albeit regular operation did not start until 1990, it is likely that they are functioning below specification.

Design was based on up to 14 hours daily operation at time of peak crop demand. In practice, the system was generally operated for less than 8 hours per day, and in the later stages up to 10 hours per day, owing primarily to funding constraints.

In the initial design, peak crop evapotranspiration need (Etc) was taken to be 8 mm/day on a gross area (2 pump stations) of 780 feddans and it was assumed that seepage and percolation from the system and fields would be available to the plant from the root zone. The value for Etc was later raised to 10 mm/day. More exact values of potential evapotranspiration (Eto) based on data from a local agro- meteorological station are now available. Average monthly values are a maximum in June at about 7 mm per day. Peak crop demand averaged for the month of July will be of the same order. The figure of 10 mm could perhaps be achieved over very short periods, but crops are likely to respond by drawing a greater proportion of their need from the water table. The increased short-term crop demand was not considered as a constraint on the area actually irrigable.

Under the combined effects of these various factors, the area which could be served, at 10 hours pumping per working day, will have been reduced to approximately 190 feddans (80 ha) per pumping station in the summer. A commanded area of around 400 feddans (167 ha) was originally envisaged and 352 fds (147 ha) subsequently estimated.

By the end of the project period, it is estimated that 214 feddans (89 ha) or 60% of the potential command were being supplied in the winter season and 73 ha in summer. It therefore appears that, given the constraints enumerated above, the system overall was performing at least to design expectations. The role played by losses to the ground water table in supplementing the surface supply has already been discussed in section(s).

A1.6 Pump operations

Provision was made in the design for automatic control of the pumps. Operation was limited to the pressure head in the pumpstand. The system was to maintain a level in the pump stand appropriate to the system demand (no of outlets operating) to avoid overflow. In practice, uncertainties in the available power supply and the modifications to the system made subsequent to the initial design meant that it was advisable to employ manual operation of the pumps. Experience elsewhere in developing world agriculture suggests that the responsibilities for operation and maintenance must be clearly assigned to ensure that systems are sustainable. One period of maintenance was undertaken within the project period.

A1.7 Pipeline

The pumps draw relatively clear water from the Mansouria canal. The design called for a minimum velocity of 0.60 meters per second to avoid problems of sedimentation in the pipe. During the three year operational period of the system there will certainly have been times when the flow was less than the design minimum, or when water will have been standing in the system. However, no problems with sedimentation were experienced.

The pipeline is made of asbestos cement. Experience during construction showed that it is not an ideal material to use when a high quality of construction cannot be guaranteed. It is also not easy for ordinary tradesmen to undertake repairs. Increasingly, plastic pipes of different materials and specifications are becoming available in larger sizes in the developing world (see Appendix 2). First class contractors will be needed if no alternative to asbestos cement can be identified.

Appendix 2

Guidelines on design for management

Appendix 2 Guidelines on design for management

A2.1 Design-general

A2.1.1 A pipeline system such as that at El Hammami may be termed a distributary pipeline. The main body of the report analyses the effect of multiple outlets and uncoordinated demands on the operations at distributary level. In order to achieve relatively steady demand, only a few outlets can be permitted; they must be reliably operated. Otherwise, management of the system becomes highly complex and correspondingly expensive for Government.

The following guidelines concern the design of systems serving a single group of farmers, as might be formed at the outlet from a distributary pipeline. In this sense the term "group" is taken to mean a number of individuals, not greater than, say, 15 in total, who have a formal agreement to share water amongst themselves. The upper limit on group size is imposed because cooperative working becomes increasingly difficult with larger numbers of individuals.

In general terms, the limitation restricts applications to the tertiary or quaternary levels of larger systems or to small schemes with a single water source.

A2.1.2 The design should :

- minimize conveyance losses
- simplify maintenance tasks
- simplify management at system and field level
- encourage efficient in-field water use

Suitable design, tight specification of materials and quality control of construction are essential to achieving low conveyance loss. System construction should be suited to skilled local construction expertise. Unless components can be repaired or, if necessary, replaced from the national market, the performance of the system will decline rapidly.

A2.1.3 The system needs to be designed from the outset with a realistic appreciation of the resources and personnel which will be available for its operation and maintenance over the long term. Without commitment from farmers and Government the scheme will not be sustainable.

Good water use at field level clearly depends on the skill and motivation of farmers. However, if water is available in quantities and at times which are not convenient to the users there is little hope of achieving badly-needed improvements in field water use. Simple, clear operations allowing farmers to take water on a regular basis rather than whenever they can gain access to the system, are a prerequisite for efficient water use.

A2.1.4 An oversized system will encourage wastage of water. One which is greatly under-designed will impose heavy burdens in terms of managing destructive conflicts, and will increase pumping costs. A limited degree of shortage, up to say 20% of assessed crop need, can be beneficial to overall water use discipline and efficiency.

However, it must be remembered that unanticipated increases in demand are possible resulting from, for example, change in crop pattern, increase in commanded area, or reduction in operating hours. Some flexibility in system capacity therefore needs to be provided. Section 5 advocates using commonly available sizes of components rather than designing down to current knowledge. It is preferable to adopt the next highest module in a range, assuming a punitive rise in associated cost does not result, to allow for uncertainties.

A2.1.5 Basic decisions about the size and layout of the system must take into account the way it will be managed. All subsequent design detailing decisions clearly depend on the initial assumptions. Background investigation, consultation with potential users and operators, critical review of alternatives are fundamental to achieving sustainability of a system.

A2.1.6 Detailed information on system design is available in other texts (Van Bentum 1994, etc. (see bibliography)). The following sections aim to set out the implications of management by smallholder farmers for sizing pipe networks. They primarily refer to arid/semiarid regions where rotational irrigation must be practised. Operational conditions are less onerous in humid areas where rice is grown because there is a reserve of water within the field basins and losses from the system may be drawn upon by the crop roots.

A2.2 Initial considerations

A2.2.1 Faced with a growing scarcity of water, farmers are likely to be receptive to the idea of a change in traditional water supply arrangements. Assuming they possess basic understanding of improved systems, possibly obtained from observing installations elsewhere, they will need technical assistance in choosing a suitable system. Government will also need to licence any abstraction to avoid over-development of resources.

A2.2.2 Improved systems will not be economically viable unless high value crops are to be grown. In changing from conventional surface irrigation methods to a more efficient system, the costs, benefits and constraints of various alternative technologies need to be quantified.

A2.2.3 Designers need to investigate the background social and economic conditions prevailing at the proposed scheme location since success is dependent on the attitude of the local farming community.

A2.2.4 Sustainability of a system requires that many socio-economic factors must be favourable: labour; land size to make the enterprise viable; stable communities; a favourable ratio of returns to costs of inputs; ready access to markets; appropriate knowledge, skills and training.

A2.2.5 Technical factors which must be favourable include: design; quality of construction; pump performance; ready availability of power/fuel and spare parts; a reliable water supply; suitable environmental conditions (natural drainage, water quality).

A2.2.6 Farmers should be encouraged to submit their proposals for scheme improvement to the irrigation authority for approval.

The authority should provide a service to help in : examining the viability of proposals; design (or checking of contractors' design); inspection of construction and enforcement of quality control; arranging for appropriate training of farmers; helping to secure credit facilities, if required.

A2.2.7 Low pressure pipelines can be seen as an intermediate step between surface irrigation and pressurized methods such as sprinklers and drip systems. The possible benefits arising from the introduction of a low pressure pipeline system need to be realistically assessed, see Section 3.

If farmers express interest and willingness to adopt new methods they may well be ready to take up overhead (sprinkler) irrigation systems in place of surface irrigation methods. Assuming that the crops they wish to grow are suited to, and economic under, overhead irrigation, low pressure pipeline systems for surface irrigation are unlikely to be appropriate. The option of using locally-made low pressure sprinklers operating off a low pressure line and performing somewhat less efficiently than high pressure systems (application efficiency of, say, 60%) could be considered.

If farmers are skilled at surface irrigation and soil/crops are suited to such methods, then appropriately sized piped systems with improved distribution facilities (pipes/hoses, lined ditches) can provide a user-friendly setup with low energy costs, operating at perhaps 50 % overall efficiency.

A2.3 Likely benefits

A2.3.1 The quantifiable benefits of pipeline systems are often cited as:

- reduced conveyance loss
- improved water distribution
- gain in cultivated land

Other anticipated benefits, including reduced risk of water-borne disease transmission, are difficult to establish and will vary between regions.

A2.3.2 Conveyance loss. In a large surface irrigation system, the main system - mains, (branches) and secondaries - may typically operate at 75%-80% efficiency. Tertiary canals and field ditches may be 70-75% efficient. Field application efficiency for basin/furrow irrigation is commonly 50%-60%. A large proportion of the overall loss therefore occurs between main system and the field.

During the present investigation of a pipeline constructed of asbestos cement it was found that conveyance losses - including losses from the pipeline, from valves and from outlets - increased from 3% to 7% as the system aged. The greater part of the loss was attributed to leakage from nominally closed outlets. The importance of regular maintenance is apparent. Estimates of losses from precast concrete pipes on systems in Bangladesh (Van Bentum, 1994) were similar, ranging from a minimum of 5% up to 15%. It is expected that systems constructed of uPVC will suffer lower line losses, but that other losses may be similar. It is likely that the direct replacement of a tertiary canal by a pipeline will have only a limited impact in reducing total losses.

It is realistic to consider a pipeline as one of a number of measures to reduce losses at, and below, the tertiary level. Other measures should include: limiting the size of cooperating groups; reducing conveyance loss to the fields, either by surface pipeline or improved ditches; training farmers in efficient water use practices.

A2.3.3 Water distribution. The El Hammami project demonstrated that a pipeline installed as a direct replacement for a conventional open channel system is subject to all the problems of water management typical of traditional irrigation schemes involving large numbers of small farmers. Deliveries from the system will be constrained by uncoordinated demand for water. Unless conditions are simplified and resources devoted to training/ education of farmers, traditional patterns of water use will persist in the face of a changed water delivery system and little overall improvement can be expected.

From the outset, the El Hammami pipeline allowed certain farmers at the tail of the system to obtain water but demand was small since the field channel network was inadequate to distribute water to remoter regions. Water tended to be used principally in the middle and upper reaches of the area. Direct outlets serving the land of a single farmer were better-served than outlets where numbers of farmers had to share the water.

Once improvements were made to the network of field channels, steady improvement was achieved in areal coverage in all reaches, but particularly at the tail. The fact supports the observation in 3.2 above that pipelines should be seen as one component of an overall package of measures to improve tertiary water use.

A2.3.4 Savings in land. The construction of the El Hammami pipeline released land formerly occupied by a deep open channel. In due course, farmers began to refill the course of the channel, a substantial undertaking in an area where local fill material is scarce. By the end of the project the land so released had still to be cropped. There is no doubt that production benefits can be obtained from the extra land, provided land rights are agreed. Figures from PR China (Van Bentum, 1994) indicate that 6 % gain in agricultural land on small command areas (5-6 ha) can be regularly achieved. However, it should be pointed out that the arrangement of multiple outlets at El Hammami is far from satisfactory. If the number of outlets were reduced, the total length of linking tertiary channels would be increased. Some productive land would therefore be lost.

A2.4 Size of the system

A2.4.1 If the area of the irrigating unit is too large, it will be difficult for farmers to organize for cooperative water use. It is unlikely that efficient and sustainable operations can be achieved.

A2.4.2 To improve collaborative working, the size of cooperating units on small surface schemes should be limited wherever possible to a maximum of around 15 farmers. It is recommended that the same number should determine the upper limit on the size of individual pipeline networks. Small farmers may typically hold 0.5 - 1.0 hectare, so the upper limit on scheme size becomes 7.5 - 15 ha. The smaller unit size is preferable. Section 5.5 sets out other factors determining unit size.

A2.4.3 Wherever possible, the designer should not require farmers to split or share the supply. Each time the flow must be divided, potential for conflicts occurs. Rights to water are clear when one farmer uses water before handing on to his/her neighbour. The stream size will therefore be limited to the size which can be effectively handled by a single farmer, Section 6.4. The command area will therefore be limited to the size which can be irrigated in the available working hours before the next irrigation becomes due on the plots first supplied.

A2.4.4 Scaling down the size of a system not only reduces the capacity required of individual components but can also simplify system functioning and reduce operational complexity generally. For example, on-line storage to accommodate surges and unsteady flows becomes less important in smaller systems. Small pumps may be less economical in terms of capital and fuel costs than larger units, but they can be operated by farmers rather than by technicians.

Components made of certain materials may also only be freely available up to a limiting size. uPVC pipe, for which a practical upper diameter is currently 250 mm, is therefore not best-suited for use as the main on larger systems. Alternative materials, such as polyethylenes, may be available in the market.

There is a general move throughout the irrigating world to hand over to farmers the management of lower levels of the system. If operations and maintenance functions are too complex for farmers to manage, they will need to hire skilled operators or to request Government support. Instead, they may respond by continuing traditional practices.

A2.4.5 It may be possible to keep systems small whilst developing a high discharge source by suitably splitting the flow at the head into separate networks. Overall control by an operator or a system of proportional division will be required.

A2.5 System components

A2.5.1 Factors which will impose further limits on block size and hydraulic elements are: command area (see above); number of possible irrigating hours; practical stream size; limiting length of field ditch.

A2.5.2 Operating hours. Farmers are increasingly reluctant to work extended, unsocial hours. Realistic estimates of the farmers' working week at peak periods are needed to determine the number of possible system operating hours. The figure will vary between countries, but 60 hours, 12 hours per day for 5 days, is probably a common upper limit.

A2.5.3 Stream size. A stream size of around 28 l/sec is the upper limit which can be efficiently managed by an individual farmer. Smaller streams of 10-15 l/sec are suitable for small basins. The various hydraulic components should be sized around these limitations, adopting practical operational minima to avoid excessive loss in conveyance to the fields.

A discharge of 28 l/sec is suited to borders up to 7 meters wide (sandy loam) and to basins up to 200 square meters (sand) . A stream size of 10-15 l/sec will irrigate borders 3-4 meters wide (sandy loam) and basins up to 80 square meters, comparable to the range of field sizes at El Hammami. The smaller stream should not be conveyed more than 50 meters unless piped, otherwise high losses will occur.

Pipe sizes corresponding to these discharges are set out in Section 5.7 below.

A2.5.4 In a given location the losses from unlined field ditches are roughly related to the depth of flow, wetted perimeter and length of the channel. Small streams will suffer a high percentage of loss.

To reduce losses, field ditches should be less than 70 meters long. If surface pipelines/hoses are used, the cost of the pipe and the labour needed to move it will be important factors in limiting size and length.

A2.5.5 Block size. The block sizes appropriate to different soils, assuming for the purposes of the example a peak evapotranspiration requirement (Etc) of 7 mm/day, are set out in Table A2.1 below.

Table A2.1 Scheduling on different soils

Soil type	Available moisture (mm/m)	Irrigation[1] interval (days)	Time to Irrigate[2] 1 ha (hours)	Land Irrigable[3] in One Cycle	No of[4] farmers involved	No of outlets
Sand	80	6	8	7.5	15	7/8
Sandy loam	120	8	12	6	12	6
Loam	170	12	17	70	14	7

Notes:
1 Irrigation at 50% available moisture depletion
2 Application efficiency of 50% assumed. Preparation time not included
3 Five day, 60 hour working week assumed
4 Unit landholding = 0.5 ha

Depending on the topography, the length of pipeline would be of the order of 200-400 meters.

If the outlets were sized or operated to provide only 15 l/sec at the field edge (small basins), the land which could be irrigated within a cycle is reduced by 50%.

A2.5.6 Systems. Systems can be of the closed or open type.
In most small applications a closed system, in which the pressure throughout the system is affected by the operation of any outlet, will be the obvious choice.

On steep ground, an open system which involves a drop in the water surface at intermediate stands to reduce the line pressure, may be necessary. Outlets located downstream of the drops cannot influence line pressure upstream.

Branched networks are simple in conception and execution, particularly when designed so that outlets operate in sequence. The additional complexity of a looped network does not seem warranted in small systems. As the outlets in such a layout are served from two directions, farmers may consider it unnecessary to operate outlets by turn, thus reducing discipline in water use.

A2.5.7 Pipe. The relative costs of various possible pipe materials will vary, depending on country. Larger diameter concrete and asbestos cement pipes are used on bigger systems. Performance of cement-based pipes is strongly affected by quality of construction and they cannot readily be repaired by farmers when damage and leakage occur.

Attempts to optimize pipe size are unlikely to result in any significant savings on small systems where the choice of pipe will be strongly influenced by the diameters available on the local market. Section 1.4 referred to the advisability of selecting the next larger size from a range.

Thick and thin-walled uPVC pipes are now manufactured in many developing countries. A wide variety of materials may be included within the generic description so manufacturers' data and advice should be obtained before specifying. uPVC pipes must be carefully laid, particular attention being required to bedding and backfilling. The pipes are easily handled but care must be taken to avoid damage particularly doing transport and storage.

The largest practical size for irrigation purposes is currently 250 mm diameter.

For a discharge of 28 l/sec, at a minimum velocity of 0.60 meters/sec to avoid sedimentation, and acceptable head loss:-

Discharge of 250 mm uPVC pipe = 29 l/sec.

For discharges to 15 l/sec:

Discharge of 200 mm uPVC pipe = 19 l/sec.

Minimum recommended depths of cover for uPVC pipe under normal loading is 0.76 meters.(ASAE Standard S376.1). Elsewhere, the cover on smaller pipes can be less:

Pipe Diameter	Minimum Cover
12-65 mm	460 mm
75-100 mm	610 mm

Maximum cover for larger pipes will vary between 3-6 meters depending on pipe size and manufacturers' recommendations.

Reference should be made to material describing the use and laying of uPVC pipe.

A2.5.8 Risers/Outlets. Non-reinforced concrete pipe will provide better resistance to damage than plastic pipe.

Outlets need to be robust and to seal adequately. It is not realistic to expect drop-tight performance in everyday conditions of use. Alfalfa valves have proved effective in many regions. Although they can be damaged by determined farmers, they can also be replaced without difficulty.

Discharge of 29 l/sec can be passed by 10" diameter valves with acceptable head loss.

The diameter of the riser will be similar to that of the pipeline so as to pass the full discharge of the line. If the system is to be linked with a flexible pipe surface delivery system then hydrants, protected in surface boxes to avoid damage during cultivation, will be needed.

The operating head required at the outlet will vary depending on topography and the system of distribution to the fields.

A2.6 Pump size

A2.6.1 Ranges of small, diesel-powered centrifugal pumps capable of delivering 15-28 l/sec at low heads are widely available in the developing world. For more permanent installations, particularly on wells, electrically-driven pumps in standardized sizes are available.

The use of diesel sets may be dictated by lack of a reliable electricity supply. Electrically-driven sets are generally preferred by farmers as they are more reliable. Power costs may also be subsidized by Government.

Standard pump and prime-mover combinations are not always well-matched so the sets do not operate at best efficiency in many locations. Nonetheless, there are strong advantages in adopting a technology which is well-understood and supported by local technicians and for which spare parts are readily available.

A2.6.2 Pump operation. Automatic operation of electrically-driven pumps using pressure sensors located within the pump stand is common practice on larger systems.

It is not suitable for diesel-driven pumps or for systems in remote areas where manual operation can usually be readily understood by users.

A2.6.3 Storage. Storage and/or systems of pressure relief are needed to:

- accommodate surges following sudden reduction in demand or supply
- damp out water hammer and vibrations
- vent trapped air, if alternative venting arrangements are not provided

Pump stands located just downstream of the pumps will be required on systems operating at up to 5 -6 m head, to maintain and limit line pressure. On pipeline systems designed for medium and higher pressures, a stand will not be required.

A tail stand is needed on larger systems to deal with sudden closure of outlets whilst the pump(s) is/are still operating. Safe means of accommodating overflow are necessary as it will be uneconomical to provide sufficient storage. Pressure relief is also needed should all outlets remain closed on system startup. On small systems below 10 ha with few outlets, tail stands are not needed but an air vent must be provided.

Gate stands are required at junctions to control flow into laterals.

A2.7 Maintenance

All components of the system will need maintenance as the system ages. Items which are particularly at risk include those with moving parts, including pumpsets, outlets and valves.

Recommended maximum periods for maintenance/inspection are:

Item	Regular Maintenance Interval
Motors, pumps, valves	Monthly test
	Annual check
Outlets	Annually
Line leakage testing	Annually

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