Water and salt dynamics at the meso-level in IIIMP areas, Mares El Gamal canal

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IWMI
International Water Management Institute

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ARC	Agricultural Research Center
EC	Electrical Conductivity
ET	Evapotranspiration
HP	Horse power
IP	Individual pump(s)
IWMI	International Water Management Institute
m	meter(s)
MALR	Ministry of Agriculture and Land Reform
MWRI	Ministry of Water Resources and Irrigation
PS	Pump station(s)
WMRI	Water Management Research Institute

1 Introduction

It is a particularity of the Nile Delta to present intertwined irrigation and drainage networks, with a connectivity that is increased by the intensive conjunctive use of canals and drains by farmers when irrigating their crops. In order to better understand the water and salt dynamics at the meso level (i.e. a portion of a secondary canal command area) we set out to monitor the quantity and quality of water flows and stocks in a suitable area. Ideally the area should be equipped with collective pump stations (PS) put in place by the Irrigation Improvement Project (IIP) or the Integrated Irrigation Improvement and Management Project (IIIMP) projects (see report No. 4), so that the number of lifting points is more easily amenable to measurement; and also have a drainage outflow concentrated in one particular drain. This activity was planned for implementation in summer 2013 but we were not able initially to identify a site that would lend itself to such measurements. We eventually found a suitable site in the Mares El-Gamal canal command area that had just been equipped with IIIMP collective pumps. Researchers from the four institutions (IWMI, WMRI, ICARDA, ARC) worked together on the methodology and on setting up the equipment to start monitoring for summer 2014, with the following objectives and tasks:

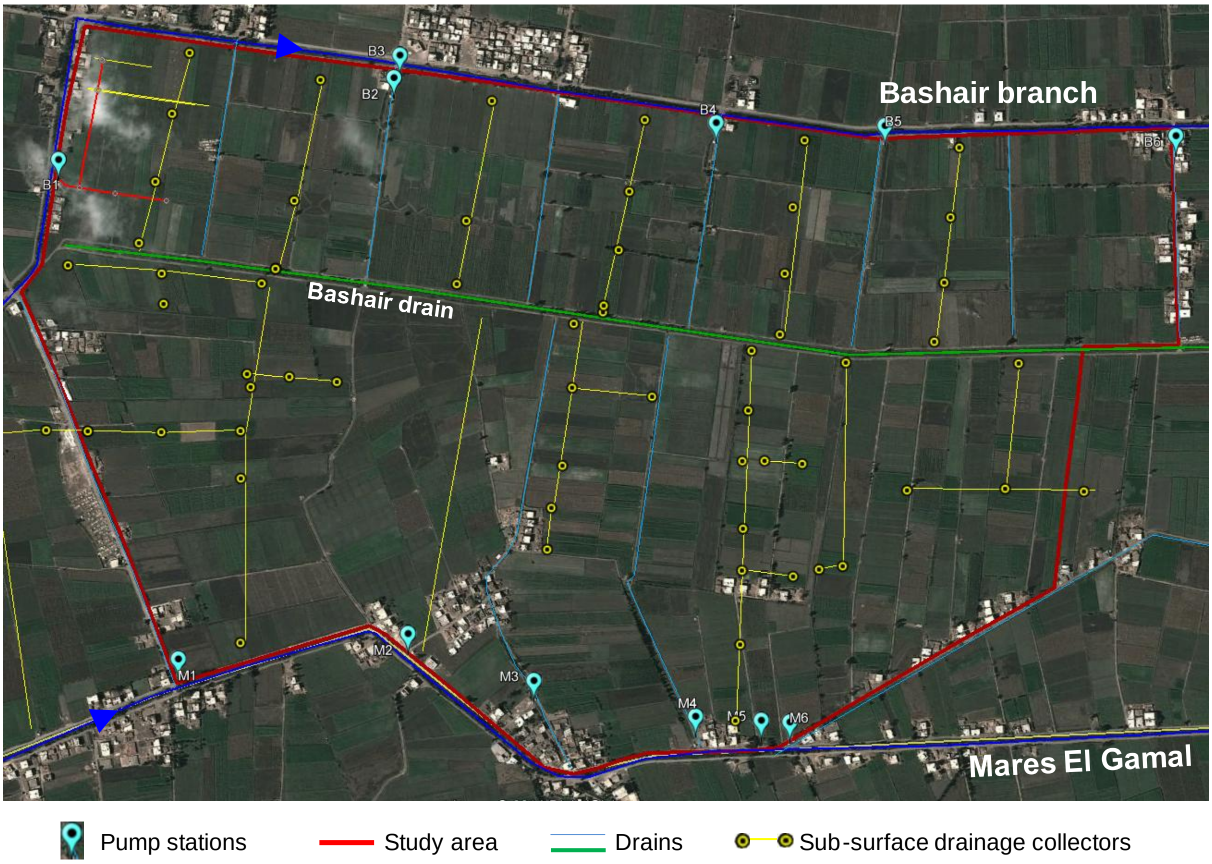
- Observe actual water management at the branch canal level, and compare it with the theoretical rotational system.
- Understand the temporal variability of drainage outflow and salt mobilization, to help in identifying the linkages between water management practices and salt movements/accumulation.
- Provide insights into the variability of salt mobilization at an hourly/daily time step, as a function of on/off supply rotations and of the current status of subsurface collectors.
- A water and salt mass balance approach will be applied to the area considered. This will in particular yield understanding of the efficiency of irrigation at that scale. Similar assessments of use efficiency will also be done at the pump station level.
- Assess the performance of the IIIMP pumps and explain variations in management between the 15 pumps. It will provide insight in how farmers organize at the very beginning, after reception of the pump station.

In addition to the measurements in the meso-level area, the research team conducted a series of field-visits during the summer of 2014 and carried out surveys and documented field observations in the selected pumping stations, which has produced a rich body of quantitative and qualitative data on the operation and maintenance of PS, on which we draw in this report and elsewhere (see also IWMI-WMRI report 1 & 4).

2 The study area

The study area includes approximately 480 feddan[1] (about 200 ha) of cultivated land and is bordered and supplied by two secondary canals, the Mares El Gamal branch canal, and one of its sub-branches, the Bashair branch canal. The area entirely drains towards the Bashair drain, as shown in Figure 1. Six IIIMP[2] pump stations (PS) are found on each of the two branches. They are numbered M1 to M6, and B1 to B6[3], for Mares el Gamal and Bashair respectively. The area is fully equipped with a network of subsurface drainage pipes and collectors. Despite the construction of 12 pump stations a number of individual pumps (IPs) are still in place (Figure 2). Some of these IPs are fully in operation (like in M4, where the pump station has not been completed), near other pump stations like B1 (in case of power cuts), along the canals (to irrigate independently of the pump stations), or along the drain (for additional supply). Figure 3 illustrates the main features of the study area.

Figure 1. Meso-level research site general layout



[1] Feddan = 4200 square meters (m^2) = 1.038 acres

[2] Integrated Irrigation Improvement and Management Project (IIIMP); see IWMI and WMRI, 2013.

[3] To which we have later added B0, a station constructed in early 2015 and which replaced a pump sump of 14 individual pumps.

Figure 2. Individual pumps in the study area (location, and number, when more than one)

In addition of all these collective and individual pumps, several of the stations have been fitted with an additional diesel pump, at the request of farmers to IIIMP (and at their cost): B4, B5, B6, M3 and M6. This makes the monitoring of water use more complicated because the operation of these diesel pumps has to be monitored through thermo-managers that record their temperature, which could then be compared with the air temperature (the difference indicates periods when the motors heat up, meaning that the motor is functioning).

The operation of electric IIIMP PS has been monitored through the use of data loggers which record the 'on' and 'off' operations of each pump. Most pump stations have two electric pumps, which makes a total of 20 electric pumps/engines to be monitored.

The water levels and water salinity have also been monitored at the head of Mares El Gamal and Bashair branches, at the point of bifurcation, providing hourly indications on rotation patterns. Likewise, the water level and salinity in the Bashair drain have been monitored on an hourly basis through a sensor fixed to the bridge at the outlet of the study area (Figure 4).

Plot level evolutions of groundwater, water moisture, soil salinity, and drainage water salinity have been monitored by ARC as a separate component of this research activity. A network of 18 piezometers has been installed to monitor the fluctuation of the water table. Data collection included:

- Water table level every hour in 5 piezometers (automatically recorded)
- Soil salinity at initial, mid-season, and end of the season
- Survey of the farmer practices in the investigated area, through periodic visits (either during the on or off periods)
- Survey of cropping pattern of summer 2014, winter 2014 and summer 2015
- Hourly monitoring of electric conductivity in 2 manholes
- 10 soil profiles sampled and analyzed for two times (0-30, 30-60, and 60-90 cm)

Unfortunately, it has not been possible to install all the monitoring equipment in time for the summer 2014 season (although some data have been recorded and are analyzed in what follows). Monitoring has been extended to winter 2014/2015 and summer 2015.

Figure 3. Features of the study area

Pump station B1 (with one pump only)		Pump station M6 with an additional diesel pump (linked to distribution pipe)	
Individual pumps nearby M4 pump station		Individual pumps along Bashair canal	
Individual pumps along Bashair drain		Pump sump (B0) on Bashair branch (now replaced by a PS)	
Mares el Gamal canal (canal is subject to sliding of em-bankments)		Bashair drain (after cleaning)	
One valve and the marwa served by it		One hydrant in a paddy field	

Figure 4. Monitoring equipment.

Water level sensors at the head of canals		Water level sensor on the bridge of Bashair drain	
Data loggers for the monitoring of PS operations (inserted in the control board)		Thermo-manager to monitor pump temperature	
Pump calibration with ultrasonic device		Sensor fit in an iron pipe, within a manhole	

3 Water supply (irrigation canal)

3.1 Management of the Mares el-Gamal Canal

Mares el-Gamal Canal is the first branch canal of the Zawiya Canal, and has a theoretical rotation of 9 days on (3 days for each subbranch: Mafruza, Mares el-Gamal and el Bashair), with 2 days off. Figure 5 shows upstream and downstream levels at the head gate and the gate opening, during the summer 2007 (IIIMP monitoring data). A number of observations is possible. First, we can observe that gate openings and closings (larger than 50 cm) result in changes in upstream levels – in Zawiya canal – of around 20 cm. Second, canal closure varies between 1 and 2 days (with an average of 1.4). Third, the 'on' periods vary between 2 and 11 days and have little to do with the 9 day theoretical rotation. One possible explanation is that sequences C and D, as well as G and H (indicated at the bottom of the chart in Figure 5), have been interrupted by a 1-2 day 'off' period, possibly due to a crisis at the tail end of the Zawiya canal which led the engineer to request a closure of Mares el-Gamal, resulting in a gain of 20-30 cm in water level upstream; supply to Zawiya is therefore substantially improved by such an intervention. Fourth, one can hypothesize that the long 11-day 'on' period observed in June is related to the fact that the downstream water level is lower than the target, resulting in a lengthening of the rotation. Fifth, we can see that during 'on' periods there are quite a few (small) gate adjustments that are likely to be both causes and consequences of variations in either upstream or downstream levels.

Figure 5. Upstream and downstream water levels at the head of Mares El Gamal in Summer 2007 (Data from IIIMP monitoring).

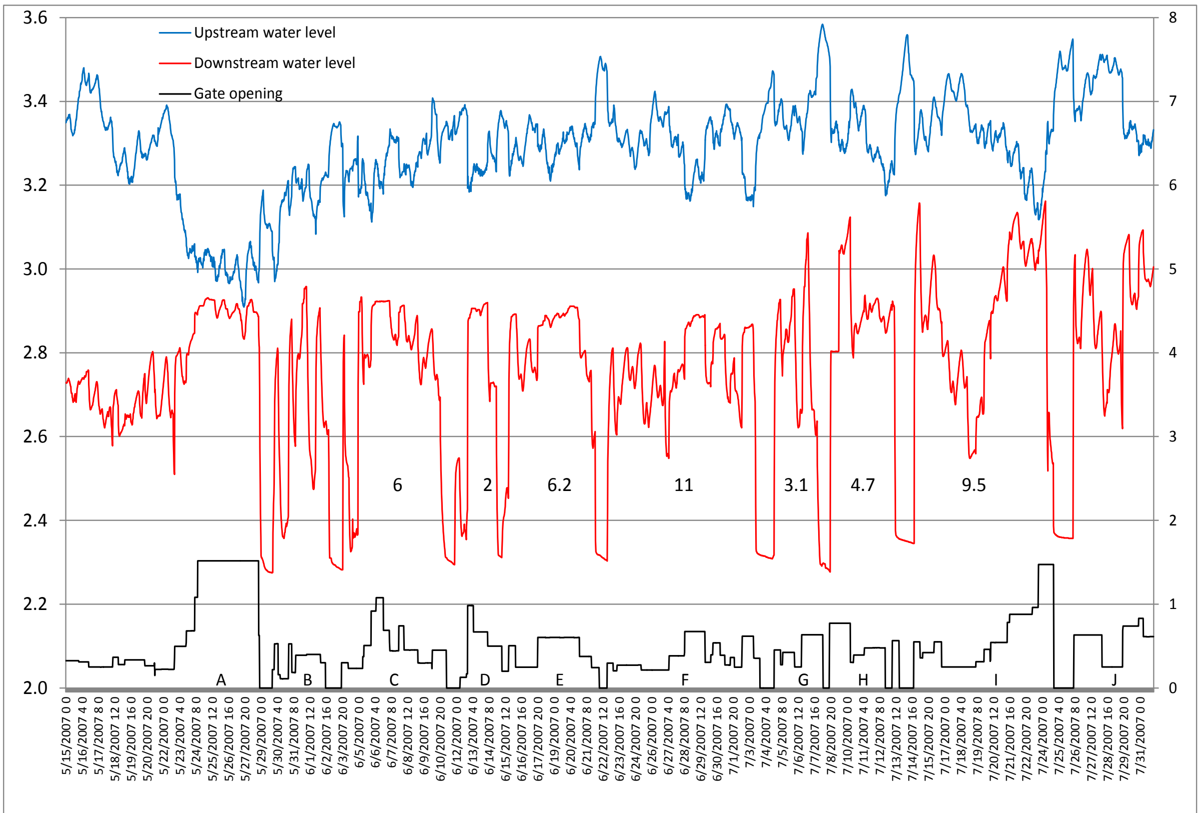
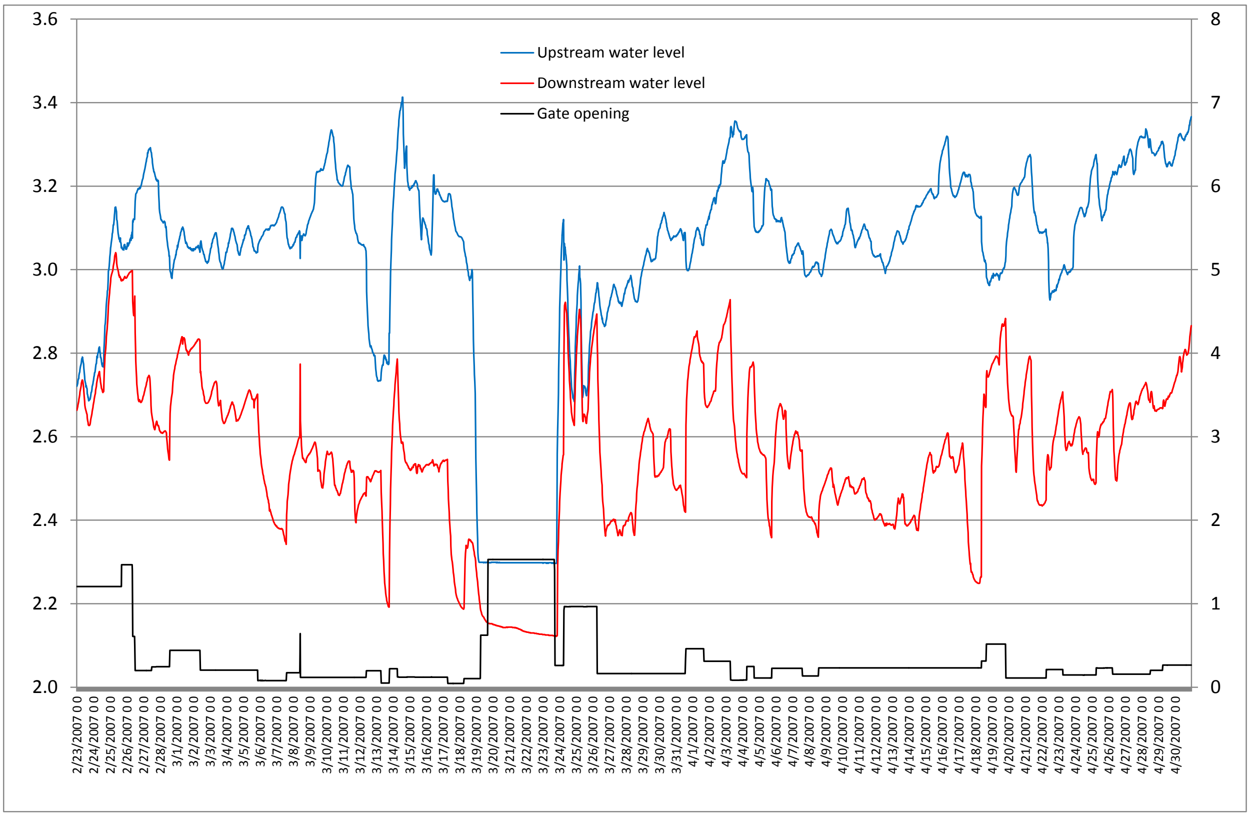


Figure 6 shows upstream and downstream water levels in winter (February and March 2007). We can see that the gate is never closed and that there is no clear rotation pattern. The canal has been closed during five days at the beginning of March, presumably for maintenance and cleaning operations.

Figure 6. Upstream and downstream water levels at the head of Mares El Gamal, from February to March 2007.



3.2 Rotation between Bashair and Mares El Gamal sub-branches

Mares El Gamal is a long branch canal which, as shown in the preceding section, is supplied with water almost continuously and has an internal rotation. It is divided in three reaches by two cross regulators, each reach having around four days of supply. But when the downstream reach is 'on' (that is, the second cross regulator is open), water flows through the first two head reaches and farmers can still abstract water, unless the engineer enforces the rotation and prevents them from doing so.[4] Bashair branch is open when the middle reach is 'on'. The rotation system is made explicit in Figure 7. During Turn 3, water should be abstracted only by pumps located after regulator R2, namely M4 and M5. But since water flows in front of stations M1, M2 and M3 these three stations, in practice, can still abstract water during that turn. In other words, while the pump stations in Bashair (B0 to B6) receive water during Turn 2, and M4 and M5 during Turn3, stations M1 to M3 can abstract water during Turn 2 and Turn 3.

[4] This requires a lot of commitment and patrolling along the canal and can only be effective during the day.

Figure 7. Water distributions schedule in the meso level area.

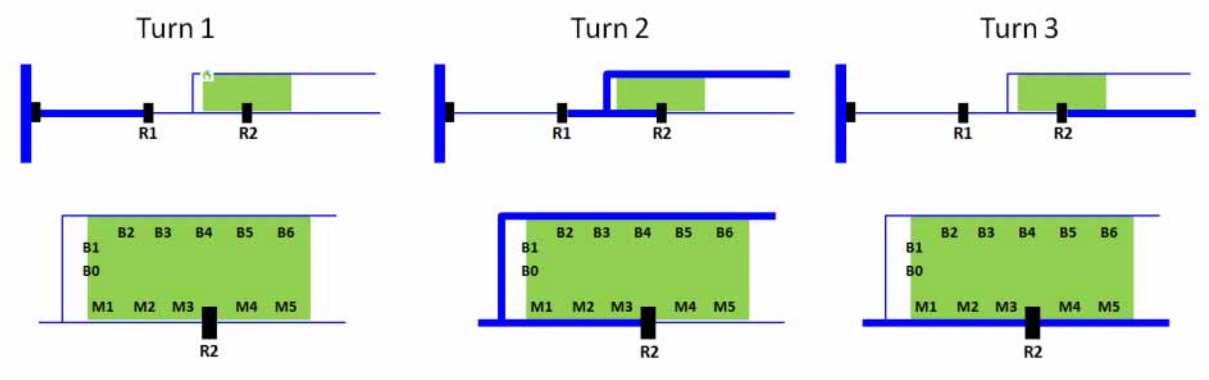


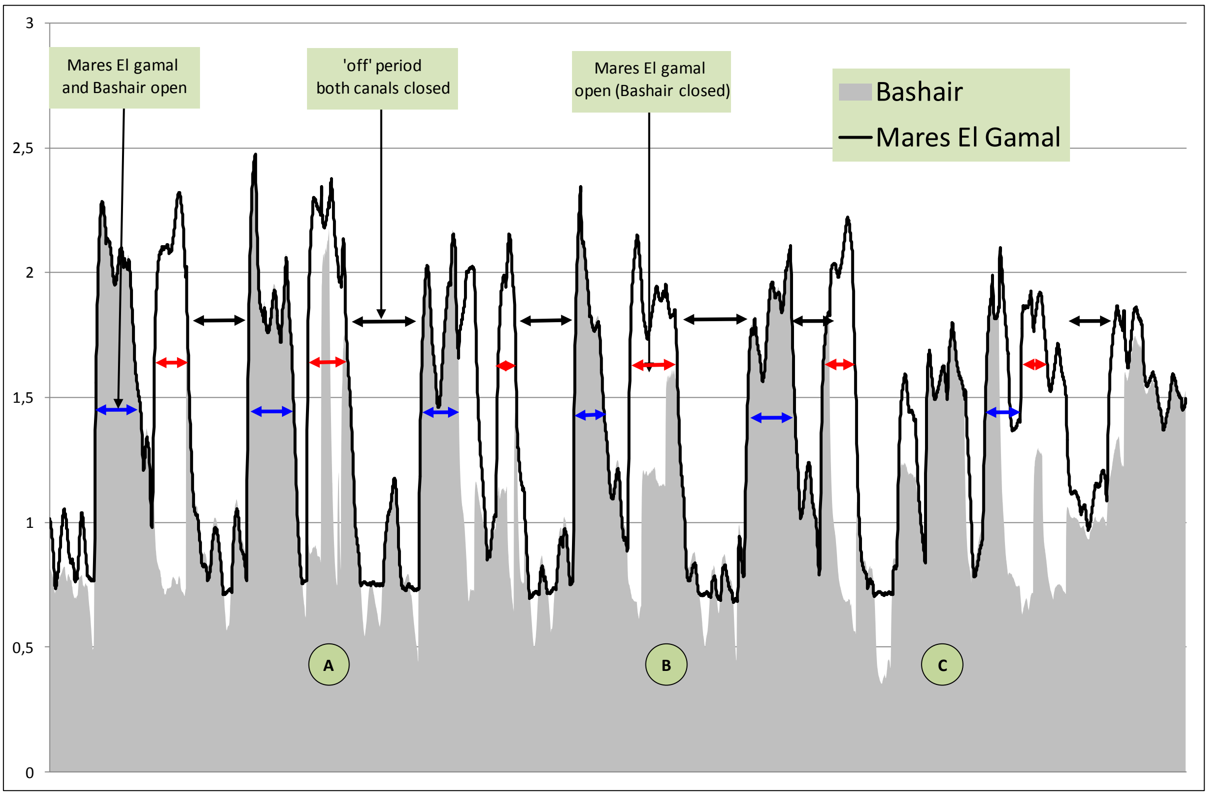
Figure 9 shows the variation of the two water levels during one year. The rotation schedule becomes less clear by the end of the year 2014 and then disappears during winter with a particularly large break without supply in January.

Figure 8 (a and b) shows the water level in Mares El Gamal canal and at the head of the Bashair branch during two weeks, one in July, one in August. The pattern of the rotation described above appears with a number of adjustments. During event A, for example, it can be seen that the gate of the Bashair branch has been opened twice, for a short period of time, which is during Turn 3 reserved for the downstream area of Mares El Gamal. The same happened during event B, but the gate was half opened for some time, and then almost fully opened (the water level remains slightly lower than in the Mares El Gamal canal). In event C, the turn (T2) should start with Bashair fully open, but supply is low and Bashair gate is partly shut. This is probably the result of the downstream area not having received enough water during the preceding T3 turn (indeed shorter than usual: 1.5 day). After a sudden closure, probably due to problems experienced upstream, T2 is resumed.

At the time of event D, Bashair has been closed for a long period of 11 days and is given water during 15 days, with two sharp but short interruptions. As a result the rotation is disrupted and the next four 'on' periods see a reversal of T3 and T2. This is a good illustration of the gate adjustments made by the district engineer depending on what is happening within the command area of the branch canal, but also at the wider level of the Meet Yazid canal. Such events translate into orders from the Directorate to open and close the head regulator at times that do not correspond with the theoretical rotation or expected patterns.

Figure 9 shows the variation of the two water levels during one year. The rotation schedule becomes less clear by the end of the year 2014 and then disappears during winter with a particularly large break without supply in January.

Figure 8. Water levels in Mares El Gamal canal and head of Bashair branch (Weeks a and b)



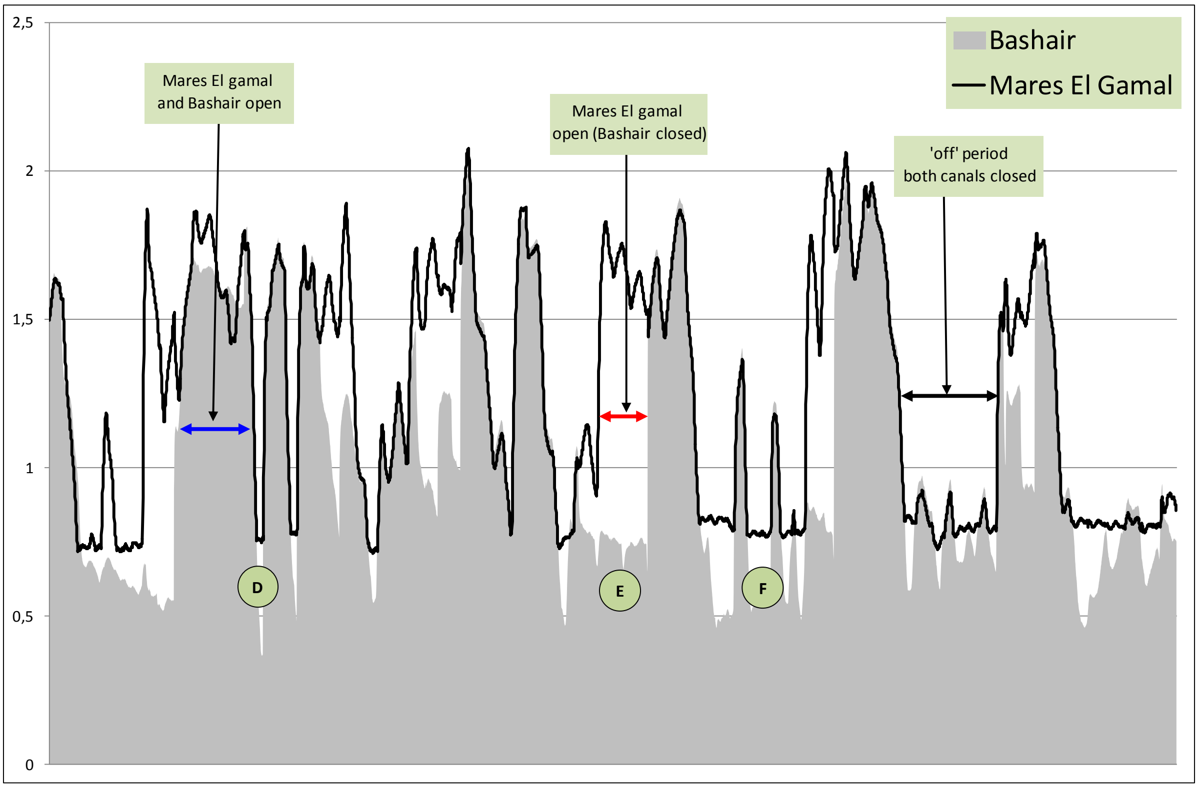
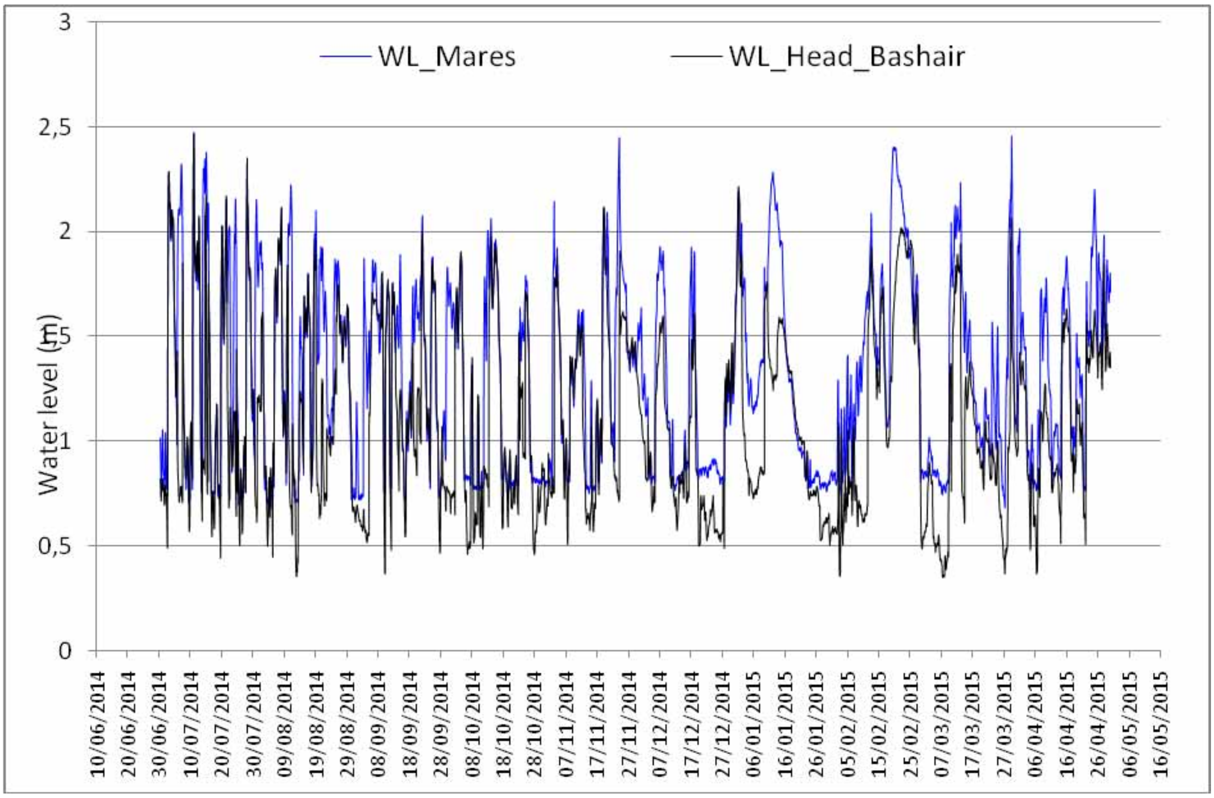


Figure 9. Water levels in Mares El Gamal canal and at the head of Bashair Branch



4 Drainage

The agricultural land in the meso-level area is drained by field level - and tertiary drains, which discharge in the Bashair secondary drain (Figure 10). A network of subsurface drainage collectors also drains the plots and discharge in the Bashair drain. In summer, however, the water level in the drain is rather high and the outlets of these collectors are submerged.

Figure 10. Drainage in the study area: Field drain (2 left) and tertiary drain outlets (2 right)

In other words, the Bashair drain receives water from superficial drainage (from the plots directly to the ditches), from subsurface drainage (through the buried collectors), and -when its water level is low enough- by direct lateral seepage. These three components of drainage water, in that order, have growing concentrations of salt.

Figure 11 shows the evolution of the water level in the Bashair secondary drain, measured at the bridge at the exit of the research area, from June 2014 to April 2015. Fluctuations are superimposed with a variable indicating the degree of gate opening (of both the head gate of Bashair canal and Regulator 3 on Mares el Gamal). The gate openings were calculated based on the water level at the head of the two branches. If the water level was higher than 1.3 m (up to 2.4 m), then the gate was considered fully open (1) in the corresponding canal. If the level was between 0.8 and 1.3 the gate was considered as half open (0.5). If the water level was below 0.8, then supply would be considered as nil (0). The sum of these two gate opening variables provides a simplified proxy for the supply of the meso level area. When supply to the area is 'off' during summer, the water level in the drain drops by 40 cm. The average water level is also 50 cm higher in summer than in winter, on account of the much larger quantities of water supplied to the area, reflecting both higher crop requirements and the presence of rice.

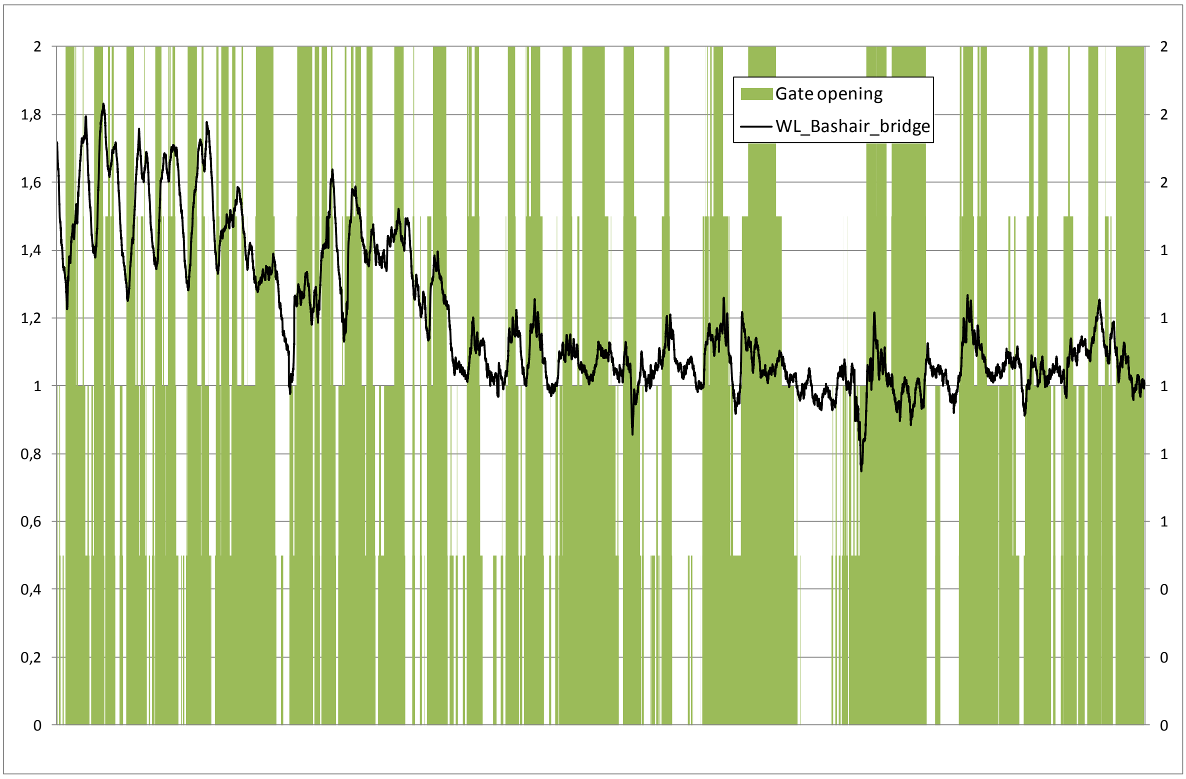
Figure 12 displays the evolution of salinity of drainage water in the Bashair drain during one year. The first striking observation is the huge amplitude of that variability, with electrical conductivity (EC) varying between 1000 and 7000 µmhos. Variability is lower in summer, when EC fluctuates around 2000 µmhos, which again reflects the larger amounts of water applied during that season.

Also noteworthy is the countercyclical evolutions of EC and water levels, which is more clearly observed in summer. When the water level drops, indicating a reduction of irrigation operations, EC tends to increase. This shows that the proportion of drainage water that comes from the action of the drain itself, which drains deeper soil layers, supersedes the proportion of agricultural drainage coming from both a) surface drainage (removal of excess water, for example after land preparation), and b) subsurface drainage collectors (which has a lower EC). In winter this correlation is less clear because water levels are always very low. A flush effect of even a limited irrigation can only be observed from the EC, not from the water levels.[5]

On October, 9 there is a sudden hike in EC that is most likely due to some problem with the device during a period of approximately one month. Data are thus less reliable during this period.

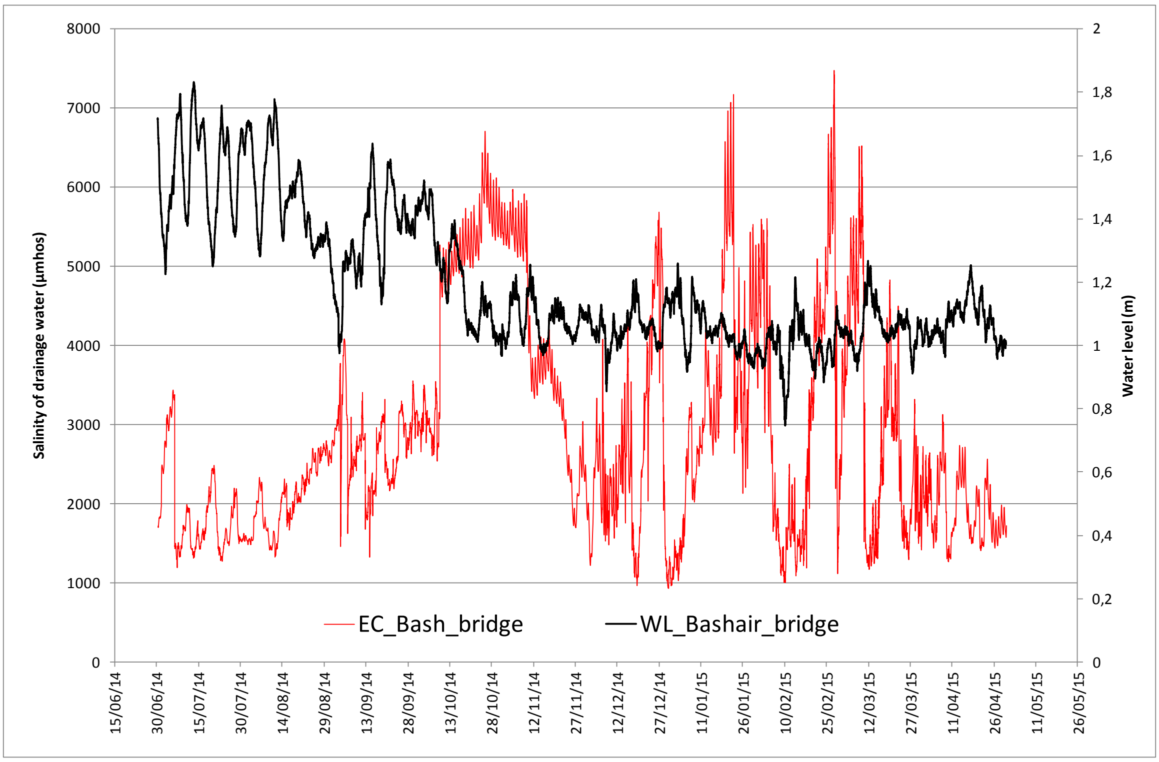
We attempted to estimate the outflow of our study area by measuring discharge in the Bashair drain, under the bridge where water levels and EC were recorded. Because of the very low discharge at most times, we could not establish a relationship between water levels and discharge. Further, this relationship was similarly affected by the changing conditions in the drain itself, where the growth of weeds was intense and cleaning occurred twice a year. In addition, constructing a V notch weir was not possible because it would have required a special authorization from the ministry, since drainage conditions might have been altered by the weir. We then tried to identify an ultrasonic device that would fit the width and depth of the cross-section of the drain under the bridge, but the level was too shallow to allow the use of such equipment. As a result, we had to give up the idea of measuring the outflow of our study area.

Figure 11. Relationship between canal supply and water level in the drain.



[5] Dredging operations carried out at least twice a year in this drain may also be responsible for sharp drops in the water levels.

Figure 12. Variation of drainage water salinity in Bashair drain.



Water salinity in the drainage system is addressed in IWMI-WMRI Report No. 7.

5 Operation of the pump stations

The main characteristics of the 12 pump stations (PS) are given in Table 1. Six stations serve an area between 22 and 30 feddan, and another six larger ones serve areas between 43 and 56 feddan. The total number of farmers in the study area is around 200 which, for a cultivated area of 480 feddan, which gives an average of 2.4 feddan (or one hectare) per farmer (but a large part of the area is cultivated by tenants renting and sharecroppers cultivating the land). The power of the electric motors is 7.5, 10 or 15 HP. Four PS along Bashair branch are also equipped with piped marwas and hydrants (on-farm improvement; see IWMI-WMRI report 1, 2013), against only one on the Mares el Gamal side.

The operation of the PS has been recorded with two objectives. First, it was attempted to estimate the total quantity of water abstracted from the two branch canals by both individual and collective pumps to irrigate our study area. This quantity of water can then be compared with theoretical water requirements in order to estimate the efficiency of water use. Second, since the pump stations had just been installed and some of them were being established during the course of the monitoring, there was an interest in a) observing how farmers were dealing with the new technology just after receiving it, b) comparing the timing and duration of the operations of the 12 PS in order to assess whether, even on a limited area, locational differences resulted in varied levels of access to water (some PS having better access to canal water).

Table 1. Main characteristics of the PS

PS	Area (fed)	No. farmers	Start	Diesel pump	Marwa pipes	IPs	Motor/ pump	Power (HP)	Nominal Q (l/s)
M1	50	14	Nov. 13	0	No	4	M1a	10	30
							M1b	10	30
M2	50	30	Aug. 13	1	No	8	M2a	10	30
							M2b	10	30
M3	22	22	Nov. 13	1 (22 HP)		1	M3	10	
M4	43	15	Jun. 13			5	M4a	7.5	30
							M4b	7.5	30
M5			Not yet			7	M5		
M6	56	25	Jul. 13	1			M6a		30
							M6b		30
B0	27	13	Feb. 15	1		0	B0	15	
B1	30	9	Nov. 13			3	B1	15	
B2	30	25	Feb. 14		Yes		B2a	7.5	30
							B2b	7.5	30
B3	30	9	Apr. 14		Yes		B3a	7.5/10	30
							B3b	7.5	30
B4	56	4	Apr. 13	1	No		B4a	10	30
					(15va)		B4b	15	
B5	24	8	Apr. 14	1	Yes		B5a		30
							B5b		30
B6	54	9	Oct. 13	1	Yes		B6a		30
							B6b		30

5.1 Collective pump stations

Collective pump stations were monitored by using data loggers fitted on electric pumps (devices recording on/off sequences) and thermo-managers recorded the temperature of the diesel pump body. Air temperature (for comparison), as well as atmospheric pressure (for correction of water level sensor data), were also recorded. Data collection was partly impaired by 1) deficiencies in the data loggers that had to be replaced, 2) removal of the devices by the farmers themselves for diverse reasons. Low recorded pumping time values (or the absence of pumping) can be the result of such problems, but also of power cuts or mechanical problems. Even though we tried to record the occurrence of such problems it was not always possible to determine their exact duration.

5.1.1 Operation time of collective pumps

After organizing our database of operation events at pump stations and with individual pump motors, we can first of all analyze at what time do pumping operations start. As illustrated by Figure 13, which shows results for pump B4b, farmers preferably start pumping early in the morning as well as late in the afternoon. Pumping early in the morning suits farmers because of the lack of heat, but also because limited pumping during the night results in water being stored in the canal, and therefore higher water levels (and availability) in the morning.

Another interesting issue is that of the duration of pumping events. The time to irrigate one hectare depends - among other things- on the type of crops, the initial soil moisture, and on the discharge delivered at the level of the valve. This discharge, in turn, depends on the water level in the canal, how clean the grid and mesh of the inlet are, and on how many valves are open at the same time. In general, irrigation of the plots takes one or a few hours, which leads to the expectation that pump operations would last a few hours. As illustrated by Figure 14 (for pump B6b), the majority of pumping operations last less than one hour, with a very large proportion lasting less than five minutes (45% in that particular case). This vividly shows problems of water availability in the canal and the high frequency of cases where farmers attempt to pump residual water to the last drop. Attempting to do so, they are forced to discontinue pumping after a few minutes to avoid pump cavitation, which is air being sucked up instead of water. Another cause for very short operations is the condition of motor overheating in the middle of the day, which automatically triggers the pump to switch off. PS B6, for example, was equipped with a pump that was abnormally subject to this problem. Farmers complained several times, until the motor was eventually changed.

Pumping in the middle of the night is clearly associated with pressing water needs. The month of May, in which rice is transplanted, distinguishes itself by 15 pump operations between 2 and 3 o'clock in the morning. A comparison between the pump stations of the two branches (Mares el Gamal and Bashair) shows little difference, in both cases aggregated data show around 34% of operations with a duration of under five minutes.

Figure 13. Hour at which pumping operations start (B4b)

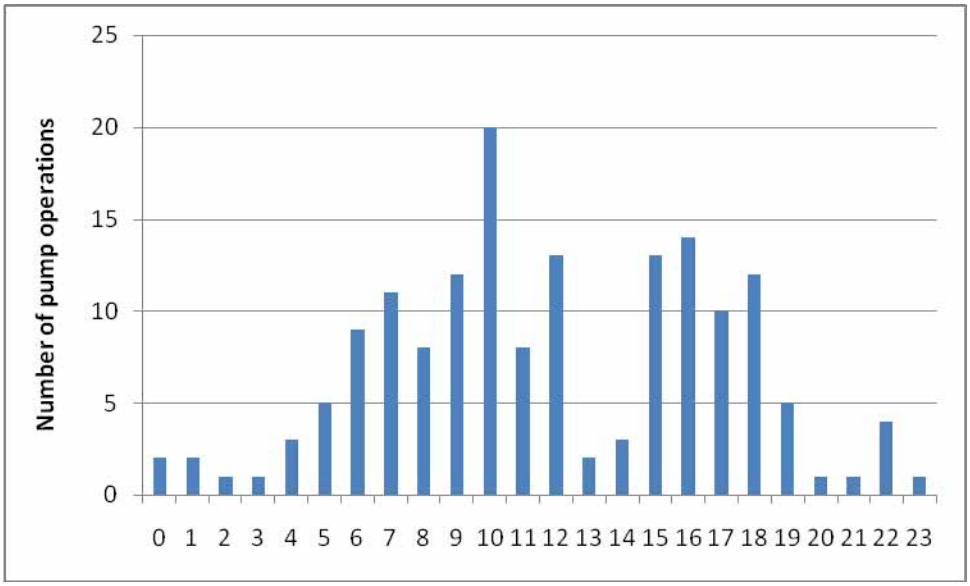
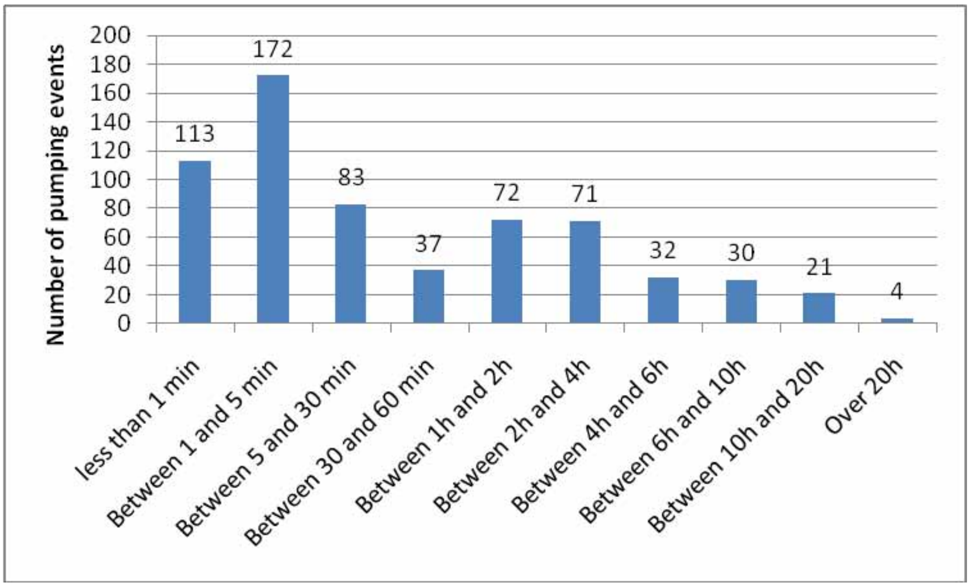


Figure 14. Distribution of pump operation durations (B6b)



5.1.2 Operation time of collective pump stations

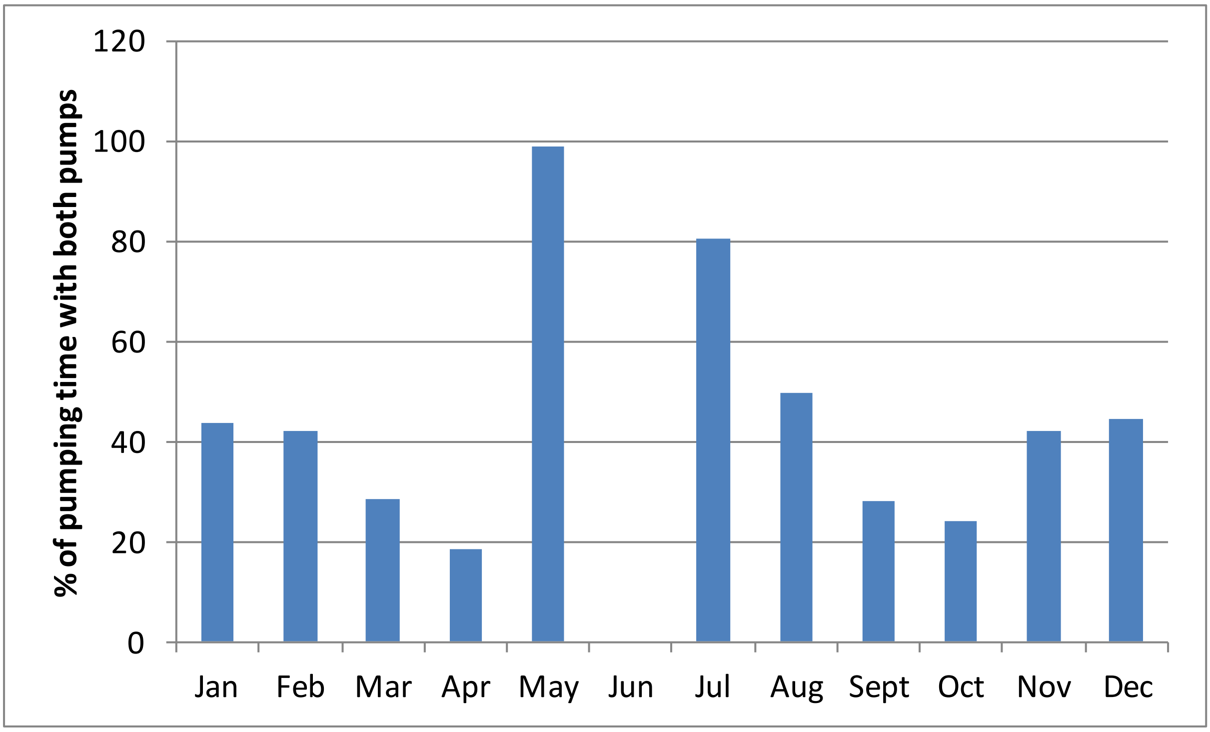
Because of some problems experienced with data recording mentioned above, some corrections for missing data had to be made. Correlations between monthly pumped volumes of the different pumps were used to correct values for months in which data was partial. Periods with mechanical problems or power cuts were difficult to deal with because they probably corresponded to periods in which farmers installed or used existing individual pumps as a substitute, which could not be recorded. Average values are used to fill in these gaps.

5.1.3 Simultaneous operation of pumps within the same PS

Analysis of pump records allows knowing the percentage of time that each motor was operated, for a pump station with two pumps, as well as the percentage of time that both were operated simultaneously.

Figure 15 provides an illustration (for PS M6) of the percentage of all pumping operations in which both pumps are operated. Unsurprisingly, summer months (June data are incomplete) show that both pumps are operated whenever there is water available. In contrast, in winter only one pump is operated in most of the time.

Figure 15. % of pumping time with both pumps working (PS M6)



5.2 Individual pump stations

According to IIIMP rules, individual pumps had to be removed after the inauguration of the PS, but a significant number were in fact maintained by farmers at the place where they abstracted water from the canal before. In most cases, these individual pump sets were not used, suggesting that the collective PS were sufficient to abstract water at the time when it was available.[6] A few IPs, however, were used to supplement supply to individual plots along the Bashair canal and drain. It has not been possible to monitor the use of these IPs. The survey was carried out in order to identify whether they were a) used as the only source of irrigation (in

[6] But as we will see, in many instances the capacity of the pumps was higher than the discharge available in the canal, forcing farmers to discontinue pumping after a few minutes. Therefore, the limited use of IPs should not always be considered as an indication of sufficient supply.

which case the corresponding irrigated area was recorded), b) used as a complementary resource (in which case the frequency of use was estimated based on farmers' information in order to add the corresponding volume to the total inflow into the survey area).

In all cases, the contribution of these IPs was minor, with the exception of the group of 14 IPs presently turned into B0 PS on Bashair; and of the 7 IPs that continue to be used at the site of M5, which has not been completed because of a conflict between farmers. The area corresponding to these two groups of IPs (27 + 30 fed) has been deducted from the total cultivated area and the calculation of the total theoretical water requirement of the study area has been corrected accordingly.

6 Elements of a water balance

6.1 Total inflow

The cumulative monthly pumping operation time of each pump must be multiplied by the average discharge of that pump. Pump discharge varies with the water level in the canal and with the number of valves that are open at the same time. By considering average values, we necessarily introduce some error in the evaluation of the volumes pumped. We considered the nominal design value of the pump discharges as well as actual values checked in the field. We used ultrasonic equipment to measure discharges in the main pipe of each pump.[7] Some of the discharges recorded were higher than the nominal discharge, probably because more than two valves were open at the same time. In two cases the discharge was around half of the theoretical value, which was attributed to mechanical problems with the pump inlet valve, or material obstructing the pipe filter. In these cases, we have arbitrarily considered 80% of the nominal discharge (since farmers clean the filters it is impossible to really ascertain what the average discharge is). It is important to stress that the variability of the relationship between the pumping time and the actual discharge may be substantial, which introduces a degree of error in our calculations.

6.2 Crop consumption

The estimation of crop consumption was based on the assumption that there was no substantial stress in the area and that, therefore, actual consumption could be equated with theoretical water requirements. The question of what the theoretical water requirements are, however, is thornier than one would believe. There is no agreement between the Ministry of Water Resources and Irrigation (MWRI) and the Ministry of Agriculture and Land Reform (MALR) about the water consumption of different crops. A survey of ET values used in the delta (see IWMI and WMRI report 1, 2013) has evidenced very large discrepancies between the values considered by different official documents. For this particular study we have used the values proposed by WMRI (see Annex).

Another problem with comparing requirements and supply at the monthly level is that cropping calendars are staggered and not well represented by our fixed average calendar (applied to all plots with the same crops). This introduces some bias. Another difficulty is linked to the specific need for water at the time of land preparation for rice cultivation, a quantity that is not well known and varies substantially according to soil type.

6.3 Efficiency of irrigation at the level of the study area

Considering data on water abstraction by the different pump stations, and allowing for corrections in case of missing data, we may compare actual supply (with the addition of rainfall) with theoretical crop requirements, calculated on the basis of cropping calendars. These calculations have been done for each of the two sub-branches.

[7] There was some uncertainty with the exact nominal design discharge of some pumps, as several farmers complained that some of the pump sets received had a pumping capacity lower than indicated on the plaques. In two or three cases this perception was based on the comparison of their pumps with those of other groups.

Figure 16 and Figure 17 are presented here considering an efficiency of water use at the level of the pump station of 0.55 and 0.70, respectively for rice and field crops on the Mares el Gamal canal side, and 0.50 and 0.60 for rice and field crops on the Bashair canal side.

The choice of these efficiency coefficients is approximate and corresponds to a relative (visual) fit between demand and total supply (irrigation + rainfall).[8] If we calculate the total requirements (net of rainfall) for each canal in the period June 2014 to September 2015 (15 months for which we have data for all pumps), and divide this value by the estimated irrigation supply we obtained overall efficiencies of 0.52 and 0.62 for Bashair and Mares el Gamal respectively. This period includes two successive summer seasons and as is apparent in the figures, requirements were higher in 2015 than in 2014, on account of a larger rice area, most especially on the Mares el Gamal side. The quantities of water applied to the field during the 15 month observation period seasons were 29,378 and 30,112 m^3/ha for Bashair and Mares el Gamal respectively, that is, comparable per hectare water supply volumes. Considering a full year (from October 2014 to September 2015), corresponding values were 19,139 and 19,845 m^3/fed (around 10% more than the preceding year, however[9]).

One should not necessarily interpret these data by concluding that the Mares el Gamal side is more efficient than the Bashair side (0.62 against 0.52). A higher efficiency may equally correspond to a difficulty in covering needs, or a difference in the type of soils (e.g. heavier soils that better retain water in paddy fields).

In summer supply averages 39 m^3/feddan/day at the head-gate of Meet Yazid canal, 33 m^3/feddan/day for Mares el Gamal branch canal (IWMI and WMRI, 2013). Our Mares el Gamal and Bashair areas received an average of 32 and 34 m^3/feddan/day, respectively, in Summer 2015 (April to September), which shows that they have not been at a disadvantage with regard to the average supply for the whole branch canal.

[8] The comparison attempted here can only be crude. In addition of the lack of precision on the variable measured it is probably incorrect to consider that irrigation efficiency is constant: it does increase when supply decreases, with reference to needs.

[9] Comparing values from June to September only.

Figure 16. Comparison of net water requirements and supply (to Mares el Gamal side)

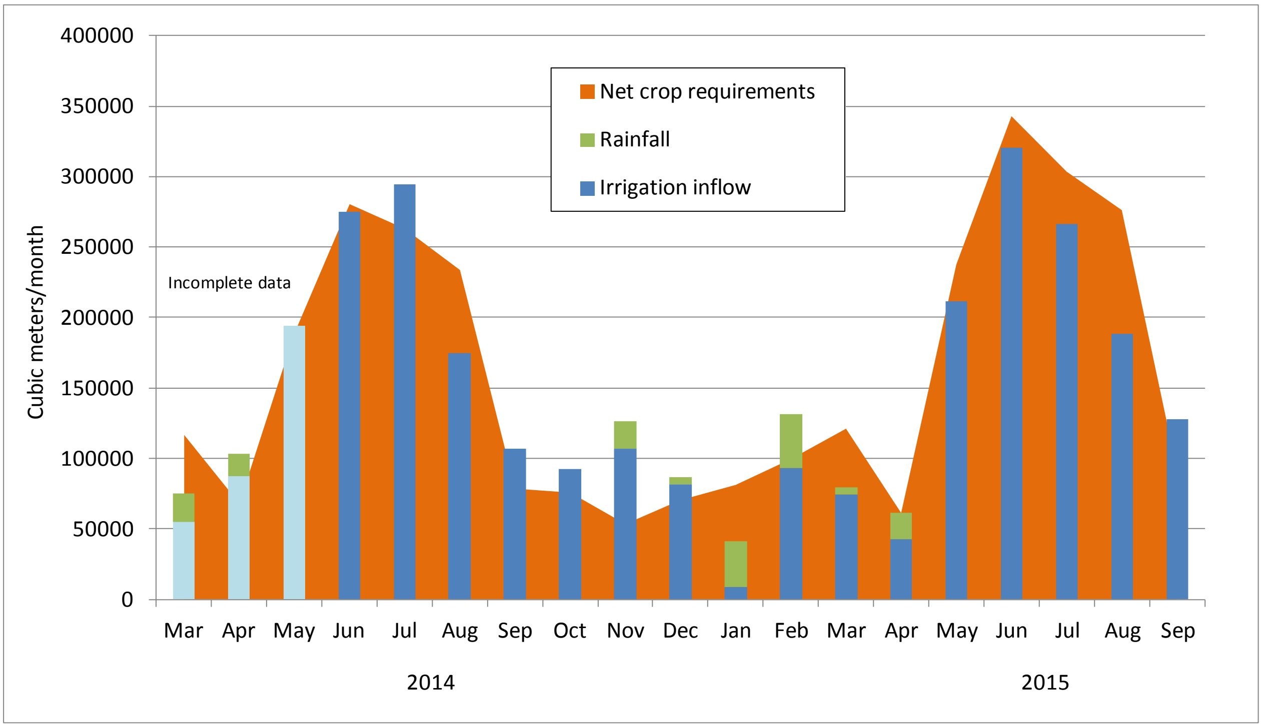
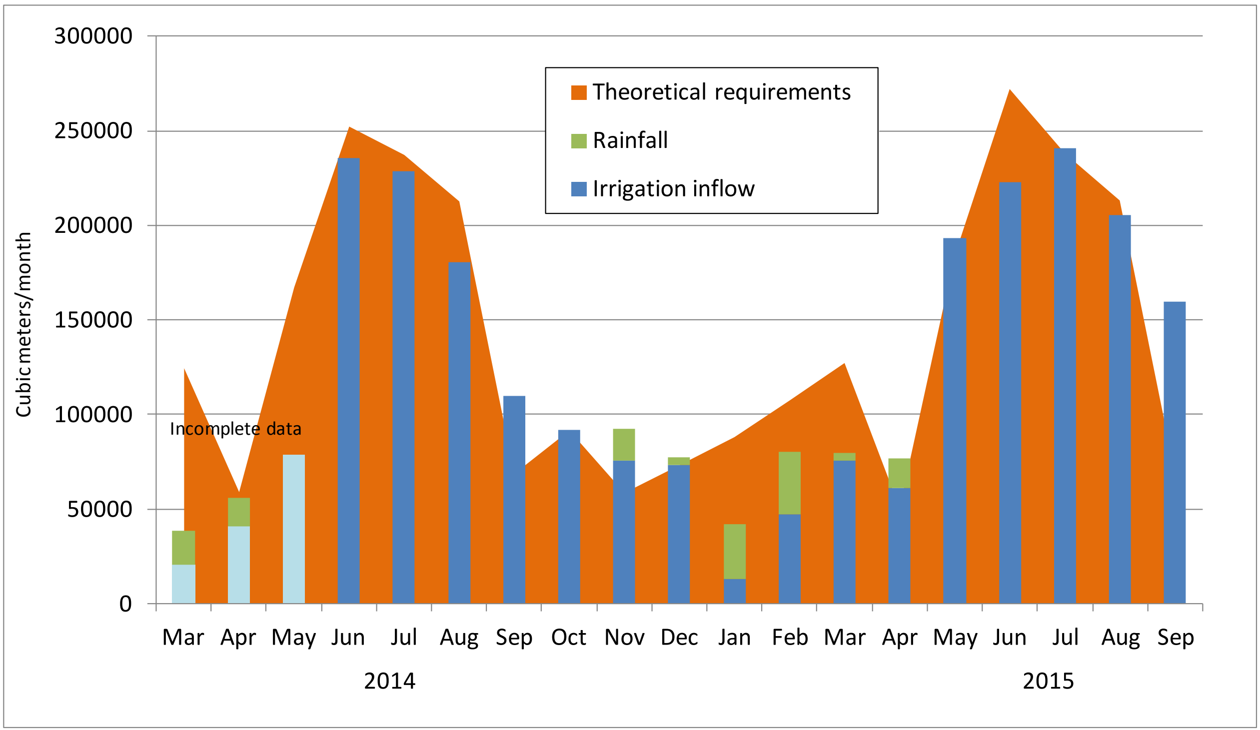


Figure 17. Comparison of net water requirements and supply (to Bashair side)



7 Observations on the O&M of the pump stations

The research activities undertaken in the meso-level area were also a golden opportunity to observe the implementation of IIIMP pump stations. The first of the 12 PS was implemented in June 2013, with the others being gradually implemented until the end of 2015 (with the recent construction of B0 and the news that farmers in M5 had finally resolved their conflict and agreed to request their PS' termination).

7.1 Implementation problems

Farmers have experienced various problems with regard to their pump motors, foot-valve (in the inflow pipe), electricity connections, mesqa valves and marwa hydrants, etc. Implementation problems have been pervasive and well identified since the beginning of IIP projects. They seem however to have proved very resilient (see IWMI and WMRI Report No 4, for a discussion). Here is a selection of such problems, for the sake of illustration.

The head of B1 WUA bitterly complained to have been given only one pump (although his station shows indeed two slots, for two pumps). He pointed to the 4 IPs that are still near the pump station which he uses in case of power cuts, and also to supplement the discharge of his only pump. He was told that the motor had a higher capacity (15 HP) than the one planned initially, which is however not apparent from the rather limited size of the motor. (In another station, farmers also claimed that the actual power of one of the motors was not the number which was written on the plaque.) Farmers have to open at least three valves to avoid over-pressure, which means they have to coordinate between themselves to irrigate at the same time; this is cumbersome and makes farmers whose fields are located near the PS to use their IPs.

Others signaled what they considered as design mistakes. A group (on the other side of Bashair canal) with 30 feddan and two pumps of 7.5 HP explained that the outlets of the pump are 4 inches while the main distribution pipe itself is 6 inches in diameter, creating an important head loss (they also referred to IIP pumps in Daqalt which were much better and had 12 inch diameter pipes). In B3, farmers also complained that the pipes of the distribution system are not compatible with the motors. Indeed, IIIMP changed one of the motors which was 7.5 HP and is now 10 HP.

More importantly, one of the two pumps in PS B3 was not working since the beginning and could not be used most of the winter 2014/15; they complained many times to the IIIMP office, which sent several engineers to look at the matter but until recently it was not yet repaired. There was another problem with the foot-valve at the entrance of the inlet pipe. Improper suction is damaging the pump and farmers are forced to switch it off.

Forced switch-offs are quite common and have several causes. In M6, there have been some power cuts because of overload of the line (in which case they have to call the engineer who comes and connects again). In B6, the PS was closed by the overheating of the engine (which has now been solved by the electrician of IIIMP), a problem also frequent in B4 (where the motor switches off for unclear reasons, which caused farmers to fight for irrigation at the time of rice transplanting).

In PS B4, farmers complained that the diameter of the main distribution pipe was 5 inches, against the 10 inches they had observed to be the rule in other stations of the same size, which created problems of overpressure (and possibly also with the electric system).

A more serious problem bedeviled the small station M3, which has only one motor. The station suffered from power cuts caused by faulty connection of (buried) wires and had to spend most of summer 2014 without being able to operate the pump, causing much anger. It took several months to have the electricity engineers visit the area and several visits of IIIMP engineers to detect a problem with a connection which was then fixed. However, since that time the problem has repeated itself three or four times, according to farmers. In the end, they wanted a connection through electricity poles (which IIIMP had originally proposed but farmers found too expensive), but neither side wanted to pay for this solution. Finally, a solution was reached.

During our recurrent field visits we observed that escape valves are leaking in several stations, such as in M1, B3 and B4.

Figure 18. Examples of implementation problems

Open pit	Loose electric connection	Unfinished work
		
Leaking escape valves	Broken keys	Blind screens
		

7.2 New O&M requirements

7.2.1 Operating valves and hydrants

The fact that the pump stations had been recently implemented afforded us the possibility to make some observations on the design of collective rules to schedule irrigation (or the lack thereof). Station B2 was visited at the time of rice transplanting and we observed that the 10 on-farm hydrants were opened at the same time. The operator merely stated that in case of conflicts he would ask some of the farmers to close their hydrants. But near the drain a farmer and his wife had been waiting in their fields from the day before at 11 in the evening and anxiously looking at the small discharge of water out of their hydrant. They were in bad need to flood their plot to complete land preparation before the following day, for which they had hired a group of transplanters. We even saw a couple of hydrants opened near rice nurseries, without their lid. We were told that farmers had taken the lids away with them so that other farmers would not close their hydrants. This was a typical situation of unregulated access resulting in uncertain supply and harm to some farmers, because the PS and its improved pipe-network had only recently been taken into operation (anecdotic evidence shows that after several crises events like this one and a couple of seasons farmers are usually able to design their own collective management rules: see IWMI and WMRI reports 1, 2 and 5).

In other stations like in M6, a rotation was implemented after rice transplanting time, with 3 tracts of 20 feddan receiving 10 hours of water each. The valves are open and closed by the pump operator himself; everyone has signed a paper saying that if he opens out of turn he will be fined 1000 EP. The operator has a table with a roster and people call him to ascertain their time. If someone does not pay his part of the electricity bill he can easily cut him out.

In B4, farmers explained that they have been opening all the valves together, but have succeeded in establishing a rotation between the two halves of the command area, giving 12 hours to each side. However, they were using their IPs more than the PS, which had one of its motors out of work for several months. The last eight feddan at the end of the area were (partly) irrigated from the drain. Outside of the rotation, however, it is impossible to stick to the rules because of the uncertain and chaotic evolution of the water level in the canal.

M5 station had not been completed yet and farmers were still using seven IPs. But when the big station downstream (M6) is working, there is not enough water for them and they can only operate two IPs if they want to avoid drying up the canal. This implies that farmers need to stay close to the pump, to switch them off when water in the canal is not enough.

Management has also to be adjusted to the technical characteristics of the PS. A good illustration is given by PS B1, which has a 15 HP motor which puts the network under a lot of pressure and makes it necessary for farmers to open at least three valves at the same time, to avoid problems of over-pressure. This means that farmers have to coordinate between themselves when they want to use the pump, so that they irrigated at the same time. Because of the difficulties of such coordination, many farmers prefer to use their IPs and remain independent from the group.

7.2.2 Maintenance requirements

The new technology implemented by the IIIMP project comes together with new requirements also in terms of maintenance. This includes: cleaning the grid of the pipe inlet that connects the canal and the pumping pit of the station, cleaning the mesh of the suction pipes in the pit, and repairing components like the foot valve, the escape valve, the distribution valves and the hydrants, let alone the pumps and the motors themselves. The difference with former maintenance needs is that they are now collective and that the technical solution is not always easily accessible to farmers.

One of the main complaints of farmers is the difficulty to get assistance in case there is a problem with the electric transformer, wiring, or electric mainboard, as well as with the motors or even the foot valves. The contracted companies that have constructed the PS and its piped network are normally also responsible for attending to mechanical problems during the first year after reception of the pump station. It is less clear whether this is also the case for the electricity company, which provides the electrical connection to a separate electricity grid. In any case, there were numerous reports of difficulties with securing the required maintenance interventions. This will problem will be heightened after the one-year 'guarantee' elapses.

A crisis that occurred in station B4 illustrates an extremely negative impact of the lack of maintenance options in the area. At the time of rice transplanting in May 2015, with the highest water demand of the season, the electric switchboard broke down, making it impossible to use the two electric motors. By lack of chance, the diesel pump that is to be used in such situations also stopped due to a problem with its shaft. This left the group of farmers divided in three parts from head to tail: thanks to the small size of the area, the first third could irrigate by pumping from the canal with conventional individual pumps, while the last third could irrigate from the drain, leaving a middle tract of 13 feddan without access to water. Recently transplanted paddy fields started to dry up. In this occasion the helplessness of farmers in front of two technical problems that could not easily be solved locally was glaring.

Figure 19. Example of maintenance needs in IIIMP stations

Cleaning inlet grid	Cleaning suction pipe mesh in the pit	Damaged escape valve
		

7.2.3 The micro-level conditions of access to water

Although, on a map, all stations seem to be uniform and to have a similar access to water, several parameters induce a much higher heterogeneity in access than is generally understood. A first difference, of course, comes from the fact that M1, M2 and M3 can access water during two turns out of three, as explained earlier, while other PS only get water during one turn. Even the situation regarding power cuts is not uniform, since PS are grouped under different transformers and are not necessarily facing outages at the same time and in the same proportions. Water supply, especially at low flows, is further very much influenced by the (micro) topography of the irrigation system in general, and of canals in particular.

In PS B4, the inlet of the station is located just before a bridge and its concrete base (as is often the case). This creates an obstacle/weir and therefore an impoundment to the flow, which benefits B4. Another pumping station on the other side of the road (just in front of BS B4) is also benefiting from this; actually the inlet is lower and most of the water seems to be flowing to the station (Figure 20, e). The same happens in PS B2, located before a bridge, and PS B3 which takes its water just after the concrete sill. The former is at an advantage but claims that people downstream of the bridge have an over-excavated canal reach (as can be seen indeed from Figure 20, f), in which they can store water to be used during two days after the end of the rotation. There are many locations and segments of canals that are indeed over-excavated, probably as a result of canal dredging (this may sometimes be intentional when farmers pay the machine operator to do so, in order to benefit from some storage).

Flow is very much conditioned, of course, by the canal profile and by the growth of weeds. In some places of the Mares el Gamal canal area the soil is of a lighter texture and the canal is prone to embankment sliding (Figure 20, g, h, i), which obviously provokes drastic disturbances in water distribution.

Figure 20. Micro-environmental conditions affecting water supply

Obstacles in the canals built by farmers (a, b, c)

Bridge sills and other obstacles (d, e, f)

Sliding of embankments (g, h, i)

Conditions may also vary for exceptional reasons. PS M6 was seen to be operating during the 'off' period and we were explained that the (low) water level in the canal was due to construction of new PS further downstream, which raised the water level. Having realized this temporary benefit, farmers under M6/M7 have grown 50 feddan of rice against 40 the year before, giving a striking illustration of how farmers are aware of, and keenly take advantage of, changes in their environment.

Other micro-level environmental variations can also be seen at the plot level, where infiltration rates (notably for paddy fields) vary a lot depending in particular on the soil type. But conditions also depend on what farmers do: In B0 a farmer reported that he needs three hours to irrigate one feddan of rice because his field is near the canal and not surrounded with other rice fields, therefore incurring a lot of seepage.

But beyond the complexity and heterogeneity of these micro-level environmental conditions, farmers are also masters in modifying these conditions, to alter the natural flow of water to their benefit. We observed for example, that some garbage had been organized in order to obstruct the flow to the Bashair branch canal at the head of the branch (Figure 20, a), increasing as a result the flow to the Mares el Gamal branch. Figure 20 (b and c) shows some small weirs built with stones that farmers used to raise the water level in front of their PS. Figure 20 (g) illustrates how a pillar can be made use of to pile up garbage that constricts the flow and slightly raises the water level to the PS located immediately upstream.

8 Conclusions

The monitoring of 12 IIIMP pump stations in the command area of the Mares el Gamal canal (together with its Bashair sub-branch) has provided valuable information on water management under the IIIMP design. This has necessitated the monitoring of land use of 4 successive seasons, and of 22 electric pumps and 7 diesel pumps during a period of 18 months, requiring a considerable effort in terms of equipment and data collection. Data loggers and thermo-managers have come with a percentage of technical failures that have impaired data, but have also been subject to tampering or removal by some PS operators. In addition, frequent mechanical or electrical shortcomings have resulted in farmers resorting to their individual pumps which could not be monitored. Data analysis and observations made during field visits yielded the following principal conclusions:

- The 12 PS, although serving a contiguous area of 430 fed (around 180 ha), were supplied on a three-turn rotational scheduling at canal-level, with three sub-groups of pumps served on different turns. This, however, did not result in significant differences in terms of supply per hectare.
- Despite the recent installation of pumping equipment, numerous technical problems have been observed during the monitoring period. This has created a lot of frustration and anger with some farmers. It was apparent that the institutional channels to be used by farmers in case of problems or a breakdown are not clearly identified or even available. The IIIMP project needs to have a 'hot line' to link farmers with state services and/or contractors, depending on the type of problems and the guarantees running. Another recommendation is that the Ministry could help to set up independent local entrepreneurs who may intervene in case of mechanical of electrical problems (see also IMWI-WMRI report 4).
- In addition of technical failures, and perhaps partly related to them, there were a few cases where the installed pipes or engines were allegedly different from design specifications. This problem has also been identified in earlier surveys (see IWMI-WMRI report 1, 2013).
- The PS equipped with on-farm pipe and hydrant systems through the OFIDO project run in parallel to the IIIMP by the MALR also showed weaknesses. The poor quality of the material chosen has been pointed as very inadequate and the project has taken steps to remedy to this situation (see more in IMWI-WMRI report 4).
- With the uncertainty attached to the theoretical crop requirements, the actual staggering of cropping calendars in the fields, the variability of the infiltration rate in paddy fields, the amount of efficient rainfall, we have compared monthly water requirements for each of the two sides of our study area, respectively served by Mares el Gamal canal and Bashair sub-branch. Over a period of 15 months (including two summer seasons), the estimated irrigation efficiency was 0.52 and 0.62 for Bashair and Mares el Gamal respectively. The quantities of water applied to the field during this period were

29,378 and 30,112 m^3/ha, that is, comparable water supply volumes (but with a larger share of rice cultivated on the Mares el Gamal side).

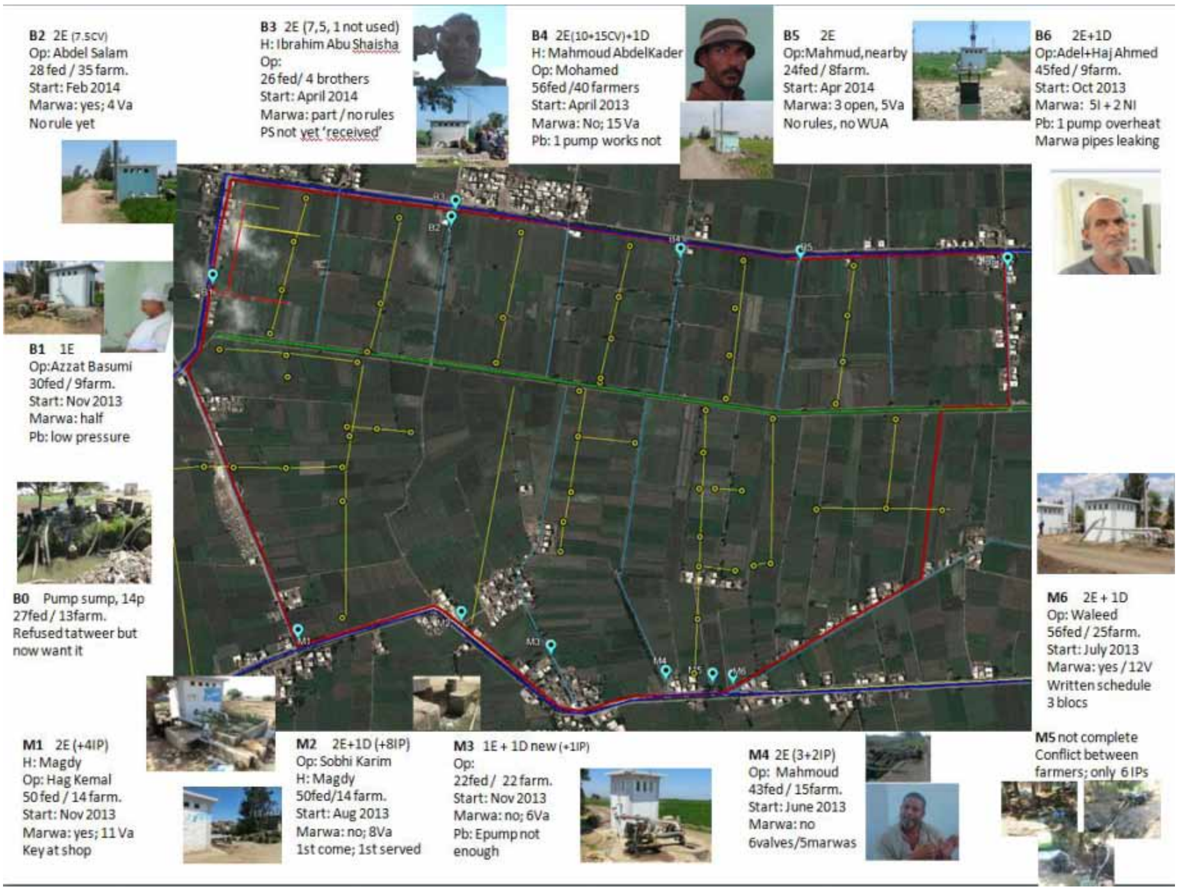
- Corresponding values for the period from October 2014 to September 2015 were 19,139 and 19,845 m^3/ha (around 10% more than the preceding year, however). in Summer 2015 (April to September), our Mares el Gamal and Bashair areas received an average supply of 32 and 34 m^3/feddan/day, respectively, which compares favorably with summer supply averages of 39 m^3/feddan/day at the head-gate of Meet Yazid canal, 33 m^3/feddan/day for Mares el Gamal branch canal (IWMI and WMRI, 2013), and a target - at peak time- of 35 m^3/feddan/day.
- The amount of water abstracted in 2015 was 10% higher than in 2014 but it is not possible to fully distinguish whether this is a cause or a consequence of the increase in rice cultivation between the two seasons. Part of the explanation of the increase in rice and water supply is that farmers in Mares el Gamal took advantage of the extra supply resulting from work conducted further downstream. Slight differences in efficiency are more likely to reflect actual supply rather than changes in farming practices. Years with limited supply show higher efficiencies but this might also come with a degree of stress in some parts of the area. It has not been possible to factor in additional punctual individual abstractions from the drain.
- An efficiency of 50 to 60% for irrigation at the tertiary level is consistent with earlier studies on irrigation in the delta. This is an average between higher efficiencies for field crops and lower values for rice.
- The study has also identified a rather typical feature of irrigation systems: the very high (micro)heterogeneity of environmental and social conditions. Access to water is shaped by the physical status of the canal and the resulting canal flow. This includes the impact of sliding embankments, over-excavated canal reaches, changing canal profiles, obstacles created by the concrete sills of bridges, not to forget the various obstacles that farmers construct to retain, impound or divert water in their favor. This was also true at the PS level, depending on the design of the system.
- Heterogeneity in social conditions has also resulted in differences in the capacity to set up collective arrangements, such as rotations or fixed irrigation times per hectare at times of water shortages. While some groups were found to readily handle their (new) collective pumps, others could not avoid conflicts and inequity in supply. This must be seen as a temporary observation, since this was the first season of operation of the PS; however, this also shows limited preparedness and/or training to manage the new technology.

Australian Government
Australian Centre for International Agricultural Research

International Water Management Institute

9 Appendices

9.1 Overview of pump stations and their main characteristics in meso-level area



9.2 Distribution of pumping operation durations (for each canal)

Figure 21. Distribution of pumping operation durations in the 6 stations of Mares el Gamal

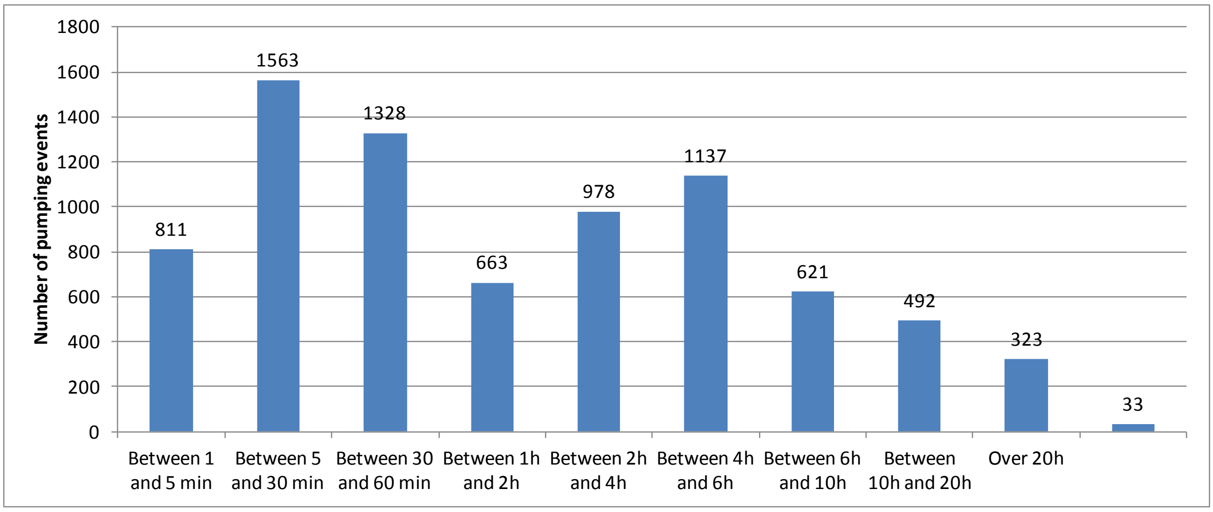


Figure 22. Distribution of pumping operation durations in the 6 stations of Bashair

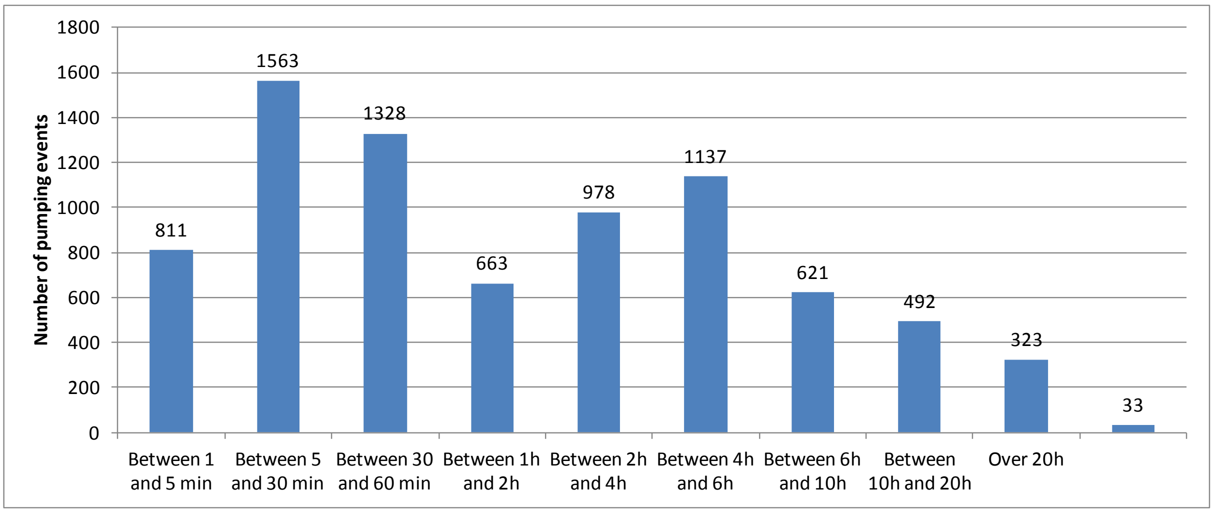
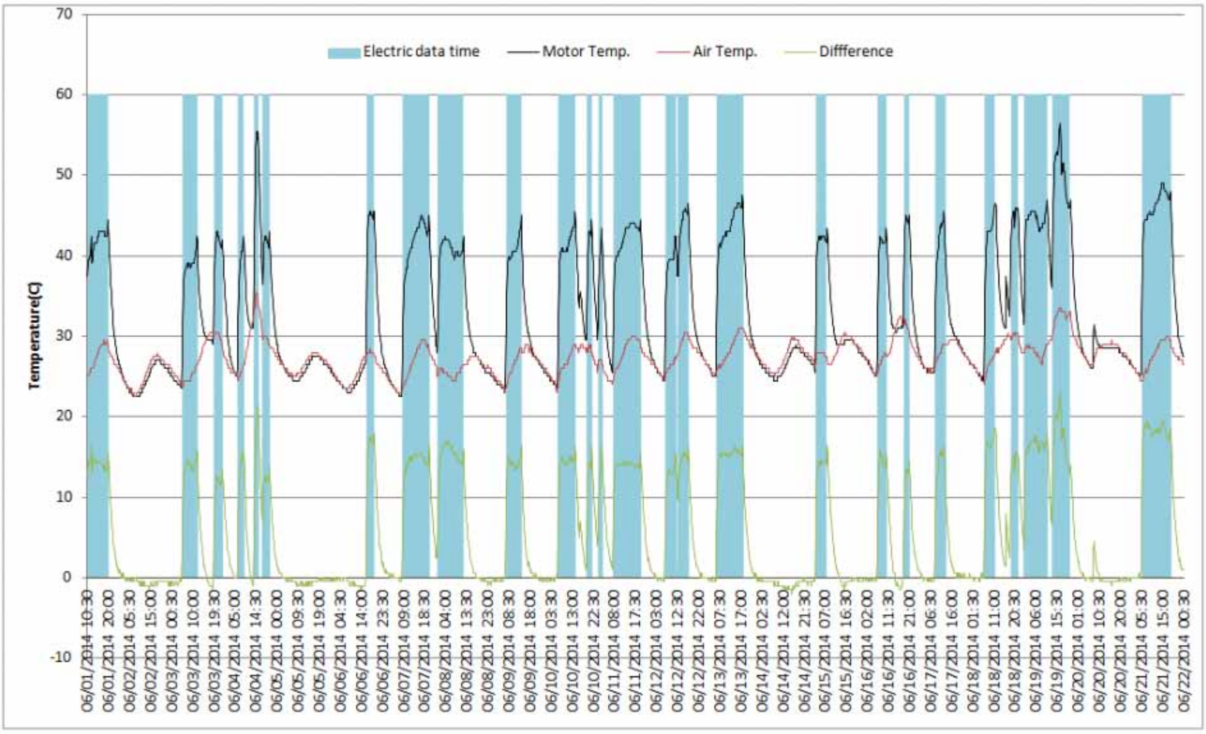


Figure 23. Comparison between motor and air temperatures (and deduction of operation periods)



9.3 Land use by season and canal (ha)

Canal	Bashair				Mares el Gamal			
Season	W13-14	S14	W14-15	S15	W13-14	S14	W14-15	S15
Cotton		12,7521		13,4111		15,5689		9,8568
Maize		19,2202		6,5576		27,1376		10,0973
Rice		36,3055		44,1279		55,6308		82,3199
Seedmelon		6,5451		5,8349		10,2850		7,4462
Seedmelon+Maize				0,0000				0,0576
sunflower				0,0000				0,1010
Alfalfa	16,8424		14,3917		26,1311		24,5225	
Bean	0,0000				0,6646			
Onion	0,3938				0,0000		2,1950	
Sugerbeet	26,2053		32,8799		38,9329		42,5458	
Wheat	28,5424		25,7696		39,7405		37,8928	
Total (ha)	**72**	**75**	**73**	**70**	**105**	**109**	**107**	**110**
Total (fed)	171	178	174	167	251	259	255	262

9.4 Theoretical crop water requirements

For Kafr El-sheikh (WMRI)

Crop	Etc (mm)
Wheat	446.85
Bean (Grain)	250.75
Barley	300.03
AlfaAlfa	484.94
Onion	499.85
Sugar beet	522.23
Cotton	885.03
Sugar cane	1063.45
Rice	774.42
Maize	473.43
Sesame	486.28
Soybean	486.28
Sunflower	486.28

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