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Spatial and temporal variability of water quality in the Nile delta

Doaa Ezzat Al-Agha, François Molle, Maha El Baily, Eman El Desouqy, Waleed Abou El-Hassan

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Water and salt management in the Nile Delta: Report No. 7

Spatial and temporal variability of water quality in the Nile delta

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Activity report

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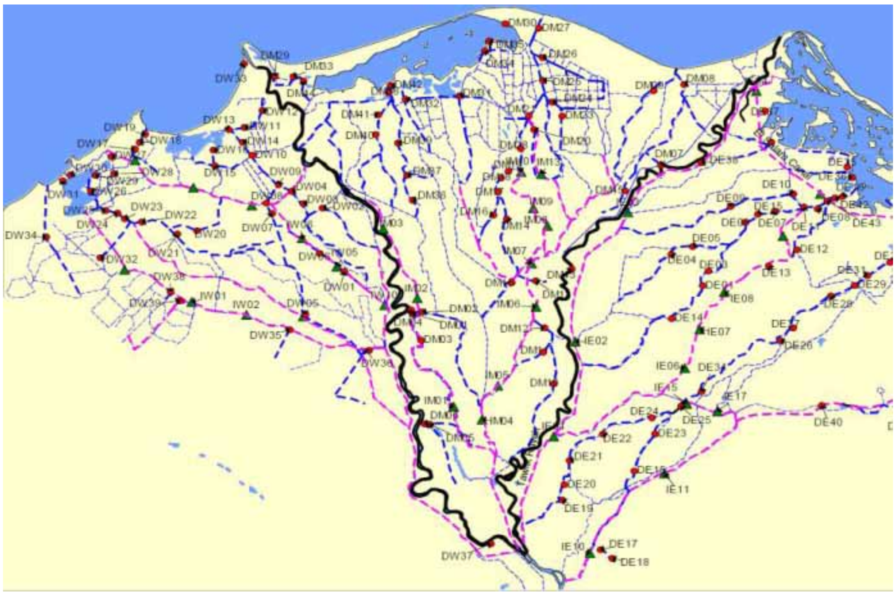
1 Introduction

Improving water management in the Nile Delta requires an overall understanding of the functioning of the irrigation and drainage system across different scales (from plot to system level). One particular complex issue is the relationship between those two systems, both in terms of water quantity and quality. Salt concentration in the drains depends on how much water is applied on the fields and how, the type of soil and other parameters. In turn, farmers irrigate from canals but also from drains, and by doing so they bring higher concentration of salts onto their plots. At the macro level the resulting salinity of drainage water at the northern fringe of the Delta has an impact on farmers reusing water in this area, as well as on fisheries located beyond the boundary drain, which include both aquaculture in ponds and wild fisheries in the lagoons.

Water quality samples in canals and drains are routinely collected by the Ministry of water resources and irrigation. According to Abdel Dayem (2012) the National Water Quality Monitoring Network covers 106 sites on the drainage canals of the Delta (Figure 1). It is based on continuous monthly data collection by the Drainage Research Institute (DRI). Twenty-four parameters are used in the assessment of water quality. The reference points are mostly located in main canals and drains and are monitored on a monthly basis, which means that the temporal and spatial resolution of this monitoring is rather coarse.

It is therefore crucial to get a better understanding of the spatial and temporal variation of drainage water quality parameters in the Delta. Observations were conducted in the Meet Yazid canal command area to understand the dynamics and movement of salts at several nested scales.

Figure 1. Network of sampling points in the irrigation and drainage systems (Abdel Dayem, 2012)



An extensive drainage network comprising 24 open drains (main and secondary) with a total length of 400 km and subsurface drains (collectors and laterals), serve the command area of Meet Yazid (IWMI and WMRI, 2013).

Multi-parameters water quality measurements were conducted at different levels of the drainage system (main, secondary, tertiary drains and also at the plot level) of Meet Yazid command area for two seasons -summer 2014 and winter 2014/2015. The parameters measured were salt concentration in drains, as measured by electrical conductivity (EC), Dissolved Oxygen, PH, total dissolved solids (TDS) and temperature. The (limited) measurements collected did not aim at a comprehensive picture of salt dynamics and cannot account for a possible large variability of reality on the ground. Yet, they provide insight on some interesting phenomena and a few tentative conclusions on the implications of managing both water quantity and quality.

2 Spatial variability of drainage water salinity

2.1 Plot/mesqa level

The relationship between the salinity of irrigation water and of the water drained by the subsurface drainage system varies substantially. The ratio between the two depends on the type of soil and its salinity, the crop cultivated and how it is irrigated, and the depth, spacing, management and status of the subsurface collectors themselves. Irrigation water in the Nile Delta typically has salinity between 350 (when passing through Cairo) and 600 µmhos (in the downstream parts of the main branches, after having been combined with return flow from the drainage system).

In an experiment carried out by Abd El Aleem (1990), in King Osman research station near Kafr el Dawar (West Delta), irrigation water salinity varied from 550 to 630 µmhos (around 400 ppm), and drainage water between 3100 and 3800 µmhos, giving a ratio of approximately 5.5. In a replication in Zankalon research station (near Zagazig, East Delta) with an irrigation water at 360 µmhos, drainage water salinity was found to be 2350 µmhos, giving a ratio between drainage and irrigation salinity of 6.5.

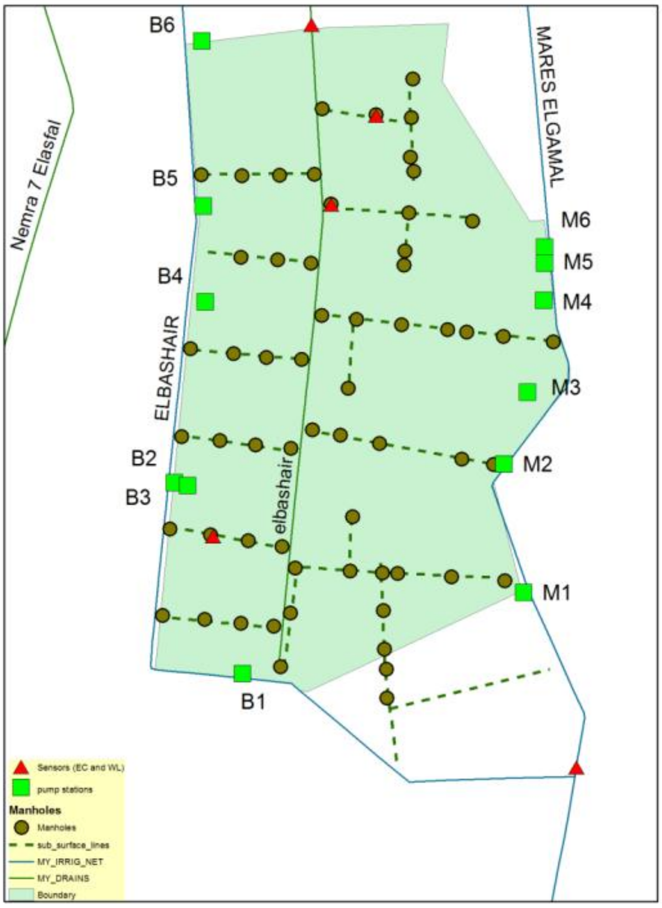
El-Atfy et al. (1999) found seasonal collector discharge salinity between 2200 and 3200 µmhos. Salinity of the drainage water in three collectors monitored by DRI in the Mahmoudia canal area (North-west of Damanhour) was 1380, 1480 and 1630 µmhos (for the month of April 2012), and these values rose the following year, when controlled drainage was applied, to 1900, 1930 and 2630 µmhos respectively (DRI, 2013). In a study area in Bahr Tira canal area (Central North Delta), salinity monitored in a manhole was 4.2 times that of irrigation water (JICA Project, unpublished data).

In an experiment conducted with good quality irrigation water (340 µmhos), Abdalla et al. (1990) found a salinity at the outlet of the main collector varying between 2500 and 7500 µmhos, corresponding to a high ratio (between 10 and 20) explained by the rather high salt content of the clay layer below the drainage lines.

El Guindy and Risseeuw (1987) have conducted research on water management of rice fields in three sites of the Nile Delta, evidencing several key aspects of the plot level drainage. Salt concentration in the soil of a farm without subsurface drainage was reduced by rice cultivation, especially in upper layers, but this could be reversed if supply was insufficient and would allow upward flux of salts from deeper layers through capillary rise. For the same reasons cultivation of field crops like cotton usually resulted in an accumulation of salt, due to insufficient leaching. In Nokrashi farm, irrigation water salinity was close to 1000 µmhos, while salinity of collector discharge was between 2000 and 3000 µmhos. Salinity in the secondary drains varied much more, between 1000 and 10,000 µmhos, and was particularly high at low discharges (when the drain receives water from the lower layers).

To study the variability of drainage water quality at the plot level, an area of 480 feddan (200 ha) was selected (meso-level area) in the command area of the Mares El Gamal canal and was equipped with four sensors to measure water level and EC in the canal, the (secondary) drain, and also at two subsurface drainage manholes, as shown in Figure 2.

Figure 2. Plot level study area (meso-level study area)



In the meso-level study area, which is irrigated with a water of 440 µmhos, the salinity measured in the different manholes of the area varied much more than what was expected (Figure 3). Measurements were made in October 2014 and differences reflect the soil type and the cropping pattern history, but also the status of the sub-surface drainage itself, as deficient or clogged-up pipes constrain drainage and salt leaching: this factor explains the very high values found in some manholes on the eastern side of the drain. It was also observed that some manholes were partly dry and it was not always possible to verify whether the probe was fully immersed. When this was not the case, higher and sometimes absurd values were recorded. In any case, the variability of drainage water salinity in the collectors varied within a ratio between 1 and 10, which is much more than what one would expect in a rather small area. Figure 3 also shows that salinity is lower on the western side of the drain (supplied by the Bashair branch). This survey will be carried out again in summer 2015 in order to confirm this high variability. With the predominance of rice in summer, one can expect to find lower values in general.

Figure 4 shows the results of in situ EC measurements in tertiary and secondary drains of the Masharqa canal command area (in W10 area), the points corresponding to individual pumps abstracting water from these drains (Salama et al., 2016). We can observe that there is more variability than one would expect, due to the difference sources of (fresh) surface drainage water and seepage from the soil or subsurface collectors, which mix together in different proportions at different places.

Figure 3. Water salinity in manholes, Meso-level study area – Winter 2014/2015

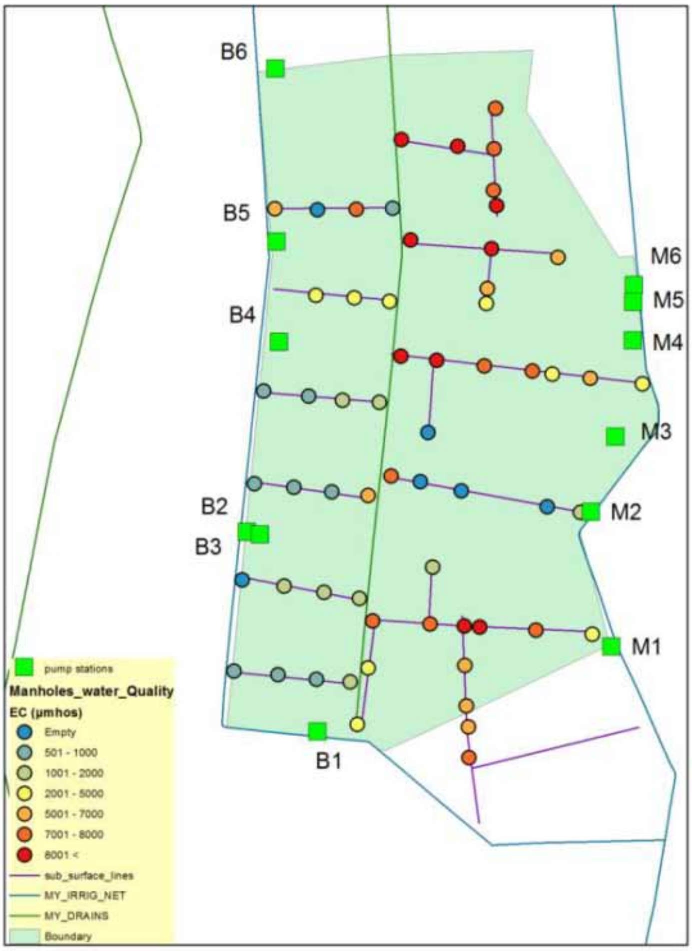
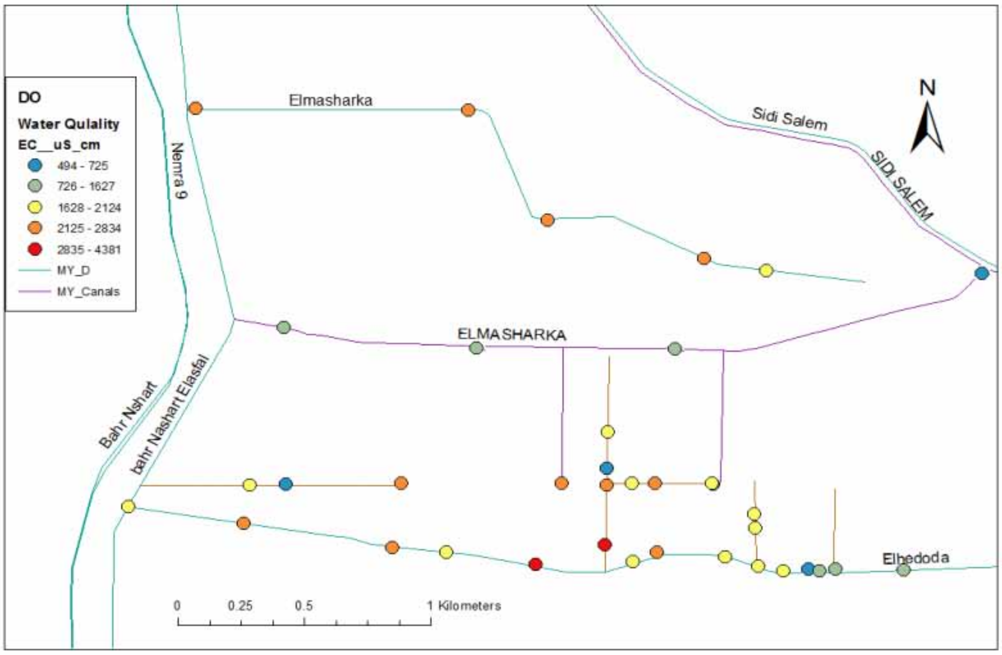


Figure 4. Variability of drainage water salinity in tertiary/secondary drains (Masharqa area) (Salama et al., 2016)



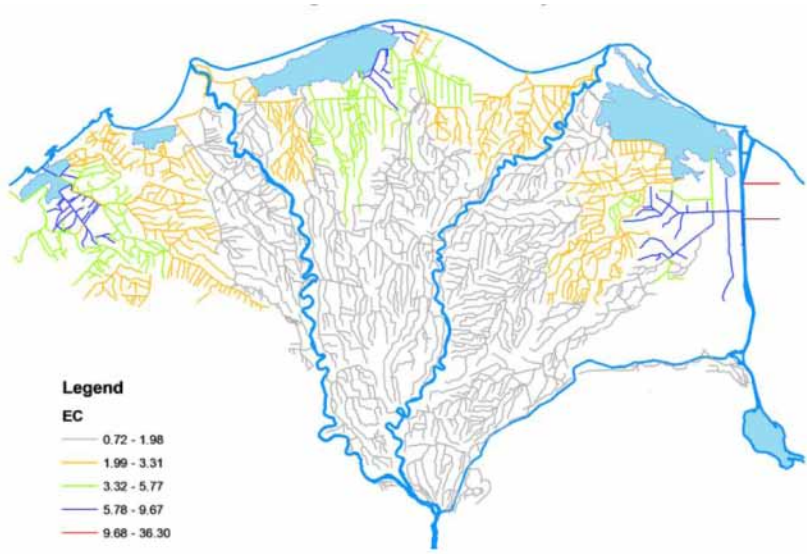
2.2 System level

The distribution of salinity in the drainage system as a whole is not known with accuracy because of the very high number of drains in the Delta. This salinity is mostly known through the monthly measurements made at DRI's 78 monitoring points. These data allow the drawing of macro-level zoning, such as illustrated in Figure 5.

A survey of drains water quality in the Meet Yazid canal command area was undertaken in summer 2014 and repeated in winter 2014/2015. Salinity and DO were measured at each bridge crossing the drains with a portable meter equipped with a GPS, totalling 481 points in summer 2014 and 149 points in winter 2014/2015 (because drainage salinity levels were quite low and rather even in the upstream part of the command area, the winter survey focused on the downstream part).

As will become clear in the next section, drainage water salinity varies substantially with time. Typically, salinity will be lower at the time of irrigation (that is, when the area drained by a particular secondary drain is receiving water and irrigating), because of the larger amount of water that reach the drain and dilutes the salts. We initially planned to visit all secondary drains in the area based on the irrigation schedule, in order to make all measurements during irrigation time, so that results would be consistent and better comparable. However, it proved very difficult to synchronize the field visits with information on rotations. In addition, since most drains receive water from two branch canal command areas (or more), it was very common to find that one of those two canals was 'on' and the other 'off'. As a result, we abandoned the idea of attempting fine-tuning the time of the visits to secondary canals.

Figure 5. Spatial variability of drainage water salinity (Al Sayed, 2011)



As can be seen from the results of the summer 2014 campaign shown in Figure 8 shows the results of the winter 2014/2015 campaign, limited to the downstream area on account of the fact that the upstream area has a rather even and good drainage salinity level. The values of the salinity measured for the winter season show a substantial increase in almost all of the drains, compared with the summer season values. If we limit ourselves to the downstream part area surveyed in winter we find that the average EC of drainage water was 3033 µmhos in winter, against 2333 µmhos in summer, an increase of 33%. That is due to the fact that the amounts of irrigation and drainage water decrease in winter compared with the summer season. Additionally, lower levels in canals and drains promote the drainage of deeper soil layers, which have a higher salt content. This average values, however, mask the fact that drain salinity in winter can reach very high values in the northern part of the delta.

As explained by Ritzema (2009) the drainage water pollution increased since 1990. Great amounts of untreated municipal and waste water from village and cities, in addition to fertilizer, discharge into the drainage system. Abdel-Gawad (2004) stated that only 5% of the population is connected to sewers in rural areas. Abdel-Azim and Allam (2005) also stressed that the topography of the Delta plain, with it is low elevation, and also the limited land resource made the drainage system as a dumping site for all kinds of waters (and solid waste).

Figure 6, the greater part of the upstream command area has a drainage water salinity under 1400 µmhos, with the exception of an area near Matboul, where salinity is between 1400 and 2500 µmhos. This area is a low lying area which actually has to be drained by a large-scale pump station in order to be cultivated. Ancient maps from the beginning of the twentieth century indeed show that this area was swampy at that time. The quite striking conclusion is that the salts accumulated in the soil profile of this area have not been fully leached even several decades after cultivation. But it is likely that the very shallow water table in the area, although drawn down by the drainage system, contributes by capillarity to uplift salts from the lower soil layers, hence the lasting salinity of drainage water.

Medium salinity is also observed on the western part, in the W10 area, which can be explained by the fact that this area is predominantly fed with drainage water from the Nashart drain, with has a higher salinity.

The figure indicates a growing salinity as one moves northward, until the Moheet drain that demarcates the limit of the agricultural area. Interestingly enough, the command area of the Abu Mustafa canal, in the middle of the command area, produces drainage water with a salinity under 2000 µmhos, which contrasts with adjacent areas, where salinity varies between 2000 and 4500 µmhos. Maps from 1913 also indicate that the Abu Mustafa area was the only area north of El-Riyad city that was cultivated at that time, most likely on account of its better soil and higher elevation. The Ghabat and Halafy drains, to the east, exhibit a clear pattern of growing salinity as one moves northward, indicating a south-north gradient of soil salinity compatible with the fact that, historically, flooding and impoundment (and seawater influence) were more pronounced and prolonged towards the sea.

When one goes along a drain northward, there are a few instances where salinity decreases slightly from one point to the next, but without affecting the general trend. This can be due to the measurement being made just downstream of the point where a tertiary drain joins the secondary drain and brings water that happens to be a little less salty than that of the secondary drain.

The fact that these drains generate a drainage water with a salinity approximately 4 times higher than in the upstream part of the canal command area indicates that the leaching of the soil through cultivation (notably rice and fish ponds) in the past 50 years has not been sufficient to eliminate these high levels of salinity. The most likely hypothesis is that deeper groundwater is constantly pushed upwards by the semi-artesian conditions of the aquifers in the northern fringe of the delta. This groundwater not only carries upwards the salts accumulated in the soil profile but is also under the influence of (underground) seawater intrusion. It is also apparent that the rather deep drains of this area intersect the aquifer and are therefore also capturing water and salts from deeper layers. The same is happening with irrigation canals and it is well known by farmers in the area that the water accumulated at the bottom of irrigation canals during the 'off' turn must be flushed at the beginning of the next 'on' turn, because of its very high salt content (during 'off' periods canals actually act as drains).Figure 7 shows the soil map of the area and confirms the relationship between soil type and drainage salinity.

Figure 8 shows the results of the winter 2014/2015 campaign, limited to the downstream area on account of the fact that the upstream area has a rather even and good drainage salinity level. The values of the salinity measured for the winter season show a substantial increase in almost all of the drains, compared with the summer season values. If we limit ourselves to the downstream part area surveyed in winter we find that the average EC of drainage water was 3033 µmhos in winter, against 2333 µmhos in summer, an increase of 33%. That is due to the fact that the amounts of irrigation and drainage water decrease in winter compared with the summer season. Additionally, lower levels in canals and drains promote the drainage of deeper soil layers, which have a higher salt content. This average values, however, mask the fact that drain salinity in winter can reach very high values in the northern part of the delta.

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Figure 6. Water salinity in drains – Summer 2014

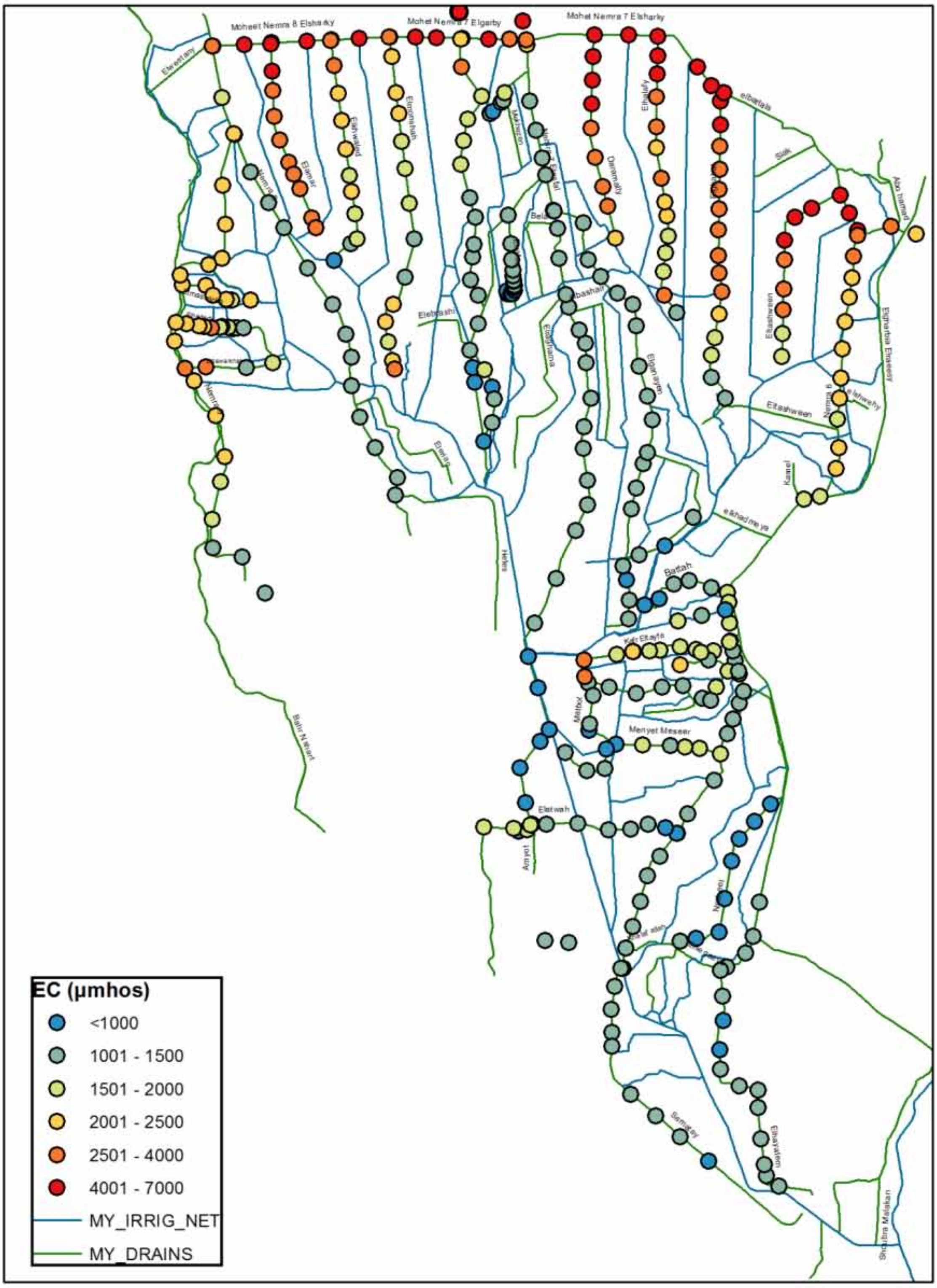


Figure 7. Soil map of Meet Yazid Command area

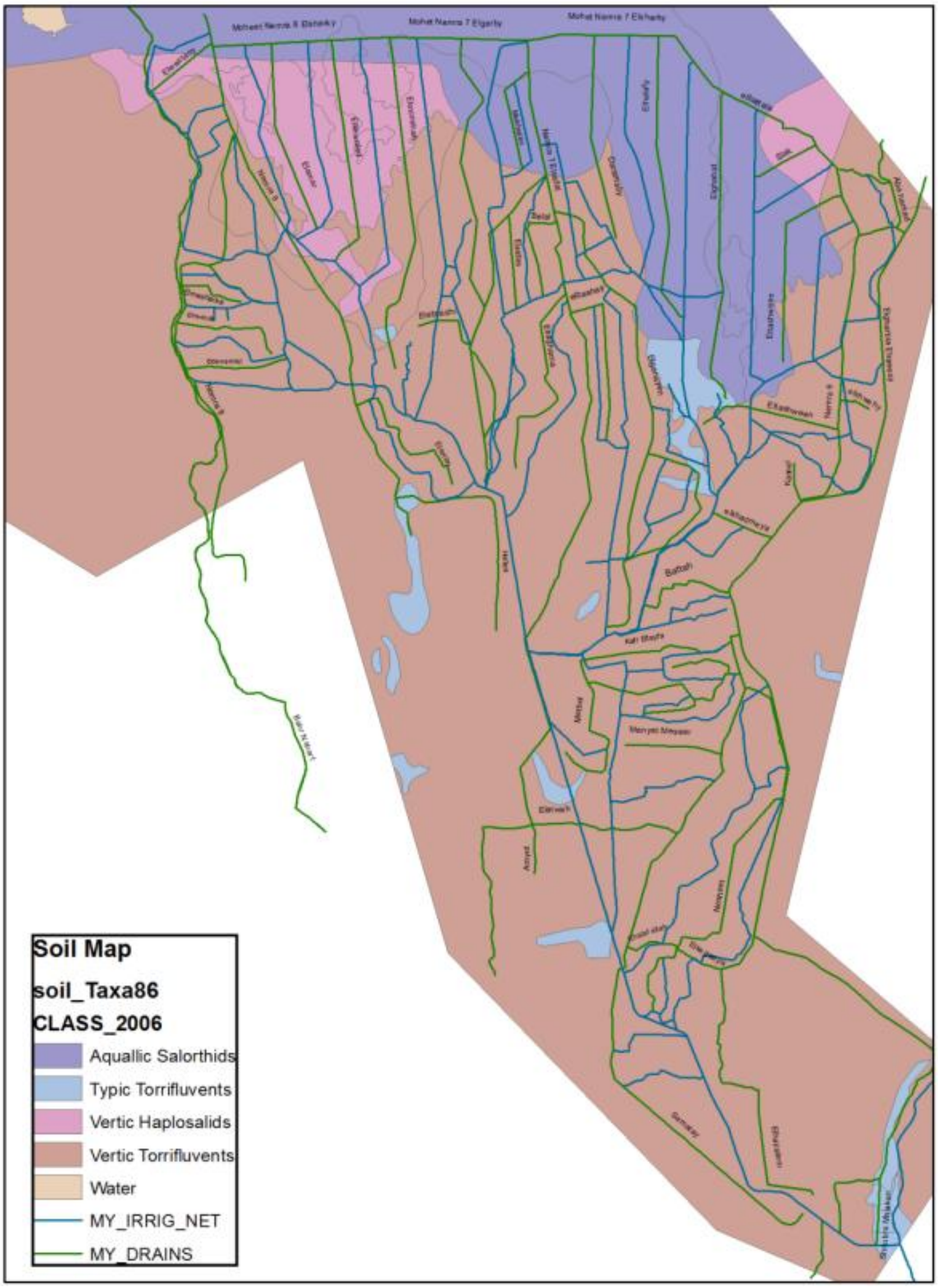
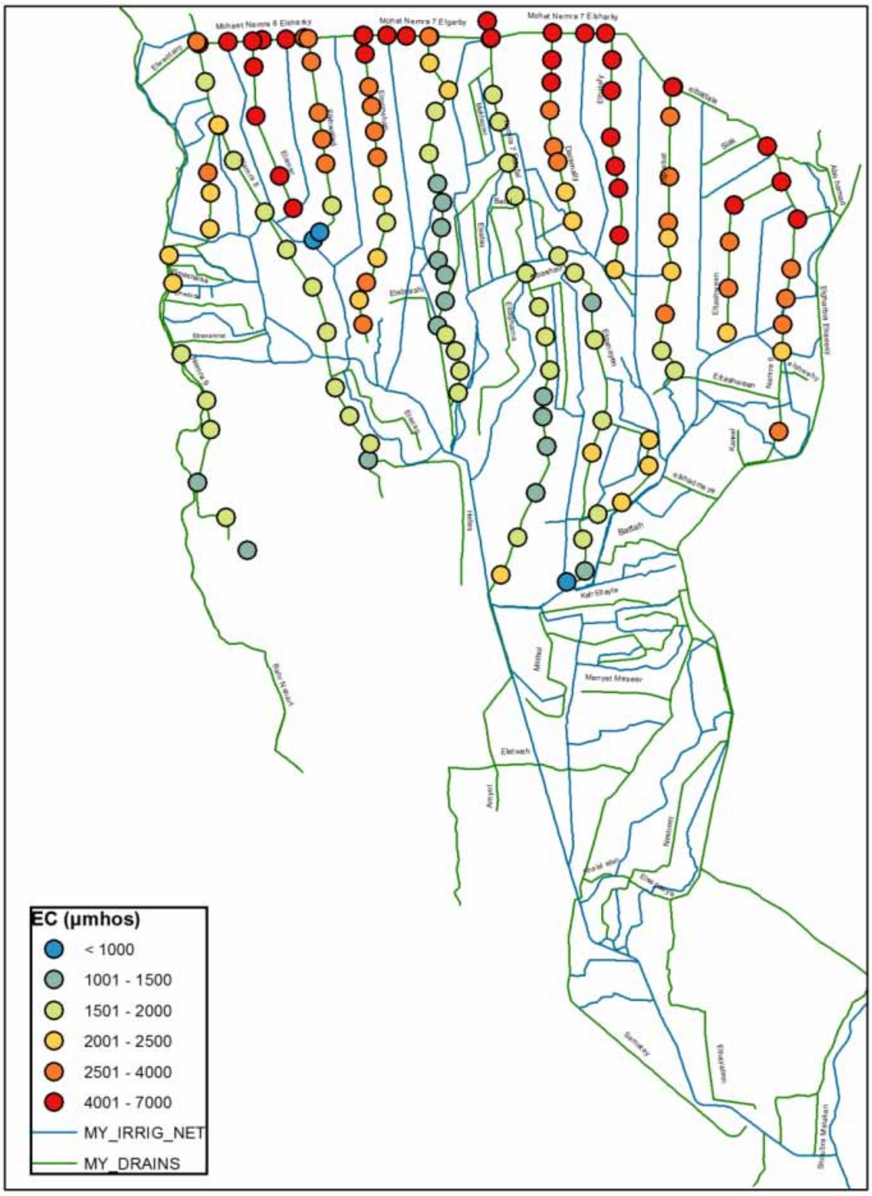


Figure 8. Water salinity in drains – Winter 2014/2015



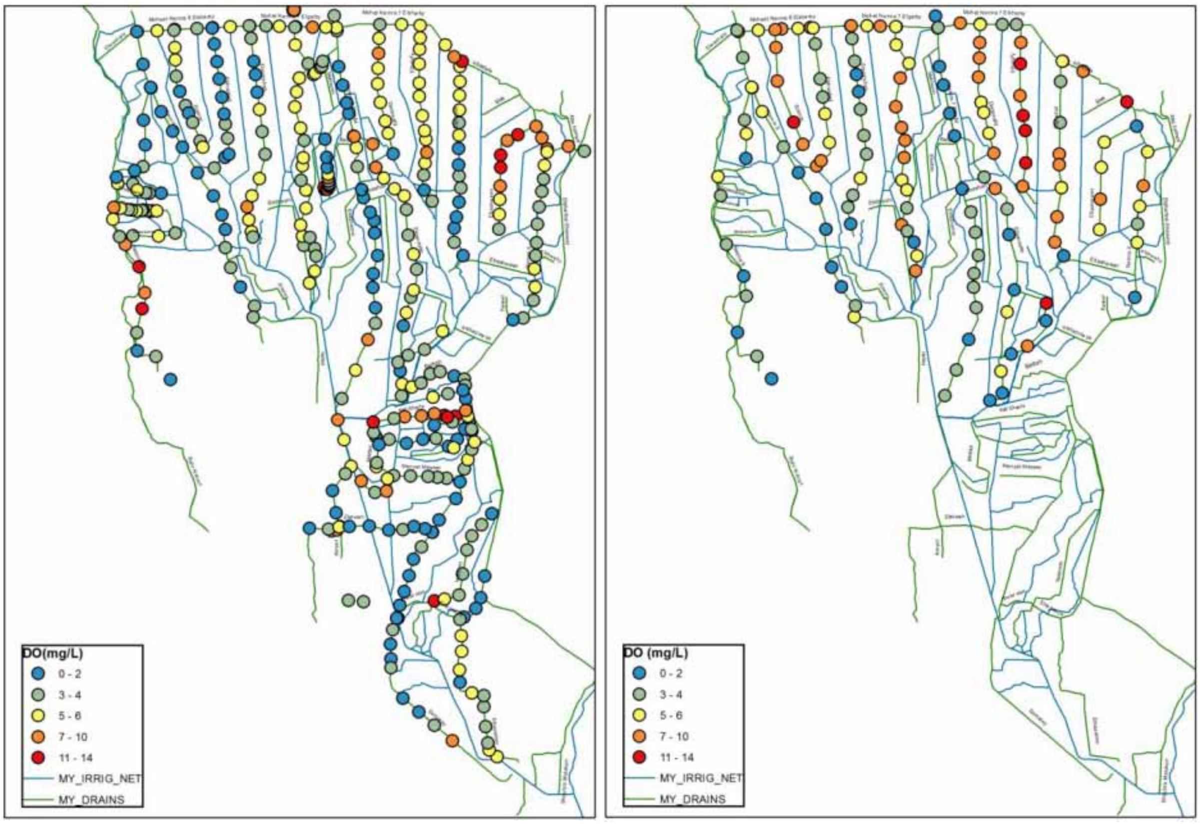
We have measured DO during summer and winter seasons 2014/2015 as shown in Figure 9. The law 48/1982 defined the standard level of drainage water quality parameters (Table 1). The values of DO should not be less than 5 mg/l. Main drains of Meet Yazid area had low DO values (less than 2 mg/l) in both summer and winter seasons (for instance Drain No.8 , Drain No. 7 and Samatay drain), and this shows an increase in organic matter, which comes from sewerage system. Also secondary drains such as El-Khwaled, El-Ammar and El-Atwah had very low values of DO (less than 2mg/l) in the summer season. DO increases in the winter season, indicating better quality of drainage water. This is the opposite of the results found for salinity, which may be explained by the much higher air and water temperature in summer (check).

These results show that DO is most of the time not meeting standards, most especially in main drains that collect and convey sewage water. Secondary drains collecting mostly or only agricultural drainage water display better DO values.

Table 1. Drain water quality parameters standard (Law 48/1982, Article 51, amended in 2013)

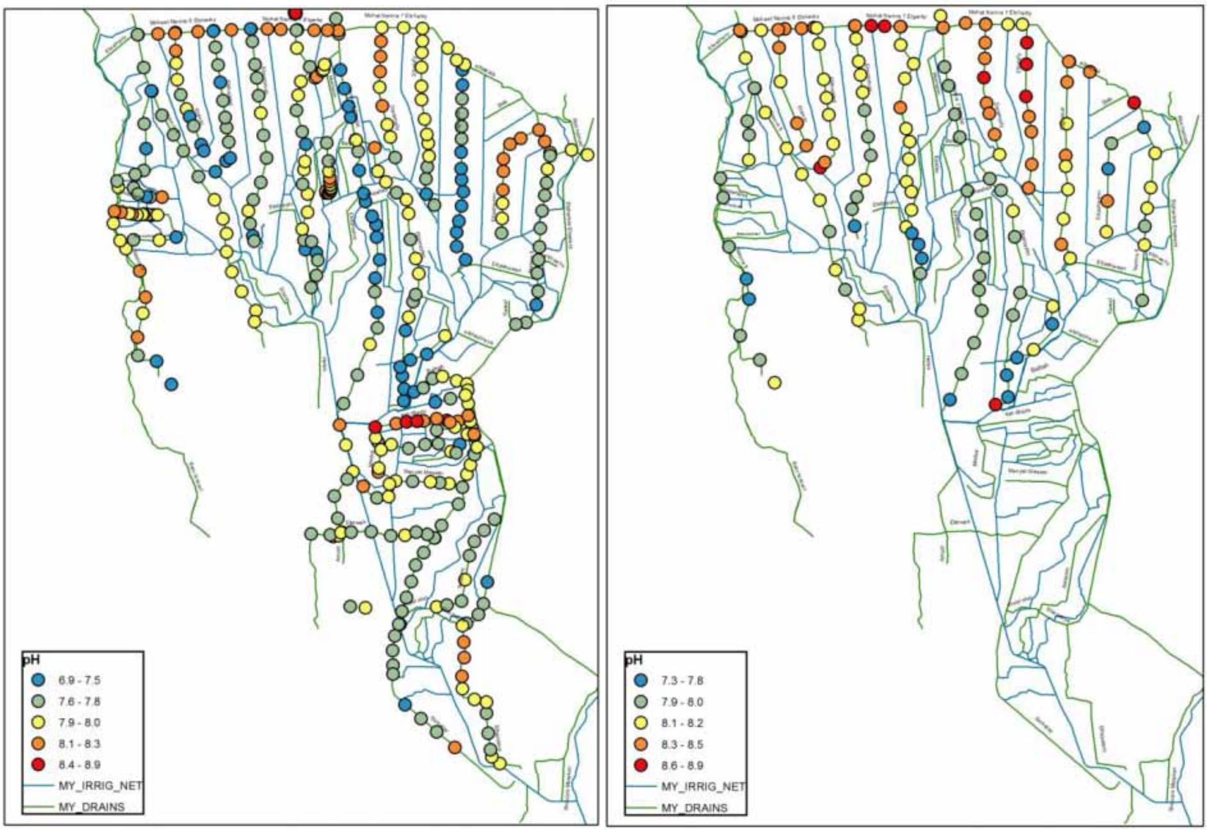
Parameter	Standard
TDS	<1000 mg/l
DO	>5mg/l
pH	6.5-8.5

Figure 9. Water DO in drains – Summer 2014 and winter 2014-2015



The pH of the drainage water was measured for summer and winter seasons as shown in Figure 10. The pH values were at the standard levels specified by the Law 48/1982, which should range from 6 to 9 for drainage water reuse.

Figure 10. PH in the drains, for the summer season 2014 and winter 2014/2015



3 Temporal variability of salinity in drainage water

In order to improve the knowledge of temporal salt dynamics in the northern part of the Nile Delta, we have monitored drainage water salinity in a number of points, from the plot level to the system-level (Moheet drain).

3.1 Plot and mesqa level

As explained earlier, we have identified a rather high variability of drainage water in subsurface collectors. Two manholes of the studied meso-level area have been equipped with sensors measuring the electric conductivity every hour. Measurements were of course discontinued when, a few hours after irrigation, the collectors dried up (the manhole monitored was the second upstream one, on a line of 4). Figure 11 shows this interrupted pattern of measurement and indicates that the salinity in the collector is rather stable, varying between 1200 and 1400 µmhos, three times the salinity of canal irrigation water (440 µmhos). Figure 12 shows results for another manhole (data collected by ARC), placed near the exit of the collector into the secondary drain. Because most of the collectors are submerged during summer this (lower) manhole did not dry up and showed salinity levels varying between 6000 and 10,000 µmhos (during the independent survey of all manholes carried out in October, as explained in above, the salinity in this manhole was recorded as 8200 µmhos).

Figure 11. Water salinity in manhole A, Meso-level study area – Summer 2014

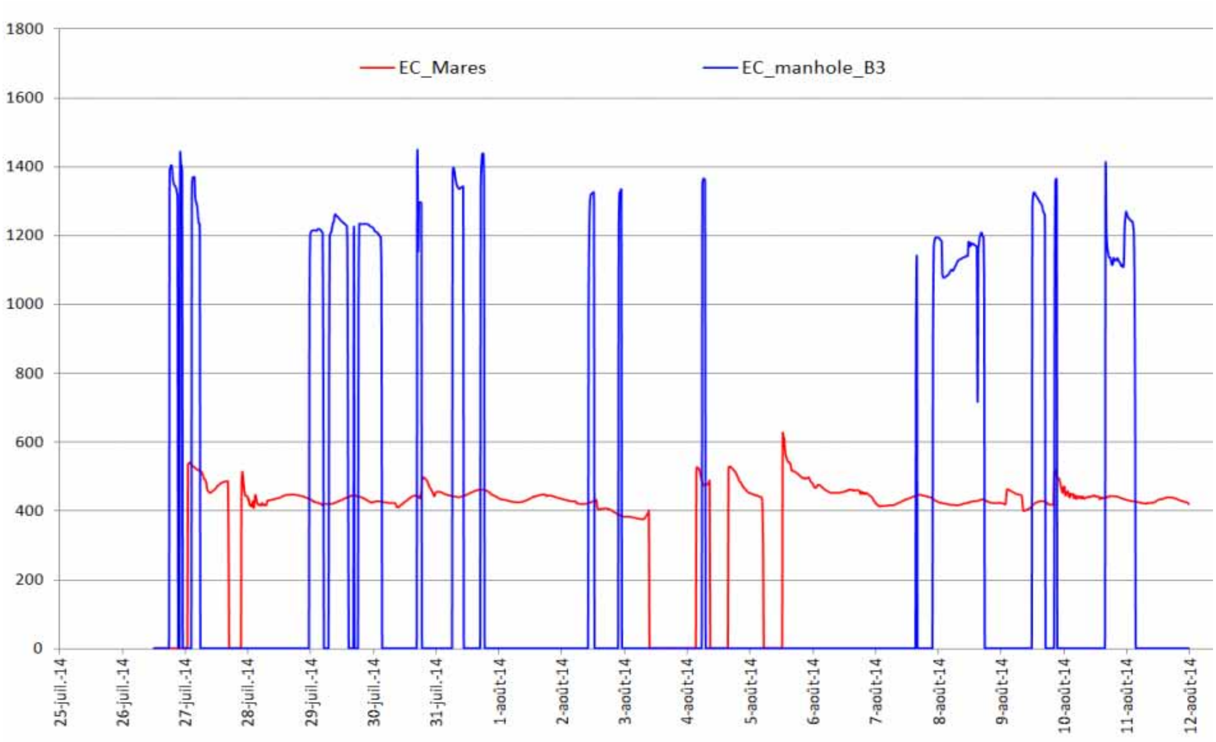
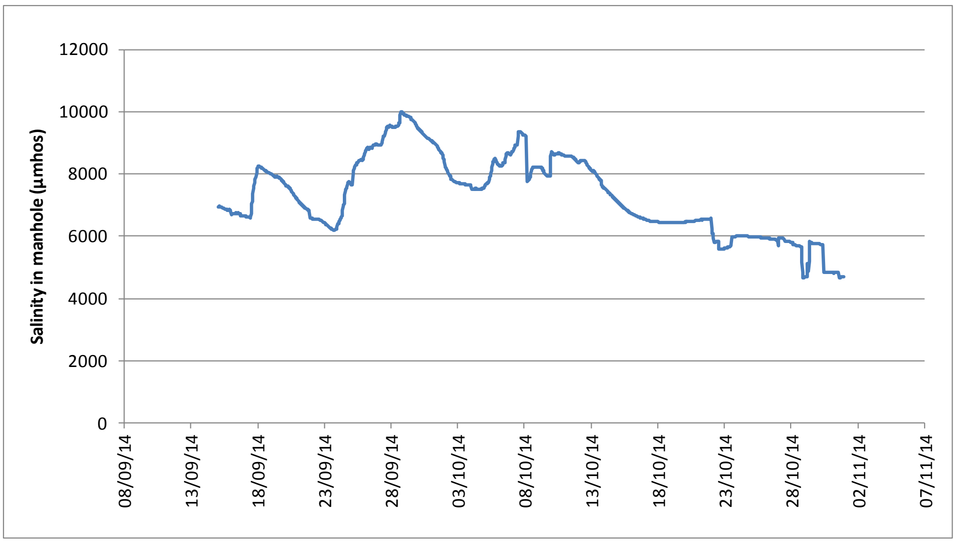


Figure 12. Water salinity in manhole B, Meso-level study area – Summer 2014 (ARC data)



3.2 Secondary drain level

The salinity of drainage water in Bashair drain has been measured every half an hour during one year in two points: one located at one third of the drain length starting from its beginning (bridge marking the outlet of our study area), and the second very close to the point where the drain joins main drain No 7 (not shown on Figure 2).

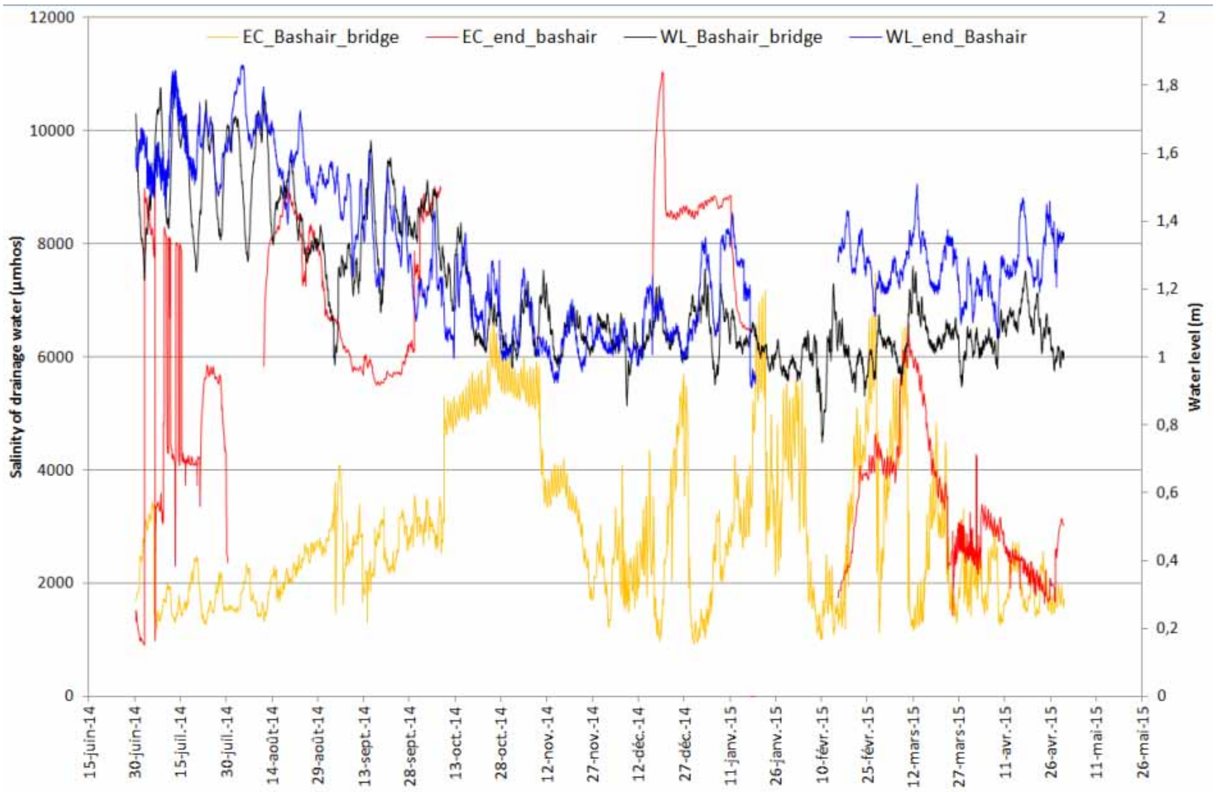
Figure 13 shows the evolution of salinity as well as the water level[1] in these two points. It can be seen that the water level in the drain is 50 cm higher during summer and that this level dovetails the irrigation 'on' and 'off' periods (with an amplitude of 40 cm). As the average water level drops (until the mid-October), the salinity in the drain rises from 1500 to 5500 µmhos[2]. During winter, the salinity under the bridge varies greatly, from 1000 to 6000 µmhos, in response to successive irrigation events. This clearly poses a challenge to the kind of spatial survey presented earlier, in which measurement were not synchronized with irrigation events. This figure shows that not considering the time of measurement is largely acceptable in summer but not in winter, because of the too high variations in salinity.

The quality of the salinity data at the end of Bashair drain has been affected by problems of siltation around the sensor. From the few time-periods when data seems to be acceptable, we can observe that the two values of salinity are similar during winter (water levels in drains are lower and drain 7 has limited influence over levels and salinity within Bashair drain). At the beginning of March the return of intensive irrigation manifests itself by a hike in water levels and a dramatic drop in salinity at the two points, but salinity at the end of the drain remains high, probably due to the influence of the mixing of water with Main Drain 7.

[1] The two levels are not expressed in absolute values (msl), and cannot be compared.

[2] The sudden spike in salinity observed at the beginning of October (when salinity rose by 2000 in half a day) could not be explained; it may reflect a transient problem with the silting of the sensor.

Figure 13. Variation of salinity in a secondary drain (Bashair)



3.3 Drainage at system level

The pumping stations on main drains 7 and 8 dispose of the drainage water in Moheet drain and pump it out to the Burullus Lake. These stations are crucial to maintain the drainage system water level much under that of the plots, in order to ensure the functionality of that system. It can be seen from Figure 14 that the water level (upstream of the pump station) seems to be maintained 60 cm lower during summer than during winter. The downstream water level increases by 1.5 m during winter, which is due to the fact that fish ponds are mostly empty and do not derive water after the pump station (while the opposite occur in summer, where abstraction/consumption by the aquaculture area depletes water levels). Only the value of salinity downstream of the pump station is available (it is likely to be close to that found upstream, as shown by the data for March 2015), but it may also be under the influence of the Burullus Lake when pumping is discontinued for some time.

A zoom on these water levels allows us to better analyse short-term changes. Figure 15 shows that pumping events (indicated by a drop in the upstream water level) result in a concomitant increase in downstream water levels, as expected, except in July when the inflow of drainage water is temporarily higher than the pump capacity. It also shows that during the month of July pump-station operators switch on the pumps once a day, in the morning.

Figure 14. Fluctuation of water levels in salinity upstream and downstream of the pumping station in Main Drain 7

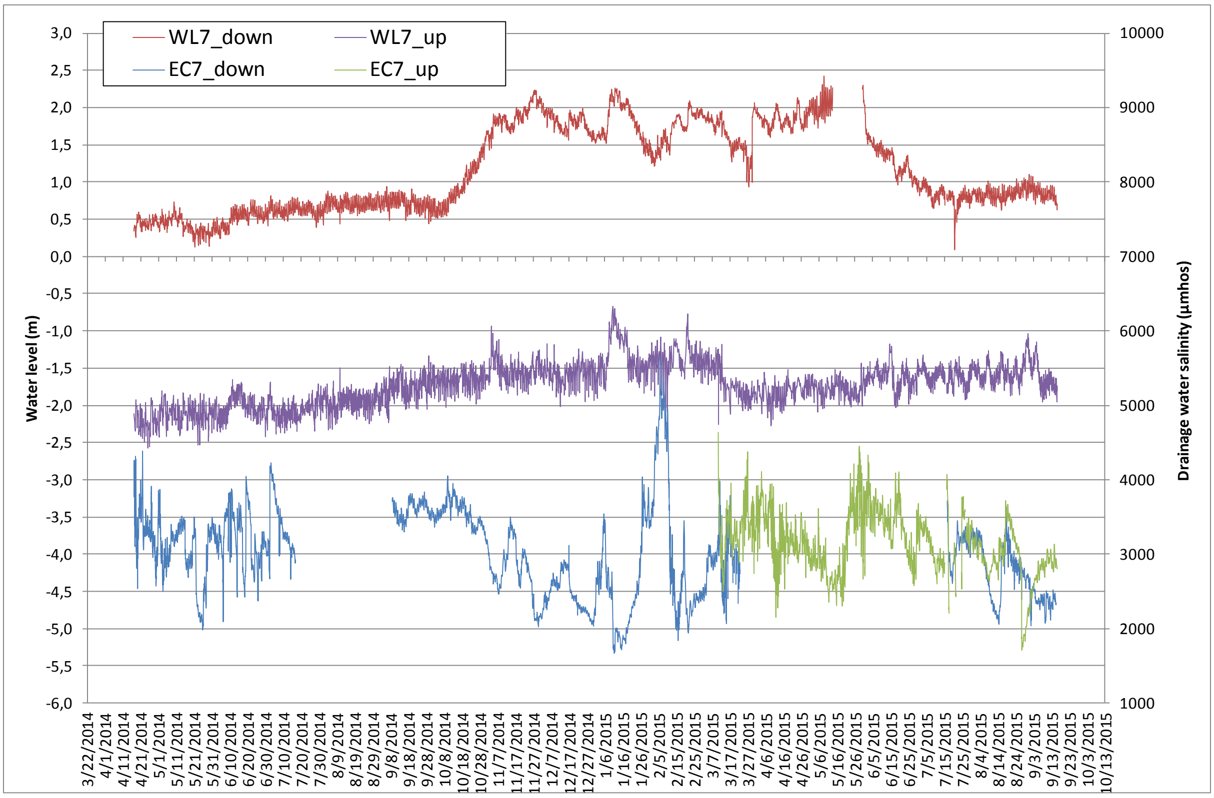
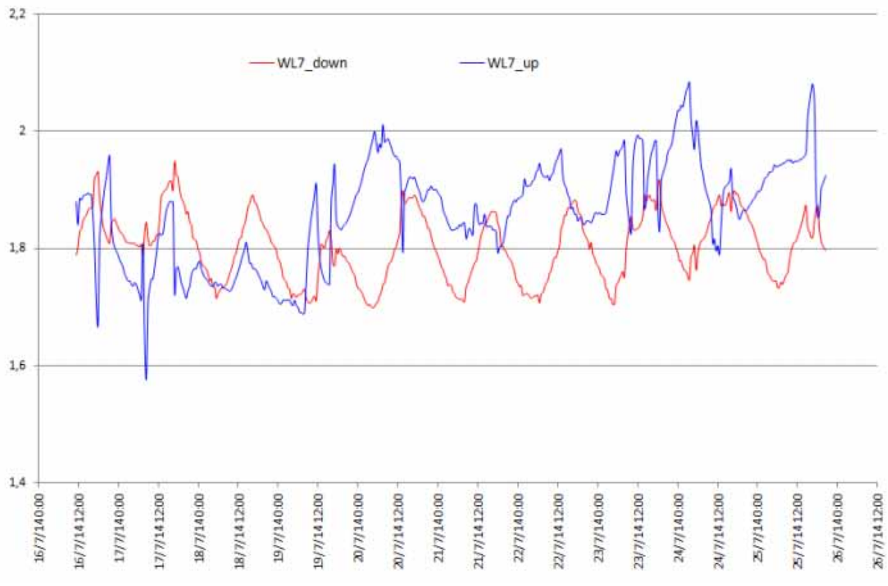
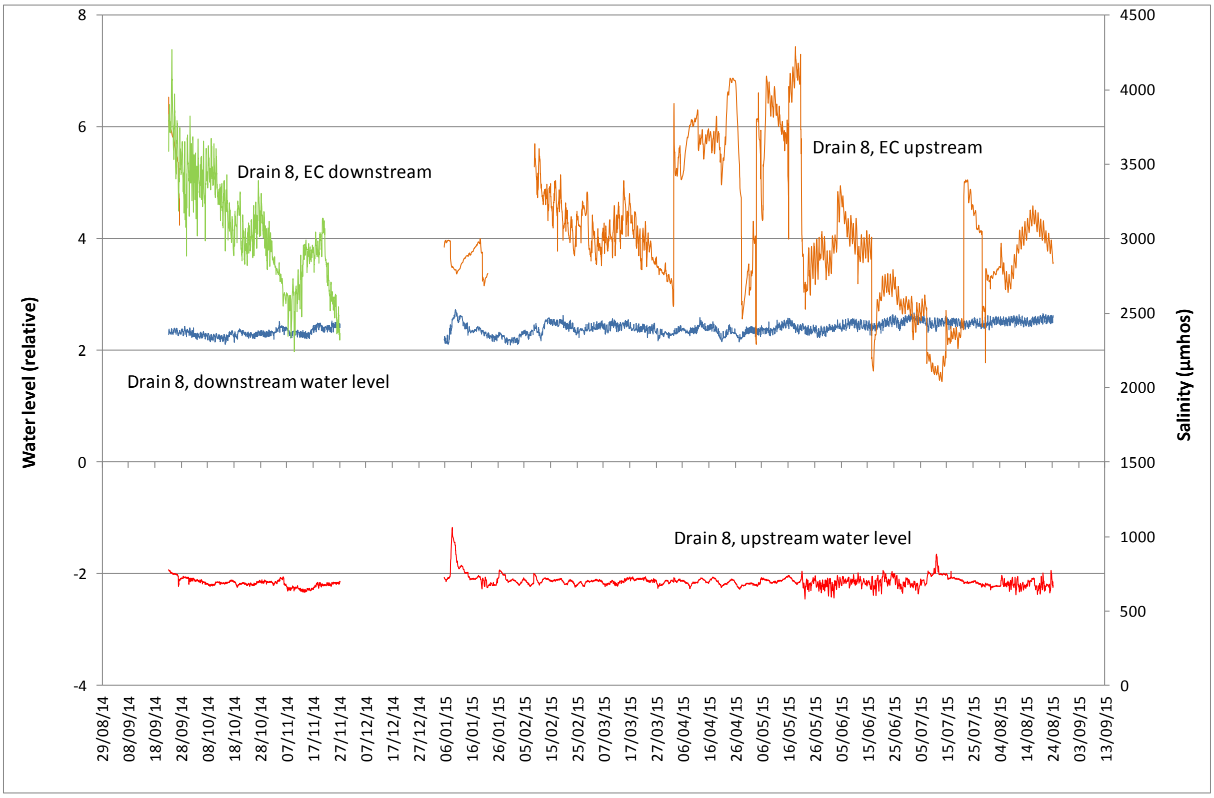


Figure 15. Fluctuation of water levels (m) in salinity upstream and downstream of the pumping station in Main Drain 7 (Zoom on one week; relative levels in order to facilitate comparison)



Similar data have been gathered at the pump station of Main Drain 8 (Figure 16). Water levels are relative, not in absolute values, and appear to be rather stable, with a slight increase in downstream levels during summer. The values of salinity upstream and downstream show some strange sudden drops/hikes probably associated with problems of silt on the membrane or other factors. The range of values is the same as in PS7 (2000-4000 µmhos).

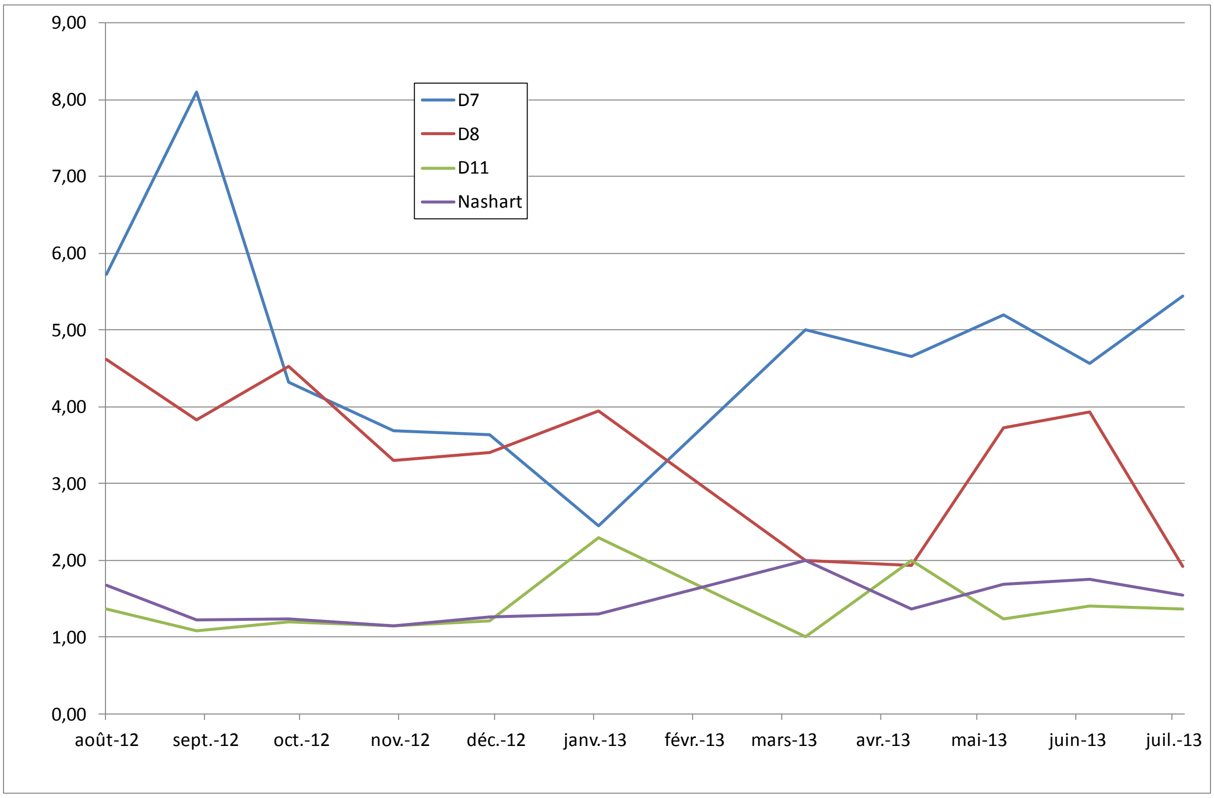
Figure 16. Fluctuation of water levels in salinity upstream and downstream of the pumping station in Main Drain 8



But the average salinity in the downstream reach of the main drains of the central part of the Delta varies substantially, depending on the average salinity of the soils of their respective drainage basins. D7 and D8 appear as the most saline drains in the data provided by DRI (Figure 17), with D11 and Nashart drain displaying salinity levels between 1000 and 2000 µmhos.[3]

[3] The September value for D7 is probably a mistake.

Figure 17. Monthly EC values (µmhos) in 4 drains around Burullus lake (DRI, 2014)



4 Conclusions

This report provided data and an analysis of the spatial and temporal variation of drainage water quality in Meet Yazid command area, at different nested levels. A few conclusions can be drawn:

1. Drainage water in the collectors of the subsurface drainage system varies a lot with both space and time, with a much larger variability for the former: while the ratio between the salinity in the collectors and that of drainage water is typically between 2 and 4, this ratio can be as high as 10 and this variability can be found within an area of a few tens or hundreds hectares.

2. This variability reflects the type of soil, the amount of irrigation water applied (which defines whether salts are being leached or not), but much more significantly; 1) the status of the collector (clogged up or not) and 2) the near-artesian nature of the aquifer in the northern part of the Delta.

3. The salinity in secondary drains also varies a lot and will be higher than in the collectors in times of low discharge (when the drain directly collects salt and water from lower soil layers).

4. The salinity of drainage water at the boundary drain of the central Delta is typically between 2000 and 4000 µmhos, with lower values during summer (when large volumes of relatively good drainage water coming from rice fields across the Delta accumulate there) and higher values in winter (with more salty groundwater being intercepted by drains, and canals during off-periods, in the northern part).

5. It is often stated that high levels of salinity in the drainage system is a consequence of multiple reuse across the Delta. Although reuse does increase concentration of salts it appears that this phenomenon is (largely) secondary to that of the production of salt by capillary rise and interception of groundwater in the northern fringe area, which corresponds to former marshes that have been reclaimed in the past 50 years. This water is loaded with both salts accumulated in the soil profile and carried by upwards seepage of groundwater influenced by seawater.

6. This level of salinity is problematic for crop production, although fortunately drain salinity is lowest during summer, at the very time when water demand and abstraction from drains are highest. However, there are noticeable impacts on yields of farmers using water above 2000 µmhos.

7. Salt concentration in the northern fringe of the Delta will increase if the overall quantity of water supply to the Delta is reduced. This will further impact farmers using drainage water.

8. However, even if actual levels of salinity were doubled, the production of fish that reuse agricultural drainage water around Lake Burullus would not be affected, because of the tolerance of Tilapia and mullets to much higher levels of salinity than the level currently observed.

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