Reuse of Drain Water in Egypt – status, limitations and challenges

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1. Introduction

As the supply of water from the Nile is limited and the population and the economy are growing, water is increasingly becoming a scarce resource in Egypt. As in most other countries, the marginal benefit from water use in Egypt is highest for drinking water and decreases progressively from domestic, industrial to agricultural uses. Not only for economic but also for political reasons municipal water demand will always be of the first priority. It becomes quite clear that a reallocation of water supplies will have to take place. Agriculture and especially the irrigation sector, being at present the main user of water, will have to get along with less and less water and will be forced to use water of marginal quality. The irrigation sector will increasingly be forced to use so-called non-conventional water resources, which include (a) the renewable groundwater aquifer in the Nile valley and Delta; (b) the reuse of agricultural drain water and (c) the reuse of treated sewage water. According to Attia et al. (1997) these water sources cannot be considered independent resources and cannot be added to Egypt's fresh water resources. In fact, use of these sources is a process of recycling previously used Nile fresh water in such a way that improves the overall efficiency of the water distribution system. These kinds of sources should be used and managed with care and the environmental impacts must be evaluated to avoid any deterioration in either water or soil quality (Attia et al., 1997 and Amer, 1999).

The drain water reuse situation in Egypt, especially in the Nile Delta was analysed by the Drainage Reuse Working Group of the EPIQ Water Policy Team[1] at the end of the nineties within the Agricultural Policy Reform Program (APRP). The situation is well documented in APRP Report No.8 "National policy for drainage water reuse" (APRP, 1998) which was prepared by the above mentioned team. The following lecture is based mainly on this report and the observations made by the author over the last three decades.

2. Present status of drain water reuse in Egypt

Egypt has a long tradition of the reuse of drain water. Drain water reuse projects in the Nile Delta started in the 1930s. During that period, an additional pumping station was constructed to support the main Serw pumping station in the Eastern Delta which was constructed in 1928. When it was discovered that the water conveyed by the additional station was of good quality, it was separated from the main station and diverted as pumped drain water into the Damietta Branch of the Nile river. In the early 1970s, Egypt adopted a long term plan to reuse drain water for irrigation on a more sustainable basis. To implement this plan several pump stations were constructed to mix drain water with fresh irrigation water (El-Din El-Quosy, 1989). The officially reused drain water increased from 2.6 billion cubic meters (bcm) to about 4.2 bcm per year in the early 1990s.

In the mean time agricultural drain water reuse has turned out to be an important source of irrigation water supply in Egypt. By now the reuse system is well developed, particularly in the Nile Delta region. However, as the demand for reuse keeps on growing, the expansion or even the continuation of drain water reuse has been threatened by the deteriorating drain water quality due to municipal and industrial wastewater pollution. The Ministry of Water

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[1] EPIQ = Environmental Policy and Institutional Strengthening Indefinite Quantity Contract

Resources and Irrigation (MWRI) faces multidimensional challenges in sustaining the current reuse and promoting more drain water reuse over the next decades. The author assumes that in the long run the active economic reform in Egypt, the improvement of the irrigation system, as well as the changing water allocations among different regions and different water use sectors, will alter the patterns of drain water generation and yield a different perspective in drain water management.

The amount of water that returns to drains from Egypt's irrigated lands is relatively high (about 25 to 30%) according to Attia at al. (1997). This drainage flow comes from three sources: tail end seepage losses from canals; surface runoff from irrigated fields; and deep percolation from irrigated fields (partially required for salt leaching). Various reuse pumping stations in the Nile Valley, Nile Delta and Fayoum convey drain water back into the irrigation canal system and/or the Nile river. Using the water twice or even three times increases the salinity by up to 3,000 mg/l or even more in drains near the lakes bordering the Mediterranean Sea. The mixing of drain water with relatively clean fresh water further diffuses all kinds of constituents, and the negative environmental and health impacts are very much related to the domestic and industrial load.

The agricultural drain water of the southern part of Egypt returns directly to the Nile River where it is mixed automatically with the Nile fresh water to be used for purposes downstream. In addition, it is estimated that some 0.65 bcm/year of drainage water is pumped to El-Ibrahimia and Bahr Yousef canals for future reuse. Moreover, drainage pumping stations lift about 0.60 bcm/year of drainage from Giza’s drains to Rosetta Branch just downstream of the delta barrages for further downstream reuse.

Water management in the Fayoum depression, located 90 km south of Cairo and 30 km west of the river Nile, is unique. The area is supplied with irrigation water through Bahr Yousef canal only, and the drain water does not flow back to the river Nile, rather it flows to Lake Qarun and the Wadi El-Rayan depression where it evaporates. This situation implies that any excessive application of irrigation water is immediately reflected in a rise in the water level of Lake Qarun. The areas in the upstream reaches of the canals receive water in excess, whereas the tail end sections suffer from shortages. As a consequence, the upstream parts of the area generate large quantities of drain water, whereas further downstream arable land either lays fallow in summer or is under-irrigated. This shortage in an adequate water supply results in low agricultural production levels in these tail-end areas. Under this circumstances the reuse of drain water was considered a solution that would secure a sufficient water supply in the tail end areas. Furthermore, it was assumed that such reuse would indirectly improve the uniformity of water distribution because the excess water drained from upstream command areas would be returned to the tail ends. The Ministry of Water Resources and Irrigation (MWRI) expected that not only the tail end areas would benefit from the reuse of drain water, but also that desert lands on the fringes of the Fayoum depression could be reclaimed with this water. Respective land development measures have been in the process of implementation for some time.

According to Ramadan et al. (1989) the reuse of drainage water in the Fayoum depression has its limitations. The most important ones are:

- to maintain Lake Qarun's average water level at –43.80 m MSL, an annual inflow of $426x10^6$ m^3 is required;
- to maintain a favourable salt balance in the first lake of Wadi Rayan, an annual inflow of $120x10^6$ m^3 is required;

- in summer, the required water application rate is 155% of the annual average, while the drainage flow is only 90% of the annual average flow;
- in winter, the situation is the reverse: requirement is 61% and drainage flow 105%;
- in the lower reaches of the drains, the salinity of the waters is high and therefore this water can only be a minor component in a mixture of drainage and fresh irrigation water.

Meanwhile approximately 0.235 bcm/year of drainage water is reused in Fayoum while about 0.65 bcm/year of Fayoum drainage is disposed of in Lake Qarun and Wadi El-Rayan.

Drain water in the Delta region is disposed of in the Mediterranean sea and the northern lakes via drainage pump stations and drainage canals. The total amount of drain water that was pumped to the sea was estimated to be 12.41 bcm in 1995/96. This has been decreased thereafter and will continue to be decreased in the future according to the development of the reuse of agricultural drain water. The total amount of agricultural drain water reuse in the Delta region was estimated to be 4.27 bcm in 1995/96 in addition to about 0.3 bcm lifted to the Rosetta branch of the Nile River from the West Delta drains. This constitutes the official reuse carried out by the pumping stations of the Ministry of Water Resources and Irrigation (MWRI).

Farmers also reuse water themselves, unofficially. The Egyptian farmer, upon feeling that fresh water supply is becoming short, especially during periods of peak demand, directly moves his portable pump to the nearest drainage canal to irrigate his field. This is not done automatically without knowing its consequences. Farmers have some clue about drainage water salinity, they know how tolerant their crops are to this water, they use the appropriate management procedure of keeping the soil profile in the root zone always in a wet condition and finally they leach accumulated salts during winter when supply is plentiful and demand is minimal. Crop rotation plays, according to El Din El Quosy (1992), an important role in this respect. If a crop which consumes little water is grown in winter (like wheat) it is usually followed by rice which leaches any accumulated salts. Or if a deep rooted crop is grown in summer (like cotton) it is usually followed by berseem which consumes much water. This succession system of cropping besides the installation of subsurface drainage, appears to be one of the main reasons for there being a state of equilibrium in most of the delta lands and explains the constant and up to now rather low salinization of these lands. Unofficial drainage water reuse was estimated in 1995/96 to be around 2.8 bcm. However, the actual unofficial reuse may be much larger - in the order of 4 to 6 bcm/year for the Nile Delta alone.

The water balance of 99/2000 for Egypt shows an official reuse of 5.96 bcm and an unofficial reuse and direct return in the order of 1.881 bcm. The reason for the difference to the data mentioned above is unclear. It may be due in part to the fact that rainfall in the Nile basin was plentiful over the last few years.

Since the large-scale installation of field sub-surface tile drainage began in the late 1960s, a well-designed and well-constructed agricultural drainage system has been operating in the Nile Valley and Delta. A number of main drains and branch or lower-order drains collect and transport drainage flows from the south to the north in the Nile Valley and especially on the Delta plain. More than forty lifting pump stations and twenty-two main reuse mixing stations are in operation in the 22 drain catchments of the Delta region. Each year, the drainage system removes more than 30 million tons of salts from the Nile irrigation system. An annual amount of 6 bcm of drain water is made available through the MWRI's official drain water reuse programme.

There is also an established monitoring network, which provides daily measurements of drainage flow and bi-weekly salinity and other chemical components at 90 locations in the drainage system. Since the mid 1980s, the accuracy of field measurements and laboratory work have steadily improved and monitoring results have been routinely published in annual data books. Recently, the monitoring programme was extended to measure more water quality parameters at environmentally sensitive locations (APRP, 1998).

The magnitude of the Delta region's drainage system operation is indicated by the volumes of the organized drain water reuse (official reuse) and the outflow drain water from the system. Table 1 and 2 give the annual drainage outflows to the Mediterranean Sea, the reused drain waters, and the corresponding salinity levels during the 12 year period of 1984-1996 (Drainage Task Force Committee, 1997).

Table 1. Annual drain water reuse in the Nile Delta 1984-1996

Year	East Delta		Middle Delta		West Delta		Whole Delta	
	Quantity (mcm)	Salinity (dS/m)	Quantity (mcm)	Salinity (dS/m)	Quantity (mcm)	Salinity (dS/m)	Quantity (mcm)	Salinity (dS/m)
1984/85	1301	1.28	763	1.29	814	1.53	2878	1.35
1985/86	1263	1.30	748	1.21	788	1.51	2799	1.34
1986/87	1420	1.34	766	1.24	807	1.53	2993	1.37
1987/88	1381	1.44	693	1.41	629	1.90	2703	1.54
1988/89	1400	1.53	704	1.46	555	1.62	2659	1.53
1989/90	1504	1.57	1506	2.24	626	1.49	3635	1.83
1990/91	1585	1.59	1999	1.70	639	1.57	4223	1.64
1991/92	1445	1.46	2058	1.80	617	1.46	4120	1.63
1992/93	1460	1.41	1841	1.69	561	1.28	3862	1.52
1993/94	1120	1.58	1691	1.76	619	1.12	3430	1.59
1994/95	1390	1.64	1843	1.86	685	1.24	3917	1.67
1995/96	1746	1.89	1815	1.79	706	1.20	4266	1.73
Avg.								
84/90	1376	1.41	863	1.48	703	1.60	2944	1.47
90/96	1458	1.60	1874	1.77	638	1.31	3970	1.63

Source: MPWWR Drainage Task Force Committee, 1997

The average annual drain water which is reused has increased from 3 bcm for the period 1984-1990 to 4 bcm for 1991-1996 in the Delta region. The official reuse levels in the East and West Delta regions have almost remained constant over the past decade. It took about a decade to obtain 1 bcm official reuse expansion in the Delta, mainly from increased reuse in the Middle Delta region in the 1990s (APRP, 1998).

The volume of reuse and outflow were both relatively low in the late 1980s due to the drought in the Nile River basin during that period. The sudden reduction in reuse of 0.5 bcm in 1993-94 was due to the shut-down of several reuse mixing stations due to unacceptable drain water quality conditions (see 4.3). Some of those stations are still closed, resulting in the stagnant overall reuse level in the Nile Delta up to 1995/96. Thereafter it increased to the present level of 6 bcm/year.

The data of table 1 and 2 demonstrate an upward trend of outflow and reused drain water salinity. The outflow salinity has risen at a faster pace from 2,378 ppm in 1984 to 2,823 ppm in 1996 (or 3.72 dS/m to 4.41 dS/m), while the salinity level in reused drain water has increased from 866 ppm in 1984 to 1,109 ppm in 1996 (or 1.35 dS/m to 1.73 dS/m). The increase of outflow salinity level in the last decade is a consequence of increased reuse, while the relatively low salinity of reused drain water indicates to some degree, according to APRP (1998), a good potential for further increasing the use of drain water in the Delta. But it is not certain that this is practical.

Table 2. Annual drain water outflow to the sea, 1984-1996

Year	East Delta		Middle Delta		West Delta		Whole Delta	
	Quantity (mcm)	Salinity (dS/m)	Quantity (mcm)	Salinity (dS/m)	Quantity (mcm)	Salinity (dS/m)	Quantity (mcm)	Salinity (dS/m)
1984/85	4391	2.12	5013	3.35	4321	5.76	13726	3.72
1985/86	4219	2.35	4883	3.71	4339	5.02	13442	3.71
1986/87	3815	2.43	4900	3.72	3955	4.72	12670	3.64
1987/88	3514	2.64	4291	3.96	4030	5.65	11835	4.14
1988/89	3181	2.76	4142	3.88	4168	6.00	11491	4.34
1989/90	3651	2.85	4159	3.99	4573	5.75	12383	4.30
1990/91	3726	2.72	3674	4.06	5116	6.24	12515	4.55
1991/92	3795	2.40	4092	4.22	5118	5.46	13005	4.18
1992/93	4094	2.45	3740	4.09	4312	5.97	12146	4.20
1993/94	4219	2.71	3569	4.32	4613	5.50	12400	4.21
1994/95	4256	2.98	3966	4.18	4252	5.68	12474	4.28
1995/96	3790	3.20	4127	4.16	4469	5.67	12386	4.41
Avg.								
84/90	3795	2.53	4565	3.77	4231	5.48	12591	3.97
90/96	3980	2.74	3861	4.17	4646	5.75	12488	4.30

Source: MPWWR Drainage Task Force Committee, 1997.

As shown in table 2, the average salinity level in drain water outflows from the East Delta was only 2.53 dS/m (1,619 ppm) and 2.74 dS/m (1,754 ppm) for 6-year periods of 1984-1990 and 1990-1996 respectively, much lower than those in the two other Delta regions, i.e. 3.77-4.17 dS/m in the Middle Delta and 5.48-5.75 dS/m in the West Delta regions. The significant differences are most likely caused by the saline groundwater upward flux in the northern part of the Middle Delta and the salts washed from the elevated Nubaria newlands in the West Delta. From viewpoint of the salt concentration, the East Delta has a larger reuse potential than the other two regions for future reuse development.

The Government of Egypt has used drain water as a main supply source for horizontal land expansion (Drainage Task Force Committee, 1997). Three major drainage reuse expansion projects have been planned since the late 1980s, namely:

- El-Salam Canal Project – to divert 2 bcm drain water of the Bahr Hadus and Lower Serw drain basins for reclaiming 185,000 feddans[2] irrigation in west Suez and 400,000 feddans in Sinai,

[2] 1 feddan = 0.42 ha

- El-Omoom Drainage Project – to reuse 1 bcm drain water of the Umoum drain basin for irrigating 500,000 feddans in Nubaria, and

- Kalapsho Project – to capture 1 bcm drain water of the Drain No. 1 and Drain No. 2 for irrigating 55,000 feddans of new land in Kalapsho.

This is, in total, a 4 bcm reuse expansion plan. Whether this will be achievable depends on the success of control measures to eliminate municipal and industrial wastewater pollution from agricultural drains, unofficial reuse management, intermediate reuse development, extension of the irrigation improvement project (IIP), and several other factors which affect the generation of drain water in the Delta, as will be discussed in detail in later chapters.

3. Government policy on drain water reuse

Egypt almost entirely depends on the fixed 55.5 bcm/year of the Nile water released from the High Aswan Dam (HAD). Over the first two decades after the construction of HAD, the basic policy of the MWRI has been to allow demands to increase on a more or less laissez-fair basis, resulting in a dramatic increase in both the intensity of irrigation and the extent of the irrigated areas. However, with the nation's growing population, industrialisation and urbanisation, this policy is no longer sufficient, and conservation of water, mainly by recycling agricultural drain water, has become the main focus of Egypt's water management (APRP, 1998).

Egypt's water conservation has progressed in several stages. In the late 1980s, during the Nile drought period, MWRI started giving priority to irrigation and municipalities and industry over that given to hydropower generation for the water released from the HAD, which effectively reduced the effect of drought on agricultural production. Later in 1995-96, MWRI implemented a policy for a shorter winter closure period by staggering closure by regions. This has resulted in 2 bcm of Nile water being saved each year.

At least since the mid 1970s the Egyptian water policy considered agricultural drain water reuse as a major part of the available water resources in order to meet the increasing agricultural water demands. The 1975 water policy estimated that the amount of agricultural drainage water that could be reused in the Delta region would be 7.6 bcm/year by 2000. This policy was also the only water policy that considered the return flows into the Nile from the upper and middle Egypt drains. It was estimated that this amount of water would be about 4.4 bcm/year by the year 2000.

The 1980 water policy estimated that the available agricultural drain water for reuse in the Delta region would be 10.0 bcm/year by 2000, while in the 1986 and 1990 water policies this amount was decreased to 7.0 bcm/year. Egyptian policy makers are aware that this amount is constrained by the fact that part of the drainage water must go to the sea to maintain the salt balance of the Delta region. It is, as shown below, also constrained by the quality of agricultural drain water.

MWRI has intensified the reuse of drain water since the 1990s. As mentioned above, drain water reuse was raised by 1 bcm in the Nile Delta region during 1991-96, reaching 6 bcm in 2000 and MWRI plans to expand further the reuse over the next decades.

Since the mid 1990s, however, many reuse mixing pump stations in the Delta have been under increasing pressure because of the deterioration in water quality by municipal and industrial pollution discharge, and some of them, were forced to stop operating (see 4.3). Drain water reuse in the Delta is creating a dilemma: on one hand, increased irrigation continues to demand that more drain water to be reused, especially, after the Salaam canal became operational; on the other hand, the official reuse system in the Delta seems to be stagnant and difficult to expand. "Unofficial" drainage reuse by farmers has been increasing in many drain basins. The area used for "illegal" rice cultivation has reached twice the officially sanctioned rice cultivation area, mainly because of unofficial drain water reuse.

The MWRI considers drain water as a main source of water to meet part of the irrigation demands. It is aware that the reuse of drain water increases the overall efficiency of the water system and also that it must be regulated to prevent any future environmental impacts due to such use. At the end of the 1990s, Egypt's future strategies for drainage water reuse included the following measures (Attia et al., 1997 and Amer, 1999):

- "Increasing the amount of drainage water reuse from about 4.5 bcm/year to 7.0 bcm/year by 2000 and to 9 bcm/year by 2017 with an average salinity of 1,170 ppm. This could be achieved through implementing several projects to expand the reuse capacity in different areas. Main future projects include the El-Salam canal, the El-Omoom drain, and the El-Batts drain projects.
- Improve the quality of drainage water especially in the main drains that are included in the ministry's plan of drainage water reuse. It is recommended to implement a series of small treatment plants at secondary drains or at the locations of the reuse pump stations.
- Separate sewage and industrial wastewater collection systems from the drainage system.
- About 50% of the total generated drainage water in the Delta should be drained to the sea to prevent seawater intrusion, and to maintain the salt balance of the system.
- Implement an integrated information system for drain water quality monitoring by updating and upgrading the existing data collection network.
- Continuous monitor and evaluate the environmental impacts due to the implemented drainage water reuse policy especially those on soil characteristics, cultivated crops, and health conditions."

Although over the next decades, drain water reuse may remain the first supply augmentation measure, policy and decision makers in Egypt have to be aware that in the long term, the potential for expanding drain water reuse, or even continuing the current level of reuse, will be limited. The reasons will be discussed later in this paper.

The MWRI, in aiming to increase the overall efficiency of the irrigation system in the Nile Delta region, implements a drain water reuse strategy and an irrigation improvement strategy. According to Abu Zeid (1997), the contradiction between the two strategies clearly emphasises the importance of an integrated water resource planning and management approach in water policy formulation. In terms of increasing the overall system efficiency, drain water reuse gives much more immediate returns and at much less cost than the irrigation improvement project. This justifies the adoption of the drain water reuse strategy in the short term. According to Abu Zeid (1997), it is expected that the two strategies may eventually reach a socio-economic and environmental balancing point rather than sacrificing one for the other in the 21st century.

4. Factors effecting drain water reuse

4.1 Reuse potential

One of the key questions with respect to future drain water reuse in Egypt is: how much more drain water can be captured, and from which locations? The problems connected to these questions have been analysed by the Drainage Reuse Working Group of the EPIQ Water Policy Team, working under the auspices of the Agricultural Policy Reform Programme (APRP, 1998).

According to the 1993-94 drainage monitoring data (Drainage Research Institute, 1995), the average salinity of the reused drain water in the Delta region was 1,076 ppm. For increased reuse, drain water pumping will need to be extended to drains containing higher salinity concentrations. Salinity levels of 1,500 -–3,000 ppm were used as reuse targets in an analysis of the APRP-Water Policy Reform Activity (APRP, 1998) to check the possible additional reuse pumping at each monitoring location. If one particular location's salinity measurement in 1993-94 was lower than the target salinity level, the drainage outflow from the location (defined as the "to sea" outflow in the Drainage Research Institute's data book) was assumed to be recaptured in full and represent that location's reuse pumping potential given that reuse target. In this analysis, locations on every main drain in each Delta region were surveyed.

The results of the above mentioned analysis show that the Delta region's annual reuse pumping potential starts at 8.1 bcm with the 1,500 ppm salinity target, it continues to increase with higher reuse targets, and reaches 13.3 bcm with the 3,000 ppm target. The 13.3 bcm reuse pumping level is near to the sum of the 1993-94 drainage outflow (12.5 bcm) and reuse (3.4 bcm). It is obvious that this would not be possible to implement. Ignoring all other factors affecting drainage water reuse, the maximum reuse pumping potential for the whole Nile Delta is considered to be in the range of 8 to 12 bcm. One of the important limitations is salinity.

Due to salt leaching requirements, the effective value of one cubic meter of drain water reuse pumping is, in fact, less than one cubic meter, and depends upon the salinity level of the reused drain water. This is because the leaching requirement increases with the increase of the irrigation water salinity.

For sandy loam to clay loam soils in low rainfall climates the leaching fraction (in %) under surface irrigation can be calculated as $EC_w/(5*EC_e-EC_w)$, where EC_w is the electrical conductivity of the irrigation water (dS/m) and EC_e is the electrical conductivity of the soil saturation extract (dS/m) for a given crop under a specific degree of tolerance in yield reduction (Ayer, R.S. and D.W. Westcot, 1976). The Nile water exhibits an average electrical conductivity of 1.0 dS/m per 640 ppm. A tolerable crop yield reduction of 10% or less was chosen for the leaching fraction calculations. The respective calculations show that leaching requirements increase from 0.6 bcm to 2.0 bcm with the expansion of drainage reuse from 1,500 ppm to 3,000 ppm. The higher the reuse salinity target is, the higher will be the leaching requirements. Irrespective of how the reuse is practised, i.e. mixed with freshwater or used directly, the effective value of the reuse will always be discounted to some extent by the leaching fraction.

4.2 Sustainability of the Mediterranean estuary ecosystem

Drainage outflow is an important component of the Mediterranean estuary ecosystem. After the construction of the High Aswan Dam, drain water became the only source of water transporting nutrient and sediment deposits to the northern lakes and sea shores. Four northern lakes, Mariut, Edko, Burullus, and Manzala are fed by drain water, which maintains their freshwater lake status. The volume and quality of the drain water is the key to preserving and protecting the northern Delta coastal area.

These lakes provide a huge aquatic environment for littoral lake fish production. During 1975-1993, the lake fishery was one of Egypt's three main fishery components. The other two are the marine fishery and the Nile water fishery. Lake fishery produced 52% or approximately 100 thousand tons of the nation's total fish production, and provided an annual gross income of LE 340 million and provided employment for 53,000 fisherman (WRSR Publication No. 20, 1996). The economic and social value of northern lake fishery production should therefore not be ignored in Egypt's water management.

The preservation of sustainable production of safe, edible freshwater fish in the northern lakes requires a sufficient inflow of drain water. Principally this means the inflows should provide adequate lake flushing and a net lake discharge to the sea. The salts imported with the water which are concentrated by evaporation need to be eliminated so that average lake salinity can be maintained below a maximum threshold.

The majority of drain water in the Nile Delta discharges to the Mediterranean Sea through the northern lakes, while a smaller portion, goes directly to the Sea, as shown in Table 3.

Table 3. Nile Delta drain water outflows 1993-94

	1993-94 Drain water outflows		
	Volume (mcm)	Salinity (ppm)	Salt Load (10^3 t)
To the lakes	9,391	2,822	26,498
to Manzala	4,219	1,779	7,506
to Burullus	1,828	2,899	5,298
to Edko	1,019	1,261	1,285
to Mariout	2,326	5,335	12,409
To the sea	3,072	2,298	7,060
Total	12,463	2,693	33,558

Source: APRP, 1998

Among the four lakes, Lake Mariout suffers from heavy pollution. The diversity of fish species surviving in the lake is limited and provide only a non-commercial food source to poor local residents. The lake's ecology may be salvageable, but it requires additional freshwater inflow and a reduction in pollution, which will be difficult to achieve in the near future. Generally it is thought that the lake will continue to become more salinized and will eventually be unable to sustain fish.

Table 4 shows the estimated status of the lakes Manzala, Burullus and Edko, for 1993-94 (APRP, 1998). Each of the three lakes had a positive net discharge to the sea. Burullus had the highest average lake salinity of 3,500 ppm and the longest water retention time, which indicates a need for additional inflow for flushing. Therefore, Burulles has none of its inflow to spare for reuse in other sectors.

Table 4. Status of lake Manzala, Burullus and Edko in 1993-94

	1993-94 Lake status			
	Outflow from lake (mcm)	Frequency of Flushing (times/year)	Detention time (days)	Mixed Lake Salinity (ppm)
Manzala	3,253	3.4	108	2,043
Burullus	1,243	1.9	193	3,581
Edko	913	10.4	35	1,334

Source: APRP, 1998

APRP (1998) used the Burullus lake as a base and selected a salinity of 3,500 – 4,000 ppm as the threshold lake salinity for continued fish production. In other words, reduction of drainage inflows to Manzala and Edko were checked against the base salinity level to assure survival of freshwater fishes after drainage inflow reductions. APRP (1998) assumed that 2 bcm of the current drainage water flow to Manzala will be diverted to the Salaam canal, and that a 50% reduction in the drain water to Edko and to the sea will occur. From its analysis APRP (1998) concluded that the diversion of 2 bcm of drainage water to the Salaam canal will not affect the salinity level of the drain water going to Manzalla. It will remain at the 1993-94 level of 1,779 ppm. However, the salinity of the drain water to lake Edko will, according to the APRP (1998) estimates, be doubled to 2,293 ppm, assuming that the outgoing salt loads remain unchanged.

APRP (1998) comes to the conclusion that after drainage reduction the average lake salinity in both lakes will be 3,800 ppm, which is within the range of the threshold salinity. However, the frequency of lake flushing in lake Manzala drops down from 3.4 times in 1993-94 to 1.3 times per year, which may have negative effects on fish yields. Lake Edko, after a 50% reduction in drainage flow, will still be flushed 5.2 times per year. Table 5 presents the proposed drainage outflow volumes and salinity concentrations, and the resulting average lake salinity levels and frequency of flushing for the northern lakes.

Table 5. Proposed minimum drain water outflows, resulting lake salinity and flushing times of the northern lakes

	Minimum drain water outflows	Lakes

	Reduced by	Volume (mcm)	Salinity (ppm)	Salinity (ppm)	Flushing (times/year)
To Lakes					
Manzala	50%	2,219	1,779	3,886	1.3
Burullus	0%	1,828	2,899	3,581	1.9
Edko	50%	560	2,293	3,715	5.2
Mariout	0%	2,326	5,335	-	-
To the sea	50%	1,536	4,597		
Sum		8,469			

Source: APRP, 1998

As shown in table 5, the preservation of freshwater fisheries in the northern lakes requires a minimum drain water outflow of 8.5 bcm. According to APRP (1998), this allows a reduction of about 4 bcm from the 1993-94 drainage outflow level, mainly to be accomplished by cutting 2 bcm of drainage flow currently going to Manzala lake (e.g. drainage being exported to Sinai thorough the Salaam canal) and by reducing 50% of the current drain flow to lake Edko.

The above mentioned results of the APRP analysis contain some uncertainty as they are based purely on salt concentrations and do not consider other water quality indicators which influence the aquatic ecosystem of the northern lakes. Furthermore it does not consider the timeliness of irrigation water supply.

4.3 Pollution in the drainage system

With a growing population and intensified industrial and agricultural activities, water pollution is spreading in Egypt, especially in the Delta region. Huge amounts of urban municipal and industrial wastewater and rural domestic wastes discharge into agricultural drains without being treated. Because of limited land and the lower elevation of the topography of the Delta plain, agricultural drains have become easy dumping sites for all kinds of wastes. After the construction of the High Aswan Dam, the seasonal Nile floods, which used to especially flush the Delta's lowlands periodically, no longer reach the Nile Valley and Delta, and the pollutants brought by municipal and industrial wastewater and solid wastes are accumulating in the drain system over the years. There is an increasingly serious threat to Egypt's drain water reuse programme. This applies especially to the Nile Delta region.

In 1982 Law No. 48 concerning the protection of the Nile River and waterways was issued. It classifies types of waterways and regulates the discharge of waste water into these waterways. It bans draining or discarding solid or liquid discharges or gases from buildings and tourist, industrial and commercial establishments, and sanitary drainage in the waterways unless a license is obtained from MWRI. To date the law has had very little effect in controlling pollution due to its weak enforcement.

The Nile Delta region (including Greater Cairo) has an estimated population of more than 50 million. Approximately half of the people live in cities and towns of different sizes, and the other half in villages. In larger cities like Cairo and Alexandria as well as many capital cities of the governorates, public sewers and treatment plants are installed or partially installed, but for 90-95% of the small towns and villages, residents have no access to sewer systems and treatment facilities (Welsh, J. and H.N. Khalil, 1991). Consequently, it is difficult to precisely estimate the amount of wastewater from those sources. At present, most industries, except for a few large ones, have not yet installed effective wastewater treatment equipment. Industrial wastewater is often mixed with municipal wastewater in combined sewers, although it is illegal and prohibited by the Egyptian laws (Ramanda, F. and S. Ahmed, 1995).

The total sewage volume in the Delta region, either treated or untreated, was estimated in 1998 to be 6.02 mcm/day, or 2.17 bcm/year. Seventy-two percent of which is from larger cities and towns, and the rest from smaller towns and villages. Wastewater from Greater Cairo (including part of Giza), Alexandria, and Tanta (Gharbia) together account for more than half of the total sewage volume in the Delta. This fact indicates the importance of controlling sewage flows from large cities (APRP, 1998). But of course the wastewater problem is not restricted to the large settlements. Waste management in small towns and villages also represents an increasing pressure as the population grows. The rural population and the residents in small towns practice disposal in casual ways, such as dumping wastes in leaching pits close to the houses, in nearby drains or even directly in irrigation or drainage canals. The urban wastes usually enter the main or larger drains as point pollution sources, while the rural wastes discharge into the smaller drains, spreading contamination over the entire Nile Delta (Kelly, R.A. and J. Welsh, 1992).

With population growth and economic development, the volume of municipal and industrial wastewater will continue to grow in the future. According to APRP (1998) the current per capita wastewater generation rate is 190 litres/day in urban areas, and 77 litres/day in rural area, averaging 135 litres/day in the Nile Delta region. It is estimated that these figures also apply to the Nile Valley. APRP (1998) projects that the wastewater volume in the Nile Delta will be 7.4, 8.2 and 9.1 mcm/day in the year 2007, 2012 and 2017 respectively. This would be an increase by a factor of 1.5 over twenty years. This expected increase in the volume of wastewater generation will most probably increase the pollution load on agricultural drains especially in the Nile Delta and will negatively affect drain water reuse. Already the Biological Oxygen Demand (BOD) of the waste water released to the water ways, for example, is relatively high. As a result of this, the water in agricultural drains in many locations looks dark, smells bad, and contains high levels of faecal bacteria.

Assuming a moderate population annual growth rate of 1.5% and with no essential changes in life style and technology it is expected that the BOD load in the Nile Delta would, by 2017, reach almost 1 million tons/year. In 1998 there were 38 wastewater treatment plants in operation with a treatment capacity of 1.7 bcm/year and 107 more are under construction or are being planned, which will provide an additional capacity of 817.6 mcm/year. The comparison of this data with the projected sewage flow of 3.3 bcm/year in the Nile Delta and Greater Cairo for the year 2017 shows the existing large gap between treatment demand and capacity. Furthermore one has to consider that the available treatment capacity in existing plants is actually less than that reported above. As a matter of fact, many of the existing treatment plants are not operating at the designed efficiency levels. Overloading and insufficient maintenance are not rare. Discharging incompletely treated flow or even raw sewage from treatment plants frequently happens (APRP, 1998). One can summarise: the present and future pictures of waste water treatment in the Delta region are not optimistic and the reuse of drainage water will be negatively affected if no solutions to the problem are found and implemented.

The Drainage Research Institute of the MWRI's Water Research Centre conducted a reconnaissance survey to evaluate drainage water irrigation practice through the Monitoring and Analysis of Drainage Water Quality Project (Abdel-Gawad, S., 1998). Concentrations of pathogens, pesticides, heavy metals, and salinity in drain water, irrigation canal water, shallow groundwater, drain and canal sediments, soils, and crops were measured at many sites of the Nile Delta region. APRP (1998) summarised the results of the survey as follows:

- Both drain water and mixed canal-drain water showed high average levels of faecal coliform bacteria counts of 15,000/100ml. Faecal coliform bacteria counts in canal water were quite high. Only 15% of the drain water sites, 17% of the mixed canal-drain water sites, and 22-24% of the canal water sites were in compliance with the sanitation requirements of the WHO irrigation water quality guidelines.

- Heavy metal concentrations in canal sediments, drain sediments, and soil were all high. At one particular site in the East Delta, measurements showed 5 mg/l of cadmium, 47 mg/l of copper, 16 mg/l of lead, and 64 mg/l of zinc. Even in irrigation water, where trace elements should not be detectable under normal conditions, the survey reported 0.12 mg/l of zinc, 0.04 mg/l of lead, 0.04 mg/l of copper, and 0.02 mg/l of cadmium in the East Delta. Evidence of uptake of trace elements in crops was also found. For instance, on sites in the Middle Delta, cadmium levels were 1.6 mg/kg in rice, 2.9 mg/kg in cotton seeds, and 1.8 mg/kg in maize.

- Concentrations of pesticide residuals were all low at non-detectable levels before pesticide applications in most monitoring sites. After application, Atrazine and Lannat were detected in magnitudes of 10^{-3} ppm in soils, 10^{-1} ppm in canal or drain water, and 10^{0} ppm in groundwater at some sites. A substantial amount of a wide variety of pesticides (620,000 tons of 200 different types) were used according to the study of the Drainage Research Institute on agricultural crops in Egypt in the 1960-70s, and they may still remain in the environmental media. There has been less use of pesticides in Egypt with the removal of price subsidy in the last decade, but the possible long-term contamination effect of pesticides should be emphasised (APRP, 1998).

According to the National Water Resources Plan Project (NWRP) average BOD values in drainage water vary between 20 mg/l in small drains with low levels of pollution to around 300 mg/l in drains receiving large quantities of untreated wastewater. In the larger drains and pump stations the values are generally between 80 and 200 mg/l. COD values are characteristically 1.5 to 2 times the BOD level. More or less all regions show the same pattern, some even reach higher values. Fayoum is unusual where the average level of BOD is generally below 60 mg/l and the COD level is higher than 150 mg/l. Altogether it is not surprising that the concentration of oxygen in most drains is below saturation level. Typical average values lie between 3 and 6 mg/l, with a large variability especially towards the lower values (NWRP, 1999).

Law 48 which concerns the protection of the Nile river and the Egyptian waterways from pollution only allows drain water with BOD concentrations lower than 10mg/l and COD lower than 15 mg/l and oxygen higher or equal to 5 mg/l to be lifted up and mixed with water in irrigation canals for reuse.

As mentioned above, some areas of the Nile Delta region are especially affected by increasingly deteriorating water quality. A hot spot in this respect is the Bahr Bagar Drain in the Eastern Delta. It starts in the Kalubia Directorate with two branch drains, Kalubia and Bilbeis. The two branch drains receive, according to APRP (1998), 1.6 mcm/d of municipal and industrial wastewater from the Shoubra El Kheima area (Greater Cairo), part of Zagazig city (Sharkia), and other smaller neighbouring towns. Wastewater discharge represents 75% of the total flow of the Bahr Bagar, effectively turning the drain into an open sewer which exhibits strong odours, dark colour, and gas bubbles. Even at the end of Bahr Bagar, monitoring readings show TTS of 134 mg/l, COD of 108 mg/l, MPN[3] of 120,000/100 ml (Drainage Task Force Committee, 1997). All these figures are far beyond acceptable levels according to Law 48 or any other recognised water quality standards. Because of these unacceptable sanitary conditions the Wadi mixing station, one main reuse mixing station on Bahr Bagar, has been totally shut down. This has resulted in a loss of 200 million cubic metres (mcm) of potential reuse water each year. Along Bahr Bagar's 200 km route to Manzala Lake in the north, salinity measurements are all lower than 1,000 ppm. If not for pollution, the drain could provide more than 1 bcm drain water for reuse per year, compared to the official reuse record of 300 mcm before 1998.

Other hot spots of drain water pollution in the Delta region are: Tanta city, the Gharbia drain in the heart of the Middle Delta, the Edko drain and the Moheit drain in the West Delta, and the Alexandria area.

Table 6. Drain water lost to pollution of drains (based on 1993/94 data)

Name of Drain	Location on the drain	Salinity ppm	To Sea 1993/94 mcm	Reuse 1993/94 mcm	Potential reuse and target	
					2000 ppm mcm	2250 ppm mcm
Umoum	Qalaa PS	1,600	0	0	0	0
	Turga PS	1,684	931	0	931	931
Alex Vicinity	Tabia PS	1,449	617	0	617	617
Drain No. 1	Lower PS	2,237	841	0	0	841
Bahr El Bagar	Bahr Barga PS	999	969	0	969	969
El Serv	Lower Serw PS	1,272	962	0	962	962
Sum			4,321	0	3,480	4,321

Source: APRP, 1998

Most main canals in the Nile Delta are multifunctional, delivering irrigation, municipal and industrial water. Mixing drain water with fresh water from the irrigation canals is therefore a problematic issue, especially when the drain water is heavily polluted. Because of unacceptable degraded sanitary conditions the following seven of the twenty-three main reuse mixing pump stations in the Nile Delta have been entirely or periodically closed since 1992 (Drainage Research Institute, 1995). The closed stations are: (1)Wadi mixing pump station; (2) Mahsama mixing pump station; (3) Uper No. 1 mixing pump station; (4) Hamul mixing pump station; (5) Potiata mixing pump station; (6) Edko mixing pump station; and (7) Umoum mixing pump station.

Due to poor water quality quite a large volume of drain water cannot be recaptured, despite the fact that salinity levels in the respective drains are acceptable for irrigation use. It is the

[3] MPN = Most Probable Number (of Bacteria)

municipal and industrial pollution that makes it difficult or impossible to reuse the water of some drains. The growing bacteriological contamination of surface and groundwater in Egypt, combined with the chemical pollution of the soil due to discharge of industrial and municipal wastewater in drains and canals is seen as being responsible for the persistence of water related diseases, especially since the polluted water has been reused officially or unofficially as irrigation water and for other purposes.

An estimation of how much agricultural drain water is lost due to pollution is given in table 6. As mentioned above, the six drains in table 6 are not all the drains suffering from pollution in the Nile Delta, rather they are just typical examples. Without pollution there would be an additional 3.5 bcm and 4.3 bcm of reusable drainage water each year from these six drains, given the reuse salinity targets of 2,000 ppm and 2,250 ppm, respectively.

5. Limitations and challenges

5.1 Limitations

Besides the factors affecting drain water reuse there are a number of additional factors that might affect drainage water reuse in the future, factors that might change drain water reuse in Egypt dramatically. These factors are:

Irrigation Improvement Project (IIP). Egypt has launched an ambitious project to improve the water delivery system, on-farm water management, irrigation methods and associated agronomic practices. All these measures will increase the irrigation efficiency, but they will also decrease the volume of drain water and therefore the drain water salinity will increase. According to APRP (1998), a 45-60% field irrigation efficiency is a reasonably acceptable estimate for the Delta region. Within efficiency levels of 45-60%, every 1% efficiency increase will cause a 1.7 – 2.2% increase in evapotranspiration, a 1.8 – 2.4% reduction in drainage volume, and a 1.9 – 2.5% increase in salinity of the drainage water. In its analysis APRP (1998) comes to the conclusion that the planned 3.5 million feddans IIP extension in the Delta will eventually result in a maximum reduction in the generation of drain water of 2.6 bcm from the 1995-96 level.

The 1986 water policy assumed that by 2000 the IIP would cover about 2.5 million feddans, and the expected total amount of saved water would be 2 bcm/year. In reality, the implementation of the project proved to be very slow and costly. Therefore, the 1990 water policy estimated that the water that could be saved by IIP to be only 1 bcm/year by 2000.

Vertical drainage. In areas where ground water is suitable for irrigation, vertical drainage by conjunctive use of groundwater for irrigation is seen as an effective means for preventing water-logging and salinization, and for water conservation. At the fringe areas of the Nile Valley and Delta vertical drainage is seen as being technically feasible and economically attractive. Since vertical drainage by conjunctive use of groundwater for irrigation uses seepage water, the generation of drain water and its reuse will be reduced by this practice.

Conjunctive use of groundwater. Farmers of the Nile Delta increasingly use wells as a on-demand irrigation system when canal water is inadequate, unreliable, or both, to reduce moisture stress and maximise irrigated crop yields. The effect of such conjunctive use would essentially be to insulate the canal irrigators from the vagaries of the canal system, especially at the tail ends. With the increase of the conjunctive use of ground water the generation of drain water will automatically decrease. This will be the case especially when the supply of fresh water is inadequate and farmers at the tail ends of the drains use this water to irrigate their crops.

Advanced irrigation methods. Field experiments have shown that sprinkler irrigation, drip irrigation, surge irrigation, and automation of irrigation have the potential to provide a higher water application efficiency and less drainage water. They also have the potential to generate higher incomes. Advanced irrigation methods are at present mainly used in the new lands but it is expected that they will also be used in the old lands in future. For instance it is expected that the 530,000 feddans of orchards in Egypt will finally be irrigated by drip irrigation methods. On average, drip irrigation methods may provide up to a 50% reduction in irrigation requirement, or a saving of 2,900 m^3/feddan in canal water. This shows that the application of advanced irrigation methods will certainly affect the future drainage pattern in Egypt, i.e. it will reduce the volume of drain water and will affect drain water reuse.

Deficit irrigation and cyclic irrigation. Deficit irrigation mainly means to deliberately allow a certain degree of water deficit in crops by reducing irrigation amounts at carefully selected crop growing stages. Cyclic irrigation means the use of different kinds of irrigation waters in different crop production stages. For instance drain water, without being mixed with canal water, will be used in the last few irrigation applications when the crop has a stronger salt-resistance capacity. According to APRP (1998) both deficit and cyclic irrigation methods have the potential benefits of preserving the value of the limited Nile freshwater, reducing drainage water pumping costs, and avoiding the pollution of soils with municipal and industrial waste water. Deficit irrigation and cyclic irrigation are both not without controversy. But if they were applied their application would result in a reduction of the volume of drain water and a further restriction of drain water reuse.

Reduction of the area under rice and sugar cane. Rice and sugarcane are very controversial crops in Egypt. Farmers favour both crops because of their high yields and economic returns. Water managers are more inclined to reduce the area under these crops so that the large amount of water for rice and sugarcane can be used to satisfy other demands such as expanding the area of arable lands. If the anticipated reduction of the area under rice and sugar cane is accomplished it will result in a reduction of drain water generation. Most probably this will not be the case in the northern part of the Nile Delta, were a large portion of excess irrigation water is lost to a salt sink such as saline groundwater, and becomes valueless for reuse.

An option to reduce water consumption in rice production is the introduction of short-duration varieties. Such a substitution of short duration varieties (approx. 120 days) for longer season varieties (approx. 160 days) which is in the process of implementation could reduce water diversions by 25%. The expected water savings on 1 million feddans could be as much as about 1.26 bcm of consumptive use or 2.0 bcm of water diverted. This reduction in diversions will soon reduce drain water generation in the Nile Delta because the introduction of short-duration varieties is already an ongoing process.

Toshka project. The Toshka project in the south of the country is Egypt's largest irrigation and land reclamation project. It is designed to develop 1 million feddans of arable land over the next 10 to 20 years. The development of this project will have a significant impact on the flows downstream of Aswan. Depending on the actual cropping pattern of the project area the flow is expected to be reduced by some 7 to 9%, that would be a reduction in releases by the HAD of 2 – 4 bcm. The flows entering the Nile Delta will be affected to a greater extent because of horizontal expansion projects in the Nile Valley and the increased future water use of municipalities and industry. It is thought that the flows entering the Nile Delta will decrease by some 13%, given the present planning horizon of 2017. The management of these forthcoming changes requires an intensification of drain water reuse and a more restricted water supply scheme for the Nile Valley and Delta. This emphasises the dual needs for both a drain water reuse programme and an irrigation improvement programme.

All these factors potentially effect future drain water generation and its reuse in Egypt, especially in the Nile Delta. While some of these factors have been estimated quantitatively, others have only been addressed in a descriptive way so far. With the currently available knowledge and information it does not seem possible to analyse the combined effects of these factors. A holistic approach in planning and research is urgently needed.

5.2 Challenges

Egypt faces a number of challenges in dealing with the impending water scarcity. The most important challenges are:

(1) The need to generally increase the efficiency of water use in agriculture, municipalities and industry. Improved efficiency in agricultural water use is required both to maintain productivity growth and to allow the reallocation of water from agriculture in the old lands to urban and industrial uses, as well as to new land developments.

(2) The quality of Egypt's restricted land and water resources must be sustained in the face of mounting pressure to degrade these resources through water-logging, salinization, groundwater mining, and water pollution.

(3) Pollution of water from industrial effluents, poorly treated sewage, and runoff of agricultural chemicals is a growing problem in Egypt and a challenge to all Egyptians. Fresh water is in Egypt a scarce resource, it is too valuable to be made unusable by pollution. It is too valuable to be used to dispose of wastes.

(4) Most Egyptians do not treat water as the scarce resource it is. Both urban and rural water users receive massive subsidies on water use. The fact that water for different uses is often provided for much less than the cost of providing it - or for free - leads users to give it a low value. Water provided free of charge does not get used wisely, or conserved. It does not give users incentives to conserve water. Nor does it provide sufficient revenues to operate and maintain water systems, to invest in new infrastructure, or to research into new technologies.

(5) Drain water reuse has been and will continue to be an important water conservation measure in the Nile Delta. But there is no question that the future of reusing drain water in Egypt's agriculture will be different from the present use. Farmers have to be aware that it is unlikely that the drain water in the present quantity and quality can be used in the future to augment the supply of fresh water from the Nile River system to the present extent. With improved water management, new irrigation methods, different cropping patterns, horizontal expansion of arable land in Sinai and Toshka, and other possible reasons, the current drain water generation and reuse pattern in the Nile Delta will gradually be altered substantially in the future. The general trend will be a decrease in drain water flow and an increase in drain water pollution, especially salinity.

(6) Despite the fact that the reuse of drain water has been and will continue to be an important water conservation measure in the Nile Delta for the time being the present concept of drain water management is questionable. Would it not be more sustainable to exert more effort on reducing drain water generation rather than on reusing drain water? As mentioned above each cubic meter of drainage water "consumes" more than one cubic meter of freshwater in the "production process". Efforts to reduce the volume of drainage water by improving irrigation management will increase the volume of freshwater available for delivery and reduce the volume of the water that must be managed, recycled, or discharged to the Mediterranean Sea. Furthermore, the smaller volume of drainage water will require smaller expenditures for operation and maintenance of the drainage system.

(7) The efficiency and productivity of Egypt's water resources may be enhanced by changing the view that drain water is a resource for augmenting irrigation supply to one such that drain water is seen as an effluent causing negative environmental impacts and imposing direct and indirect costs on farmers, municipalities, industries and the general public. According to APRP (1998) in future decades Egyptian water engineers, as well as farmers and other water users, may go through a transition from the current drainage-reuse philosophy to a drainage reduction philosophy.

6. Summary

As water resources are increasingly becoming scarce, agricultural drainage water reuse has become an important source of irrigation water in Egypt. The reuse of drain water is well developed in Egypt, particularly in the Nile Delta region. However, as the demand for reuse keeps growing, the expansion or even the continuation of drainage reuse will be threatened by the deteriorating drain water quality due to municipal and industrial wastewater disposal into the agricultural drainage system. Egypt faces multidimensional challenges in sustaining the current level of reuse and promoting the reuse of drainage water in future decades. The paper describes the present reuse system and official plans to extent the reuse of drainage water. It critically discusses the problems and limits of drainage water reuse from the perspective of an external observer.

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