# DEPLETED FRACTION ANALYSIS IN THE FERGANA VALLEY OF UZBEKISTAN

# L'ANALYSE DE FRACTION RÉDUITE DANS LA VALLÉE FERGANA d'UZBEKISTAN

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## ABSTRACT

A major problem in the Fergana Valley is the high water table, especially in the lower and central parts of the Valley. This widespread problem is particularly associated with the irrigated areas. The FWRMP-I (Fergana Valley Water Resources Management Phase-I Project) Study Area covering an area of about 67 000 ha is located on the southern edge of the Fergana Valley.

It is generally believed that the high water table is due to the absence of an adequate drainage system; or a drainage system that is no longer properly functioning, because the necessary rehabilitation and maintenance has not been carried out during the past two decades; and because of poor water management practices. As a result, the area is suffering from substantial waterlogging, soil salinization and water mineralization.

The question is where the extra water in the high irrigation duties comes from and why in the first place drainage duties are so high. Non-beneficial losses should be assumed to significantly reduce when groundwater levels are managed at appropriate levels with improved drainage systems.

There appears to be too much of a pre-conceived opinion of solutions and these are strongly biased towards drainage solutions. It should be recognized that the present problems stem from a multitude of causes, both technical and non-technical (institutional and financial) and that thus a holistic approach to finding solutions is required.

In order to identify the appropriate solution, a salt-water balance has been made for the period 2002-2006. Using the results of this balance, depleted fraction values have been calculated in order to assess the performance of the system. Afterwards, necessary implementations have been proposed.

As a result; in order to remove the excess amount of water calculated in the water balance, a combination of proposals like rehabilitation of existing tubewells, installation of artesian and pressure relief wells, construction of interceptor collectors have been made. For salinity control subsurface horizontal drainage system has been proposed. Besides these measures, rehabilitation of irrigation and drainage network and installation of water measuring structures in all the onfarm canals have been proposed for better water management.

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# LA RESUME ET LES CONCLUSIONS

Un problème important de la Vallée Fergana est la table d'eau haute, surtout des parties plus basses et centrales de la Vallée. Ce problème étendu est particulièrement associé aux régions irriguées. Le domaine d'Étude de FWRMP-I couvrant une espace du 67000 environ de ha est situé sur le bord du sud de la Vallée Fergana.

On y croit généralement que la table d'eau haute est en raison de l'absence d'un système de drainage adéquat; ou un système de drainage qui ne fonctionne plus correctement, parce que la réhabilitation nécessaire et la maintenance n'ont pas été réalisés pendant les deux décades passées; et à cause de pauvres pratiques d'administration d'eau. Par conséquent, la région souffre du fait de noter substantiel d'eau, le sol salinisation et l'eau minéralisation.

La question est d'où l'eau supplémentaire dans les hauts devoirs d'irrigation vient et pourquoi en premier lieu les devoirs de drainage sont si hauts. Les pertes non favorables devraient être supposées pour de façon significative réduire quand les niveaux de nappe phréatique sont dirigés aux niveaux appropriés avec les systèmes de drainage améliorés.

Il a l'air d'y avoir trop d'une opinion préconçue de solutions et ceux-ci sont fortement influés vers les solutions de drainage. Il devrait être reconnu que les présents problèmes proviennent d'une multitude de causes, tant techniques que non techniques (institutionnel et financier) et qu'ainsi une approche holistique à la conclusion des solutions est exigée.

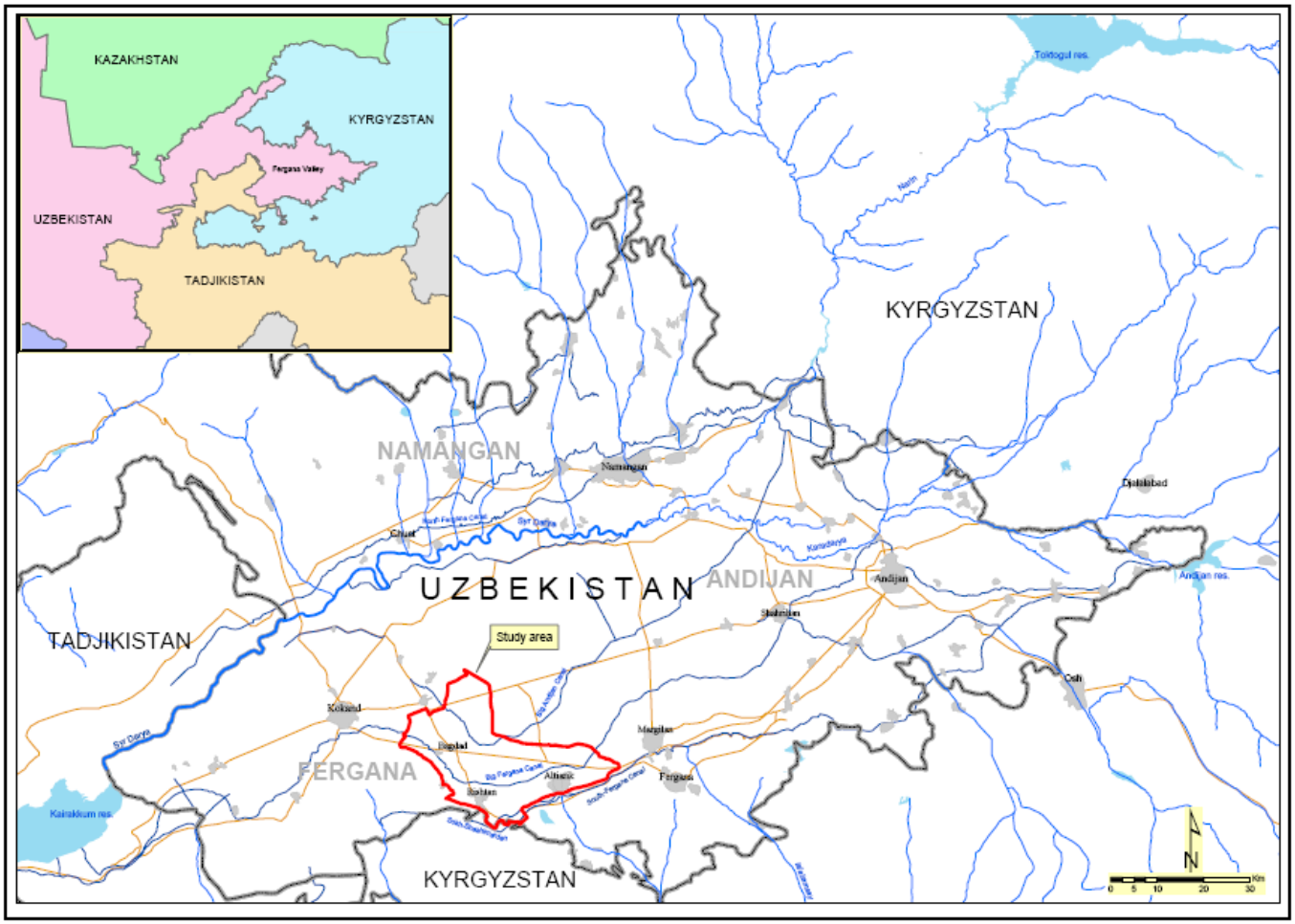
Pour identifier la solution appropriée, une balance d'eau de mer a été faite pour la période 2002-2006. En utilisant les résultats de cette balance, les valeurs de fraction réduites ont été calculées pour évaluer la performance du système. Ensuite, les applications nécessaires ont été proposées.

Des susdites analyses, les suivants peuvent être conclus :

- Les problèmes de la région de projet peuvent être classifiés comme les problèmes d'irrigation et les problèmes de drainage. Bien que ces problèmes soient hautement liés, ils ont besoin de différentes approches pour la solution.
- Les conditions d'écoulement en haut affectent la situation.
- Les problèmes d'administration d'eau affectent les deux groupes de problèmes.
- Bien que les quantités moyennes annuelles comme l'eau d'irrigation soit raisonnable, leur distribution spatiale et temporelle n'est pas optimisée qui adressent aux problèmes d'administration surtout.

Par conséquent; pour enlever la quantité d'excès d'eau calculée dans la balance d'eau, une combinaison de propositions comme la réhabilitation des puits de tube existant, l'installation d'artésiens et les puits de relief de pression, la construction de collectionneurs d'intercepteur a été faite. Car le système de drainage horizontal sous surface de contrôle de salinité a été proposé. En plus de ces mesures, la réhabilitation d'irrigation et réseau de drainage et l'installation d'eau mesurant des structures dans tous les canaux onfarm ont été proposée pour la meilleure administration d'eau.

**Figure 1.** Fergana Valley (Vallée de Fergana)



# 1. FERGANA VALLEY

The Fergana Valley comprises parts of three Central Asian States: Uzbekistan, Tajikistan and the Kyrgyzistan. (Figure 1) The total area is approximately 2.6 million ha, and there is a total population of 14 million, of which 66% live in the rural areas. Compared to the other parts of these countries, population density in the Valley is high, and the amount of land available per person is small; poverty is widespread.

The main water-sources for the Fergana Valley are Narin River, Qara Darya River, and Syr Darya River, which is formed by the confluence of the Narin and Qara Darya. Numerous small rivers flow in from the north, east and south. The Fergana Valley has appreciable groundwater that has developed over geological time. The subterranean waters associated with the rivers noted above form the main source of potable water supply for the population in the Valley.

A major problem in the Valley is the high water table, especially in the lower and central parts of the Valley. This widespread problem is particularly associated with the irrigated areas.

It is generally believed that the high water table is due to the absence of an adequate drainage system; or a drainage system that is no longer properly functioning, because the necessary rehabilitation and maintenance has not been carried out during the past two decades; and because of poor water management practices. As a result, the area is suffering from substantial waterlogging, soil salinization and water mineralization.

# 2. UZBEKISTAN FERGANA VALLEY WATER RESOURCES MANAGEMENT PROJECT

## 2.1 History of irrigation in the Fergana Valley

The Fergana Valley is home to the historic Kokand Khanate, one of the major dynasties of Central Asia in pre-modern times. The Valley accordingly has a long tradition of irrigated agriculture.

Prior to the construction of the Big Fergana Canal (BFC) in 1940, irrigation development was mainly in areas where river water could be diverted and where natural drainage was adequate enough to prevent waterlogging problems. Natural drainage took the form of recharge to a deep groundwater table. Subsequent groundwater flow towards the north emerged in swamp areas, to be evaporated and possible overflow to the Syr Darya via natural drainage channels. The river itself would also have acted as an interceptor of groundwater. In areas where the groundwater table was close to the surface, along the fringes of permanent wetlands, evaporation from the water table would have resulted in soil and shallow groundwater salinization.

The BFC commanded a large area to the north of the canal, as well as to the south. World War II halted significant development during the 1940s, and it was only in the 1950s that extensive irrigation development started.

In order to solve the employment problems for the increasing population in the Fergana Valley at the beginning of the 1960s, and to promote economic growth, development of land in the centre of the valley commenced. A complex network of canals including several major distributor canals was constructed to distribute water from the Narin and Qara Darya, and to discharge into canals which followed the natural drainage paths from the outwash fans.

Fallow lands, natural hayfields and rough pastures, which had earlier provided natural drainage were developed for irrigated agriculture. The topography of the newly developed land was intricate: undulating, sandy and boggy. A network of collectors, principally serving the central parts of the valley had also been constructed during this period.

## 2.2 Fergana Valley Water Resources Management Phase-I Project

Irrigated agriculture is the backbone of the Uzbek economy, accounting for 35% of GDP, 60% of foreign exchange receipts, and 45% of employment. In the rural areas, agriculture and processing of agricultural products is by far the main source of employment and income for the population. The most important crop is cotton which accounts for about 50% of national export earnings. The irrigated area, which extends over about 4 million ha, is served principally by the Amu Darya and Syr Darya together with their tributaries.

Improving water resources management in the Fergana Valley and rehabilitation of the irrigation and drainage systems over the whole area is an enormous task, requiring enormous investments. Therefore, it is planned that the improvement and rehabilitation process will be undertaken as a long-term program, to be implemented in several phases over the next 15 years.

The Fergana Valley Water Resources Management Phase-I Project (FWRMP-I) is the first of a series of projects to be undertaken under the Fergana Valley Water Resources Management Program. Within this context, consultants (Mott MacDonald and Temelsu) have conducted a study funded by the World Bank and prepared a feasibility report for Phase-I Project.

The FWRMP-I has been devised to address constraints on agricultural productivity in parts of the Uzbekistan territory lying within the Fergana Valley. In addition, it seeks to tackle chronic problems of waterlogging which are affecting infrastructure and buildings within this part of the Valley.

The FWRMP-I Study Area covering an area of about 67 000 ha -which is 53% of the total area of the project districts namely Bagdad, Rishtan and Altyarik of Fergana Oblast- is located on the southern edge of the Fergana Valley.

The majority of the land in the three districts currently has a depth to groundwater in the range of 1.5 to 2.0 m. The high water table has mobilized salt in the soil which, with waterlogging, has resulted in destruction of buildings and residential houses in the settlements. For crops, it has resulted in lower yields and therefore lower incomes for the people living in the area.

## 2.3 Salient features of the study area

*Topography*

The study area is part of the vast foothill apron of the Turkestan-Alay Mountains. The highest elevations are in the southern part of the area (650 to 700 m); northwards towards the Syr Darya, levels reduce to 400 m. The southern flank of the area is divided by a series of river valleys, among which the largest and deepest are the valleys of the Sokh, Shakhimardan, Altyariksai and Faizabadsai rivers.

The main irrigated areas of Rishtan and Bagdad districts are located on or adjacent to the Sokh outwash fan. Part of Rishtan and most of Altyarik district lie within the inter-fan depression between the Sokh and Altyariksai rivers.

Much of the study area is very flat with gradients typical of the general valley floor. The northern part of the study area includes former marshland and remnants of sand dune systems.

*Climate*

The study area has a sharp continental climate with hot and dry summers and relatively mild winters with moderate frost:

- The coldest month is January with an average temperature of about -2.50 ˚C and absolute minimum of -27 ˚C
- The hottest month is July with an average temperature of about 27 ˚C and absolute maximum of 44 ˚C
- The frost-free period is about 215 days each year.
- Annual precipitation is some 100 mm to 170 mm from west to east and 270 mm in the foothills; there is very little rainfall in summer.
- Evaporation is about 1 220 mm, and relative humidity ranges from 45% in June to over 80% in December and January.

*Geology*

South to north orientated geological cross sections of the study area show a consistent transition from single layered deposits of ill-sorted sand and gravels, interspersed with boulders. Further north and also associated with a flattening of the land gradient a multi-layering system of sand and gravel and silt / loam / clay layers is evident, with layers ranging in thickness generally from about 10 to 20 m, while locally thicker layers of loam are encountered (30 to 40 m). These bands are generally separated vertically by 10 to 40 m.

Some of the silt / loam / clay layers are considered to extend several kilometres (3 to 15 km) towards the centre of the Valley, whereas in other locations the bands may only be a few hundred metres long (say, 300 to 400 m).

*Soils*

Desert and transition zone soils are typical in the study area. However, hydromorphic soils of the "*saz*" mode have developed as a result of waterlogging; the persistently high watertable has resulted in soil transformation. Soils have lost not only their zonal particularities, but by being transformed to meadow and marsh-meadow types, have also lost the name that is typical to zonal soils. Due to waterlogging, a gley horizon has formed in the soil profile.

### 2.4 Problems in the study area

At the moment in the study area there is a well-developed irrigation and drainage system. However, because of the way that the canals and drains are inter-connected, operation is complex with the consequent potential for relatively low water management efficiencies. Some parts of this system are still suffering from the change in circumstances during the last two decades; the drainage tubewells, for example suffer from extensive power cuts whilst a significant maintenance backlog has arisen.

It may be expected that during earlier infrastructure design, provision would have been made to accommodate the drainage flows. However; there is evidence that some parts of the drainage system are being surcharged at present. This is attributable to some or all of:

- Changes in distribution and use of water compared with original design concept
- Changes in the upstream infrastructure, thereby increasing the flow carried
- Loss of capacity due to lack of maintenance or modification of drain function
- Increased drainage duty associated with excess water flowing in the canals or deficiencies in the canal water management
- Increased drainage duty associated with changed groundwater flows and levels.

The consequence of this is that some areas have locally raised groundwater levels due to impeded drainage. The problem can be particularly apparent at structures, though open drain channels will also be affected.

On the other hand, in the 1980's development of piedmont deposits (adirs) mainly in Kyrgyzstan started. In the adirs where traditionally orchards and gardens existed, cultivation of field crops had been started. Given the shallow soils, which are underlain by coarse sand and gravel and pebble deposits, irrigation efficiency was low resulting in excessive recharge.

In the Burgandin area in Kyrgyzstan, located not far south of the border with Uzbekistan, rice cultivation started in the late 1980's. It is probable that generally unfavorable soil conditions have most likely limited the cultivation of dry land crops. Rice cultivation has been possible by 'profile filling', which involves the application of large amount of irrigation water until the groundwater table reaches ground surface. Flooded conditions are then maintained over the vegetation period.

It is claimed that the rise in groundwater levels in the adirs and the Burgandin area has resulted in a significant increase in the groundwater gradient and thus in groundwater flow towards the north. Groundwater levels observed in Well#600 in Rishtan near the border show a gradual rise from about 12 m below ground in 1992 to about 2 m in 2005. However, Well#439 located in the northern part of the town shows a depth to groundwater consistently about 1.5 m below ground surface throughout the same period. It is thus not sure if the shallow groundwater table condition occurred in this area prior to the irrigation development across the border or whether a rise in the groundwater level was initiated earlier.

Serious waterlogging is now evident in the area and is largely attributed to the groundwater inflow from the south, although it should be said that drainage and irrigation wells constructed to alleviate the drainage problems are not operating in an optimal fashion any longer.

The question is where the extra water in the high irrigation duties comes from and why in the first place drainage duties are so high. If it is an admittance of low irrigation efficiency then should there not be an effort to improve the irrigation distribution system? The value for evapotranspiration is itself very high and presumably does take into consideration the high soil evaporation rates due to the current high groundwater table conditions. Such non-beneficial losses should be assumed to significantly reduce when groundwater levels are managed at appropriate levels with improved drainage systems.

So far, the groundwater inflow across the border with Kyrgyzstan has been seen as a burden. Although it does create significant problems that need to be resolved urgently, it also provides opportunity. The groundwater is of significant quantity and of good quality. It can therefore be seen as an additional source of irrigation water, which is beneficial, particular during the peak summer demand period when irrigation canal water can be in short supply.

There is a clear need to consider all the options available to the resolution of the problems in the study area. There appears to be too much of a pre-conceived opinion of solutions and these are strongly biased towards drainage solutions. It should be recognized that the present problems stem from a multitude of causes, both technical and non-technical (institutional and financial) and that thus a holistic approach to finding solutions is required.

In order to identify the appropriate solution, a salt-water balance has been made for the period 2002-2006. Using the results of this balance, depleted fraction values have been calculated in order to assess the performance of the system. Afterwards, necessary implementations have been proposed.

# 3. DEPLETED FRACTION ANALYSIS

## 3.1 Depleted fraction

Bos et al (2003) define the depleted fraction as the ratio of the actual evapo-transpiration (from the area)-$ET_{actual}$, to the sum of all precipitation (on this area)-P, and the surface water inflow (into the area)-$V_c$. This ratio which compares three components of the water balance of an (irrigated) area excluding the drainage component is given as:

$$Depleted\ Fraction = \frac{ET_{actual}}{P + V_c}$$

For practical reasons like the measurement of $ET_{actual}$ and the precipitation, the depleted fraction usually is quantified for the entire irrigated area. Similarly in the temporal scale, in order to avoid ripples due to the factors like rain showers and short canal closures it is recommended to calculate the depleted fraction on a monthly basis (Bastiaanssen et al 2001).

In their study, Bos et al (2003) recommend to use depleted fraction as a performance indicator on irrigation water use based on three case studies in semi-arid areas of Argentina, Brazil and Egypt. Their results show that if $ET_{actual}$ is less than about $0.6*(P + V_c)$ a portion of this available water goes into storage causing the groundwater table to rise while storage decreases if $ET_{actual}$ is greater than $0.6*(P + V_c)$. Hence at a depleted fraction of about 0.6, storage is stable.

It is concluded by Bos et al (2003) that:

- The depleted fraction relates parameters of the water balance of an irrigated area with each other in such a way that the (water) manager obtains information on the rate of change of water stored in the area (soil moisture and groundwater)
- Management of an irrigation system in such a way that the monthly values of the depleted fraction range between 0.5 and 0.8 would provide sufficient water for leaching and provide high crop yield per unit water consumed.

## 3.2 Results of depleted fraction analysis in the study area

Monthly and annual depleted fraction values have been calculated using the water balance results for the three districts for the period 2002-2006. Figure 2 shows the annual depleted fraction ratio vs. change of soil moisture in Altyarik district for this period. This figure is inline with the results of case studies given by Bos et al (2003)

and therefore demonstrates that a target value of 0.6 for the depleted fraction in the study area is applicable. Table 1 shows the annual depleted fraction values for three districts in the same period.

**Table 1.** Depleted fraction for three districts (Fraction réduite pour trois districts)

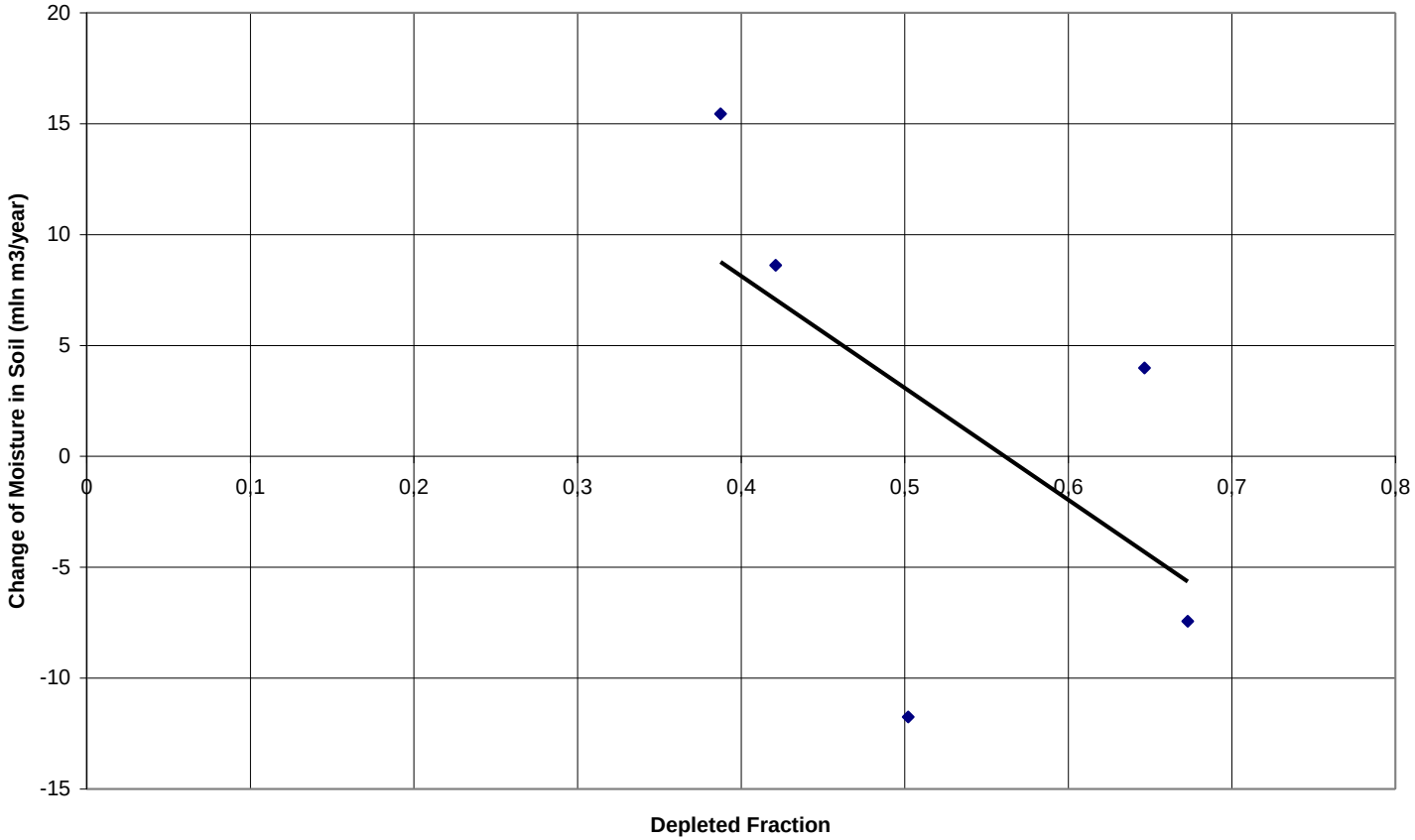
| District | Depleted fraction components | Year | | | | |
|---|---|---|---|---|---|---|
| | | **2002** | **2003** | **2004** | **2005** | **2006** |
| Altyarik | P ($m^3$/ha) | 2,092 | 2,770 | 2,929 | 964 | 1,113 |
| | $V_c$ ($m^3$/ha) | 10,887 | 14,644 | 19,686 | 20,193 | 12,782 |
| | $P+V_c$ ($m^3$/ha) | 12,979 | 17,414 | 22,615 | 21,157 | 13,895 |
| | $ET_{act}$ ($m^3$/ha) | 8,735 | 8,744 | 8,764 | 8,910 | 8,985 |
| | **DF** | **0.67** | **0.50** | **0.39** | **0.42** | **0.65** |
| Bagdad | P ($m^3$/ha) | 2,092 | 2,770 | 2,929 | 964 | 1,113 |
| | $V_c$ ($m^3$/ha) | 10,642 | 10,786 | 12,013 | 19,547 | 12,563 |
| | $P+V_c$ ($m^3$/ha) | 12,734 | 13,486 | 14,942 | 20,511 | 13,676 |
| | $ET_{act}$ ($m^3$/ha) | 8,771 | 8,792 | 8,844 | 9,184 | 9,213 |
| | **DF** | **0.69** | **0.65** | **0.59** | **0.45** | **0.67** |
| Rishtan | P ($m^3$/ha) | 2,092 | 2,770 | 2,929 | 964 | 1,113 |
| | $V_c$ ($m^3$/ha) | 13,098 | 14,397 | 14,019 | 18,828 | 13,357 |
| | $P+V_c$ ($m^3$/ha) | 15,190 | 17,167 | 16,948 | 19,792 | 14,470 |
| | $ET_{act}$ ($m^3$/ha) | 8,777 | 8,740 | 8,852 | 9,009 | 9,014 |
| | **DF** | **0.58** | **0.51** | **0.52** | **0.46** | **0.62** |

The depleted fraction values for Bagdad are close to the target value with the exception of 2005 which was reported to be a dry year. (100 mm rainfall is only half of the long term average value) Although there is not any correlation between the amount of precipitation and irrigation water supply, for this specific year the maximum amount of water was diverted to the study area.

For Altyarik during 2003-2005 period, depleted fraction is below 0.5 which results in storage in groundwater and consequent rise in the water table. For 2002, which was an average year having 200 mm rainfall, the value for ($P+V_c$) was 13,000 $m^3$/ha in Altyarik. Considering an overall system efficiency of 0.52, this results in 6,760 $m^3$/ha which is quite consistent with the annual cumulative irrigation norm (6,025 $m^3$/ha).

For Rishtan, for all years except 2006, the depleted fraction has values smaller than 0.6 which results in increase in the moisture of soil.

**Figure 2.** Annual Depleted Fraction vs Change of Moisture in Soil in Altiarik for 2002-2006 (La fraction réduite annuelle contre le changement d'humidité dans le sol dans Altyarik pour 2002-2006)



As recommended by Bastiaanssen et al (2001) monthly depleted fraction values have also been calculated and given in Figures 3-5 for the three districts. From these figures, it is observed that for the vegetation period (esp. during July, August and September) monthly depleted fraction values are higher than 0.6 with peak values occurring in September. As for these months the effect of precipitation is negligible, it can be said that increasing the $V_c$ twice halves the depleted fraction. The reasons for such high depleted fraction values can be as follows:

- The operation regime of the hydraulic facilities (e.g. reservoirs) in the upstream countries can have negative effect,
- The operation regime of the hydraulic facilities in the upstream part of Uzbekistan can have negative effect,
- The irrigation norms may be wrong,
- The real crop pattern can be different than the stated one,
- Water management problems.

The first two items definitely have contribution to the problem.

The third item does not seem to be applicable because the irrigation norms are quite similar to figures calculated using CROPWAT.

The fourth item is the most difficult to comment on as it is dependent on the official statistics. However, this should have some effect.

The fifth item has the largest effect.

To assess the magnitude of the effects of these items, the following example can be given as an illustration:

In Altyarik in July 2002, the amount of water diverted for irrigation was 1,643 $m^3$/ha. However, based on irrigation norms and present crop pattern, 2,252 $m^3$/ha should have been diverted. This has caused the depleted fraction to increase from 0.83 to 1.14. The reason for releasing less water than necessary can be upstream operation both national and international or poor water management practices.

Another scenario considered is about the differences between the planned and actual crop patterns. In this scenario, it is assumed that in 10% of the project area cotton is cultivated instead of wheat. If this change in crop pattern is taken into account and the irrigation water to be diverted is calculated accordingly, 2,800 $m^3$/ha of water has to be given which will result in depleted fraction of 0.75 for a revised $ET_{act}$ of 2,100 $m^3$/ha. However if this change is not taken into account, diversion of the previous $V_c$ will result in a higher DF value as 0.93.

**Figure 3.** Monthly Depleted Fraction Values for Altiarik (La fraction mensuellement réduite évalue pour Altyarik)

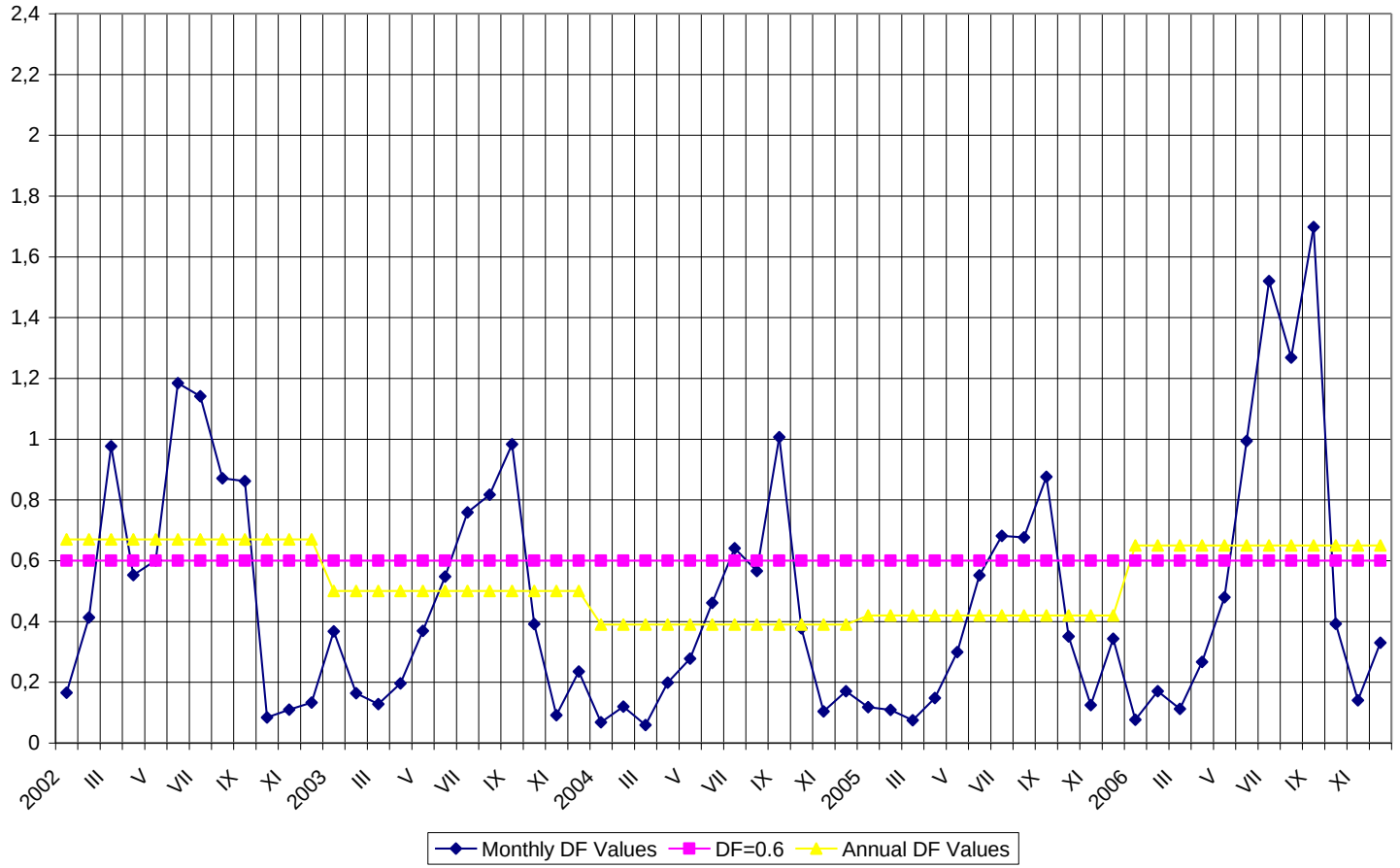


**Figure 4.** Monthly Depleted Fraction Values for Bagdad (La fraction mensuellement réduite évalue pour Bagdad)

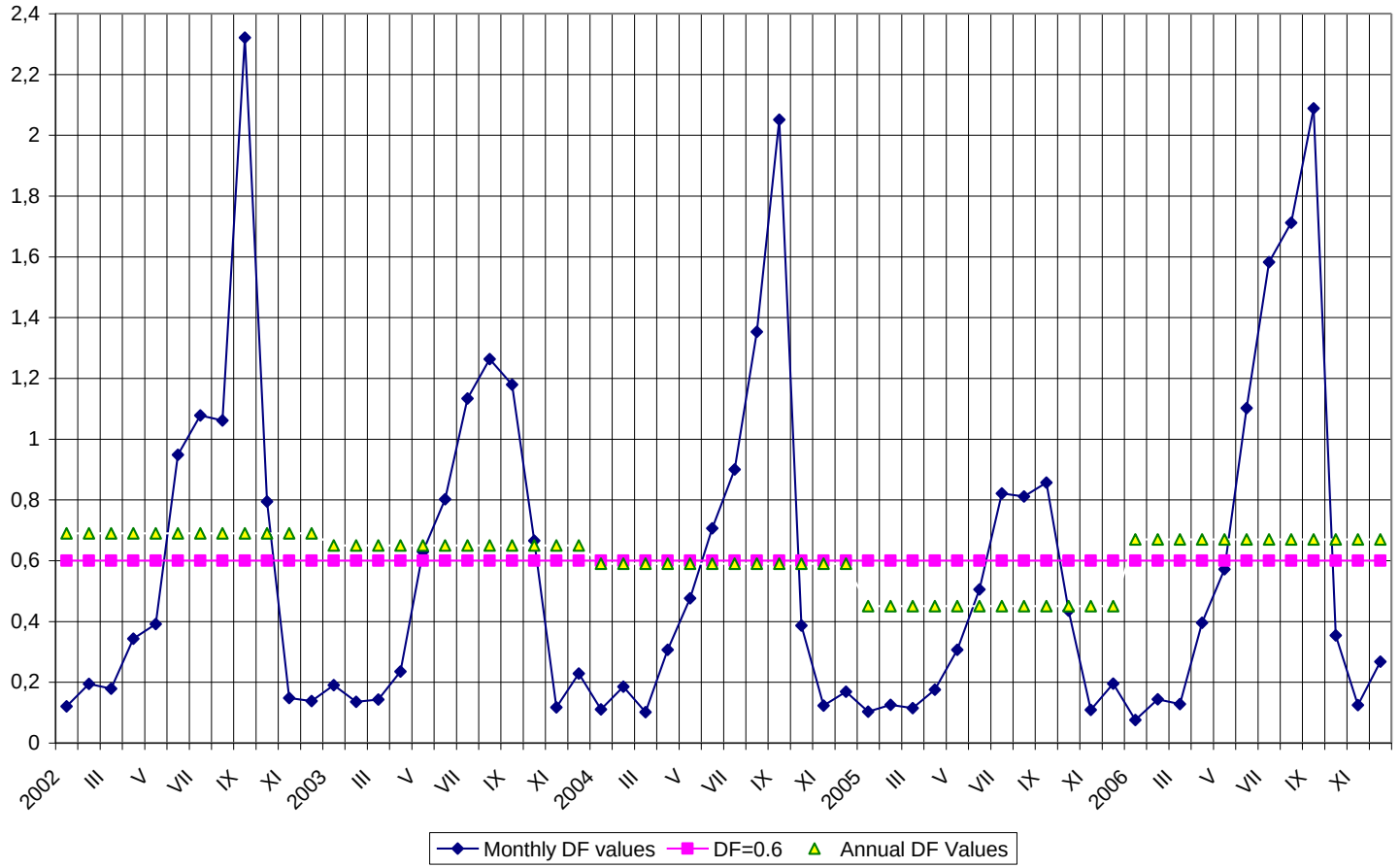
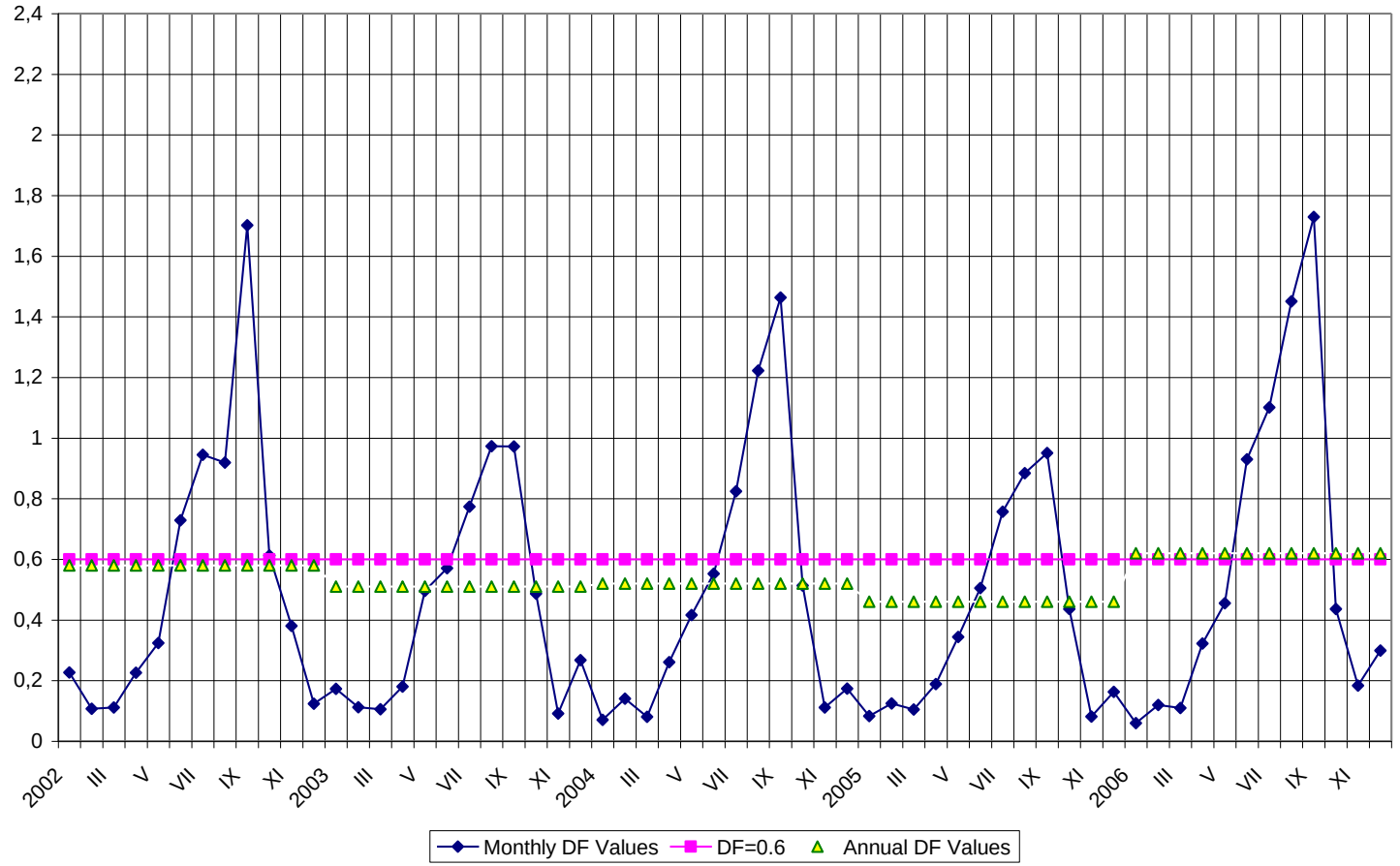


**Figure 5.** Monthly Depleted Fraction Values for Rishtan (La fraction mensuellement réduite évalue pour Rishtan)



The analysis of these different scenarios shows that upstream conditions and poor water management practices have the biggest effect on the depleted fraction.

**Table 2.** Depleted fraction values for different scenarios in Altyarik in July 2002 (La fraction réduite évalue pour de différents scénarios dans Altyarik en juillet de 2002)

| Scenarios | $V_c$ ($m^3$/ha) | P ($m^3$/ha) | $ET_{act}$ ($m^3$/ha) | DF | Crop pattern |
|---|---|---|---|---|---|
| Actual figures | 1,643 | 3 | 1,874 | 1.14 | 35% cotton<br>38% wheat |
| $V_c$ calculated according to norms | 2,252 | 3 | 1,874 | 0.83 | 35% cotton<br>38% wheat |
| 30% increase in cotton area | 2,800 | 3 | 2,100 | 0.75 | 45% cotton<br>28% wheat |
| 30% change in cotton area but $V_c$ given according to original pattern | 2.252 | 3 | 2,100 | 0.93 | 45% cotton<br>28% wheat |

For the non-vegetation season (esp. during November, December, January and February) monthly depleted fraction values are smaller than 0.6 (even smaller than 0.2 for the above stated months). When $V_c$ component (mainly used for leaching) is taken out for this period and the depleted fraction is recalculated (assuming ET remains the same, $DF_{rev}$=ET/P), $DF_{rev}$ values close to 0.5 (which is a recommended limit by Bos et al 2003) are obtained on the average for the project area. The possible reasons for this can be as follows:

- The leaching norms can be wrong
- Water management problems

The ratios given in Table 3 demonstrate that:

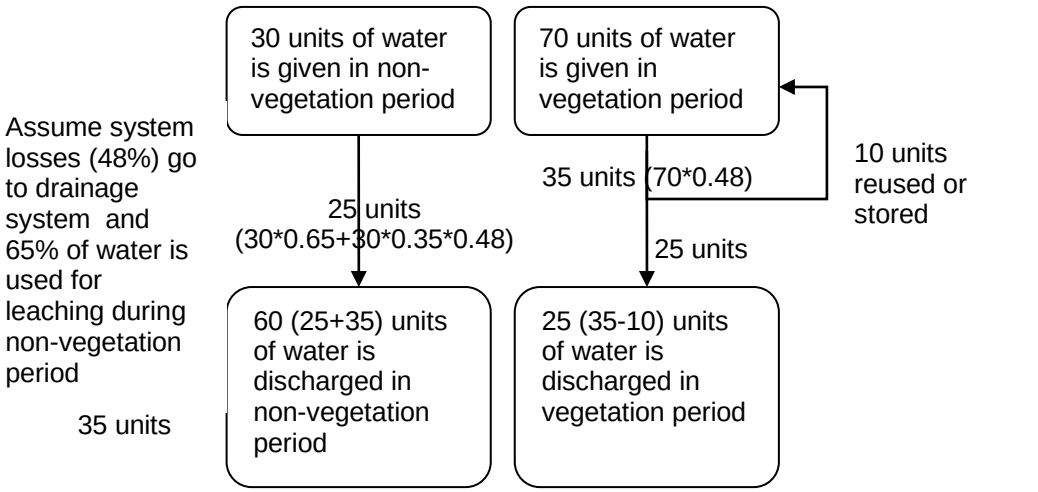
- There are considerable differences especially in the drainage volumes for different years although the same is not true for the irrigation amounts. The lack of correlation between the volumes measured for different district for the same year avoids us to think about an influence of a regional factor. Therefore, district level analysis shall be made.
- In Altyarik, Bagdad and Rishtan, on the average 85%, 65% and 145% of total irrigation water is discharged respectively.
- Irrigation limit is fulfilled with additional amount of water reaching to 15% in some years.
- The amount of water given in the vegetation period is 70% on the average.
- In Altyarik and Bagdad, one third of the total amount of drainage is discharged during vegetation period whereas in Rishtan this ratio is 50%.
- In Altyarik and Bagdad, the average annual amount of drainage water is almost the same as the amount of irrigation water given during vegetation period. In Rishtan it is twice.
- In Altyarik and Bagdad, the amount of drainage water during vegetation period is one third of irrigation water given during the same period. For Rishtan, these amounts are equal on the average. For the non-vegetation period the ratios are 1.5 for Bagdad and bigger than 2 for Rishtan and Altyarik.

**Table 3.** Annual amount of irrigation water given and water drained per districts in 2004-2006 (La quantité annuelle d'eau d'irrigation donnée et d'eau égouttée par districts dans 2004-2006)

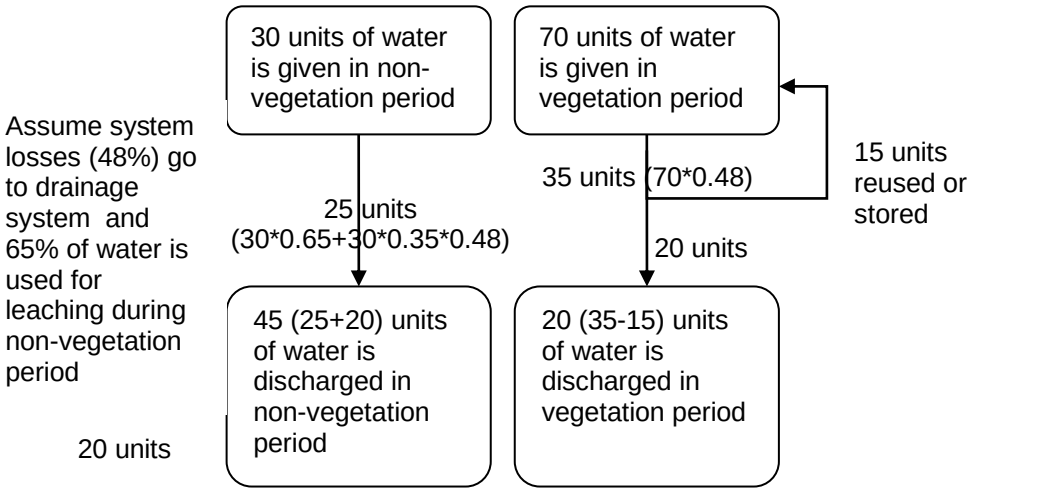
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| District | Year | Irrigation (*1,000 $m^3$) | | | | Drainage (*1,000 $m^3$) | | | 9/6 (%) | 6/3 (%) | 4/6 (%) | 7/9 (%) | 9/4 (%) | 7/4 (%) | 8/5 (%) |
| | | Limit | Vegetation | Non-vegetation | Total | Vegetation | Non-vegetation | Total | | | | | | | |
| Bagdad | 2004 | 235,900 | 192,500 | 75,546 | 268,046 | 21,660 | 134,380 | 156,040 | 58 | 114 | 72 | 14 | 81 | 11 | 178 |
| | 2005 | 255,700 | 191,600 | 82,800 | 274,400 | 68,130 | 86,310 | 154,440 | 56 | 107 | 70 | 44 | 81 | 36 | 104 |
| | 2006 | 228,540 | 170,700 | 64,290 | 234,990 | 73,790 | 109,730 | 183,520 | 78 | 103 | 73 | 40 | 108 | 43 | 171 |
| Altyarik | 2004 | 234,500 | 198,500 | 71,929 | 270,429 | 65,800 | 167,760 | 233,560 | 86 | 115 | 73 | 28 | 118 | 33 | 233 |
| | 2005 | 248,500 | 194,200 | 72,700 | 266,900 | 72,850 | 150,630 | 223,480 | 84 | 107 | 73 | 33 | 115 | 38 | 207 |
| | 2006 | 224,720 | 170,000 | 60,270 | 230,270 | 39,290 | 160,220 | 199,510 | 87 | 102 | 74 | 20 | 117 | 23 | 266 |
| Rishtan | 2004 | 238,100 | 197,100 | 79,687 | 276,787 | 232,170 | 157,890 | 390,060 | 141 | 116 | 71 | 60 | 198 | 118 | 198 |
| | 2005 | 252,500 | 194,100 | 78,000 | 272,100 | 184,130 | 196,800 | 380,930 | 140 | 108 | 71 | 48 | 196 | 95 | 252 |
| | 2006 | 233,010 | 174,500 | 65,920 | 240,420 | 123,830 | 239,260 | 363,090 | 151 | 103 | 73 | 34 | 208 | 71 | 363 |

The above results can be summarized schematically as follows:

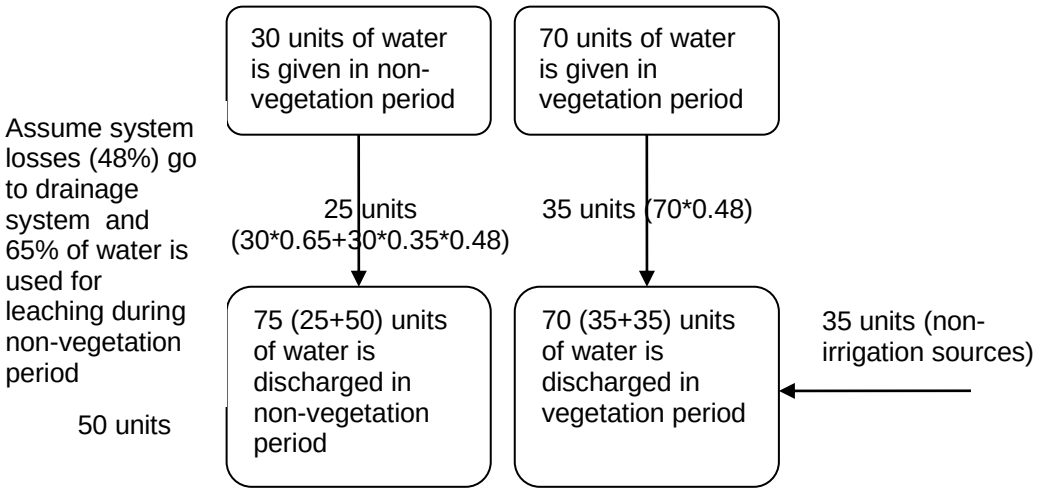
For Altyarik:




For Bagdad:




For Rishtan:



From the above analyses, it can be concluded that:

- During non-vegetation season, more water is discharged, which is an obstacle for cleaning the collector drainage network.
- In Altyarik and Bagdad, during vegetation season less water than system losses is drained. If the excess amount is not re-used it shall feed the aquifer. In Bagdad, it is known that drainage water is re-used many times. However, in Altyarik re-use is not that common.
- In Rishtan, almost constant amount is discharged throughout the year.

Reading Table 4, it can be concluded that:

- On the average for the period 2002-2006, in Altyarik and Rishtan, the excess amount of water given for irrigation is 50% more than what is needed, whereas in Bagdad this amount is the same with the norm. If it is assumed that all the other factors like agricultural, operational and management factors are similar throughout the project area, it can be said that the excess 50% is covered from reuse in Bagdad.

## 4. CONCLUSION

From the above analyses, the followings can be concluded:

- The problems in the project area can be classified as irrigation problems and drainage problems. Although these problems are highly interlinked, they need different approaches for solution.
- Upstream conditions affect the situation.
- Water management problems affect both groups of problems.
- Although annual average quantities like irrigation water are reasonable, their spatial and temporal distribution is not optimized which address to management problems mainly.

As a result; in order to remove the excess amount of water calculated in the water balance, a combination of proposals like rehabilitation of existing tubewells, installation of artesian and pressure relief wells, construction of interceptor collectors have been made. For salinity control subsurface horizontal drainage system has been proposed. Besides these measures, rehabilitation of irrigation and drainage network and installation of water measuring structures in all the onfarm canals have been proposed for better water management.

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**Table 4.** Amount of irrigation water given and crop water requirements per months for the period 2002-2006 (La quantité d'eau d'irrigation donnée et d'exigences d'eau de récolte par mois pour la période)

| | | Amount of Irrigation Water per Months for the Period 2002-2006 with a System Efficiency of 0.52 (*1000 $m^3$) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **District** | | **I** | **II** | **III** | **IV** | **V** | **VI** | **VII** | **VIII** | **IX** | **X** | **XI** | **XII** | **Total** | **$m^3$/ha** |
| Altyarik | Minimum | 2,269 | 2,876 | 1,634 | 9,573 | 12,945 | 14,320 | 14,834 | 15,374 | 6,995 | 11,384 | 5,163 | 397 | 103,764 | 7,018 |
| | Maximum | 5,345 | 5,951 | 15,793 | 21,672 | 19,783 | 20,145 | 25,445 | 25,267 | 15,769 | 16,918 | 8,913 | 1,667 | 182,674 | 12,355 |
| | Average | 4,072 | 4,176 | 11,944 | 13,395 | 16,614 | 17,410 | 19,968 | 20,758 | 11,653 | 14,347 | 7,368 | 775 | 142,480 | 9,637 |
| | CWR | 0 | 6,831 | 9,906 | 5,958 | 6,786 | 12,582 | 17,313 | 14,120 | 4,376 | 6,683 | 2,809 | 1,730 | 89,094 | 6,026 |
| Bagdad | Minimum | 4,325 | 5,140 | 9,110 | 9,537 | 12,807 | 13,885 | 19,074 | 19,239 | 6,931 | 8,748 | 6,479 | 1,084 | 116,359 | 6,511 |
| | Maximum | 9,264 | 7,688 | 15,108 | 23,252 | 24,727 | 27,696 | 26,056 | 25,396 | 19,558 | 16,566 | 13,409 | 4,624 | 213,344 | 11,939 |
| | Average | 5,980 | 6,209 | 11,944 | 10,650 | 15,449 | 17,212 | 19,677 | 17,425 | 11,147 | 14,466 | 9,225 | 1,960 | 141,344 | 7,910 |
| | CWR | 0 | 8,381 | 12,652 | 6,969 | 8,417 | 15,529 | 21,337 | 17,298 | 5,504 | 8,310 | 3,717 | 2,323 | 110,437 | 6,180 |
| Rishtan | Minimum | 4,203 | 6,304 | 11,186 | 11,053 | 12,151 | 13,185 | 15,623 | 15,961 | 6,983 | 8,285 | 6,422 | 971 | 112,327 | 8,727 |
| | Maximum | 7,273 | 4,948 | 10,592 | 14,827 | 14,899 | 19,433 | 20,139 | 16,930 | 12,782 | 11,560 | 10,740 | 4,127 | 148,250 | 11,518 |
| | Average | 5,457 | 5,130 | 10,164 | 10,721 | 12,284 | 14,853 | 16,746 | 13,980 | 9,318 | 10,059 | 7,272 | 1,398 | 117,382 | 9,120 |
| | CWR | 0 | 5,547 | 8,662 | 4,711 | 5,856 | 10,966 | 15,162 | 12,253 | 3,926 | 5,663 | 3,050 | 1,918 | 77,715 | 6,038 |