Baseline Assessment Amudarya
on water quantity, quality and ecosystems

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New Approaches to
Adaptive Water Management
under Uncertainty

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Baseline Assessment Amudarya
on water quantity, quality and ecosystem issues

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Report of the NeWater project -
New Approaches to Adaptive Water Management under Uncertainty
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Policy summary

This report presents the baseline assessment on water quality and quantity in the Amudarya basin in Central Asia from the Newater perspective. The present situation, the most important driving forces and their effects on water quantity and quality are highlighted.

The overexploitation of the basins water resources during Soviet times and in present days has caused serious ecological degradation. The region has enough water resources to sustain its population but due to low standards in water management currently all available water resources are used. Future water supply is highly uncertain due to climate change and the changing water needs of upstream areas and neighboring countries like the potential withdrawal of water by Afghanistan. Furthermore an increase in hydroelectric power generation might result in an even more regulated flow. All these changes will have an effect on the concentrations of salt and will affect the availability of water of sufficient quality downstream.

This report describes the data and models used to construct the method that is being developed in Work Package 2.3 of the EU funded Newater project. This is an analysis method to help quantify the Environmental Flow requirements of a river basin, not only with regards to water quantity but also with regards to water quality. This method can form the link between science and policy makers. It is derived from state of the art knowledge using measurements, catchment characteristics and process knowledge. But, when constructed, it will be quick and flexible at the same time. As such it can help to identify and understand the effects of future changes in land use and climate in an early stage.

Main conclusions are:

- The SIMGRO-MODFLOW modeling system creates the opportunity to evaluate the effects of both climate change and changes in the management and agricultural practices.

- In a high and mean water year there is no water shortage for agriculture or for environmental flow to the delta lakes, not in the baseline and not in the Hydromet climate scenario (this does not mean that there is enough flow for restoring or preserving the Aral sea).

- However even in a mean water year there are extended periods when no water reaches the delta. High salt concentrations in the delta lakes will be a risk. In a low water year agriculture is affected but negative impact is not equally distributed over the Delta. Northern Karakalpakstan is most affected together with parts of Turkmenistan.

- The impact of the climate change scenarios is also different for various crops. Winter wheat is less affected even downstream. But a large water consumer like rice is difficult to grow in North Karakalpakstan.

- Lake levels drop dramatically in a dry year. The sequence of dry years is very important. One dry year does not dry out most lakes, but two consecutive dry years will.

- The Amudarya system is highly managed and only models with sufficient management options will be capable of simulating the system dynamics.

- SIMGRO-MODFLOW proves to be a useful model to describe system dynamics and evaluate the impact of different scenarios by spatially integrating water demand and allocation.

- Data is not only needed to check a model, but a model is also needed to check the data. This is especially relevant in a catchment where the measurement infrastructure is deteriorating. A model can be an integrating base between different kind and different sources of data.

- Modeling a catchment the size of the Amudarya with such a complicated water management structure can not be done within the framework of one EU. It needs to be an ongoing process. It is the intention to continue the research on integration water quantity, water quality and ecosystems in cooperation with the EcoGIS center, which is part of the Institute of Irrigation and Melioration in Taskent and other partners.

This report makes clear the needed information to set up this quick analysis method, its possibilities and limitations. In the coming years the practical implications in the region will be explored.

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Keywords: Water quantity, water quality, Amudarya River, Delta, Aral Sea, drainage, irrigation, environmental flows

Contents

Preface

Within the Newater project work package 2.3 'Resolving conflicts between water quantity, water quality and ecosystems' contributed to the main goal of the Newater project to develop new approaches to adaptive water management under uncertainties.

This document is based on the activities of Newater work package 2.3 in the Amudarya case study in the past 4 years. During this period emphasis has been placed on data collection and interpretation, contacting key persons within the watershed and schematization and preparation of the available data for input in the models. In this baseline assessment the water quantity, quality and ecosystem issues in the Amudarya watershed are described, the available data is listed as well as the different modeling approaches to model these processes with the available data. Apart from the referenced scientific literature the following Newater sources of information have been used:

- Research Action Plan (Maja Schluter, 2006)
- Workshop October 2005: Overview and report on roundtable discussion on water quality (Raisa Toryanikova, 2005)
- WP 2.3 Resolving conflicts between water users related to water quantity, water quality and ecosystem services (Schoumans, 2005)
- Workshops and field visit May 2006: Ecology workshop Nukus and Transboundary workshop Urgench (Christian Siderius, 2006)
- Brief overview: Quality of Water Resources in the Amudarya River Basin: conditions and problem (Schluter et al, 2006)

The models are calibrated using the available data. The effects of the changes in driving forces like climate change or land use change and the interrelations between water quality, quantity and ecosystems are highlighted in this report.

1 Introduction

1.1 Problem definition

The Amudarya is the largest river in Central Asia. It stretches for 2,540 km from the Pandj and Vakhsh headstreams and has a basin of 309,000 km^2. It has many tributaries in the mountainous part of its catchments (the flow generation zone), the largest of which are the Vahsh, Pandj, Kunduz (from Afghanistan), Kafirnigan, Surkhandarya and Sherabaddarya. The Amudarya River does not have any significant tributaries along the 1,200 km length in the plain part of its basin. Along the Amudarya River and especially in the delta region the Amudarya water is diverted in numerous irrigation and drainage canals.

Throughout the basin, precipitation is low, on average approximately 200 mm/year. The total average annual flow in the Amudarya is estimated between 73.6 km^3 and 81.8 km^3 (Schlüter, 2005), some 19 km^3 of which is generated in Afghanistan. In a year of high water availability (5% probability) the flow is 108 km^3, while in a year of low availability the flow is 47 km^3. Currently the average volume of Amudarya water reaching the Larger Aral Sea per year is about 8 km^3, although there is considerable variation from year to year. The problem of a disappearing Aral Sea is world wide known, solutions are not.

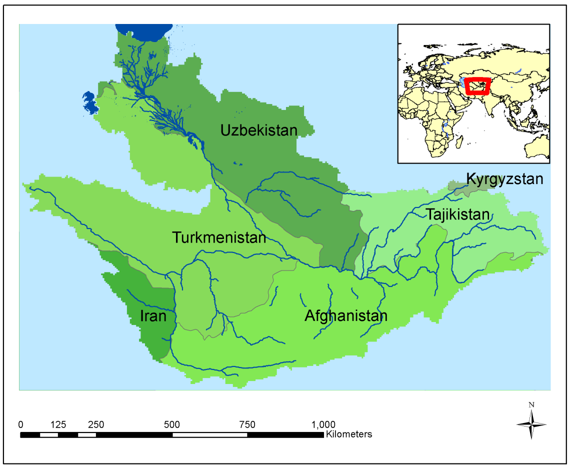


Figure 1 Location Amudarya river basin

Not only is the amount of water reaching the Aral Sea dramatically reduced, its quality has deteriorated as well. During the past 30 years the average salinity of the Amudarya water downstream of the Tuyamuyun hydro-post (main reservoir just before the downstream irrigation areas in the dleta) has almost doubled as a result of diminishing flows and saline return flows. These saline drainage flows from upstream areas in Uzbekistan and Turkmenistan are presently estimated at 6.5 km^3 with salinity levels that often exceed 5 gr/l. Due to this added salt load, the average salinity level of the Amudarya downstream of the Tuyamuyun Reservoir is now almost 1 gr/l, while during dry years salinity levels in the river can exceed 2 gr/l. The average discharge of salts is approximately 84 million tons per year (World Bank, 1998).

Due to the large amounts of water used for irrigation and the related salinization, water of sufficient quality is scarce especially downstream where different water users compete. Agriculture is the largest user of water and of high economic importance. Healthy drinking water is of course a necessity. But also the restored lakes and new ecosystems which have emerged in desert depressions to which drainage water is discharged, can only sustain salinization up to a certain limit. They provide valuable opportunities for livelihoods of local inhabitants but are vulnerable and depend on the water quantity and related quality and the timing of their availability. Modeling tools can be helpful in assessing the possibilities of improved water allocation on a catchment wide scale, integrating soil, land use, water quantity and quality in surface and groundwater.

1.2 Consequences of water scarcity and deteriorating quality

The economies of the countries within the Amudarya watershed still heavily rely on irrigated agriculture. However the productivity is decreasing mainly because of soil salinization and water shortage. Deteriorated irrigation infrastructure and bad water management lead to high water losses (Schlüter, 2005). Drainage water contains high salt concentrations limiting the possibilities of downstream users. Another dramatic side-effect of the irrigation projects is the increase of groundwater recharge from the irrigated lands. As in many irrigated areas the natural drainage capacity of the sub-soils is not sufficient to discharge this excess water, the regional groundwater levels have risen, sometimes up to tens of metres, until finally the root zones of the crops were reached. Waterlogging and salinization problems became manifest in large areas. Artificial drainage systems were installed in the affected areas to alleviate these problems. These artificial drainage systems have, however, caused significant impacts on the regional hydrogeology in terms of the groundwater flow patterns and flow rates. As a result the drainage systems not only discharge the excess water and salts introduced by the irrigation systems, but they also mobilise a significant amount of ambient salts (in some areas up to 50 % of the total amount of discharged salts). The Aral Sea basin is a closed basin the safe removal of drainage water is difficult. Natural outlets are absent or remote. Drainage water is presently evaporated in dedicated ´waste areas´ or wetlands (causing various problems), or returns to the irrigation system, thus leading to an increased salinity of the irrigation water and imposing adverse impacts on the downstream areas.

Human health problems are severe, especially in the delta region (caused e.g. by poor drinking water, but also a multitude of other factors). During the workshop in June 2006 the bad drinking water quality was addressed as a main issue by local NGO's in the delta region (Taryannikova, 2005). Low water quality in the region is considered as a significant reason for the high sickness rates among population. This is especially of relevance for the downstream areas of the Amudarya as in many cases the population uses the open water bodies for domestic purposes as well as for drinking. As a result the decreasing water quality leads to an increase of expenses for the water treatment.

Another important livelihood under stress in the delta region is fishery in the lakes in and around the irrigated areas. As most of these lakes are (partially) fed by drainage water salt levels can reach high levels, up to 25 g/l. These high salt concentrations lead to a reduction of fish quantity and thus income. Salt concentrations and quantity of drainage water as well as availability of fresh (irrigation) water to buffer the salinity especially during vulnerable periods (for example hatching of fish eggs) are critical elements in the management of these vulnerable ecosystems.

Other negative effects are the loss of ecological balance caused by anthropogenic pollution, the loss of biological diversity like the Tugai forests and degradation of landscape and recreation areas (Taryannikova, 2005)

1.3 Main drivers

The overexploitation of the basins water resources during Soviet times and in present days has caused serious ecological degradation. The region has enough water resources to sustain its population but due to low standards in water management currently, all available water resources are used. Future water supply is highly uncertain due to climate change and the changing water needs of upstream areas and neighboring countries like the potential withdrawal of water by Afghanistan (Schlüter, 2005). Furthermore an increase in hydroelectric power generation might result in an even more regulated flow. All these changes will have an effect on the concentrations of salt and other species and will affect the availability of water of sufficient quality. The effect of the following driving forces on water quality will be evaluated in WP 2.3.

1.3.1 Water management

Along the main river, there are two reservoirs with hydroelectric power stations, representing the main structures for management of water flow and salinity, several distribution points to serve irrigation water needs, main and side inflows including return flow, and water intake for communal needs. At present additional large dams are being constructed along the Amudarya river (pers. com. A. Savitsky). Their effects could include an increase in the available regulated water resources, or the provision of additional hydropower, but could as well include a decrease of available resources downstream due to increased irrigation diversions upstream (Schlüter, 2005). In general the Amudarya river flow will be a more regulated.

1.3.2 Climate

The natural flows are generated mainly by snow and glaciers melt and are highest in summer (July-August) and lowest in winter (January-February), although the pattern of flows in downstream ranges is modified by diversions and the reservoirs in the system.
Prior to the massive expansion of irrigated agriculture in the basin during the Soviet Union mainly in the 1960s to 1980s about 40 km^3 of the Amudarya discharge reached the Aral Sea. From 1971 to 1980, inflow was reduced to 30 %, going down to only 6 % from 1981 to 1990 were a series of low water years occurred. The following nine years 1991 to 1999, it increased to 13 % of the average long-term level again (Schlüter, 2005).
Changing climate can influence the amount of snow falling in winter or the pattern of melting in spring and summer. These changes will affect both quantity and timing of Amudarya discharges on which most downstream irrigated agriculture depend.

1.3.3 Land use

Irrigated agriculture, mainly cotton and wheat (in current years), is the main water user, which accounts for more than 90 % of water intake. During Soviet times, a huge irrigation network has been constructed, including the Karakum canal with a length of more than 1500 km and a water intake of 500 m3/s (and more), providing Turkmenistan with most of its water needs. The irrigated area in the Amudarya basin is on average 3.8-4.0 million ha (Schlüter, 2005). Table 1 shows the increase in irrigated area (in the whole Aral Sea Basin) over recent years and projected future extent.

Table 1 Past and Projected Future Extent of Irrigated Area (´000 ha) in the Aral Sea Basin

Year	*Tajikistan*	*Turkmenistan*	*Uzbekistan*	*Total*
1990	706	1,329	4,222	6,257
1995	719	1,736	4,298	6,753
2000	927	1,714	4,259	6,900
2010	1,064	2,240	4,355	7,659
2025	1,188	2,778	6,441	10,407

Source: NWG Reports from GEF Water and Environmental Management Project

In recent times, Afghanistan was almost excluded from the list as water user. However an additional quantity of water could be used for the irrigation of the fields in Afghanistan very soon (up to 10 km^3). The future development of Tajikistan’s and Afghanistan’s vast water resources in the Amudarya River basin, which are to a large extend unregulated at the present time, will affect the water quantity and quality of downstream countries.

2 Methodology

2.1 Set-up

Within this study water quality aspects will be related to water quantity aspects and water ecological aspects. The focus is on new approaches to balancing water quantity and water quality for adaptive management. Figure 2 shows a diagram of possible approaches. The main driving forces have been described in paragraph 1.3. This chapter describes briefly the process oriented approach in the Amudarya catchment. Data availability on river basin characteristics and water quality measurements will be described in chapter 3.

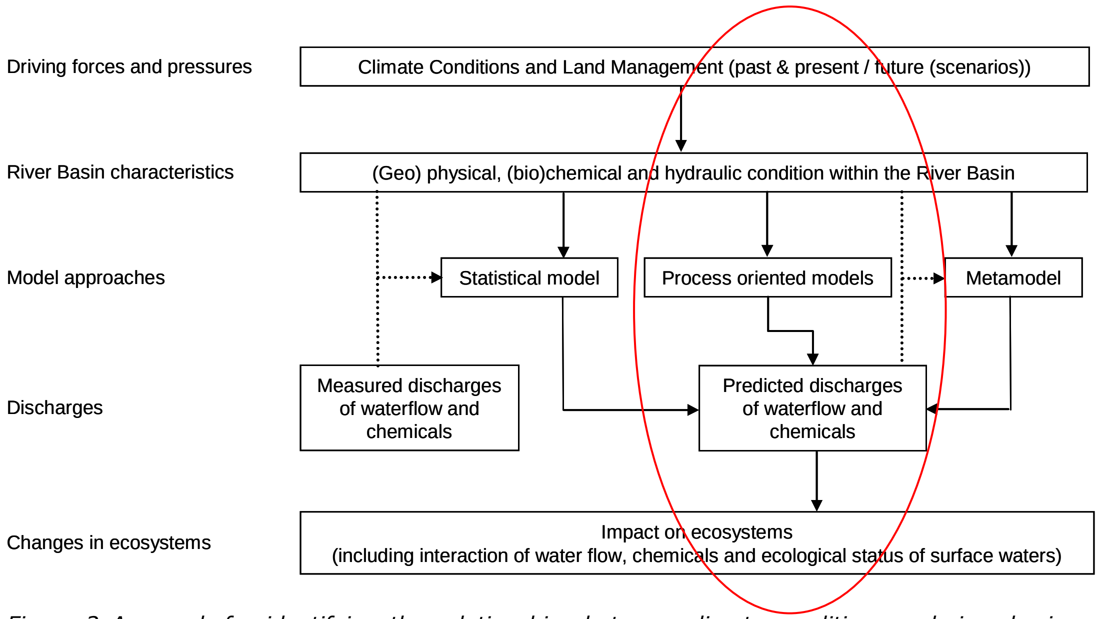


Figure 2 Approach for identifying the relationships between climate conditions and river basin characteristics and their effects on water quality aspects (red circle = focus of this report).

The application of process oriented models is used to predict the water quantity and quality at catchment scale. These models can be used to predict the salinity status of the river basin in time and space after calibration of the models on measured water quantity and quality aspects like discharges and concentrations.

Based on the outcome of these modeling results, simple relationships (meta-models) will be derived between the meteorological conditions and the within-basin characteristics with respect to chemical effluents in the basin. These relations will then be used to develop and apply strategies for incorporating ecosystem services into river basin management.

2.2 Focus

2.2.1 Thematic

In this study the relation between water quantity, water quality and ecosystems will be illustrated with the purpose of helping to solve the conflicts deriving from the pressure on water resources and a deterioration of its quality and connected ecosystems. In a workshop in Tashkent, October 2005 the following main causes of this deterioration in quality were identified:

- Irrevocable flow withdrawal;
- Distributed contamination sources: collector-and-drainage flow from the irrigated areas;
- Point contamination sources: industrial, municipal, live-stock farming sewage;
- Surface and ground sinks from the industrial and urban urbanized areas;
- Recreational stress on the riverine and coastal ecosystems.

This report will focus on the impact of the main drivers (paragraph 1.3) behind the first two causes which are directly related to the high salt concentrations in surface and ground water. Industrial/chemical pollution and pollution by agriculture in the form of nutrients and pesticides and problems related to human waste water management are important issues as well but will not be part of this study.

Next to the direct causes of deteriorating water quality as listed above there are also several more institutional related causes which prevent a quick solving or proper analysis according to the workshop held at Hydromet, Tashkent, in October 2005:

- First one is a lack of adequate information. The available monitoring systems do not provide for the assessment of the water resources quality and the real level of their contamination to a full extent. Bad monitoring causes considerable economical losses and damages in a social sphere.
- Second one is the absence of the system and experience in the estimation of damage and risk in the result of bad water quality.
- The third one that is also important is that the officials and experts do not have the relevant experience and knowledge in the field of the water quality management. It is necessary to carry out studies and to set up the training system (raising the level of one's skill) for the specialists of the different levels on a permanent basis.

This study will partly address these issues. The available data from the monitoring system will be used in the watershed models. This results in an indirect evaluation and comparison of the different point measurements, mutually and against the water and salt balances for different regions. By using models a wider area can be evaluated and focus areas can be highlighted where measurements are most useful. Furthermore, by linking water quality to ecosystems and ecosystems services, the effect of changes in water quality and the damage and risk this imposes will become clearer. Finally, the assessment will hopefully result in a better understanding, by both experts and officials, of the water quality situation within the Amudarya river basin and the effect that changes in climate, land- and water use will have on the ecosystems and the services they provide.

2.2.2 Spatial

Stakeholders and local scientists voiced very strongly their wish to use the opportunity of the NEWATER project to address issues of monitoring, water quantity and quality management on a river basin scale (Schlüter, 2005). Figure 2 shows the greater extent of the Amudarya basin, derived from the SRTM elevation (AVSWAT, Luzio *et al*. 2001, 90m SRTM DEM, resampled to 1 km DEM). The spatial spatial extent of the modeling efforts focuses on the inner Amudarya catchment, without the large area drained or fed by the Karakum channel in Turkmenistan or the Zerafshan river. The connections between the Amudarya and the Karakum channel and the Zerafshan river are important as large amounts of water are diverted from the Amudarya to these catchments. However the connections are completely regulated by weirs and pumps and can therefore be treated as boundary conditions for the analysis.

As figure 2 shows the inner catchment consists of the catchment area, a small midsection without any tributaries and the delta were the Amudarya is diverted into numerous irrigation canals. The water quality model will focus on the Amudarya delta region. By incorporating climate change scenarios and studies on Amudarya river runoff also the hydrological changes in the upstream area will be taken into account.

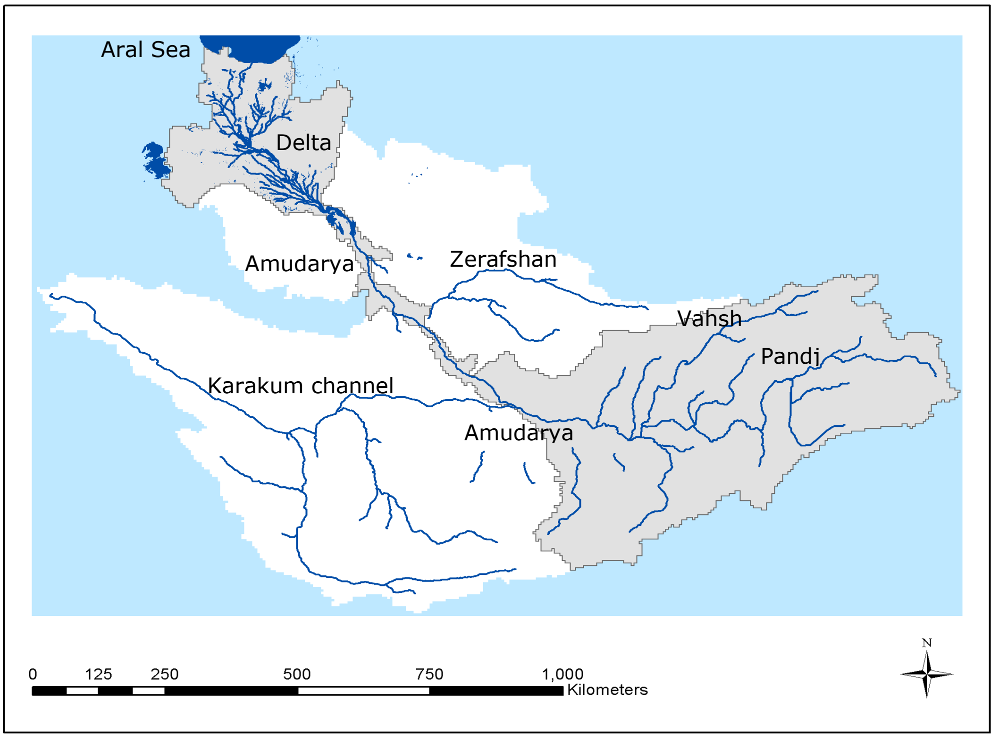


Figure 2 Greater Amudarya catchment (grey and white) and inner Amudarya catchment (grey)

2.3 Approach

The process oriented model Modflow-Simgro is applied in the Amudarya delta, on a 1 km grid scale. The model is an integration of a groundwater module, an unsaturated zone module and a surface runoff module. For all compartments both the discharge of water and species/chemicals can be simulated. Schematization of the catchment is based on the SRTM elevation data and river and channel shape files.

Calibration is done using collector drain discharges. Furthermore water balances for the most important subcatchments and river stretches will be checked as this provides the only possibility to gain confidence in the model when important ground and surface water data is lacking.

Evaluation focuses on the effects of upstream changes on the downstream irrigation areas of the Amudarya Delta. The following impacts of important driving forces will be inserted:

- Impacts of climate change on river flows will be simulated on this scale.
- Impacts of changing land use. What will the effect be on salt and water concentrations in downstream river stretches? This includes the possible increase use of water for irrigation in the Afghan part of the Amudarya catchment.

Finally the focus will be on water quality at the Amudarya outflow and main collector drains going to the Aral Sea and the lake ecosystems. This provides the opportunity to link concentrations of salt and discharges of water to the requirements of these lake ecosystems and to link the uncertainty of driving forces like climate change to the ecosystem service they can provide. This will provide a tool for quick analysis and will produce the data on which the guidelines for the ecosystem services and environmental flow concepts can be based.

2.4 Scenarios

The final step will be to study the catchment response in the form of changes in yield, runoff and water quality as a result of different changes in climate and socio-economic circumstances. Table 2 shows the various changes which have been taken into account. These (components of) likely or less likely scenarios originate from the following sources:

- Hydromet climate scenarios: estimations by the Hydrological department of Uzbekistan
- Demand assumptions made by the UZGIB, research institute of the ministry of agriculture

In the climate change scenario runoff into the delta is decreased by 12% while at the same time potential evapotranspiration for both agriculture and lakes is increased by 12%. In this scenario it is also expected that domesticand industrial use of water increases. In the technical scenario it is expected that improvements in irrigation will reduce the amount of irrigation given per gift can be decreased by 20%. In the central part of the delta lake system, storage increases with maximum level going from 3 m to 4 m. In the environmental flows scenario the environmental flows will be guaranteed, if available at Tuyamuyun at the beginning of the delta. This is done by giving them the same priority as agriculture (but after domestic use). The different scenarios are cumulative; the new scenario also includes all changes from the previous scenarios, so the Environmental flows scenario is also influenced by climate change and Technical improvements.

Table 2 Climate and socio-economic changes

	inflow	priority	infrastructure	demand
Baseline				
Domestic + industry		1		0.8 km3/yr
Agriculture		2		
Wetlands		3		
Climate change	-12%			
Domestic + industry		1		2.4 km3/yr
Agriculture		2		higher temperatures, higher evapotranspiration
Wetlands		3		
Technical	-12%			
Domestic + industry		1		2.4 km3/yr
Agriculture		2		better efficiency; higher temperatures, higher evapotranspiration
Wetlands		3	improves	
Enfironmental flows	-12%			
Domestic + industry		1		2.4 km3/yr
Agriculture		2		better efficiency; higher temperatures, higher evapotranspiration
Wetlands		2	improves	5 km3/yr

MPI climate scenarios based on model calculation with the REMO model (NEWATER wp 2.1) were not used in this analysis as they were not yet available. The effects of these changes will be highlighted in chapter 6.

3 Data

3.1 Sources of information

Within the NEWATER WP 2.3 process oriented models are used which need to be filled with geophysical data. A hybrid data source approach is used which is characterized by the following data levels:

1st level	global data: FAO soil types, GLC landcover, GCM meteo data, satellite data like LandSat and SRTM elevation data. Public domain. Can, in general, be derived from internet. Variation in scale and resolution.
2nd level	catchment specific data: Man made channels, reservoirs, structures, weirs, local land use. Derived from local experts, models, country specific mapping and schematization.
3rd level	location specific data: point source data e.g. meteorological stations, soil characteristics based on field measurements, site specific discharges or weir levels. Based on on-site research and measurements.

Considering the time frame of wp 2.3 the resources available and the difficult access to data, mostly 1st and 2nd level data will be used.

3.2 Input data

The following input data is made available (figure 3a tm 3g):

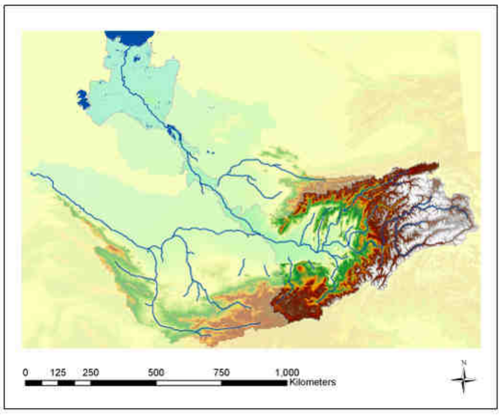


Figure 3a
Type: Elevation data
Source: SRTM shuttle mission
Date: 2000
Scale: 90m grid

Use: elevation, derivation of streamflow and (sub)catchment boundaries

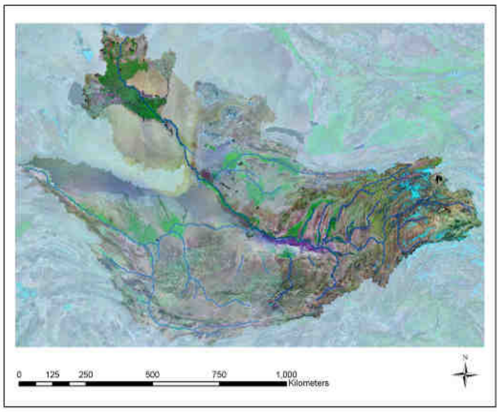


Figure 3[b]
Type: Satellite data
Source: EarthSat
Period: between 19-08-1999 and 03-08-2001
Scale: 14m grid

Use: derivation of irrigated areas, check of streamflow patterns, landuse

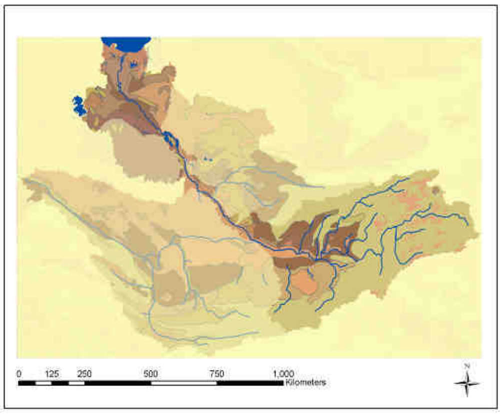


Figure 3[c]
Type: Soil type data
Source: Soil and Physiographic database for north and central Asia, FAO land and water media series nr 7
Date: -
Scale: 1:5 million

Use: spatial distribution of soil properties (derived from global pedon database)

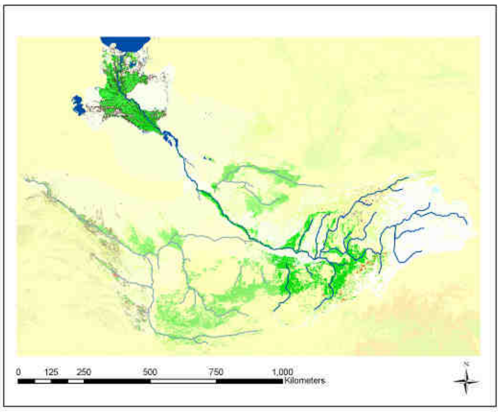


Figure 3[d]
Type: Land cover data
Source: JRC (GLC2000)
Date: 2000
Scale: 0.0089 degrees (70-1000m grid)

Use: spatial distribution of land cover to be used in combination with FAO 56 crop parameters or locally derived crop parameters

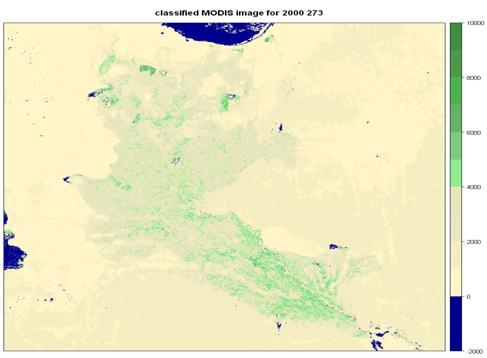


Figure 3[e]
Type: MODIS vegetation reflection NDVI
Source: NASA
Date: 2000-2008
Scale: 250m grid

Use: spatial distribution of land cover over time

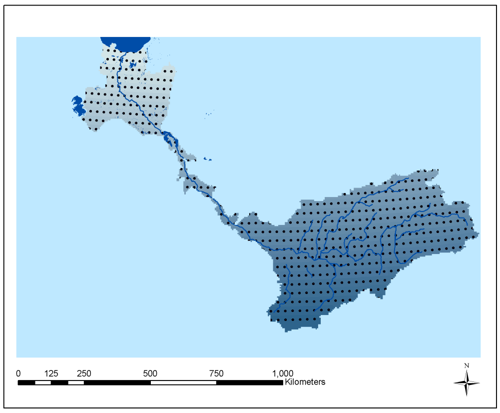


Figure 3[f]
Type: Meteo data
Source: ECMWF EA 40 climate model
Period: 1970-2001
Scale: 0.3 degrees

Use: temp, wind, radiation to calculate potential evapotranspiration

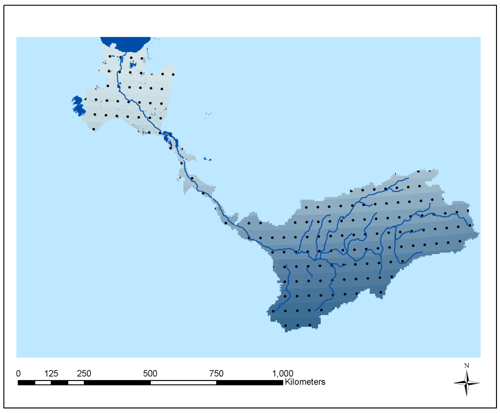


Figure 3[g]
Type: Meteo data
Source: DWD station interpolation
Period: 1951-2004
Scale: 0.5 degrees

Use: precipitation

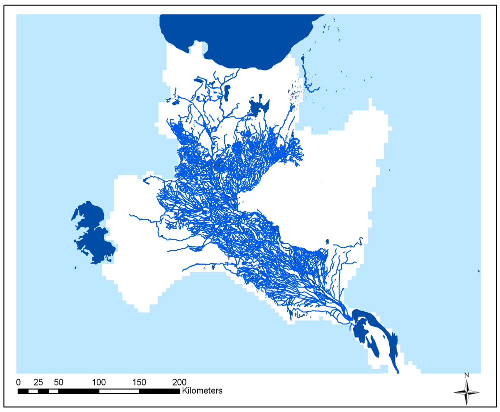


Figure 3[g]
Type: Irrigation and drainage canals in Delta
Source: -
Date: -
Scale: primary, secondary and tertiary channels and main collector drains

Use: refine watercourse network

Most data is first level data, suitable for modeling on a catchment scale. Care should be taken when zooming in. Second level data is only available on canal and drainage outlay in the delta area. However this is very important as the delta will be the target area for evaluating the impact of changes upstream. The elevation data is the most high resolution data available, together with the delta canals shapefile. FAO soil and JRC land cover data from the Amudarya are less site specific.

Not all data is easily available not even on larger scale. Maps on the spatial extent of geological layers and hydro-geological properties are not available in digital form although they are known to exist in hardcopy.

3.3 Measured data on water quantity and salt

The following measured data is made available (Schlüter *et al.*, 2005). Many stations have been in operation for short period. In figures 4^a and 4^b the stations measuring water discharges and salt concentrations are shown. For wp 2.3 an initial selection of four stations has been made on which the models will be calibrated (figure 4^c).

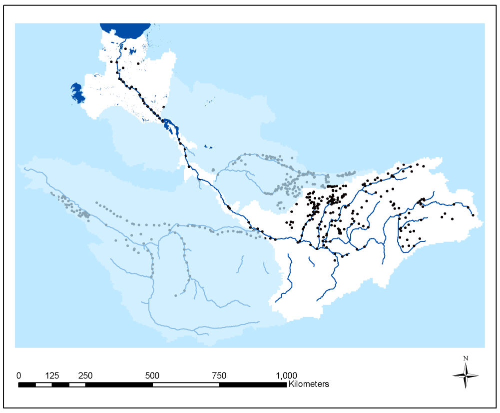


Figure 4^a
Type: Water measurement stations
Source: hydromet
Period: (1911/1934/) 1956 - 1991
Frequency: monthly average

Parameters: discharge

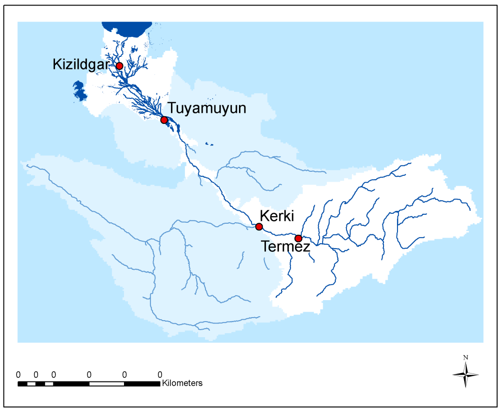


Figure 4^b
Type: Salt measurement stations
Source: hydromet or nature protection
Period: various, between 1938 and 1997
Frequency: once every 1/2 months

Parameters: Ca, Mg, Na, Ka, HCO_3, HSO_4, Cl

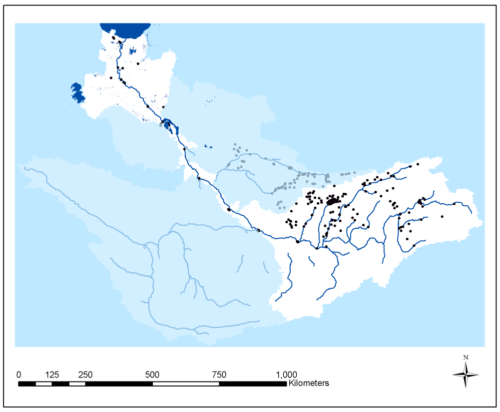


Figure 4^c
Type: Focus discharge and salt measurement stations
Source: hydromet or nature protection
Period: (1938/1953/) 1974 – 1990 (/1997)
Frequency: once every 1/2 months

Parameters: Ca, Mg, NaKa, HCO_3, HSO_4, Cl

4 Water balance

In paragraph 4.1.1 to 4.1.4 the different components of the water balance of the Amudarya Delta are described based on data and literature values. Additionally, the way in which this information is used in the model is briefly explained in each paragraph.

4.1 Water balance components

4.1.1 Precipitation and evaporation

Theory and data
Tables 2 shows the long term average monthly evapotranspiration for Tashkent from the FAO CLIMWAT database. In Table 3 local values are presented for the year 2003. These local values are on average 25% lower than the long term average values for Tashkent.

In table 3 also the monthly precipitation at this research farm in the Amudarya delta is shown. Most rains falls in spring with a peak in May. During the dry summer months hardly any rain fell. Agriculture in these months is totally dependent on irrigation from the Amudarya river which has the highest discharges during these months.

Table 2 Long term average monthly potential evapotranspiration for Tashkent (source; FAO)

	ETo [mm/d]	*ETo [mm/month]*
Jan	0.73	22.6
Feb	1.10	30.8
Mar	1.95	60.5
Apr	3.21	96.3
May	4.87	146.1
Jun	6.46	193.8
Jul	6.75	209.3
Aug	5.99	185.7
Sep	4.34	130.2
Oct	2.36	73.2
Nov	1.35	40.5
Dec	0.99	30.7

Table 3 Monthly mean temperature (*T*), relative humidity (*RHmean*), wind speed (*u2*) and short wave radiation (*Rs*) as well as potential evapotranspiration (*ET0*) and precipitation (*P*) per month at the research farm in 2003 (source; Forkutsa, 2006)

	T [ºC]			*RH [%]*			*u2 [m sec-1]*			*Rs [MJ m-2day-1]*	*Eto [mm]*	*P [mm]*
	Mean	*Max*	*Min*	*Mean*	*Max*	*Min*	*Mean*	*Max*	*Min*	*Mean*		
Jan	-0.8	3.3	-4.4	85	97	74	1	2.1	0.2	5.5	13	14.6
Feb	0.5	3.9	-2.3	78	91	51	1.5	2.9	0.1	6.9	21	23
Mar	5.1	10	1	72	88	57	1.5	4.9	0.1	12.2	46	25.8
Apr	13.2	18.8	7.8	53	90	28	2	6	0.5	16.1	95	16
May	20	25.7	14.2	58	85	36	1.2	2.9	0.5	21.3	129	53
Jun	24.2	30.5	17.3	48	70	28	1.2	2.9	0.5	22.5	150	15.2
Jul	27.8	33.9	21.5	44	59	30	1.6	2.9	0.5	24.7	188	0
Aug	26.5	33.6	18.8	49	59	40	0.8	2	0.4	24.3	153	0
Sept	19.4	26.8	12.5	51	62	42	0.9	1.8	0.3	19.8	102	2
Oct	14.5	22.4	7.7	51	77	32	0.8	2.1	0.1	13.3	60	5.8
Nov	5.4	9.5	2.1	77	94	46	1.3	4.2	0.1	5.5	21	13.4
Dec	0.6	5.7	-3.3	73	95	46	1.2	3	0.2	6	16	2.8
TOTAL:											994	172

Implementation

Precipitation and the parameters to derive potential evapotranspiration are measured on several locations in the Amudarya catchment. However it is difficult to get a complete dataset. Furthermore to get coverage of the whole catchment data needs to be interpolated. Therefore pre-processed data sets of the Deutsche Wetterdienst (DWD, 2006) were used which are based on actual measurement and extrapolated to cover the whole world on a 0.5° grid scale.

The temporal resolution of the DWD dataset is one month. The hydrological models however preferably need daily data. To spread the monthly totals the ECMWF climate model data (ECMWF, 2006) was used which gives an predicted precipitation for each day. This precipitation was then transformed into a fraction of the monthly total. ECMWF data was not used itself as it showed some unexplainable abnormalities.

Figure 5 shows the spatial spread of precipitation over the delta area for the year 1990.

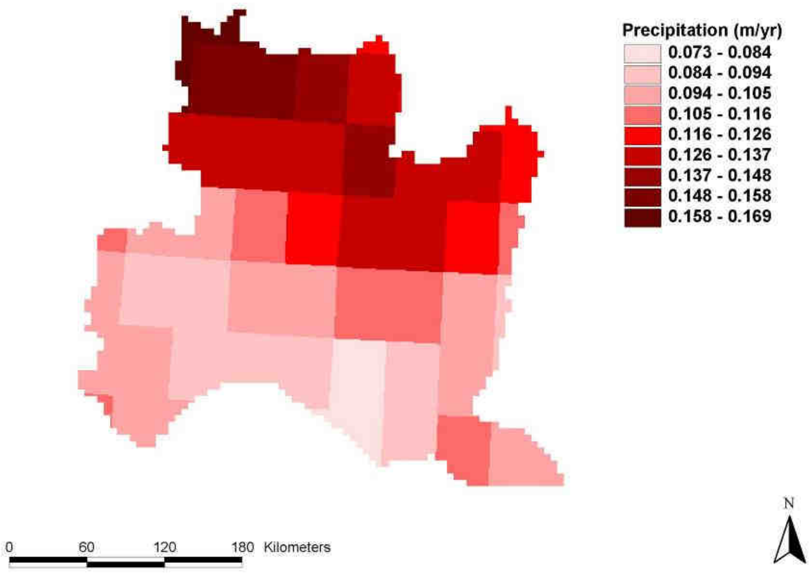


Figure 5 precipitation over the delta area for the year 1990 (source DWD, 2006)

For evapotranspiration values FAO long term averages were used. Actual evapotranspiration is calculated by the hydrological model based on this potential evapotranspiration, specific crop factors and the availability of soil moisture.

4.1.2 Amudarya river flow

Theory and data

In figure 6 the average monthly discharge at the Tuyamuyun measurement station is shown for an extensive period stating in 1934, with a large data gap between 1938 and 1953. The average annual river discharge has declined from 59 km^3 during the period of 1955-1960 to 29 km^3 for 1985-1990. The main reason for this decline is the increase water use for irrigation in upstream areas and especially the construction of the Karakaum canal which started in 1954. This canal diverts about 500 m3/s of water from the Amudarya River. Another reason for the decrease in discharge, mainly during the period 1970-1980, is diversion of drainage water into desert lakes to prevent the Amudarya to be polluted with highly saline drainage water (Roest, 1995).

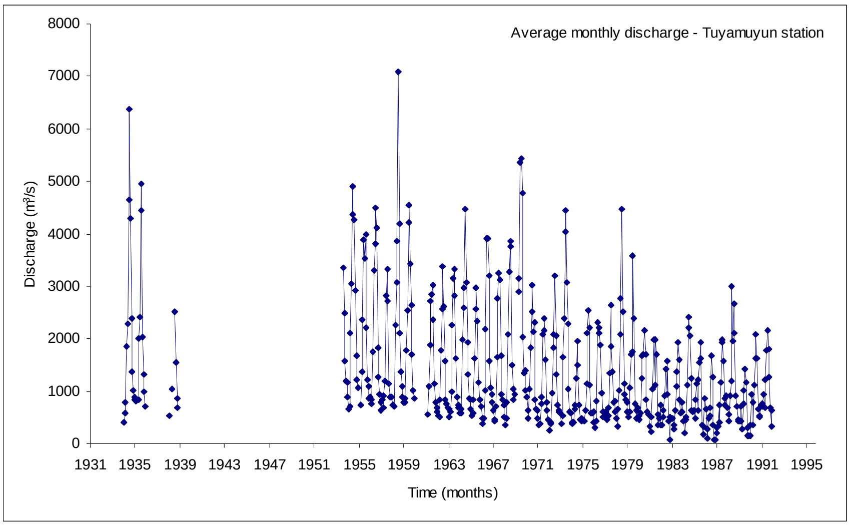


Figure 6 average monthly discharge just downstream of the Tuyamuyun reservoir

Implementation

Table 4 shows the imported monthly averages for 1985 as used in the model calibration run.

Table 4 average discharges for 1985 at the Tuyamuyun Reservoir

month	*Discharge(m^3/s)*
January	1920
February	2462
March	2334
April	2142
May	3797
June	3389
July	3597
August	2694
September	565
October	325
November	1372
December	2202

4.1.3 Irrigation and drainage

Theory and data

An extensive network of irrigation channels and collector drains divert the water of the Amudarya River to the cotton, rice and wheat fields and from these fields back to the river or in most cases to drainage lakes and desert depressions. Three main regions are supplied with river water; Khorezm on the south western side of the Amudarya, The Tashauz region in Turkmenistan and the autonomic republic of Karakalpakstan on the eastern and northern side of the Amudarya. Figure 6a and 6b give an indication of the complexity of this vital system.

Almost all (99%) of the Khorezm area is supplied by furrow irrigation. Unlike the historical irrigation system, the planning and operation of irrigation systems in Khorezm today is poorly adapted to the climate, crops, and soils of the region (Forkutsa, 2006).

The total irrigation canal system in Uzbekistan amounts to 167 785 km, only 19% of which are lined. As a result, the actual water consumption reaches 14 700 m3 per ha, whereas only 5 500 m3 per ha arrive at the field. Overall water use efficiency in Khorezm is said to be less than 50% and even reported to be less than 30% (Vlek *et al.*, 2001). Thus, Khorezm appears to have substantial scope for improvement of the water use efficiency. Bos & Wolters (1989) calculated overall efficiencies from representatively gathered data using a differentiation according to the regional precipitation. In the analyzed irrigation projects in areas with precipitation lower than 200 mm per year (comparable to the situation in Khorezm), the calculated average overall efficiency amounts to 42 %; the average value minus standard deviation is in the order of 25 %. In comparison with the worldwide-analyzed overall efficiencies, the estimated amount of less than 30 % for the region of Khorezm can be considered in the lower range.
Figure 7 clearly shows the large amount of water used for irrigation between the reservoir of Tuyamyun at the beginning of the Delta and at Kizildgar where most water has already been diverted into the irrigation canals.

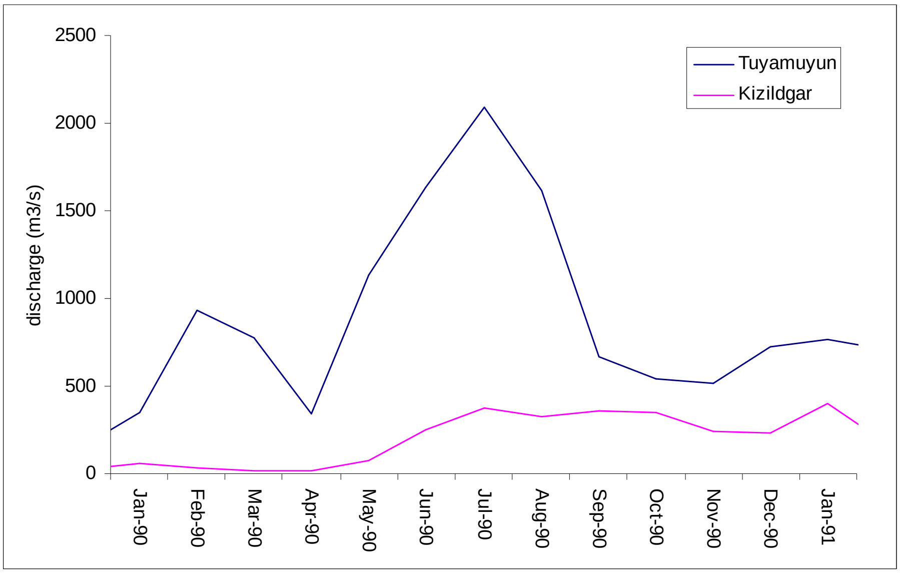


Figure 7 discharges at Tuyamuyun and Kizildgar for the year 1990

Although 92 percent of the land in Khorezm is drained, underground field drainage is lacking and drainage ditches are too widely spaced and too shallow to prevent a rising water table. In fact, the on-farm drain network has declined from 33m/ha to 29m/ha between 1982 and 1999. Drainage is strictly horizontal, with only 431 km of drainage pipes and a network of 6229 km of open drains feeding into 3 400 km of main and inter-farm collectors. Drain depth is 2.5 to 3.5 m. consisting of open drains or widely spaced tubes, generally 800 m apart. (Vlek *et al.,* 2006)

Implementation
In our assessment all main irrigation and drainage collectors where schematized (figure 8 a, b and c). In total, 990 sections divide and recollect the water of the Amudarya delta

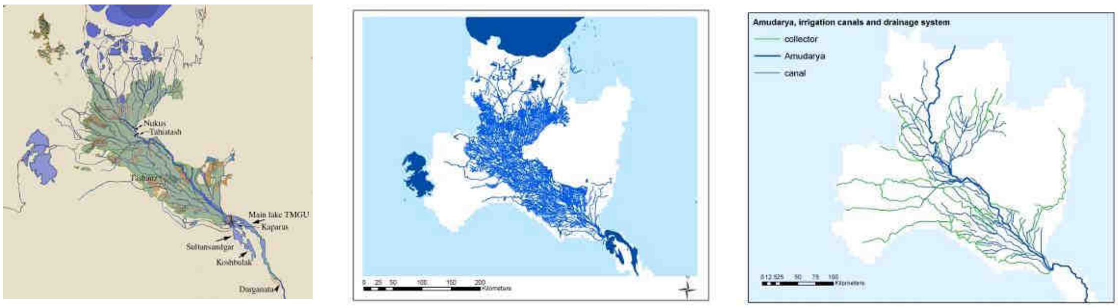


Figure 8a, b and c   Irrigated area in the Amudarya delta; from map to model input

Table 5 gives the average discharges for the main channels for each month/day. These data were used to determine the maximum pump capacities in the model.

Tabel 5 irrigation channel and drainage collector properties

	Max monthly Discharge (m^3/s) over 1988-2003	*Depth*(m)*	*Width** (m)*	*Maximum model pump capacity*** (m^3/s)*
irrigation canal				
Pahtaarna	98.7	Variable	30	150
Right canal	73.5	"	"	100
Kizketken	418.7	"	"	500
Suali	263.2	"	"	300
Tashsaka	274.5	"	"	300
Klichbay	127.7	"	"	200
Kipchakboszu	19.1	"	"	50
Sovietjab	245.4	"	"	400
Octiabrarna	69.4	"	"	100
Shavat	276	"	"	300
Collector drains		3	20	

* Model parameter, derived form literature values
** Model parameter, estimate
*** Model parameter, based on maximum monthly discharge measurements

4.1.4 Groundwater

Theory
Uzbekistan possesses an estimated 20 million m3/day of groundwater reserves, mostly at depths exceeding 100m. Only 0.016% of this is found in Khorezm. More than 50% of the total area in Khorezm has a shallow ground water level of 1.5 m below the surface. In general 60% of the irrigated areas have groundwater levels within the critical level of 2 m below soil surface (Vlek *et al*., 2006)

Average levels have risen from 180 cm in 1982 to 142 cm in 1999 (an increase by 21%). A high groundwater table is one reason for high soil salinity. Salinity is one of the major problems in irrigated agriculture in Khorezm and leads to crop yield losses of up to 50%.

Implementation
Groundwater levels are fixed at 33 meters along the northern border, where the delta reaches the Aral Sea. This represents the level of the Aral Sea. It is assumed that groundwater flow will also take place into this northern direction to this natural drainage base. Along all other boundaries in the south, east and west zero flow is assumed levels can freely fluctuate.

4.2 Model results

The model results for the calibration year of 1985 are shown. This year is chosen as it is a year for which both runoff data and measured collector drain discharge data were available. It is a year with average runoff. Figure 9 shows the comparison between the cumulative measured and simulated monthly drainage discharge for the main collector drains in North Karakalpakstan, the most downstream irrigation region in the Amudarya delta. Measured and simulated values correspond rather well, with the exception of the discharge in April, which the model overestimates and August, which the model underestimates. A process which could explain the difference in August is the opening of rice fields at the end of the cropping period to get rid of the ponding water, which can cause a high runoff. This is however not a standard option in the model. In the model water slowly infiltrates and is lost to soil evaporation. The slight overestimation of drainage in April and May could be caused to the fact that the model uses the same crops with the same planting dates and growth development for the whole delta, whereas in north Karakalpakstan crop development and thereby evapotranspiration is somewhat delayed due to climate circumstances.

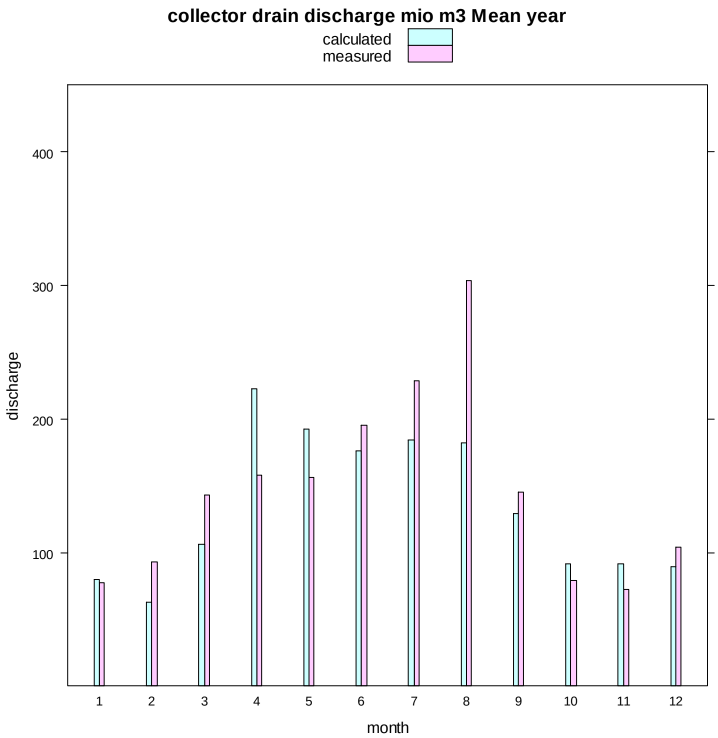


Figure 9 Total monthly drainage volumes for the collector drain in North Karakalpakstan

In figure 10 the groundwater levels for the end of June in a mean runoff year are shown. As can be seen from this graph most groundwater levels in the irrigated areas fall within the class of 2 to 5 meters below soil surface. Some of the drainage lakes are clearly visible in the north.

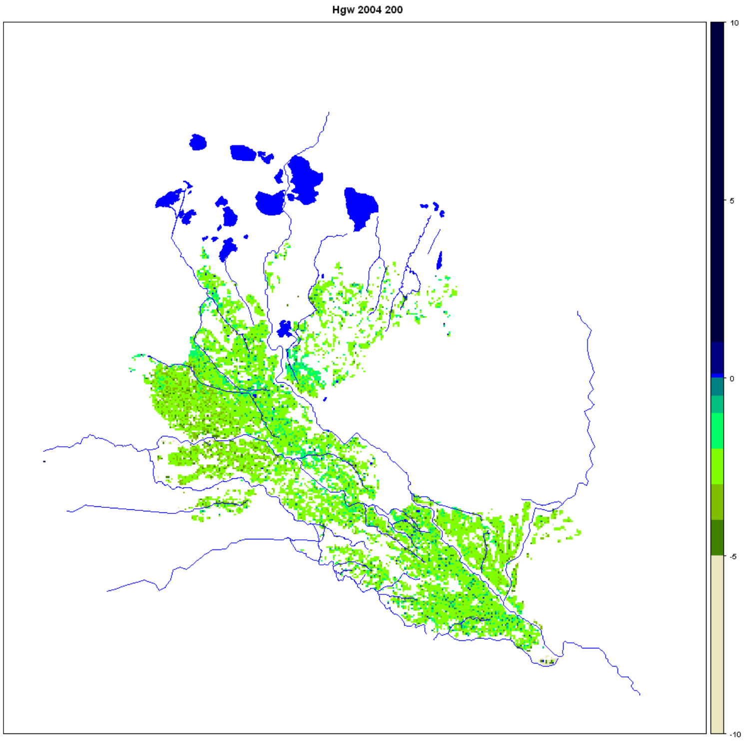


Figure 10 average simulated groundwaterlevels in the Amudarya delta over 1986

On several locations the groundwater levels are within 2 m from soil surface. In literature it is stated this is the case in 50-60% of the irrigated areas. Most areas in the models show groundwater levels between 2-3 meter. The main reason for this difference is the fact that irrigation water is at present divided over the whole cropped area while in reality it will be added in higher and more various quantities on parts of the cropped area resulting in higher groundwater levels. More detailed information on land use and irrigation gifts as well as on groundwater levels itself is needed.

In table 6 the most important water balance terms for the different crops in the different regions are shown. As can be seen in a normal runoff year most crops can reach maximum transpiration. Only Turkmenistan shows slightly lower values, mainly caused by difficulties in getting the water in time in the region via the various irrigation canals in the model.

Table 6 waterbalance terms for different regions and crops in the Amudary delta for a mean water year (in m)

Region	Crop	Irrigation	Precpitation	Potential Transpiration	Transpiration	Evaporation	Storage	Drainage	Seepage	TactTpot	DepletedFrac	area_km2
Khorezm	rice	3.300	0.087	-1.11	-1.106	-0.232	0.002	-1.846	-0.201	100%	33%	389
Khorezm	cotton	1.433	0.087	-0.89	-0.891	-0.153	0.036	-0.414	-0.026	100%	59%	967
Khorezm	winterwheat	1.327	0.086	-0.98	-0.964	-0.094	0.013	-0.335	-0.008	98%	68%	824
Khorezm	other crops	1.180	0.087	-0.82	-0.813	-0.117	0.005	-0.330	-0.002	100%	64%	570
Turkmenistan	rice	2.439	0.094	-1.11	-1.017	-0.202	0.030	-1.124	-0.161	92%	40%	569
Turkmenistan	cotton	1.169	0.094	-0.89	-0.842	-0.156	0.036	-0.227	-0.003	94%	67%	2027
Turkmenistan	winterwheat	1.231	0.094	-0.98	-0.952	-0.092	0.016	-0.210	-0.056	97%	72%	1820
Turkmenistan	other crops	1.014	0.094	-0.81	-0.783	-0.124	0.016	-0.185	0.000	96%	71%	1373
NorthKarakalpakstan	rice	3.201	0.112	-1.11	-1.106	-0.244	0.011	-1.738	-0.213	100%	33%	299
NorthKarakalpakstan	cotton	1.386	0.112	-0.89	-0.888	-0.176	0.041	-0.331	-0.063	99%	59%	1103
NorthKarakalpakstan	winterwheat	1.244	0.112	-0.98	-0.960	-0.093	0.015	-0.232	-0.056	98%	71%	990
NorthKarakalpakstan	other crops	1.135	0.111	-0.81	-0.812	-0.132	0.013	-0.247	-0.042	100%	65%	738
SouthKarakalakstan	rice	3.268	0.093	-1.11	-1.106	-0.230	0.026	-1.800	-0.198	100%	33%	14
SouthKarakalakstan	cotton	1.389	0.093	-0.89	-0.889	-0.155	0.041	-0.309	-0.088	100%	60%	482
SouthKarakalakstan	winterwheat	1.304	0.093	-0.98	-0.960	-0.095	0.013	-0.258	-0.072	98%	69%	477
SouthKarakalakstan	other crops	1.164	0.093	-0.82	-0.813	-0.116	0.017	-0.269	-0.041	100%	65%	417

5 Salt balance

In paragraph 5.1.1 to 5.1.4 the different components of the salt balance of the Amudarya Delta are described based on data and literature values. Additionally, the way in which this information is used in the model is briefly explained in each paragraph.

5.1 Salt balance components

5.1.1 Amudarya river flow

In figure 11 the increasing salt concentrations downstream of the Tuyamuyun reservoir are shown. Total salt have increased from an average of 450 mg/l in the '50ies till about 900 mg/l at present. The decrease of discharge and increase of concentration indicates more use of river water and returned drainage water upstream of this point.

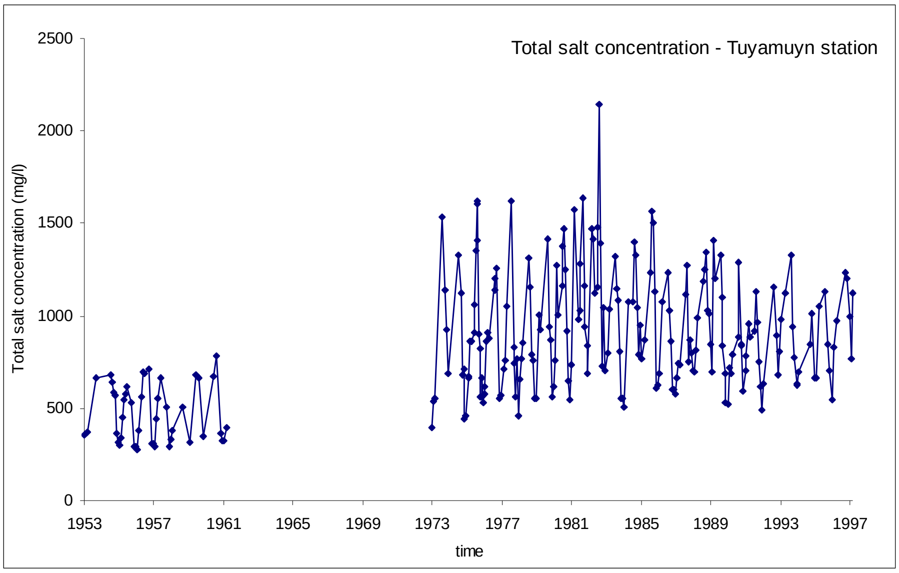


Figure 11 measured total salt concentrations just downstream of the Tuyamuyun reservoir (source: Hydromet)

In figure 12 the Total salt concentrations for three focus measurement stations (see figure 4[c]) along the Amudarya for the period 1980-1997 are shown. It is clear that concentrations increase downstream, with average concentrations being approximately twice as high.

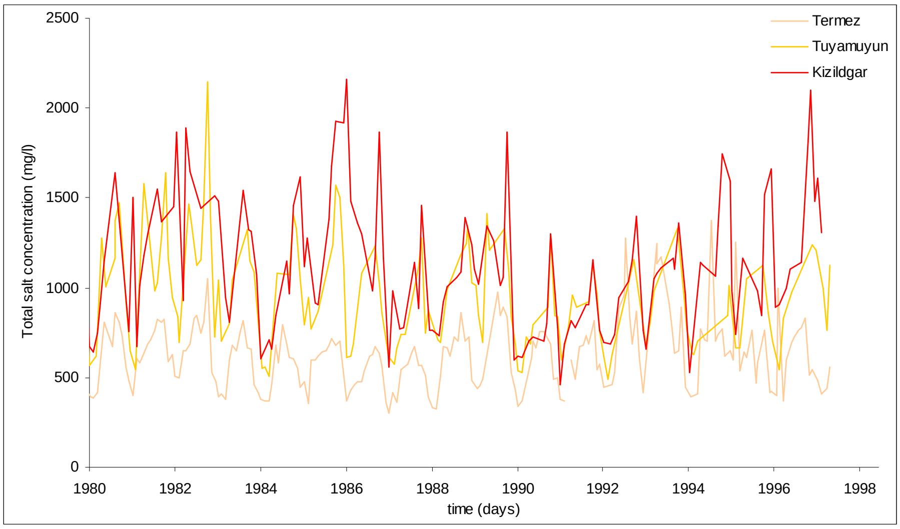


Figure 12 total salt concentrations for three stations along the Amudarya river

In figure 13 the variations over 2004 for two stations are shown. Again it can be seen that the total salt concentration increases downstream.

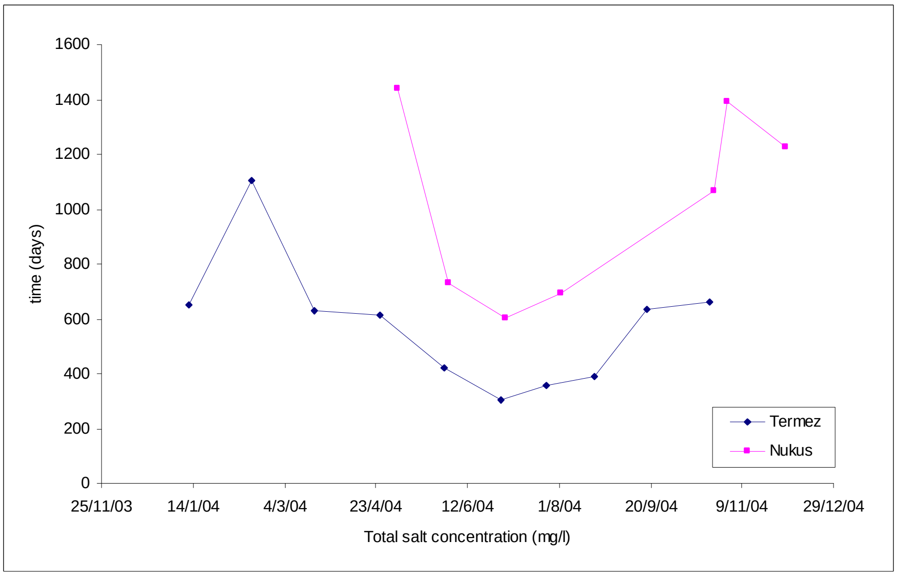


Figure 13 total salt concentrations for Termez and Nukus (Takhiatash gauge) stations

Important missing data are groundwater levels and volumes as well as concentrations as these play an important role in the water and salt balances. Effort should be taken to acquire these data as measurements are definitely made.

5.1.2 Irrigation and drainage

In Karakalpakstan, the neighboring province of Khorezm, 90% of the irrigated soils are considered saline, compared with a figure of 51% in the whole republic of Uzbekistan (Zhollybekov 1996), and the figures for Khorezm should not be expected to be much different.

Salt concentrations in drinking water peak up to 2 g/l in delta areas (world bank maximum 1.5 g/l) (World Bank, 1998)

5.1.3 Groundwater

As in many irrigated areas the natural drainage capacity of the sub-soils is not sufficient to discharge this excess water, the regional groundwater levels have risen, sometimes up to tens of metres, until finally the root zones of the crops were reached. Waterlogging and salinization problems became manifest in large areas. More than 50% of the total area in Khorezm has a shallow ground water level of 1.5 m below the surface. Average levels have risen from 180 cm in 1982 to 142 cm in 1999 (an increase by 21%; Figure 7). A high groundwater table is one reason for high soil salinity, which is one of the major problems in irrigated agriculture in Khorezm and leads to crop yield losses of up to 50%. Groundwater can reach salt concentrations up to 10 g/l in Khorezm and Karakalpakstan (Jansen, 2003).

5.1.4 Atmospheric deposition

No reported values found. No values inserted.

5.2 Model results

Salt is modelled with TRANSOL, a model which uses the output of the SIMGRO-MODFLOW model to calculate salt fluxes in the topsoil. Only vertical fluxes for individual cells are calculated. Groundwater flow from one cell to another is not taken into account in this study as accurate data on groundwater flows is lacking. Figure 14 shows the salt concentration at 30cm for the irrigated areas in the Amudarya Delta. This salinity is based on the water flow components of irrigation, rain, evapotranspiration, capillary rise to the root zone and percolation to deeper soil layers. It gives and indication of the areas which have a high risk of becoming too saline. As is shown the most downstream area in Turkmenistan has the highest salt contents. In the simulations less water reaches this area so there is less opportunity for leaching.

Thee results can only give an indication as many variables are unknown and important information on for example groundwater flows and leaching is missing. In addition there currently is no feedback from the salt module back to crop growth and thus evapotranspiration. Furthermore only monthly concentrations of irrigation water measured in one year could be used. The results however indicate the important processes and give possibilities for further improvement.

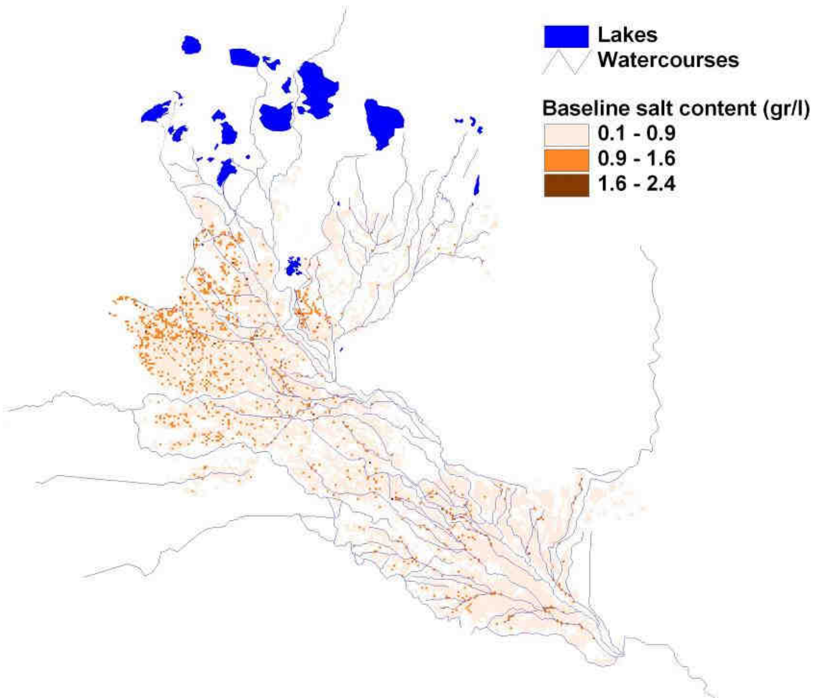


Figure 14 salt concentration in the root zone as simulated for a dry year in the irrigated areas of the Amudarya Delta

6 System analysis; impact of various scenarios

6.1 Introduction

The following paragraphs will focus on the impact of various changes on crops and environmental flows. Paragraph 6.2 shows the effects on agriculture. Water stress and yields are important indicators. Paragraph 6.3 highlights some aspects of the effects on salinity in the root zone. Paragraph 6.4 focuses on the impact of climate and socio economic changes on the environmental flows into the delta lake system. A selection of results will be shown in this document to show the capabilities of the developed approach. A more comprehensive description will be published in Siderius *et al*. (2009)

6.2 Impacts on water stress

Figure 15 shows the increase in water stress in a Low water year under the three scenarios. In the climate scenario water stress strongly increases, especially downstream, due to the lower inflow and higher transpiration. The technical improvements (20% reduction in over-irrigation) show a slight reduction in water stress compared to the climate scenarios. With the environmental flow requirements less water is available for agriculture in the low water years. Not only The downstream delta but also parts of South Karakalpakstan are effected.

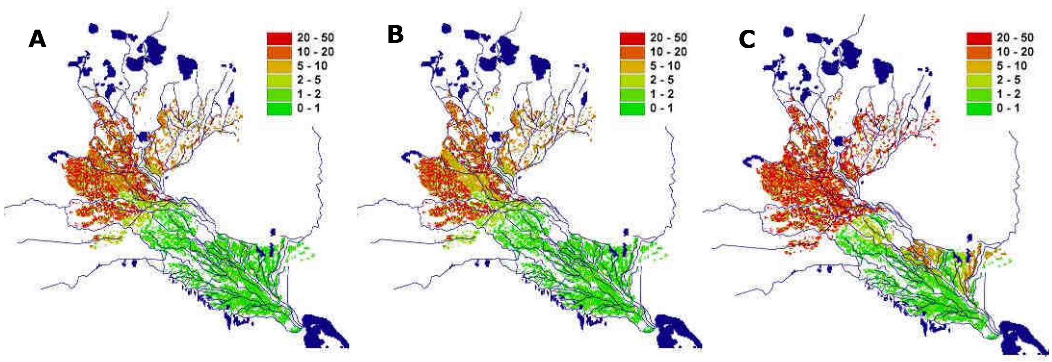


Figure 15 Increase(%) in water stress compared to the baseline scenario for a low water year under a) Hydromet climate scenario, b) with technical improvement and c) with environmental flow requirements

In table 7 the resultant change in water requirements and collector drainage is shown. As a result of the higher temperatures under the climate scenario water demand increases. As inflow decreases part of this extra demand is derived from soil or groundwater depleting storage but increasing field efficiency. As a result the collector drainage flow decreases.

Table 7 measured and calculated irrigation requirements and drainage volumes in North Karakalpakstan ($10^6 m^3$) (in a mean runoff year)

MEAN runoff year	Crop Water Requirements	Collector discharge
Estimated/measured	5100*	1759**
Simulated		
Baseline scenario	4343***	1467
Climate scenario	4694***	1361
Technical scenario	4424***	1172
Environmental flows scenario	4424***	1171

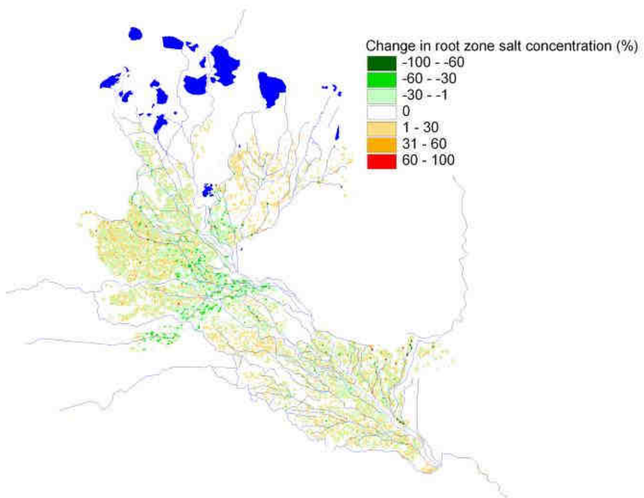
* GEF Water and Environment Management Project, 2001

** Measured collector drainage in a mean runoff year (1985)

*** Modeled irrigation amounts

6.3 Impacts on root zone salinity

Also the root zone salt concentrations and drainage water concentrations can be compared between the different scenarios. However salt concentrations were not calibrated due to lack of data so figure 16 gives only an indication. Simulations for a low runoff year show an increase in salinity in the root zone in the climate change scenario which can be explained by a higher water demand for evapotranspiration but with less water available for leaching. In the technical scenario this is compensated a little bit by a reduction of over-irrigation especially upstream. The Environmental flows scenario shows a totally different picture with decrease salt content in the root zone. One of the reasons is a total lack of water so there is no addition of salt at all during the summer period, especially in Turkmenistan. These simulations however have to interpreted with care as groundwaterflows and salinity will changes as well as is watermanagement to combat salinity after or during dry years which is at present not taken into account in the model.



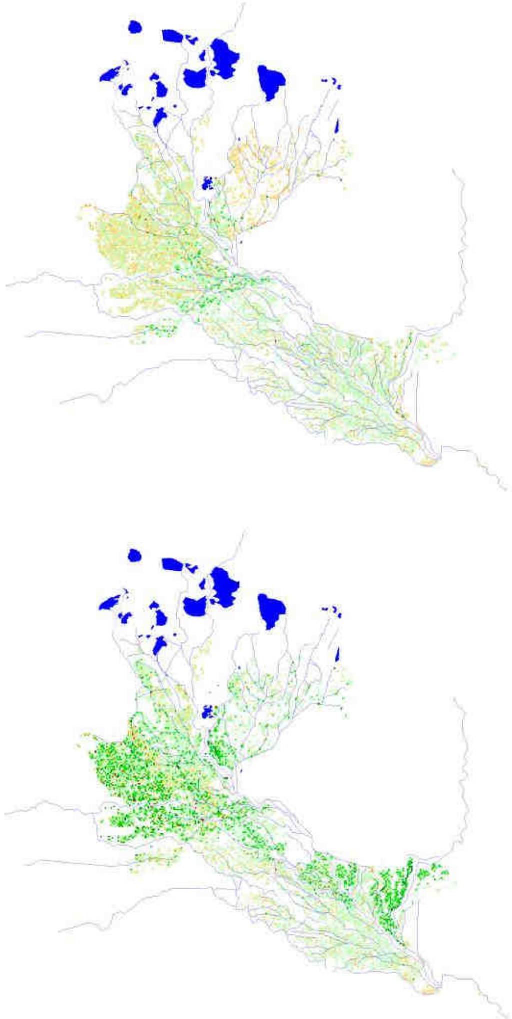


Figure 16 Increase(%) in in rootzone salt concentartions compared to the baseline scenario for a low water year under a) Hydromet climate scenario, b) with technical improvement and c) with environmental flow requirements

6.4 Impacts on environmental flows

In this study we not only focus on water quantity and agriculture but also on the environmental flows into the delta lake ecosystem. Figure 17 shows the change in lake volume during a low runoff year. Impact of the the hydromet climate change scenarios is dramatic. Especially the Domolak lake in the centre, which receives water only after the more upstream Mejdureche lake, decreases drastically by 80% according to these simulations. In the Technical scenario water use in agriculture slightly decreases and storage in Mejdureche increases with reduces the impact of the climate change to some extend. As expected the environmental flow scenario shows a large improvement in lake volumes for the central lakes. In the current model setup the Sudoche and Jeltirbas lake system are mainly fed by drainage water. This drainage water decreases due to the decrease in water available for irrigation so lake volumes drop in these lakes. However with minor adjustments also these lakes could profit from the environmental flows.

It has to be stated that most flows between the lakes are controlled so that in reality effects might be spread among the different lakes. Still however, the scenarios show interesting differences, mainly in the low discharge years. In the medium and high discharges years, more water is available to compensate for leaching and evaporation losses in the lakes so differences are less pronounced.

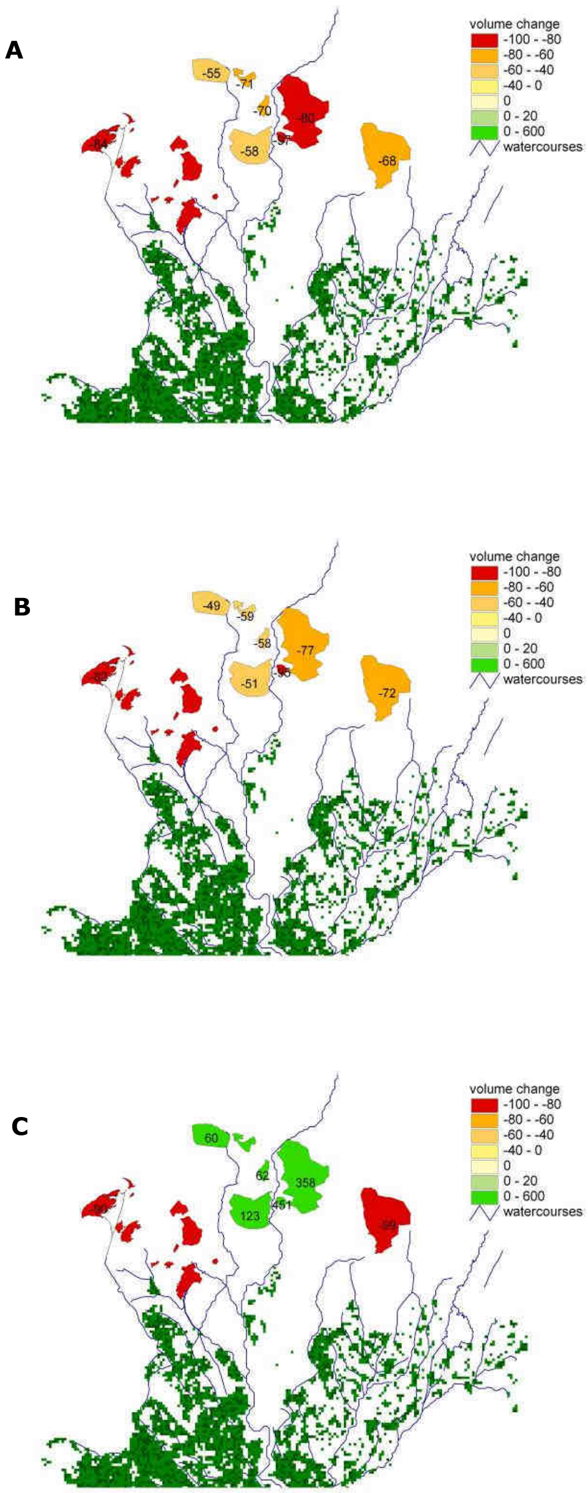


Figure 17 Decrease in lake levels a) in the Hydromet climate scenario, b) with technical improvement and c) with environmental flow requirements

7 Discussion and conclusions

7.1 Water balance

A process oriented hydrological model is constructed to simulate the water flow in the Amudarya delta. Rainfall, river flow, evaporation, irrigation, infiltration and drainage can now be quantified for different scenarios. Site specific pumps capacities, irrigation channel and drainage collector properties have been inserted.

In general the model shows a good reaction to changes in drivers and input variables. It does properly simulated the water balance terms on which the salt balance can be based. The calibration needs to be refined based on more measured groundwater levels. A start was made to make this information available by collecting and digitizing digital groundwaterlevel maps. However these maps are only representative for on moment in time so more information is needed to calibrate the dynamics and improve the understanding of both reality and model results. This however is a project on its own.

The current land use is based on satellite images, the JRC global land use map and MODIS vegetation reflection in combination with region level statistical data. This has resulted in a land use map which is quite accurate in its extent of cropped area but cannot be precise in the exact location of specific crops. Model results therefore represent a response of a mixed land use and should always be aggregated. More detail on irrigated area in the form of local land use maps or more detailed statistics for local districts could improve model results.

Al lot of attention is paid to the changes in cropping pattern between different years. An interesting characteristic of the Amudarya river flow is its relative predictability as a result of it originating from upstream snowmelt and early season rainfall which can be measured in advance. The analysis of MODIS vegegation cover times series data in combination with a local empirical runoff prediction model and crop yield statistics has resulted in a offshoot article on forecasting land use and crop yield (Siderius and Savitsky, 2009).

7.2 Salt balance

Based on the water balance components of precipitation, irrigation, infiltration, evapotranspiration, capillary rise, percolation and drainage a salt model is constructed to simulate the salt concentrations the root zone in the Amudarya delta.

The calculation is based actual root zone concentrations and its temporal fluctuations and the contribution to salt concentration in the drainage water. For this information on actual salt contents is collected for one year. Similar to the groundwater level data however, much more information is needed to understand the temporal and spatial dynamics.

7.3 Scenarios

In a high and mean water year there is no water shortage for agriculture or for environmental flow to the delta lakes, not in the baseline and not in the Hydromet climate scenario (this does not mean that there is enough flow for restoring or preserving the Aral sea).

However even in a mean water year there are extended periods when no water reaches the delta. Salinization will be a risk.
In a low water year agriculture is affected but negative impact is not equally distributed over the Delta. Northern Karakalpakstan is most affected together with parts of Turkmenistan (this might also be the result of distribution problems).

The impact of the climate change scenarios is also different for various crops. Winter wheat is less affected even downstream. But a large water consumer like rice is difficult to grow in North Karakalpakstan.

Lake levels drop dramatically in a dry year. The sequence of dry years is very important. One dry year does not dry out most lakes, but two consecutive dry years will.

7.4 General conclusions

The Simgro modeling system creates the opportunity to evaluate the effects of both climate change and changes in the management and agricultural practices.

The Amudarya system is highly managed and only models with sufficient management options will be capable of simulating the system dynamics.

Data is not only needed to check a model, but a model is also needed to check the data. This is especially relevant in a catchment where the measurement infrastructure is deteriorating and were there are large differences between official limits, facts and 'real facts'. A model can be an integrating base between different kind and different sources of data.

Modeling a catchment the size of the Amudarya with such a complicated water management structure can not be done within the framework of one EU. It needs to be an ongoing process. It is the intention to continue the research on integration water quantity, water quality and ecosystems in cooperation with the EcoGIS center and the Institute of Irrigation and Meleoration in Taskent and other partners.

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