# TOWARDS A SUSTAINABLE USE OF NATURAL RESOURCES IN THE ARAL SEA BASIN

***Paper prepared for STE-ICG Summer School "Water and Sustainable Development"***

Christopher Martius, John Lamers, Mirzakhayot Ibrakhimov, and Paul Vlek
*Center for Development Research (ZEF Bonn)*
*D-53113 Bonn, Germany*
*c.martius@uni-bonn.de*

This paper discusses the environmental, social and economic aspects of the Aral Sea crisis, and describes a proposal designed to overcome the problem of unsustainable land and water use in the region. The Aral Sea has lost >60% of its surface compared to 1960, due to increased water diversion in irrigation systems. The production of cotton in huge irrigation systems has brought about water misuse and land degradation, and due to the tough economic transformation process faced by the central Asian countries, the region is characterized by increasing poverty. Therefore, international development efforts today concentrate on improving ecological sustainability and economic efficiency of natural resource use in the region, as a contribution to combating poverty and desertification in the Basin, rather than on saving the Aral Sea as such. The Center for Development Research (ZEF) at the University of Bonn, together with its partners, has set up a research program aimed at providing options for a restructuring of land and water use that are based on sound, long-term, interdisciplinary integration of different disciplines of science, and that are aiming at strengthening local institutional and individual capacity building. The elements of this program and first results are presented.

## 1 Introduction

The Aral Sea Crisis, the most visible and best-known symbol of which is the shrinking of the Aral Sea surface - has become a symbol for large-scale man-made social and ecological disasters. Desertification is progressing in this area, with highly unfavorable environmental and socio-economic consequences. In 40 years, from 1960 to 2000, the Aral Sea, formerly the world's fourth largest inland water body with an estimated size of 68.000 km$^2$ in 1960 [1] has lost 62% of its water surface area, and over 80% of the original water volume [2].

In 1992, the UN declared the Aral Sea region as a world "ecological disaster area". The "Aral Sea Syndrome" has been coined by the WBGU [3]; the Aral Sea being used here as a typical example for environmental damage as a result of poorly managed or unsuccessful large-scale development projects (in this case, the expansion of irrigated land at the expense of ecological sustainability during Soviet times). Glantz [4] has defined the Aral Sea problem as a typical example of a “creeping environmental problem” (CEP), i.e. an environmental change that evolves slowly and almost imperceptibly, making both its perception and the start of counterbalancing actions especially difficult (“...the demise of the Aral Sea has become acknowledged as one of the major examples of human-induced environmental degradation in the twentieth century”).

## 2 Environmental Consequences of the Aral Sea Crisis

The shrinking of the Aral Sea has several consequences for the environment and for the local population (cf. [5] and references therein), such as:

- The dry Aral Sea bed in 2000 amounted to >4 million ha, and today represents an area of newly formed sandy-loamy sand and salt desert, the so-called Aralkum [2]. This area is thought to be a chief source for salt drifts and deposits in the region, because strong winds or storms (300 out of 365 days) carry sand and salt particles throughout the Aral Sea basin, sometimes as far as >200 km [6]. The shrinking process has continued since then.
- Due to the shrinking of the Aral Sea the average temperature in July in Muynak increased from 25.7 °C to 28.3 °C between 1960 and 1985, and the frost-free period shortened to 170 days in the delta area. Today, the first frost sets in 10-12 days earlier compared to the situation before 1960 [5].
- The formerly important fishery industry has disappeared, from a total of 43.000 metric tons of fish that were caught in the Aral Sea in 1960 down to no fish production at all since 1980 [7]. The view of fish trawlers lying in the sand has become a well-known visual metaphor of the Aral Sea catastrophe.
- The whole of Central Asia suffers from a severe loss of biodiversity. The quality of surface water bodies has changed, soils have become halomorphic and chemical pollution of water and soils in irrigated lands is very high (see below), which all affects the biodiversity of the organisms facing these conditions. Besides having been put under high ecological pressure due to receding river water availability, most of the so-called Tugai forests, the extensive river floodplain forests along the major rivers, have been cut down in order to make space for agricultural land [8]. The ecosystems of the deltas formed by the Amu Darya and Syr Darya Rivers have largely been destroyed. In the Aral Sea, the composition of the fish fauna has strongly changed because only a few fish species survived the highly increased salinity of the water [7].

## 3 The Causes for the Aral Sea Crisis

What were the causes for this development? Since the 1920ies, the desert areas in the Aral Sea Basin (ASB) were transformed into artificially irrigated agricultural land for the production of cotton, which was a major strategic crop for the Soviet Union. Over 60% of all cotton produced in the Soviet Union was produced in the ASB. In order to achieve this, the irrigation system was gradually but steadily increased in a huge engineering effort, from 2.0 million ha of irrigated farmland in the early 20es to 7.9 million ha in 1999 (Figure 1). Large quantities of river water have been withdrawn from the tributaries of the Aral Sea into the various irrigation systems along the rivers. The present system of main & inter-farm irrigation canals in the ASB has a total length of 28.000 km, and main & inter-farm drainage canals amount to 30.000 km; the total length of on-farm irrigation and drainage canals is 168.000 and 107.000 km, respectively [9]. In 1999, these immense irrigation systems used 96.3 $km^3$ of water $yr^{-1}$, which corresponds to 83% of the average water resources available in all rivers in the ASB (cf. Table 1). This figure explains why in most years nowadays, and principally so in dry years, the water of the rivers rarely reaches the Aral Sea.

Water losses in the mostly unlined irrigation canals are estimated to be up to 40 $km^3$ of water $yr^{-1}$; an amount which, if it could be saved, would be enough to slowly refill the Aral Sea. However, the costs of lining and refurbishing the whole system prohibit accomplishing this task in face of the huge extension of the irrigation system. Also, any radical solution like simply stopping all water diversion to the irrigation systems in order to restore the Aral Sea would not be feasible. It would take several decades to fill up the Aral Sea again to its former levels, and, worse, such a decision would throw the 39.9 million inhabitants (1998) of the ASB into chaos, 62% of which are rural population directly or indirectly depending on agriculture in the irrigated land.

## 4 Land and water use for crop production

In the ASB, 90% of the crops are produced under irrigation. Overall cotton yield in the agricultural production systems that is characterized by the long-term growth of cotton has decreased from 3.0 ton/ha in 1976 over 2.8 ton/ha in 1992 to 2.3 ton/ha in 1996 (Trevisani unpublished). In order to maintain the agricultural production levels, the use of fertilizers, pesticides and other inputs has been increased.

Also, it is well known that the long-term irrigation with surface water in drylands almost invariably leads to soil salinization [10]. Large parts of the irrigated land in Uzbekistan are nowadays seriously compromised by salinity; in Khorezm, for example, the areas with moderately and strongly saline soils (soils with 0.06 to >0.12 meq $L^{-1}$) in the period 1990 and 2000 invariably amounted to about 50% of the total irrigated land [11]. In Khorezm, areas at risk of waterlogging and salinization represent about 65-70% of the irrigated areas and only huge amounts of water used for irrigation and leaching of the soils (washing out of salts during winter time) allow keeping the land productive. This is why the amount of water used for crops in central Asia is much higher than in other parts of the world; e.g. for cotton in Khorezm, for example, between 5.000 and 20.000 $m^3$ of water are used per hectare [12, 35].

The environmental consequences of the salinization and extensive use of agricultural inputs are that drinking water is highly saline, and that soils and water are contaminated by salts, pesticides and nitrates, all factors that present serious problems for the health of the local population. In the region, salt-related diseases like kidney and heart diseases are common [5]; contamination of drinking water and breast milk with DDT is widespread and by far exceeds the critical threshold levels [13], respiratory diseases affect large parts of the population [14] and the psychosocial effects of the environmental situation are felt by respondents to a study of Médécins sans Frontières [15]. Pesticides such as DDT and Lindane also accumulate in fish and in drinking water reservoirs like the Tuyamuyun on the Amu Darya, although DDT is reported to not being used any more. The total use of fertilizers and pesticides has decreased from 1989 to 1993 but effects are still felt. Over 50% of the rural population in Khorezm obtains drinking water from surface water bodies, which contributes to the large amount of drinking-water related dieases. To improve the health situation in the Basin as a whole, water supply will be one of the major factors, because over 40% of the drinking water does not correspond to the sanitary and bacteriological standards [16].

At the same time, it is well-known that poverty in the central Asian states has increased since independence [17, 18]; e. g. in Uzbekistan GDP has halved in the last five years since 1999 (Table 2). 24% of the Kazakh population in 2002 lived in absolute poverty with incomes below the subsistence minimum of 31 US Dollars per month [19].

Therefore, leading development agencies in the world nowadays agree that restoring the Aral Sea to its former size is not a feasible development goal; instead, developing the region towards increased sustainability of natural resource use and a better livelihood of the local population are high on the agenda because they recognize the social dimension of the project and can be achieved [12].

## 5 Economic Aspects of the Crisis

Of all central Asian states, Uzbekistan has the largest population living in the ASB (14 million inhabitants). Therefore, the political analysis here is concentrated on this country. Uzbekistan is today the world‘s 5th largest cotton producer, and the world‘s 2nd largest cotton exporter after the USA; cotton accounts for 45% of Uzbekistan‘s export earnings (after gold, with 22%) [20,21]. It is the declared policy of the government of Uzbekistan is to use export earnings from cotton production to build up the industry in the country [22]. The agricultural production of main crops like cotton, wheat and rice is therefore controlled by the “state order”, meaning that there are production targets for these crops which are defined centrally and broken down by region, district, and individual farms [23]. Individual private farmers have to allocate a certain share of their total land to cotton and grain production. Until 2002, this amounted to 100% of the cotton harvest and 50% of the planned grain quantity. The production must be delivered to the government agencies at pre-set prices which for cotton are approx. 30% of the world market prices; the potential surplus can be sold on the free markets where prices normally are higher than those paid by government agencies.

This system gives the state strong control over the agricultural production; however it is often overlooked that in compensation, the farmers receive all inputs from the state. The government controls not only distribution and prices of major inputs (e.g. fertilizers and biocides), but also the processing of the production and the marketing and exports of agricultural commodities. Not least, the government also is responsible for maintaining the extensive irrigation system and providing water at no cost to the farmers. Thus, possible benefits but also potential shortcomings of any attempts at privatization in the agricultural system should be carefully balanced.

Macro-economic reforms have been slow in Uzbekistan. One reason for this has been the attempt to buffer the negative social effects of economic transition, in view of the experience in neighboring countries where too quick reforms often led to huge social problems (e.g. [19]). For example, inflation increased at relatively low annual rates of <50% in Uzbekistan, and one objective of the gradual reform approach was to keep food prices at affordable levels [5]. The gradual, almost reluctant approach to change may be responsible for the relative stability in the country, but has delayed economic reforms in all sectors of economy and may be impossible to be maintained at the same pace for the near future.

## Economic and Ecological Restructuring as a Pilot Project to Improve Resource Utilization in Khorezm (Uzbekistan)

Ecology and Development in the Aral Sea Basin are therefore characterized not only by the well-known and much emphasized ecological problems due to unsustainable resource management, such as the large water losses in irrigation system, the salinized irrigation and drainage water that leads to salinized and degraded soils, the large (though receding) use of pesticides and herbicides, the ensuing air and water pollution (due to wind-borne dusts, pesticides and salts), the biodiversity loss, and the regional climate change towards a more continental climate. The situation is also characterized by the reduced livelihood affected by the economic transformation process, the widespread poverty, above all in rural areas (Table 3), the widespread health problems, the high child mortality and low life expectancy. Furthermore, one should keep in mind the strong path dependency given by the predominance of cotton in the Uzbek agricultural sector, the extensive irrigation system, and the Soviet legacy in institutions as well as the slow reforms towards market economy.

No easy solutions can be given to the challenge of finding ecologically sustainable and economically effective options for land and water use in the region. Technical solutions to land and water use require some research to be done, but basically, many options are available and well known, such as better drainage and leveling of irrigated fields, the introduction of conservation agriculture, water-saving irrigation technologies and the like. However, the strong control the Uzbek state holds on the agricultural sector requires that institutional aspects must be addressed in the first place, and the economic feasibility of any measures under the peculiar local conditions must be carefully assessed before recommendations can be given.

ZEF has therefore designed, in consultation with its partners (UNESCO, DLR, University of Urgench and TIIAME in Uzbekistan and many others), an interdisciplinary, application-oriented research program with the aim to provide appropriate regional development concepts based on sustainable and efficient land and water use. The program started in 2001 and is based on an integration of natural resource management, economic studies and studies of institutions. The philosophy is that of a long-term, participatory commitment to deliver de-centralized development options based on a system where markets function and sound ecological principles are adhered to. The program includes a strong human capacity building component, particularly the training of young Uzbek scientists from the Aral who will be the potential future decision-makers in the region.

Recognizing that most of the Aral Sea is lost, the ZEF program assumes that a sustainable restructuring of land and water use in the Aral will have to improve the livelihood of the local population through a careful transformation towards privatization of agriculture based on (ecologically, economically and socially) sustainable land-use options. A more efficient use of the existing resources is required. One approach is a reduction in the area of cropped land, which we expect to achieve through diversification of land use, utilization of the “service potential” of ecologically sound land-use systems, efficient use of production factors, liberalization of the input and output markets, increase in rural income and careful modification of existing legislation and decision-making systems to enable this process.

The inhabitants of Karakalpakstan and Khorezm, two districts on the lower reaches of the Amu Darya River, the largest of the Aral Sea’s tributaries, suffer most from the accumulated effects of low water availability, soil degradation and salinization, and from the economic and administrative orientation of Uzbekistan towards soviet-style centralized structures. The region of Khorezm was chosen as a target region to this project due to several reasons. Khorezm is located downstream in the Amu Darya basin, but still has a downstream area (Karakalpakstan) itself, and is therefore more typical for irrigation systems in Uzbekistan. Karakalpakstan has arguably the most severe environmental problems, but is relatively untypical of Uzbekistan as a whole. Khorezm is a small district for Uzbek measures, with clear boundaries, thus relatively easy to study, and it is important in the Uzbek cotton trade because it only delivers 5% of the total Uzbek cotton production, but, due to its high quality, accounts for about 20% of the Uzbek cotton export revenues.

The ZEF project aims at increasing economic efficiency through improved economic farm management, a wiser utilization of inputs (fertilizer and rotation management, alternative crops), a diversification of sources of income (trees, aquaculture), and at increasing ecological sustainability through a reduction in water use, the halting or reversing of soil degradation, e.g. through the introduction of conservation agriculture (this is also a goal of a recently initiated FAO project). We expect to be able to set marginal land, actually used for agricultural production at high costs, free for ecological services, and to achieve a diversification of the landscape in order to draw ecological service functions into the system.

Under the conditions of the existing “path dependencies” (predominance of cotton as a major crop in the prevailing economic reasoning, the existence of vast irrigation systems, the population pressure, and the prevailing of the state order), the steps needed for developing options for restructuring land and water use in Uzbekistan are:

1. The development of adopted sustainable resource management options (water, soils, and crops management; diversification);
2. the privatization of agriculture, of input- and output markets (a loosening of the state order, the introduction of basic principles of economic farm management (training is required here), the liberalization of the markets, and the scientific research of market options for new agricultural products, e.g. for fish, wood, and new crops);
3. the improvement of institutional performance in the sector of water distribution (efficient and reliable water distribution, unambiguous rights and obligations for users, e.g. concerning withdrawal of water and maintenance of the irrigation system);
4. Finally, instead of parting from the apparent “optimum technical solutions”, those technologies must be identified that will be embraced by the farmers because they respect the farmer’s priorities, needs and economic possibilities and adapt to their intellectual and ideological universe without giving up the need for ecological sustainability.

### *A long-term project in four phases*

The project is planned for a total of four phases covering a 10- to 12-year program (Table 4).

In Phase I (18 months) started in 2001 the project concentrated its efforts on assessing the state-of-the-art, based on secondary data acquisition, surveys of land use, ecological conditions and current economic, institutional and social/health conditions of the Khorezm region [5]. The project has by now been firmly established with excellent institutional arrangements, infrastructure and national and local support. Moreover, there is a clear tendency in the country to shift to privatization and liberalization of markets, so that the project is drawing increasing interest from various government levels.

In Phase II, the main aims of the project are (1) to gain the necessary understanding of natural, economic, and social processes that allow the proposition of a alternative restructuring concepts; (2) to develop an Ecological-Economic Optimization Model (KEOM) that will help assess the impact of various restructuring concepts on economic and ecological developments; and (3) to develop together with the local land users and with the help of KEOM, a pilot scheme for large-scale privatization of Shirkats (communal farms). Thus, the model developed in Phase II will provide the concepts to be tested on the pilot farms in Phase III, when also the DSS will be fully developed.

In Phase III, the scope of the project will be in applying the results of the research of the first 2 phases including the research on technologies and the options for institutional re-organization under real-life conditions, on-farm. The concept of pilot farms has been extensively discussed and much criticized in the development literature, but should be seen in the context of a strategy for stakeholder involvement that addresses two levels, (a) the private farmers who have to be convinced that new technologies aimed at ecological sustainability will also improve their livelihood; and (b) the decision-makers at the administrative level in government organizations both at the district as well as at the national level where agricultural policies are defined. Therefore, we see a need for establishing pilot areas, farms and fields on which demonstration trials of best practices in land and water management, crop production and agricultural management will be demonstrated.

The activities on these demonstration farms will be based on KEOM as the platform on which important economic and biophysical processes have been modeled while taken into consideration the social framework, and which will be used to simulate the effects of different scenarios (business-as-usual, minimum improvements, optimum improvements) on social, economic and ecological indicators. Based on this, the most promising restructuring options will be selected that will then be implemented in the demonstration scheme. Participatory approaches will be used to closely link the project activities to the target groups (both farmers and decision-makers among the local and national authorities) and to assure that the solutions are user-driven, and not donor- or project-driven**.**

The goals of Phase III will therefore be (1) to demonstrate good farm management practice concerning both resource management and farm management; (2) to raise perception and adoption of improved technologies by collaborating partners and farmers; and (3) to demonstrate sustainable, applicable water and land management options on a larger (geographical and administrative) scale.

Phase IV will then be used to draw on the lessons from Phase III and on further simulations in the improved KEOM, to implement the emerging restructuring concept on a larger spatial scale, i.e. in Khorezm.

*Interdisciplinary Research to provide feasible development options*

The project in Phase II is divided into four thematic research areas that provide the baseline data input for the integrative, interdisciplinary model (KEOM) (cf. Figure 2). These areas are discussed in the following section.

The sub-models (representing the thematic components) developed during Phase I and II of the project will be integrated in the central model (KEOM). The model's main purposes are research, planning and teaching; however, it will also provide the basis for a concept to implement changes in land and water use, free of the Uzbek state order, in experimental pilot farms at a later stage in Phase III.

Natural Resource Management Strategies to support Decision Makers

In the field of natural resource management strategies (research area N) optimal land-use patterns (including the introduction of trees and ponds as alternative land uses with ecological functions) will be determined through field research and remote sensing, in order to prepare an efficient and sustainable management of the two most important resources, water and land. Furthermore indicators for a sustainable resource use, for example for soil quality (such as soil ecology and carbon storage) and water use (quantity) and water quality (such as water salinity and a positive balance of the total water budget) will be established to allow assessing the success of the restructuring measures. The results of this research area are primarily addressing the decision makers.

Resource utilization begins with the allocation of land to various land uses. One alternative for land use is the establishment of tree plantations. Trees can provide ecological services such as biodrainage, organic matter input, improvement of the microclimate through shadow, and they provide marketable products such as wood, fruit or fodder. Actually the suitability of 15 tree species from the region is being assessed, through the monitoring of growth characteristics, and biological as well as production parameters such as fodder value or the energy content as a basis for the use as fuelwood [24]. Furthermore, the mapping of existing tree stands from aerial photographs and of indicators showing sites suitable for trees will allow the later implementation of the tree plantation schemes on a larger scale.

Another alternative explored in this program is the installation of ponds for fish farming in the region. The concepts for this are basically available, but details as for example the availability of local plants (trees as well as annual plants such as Amaranth) for providing cheap fish feed are actually being studied.

The status quo of land use over the region is being established through remote sensing of the Leaf Area Index (LAI), through which we expect, in combination with biophysical parameters, to be able to provide optimum watering options [25].

Detailed hydrological and soil quality studies have been undertaken, e.g. a study of the groundwater depth and salinity dynamics in time and space over the last 10 years, which revealed that the areas east and south of Khorezm, i.e. those deeper in the topographical profile and in longer distance to the irrigation water inflow from the Amu Darya suffer from higher groundwater salinity risk. Also, it was found that some areas experience a higher and faster increase of groundwater salinity than others. These so-called “hotspots” reveal a high spatial heterogeneity of groundwater salinity dynamics and will provide the basis for site-specific approach for water resources management that is needed in the region [11].

The project has further established a research program on indicators that will allow assessing the effects of the measures to be introduced on a larger scale at a later stage in the program (Phase III). For example, the spatial distribution of health-related aspects of drinking water quality, such as the incidence of hepatitis A and diarrheal diseases related to drinking water contamination have documented [26, 27] and will serve as a base-line from which to assess the impact of restructuring in the pilot scheme at a later date.

A soil-ecological monitoring program has been established in 2004 to evaluate the impact of the newly introduced land-use and cropping systems on soil “health”, its ecological functionality. This is coupled to an intensive investigation of the dynamics of carbon and nitrogen budgets in these systems under different irrigation regimes starting in 2004 also.

### Production Systems Research as Support to Farmers

Field research on production systems (P) has been intensified in 2004, covering all major aspects needed to develop recommendations for farmers as the main land users. These include research on the potential for a diversification of crops through the introduction of alternative crops (e.g.; potatoes, sunflower, and sorghum) and the improvement of the existing cropping systems and rotations. Also, the optimization of fertilizer use and its efficiency is addressed through extensive on-farm field research in close collaboration with the farmers, and a study of irrigation efficiency on the field level is carried out in which for the first time detailed measurements of the farmer’s irrigation practice are carried out.

As agriculture consumes about 80% of all water resources in Uzbekistan, and as the agricultural water-use efficiency in Khorezm is low, field research on how to establish alternative cropping and crop management systems that have been successful elsewhere has been initiated in close cooperation with the International Wheat and Rice Center (CIMMyT) and TIIAME, an agricultural university in Tashkent. These include the introduction of a permanent bed-and-furrow system, the development of adequate planters and seeders, and improved irrigation techniques in combination with optimized fertilizer management via a judicious combination of organic and mineral materials.

Furthermore, the introduction of alternative crops like potatoes, sorghum, or sunflowers, is being studied in on-farm pilot trials, some of them in cooperation with German Agro Action (Welthungerhilfe). The competitive advantages of crops with a high value density such as flowers or spices that can be advantageously grown, processed and marketed in Khorezm, will be assessed in another economic study.

## Economic Research to provide efficiency of farming operations

The research on economic aspects (research area E) aims at establishing development pathways for transforming the local economy from a command-structured to a market-oriented system, and the acquisition of primary research data on farm management, market conditions, profitability of diversified crop production systems, expenditures of regulating the economy as well as costs of intergenerational distribution.

In the context of the Uzbek economy it is necessary to assess up to which point privatization and land set-aside policies may diminish the employment opportunities in the farm sector, and how far market restructuring might be able to compensate for these losses [28]. An in-depth analysis of the institutions necessary to create functioning markets, of constraints prevailing in input markets as well as in those affecting output at various stages (processing, storage, and marketing) will be undertaken in order to assess the various options for privatization of these sectors as a viable alternative to the procurement system of the government. In addition, a socio-economic evaluation of possible winners and losers of agricultural reform is providing the necessary background information to minimize or avoid social disruptions. Judgment on the economic effects of re-allocating land and water use will be mainly based on analyses of individual farms started in 2002 and carried out with Linear Programming Models (LPM) that will represent the three major farm types at each district level. These investigations not only will provide insight into the status quo, but will also provide the levers for economic re-organization of the agricultural sector. The economic studies will be integrated on different levels; in an Uzbekistan-wide economy model, in an economic model of the Amu Darya river basin that allows a larger disaggregation, and the integration of the farm data gathered in intensive interviews of farmers into the so-called Farm Level Change Sub-Model (FLCM) to support the overall model, KEOM.

## Research on Institutional Performance

The research on society and institutions (S) aims at (a) understanding the formal (legal) ways of resource distribution in the state institutions and the newly formed Water User Associations, (b) increasing our understanding of the informal ways of by-passing these institutions in decision-making, (c) assessing environmental legislation and the legal aspects of land tenancy and land use with the aim of identifying the possibilities for legal, institutional and administrative modifications needed for a land reform, market liberalization and an effective increase in land/resource use efficiency and sustainability

Any implementation of modifications of resource use will involve regulatory, organizational and social issues. Current studies look at the conflict potential that lays in the Uzbek reform process, and ways of how to mitigate it; at the functioning of the newly introduced water user associations that substitute the water distribution according to farms in favor of water allocation based on hydrological units; and try gauging the perceptions and expectations of farmers towards a project that supposedly will provide changes in their day-to-day life [29]. Privatizing farms and liberalizing markets calls for alternative institutional arrangements in water delivery as well as in monitoring markets. Research will be intensified on appropriately anchoring the new institutional settings in the formal and traditional societal structures in Khorezm.

## Integrative Modeling

The modeling of economic and ecological processes is undertaken in order to understand the dynamics of these highly complex and intertwined processes. It is expected that through simulations with this model, it will be possible to develop scenarios for optimization of land and water use. We expect this model to be a spatially distributed computer model that allows differentiating land use in the sub-units (“pixels”) of a grid laid over the region. The model (dubbed the Ecological-Economic Optimization Model; KEOM) furthermore accounts for resource utilization, natural constraints, economical and human driving forces. The process of developing KEOM is deliberately not focusing on developing the software as such, but on using it as a strongly stakeholder-driven integration tool that should bring together the different disciplines as well as researchers and farmers. It is based on applying the Unified Modeling Language (UML; cf. [30]) as an integrative tool that guides a social process much more than a software developing process. KEOM should then allow assessing the impact of different possible scenarios (climatic changes, policy changes, introduction of different land management, etc.) on the long-term sustainability of ecological and economic conditions of Khorezm and Uzbekistan. KEOM will assemble the different parallel multi-disciplinary approaches into a truly integrated interdisciplinary research tool.

## Concluding Remarks

This project intends to make a difference by supplying applicable, operational concepts based on four pillars that form its basic philosophy. These are (1) the establishment of a long-term scientific cooperation between German and Uzbek research institutions including other internationally important players such as UNESCO and CIMMyT; (2) the strong emphasis on human capacity building of young Uzbek students as integrants of an international work group; (3) the interdisciplinary integration of different science disciplines; and (4) the development of a science-based concept for land and water use. We thus expect this project to be of competitive advantage in the development scene in Central Asia where natural resource exploitation, strongly hierarchical institutions and the shortfalls of a transition economy mingle to form a complex situation that is translating into natural resource degradation and poverty. To overcome these requires uniting “the best of both worlds”.


## Acknowledgements

This paper was prepared based on contributions of many people at the Center for Development Research. It dwells on contributions by Ruzimbay Eshchanov, Peter Mollinga, Alim Pulatov, Gerd Rücker, Anja Schoeller-Schletter, and Peter Wehrheim as well as the work of numerous Ph.D. students of the project. This study was funded by the German Ministry for Education and Research (BMBF; project number 0339970A).

## Tables

Table 1: Water resources in the Aral Sea Basin and their use. From [31].

| Indicator | Unit of measurement | 1960 | 1970 | 1980 | 1990 | 1999 |
|---|---|---|---|---|---|---|
| Population | Million people | 14.1 | 20 | 26.8 | 33.6 | 39.9 |
| Irrigated land area | 1000 ha | 4510 | 5150 | 6920 | 7600 | 7900 |
| Summary water intake | $km^3$ per year | 64.7 | 83.5 | 120.7 | 118.1 | 107.6 |
| For irrigation | $km^3$ per year | 55.2 | 74 | 108.5 | 106 | 96.3 |
| Specific intake per 1 ha of irrigation | $m^3$ $ha^{-1}$ | 12240 | 14370 | 15680 | 13950 | 12190 |
| Specific intake per capita | $m^3$ per capita per year | 4590 | 4174 | 4500 | 3515 | 2700 |

Table 2: Economic indicators in Uzbekistan. Source: [32] and own calculations.

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 |
|---|---|---|---|---|---|---|
| Population (million people) | n.a. | n.a. | n.a. | n.a. | 25.8 | 26.3*) |
| GDP (billion US$) | 17.0 | 13.7 | 11.6 | 9.7 | 9.0 | 10.1 |
| GDP per capita, US$ | 70 | 551 | 463 | 380 | 347 | 384**) |

*) value for the population in 2004 calculated from population in 2003, assuming an annual growth rate of 2.5 [33]

**) per-capita GDP of 2004 calculated from GDP/population

Table 3: Rural poverty in Uzbekistan. Modified from [22].

| | Average cost of consumption, per capita, Uzbek Soum*) | % of people living below of a half of the mean level of consumption |
|---|---|---|
| Urban | 10 926 | 18,6% |
| Rural | 7 539 | 39,6% |

*) exchange rate: approximately 1000 Uzbek Soum = 1 US$ (values of 2000)

Table 4: The different planned phases in the ZEF development project for land and water use in Khorezm (Uzbekistan)

| Phase | Years | Main activities | Status |
|---|---|---|---|
| I | 2001-2003 | Inventory; establishment of central databases and infrastructure | finished |
| II | 2004-2006 | Field trials for process understanding, development of a Modeling and Decision Support Tool (Khorezm Ecological-Economic Model, KEOM) for research purposes | started |
| III | 2007-2010 | Testing of the concept for the restructuring of the land use, and demonstration of “good practice” on pilot farms, fields and plots | planned |
| IV | 2011-2012 | Adaptation of concept and implementation in the region (Khorezm-wide) | planned |

## Figures

Figure 1: Development of the extension of the irrigated area in the Aral Sea Basin, and of the population in Uzbekistan. Adapted from [34]

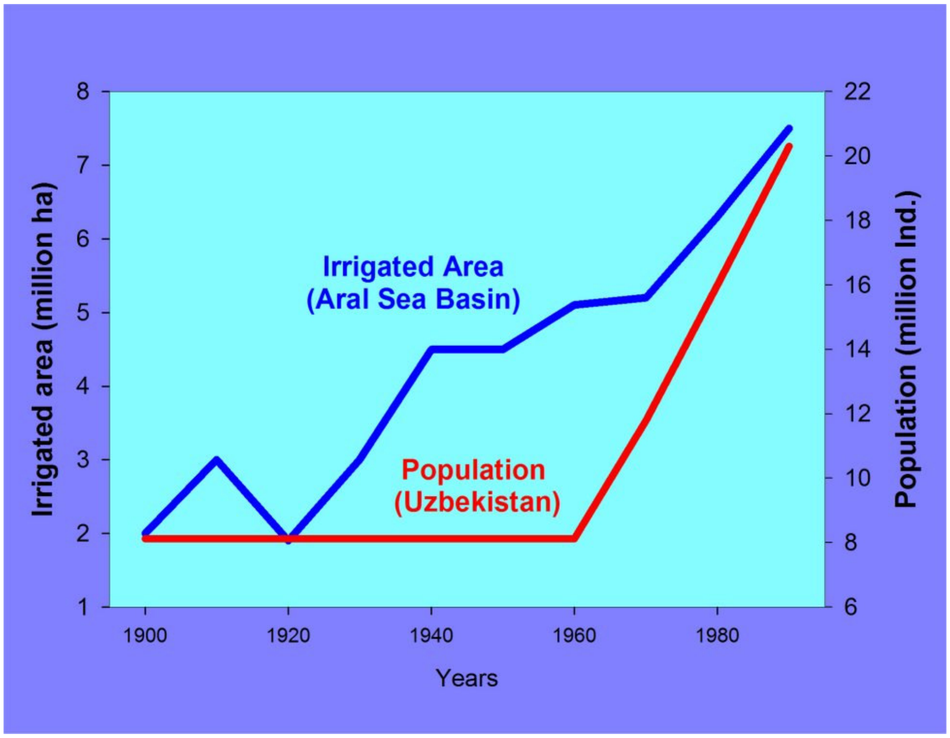
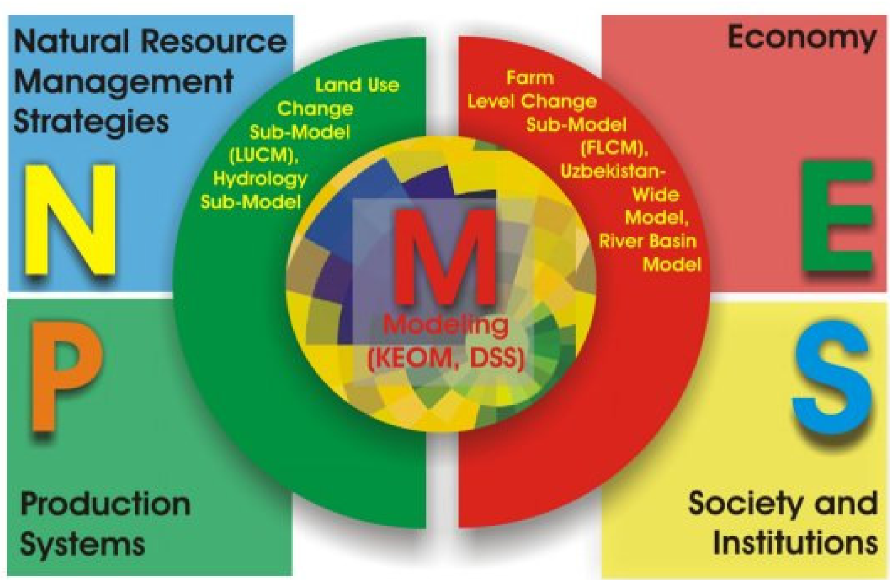



Figure 2: The four project research areas feed through sub-models into the Khorezm Ecological-Economic Optimization Model (KEOM).



## References


[1] P.P. Micklin and W.D. Williams. 1996. The Aral Sea Basin. NATO ASI Series 2. Environment, Vol. 12. Springer Verlag, Berlin, Heidelberg.

[2] G. Strunz, G. Rücker and R. Colditz (2003): Mapping of desertified areas in the former Lake Aral region and evaluation of the suitability for tree-growth. Unpublished Report. DFD-DLR, Oberpfaffenhofen, 8 pp.

[3] WBGU (1998): Worlds in transition. Ways towards sustainable management of freshwater resources. Berlin, Springer-Verlag, 419 p.

[4] M.H. Glantz (1998): Central Eurasian water crisis: Caspian, Aral, and Dead Seas. In: I. Kobori. and M.H. Glantz (eds.): United Nations University Press, New York, pp. 25-52.

[5] Vlek, P.L.G., Martius, C., Wehrheim, P., Schoeller-Schletter, A., Lamers, J. (2001): Economic Restructuring of Land and Water Use in the Region Khorezm (Uzbekistan) (Project Proposal for Phase I). ZEF Work Papers for Sustainable Development in Central Asia, 1, 79 pp. Available at http://www.khorezm.uni-bonn.de/ [last checked 6-6-2004]

[6] E. Giese (1998): Die ökologische Krise des Aralsees und der Aralsee Region:Ursachen, Auswirkungen, Lösungsansätze. In: Giese, E., Bahro, G. and D. Betke: Umweltzerstörungen in Trockengebieten Zentralasiens (West- und Ost-Turkestan). Franz Steiner Verlag, Stuttgart, Erdkundliches Wissen 125, 189 p.

[7] R. Létolle and M. Mainguet (1996): Der Aralsee - Eine ökologische Katastrophe. Springer Verlag, Berlin, Heidelberg, New York, 517 p.

[8] S.Y. Treshkin, S.K. Kamalov, A. Bachiev, N. Mamutov, A.I. Gladishev, and I. Aimbetov (1998): Present status of the Tugai forests in the Lower Amu-Dar'ya Basin and problems of their protection and restoration. In: UNESCO: Ecological research and monitoring of the Aral Sea Deltas. UNESCO Aral Sea Project. 1992-1996, Final Scientific Report, UNESCO, Paris.

[9] FAO AQUASTAT (2004): County Profile Uzbekistan. Available at http://www.fao.org/ag/agl/aglw/aquastat/countries/uzbekistan/index.stm [checked 6.6.2004]

[10] D. Hillel (2000): Salinity Management for Sustainable Irrigation. Integrating Science, Environment and Economics. The International Bank for Reconstruction and Development/The World Bank, 92 p.

[11] M. Ibrakhimov (2004): Spatial and temporal dynamics of groundwater table and salinity in Khorezm (Aral Sea Basin), Uzbekistan. Ph.D. thesis, Univ. Bonn.

[12] UNESCO (2000): Water related vision for the Aral Sea Basin for the year 2025. UNESCO, Division of Water Sciences with the Co-Operation of the Scientific Advisory Board for the Aral Sea Basin. United Nations Educational, Scientific and Cultural Organization.

[13] V. Chashchin, and A. Kuzmin. (2003). The Khorezm Region Water Quality and Health Study: Persistent Toxic Substances in Drinking Water and Human Blood. INTAS Project 00-1015 (1). Available at http://www.intas.be/news/conferences/ASBC%20presentations/abstract/abstract%20project%201015-1.pdf

[14] S.L. O'Hara, G. Wiggs, R. Hubbard, J. Wegredt, D. Falzon and J. van der Meer (2001): Dust exposure and health respiratory health amongst children in the Environmental disaster zone of Karakalpakstan, Central Asia: preliminary findings of the ASARD project. First International Conference on the Impact of Environmental Factors on Health 10 - 12 September 2001, Cardiff, Wales, UK, MSF Kiev, 10 pp. Available at http://www.msf.org/aralsea/linked%20documents/ASARD-cardiff.pdf [checked 6.6.2004]

[15] E. Crighton, J. van der Meer, V. Yagodin, and S. Elliott (2001): Impact of an Environmental Disaster on Psychosocial Health and Well Being in Karakalpakstan. MSF Aral Sea Ara Program, 1999. 32 pp. Available at http://www.msf.org/aralsea/linked%20documents/psychosocial.pdf [checked 6.6.2004]

[16] U.A. Karimov, O.S. Machmudov, T.B. Eshanov, and G.A. Mambetkarimov (1999): Aktualnie voprosi ochrani sdorovja detei v ekologisheski neblagoptijatmom regione Usbekistana. Vestnik KKOAN No. 2 (160), pp. 15-17.

[17] A. Bauer, D.Green, and K. Kuehnast. 1997. Women and Gender Relations. The Kyrgyz Republic in Transition. Asian Development Bank (ADB), Manila.

[18] A. Bauer, N. Boschmann, D. Green, and K.A. Kuehnast. 1998. Generation at Risk. Children in the Central Asian Republics of Kazakstan and Kyrgyzstan. Asian Development Bank (ADB), Manila.

[19] UNDP Kazakhstan 2004: Poverty in Kazakhstan: Causes and Cures. UNDPKAZ 08. 122 pp.

[20] USDA-ERS (United States Department of Agriculture – Economic research Service) (2004): Briefing Room: Cotton trade. Available at http://www.ers.usda.gov/Briefing/Cotton/trade.htm [checked 31.5.2004]

[21] Bharat Textile (2004): Global Textile Statistics – World Cotton production. Available at http://www.bharattextile.com/textstat6.php [checked 31.5.2004]

[22] T. Trevisani (2004): Uzbekistan's agricultural sector as a context for development. Unpublished Report, Urgench, Khorezm, 2004

[23] ZEF (2003): Economic and Ecological Restructuring of Land- and Water Use in the Region Khorezm (Uzbekistan). A Pilot Project in Development Research. Project Phase II: Field Research and Development of a Restructuring Concept (2004-2006). ZEF Bonn. 58 pp.

[24] A. Khamzina , J.P.A. Lamers , M. Worbes , E. Botman , and P.L.G. Vlek (2004 submitted): Assessing the potential of trees for afforestation of degraded landscapes in the Aral Sea Basin of Uzbekistan. Establishment, growth, nutritive and calorific values. Agroforestry Systems

[25] G. Ruecker, and C. Conrad (2004): Exploring leaf area index development and land cover classification in the lower Amu Darya Basin in Uzbekistan based on multi-temporal and multi-spatial remote sensing data. ZEF Work Papers for Sustainable Development in Central Asia, 4. 24 pp. Available at http://www.uni-bonn.de/khorezm [last checked 6.6.2004]

[26] S. Herbst, T. Kistemann, and D. Fayzieva (2003): Comparison of the incidence of diarrhoeal diseases in two regions of the Aral Sea area, Uzbekistan. Brebbia CA, Fayzieva D (eds.): Environmental Health Risk II, 153-161, WIT Press, Southampton, 2003

[27] S. Herbst, T. Kistemann, and D. Fayzieva (2004): Monitoring of microbial drinking water quality and diarhoeal disease in the Aral Sea region, 6th International Congress "Water: Ecology and Technology" ECWATECH-2004, Moscow, 01.-04.06.2004

[28] B. Ruzmetov, Z. Rahimov, and I. Rudenko (2004): Analysis of farm enterprises and agricultural markets in the region Khorezm (Uzbekistan). ZEF Work Papers for Sustainable Development in Central Asia, 2. 39 pp. Available at http://www.uni-bonn.de/khorezm [last checked 6.6.2004]

[29] C. Wall and J. Lamers (2004): Farmer Priority Setting: Issues and Research Needs for Khorezm, Uzbekistan. ZEF Work Papers for Sustainable Development in Central Asia, 5. 39 pp. Available at http://www.uni-bonn.de/khorezm

[30] M. Fowler (2004): UML distilled. Third edition. Addison-Wesley, Boston etc. 175 pp.

[31] Grid-Arendal (2001): State of Environment of the Aral Sea Basin. Regional report of the Central Asian States' 2000. Available at http://www.grida.no/aral/aralsea/english/water/water.htm [last checked 6.6.2004]

[32] Australian Government. Department of Foreign Affairs and trade (2004): Uzbekistan fact sheet. Available at http://www.dfat.gov.au/geo/fs/uzbe.pdf [checked 6.6.2004]

[33] UNICEF (2004): At a glance: Uzbekistan - Statistics. Available at http.//www.unicef.org/infobycountry/Uzbekistan_statistics.html [checked 31.5.2004]

[34] J. Shirokova (2000): Problemy uchudshenia kachestva pochv v Usbekistane. Unpublished work paper, Tashkent.

[35] M. Müller (2004): Where Has All The Water Gone? Estimation of a production function for the agricultural sector in the region Khorezm, Uzbekistan. Unpublished Draft Paper, ZEF Bonn, 19 pp.